RULES FOR CLASSIFICATION

Naval vessels

Edition December 2015

Part 4 Sub-surface ships

Chapter 1 Submarines

DNV GL AS

FOREWORD

DNV GL rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CURRENT – CHANGES

This is a new document.

The rules enter into force 1 July 2016.

CONTENTS

SECTION 1 CLASSIFICATION OF NAVAL SUBMARINES

1 Classification and characters of classification

1.1 Classification

1.1.1 Rules for classification

The following rules for classification and construction constitute the basis for the Classification of naval submarines.

The term "rules for classification" includes, as far as applicable, the SHIP Pt.2 Ch.1 – SHIP Pt.2 Ch.4 Materials and Welding as well as other rules for classification and construction issued by the Society.

1.1.2 Considered types of submarines

For the purpose of these rules, naval submarines comprise:

Manned military self- manoeuvring and surface independent vessels with non-nuclear propulsion.

The purpose and design principles of Diver Transport Submarines, Diver Delivery Vehicles, Diver Propulsion Devices and Rescue Submarines are subject of Sec.17 and UWT Pt.5 Ch.6.

For further definitions, see Sec.2 [2].

1.1.3 Scope

The Classification covers the entire submarine including its structural elements, machinery and electrical/ electronic equipment. Other systems and components may be included in the Classification and/or Certification procedure upon request of the naval administration.

1.1.4 Confidentiality

1.1.4.1 The Society maintains confidentiality with respect to all documents and other kinds of information received in connection with the orders entrusted to the Society. The Society shall comply with the security procedures agreed upon with the naval administration.

1.1.4.2 The Society will instruct its personnel engaged in a naval project to follow the security procedures, including the necessary safe handling and storage of confidential information and documentation as agreed upon with the naval administration.

1.1.5 DNV GL data file

Submarines classified by the Society will be included in the Society data file observing the secrecy requirements of the naval administration. An extract of these submarine data will be entered in the Register published by the Society, if the naval administration agrees.

1.1.6 Certificate of classification

The class certificate for naval submarines is issued by the Society. It shall be kept on board.

1.1.7 Submarine certificate

Submarines which are not classed with the Society but which are constructed in accordance with the rules and under the survey of the Society may receive an appropriate statement to this fact from the Society.

1.1.8 Log book

Submarines are required to carry a log book in which details of pressure and diving history, repairs, etc. are to be entered. The log book shall be presented to the surveyor on request.

1.1.9 Deviation from the rules
Designs which deviate from the rules may be approved provided that such designs have been examined by the Society for suitability and have been recognized as equivalent.

1.1.10 Novel machinery
Hull and Machinery installations which have been developed on novel principles and/or which have not yet been sufficiently tested in shipboard service require the Society's special approval.

1.1.11 Additional documentation and trials
In the instances mentioned in [1.1.9] and [1.1.10] the Society is entitled to require additional documentation to be submitted and special trials to be carried out.

2 Surveys for classification

2.1 Surveys for maintenance of class

For surveys for maintenance of Class, definitions and due dates, see Pt.1 Ch.5 Sec.2.

2.2 Performance and scope of surveys

For performance and scope of surveys, see also Pt.1 Ch.5 Sec.3 [3], as far as applicable. The individual scope of surveys is based on the design of the submarine and determined during the plan approval phase.

Flag State requirements can be considered case by case in agreement with the naval administration.

For constructional survey and acceptance testing during newbuilding see Sec.2 [5].

2.2.1 Annual survey
The Annual Survey of the submarine shall include at least the following tests and checks:

2.2.1.1 Inspection of the documents relating to the submarine and scrutiny of the maintenance records.

2.2.1.2 A tightness test shall be performed on the pressure hull at an internal underpressure of at least 0.1 bar below atmospheric pressure.

2.2.1.3 The pressure hull and external structure including all fixtures, penetrations, doors and covers, seals, locking systems, etc. are to be inspected for visible damage, cracks, deformation, corrosion and fouling.

2.2.1.4 All other pressure vessels, heat exchangers and filters, as well as valves, fittings and safety equipment are to be subjected to external inspection. Safety valves have to be tested for correct functioning, regarding set points and flow, etc.

2.2.1.5 The entire machinery installation including the electrical equipment shall be subjected to external inspection.

2.2.1.6 The function of the electrical power supply shall be tested. Special attention shall be given to the function of the generators and the results of the 3 monthly battery charging protocols and the yearly capacity test.

2.2.1.7 Insulation measurements are to be performed on the electrical systems/components.

2.2.1.8 The accuracy of all important instrument readings shall be checked, e.g. depth gauge, gas analyser, etc.

2.2.1.9 Wherever appropriate, all emergency rescue and safety systems and alarms are to undergo a functional test.

2.2.1.10 High-pressure hoses (dynamic load characteristics) are to be checked for visible damage and tightness.

2.2.1.11 The communication system including the broadcast system shall be subjected to a functional test.

2.2.1.12 The functional efficiency of the total system, especially the manoeuvring and diving equipment shall be checked by means of a trial dive at periscope depth and minimum 0.5 x *NDD*.

2.2.1.13 Visual inspection of safety relevant rescue systems and equipment.

2.2.2 Intermediate survey

The intermediate survey falls due at half the nominal time interval between two class Renewal Surveys (i.e. *p*/2). If *p* is an uneven number of years, the survey may be carried out on the occasion of the preceding or following annual survey. If *p* is an even number of years, the intermediate survey replaces the annual survey.

An Intermediate Survey is an Annual Survey extended as follows:

Performance of a tightness test on pressure hull penetrations and closing appliances e.g. by application of an inside underpressure of at least 0.2 bar.

2.2.2.1 Pressure chambers/diver's lockouts are to undergo a tightness test at maximum operating depth for diver's operation. Furthermore the structure influencing the pressure hull has to be tested with *TDP*.

2.2.2.2 Internal inspection of main ballast tanks, if applicable. Tightness test on diving/ballasting, regulating/compensating and trimming systems as well as the hull valves of all systems subjected to the diving pressure for 30 minutes with 1.0 x maximum allowable working pressure of the system.

2.2.2.3 Verification of the set pressures of safety valves and of safety and alarm systems.

2.2.2.4 Functional tests on mechanical and electrical equipment.

2.2.2.5 Functional tests of elements of life support systems and tightness test of these systems, if applicable.

2.2.2.6 Functional tests on fire warning and extinguishing systems.

2.2.2.7 Functional tests on all alarm systems.

2.2.2.8 Functional test and quality check on all breathing gas systems.

2.2.3 Class renewal survey

A class Renewal Survey is performed every *p* years. The following tests and examinations are to be carried out in addition to the inspections called for under [2.2.1] and [2.2.2]:

2.2.3.1 A tightness test shall be performed on the pressure hull at an internal underpressure of at least 0.2 bar below atmospheric pressure.

2.2.3.2 Dimensional checks and non-destructive, spotwise tests (wall thickness, cracks, etc.) are to be performed on the pressure hull and lockouts. Where necessary, buoyancy aids, cladding and layers of thermal insulation are to be removed for this purpose.

2.2.3.3 Buoyancy tests are to be performed.

2.2.3.4 Internal inspection of pressure vessels, heat exchangers and filters has to be performed. If they cannot be satisfactorily inspected internally and those whose satisfactory condition cannot be fully verified by internal inspection, have to be proven by another non-destructive test method. The methods and the interval have to be agreed by the Society and naval administration.

Compensators are to be visually inspected.

Check that accessories, especially hose lines and compensators are changed according to the maintenance plan. The changed accessories have to be tested regarding function with maximum allowable working pressure.

2.2.3.5 Load tests are to be performed for all lifting gear and lifting accessories as required by rules and Guidelines for Lifting Appliances.

2.2.3.6 Where surveys are performed on a submarine or parts thereof during the period of Class, the scope of which corresponds to a class Renewal Survey, then the regular class Renewal Survey for the parts concerned may be deferred accordingly at the naval administration's request.

2.2.4 Damage survey

Each damage has to be reported to the Society.

2.2.4.1 If the submarine or its ancillary systems has suffered damage affecting its class or if such damage may be assumed, a Damage Survey shall be carried out.

2.2.4.2 Following damage, the submarine shall be presented for survey in such a way that a satisfactory inspection can be carried out. The extent of the Damage Survey will be determined by the Society in each individual case.

2.2.5 Extraordinary survey

2.2.5.1 When any modification is made in respect of design, mode of operation or equipment and after major repairs to the submarine, an Extraordinary Survey shall be carried out.

2.2.5.2 Where modifications are made to the submarine, which affect its buoyancy or stability, appropriate heeling and trim test are to be performed in the presence of the surveyor.

3 Workmanship

3.1 General

3.1.1 Requirements to be complied with by the shipyard and the manufacturers

3.1.1.1 Every manufacturing plant shall be provided with suitable equipment and facilities to enable proper handling of the materials, manufacturing processes, structural components, etc. the Society reserves the right to inspect the plant, facilities of subcontractors and test facilities accordingly or to restrict the scope of manufacture to the potential available at the plant.

The manufacturing plant shall have at its disposal sufficiently qualified personnel. The Society shall be advised of the names and areas of responsibility of all supervisory and control personnel. The Society reserves the right to require proof of qualification.

3.1.1.2 The shipyard or manufacturing plant and its subcontractors have to get approval from the Society for the type of work they provide for the manufacture and installation of naval submarines. Approval can only be given if the conditions defined in detail in Materials and Welding SHIP Pt.2 Ch.1 – SHIP Pt.2 Ch.4 are complied with.

3.1.1.3 The fabrication sites, stores and their operational equipment shall also comply with the relevant safety requirements. The shipyard or manufacturing plant is alone responsible for compliance.

This is also valid for transport and storage companies, sub-contractors and test facilities.

3.1.2 Quality control

3.1.2.1 The Shipyard shall operate a quality assurance system, such as ISO 9001 or equivalent.

This is also valid for transport and storage companies, sub-contractors and test facilities.

3.1.2.2 As far as required and expedient, the manufacturer's personnel has to examine all structural components both during the manufacture and on completion, to ensure that they are complete, that the dimensions are correct and that workmanship is satisfactory and meets the standard of good engineering practice.

3.1.2.3 Upon inspection and corrections by the manufacturer, the structural components shall be shown to the surveyor for inspection, in suitable sections, normally in unpainted condition and enabling proper access for inspection.

3.1.2.4 The surveyor may reject components that have not been adequately pre-checked by the manufacturer and may demand their re-submission upon successful completion of such checks and corrections by the manufacturer.

3.2 Structural details

3.2.1 Details in manufacturing documents

3.2.1.1 All significant details concerning quality and functional ability of the components concerned shall be entered in the manufacturing documents, workshop drawings, etc. This includes not only scantlings but, where relevant, such items as surface conditions (e.g. finishing of flame cutting edges and weld seams), and special methods of manufacture involved as well as inspection and acceptance requirements and, where relevant, permissible tolerances.

A production standard which considers the special requirements for the manufacturing of naval submarines has to be defined by the Shipyard or manufacturing plant and to be approved by the Society.

3.2.1.2 If, due to missing or insufficient details in the manufacturing documents, the quality or functional ability of the component cannot be guaranteed or is doubtful, the Society may require appropriate improvements.

This includes the provision of supplementary or additional parts, e.g. reinforcements, even if these were not required at the time of plan approval or if – as a result of insufficient detailing – could not be assessed.

4 Disposal and recycling

4.1

The submarine shall be designed and maintained to enable its safe disposal at the end of its service life to protect those involved in the dismantling process. For further details, see SHIP Pt.6 Ch.7 Sec.4.

SECTION 2 GENERAL REQUIREMENTS

1 General principles and scope

1.1

Submarines shall be designed and constructed in such a way that failure of any single component cannot give rise to a dangerous situation.

1.2

Submarines and their components shall be designed to meet the service conditions stated in the Concept of Operations by the naval administration. In the Concept of Operations Statement all main parameters for military tasks, external and internal hazards to cope with, limitations of operation, duty period, survival time, survey and maintenance philosophy, etc. shall be well defined and documented as the basis for each actual submarine project.

1.3

A Failure Mode and Effect Analysis (FMEA) showing a safety envelop for the nominal diving depth *NDD* in relation to the submarine's velocity shall be submitted to the Society, compare [4]. The following cases have to be investigated:

— jamming of hydroplanes at maximum angle
— partly flooding

1.4

Submarines shall be designed and built to ensure safe operation and facilitate proper maintenance and the necessary surveys.

1.5

Submarines shall be equipped for all-round vision when navigating on the surface. This can be reached either by suitable windows or optical instruments.

1.6

The following requirements contain additional requirements for the classification and construction of submarines and are complementary to the Pt.1,Pt.2, Pt.3 and to SHIP Pt.2 Ch.1 – SHIP Pt.2 Ch.4, as far as applicable.

1.7

For submarines with escape trunks or a diver's lockout, the mating system and parts concerned are also required to conform to rules for UWT Pt.5 Ch.1 and UWT Pt.5 Ch.2 in addition to the rules set out in the following.

1.8

Designs differing from the rules of Construction may be permitted provided that they have been recognized by the Society as equivalent.

1.9

Submarines, systems or parts thereof whose development is based on new principles and which have not yet been sufficiently tested in practical operation require special approval by the Society.

1.10

In the cases mentioned in [1.8] and [1.9], the Society is entitled to require the submission of additional documentation, risk analyses and the performance of special tests.

1.11

The Society reserves the right to impose additional demands to those contained in the rules in respect of all types of submarines when such action is necessitated by new knowledge or practical experience, or to sanction deviations from the rules in specially justified cases.

1.12

National regulations or own rules of naval administrations existing alongside the Society rules are unaffected.

2 Definitions

2.1 General

2.1.1 Breathing gas

Breathing gas are all gases/mixtures which are used for breathing during special purpose and emergency operations.

2.1.2 Centre of buoyancy

The centre of buoyancy for the submerged submarine has the designation $B\downarrow$ and is related to the submerged displacement $\Delta\downarrow$.

The centre of buoyancy for the surfaced submarine with the designation $B\uparrow$ and is related to the surfaced displacement $\Delta\uparrow$.

2.1.3 Centre of gravity

The centre of gravity for the relevant load condition has the designation G.

2.1.4 Compression chamber

A compression chamber is a chamber for accommodation of persons at more than atmospheric pressure.

2.1.5 CONOPS

The Concept of Operations Statement shall be created by naval administration and shall firmly define the tasks and abilities of the submarine, as well as foreseeable damage survivability, maintenance philosophy and environmental conditions. It forms the basis for the design of the submarine. A guidance is given in NSubC Ch.I App.A.

2.1.6 Control station

Central area at which all essential indicators, control and monitoring devices, communication systems of the submarine are arranged.

2.1.7 Diving pressure

The overpressure corresponding to the relevant diving depth to which a submarine is exposed during underwater operations.

2.1.8 Duty period

The duty period is the time of endurance (normally expressed in days) in which the submarine can operate under wartime circumstances without getting additional supplies from outside.

2.1.9 Emergency condition

Condition where the safety of the submarine and the personal on board cannot be established any more by one or more systems for normal operation but back-up systems for life support, diving/ballasting, regulating/compensating, trimming, freeing, internal and external communication, power supply and power distribution, hydraulic oil supply, steering and rudder operation indication, lighting, fire detection and alarm, locating equipment, etc. have to be used to allow safe operation of the submarine under reduced capability.

2.1.10 Exostructure

External cladding, supporting structures and fixtures outside the pressure hull which normally are not designed to withstand the diving pressure.

2.1.11 Life support systems

Systems for breathing gas supply, purification, exchanging and conditioning of the atmosphere in the pressure hull, for the supply of water and food and for the removal of waste.

2.1.12 Lockouts

A trunk including 2 hatches in a submarine for locking in and out of divers in case of special operations or the crew in case of SMERAS at diving pressure.

2.1.13 Mating system

The necessary equipment for the connection and disconnection of a submarine with a DSRV or a submarine rescue system.

2.1.14 Metacentre

The metacentre with the designation M is the point of intersection between the buoyancy resultant through the centre of buoyancy and the middle axis for heeling angles $0° < \varphi \leq 5°$. For bigger heeling angles φ the metacentre shall be specially evaluated.

2.1.15 Naval Submarine

A naval submarine is a manned surface-independent unit capable of operating underwater and is being under military command.

2.1.16 Persons

Persons embarked on board of submarines shall fall into one of the three following categories:

2.1.16.1 Crew/crew members

Persons carried on board the submarine to provide navigation and maintenance of the submarine, operation and maintenance of its machinery and systems (including weapon and radio-communication systems), and arrangements essential for propulsion and safe navigation or to provide services for other embarked persons. Crew members are expected to be well-disciplined and able bodied and have excellent knowledge of the layout of the submarine and its safety equipment.

2.1.16.2 Special personnel

Persons who are not members of the crew and who are carried on board in connection with the special purpose of the submarine or the special work carried out aboard the submarine. Special personnel (which may include scientific staff, trials personnel and equipment engineers, surveyors, or persons under training) are expected to be disciplined and able-bodied and have a fair knowledge of the layout of the submarine and its safety equipment.

2.1.16.3 Other persons
Persons embarked who are not employed or engaged in any capacity on board the submarine and who do not fall into any other categories. Passengers and other embarked persons may include visiting dignitaries and families. If they are embarked they shall have a basic knowledge of the submarine and its safety procedures.

2.1.17 Pressure gas cylinder
A pressure vessel for the storage and transport of gases under pressure.

2.1.18 Pressure hull
The main component of a submarine which accommodates the crew at atmospheric pressure and withstands the external diving pressure.

2.1.19 Pressure vessel
Pressure vessel is a vessel, heat exchanger or filter capable of withstanding an internal or external working pressure of more than 1 bar.

2.1.20 Rescue system
Systems and equipment used for recovering the submarine and/ or rescuing the persons on board.

2.1.21 Safe navigation
Safe navigation means safe participation in the maritime traffic under defined surface and submerged operating conditions for the purpose to protect and save the life of all persons on board, to protect the submarine, other traffic participants and the environment. For this at least the applicable SOLAS, COLREG Regulations, etc. and additionally the recommendations contained in CONOPS shall be considered. Existing national regulations (Flag State Requirements) are unaffected.

2.1.22 SMERAS
Procedures for SubMarine Escape, Rescue, Abandonment and Survival.

2.1.23 Survival time
The survival time is the time (normally expressed in hours) in which the persons on board of a damaged submarine can survive until they are rescued by own efforts or help from outside.

2.1.24 Total system
The submarine including its mating, operating and supply systems and ancillary equipment shall be understood as the total system.

2.1.25 Watertight
Watertight, in relation to an element of the structure means that it is capable of preventing the ingress of water under the head of water for which the element and its surroundings are designed.

2.1.26 Weather tight
Weather tight in relation to an opening above the waterline and its cover means, that water will not penetrate into the surfaced submarine in any thinkable seaway condition.

2.2 Main dimensions and main parameters
All dimensions are related to permanently installed equipment in drawn in/turned in condition.

2.2.1 Co-ordinate system
In relation to the submarine a fixed, right-handed coordinate system x, y, z according to Figure 1 is introduced. The origin of the system is defined by the aft perpendicular, the centre line and the basis line of the submarine. The x-axis points in longitudinal direction of the unit positive forward, the y-axis positive to port and the z-axis positive upwards. Angular motions are considered positive in a clockwise direction about the three axes.

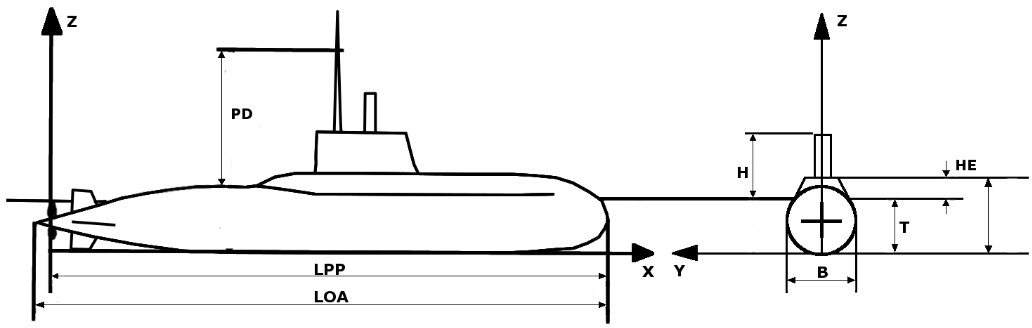

Figure 1 Fixed co-ordinate system and main dimensions

2.2.2 Aft perpendicular AP

The aft perpendicular *AP* is vertical to the x-axis through the intersection of rear edge of the stern boss with mid of propeller for submarines with central shaft. For submarines with several shafts and special propulsion arrangements *AP* shall be defined case by case.

2.2.3 Forward perpendicular FP

The forward perpendicular *FP* is vertical to the x-axis through the intersection with foreside of the stem, for special arrangements to be defined case by case.

2.2.4 Length between the perpendiculars LPP

The length *LPP* is the distance between *AP* and *FP* measured parallel to the x-axis [m].

2.2.5 Length over all LOA

The length *LOA* is the length between the most forward and most aft point of the submarine including fixed installed components of equipment, measured parallel to the x-axis [m].

2.2.6 Total breadth B

The total breadth *B* is the maximum breadth of the submarine including all fixed installed parts of equipment, measured parallel to the y-axis [m].

2.2.7 Radius of the pressure hull R_m

The radius of the pressure hull R_m is the radius of the cylinder or the sphere related to the middle of the wall thickness [m].

2.2.8 Heights

2.2.8.1 Total height H

The total height *H* is the total height from baseline to upper edge of the submarine including all permanently installed parts of equipment, measured parallel to the z-axis [m].

2.2.8.2 Height of watertight exostructure H_E

The height H_E is the height from baseline to the upper edge of watertight exostructure elements.

2.2.9 Draught T

The draught *T* in surfaced condition is the maximum vertical distance between the baseline and the water surface [m].

2.2.10 Displacement Δ

The displacement of the surfaced submarine ready for surfaced operation is Δ↑, the displacement of the completely dived submarine with fully lowered periscopes, masts and snorkels is Δ↓ [t].

2.2.11 Military load ML

The maximum additional load *ML* [kg] for military movable equipment and weaponry, like torpedoes, missiles, ammunition, etc. is contained here. Special personnel and other persons are included, but the crew is not part of the military load.

2.2.12 Diving depths

All diving depths are related to the lower edge of the pressure hull.

2.2.12.1 Nominal diving depth NDD

The nominal diving depth NDD is the diving depth for the unrestricted operation of the submarine [m]. The corresponding pressure is the nominal diving pressure *NDP* [bar].

2.2.12.2 Test diving depth TDD

The test diving depth *TDD* is the diving depth which is related to an external overpressure, to which the submarine is subjected under test conditions after completion or after essential repairs [m].

The corresponding pressure is the test diving pressure *TDP* [bar].

2.2.12.3 Collapse diving depth CDD

The collapse diving depth *CDD* is the diving depth decisive for the design of the pressure hull, where a collapse of the pressure hull shall be expected [m].

The corresponding pressure is the collapse diving pressure *CDP [bar]*.

2.2.12.4 Periscope depth PD

The periscope depth *PD* is the depth where the submarine can safely navigate in submerged condition with the periscope, a snorkel or optical hoistable masts [m] .

2.2.12.5 Snorting depth STD

The snorting depth *STD* is the depth where the submarine can operate in submerged condition, but with extended snorkel for provision of external air for machinery [m] .

2.2.12.6 Safety depth SD

The safety depth *SD* is the minimum depth at which the submarine operates without risk of collision with a large draught surface ship or any floating installation [m]. (Typically 30 – 40 m)

2.2.13 Velocities

2.2.13.1 Velocity v0↑

The velocity *v0*↑ is the maximum operational speed of the surfaced submarine [kn] at a number of revolutions of the propeller(s) according to the maximum continuous propulsion power surfaced (MCR [1])

2.2.13.2 Velocity v0↓

The velocity *v0*↓ is the maximum operational speed of the dived submarine [kn] at a number of revolutions of the propeller(s) according to the maximum continuous propulsion power dived (MCR[1]).

2.2.13.3 Cruise speed

The cruise speed is the expected economic, continuous ahead cruising speed of the submerged submarine, which provides the maximum radius of action.

[1] MCR = maximum continuous rating

3 Documents for approval

3.1 General

Before handling/ submission of any documents, information etc., a formal security agreement (FSA) between all parties (Class, yard, System supplier, Owner, naval administration) has to be available, in which the security classification and safe handling of the documents, certificates as well as other information shall be described and formally regulated.

Classified documents have to be submitted within a suitable transfer procedure agreed between naval administration and the DNV GL Security Officer.

Before the start of manufacture, documentation of the total system and drawings of all components subject to compulsory inspection, wherever applicable and to the extent specified below, shall be submitted to the Society in triplicate respectively in case of electronic submission as single issue.

Documents shall be written in English or another agreed language and SI units shall be used.

The documentation shall contain all the data necessary to check the design and loading of the system. Wherever necessary, calculations relating to components and descriptions of the system shall be submitted.

3.1.1 Once the documents submitted have been approved by the Society, they become binding for the execution. Any subsequent modifications require the Society's consent before they are implemented.

3.1.2 The Society reserves the right to request additional documentation if the submitted one is insufficient for an assessment.

3.2 Total system

The following documents shall be submitted:

3.2.1 A description (CONOPS Statement) of the submarine with details of its mode of operation, the proposed application and the essential design data including:

— nominal diving depth
— maximum operating time and maximum survival time
— maximum range of a mission
— external loads
— shock loads (if applicable)
— environmental conditions
— maximum number of persons in pressure hull
— general safety equipment arrangement plan
— divers' compression chamber, if applicable
— diving procedure
— speed (surfaced and submerged)
— type of power resp. propulsion and manoeuvring equipment
— weight of submarine, deadweight and ballast, displacement (submerged) including payload calculation
— residual displacement resp. reserve buoyancy
— further requirements defined by the naval administration.

3.2.2 General arrangement plan and drawings showing design details of the submarine, including specifications for materials, manufacture and testing.

3.2.3 Arrangement drawings (block diagrams) of the total system.

3.2.4 Failure Mode and Effects Analysis (FMEA), as far as required.

3.2.5 A comprehensive presentation of the intended corrosion protection measures.

3.2.6 Stability documentation

For every submarine a proof of stability shall be delivered, which shall contain:

— results of the stability investigations for the intact and damaged submarine, as well in submerged as surfaced condition and if applicable also in intermediate conditions
— permissible ice load (if applicable)
— presentation of the stability behaviour of the submarine
— measures for maintaining sufficient stability.

3.2.7 Manual for operation and maintenance

The manual for the operation shall include in detail the steps necessary for normal operation as well as for emergency operation in a clear and conceptual form and in the necessary sequence (e.g. as checklist). In addition the measures for the loading of the operating systems (e.g. batteries, gases) shall be defined. In addition the planned lifetime and the permissible load and mission cycles of components of the equipment (e.g. batteries, etc.) shall be defined herein.

The maintenance manual shall include all procedures for the preventive maintenance as well as for periodic inspections.

3.2.8 Operational records

All conditions relevant for operation (diving depth, mission time, damages, etc.) shall be documented herein.

3.2.9 Test and inspection program.

A test and inspection programme shall be developed in agreement with the Society.

3.2.10 Trial program.

A test and inspection programme shall be developed in agreement with the Society

3.3 Pressure hull

3.3.1 Drawings and calculations for the pressure hull shall be submitted with all essential particulars and details necessary for appraising the safety and including the specifications for materials, manufacture, welding and testing. The drawings are to show all the internal and external fixtures of the pressure hull (e.g. strengthening framing, bulkheads, machine bedplates, mountings, etc.), welding details, etc.

3.3.2 In addition, component drawings of the pressure hull equipment shall be submitted including:

— entry and exit hatches
— door panels and door frames
— block flanges
— pressure hull wall penetrations and their arrangement incl. torpedo tubes
— pressure tight bulkheads including doors and equipment
— diver’s lockouts, if existing
— escape trunks.

3.3.3 Drawings and descriptions of the space allocation and internal arrangements shall be submitted.

3.4 Exostructure

Plans and sectional drawings of the submarine's exostructure and supporting structure shall be submitted including details of such pressure hull fixtures as diving/ballasting tanks, gas tanks, stabilizing fins, rudders, streamlining elements, extension devices, snorkels, anchoring equipment, masts and venting pipes, etc.

3.5 Diving/ballasting, compensating/ regulating/ and trimming tanks

3.5.1 Arrangement details of diving/ballasting, compensating / regulating and trimming tanks with calculated proof of the submarine's static diving capability and stability when submerged and on the surface, including the intermediate conditions occurring when the submarine is diving or surfacing both normally and under emergency conditions.

3.5.2 For the open and closed loop control shall be submitted:

Assumed range of seawater density for operation description of the safety devices to prevent the nominal diving depth *NDD* from being exceeded, including the necessary piping diagrams and component drawings. This includes drawings of:

— solid buoyancy elements and their mountings

3.6 Pressure vessels, heat exchangers and filters

Drawings of the pressure vessels, heat exchangers and filters shall be submitted with all essential particulars and details necessary for appraising the safety of the equipment and including the specifications for materials, manufacture, welding and testing.

3.7 Piping systems, pumps and compressors

3.7.1 Schematic diagrams of all piping systems including details of:

— materials
— maximum allowable working pressure (inside and outside pressure, if applicable)
— allowable working temperature
— dimensions (diameter, wall thickness)
— media carried
— type of valves, armatures and connections used
— opening and closing times for automatic valves, etc.
— set points of safety valves
— description of normally open and normally closed positions
— type of hoses and compensators used.

3.7.2 Description of pumps, compressors and their drives together with all important design and operating data.

3.7.3 Listing of components filled with liquids with definition of the type of liquid (e.g. oil, water, etc.).

For hazardous medias additional data sheet and safety instruction to be delivered.

3.8 Control systems for depth, buoyancy and trim

Description of the control systems for depth, buoyancy and trim. This includes drawings and necessary piping diagrams of:

— compressed air system for blowing diving/ballasting tanks
— freeing systems
— emergency blowing
— diving and ballasting system
— regulating/compensating system
— trimming system

— control system.

3.9 Propulsion and manoeuvring equipment

Drawings and descriptions shall be submitted of the propulsion and manoeuvring equipment including engines, gears, couplings, shafting, propellers and rudders with details of:

— method of power generation
— mode of operation and control of the systems
— power consumption (type and quantity)
— method of power transmission to propulsion unit
— seals of pressure hull penetrations
— emergency sealing elements (for e.g. pneumo-stop etc.)
— hydraulic systems for operation of ruder, fins and plane
— operating range and response time of rudder, fins and plane.

3.10 Electrical equipment

3.10.1 A general arrangement drawing of the electrical equipment containing at least the following information:

— data sheet of battery
— voltage rating of the systems
— power or current ratings of electrical consumers
— switchgear and safety devices (e.g. overcurrent protection) with indicating settings for short-circuit and overload protection; fuses with details of current ratings
— cable types and cross-sections.

3.10.2 The power balance of the main and emergency/redundant power supply systems. (incl. Hotel load calculation)

3.10.3 Drawings and part lists of switchgear and distribution equipment.

3.10.4 Complete documentation for electric motor drives with details of control and monitoring systems.

3.10.5 Battery installation drawing with details of battery types, battery sub systems (like acid circulation, battery cooling etc.), chargers and battery room ventilation.

3.10.6 Details of electrical penetrations pressure hull, bulkheads, watertight or airtight bulkheads.

3.10.7 Diagrams showing allocation of pressure hull penetrations.

3.10.8 Diagrams showing arrangement of emergency light fittings.

3.10.9 Calculation of short-circuit conditions with details of circuit-breakers, power protection switches and fuses fitted to the main and distribution switchboards indicating their current ratings and breaking capacity.

3.10.10 Hazardous area lay out.

3.10.11 A list of electrical components installed in hazardous area including the type of explosion protection of these components.

Confirmation shall be submitted on DNV GL form F 184, the form can be obtained from the Society. The explosion certificates have to be added

3.11 Automation, communications, navigation and locating systems

3.11.1 Description of the complete instrumentation layout.

3.11.2 Description of the control and operating elements for the submarine and its equipment.

3.11.3 Description of the navigational and diving instrumentation, including speed, depth and position indicators.

3.11.4 A description of the safety and alarm systems, including H_2, O_2 and CO_2 monitoring.

3.11.5 Arrangement drawings/block diagrams of monitoring systems including lists of measuring points.

3.11.6 Documentation for electronic components such as instrument amplifiers, computers and peripheral units.

3.11.7 General diagrams and equipment lists for the communication systems and signalling equipment.

3.11.8 General diagram and description of the surveillance/camera system, if applicable.

3.11.9 Descriptions, general diagrams and equipment lists for the locating equipment.

3.12 Life support systems

3.12.1 Piping diagrams, block diagrams and descriptions of the systems and equipment used for breathing gas supply, circulation, purification and conditioning of the atmosphere in the pressure hull, including the monitoring equipment, for both under normal and emergency conditions.

3.12.2 Calculated proof of the adequate capacity of the breathing gas supply and air renewal systems under normal and emergency conditions.

3.12.3 Description of the facilities for supplying water, food and medicines and for the disposal/removal of waste.

3.13 Fire protection and fire-extinguishing equipment

3.13.1 Description of preventive fire precautions including fire resistant bulkheads and walls.

3.13.2 Fire protection plans.

3.13.3 Details of the nature and quantity of combustible materials in the submarine.

3.13.4 Drawings and descriptions of:

— fire detectors
— fire alarms
— fire extinguishers
— fire extinguishing system including safety devices for fire extinguishing media used
— ventilation system and operating procedure.

3.13.5 Analysis of the potential dangers in the event of fire.

3.14 Rescue system

3.14.1 Systems and Equipment
Drawings and descriptions of the measures inside the pressure hull and the rescue systems and equipment applied in the actual case for recovering the submarine and rescuing the crew shall be submitted. Details about the possible elements are defined in Sec.16.

3.14.2 Rescue Concept
A Rescue Concept indicating where damage control equipment is stored and evacuation routes are located shall be submitted. The frequency of checking and certifying the equipment shall be submitted with the plan.

3.15 Mating system

3.15.1 Description of system with details of operating parameters.

3.15.2 Design drawings of mechanical, electrical, hydraulic and pneumatic operating equipment.

3.15.3 Data concerning connecting conditions.

3.16 Class notations

If class notations are issued, the relevant documents have to be approved.

4 Failure mode and effects analysis (FMEA)

4.1 General

4.1.1 The Failure Mode and Effects Analysis (FMEA) has the purpose to identify possible failures in the total system, in subsystems and components of submarine and to describe the effects on the total system and its components.

4.1.2 For submarines an analysis concerning the function and availability of the submarine after occurrence of a single failure has to be submitted if requested by the Society.

4.1.3 The FMEA shall be executed in an early phase accompanying the design to be able to realize system modification in due time. A tabular form, e.g. according to IEC 60812 or IMCAD 039 shall be used.

4.2 Description of the subsystems relevant for the analysis

4.2.1 The FMEA shall represent an independent document and be understandable without consulting further documentation. This means that all relevant subsystems shall be described concerning the structure of their basic functions, the installed redundancies and especially the interfaces of the subsystems to each other.

4.2.2 The description shall provide the crew with a good overview of the submarine structure and the functionalities of the relevant subsystems. For all subsystems typical failure modes and their effects on the overall function of the submarine shall be indicated. Further on the corrective actions to manage these failures and their effects shall be provided.

4.2.3 For submarines the following subsystems are relevant for maintaining the overall function:

- pressure hull penetrations and equipment
- interior arrangement
- exostructure and related equipment
- systems for diving/ballasting, compensating / regulating and trimming
- vessels and apparatus under pressure
- piping systems, pumps and compressors
- propulsion and manoeuvring equipment
- generation and distribution of electrical power
- emergency power concept
- electrical protective systems
- automation, communication, navigation and locating equipment
- life support systems
- fire protection
- rescue systems
- additional arrangement for divers or special forces, as far as relevant
- mating equipment.

The system descriptions shall be completed by block diagrams according to [4.3].

4.3 Block diagrams of the relevant subsystems

For each relevant subsystem a block diagram shall be established. This block diagram shall contain the essential information on the system required for the failure analysis, which is normally:

- definition of the subsystems
- all essential components of the subsystems
- interfaces between the components of the subsystems
- interfaces to or from other subsystems (typical for hydraulic drives, compressed air systems and controls, etc.)
- arrangement for control of the total system
- supplies from outside the total system, if applicable
- further aspects depending on the actual design of the total system.

At interfaces the different types of power, media and data may be transferred.

4.4 Analysis of the different relevant subsystems

Each relevant subsystem shall be analysed with regard to the following essential aspects, in course of which further aspects may occur during the execution of the analysis, compare worksheet in [4.5]:

- failure of subsystems
- malfunctions of subsystems
- failure of components in a subsystem
- malfunctions of components
- interface failures between the subsystems, a subsystem and its components as well as between components themselves
- Interface analysis of which data, medium and power are transferred and how failures are spread via the interfaces to other subsystems/components.
- hidden failures
- check for hidden failures and the evidence of alarms to be provided
- arrangement of periodic testing where alarms are not practical

— failures because of external influences which may lead to simultaneous failure of redundant subsystems, e.g. changed environment conditions and their control, voltage and amperage fluctuations on power supply, contamination of supply media, etc.
— faulty operation of subsystems or components, only with certain probability.

4.5 Tabular work sheet

The analysis shall be carried out in tabular form with a work sheet according to the following example or e.g. according to IEC 60812.

The analysis has to consider all operational modes.

Table 1 Example of a tabular work sheet

ID Number	*Sub-system/ component*	*Type of Failure*	*Failure cause*	*Failure detection*	*Consequences for subsystem / component*	*Consequences for total system*	*Failure correction*	*Remarks*

4.6 Assumptions and defined limits for the analysis

During the analysis the assumptions shall be defined which influence the result of the analysis. Typical assumptions are e.g.:

— the crew is qualified and trained to safely operate the submarine
— the adjustments and switching operations prescribed in the operation manual are followed by the crew, etc.

4.7 Treatment of changes

In case of changes at the submarine FMEA shall be adjusted accordingly.

4.8 Conclusions

The FMEA shall contain a summary of the results of the analysis for the relevant submarine. In addition it should contain a listing of the main failures which may occur for the operation of the submarine and especially for keeping the manoeuvrability and ability for surfacing as well as the desired atmosphere in the pressure hull. For the crew training measures for incontestable handling of the submarines in the event of such failures shall be proposed.

A periodic check of the FMEA including practical trials is recommended.

4.9 FMEA test program

4.9.1 According to the FMEA a test program shall be established. The purpose of this program is to verify the assumptions and the expected operation behaviour of the submarine as defined in the analysis.

4.9.2 The program has to consider typical modes in the relevant systems and components including the worst case failure. All possible operational modes of the submarine shall be reflected.

4.9.3 The test program shall be agreed with the Society and needs to specify in detail how the test shall be carried out respectively how simulation is done and the responsible person to be in charge of the test.

5 Tests and trials

5.1 General

5.1.1 Submarines and their ancillary equipment are subject to constructional and acceptance testing. As a minimum requirement, this shall include verification of compliance with the workshop approval documents, inspection of workmanship, verification of materials and the relevant documentation and checking of dimensional tolerances. In addition, all the tests prescribed in the following shall be performed and documented, wherever applicable. About the presence of surveyors at these tests and trials the Society will decide in each individual case.

5.1.2 For series-manufactured parts, test procedures other than those prescribed may be agreed with the Society provided that they are recognized as equivalent by the Society.

5.1.3 The Society reserves the right to extend the scope of the tests where necessary and also to subject to test those parts for which testing are not expressively required by the rules.

5.1.4 Parts subject to compulsory inspection shall be replaced by tested parts. This is also applicable to spare parts.

5.1.5 Where submarines are equipped with a diver's lockout, the components and equipment concerned are also to be subjected to the tests prescribed in UWT Pt.5 Ch.1 and Pt.5 Ch.2.

5.2 Total system

On completion, the submarine shall be subjected to a functional and acceptance test in accordance with the trial programme approved by the Society. This shall include at least the following individual tests:

— inspection of assembly (where not already performed during supervision of manufacture)
— measurement of weight and buoyancy and checking of stability under normal and emergency conditions
— inspection of internal equipment, partition bulkheads with doors, floors and ladders
— testing of all safety devices including shut-off devices
— functional testing of diving/ballasting, regulating/compensating and trimming system
— functional testing of mechanical and electrical equipment
— high voltage test and insulation test on the electrical equipment
— check of electrical connections/penetrations in power distribution system (torque wrench)
— heeling test surfaced and submerged
— trimming test surfaced and submerged
— testing of the ballast release system (if provided)
— trial trip on surface with verification of buoyancy
— stopping test for different speeds ahead
— test of turning circles surfaced and submerged for different speeds
— trial trip submerged
— test of buoyancy influence of fin positions for different speeds
— hydrodynamic influence of all rudders
— testing of mating system
— functional testing of life support systems
— verification of the accuracy of all important instrument readings.

The tests of the total system under water shall be performed with diving depths up to the nominal diving depth *NDD*, see Sec.4.

5.3 Pressure hull

5.3.1 On completion of the machining work and any necessary heat treatment, before painting and installation of exostructure elements a visual check and NDT testing according to. Sec.5 [3.2] have to be executed, afterwards the pressure hull shall be subjected to a hydraulic external pressure test. This test may be performed either in a pressurized environment or as part of a submersion test carried out on the completed submarine. The test pressure shall be determined in accordance with Sec.4 Table 2. Test duration and temperature shall be agreed with the Society.

An underpressure test is recommended before the pressure test.

Pressure hull compartments (tanks) in which an internal overpressure may occur shall be subjected to a hydraulic pressure test at 1.5 times the maximum allowable working pressure of the compartment.

After the pressure tests, the pressure hull shall be examined for leaks, permanent deformations and cracks.

5.3.2 Pressure hull penetrations and closing appliances shall be tested for tightness by the application of an underpressure of at least 0.2 bar below atmosphere pressure inside the submarine.

5.3.3 If pressure hull windows are fitted, they shall be subjected to a hydraulic pressure test. The test may be performed after installation together with the pressure hull or individually in a testing device. The test pressure shall be determined in accordance with Sec.4 Table 2. Test duration and temperature shall be agreed with the Society.

After the pressure test, windows may exhibit no scratches, cracks or permanent deformation.

5.3.4 At the pressure test of the submarine the tightness of pressure-tight hatch covers shall be verified with test diving pressure *TDP*.

5.3.5 Doors in pressure-tight bulkheads are, if not possible otherwise, to be tested at the manufacturer's works with the test diving pressure *TDP*.

For pressure-tight bulkheads and doors in pressure tight bulkheads a tightness test with 0.2 bar underpressure shall be performed.

5.4 Exostructure

5.4.1 A inspection and load test shall be carried out on the arrangement, mounting and fastening of such equipment items as stairways, gratings, handrails, bitts, masts, navigating lights, towing devices, draught marks and other load bearing elements see also DNVGL ST 0377 *Standard for shipboard lifting appliances* (if applicable).

5.4.2 External structural components such as anchors, rudders, etc. shall be subjected to a functional test.

5.5 Diving/ballasting, compensating / regulating and trimming tanks and systems

5.5.1 Ballast tanks shall be subjected to a tightness test using air at an excess pressure of about 0.2 bar.

If such a test cannot be performed an adequate proof has to be submitted and agreed by the Society.

5.5.2 Pressure prov tanks, which vary their filling level by compressed air, shall be subjected to a hydraulic pressure test at 1.5 times the maximum allowable operating pressure, but at least at test diving pressure *TDP* of the pressure hull.

5.5.3 Trimming tanks, which are located internally in the pressure hull and which change their filling level by pumps shall be considered as gravity tanks, but if the filling level is varied by compressed air , they shall be subjected to an internal hydraulic pressure test with 1.5 times the maximum allowable working pressure.

Trimming tanks, which are arranged outside the pressure hull in the exostructure and which are varying their filling level by pumps shall be subjected to a test at external test diving pressure *TDP*, for the case of varying the filling level with compressed air, an additional internal test at 1.5 times maximum allowable working pressure will be required.

5.5.4 Diving, ballasting, compensating, regulating and trimming systems shall be subjected to a functional test for normal and emergency operation.

5.5.5 Safety devices shall be checked and tested with set pressure + 10% pressure ingrease after full opening of the safety valve, if applicable.

The measuring system and the safety as well as alarm systems shall be checked.

5.5.6 The manual filling indicators (like sounding pipes etc.) of the tanks and the elements for operation shall be subjected to a functional test.

5.6 Pressure vessels including heat exchangers and filters

5.6.1 Pressure vessels are to undergo a hydraulic pressure test before being insulated or painted. The test may result in no leakage or permanent deformation of the vessel walls.

5.6.2 The test pressure applied to pressure vessels shall generally be equivalent to 1.5 times the maximum allowable working pressure.

5.6.3 Pressure vessels and apparatus which may be subjected to external overpressure shall be subjected to an external pressure test. The test pressure shall be at least the test diving pressure *TDP* of the pressure hull.

5.7 Piping systems, pumps and compressors

5.7.1 Pipes

5.7.1.1 On completion but before being insulated or painted, all pipes are to undergo a hydraulic pressure test at 1.5 times the maximum allowable working pressure. Pipes under diving pressure shall be checked in addition with test diving pressure *TDP* (inside or outside pressure according to the actual load case).

5.7.1.2 After installation on board, all pipes are to undergo a tightness test at 0.8 to 1.0 times the maximum allowable working pressure complete systems. The duration and test media has to be agreed by the Society.

5.7.1.3 The safety devices shall be checked.

5.7.2 Pumps and compressors

5.7.2.1 Pump and compressor components including air dryer subjected to pressure are to undergo a hydraulic pressure test. For pumps the test pressure shall be 1.5 times the maximum allowable working pressure and for compressors 1.5 times the delivery pressure of the compressor stage concerned.

5.7.2.2 On completion, pumps and compressors shall be subjected to a tightness test at their maximum allowable working pressure. In addition, a performance test shall be carried out. With breathing gas compressors, the final moisture content and any possible contamination of the compressed gas are also to be determined.

5.7.2.3 The safety devices are also to be checked.

5.7.3 Other systems

5.7.3.1 The pressurized sanitary facilities including waste water tank shall be pressure tested with 1.5 x maximum allowable working pressure or in case of influence to the pressure hull with TDP.

Functional test of the safety blocked system shall be required.

5.7.3.2 A functional test of the galley waste ejecting system shall be carried out at *NDD*.

5.7.3.3 A functional test of the decoy flares ejecting system shall be carried out at *NDD*.

5.8 Control systems for depth, positive and negative buoyancy and trim

5.8.1 Diving/ballasting, regulating/compensating, trimming and freeing systems shall be subjected to a functional test under normal and emergency conditions. The indicating devices as well as the safety and alarm equipment shall be checked.

5.8.2 The diving/ballasting tank venting systems and the operating elements shall be subjected to a functional test under normal and emergency conditions.

5.9 Propelling and manoeuvring equipment

5.9.1 The installation of the propelling and manoeuvring equipment shall be checked and a performance test is required (Z-manoeuvre, turning circle, pitch of rudders and plains, max. speed, etc.).

5.9.2 The entire propulsion plant shall be subjected to a functional test, surfaced and submerged.

5.9.3 A lubricating test (oel analysis) shall be performed after at least 720 hours operating time if not otherwise specified by the manufacturer.

5.10 Electrical equipment

5.10.1 In principle all electrical motors, components, including steering and control panels, cables and lines shall be tested in the manufacturer's works in accordance with Pt.3 Ch.3. A detailed inspection scope has to be agreed with the Society.

5.10.2 All electrical systems and equipment shall be inspected and tested before the submarine is put into service.

5.10.3 Electrical protective devices shall be checked; in addition, an insulation test shall be performed on the electrical equipment in the pressure hull.

5.10.4 Electrical cables under external pressure shall be checked according to agreement between naval administration and the Society, see also Sec.12 [4].

5.10.5 All electrical equipment which is exposed to diving pressure shall be checked additionally for isolation after the first diving exposed to *NDD*.

5.11 Automation, communication and navigation equipment

5.11.1 Indicating and monitoring instruments shall be tested for the accuracy of their readings and their limit value settings.

5.11.2 Automatic control systems shall be checked for satisfactory performance under service conditions.

5.11.3 Normal and emergency communications equipment shall be subjected to a functional test.

5.11.4 Proof is required of the autonomy of the safety systems.

5.12 Life support systems

5.12.1 A functional test shall be carried out to verify the satisfactory functioning of the life support system under normal and emergency conditions.

5.12.2 The arrangement of the O_2, CO_2 and H_2 measuring devices shall be inspected, and they shall be checked for the accuracy of their readings at different abient pressure levels and their limit value settings.

5.12.3 Pipes for breathing gas and oxygen shall be tested for cleanliness (check of documents for cleaning procedure).

5.12.4 The installation of the ventilation system shall be inspected and the operation of the fans and fire flaps shall be checked.

5.13 Fire protection

5.13.1 The fire behaviour of the internal fittings and equipment shall be checked by reference to the relevant test Certificates and symbols, as applicable.

5.13.2 A check shall be made that the electrical heating systems and heaters are fitted with protection against overheating.

5.13.3 Fire alarm, detection and extinguishing appliances and, if provided, the fire extinguishing system shall be subjected to a functional test.

5.13.4 The CO_2 system has to be checked with air or other non-toxic gases as follows.

— pressure test
— tightness test
— function test.

5.14 Rescue system

5.14.1 Elements of the rescue system arranged outside the pressure hull shall be tested at test diving pressure *TDP*. In addition it shall be proven that the rescue systems function properly even with the submarine at the maximum permissible inclination and that sufficient stability of the submarine is maintained.

5.14.2 Where a mating device is provided, a test shall be performed to verify that release and transfer can only take place when the trunk is not under pressure. The safety devices shall be checked.

5.14.3 A functional test of the signal ejector shall be carried out at *NDD*. In case that a manual emergency operation mode is provided for the signal ejector this additional test shall be carried out at a diving depth of 50 m to avoid dangerous situation to the crew during operation.

5.14.4 As far as applicable functional or other tests of the applied rescue system used for recovering the submarine and rescuing the persons aboard shall be made.

6 Marking

6.1 Fittings, indicators and warning devices

All valves, fittings, controls, indicators and warning devices shall be provided with identification plates made of a material which is at least flame retardant. The identifying marks shall be clear and unmistakable (e.g. stating the short designation and/or the function of the item concerned).

6.2 Pressure vessels, gas cylinders

All pressure vessels and pressure gas cylinders shall be prominently and permanently marked with the following details:

— name or company designation of manufacturer
— serial number and year of manufacture (pressure vessels)
— serial number (gas cylinders)
— fluid(s)
— maximum allowable working pressure [bar]
— maximum allowable working pressure (for > 50°C and < -10°C)
— test pressure [bar]
— capacity (in litres)
— empty weight (of gas cylinders) [kg]
— date of test
— test stamp.

6.3

Permanently installed pressure gas cylinders, pressure vessels and gas piping systems are, in addition, to be marked with a permanent colour code in accordance with Table 2 and with the chemical symbol designating the type of gas concerned, if not otherwise defined by the naval administration. The marking of pressure gas cylinders shall be visible from the valve side.

Table 2 Marking of gas systems

Type of gas	*Chemical symbol*	*Colour code*	*NATO Colour code*
Oxygen	O_2	white	blue
Nitrogen/ CO_2	N_2/ CO_2	black	black
Compressed Air	----	white and black	brown
Helium	He	brown	white & brown
Oxygen/Helium gas mixture Breathing gas	O_2/He	white & brown	white & brown
Breathing Air		white	white
Control Air	----	white and black	black

The mating appliance shall be fitted with a prominent and permanently mounted name plate containing at least the following information in easily legible characters:

— name of manufacturer

— serial number and year of manufacture
— date of test and test stamp
— other data required by naval administration.

7 Spare parts

7.1

Submarines shall be provided with spare parts.

7.1.1 In order to restore machinery operation and manoeuvring capability of the submarine in the event of a damage at sea, spare parts for the main propulsion plant and the essential equipment shall be carried on board together with the necessary tools.

7.1.2 For batteries arranged within the pressure hull a sufficient set of cables with adequate cross section to bridge parts of the batteries or single cells has to be on board.

7.1.3 The scope of spare parts shall be documented and a relevant listing has to be on board.

7.1.4 The maximum life time of special spare parts, like gaskets, O-rings, hoses and other rubber materials has to be defined.

8 Maintenance

8.1 Maintenance program

A complete maintenance program (preferably based on computer program) including spare parts administration shall be presented to the Society.

The maintenance program shall be coordinated with the regular surveys for classification.

8.2 Maintenance by the crew

The command of the submarine is held responsible for the crew performing their part of the maintenance program regularly and with the necessary care.

8.3 Testing and inspection

After maintenance an inspection and testing of the maintained systems by the crew shall take place.

8.4 Repair and overhauling

Repair and overhauling have to be executed only by qualified shipyards and industrial companies, compare Sec.1 [5.1.2].

8.5

For spare parts see [7].

SECTION 3 BUOYANCY AND STABILITY

1 General

1.1 Classification

1.1.1 Submarines will be assigned class only after it has been demonstrated that their buoyancy and their static and dynamic stability in intact condition is adequate for the service intended. The level of intact stability for submarines shall generally meet the standard defined in the following, unless special operational restrictions reflected in the class notation allow a lower level.

The naval administration may apply for judgement according to other existing standards regarding intact stability, if the Society is accepting such standards as equivalent.

1.1.2 For the stability in damaged condition of the submarine relevant here, it is assumed that the pressure hull is undamaged but an important tank in the exostructure is not functioning because of damage. For this case sufficient stability has still to remain, see [4].

1.2 Documents for approval

The documents to be submitted are summarized in Sec.2 [3.2.6] to Sec.2 [3.2.8].

1.3 Definitions

The general definitions and also specific definitions for this section, like watertight, weathertight, centre of gravity, metacentre, etc. are given in given in Sec.2 [2].

2 Buoyancy

2.1 Buoyancy in surfaced condition

2.1.1 Depending on the type of submarine and the operation area the distance between the waterline in fully surfaced condition and the upper edge of entrance openings, air pipes, etc. which may be open for surfaced operation, has to be approved by the Society.

If there are bulwarks/hatchway coamings which are open at the upper side, adequate bilge systems shall be provided.

2.1.2 All submarines shall have a sufficient reserve of buoyancy in surfaced condition to meet the stability requirements of this section. This buoyancy reserve shall be proven by calculation.

2.1.3 The buoyancy reserve shall be at least 10% of the pressure tight volume of the submarine in surfaced condition.

2.1.4 Reserve buoyancy can be created with diving cells and hard foam elements. The foam elements are safely to be protected against external damage. Their pressure resistance, water absorption, resistance against ultraviolet radiation shall be proven in coordination with the Society. Heel compensation with hard foam elements shall be avoided. Exceptions shall be approved by the Society.

2.1.5 For open diving tanks it shall be proven for all intended seaway conditions that sufficient buoyancy is available at the heeling and trimming conditions to be expected.

2.1.6 For calculation and checking of the weight and moment balance of the submarine formal loading instructions are recommended.

2.1.7 Freeboard is the distance between the waterline and the upper point of watertight hatches at the deck of the exostructure. It has to be evaluated for all load cases acc. to Table 1.

2.2 Submarines with different watertight compartments

If the submarine is divided into two or several watertight compartments by watertight transverse bulkheads, the buoyancy behaviour of the partly flooded submarine has to be investigated. In the stability documentation shall be stated with which flooding condition buoyancy is still sufficient.

3 Intact stability

3.1 Load cases for stability

3.1.1 General

In general the following stability load cases have to be investigated. If these load cases are not to be applied for the actual case, other or additional load cases shall be agreed with the Society.

All load cases shall be investigated with the lowest as well as the highest defined water densities, compare Sec.4 [2.2].

Even keel of the submarine shall be assumed for dived condition.

Tanks with great breadth resp. great length shall be protected against the influence of free liquid surfaces by separating/baffle plates.

A summary of the different load cases is given in Table 1.

Table 1 Summary of stability cases

	1a	*1b*	*1c*	*2a*	*2b*	*2c*	*3a*	*3b*	*4a*	*4b*
	Surfaced						*Submerged*			
	Without ML[4]		*Icing*	*With ML [4]*		*Icing*	*Without ML[4]*		*With ML[4]*	
	All values are percentages of the maximum possible load …[%]									
Submarine [1]	100	100	100	100	100	100	100	100	100	100
Crew	100	100	100	100	100	100	100	100	100	100
Diving tanks	0	0	0	0	0	0	100	100	100	100
Trimming tanks	50	50	50	50	50	50	50	50	50	50
Compensating tanks [2]	[2]	[2]	[2]	[2]	[2]	[2]	20[3]	80[3]	10[3]	70[3]
Air	100	50	50	100	50	50	100	50	100	50
Oxygen	100	10	10	100	10	10	100	10	100	10
Hydrogen	100	10	10	100	10	10	100	10	100	10
Provisions	100	10	10	100	10	10	100	10	100	10
Fuel, lube oil	100	10	10	100	10	10	100	10	100	10
Ice loads			100			100	0	0	0	0

	1a	*1b*	*1c*	*2a*	*2b*	*2c*	*3a*	*3b*	*4a*	*4b*
	Surfaced						*Submerged*			
	Without ML[4]		*Icing*	*With ML* [4]		*Icing*	*Without ML*[4]		*With ML*[4]	
	All values are percentages of the maximum possible load …[%]									
Special personnel	0	0	0	100	100	100	0	0	100	100
Other military loads	0	0	0	100	100	100	0	0	100	100
1) submarine fully equipped 2) Depending on the geometrical arrangement of the buoyancy tanks the percentage for the most unfavourable stability case shall be applied 3) Exact percentage depending on ambient conditions, e.g. seawater density 4) Military load										

3.1.2 Load case 1a: Surfaced, start of the journey with 100% stocks, no military load ML
The submarine is fully equipped and manned, diving tanks are empty, trimming tanks 50% full, Buoyancy tanks empty, stocks and fuel tanks 100% full, any periscopes and masts drawn out, no military load ML (means no weapons, no ammunition, no special personnel and/or no additional equipment, etc.)

3.1.3 Load case 1b: Surfaced, end of the journey with 10% stocks, no military load ML
The submarine is fully equipped and manned, diving tanks are empty, trimming tanks 50% full, buoyancy tanks empty, stocks and fuel tanks 10% full, compressed air 50% and oxygen 10% full, any periscopes and masts drawn out, no military load *ML*.

3.1.4 Load case 1c: Surfaced, end of the journey with 10% stocks, no military load ML, ice accretion on parts above water level
The submarine is fully equipped and manned, diving tanks are empty, trimming tanks empty, buoyancy tanks empty, stocks and fuel tanks 10% full, compressed air 50% and oxygen 10% full, any periscopes and masts drawn out, no military load *ML*. Maximum thinkable ice loads considered, compare Sec.4 [2.2.3].

3.1.5 Load case 2a: Surfaced, start of the journey with 100% stocks, with military load ML
The submarine is fully equipped and manned, diving tanks are empty, trimming tanks are 50% full, buoyancy tanks empty, provisions and fuel tanks 100% full, any periscopes and masts drawn out, with military load *ML* (means including weapons, ammunition, special personnel and/or additional equipment, etc.).

3.1.6 Load case 2b: Surfaced, end of the journey with 10% stocks, with military load ML
The submarine is fully equipped and manned, diving tanks are empty, trimming tanks 50% full, buoyancy tanks empty, provisions and fuel tanks 10% full, compressed air 50%, oxygen and hydrogen 10% full, any periscopes and masts drawn out, with military load *ML*.

3.1.7 Load case 2c: Surfaced, end of the journey with 10% stocks, with military load ML, ice accretion on parts above water level
The submarine is fully equipped and manned, diving tanks and trimming tanks are empty, buoyancy tanks empty, provisions and fuel tanks 10%full, compressed air 50%, oxygen and hydrogen 10% full, any periscopes and masts drawn out, with military load *ML*. Maximum thinkable ice loads considered.

3.1.8 Load case 3a: Dived, start of the journey with 100% stocks, no military load ML
The submarine is fully equipped and manned, diving tanks are flooded, trimming tanks 50% full, buoyancy tanks 20% full, provisions and fuel tanks 100% full, any periscopes and masts drawn in, no military load *ML*.

3.1.9 Load case 3b: Dived, end of the journey with 10% stocks, no military load ML
The submarine is fully equipped and manned, diving tanks are flooded, trimming tanks 50% full,

buoyancy tanks 80% full, provisions and fuel tanks 10% full, compressed air 50%, oxygen and hydrogen 10 % full, any periscopes and masts drawn in, no military load *ML*.

3.1.10 Load case 4a: Dived, start of the journey with 100% stocks, with military load ML

The submarine is fully equipped and manned, diving tanks are flooded, trimming tanks 50% full, buoyancy tanks 10% full, provisions and fuel tanks 100% full, any periscopes and masts drawn in, with military load *ML*.

3.1.11 Load case 4b: Dived, end of journey with 10% stocks, with military load ML

The submarine is fully equipped and manned, diving tanks are flooded, trimming tanks 50% full, buoyancy tanks 70% full, provisions and fuel tanks 10% full, compressed air 50% full, any periscopes and masts drawn in, with military load *ML*.

3.1.12 Further load cases

If required, further load cases have to be investigated in agreement between the naval administration and the Society, e.g. for carrying a smaller Diver Transport Submarine or a Rescue Submarine (acc. to Sec.17 [2]. or Sec.17 [5].) piggyback on the rear exostructure deck or with different flooded compartments, etc.

It is within the responsibility of the naval administration to make allowance for extreme loading scenarios in case of severe situations (crisis/wartime). The Society may assist in the evaluation of such scenarios in which a defined deviation of the stability standard occurs.

3.2 Assumptions for the calculation

For unification and comparability between different projects the following assumptions shall be observed for the calculations submitted to the Society:

— The displacement shall be computed in metric tons (1000 kg).
— The range of the salt content for which the submarine shall be used shall be defined.
— The weight of the crew resp. of special personnel is normally assumed with 75 kg/person.

Depending on area of operation and the duty of operation this assumption may be too low and has to be agreed with the naval administration.

The density of all liquids used in tanks and bunkers shall be agreed with the naval administration.

Note:

If no other information is available, the following densities of liquids may be used:

— freshwater 1.000 t/m^3
— bilge water 1.005 t/ m^3
— waste water 1.050 t/ m^3
— fuel (diesel) 0.83 t/ m^3
— lubricants 0.90 t/ m^3
— fire extinguishing foams 1.15 t/ m.^{3}

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3.3 Righting levers

3.3.1 Definition

A righting lever h is defined as follows:

h = righting moment [mt] / displacement Δ ↑ or Δ ↓ [t]

3.3.2 Surfaced submarine

The righting levers h_{sw} of the surfaced submarine in still water have to be evaluated for the load cases defined in [3.1] and for the following conditions:

The levers in still water have to be evaluated for the heeling angles φ = 10°, 20°, 30° and 45° and shall be presented as lever arm curves. For operation in a seaway see [3.5.5].

3.3.3 Submerged submarine

The righting levers of the submerged submarine are following from the fact that the centre of gravity has to be situated below the centre of buoyancy:

$h_{Sub} = B\downarrow G \cdot \sin \varphi$ [m]

$B\downarrow G$ = vertical distance between centre of buoyancy and centre of gravity

3.4 Heeling levers

3.4.1 Definition

A heeling lever k is defined as follows:

k = heeling moment [mt] / displacement $\Delta \uparrow$ or $\Delta \downarrow$ [t] [m]

The heeling levers shall be determined for heeling angles φ = 10°, 20°, 30° and 45.

3.4.2 Surfaced submarine

The following heeling influences shall be considered:

3.4.2.1 Free liquid surfaces

In partially filled tanks and bunkers the liquids have free surfaces which contribute to the heeling moment by a heeling lever k_F as follows:

$k_F = \Sigma (p_i \cdot b_{\varphi i}) / \Delta \uparrow$ [m]

p_i = mass of liquids in tank/bunker i with free liquid surface [t]

$b_{\varphi i}$ = change of the centre of gravity in relation to the upright submarine, measured parallel to the design water line [m]

3.4.2.2 Turning circle

As far as necessary the motion in the turning circle with heeling lever k_D shall be considered. See also Sec.4 [4.6].

For the surfaced submarine the heeling lever k_D can be estimated with the following equation:

$k_D = 0.2 \cdot (v_0\uparrow^2 / LOA) \cdot (KG - T/2)$

KG = height of centre of gravity above baseline [m]

3.4.2.3 Wind

The calculation of the wind forces at the elements above the waterline has to be done according to Sec.4 [2.2.5]. These results in a heeling lever k_W. According to the area of operation the values for the wind velocity to be used shall be agreed with the Society.

3.4.2.4 Ice loads

If the planned area of operation of the submarine requires it, the calculation of the ice loads at the elements above the waterline has to be considered. These results in a heeling lever k_E.

For ice accretion the following ice allowance should be made:

- 30 kg/m^2 on the exposed weather deck
- 7.5 kg/m^2 for the projected lateral area of each side of the submarine above the water plane

— For other small objects, like masts, periscopes, etc., the projected lateral area should be computed by increasing the total projected area by 5% and the static moments of this area by 10%.

3.4.2.5 Load-handling loads
During the transfer of equipment, provisions and persons from land or a support ship to the one side of the submarine a heeling lever k_P may to be considered.

3.4.2.6 Tow-rope pull
During towing of the submarine a heeling lever k_T may be created by the tow-rope pull.

3.4.2.7 Military load ML
If the military loads are able to change their weight and position in transverse direction, a heeling lever k_M shall be considered for the situation creating the largest heeling lever.

3.4.3 Submerged submarines

For the submerged submarines the following influences which lead to heeling levers shall be considered:

— free liquid surfaces in tanks and bunkers, compare [3.4.2.1] with heeling lever k_F. $\Delta\downarrow$ shall be inserted instead of $\Delta\uparrow$.
— motions of the submarine in the three dimensional space with heeling lever k_D , compare [3.4.2.2] and Sec.4 [4.6].
— influence of military loads with heeling lever k_N, compare [3.4.2.7].

3.5 Criteria for intact stability

3.5.1 Summary of influences

The righting and the heeling levers are summarized in Table 2.

3.5.2 Proof of stability

3.5.2.1 The following weight reserves shall be included at least in the deadweight calculation:

— design: 1%
— construction: 2%
— maintenance: 1%.

A sufficient part of ballast shall be reserved for equalization of trimming moments. This reserve shall be proven by a trimming test, see [5.5].

3.5.2.2 Lever arm curves
The proof of sufficient stability shall be done by comparison of the curves of the righting levers h and the heeling levers k. Combinations of heeling moments according to Table 3 have to be considered. Decisive for the evaluation is the size of the remaining righting lever and of the static angle of heel. As remaining lever h_{rem} the remaining lever above the curve of the heeling levers is designated, see Figure 1.

3.5.2.3 Minimum values of stability
Between the angle of the static balance φ_{stat} and the angle of immersion of the first unprotected openingφ_{ref} or the angle φ' of the second intersection of the curves of the heeling and righting levers or the intersection of the righting lever with the abscissa, whereas the smallest angle has to be considered, positive remaining levers h_{rem} of at least 0.05 m in dived condition and 0.1 m in surfaced condition have to exist.

Decisive for the proof of initial stability is the size of the value *GM* (= vertical distance between centre of gravity and metacentre) for the surfaced submarine respectively the distance $B\downarrow G$ (= vertical distance between centre of buoyancy and centre of gravity) for the submerged submarine.

Table 2 defines the recommended minimum values for *GM* and $B\downarrow G$ depending on the displacement of the submarine.

Table 2 Minimum GM and B↓G values

Displacement [t]	*GM [m]*	*B↓G [m]*
200 - 500	0.15	0.22
500 - 1000	0.18	0.27
1000 - 2000	0.20	0.32
> 2000	0.22	0.35

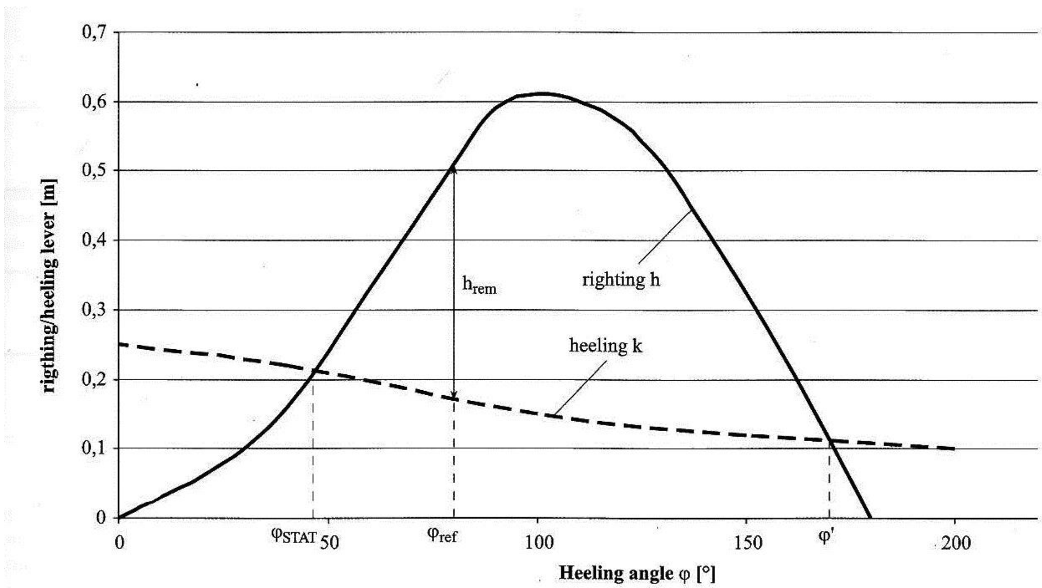

Figure 1 Lever arm curves

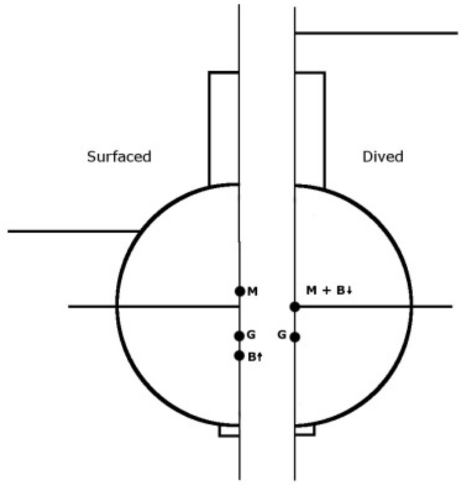

Figure 2 Characteristic centres of intact stability for surfaced and submerged submarines

3.5.2.4 Load cases

It is recommended to consider the load cases defined in Table 3 for practical operation.

Table 3 Summary of the righting and heeling lever arms

Load cases		*Surfaced / without seaway*		*Submerged*	
No.	*Designation*	*Righting*	*heeling*	*righting*	*heeling*
1a	100% stocks no military load	h_{SW}	$k_F + k_D + k_W$ $k_F + k_P + k_W$ $k_F + k_T + k_W$	---	---
1b	10% stocks no military load	h_{SW}	$k_F + k_D + k_W$ $k_F + k_P + k_W$ $k_F + k_T + k_W$	---	---
1c	10% stocks no military load, ice loads	h_{SW}	$k_F + k_D + k_W + k_E$ $k_F + k_P + k_W + k_E$ $k_F + k_T + k_W + k_E$	---	---
2a	100% stocks with military load	h_{SW}	$k_F + k_D + k_W + k_M$ $k_F + k_P + k_W + k_M$ $k_F + k_T + k_W + k_M$	---	---
2b	10% stocks with military load	h_{SW}	$k_F + k_D + k_W + k_M$ $k_F + k_P + k_W + k_M$ $k_F + k_T + k_W + k_M$	---	---
2c	10% stocks with military load, ice loads	h_{SW}	$k_F + k_D + k_W + k_M + k_E$ $k_F + k_P + k_W + k_M + k_E$ $k_F + k_T + k_W + k_M + k_E$	---	---

Load cases		*Surfaced / without seaway*		*Submerged*	
No.	*Designation*	*Righting*	*heeling*	*righting*	*heeling*
3a	100% stocks no military load	---	---	h_{sub}	$k_F + k_D$
3b	10% stocks no military load	---	---	h_{sub}	$k_F + k_D$
4a	100% stocks with military load	---	---	h_{sub}	$k_F + k_D + k_M$
4b	10% stocks with military load	---	---	h_{sub}	$k_F + k_D + k_M$

3.5.3 Draught

The draught of the surfaced submarine is the permissible draught which is possible because of buoyancy and stability. In general it will be achieved by load case 2a, for ice loads see load case 2c.

The draught has to be clearly marked in an unchangeable way on both sides of the submarine admidships as usual for ships classified by the Society.

3.5.4 Trimming diagram

The trimming diagram serves as graphic presentation of the range of mass and trimming moments in longitudinal direction of the submarine, which can be reached by the control of the water in compensating and trimming tanks as well as in special spaces (e.g. diver's lock-out).

These possibilities shall be shown in the trimming diagram in form of a polygon line. It has to be proven that the displacement due to additional loads (e.g. because of taking up of military loads) can be compensated by changing the filling of the compensating tanks as well as the trim by changing of the content of the trimming tanks. If the points representing the different load cases are lying within the polygon line, compensation is possible with operational measures on board.

3.5.5 Dynamic intact stability

3.5.5.1 This possible stability case for the surfaced submarine in a seaway has to be investigated in addition to [3.3.2] if longer journeys in a certain sea area according to CONOPS are planned.

In this case it is advisable to perform such investigations already in the design stage:

— for the submarine in the seaway in wave crest condition: h_C
— for the submarine in the seaway in wave trough condition: h_T
— for the submarine in the seaway, average value of wave crest and wave trough conditions: h_{WV}.

In the seaway especially the length of the submarine in relation to the critical wave lengths and heights in the operation area have to be considered. Thus a reduction of the above conditions may occur.

3.5.5.2 The dynamic stability shall be investigated in any case. The Society is able to offer for such a case special advice and relevant computation procedures.

3.5.6 Special construction types

For special types of construction of submarines the criteria defined above may not be directly applicable.

In this case special agreements have to be made with the Society.

3.5.7 Special transport situation

The stability of the submarine has to be reconsidered if it carries a smaller Diver Transport Submarine or a Rescue Submarine (acc. to Sec.17 [2] or Sec.17 [5].) piggyback on the rear exostructure deck. The lifting up of the combined centres of buoyancy and gravity shall not worsen the original stability situation to a remarkable extent.

Each load case has to be calculated separately and depending on the results, the amount of hard ballast has to be adjusted accordingly.

4 Stability in damaged condition

4.1 Extent of damage

According to [1.1.2] for the stability in damaged condition it will be assumed for the submarines relevant here, that:

— the pressure hull is undamaged,
— the exostructure is distorted,
— one important tank (e.g. a diving tank) within the exostructure fails because of damage,
— an emergency operation of the submarine is possible without endangering the embarked persons.

4.2 Surfaced submarine

4.2.1 Righting levers

Buoyancy and righting levers may be reduced in relation to [3.3.2] by the changed centre of gravity of the exostructure and the loss of buoyancy of the damaged tank.

4.2.2 Heeling levers

The lever k_F for free surfaces according to [3.4.2.1] has to be checked. Concerning the lever k_W for the wind load according to [3.4.2.3] it has especially to be proven as far as the area of wind pressure and its centre of gravity are changed because of the new floating conditions.

4.2.3 Criteria for buoyancy and stability

The following assumptions have to be met after damage:

— Openings to the pressure hull shall have sufficient freeboard to avoid ingress of water into the pressure hull with hatches open.
— The heel of the submarine shall not exceed φ = 22.5°. At the same time the trim forward and sternward shall remain below 10°.
— A positive remaining lever h_{rem} shall be guaranteed. Its value shall be agreed with the Society according to the type of construction.

4.3 Submerged submarine

4.3.1 It shall be checked how the centre of buoyancy is changed and if therefore more critical conditions arise.

4.3.2 Criteria for diving capability and stability

The following assumptions have to be met also after damage:

— The submarine has still to be able to surface in a safe way.
— The centre of weight has still to be below the centre of buoyancy.

5 Diving, trimming and heeling tests

5.1 General

5.1.1 Practical tests with the fully equipped submarine intended for normal operation shall be performed for a newbuilding or after essential conversions.

5.1.2 If an identical series of submarines is built on a yard, the following tests shall be performed for the first submarine only. If identical submarines are built in different yards, the tests have to be performed with the first unit of each yard.

5.1.3 The tests shall be performed in presence of a surveyor.

5.1.4 The tests defined in [5.2] to [5.5] shall be performed in the given sequence.

5.2 Diving test

The following steps shall be performed:

— An adequate depth of the water has to be chosen.
— The density of the water shall be evaluated.
— The diving tanks shall be filled completely with water, entrapped air shall be avoided.
— By adequate filling of the compensating tank(s) the weight condition of the submarine in the hovering condition of the submarine submerged shall be evaluated.
— By adequate distribution of the water between the trimming tanks the submarine shall be brought to even keel and the required filling of the buoyancy and trimming tanks shall be evaluated.

5.3 Heeling test submerged

The heeling test with the submerged submarine serves to evaluate the centre of gravity under water as basis for the stability considerations described in [3.1].

The condition of the submarine is according to the diving test in [5.2].

For the preparation of the test the following has to be considered:

— The influence of free surfaces in tanks, pipes, etc. shall be kept to a minimum.
— Starting angles of heel of more than 1° shall be avoided using weights/ballast.

The following steps shall be performed:

— The heeling/trimming of the submarine shall be started by a displacement of delivered test weights to the sides resp. forward and astern.
— These weights shall be chosen in such a way, that a heeling of 1.5 to 3.0 degrees to each direction occurs.
— The heeling angle shall be measured with two suitable devices, one of which shall be at least a damped pendulum with a reticule plate.
— The test shall be repeated at least 2 times to each side resp. forward and astern with different heeling moments, the average of the measurements shall be determined.
— At the end of the test the starting condition of the loads shall be re-established and the floating condition shall be checked for conformity with the starting position.
— The displacement has to be constant during the test.

5.4 Heeling test surfaced

The heeling test with the surfaced submarine with 100% empty diving tanks serves to evaluate the centre of gravity surfaced as basis for the stability considerations described in [3.1].

For the preparation of the test the following has to be considered:

- The test has to be performed in calm water with only slight wind.
- The draught forward, midships and astern shall be evaluated at port and starboard.
- All tanks shall be completely empty to avoid for certain the influence of free surfaces, the valves of the piping systems have to be closed.
- Starting angles of heel resp. starting trimming angles of more than 1° shall be prevented using additional ballast.
- The displacement has to be constant during the test.

The same steps shall be performed as for the heeling test submerged ([5.3]).

5.5 Trimming test

For the fully surfaced submarine with 100% empty diving tanks it has to be investigated by variation of the filling of the forward and aft trimming tanks if a floating condition on even keel can be reached and which trimming conditions can be reached forward and aft.

For the evaluation of the trimming status suitable measuring devices have to be used or the draught marks forward and astern have to be read.

SECTION 4 DESIGN LOADS

1 General

1.1 Scope

This section summarizes all loads to be considered for the design of a naval submarine.

1.2 Use of actual loads

The following rules for the loads do not release the designer and the shipyard from the proof of the actual loads in the special case. If it becomes known during the design procedure that the actual loads are higher than in these rules, the effective loads have to be considered in the calculation and the causes for it shall be defined.

1.3 Load plan

All relevant loads for a naval submarine shall be summarised in a load plan. From the loads defined in the following only the loads relevant for the actual case have to be considered.

2 Environmental conditions

2.1 General

As a minimum requirement, the design, selection and arrangement of all machinery, instruments and equipment located on board of submarines are required to conform to the environmental conditions stated in the following. Environmental conditions other than those stated may be approved for submarines for service only in particular areas of the world.

2.2 External environment

2.2.1 Water

If not agreed otherwise, the design of submarines and components is generally to be based on seawater within the temperature range from – 2°C to + 32°C, with a salt content of 3.5% and a density of 1028 kg/m^3. A value of 0.101 bar/m is to be applied when converting diving depth to pressure.

2.2.2 Sea states

2.2.2.1 Submarines shall be designed for sea states defined by the naval administration. At least allowance shall be made for accelerations of 2 g rms downwards and 1 g rms upwards in the vertical and 1 g rms each in the longitudinal and transverse directions (g = 9.81 m/s^2).

2.2.2.2 Wash of the sea

The load from wash of the sea is defined for all parts of the outside areas which are emerging from the water by a static substitutive pressure of:

$$p = 50 kN/m^2$$

All emerging parts such as tower, upper deck, etc. need in general only be considered up to 1 m above water surface at minimum.

For convex areas the substitutive pressure may be multiplied with cos α. The angle α is the angle between the line normal to the area and the assumed direction of the wash of the sea. It has to be proven that the wash of the sea can be locally borne, always under the assumption of normal loading. In addition it has to be proven that the resulting forces are absorbed by the relevant elements of the construction. This has to be proven for the most unfavourable direction of the wash of the sea and the maximum speed relations. If a more detailed investigation results in different loads, these shall be used.

2.2.2.3 Accelerations from submarine movement and seaway

The accelerations from the movement of the submarine in the sea depend very much on the type of task and the mode of operation of the submarine. They have to be defined by the naval administration and agreed with the Society.

Note:

As guiding values accelerations of 2 g rms vertically down, 1 g rms vertically up and 1 g rms sideward and in longitudinal direction may be assumed ($g = 9.81 m/s^2$).

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2.2.3 Ice

2.2.3.1 Ice accretion

On the parts of the submarine above the waterline ice may accrete during a mission in cold operating areas.

If there is no other data available, the following loads may be used:

— 0.30 kN/m^2 on upper deck and other horizontal areas
— 0.075 kN/m^2 for the projected side area of the superstructure on both sides
— for other little constructional elements, such as guard rails, the projected areas of the superstructure should be increased by 5%, the statically moment by 10%.

2.2.3.2 For special missions, like diving under ice the environmental conditions experienced shall be considered and special measures agreed with the Society.

2.2.4 Climate

For the external climate air temperatures in the range of -20°C to +45°C are assumed. Relative atmospheric humidity is assumed to be 80% and the atmosphere may be salt laden.

2.2.5 Wind

2.2.5.1 General

Wind loads shall be considered for strength analysis of extremely exposed parts of the surfaced submarine, (such as tower, if applicable masts, periscopes, etc.). In addition they have to be considered for stability considerations.

Maximum wind speeds, air density, etc. have to be agreed on with the naval administration according to the area of operation of the submarine. In the following sections standard values are provided.

2.2.5.2 Wind forces

$F_W = q_W \cdot c_f \cdot A_W$ [kN]

q_W = wind pressure
= $0.5 \cdot \rho_L \cdot v_W^2$ [kN/m^2]
ρ_L = density of air [t/m^3]
v_W = wind speed [m/s]
c_f = form coefficient
A_W = projected area exposed to wind forces [m^2]

Note:

For plane areas the form coefficient may be assumed to be c_f = 1.0; for rounded areas, the coefficient may be assumed to be c_f = 0.6.

The water content in the air may increase the air density ρ_L by about 30 percent.

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2.3 Internal environment

2.3.1 Internal climate

In all spaces, oil and salt-impregnated air ranging in temperature from 0 to 55°C is to be anticipated. Atmospheric humidity may attain 100% in the lower temperature range. Condensation is liable to occur. In specially protected control rooms, a relative atmospheric humidity of 80% at a reference temperature of 40°C shall be assumed.

2.3.2 Internal pressure

Equipment and instruments shall continue to function satisfactorily despite fluctuations in the air pressure inside the pressure hull ranging from 0.8 to 1.3 bar. In the diver's and escape lockout and in compression chambers, equipment and instruments should be designed for 1.5 times the maximum allowable working pressure.

2.3.3 Inclined positions

Satisfactory operation shall be ensured at (static and dynamic) inclinations of up to 22.5° in any direction measured in relation to the as-installed datum if not otherwise agreed between the naval administration and the Society. Short time (less than 5 minutes) inclinations of up to 45° shall not adversely affect operation and shall not cause damage, particularly to machine supports. Greater operational inclinations have to be adequately observed for design and testing.

2.3.4 Vibrations

Machinery shall not cause any vibration which imposes unacceptable stresses on other machines, equipment or the hull of the submarine. The amplitudes and accelerations defined in SHIP Pt.3 Ch.2 Sec.1 [4.2] shall be complied with.

3 Pressure heads

3.1 General

3.1.1 Pressure head plan

As part of the load plan a plan has to be established which contains all pressure heads to be considered for the different parts of the construction.

It has to be defined in which way the pressure tests have to be carried out.

It has to be defined for which components (e.g. diving/ballasting tanks, battery spaces, pressure hull, acoustic insulation bulkheads) underpressure tests respectively overpressure tests have to be carried out.

3.2 Pressures for the pressure hull

Reference points for the pressure heads are the water surface and the lower edge of the pressure hull respectively of a constructional element. The following pressure heads shall be considered.

3.2.1 Pressure for nominal diving depth

The nominal diving depth *NDD* [m] is the diving depth for unrestricted operation of the submarine. The nominal diving pressure *NDP* [bar] for this depth follows by multiplying the *NDD* value by 0.101 [bar/m], if not otherwise agreed with the Society for special operations.

For the fatigue life it has to be defined how often the *NDD* can be reached. The minimum number to be assumed for the calculation is 10 000 load cycles.

3.2.2 Pressure for test diving depth

3.2.2.1 The test diving depth *TDD* [m] is the diving depth to be reached during sea trials of the new building or after main overhauls under test conditions. The test diving pressure *TDP [bar]*, which has also to be included in the pressure head plan, is the pressure used for testing the pressure hull and equipment for its tightness and function. The test diving pressure *TDP* for the pressure hull is defined in Table 1.

3.2.2.2 For all pressure tight hatch covers including closures of the torpedo tubes and hatches of diver lockouts an additional pressure test shall be carried out see Table 2.

This pressure test has to be applied with a suitable device.

3.2.3 Pressure for collapse diving depth

The collapse diving depth *CDD* is the theoretical absolute maximum diving depth of the submarine. The collapse diving pressure *CDP* is the pressure for which the pressure hull may collapse at the earliest under a load endured for 1 minute. In general the coefficient for the collapse diving pressure is chosen according to Table 1.

3.2.4 Safety factor

The safety factor S_2 of the pressure hull is gained by dividing the collapse diving pressure *CDP* according to [3.2.3]. by the nominal diving pressure *NDP* according to [3.2.1].

The safety factor S_2 shall cover the following uncertainties:

— influences not covered by the calculation procedure
— influences as consequence of fabrication mistakes (material failures, manufacturing inaccuracies, welding mistakes, residual stresses from manufacturing), compare also App.B.
— negative influences during operation (corrosion deficiencies, unobserved buckling, alternating stressing)
— time dependent strength characteristics of the material.

Table 1 Safety factors S for test diving pressure and collapse diving pressure in relation to nominal diving pressure

Nominal diving pressure NDP [bar]	*10*[1]	*20*	*30*	*40*	*50*	*≥ 60*
Test diving pressure/nominal diving pressure $S_1 = TDP/NDP$ [2]	1.40	1.25	1.20	1.20	1.20	1.20
Collapse diving pressure/ nominal diving pressure $S_2 = CDP/NDP$ [3]	2.40	2.00	1.87	1.80	1.76	1.73

1) Minimum nominal diving pressure 5 bar
2) In the range *NPD* = 5 ….. 30 bar: $S_1 = 3/NPD + 1.1$
3) In the range *NPD* = 5 ….. 60 bar: $S_2 = 8/NPD + 1.6$

3.3 Pressures for pressure vessels and tanks

3.3.1 Nominal pressure

3.3.1.1 For pressure vessels and tanks which are not exposed to diving pressure, the nominal pressure is equal to the maximum allowable working pressure.

3.3.1.2 The additional layout pressure for pressure vessels and tanks exposed to diving pressure is 1.1 times the collapse diving pressure *CDP*.

3.3.1.3 The design and layout pressure is not decisive for the proof of fatigue strength, decisive is the maximum pressure occurring during operation which means the nominal diving pressure *NDP*.

3.3.2 Test pressure

3.3.2.1 The test pressure is the pressure for the proof of strength. The functional test shall be executed after the tightness test.

3.3.2.2 The test pressures are defined in [7] Table 2.

4 Other external loads

4.1 Flow resistance

If not the local hydrodynamic pressure is decisive but the resultant of the hydrodynamic forces, the maximum flow resistance for possible speeds shall be calculated using resistance coefficients or shall be evaluated by adequate tests.
For all parts of the shell area the local hydrodynamic pressure for maximum speed shall be considered.

4.2 Loads at emerging

If additional loads are occurring at normal emerging or at emerging in an emergency, e.g. by temporary water in the exostructure, these loads shall be considered.
A nominal (operational) pressure of at least 0.3 bar has to be assumed.

4.3 Accelerations from collisions

In longitudinal direction an acceleration from collision of 3 g has to be taken into account (g = 9.81m/s^2).

4.4 Loads from towing, anchoring, manoeuvring

The rupture load of the chosen anchor chains and the wire ropes shall be taken as design load for the relevant elements of the submarine structure.

If a winch is provided, the maximum load of the winch shall be considered for local loads.

4.5 Load on the propeller shaft

Where the propeller shaft penetrates the pressure hull, an additional load has to be considered. To the propeller thrust gained from calculations and/or model tests, the diving pressure, which acts on the propeller shaft at nominal diving depth *NDD*, shall be added to evaluate the total force on the propeller shaft respectively the thrust bearing.

4.6 Forces on rudders, fins and propulsion drives

The forces on rudders and fins shall be considered according to SHIP Pt.3 Ch.1 Sec.12.

Thrusts and moments from additional (mostly rotatable) propulsion drives shall be determined case by case.

4.7 Shock and noise

4.7.1 Naval submarines may also be exposed to shock forces created by air or underwater explosions from weapons. The limit loads in case of shock have to be defined by the naval administration and agreed with the Society.

For naval submarines with special ability to withstand shock loads class notation **Shock** may be assigned, compare Sec.1 [1.2].

4.7.2 Noise emissions should be kept to a minimum.

4.7.3 For shock and noise see also GL rules Naval Ship Technology Pt.3 Ch.1 Sec.16.

5 Loads on internal structures

5.1 Loads on watertight and non-watertight partitions

5.1.1 Watertight partitions

The static load is:

$p_{WTstat} = g \cdot \rho \cdot DD$ [kN/m²]

g = acceleration due to gravity
= 9.81 [m/s²]
P = density of water [t/m³]
DD = for load case II as per [6.3]: nominal diving depth *NDD* according to [3.2.1] [m]
= for load case III as per [6.4]: collapse diving depth *CDD* according to [3.2.3] [m]

In special cases the design depth for bulkheads shall be agreed between naval administration and the Society.

5.1.2 Non-watertight partitions

The static load p_{NWT} shall be defined by the naval administration or the Shipyard, but shall not be less than:

p_{NWT} = 2 kN/m²

5.1.3 Additional loads

In addition, static and dynamic loads from equipment mounted on bulkheads and walls have to be considered.

5.2 Loads on internal decks

5.2.1 Single point loads

P_E [kN] shall be taken as a part of the total load of the device, system, etc. according to the type of foundation.

5.2.2 Loads on accommodation and service decks

The following loads are minimum values. These loads may be higher, depending on the definitions in the load plan.

The static uniform deck load is:

p_{Lstat} = 3 kN/m²

The minimum static point load is:

P_{Estat} = 1.5 kN

5.2.3 Loads on machinery decks

The following loads are minimum values. These loads may be higher, depending on the definitions in the load plan.

The uniform static deck load is:

p_L = 4 kN/m²

The minimum static point load is:

P_E = 3 kN

5.3 Loads on tank structures not subjected to additional internal pressure

The static pressure is:

$p_{T1} = g \cdot h_1 \cdot \rho + 100 \cdot \Delta p$ [kN/m^2]

h_1	=	distance of load centre from tank top [m]
ρ	=	density of tank liquid [t/m^3]
Δp	=	adjusted pressure of the safety valve (if existing) respectively additional pressure component created by overflow systems [bar]

For fuel tanks, diving/ballast tanks, regulating/compensating tanks and trimming tanks connected to an overflow system, the dynamic pressure increases due to overflowing has to be taken into account in addition to the static pressure.

6 Load cases

6.1 Overview

In general the following load cases shall be investigated:

Load case I:	Surfaced submarine
Load case II:	Submerged submarine at nominal diving pressure
Load case III:	Submerged submarine at collapse diving pressure
Load case IV:	Submerged submarine at test diving pressure
Load case V:	Submarine during launching/docking
Load case VI:	Submarine suffering from foreseeable damage
Load case VII:	Submarine suffering from extreme threat damage

Further load cases may be agreed between naval administration and the Society.

6.2 Load case I: surfaced submarine

The following loads have to be included:

— water pressure according to draught *T*
— wind loads according to [4.1].
— flow resistance according to [4.2].
— wash of the sea according to [4.3].
— ice accretion according to [4.4].
— accelerations from submarine movements and seaway according to [4.6].
— acceleration from collision according to [4.7].
— loads from towing, etc. according to [4.8].
— load on the propeller shaft according to [4.9].
— forces on rudders, fins and propulsion drives according to [4.10].
— loads on internal decks according to [5.2].
— loads on tanks not subjected to additional internal pressure according to [5.3].

6.3 Load case II: submerged submarine at nominal diving pressure

The following loads have to be included:

— nominal diving pressure *NDP* according to [3.2.1]
— flow resistance according to [4.2].
— loads at emerging according to [4.5].
— acceleration from collision according to [4.7].
— load on the propeller shaft according to [4.9].
— forces on rudders, fins and propulsion drives according to [4.10].
— loads on subdivisions of the pressure hull according to [5.1].
— loads on internal decks according to [5.2].
— loads on tanks not subjected to additional internal pressure according to [5.3].

For the proof of the fatigue strength of the pressure hull at least 10^4 load cycles and a rectangular spectrum has to be used if not otherwise agreed by the Society.

6.4 Load case III: submerged submarine at collapse diving pressure

For the elements exposed to outside pressure load case III characterizes the ultimate loads at the collapse diving depth *CDD*:

— the pressure hull has to endure the collapse diving pressure *CDP* according to the pressure head plan
— single components have to endure 1.1 times collapse diving pressure *CDP*
— other loads are not to be considered.

6.5 Load case IV submerged submarine at test diving pressure

The following loads have to be included:

— test diving pressure *TDP*
— loads from strength, tightness and functional tests of different elements or at the submarine as a whole
— pressure loads on the different elements as defined in pressure load plan according to [1.3].
— additionally loads from load case II, which may occur at the tests (e.g. flow resistance, propeller thrust, rudder forces, etc.) shall be superposed.

6.6 Load case V submarine during launching/docking

The following situations have to be included:

— launching after new construction
— limiting docking conditions as defined in the docking plan
— worst docking condition taking account of any overhang at bow or stern
— possible extra loads on exostructure.

6.7 Load case VI: submarine suffering from foreseeable damage

The following loads have to be included:

— loads created by events that should be avoided, but the possibility of their occurrence cannot be ignored in the design. These may be navigation errors, fire or explosion, mal operation, etc.
— the extent of foreseeable damage is defined in Sec.3 [4.1]
— the assumed speeds, power, etc. shall be defined by the naval administration.

6.8 Load case VII submarine suffering from extreme threat damage

The following loads have to be included:

— the demand shall be defined in the CONOPS
— operational loads according to load case II
— military loads, like shock loads according to [4.11] shall be defined by the naval administration
— the resulting damage shall be defined case by case.

7 Summary of pressures for the elements of submarines

Table 2 presents a summary of the pressures which are defined in the different sections of these rules.

The following pressures are defined:

— design pressure PR:
  pressure as input in a calculation procedure, which includes certain safety requirements according to the respective professional field
— layout pressure PA:
  limit value of the pressure equal to or in relation to the collapse diving pressure *CDP*, which can
  be barely endured without consideration of the creeping behaviour and the creep rupture strength of the material
— test pressure PP:
  pressure to be used for practical tests
— pressure PB:
  maximum allowable internal working pressure, usually limited by safety equipment
— nominal pressure of components PN:
  the nominal pressure defined by the manufacturer
— tightness test pressure TTP:
  test to be applied for tightness tests.

Table 2 Summary of pressures

Element group/ Element	*Reference: Section or Appendix/ A-Z/No.*	*Layout/Design*		*Tightness test pressure TTP*	*Test Pressure PP*	*Further conditions*
		External pressure	*Internal pressure*			
Pressure hull and related elements:						
Pressure hull totally	Sec.5 App.A	PA = *CDP*	--	--	TDP	--
Torpedo Tubes	Sec.5	PA=1,1 x *CDP*	*PR=PB*	*TDP*	*1,5 PB*	--
Fatigue strength		PA = NDP	--	--	--	--
Bulkheads	Sec.5 [3.8]	PA = *CDP*	--	0.2 bar underpressure	--	--
Bulkhead doors	Sec.5 [3.6]	PA = 1.1 x *CDP*	--	0.2 bar underpressure	TDP	--
Compartments under internal overpressure	Sec.5	--	PR = PB	--	1.5 x PB	--

Element group/ Element	*Reference: Section or Appendix/ A-Z/No.*	*Layout/Design*		*Tightness test pressure TTP*	*Test Pressure PP*	*Further conditions*
		External pressure	*Internal pressure*			
Penetrations and closures	Sec.5 [3.3]	PA = 1.1 x *CDP*	--	0.2 bar underpressure	--	--
Pressure tight hatch covers lock out hatches	Sec.5 [3.6]	PA = 1.1 x *CDP*	--	TDP 0,2 bar underpressure	--	--
Syntactic foam	App. C	Design and tests to be agreed with the Society				
Snorting flaps and exhaust valves	Sec. 11 [2.1.3]	PA = 1.1 x *CDP*	--	TDP	--	--
Further fittings	To be designed and tested in coordination with the Society					
Tanks:						
Diving tanks	Sec.8 [3]	Wash of the sea	Static pressure	--	0.2 bar	--
Compensating tanks exposed to diving pressure/ pumps	Sec.8 [4]	PA = 1.1 x *CDP*	PA = gravity	--	*TDP*	--
Compensating tanks exposed to diving pressure/ com-pressed air	Sec.8 [4]	PA = 1.1 x *CDP*	PR = PB	--	*TDP* 1.5 x PB	--
Compensating tanks inside pressure/pumps	Sec.8 [4.2.3]	--	PA = gravity	--	*TDP*	--
Compensating tanks inside pressure hull / compressed air	Sec.8 [4]	--	PR = PB	--	*TDP* 1.5 x PB	--
Trimming tanks exposed to diving pressure/pumps	Sec.8 [5]	PA = 1.1 x *CDP*	PA = gravity	--	TDP	--
Trimming tanks exposed to diving pressure/com-pressed air	Sec.8 [5.2.2]	PA = 1.1 x *CDP*	PR = PB	--	TDP 1.5 x PB	--
Trimming tanks inside pressure hull/pumps	Sec.8 [5.2.3]	--	PA = gravity	--	--	--

Element group/ Element	*Reference: Section or Appendix/ A-Z/No.*	*Layout/Design*		*Tightness test pressure TTP*	*Test Pressure PP*	*Further conditions*
		External pressure	*Internal pressure*			
Trimming tanks inside pressure hull/compressed air	Sec.8 [5.2.3]	--	PR = PB	--	1.5 x PB	--
Waste water tank	Sec.9 [9]	PA = 1.1 x *CDP*	--	--	TDP 1.5 x PB	--
Vessels and apparatus:						
Exposed to diving pressure	Sec.5 App.A	PA = 1.1 x *CDP*	--	--	*TDP*	--
Exposed to diving pressure/fatigue strength	Sec.5 App.A	PA = *NDP*	--	--	--	--
Exposed to internal pressure	Sec.10 [2.3]	--	PR = PB	--	1.5 x PB	--
Fuel cells: valves, couplings, armatures	Sec.11 [3]	PA = *CDP* if outside PH	PA = 2 x PB	Leak test with He	1.5 x PB	--
Decoy/Signal ejector	Sec.9 [7]	PA = *CDP*	--.	--	*TDP*	--
Galley waste ejector	Sec.9 [8]	PA = *CDP*	--	--	*TDP*	--
Piping systems, pumps and compressors:						
Systems exposed to diving pressure	Sec.9 [2]	*1.1 x* CDP	*PR = PB*	*PB*	*TDP* *1.5 x PB*	--
Systems exposed to internal pressure/pumps	Sec.9 [2]	--			*1.5 x PB*	--
Compressors	Sec.9 [4]	--			*1.5 x PB*	*Test pressure related to each stage*
Hose lines and cables:						

Element group/ Element	*Reference: Section or Appendix/ A-Z/No.*	*Layout/Design*		*Tightness test pressure TTP*	*Test Pressure PP*	*Further conditions*
		External pressure	*Internal pressure*			
Type tests for liquids	Sec.9 [2.10]	PA = 1.1 x *CDP*	PR = PB	PB	4 x PB	For external pressure: PP = 1.5 Dp
Type tests for gases					5 x PB	
Type test for electric cables	Sec.12	PA = 1.1 x *CDP*	--	--	2 x PN (cyclic)	--
Routine test for electric cables	Sec.12	--	--	--	1.5 x PN (cyclic)	--
Routine test for metallic hoses	Sec.9	--	--	--	1.5 x PB	--
Routine test for non-metallic hoses	Sec.9	--	--	--	2.0 x PB	--
Drives and electrical equipment:						
Housings exposed to diving pressure		PA = 1.1 x CDP	--	--	Test pressure without mathematical proof: CPD	
Electric pressure hull penetrations and type test	Sec.12 [4.7.2]	PA = 1.1 x *CDP*	--	With air: 2 x PN with helium: 1.5 x PN	Hydrostatic 2 x PN (cyclic)	--
Electric pressure hull penetrations and plug-in connections/ routine test	Sec.12 [4.7.3]	--	--	--	Hydrostatic 1.5 x PN (cyclic)	S1 = TDP/ NDP ≥ 1.5
Rescue systems:						
Marker buoy		PA = 1.1 x CDP	--	--	TDP	--

Element group/ Element	*Reference: Section or Appendix/ A-Z/No.*	*Layout/Design*		*Tightness test pressure TTP*	*Test Pressure PP*	*Further conditions*
		External pressure	*Internal pressure*			
Refuge compartment	Sec.5 [7.5.2]	PA = *CDP*	--	--	TDP	--
Refuge compartment/ hatches	Sec.5 [7.5.2]	PA = 1.1 x *CDP*	--	--	TDP	--
Floatable rescue sphere	Sec.5 [7.6.2]	PA = *CDP*	--	--	TDP	--
Floatable rescue sphere/hatches	Sec.5 [7.6.2]	PA = 1.1 x *CDP*	--	--	TDP	--

SECTION 5 PRESSURE HULL

1 General

1.1

The following requirements apply to pressure hulls of submarines in which the crew is accommodated at atmospheric pressure.

1.2

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

2 Materials

2.1 General

2.1.1 Materials shall be suitable for the purpose intended and for the processes applied, e.g. welding, and shall meet the requirements stated below. Materials for which no special requirements are stated in this section are subject to recognized standards. See also Materials and Welding, Pt.2 Ch.5 – Special materials for Naval Ships.

2.1.2 The manufacturing, processing and testing of materials are subject to SHIP Pt.2 Ch.1 – SHIP Pt.2 Ch.3.

2.2 Approved materials

2.2.1 Rolled or forged steels and steel castings with guaranteed ductility and toughness are normally to be used for pressure hull fabrication. Steel plates, profiles and bars shall be made of fine-grained special steels with sufficient share of fine grain creating elements, e.g. Al, NB, V or Ti according to SHIP Pt.2 Ch.2 Metallic Materials and shall be produced keeping the requirements in [2.3]. Approved materials for pressure hulls are listed in Table 1.

Table 1 Approved materials for pressure hulls

Product type	*Grade of material*	SHIP Pt.2 *Materials and Welding*
Plates	Normalized and heat treated fine grained steels and pressure vessel steels with characteristics according to [2.3].	SHIP Ch.2 Sec.2 [3] SHIP Ch.2 Sec.3 [3]
Ends	Normalized and heat treated fine grained steels and pressure vessel steels with characteristics according to [2.3].	SHIP Ch.2 Sec.3

Product type	*Grade of material*	SHIP Pt.2 *Materials and Welding*
Profiles and bars	General-purpose shipbuilding and structural steels, provided these are killed, also fine-grained structural steels with characteristics according to [2.3].	SHIP Ch.2 Sec.2 [2]
Pipes	Seamless and welded ferritic steel pipes with characteristics according to [2.3].	SHIP Ch.2 Sec.5 [2] SHIP Ch.2 Sec.5 [4]
Forgings	Forgings, pressure vessels and piping with characteristics according to [2.3].	SHIP Ch.2 Sec.6 [6]
Steel castings	Steel castings pressure vessels and piping with characteristics according to [2.3].	SHIP Ch.2 Sec.8
Bolts and nuts	Unalloyed or alloy steel bar with characteristics according to [2.3].	SHIP Ch.2 Sec.5

2.2.2 Materials other than those mentioned in [2.2.1], e.g. austenitic stainless steels, may be used provided they have been proved to be suitable for the intended application. If no recognized standards are available, the relevant specifications shall be submitted to the Society for examination and approval. The use of brittle materials such as grey cast iron is not permitted.

2.2.3 If elements of the pressure hull shall be made of fibre reinforced plastics the Pt.4 App.C – Manufacture and Treatment of Fibre Reinforced Plastics (FRP) and Syntactic Foams has to be applied.

2.3 Special requirements applicable to materials for pressure hulls

2.3.1 Ductility

All metals shall have sufficient ductility (in terms of the elongation measured by tensile test). The elongation at fracture (A) shall conform to the values stated in the standard or material specification and shall not be less than 16 %. For screws an elongation of fracture A ≥ 14 % is required.

2.3.2 Impact energy

- Steel grades have to be conform to the impact energy values measured by notched bar impact test stated in the standard or material specification. In addition there is valid:
- Plates shall have an impact energy of at least 30 Joule measured on ISO V-notch transverse specimens at a test temperature corresponding to the plate thickness in accordance with Table 2.
- Pipes shall possess an impact energy of at least 27 J measured on ISO V-notch transverse specimens resp. 41 J on longitudinal specimens at 0°C.
- Cast iron shall possess an impact energy of at least 31 J measured on ISO V-notch specimens at 20°C.
- Forgings and steel profiles and bars which are load bearing and welded direct to the pressure hull, e.g. reinforcing rings or stiffeners, shall have an impact energy of at least 27 Joule measured in ISO V-notch longitudinal specimens at a test temperature of 0°C.
- Screws shall possess an impact energy of at least 52 J for tempered steels resp. at least 40 J for untempered steels measured on ISO Vnotch specimens at a test temperature of 20°C.

Table 2 Test temperature for notched bar impact test

Plate thickness [mm]	*Test temperature [°C]*
≤ 20	0
> 20 ≤ 40	-20

Plate thickness [mm]	*Test temperature [°C]*
> 40 ≤ 60	-40
> 60	by agreement

2.3.3 Non-destructive tests

2.3.3.1 With regard to their internal defects, plates with a thickness exceeding 8 mm shall as a minimum requirement satisfy the conditions for class 2, Table 1, of Stahl - Eisen -Lieferbedingungen (SEL) 072 or S_2/E_3 of the standard EN 10160 or equivalent standards.

Zones for longitudinal, round and socket seams with a width equivalent to the plate thickness, but at least 50 mm, shall satisfy the requirements according to class 1, Table 2 according to SEL 072 respectively of quality class $\mathbf{E}_3$ according to EN 10160.

Areas for the connection of lifting eyes, elements of the exostructure and other plates, which may also be stressed in thickness direction, shall satisfy the requirements according to class 0, Table 1 according to SEL 072 respectively of quality class S_3 according to EN 10160.

2.3.3.2 For forgings greater DN 250 the material quality shall be checked by the producer using suitable test procedures according to the SHIP Pt.2 Ch.2 Sec.6. The tolerance boundaries shall be agreed with the Society depending on the type of the component.

2.3.3.3 The producer has to submit to the Society the proof for the non-destructive tests.

2.4 Proof of characteristics

2.4.1 Proof of the characteristics of materials used for pressure hulls shall be supplied in the form of materials test Certificates according to SHIP Pt.2 Ch.4. The type of Certificate required for the product concerned is indicated in Table 3. Unless otherwise specified, the testing authority for acceptance tests to Certificate A / VL is the Society.

2.4.2 The evidence to be supplied in respect of the characteristics of products not included in Table 3 shall be agreed with the Society.

2.4.3 For small parts, like e.g. supports for consoles, welding lugs or other, not load-bearing and not pressure loaded elements Manufacturer Inspection Certificates shall be provided.

Table 3 Proof of quality characteristics

Product type	*Type of Certificates* [1,2]		
	A / VL	*B / W*	*C / TR*
Plates for the pressure hull	X	—	Not applicable for pressure hull materials
Steel profiles and bars (load-bearing elements)	X	—	
Pipes and sockets			
> DN 30	X	—	
≤ DN 30	—	X	
Forgings, forged flanges			

Product type	*Type of Certificates* [1,2]		
	A / VL	*B / W*	*C / TR*
> DN 250	X	—	
≤ DN 250	—	X	
Steel castings	X	—	
Bolts			
≥ M 30	X	—	
≥ M 16 alloyed and tempered steel	X	—	
other not here defined bolts	—	X	
Nuts			
≥ M 30	X	—	
Other	—	X	

1) Test Certificates shall be issued in accordance with SHIP Pt.2 Ch.1 – Materials - general. with following abbreviations:
A: DNV GL Material Certificate, B: Manufacturer Inspection Certificate, C: Manufacturer Test Report

2) 2 Test Certificates acc. to SHIP Pt.2 Ch.4
VL: DNV GL Certificate W: Works Certificate TR: Test report

3 Principles of manufacture, construction and testing

3.1 Treatment

3.1.1 Treatments applied to materials shall be properly carried out. Materials whose characteristics have been impaired by hot or cold forming shall subsequently be suitably heat-treated, see SHIP Pt.2 Ch.2 - Metallic Materials Sec.2 [1.8].

Concerning the criteria for adequate workmanship see also Sec.1 [5].

3.1.2 Concerning corrosion protection and corrosion allowance see [6].

3.1.3 Materials shall be so marked as to enable them to be identified and correlated with their respective test Certificates even during and after the fabrication of the pressure hull.

3.2 Welding

3.2.1 Approval

Companies wishing to undertake the fabrication of pressure hulls for submarines shall be approved by the Society with regard to their facilities, welding personnel and professional supervision.

3.2.2 Procedure tests

Before welding work is commenced, the properties of the joints to be welded have to be proven to the Society by welding procedure tests at the manufacturer's works.

3.2.3 Butt welds

All butt welds in the pressure hull shall be performed as full-penetration, multi-pass welds executed from both sides. In addition, the work shall be performed in such a way that it can be assigned a weld factor v of [1].

3.2.4 Fillet welds

The proof of the fillet welds shall be performed according to SHIP Pt.2 Ch.1 Sec.15 [2] and SHIP Pt.2 Ch.1 Sec.15 [3]. If no detailed proof by computation is required, the dimensioning shall follow Table 4.

Depending on accessibility a suitable test procedure shall be applied and to be agreed with the Society.

Table 4 Thickness of seams for double sided full-penetration fillet welds and double-bevel welds

Construction elements depending on the load	*Seam thickness* a / t_{min}
Pressure hull (PH):	
– Web of frame with shell of pressure hull (PH)	0.35
– Web of frame with flang	0.35
– Web frame with PH	0.50
– Bulkhead (Exception pressure tight bulkhead) with shell of PH	0.50
– Bulkhead (Exception pressure tight bulkhead) with flange of web of PH	0.35
– Deck with shell of PH	0.40
– Pressure tight bulkhead with shell of PH	1
Pressure tight bulkhead:	
– Stiffeners on bulkhead	0.50
– Flange of web with web	0.50
– Penetrations in bulkhead	0.50
– Supporting deck with bulkhead	0.50
Compensating tanks:	
– Connection to the main structure	0.50
Walls/decks/bulkheads of tanks:	
– Plating together	0.40
– Plating with shell of PH	0.40
– Stiffeners with plating	0.25
– Girders with plating	0.30
Exostructure:	
– Plating together	0.35
– Frames with shell	0.25

Construction elements depending on the load	*Seam thickness* *a / t_{min}*
– Web frames	0.30
– Bulkheads	0.30
– Frame connections to shell of PH	0.40
– Plating to the shell of PH	0.35
– Keel plates with web	0.50
– Brackets	0.45
Foundations:	
– Longitudinal and transverse girders	0.50
– Stiffeners and brackets	0.40
Decks and walls:	
– Plating together	0.30
– Plating with shell of PH	0.30
– Stiffeners with plating	0.15
t_{min} = smaller thickness of the plates to be connected Tension and bending loaded cruciform joints shall be connected with a/t = 0.7 $a = (t_{min})^{0.5} - 0.5 [mm]$	

3.2.5 Wherever practicable, no attachment shall be welded on the immediate vicinity of a weld joint. If this cannot avoid, the welds shall cross each other completely.

3.2.6 Where ends are made of welded plates, the welds shall be so arranged that they are exposed to the least possible stress. Welded joints passing through flanged curvatures shall be right angles to these.

3.3 Testing

3.3.1 On completion of the manufacturing work prior to coating of the pressure hull or pressure hull segments shall be subjected to a constructional check at the manufacturer´s workshop in presence of a DNV GL surveyor. The dimensions, thicknesses, materials, welding, etc. shall be checked for compliance with the approved drawings.

3.3.2 For pressure hull and loadbearing elements non-destructive testing shall be carried out as follows:

- all welded joints shall be subjected to visual inspection and shall also be examined for surface cracks
- all longitudinal butt welded joints and circumferential butt welded joints shall be subjected to 100 % radiographic testing
- at set-in plates the pressure hull shall be tested for lamellar tearing in the vicinity of the welding seam at the set-in plate
- welded joints between penetrations and pressure hull shall be magnetic particle tested if volumetric non-destructive test methods cannot be applied.

3.3.3 For carbon and carbon-manganese steel with thickness greater than 30 mm and for completion alloy steels the non- destructive testing is normally to be carried out not earlier than 48 hours after competition of the welds in question. For carbon and carbon-manganese steels with thickness 30 mm and less the time limit may be reduced to 24 hours.

3.3.4 All testing shall be carried out by qualified and certified personal. The NDT operators and the supervisors shall be certified according to the third party certification scheme based on EN ISO 9712 or ASTN central certification program (ACCP).

3.3.5 A x-ray sources shall be used for radiographic testing (RT) whenever possible. Gamma-ray sources may be used when qualified trough examination by the society.

RT may be replaced by ultrasonic testing and vice versa, when methodologically justifiable and in agreement with the society. Processing and storage shall be such that the radiograph recordings maintain their quality throughout the agreed storage time. The radiograph recordings shall be free from imperfections due to processing.

3.3.6 For ultrasonic testing (UT) the following apply:

The welded connection in question shall be tested for lamellar tearing, transverse and longitudinal defects.UT shall not be carried out on welds with thickness < 10 mm if not qualified and accepted down to permission for less than 8 mm.

3.3.7 For magnetic particle testing the following applies:

The object may be directly or indirectly magnetised. AC yoke or prods shall be used. Care shall be taken to avoid local heating of the test surface. The use of prods for permanent magnets is not permitted. The testing on each area shall be performed with the magnetic field shifted in at least two directions approximately perpendicular to each other.

3.3.8 For penetrant testing the following applies:

Colour contrast penetrants shall be applied at welds in unmachined welded condition. For smooth (flush grinded welds) fluorescent penetrants may be used. The surface temperature during testing shall be within the temperature range 10 – 50°C, if not, a procedure qualification test using ASME comparison blocks shall be carried out. The penetration time shall be at least 15 minutes.

3.3.9 Testing not described in this section may be required for certain products. In such case the testing standard or procedure shall be accepted by the Society or shall be carried out according to rules for classification SHIP Pt.2 Ch.4.

3.3.10 Acceptance criteria for welds in pressure hull are specified in Table 5:

Table 5 Acceptance criteria

Testing method	*Acceptance level*
Visual testing	EN ISO 5817 - Level B[1]
Magnetic particle testing	EN ISO 23278 -Level 2x
Penetrant testing	EN ISO 23277- Level 2x
Radiographic testing	EN ISO 10675 –Level 1
Ultrasonic testing[2]	EN ISO 11666 – Level 2

1) except for imperfection types as follows, for which Level C may apply: excess weld metal, excess convexity, excess throat thickness and excessive penetration
2) all imperfections from which the reflected echo amplitude exceeds the evaluation level shall be characterized and are characterized as planar, e.g. cracks, lack of fusion, incomplete penetrations, shall be rejected.

3.4 Cutouts and penetrations

3.4.1 Penetrations causing a weakening of the pressure hull shall be suitably strengthened, see App.A 6.7. The reinforcement has to form an integral part of the pressure hull or connecting piece. Set-on reinforcing rings are not permitted.

3.4.2 Openings and cutouts, e.g. pipe, cable and mechanical linkage penetrations in bulkheads and web frames, shall be rounded with a radius according to their load and are normally to be flanged.

3.4.3 Penetrations for piping, hoses and cables shall be protected, as far as possible, against mechanical damage by appendages or covers to the pressure hull.

3.4.4 The lay out of the penetrations through the pressure hull according to [3.4.1] to [3.4.3] has to be done at least for 1.1 times the collapse diving pressure *CDP*. In addition the lay out shall be done for an internal pressure of 1.3 bar absolute.

3.5 Pipe connections and flanges

3.5.1 The wall thickness of pipe connections shall be so dimensioned that they are fully able to withstand additional external loads. The wall thickness of socket-welded pipe connections shall be compatible with the wall thickness of the part into which they are welded. Pipe connections and flanges shall be socket-welded in such a way that the weld configuration includes the whole wall thickness of the pressure hull.

3.5.2 Pipe connections in accordance with Pt.3 Ch.5 Sec.11 [4] shall be provided for the connection of pipes.

3.6 Dished ends

The movement of the knuckles of dished ends shall not be inadmissibly restricted by mechanical restraints of any kind, e.g. retaining plates, stiffeners, etc.

3.7 Hatches, doors and access ports

3.7.1 Submarines shall be equipped with entry and exit hatches as defined by the naval administration. They shall be capable of being operated from both sides by one person at all expected angles of heel and trim. If necessary, mechanical aids without external power may assist. Each entry/exit hatch shall be designed to allow safe entry into and safe exit from the submarine without water penetrating into the interior.

The hatch covers shall open to outside and it shall be possible to secure them in the open position.

3.7.2 Entry/exit hatches shall be provided with a closing mechanism which enables sufficient pressure to be exerted on the hatch seal even when surfaced. The design of the closing mechanism shall further ensure that the hatch cannot be opened until pressure equalization has taken place.

Two measures shall be provided to guarantee that the hatches are closed and secured before diving, one of the measures shall be visibly noticeable.

3.7.3 Provision shall be made to enable doors to be opened from both sides. Door casings or hatches shall be provided with pressure-equalizing valves.

3.7.4 Doors and access ports for persons shall have a clear diameter of at least 500 mm. That of diver entry and exit hatches shall be at least 600 mm.

3.7.5 Sealing systems for hatch covers shall be approved by the Society. Pressure hull penetrations of shafts shall be provided with double sealing.

3.8 Propeller shafts

For the penetration of all propeller shafts from the exostructure into the pressure hull it shall be avoided that elastic deformations and vibrations are transferred into the pressure hull. For testing of the shaft see SHIP Pt.2 Ch.4 Materials and welding.

3.9 Pressure tight bulkheads

The layout of pressure tight bulkheads for division of the internal space has to be based on the collapse diving pressure *CDP*. The lay out of doors in these bulkheads shall be done according to [3.6].

4 Calculations

4.1 General

4.1.1 Pressure hulls, pressure bulkheads, hatches, windows, suspensions etc. shall be calculated in accordance with the relevant DNV GL rules or other code of engineering practice, agreed with the Society.

The calculations have to investigate the load cases defined in Sec.4 [6] as far as they are relevant for the actual project.

For pressure vessels which are designed partly or completely like pressure hulls and where the safety of the submarine depends in the same way (e.g. entrance trunks, torpedo tubes, containers for rescue equipment) calculations have to be designed and tested according to Sec.4 Table 2.

For pressure hulls and pressure vessels subjected to external overpressure see App.A.

4.1.2 For the calculation of acrylic windows reference is made to UWT Pt.3 App.C.

4.1.3 The calculations on which the design is based shall be submitted to the Society. The calculation may follow recognized procedures of continuum mechanics or finite element analyses may be used. If generally available programs are used, the user handbooks for their explanation have to be defined in the list of literature. In the calculation it has to be presented in clearly arranged way how the structure is divided into the elements and which elements have been used. It shall be possible to examine the calculation by definition of - among others – loads, boundary conditions, model description and comparison of the results with the requirements.

4.1.4 Allowance shall be made for the loads due to nominal diving pressure, test diving pressure, collapse diving pressure, internal overpressure and any dynamic loads, reaction forces and additional local stresses caused by fastening attachments and supports as defined in Sec.4. The calculations are also to take account of the environmental conditions stated in Sec.4 [2].

4.1.5 The load factors for dynamic loads shall be agreed with the Society.

Account shall be taken of the fatigue strength of the material. Pressure hulls shall be designed for a number of operating cycles to be agreed with the naval administration, but at least 10000 operating cycles.

The calculations for the proof of fatigue strength shall be done according to the requirements defined in Pt.3 Ch.1 Sec.20 unless otherwise agreed by the Society

4.1.6 For the weld factor of welds see 3.2.3.

4.1.7 The wall thickness of the shells and ends of seamless or welded pressure hulls shall generally not be less than 6 mm.

4.2 Design criteria

The following design criteria shall be applied to the calculation of components subjected to external overpressure:

- Tensile, compressive and bending stresses at nominal diving pressures shall not exceed the permissible values stated in [4.3].
- Other stresses like local or peak stresses have to be evaluated according to recognized standards.
- Components critical to stability shall be designed with a sufficient margin to withstand buckling, bulging and lateral buckling at collapse diving pressure *CDP* in conformity with the safety factors stated in [4.4]. For cylindrical shells, proof shall be provided of resistance to both asymmetrical and symmetric buckling.
- The possibilities of failure critical to stability and of plastic failure shall be analysed. Allowance shall be made for the reduction in the modulus of elasticity between the limit of proportionality and the yield point or 0.2% proof stress. Generally, the material shall be assumed to behave elastically and plastically (e.g. as specified in DIN 4114, sheet 2) without strain hardening. Where the compressive load/ deformation curve for the material has been determined in the presence of the Society's representative, this curve may be used as the basis for calculations.
- The collapse pressure/nominal diving pressure ratio indicated in Sec.4 Table 1 shall not be undercut.

4.3 Permissible stresses

For the nominal diving pressure is valid:

$$\sigma_{zul,NDP} = \min\{R_{m,20°}/A;\ R_{eH,t} / B\}$$

For the test diving pressure is valid:

$$\sigma_{zul,TDP} = \min\{R_{m,20°}/A';\ R_{eH,t} / B'\}$$

For the collapse diving pressure is valid:

$$\sigma_{zul,CDP} = \min\{R_{m,20°}/A'';\ R_{eH,t} / B''\}$$

$R_{m,20°}$ = guaranteed minimum tensile strength [N/mm^2] at room temperature (may be disregarded in the case of established fine - grained steels with R_{eH} ≤ 360 N/ mm^2 or where external overpressure exerts a compressive load)

$R_{eH,t}$ = guaranteed yield point or minimum value of 0.2% proof stress at design temperature

The safety factors A, A′, A′′ and B, B′, B′′ are shown in Table 6.

Table 6 Safety factors

Material	*Nominal diving pressure NDP*		*Test diving pressure TDP*		*Collapse diving pressure CDP*	
	A	*B*	*A′*	*B′*	*A′′*	*B′′*
Ferritic materials	2.7	1.7	—	1.1	—	1.0
Austenitic materials	2.7	1.7	—	1.1	—	1.0
Titanium	2.7	1.7	—	1.1	—	1.0
Note: Further materials have to be agreed with the Society						

4.4 Safety factors against buckling and tripping

Cylindrical and spherical shells shall be designed at collapse diving pressure to withstand elastic-plastic buckling under consideration of manufacturing influences. The adequate reduction factors are defined in App.A [6.2.5], App.A [6.3.3], App.A [6.6.6].

For frames a proof of stability against tripping on the basis of a stress calculation shall be performed, which meets the balance in deformed condition. The relevant limit values for stresses are defined in App.A [6.4.2], App.A [6.5.1], App.A [6.5.3] and App.A [6.5.4].

4.5 Allowance for manufacturing tolerances

4.5.1 In design calculations relating to pressure hulls, allowance shall be made for deviations from the ideal shape, e.g. with regard to the circularity of the shell configuration or the positioning of the stiffening rings see App.B.

4.5.2 If the manufacturing tolerances on which calculations have been based are exceeded, the deviations observed shall be used to carry out a mathematical verification of the maximum permissible pressure.

5 Proof of strength using numerical methods

5.1

For areas for which a numerical stress proof is required (see App.A) the ultimate strength limit has to be numerically proven. Should in exceptional cases a numeric proof for convex dished ends be required, than the critical area has to be modelled with the actually measured or the maximum permissible radius of curvature.

5.2

The computation has to consider the deformations in the balance and the elastic-plastic material behaviour as defined in App.A [6.2.3].

5.3

The suitability of the method and the choice of the element type have to be demonstrated with a computation model evaluating the failure pressures for the symmetrical and asymmetrical buckling in the area of the regularly stiffened cylinder. The numerically evaluated values should be 2% to 4% lower than the values analytically evaluated in App.A [6.2] and App.A [6.3].

5.4

The numerically evaluated failure pressure for cylindrical and conical pressure hulls shall in areas where a numerical computation has been applied, show a safety factor of 1.07 related to the collapse diving pressure *CDP*. For spherical shells the safety factor has to be agreed separately with the Society.

6 Corrosion protection and corrosion allowance

6.1 Corrosion protection

6.1.1 Submarines and all their accessories shall be effectively protected against corrosion. The principle requirements of SHIP Pt.2 shall be observed.

An active corrosion protection shall be secured, e.g. by mounting of sacrificial anodes in sufficient number and composition.

A overview plan with position and size of the anodes has to be evaluated.

6.1.2 Parts of the submarine which are later rendered inaccessible by the design shall be given permanent corrosion protection during construction.

6.1.3 Coating as anti-corrosion protection shall be applied according a plan. The content of the coating plan shall be: definition of wet and dry areas, materials to be protected, pressure vessels, areas with electrical protection, types of coating, thicknesses of coatings and test requirements.

If not otherwise defined the DIN EN ISO 12944-5 and for stainless steels DIN EN 10020:2000 to be applied.

6.1.4 Anti-corrosion additions applying to the interior of submarines shall meet the requirements under Sec.4 [2.3] and Sec.4 [7.1.1] of this section.

6.2 Corrosion allowance

6.2.1 The following corrosion additions apply provided an effective corrosion protection system is used and continuously maintained. Different additions required by the naval administration may be accepted by the Society.

6.2.2 Additions for steel

Based on the calculated values the scantling determination requires the corrosion addition t_K to the theoretical plate thickness:

- t_K = 0.5 mm in general
- t_K = 0.7 mm for lubrication oil, gas oil or equivalent tanks
- t_K = 1.0 mm for water ballast and wastewater tanks
- for special applications t_K shall be agreed with the Society
- For all elements of the submarine's structure which are forming a boundary of tanks, the t_K values for tanks have to be considered.

7 Equipment and interior facilities

7.1 Interior facilities of the pressure hull

7.1.1 For equipment, fittings, insulation, paintwork and preservative coatings inside pressure hulls, use may only be made of those materials and media which do not release any toxic or severe irritant gases under the atmospheric conditions mentioned in Sec.4 [2]. Wherever possible, this also applies to the effects of heat.

If gases which are not mentioned in these rules may occur because of special missions and requirements, these shall be monitored.

7.1.2 Wherever possible, only non-combustible or at least flame-retardant materials and media shall be used inside the pressure hull.

7.1.3 Battery spaces shall be so designed that they can accommodate the equipment needed for ventilation, air circulation, acid measurement and cooling. Compare also Sec.12 [3.4].

7.1.4 Tanks and bunkers located within the pressure hull shall be functionally designed and provided with sufficient ventilation and drainage facilities in each case. All tanks and bunkers shall be provided with manholes.

7.2 Allocation of space

As far as possible, the space occupied by the crew shall be separated from that in which machinery and equipment is installed and shall be acoustically and thermically insulated. Details about accommodation, sleeping facilities, sanitary arrangements, etc. shall be defined by the naval administration.

7.3 Equipment

7.3.1 The pressure hull shall be equipped with living quarters for the crew depending on the planned Concept of Operations.

The equipment shall include:

— berthing area
— mess area
— galley and provision store rooms
— refrigeration spaces
— sanitary rooms (toilets and baths).

The design has to facilitate regular cleaning of these areas to achieve an excellent hygienic working environment for the embarked persons.

This equipment is in the majority not subject to Classification and has to be arranged by the designer and shipyard according to the requirements of the naval administration.

7.3.2 The equipment for command and control systems, propulsion and auxiliary machinery, etc. is treated in other sections of this Rule.

7.3.3 Weapon systems are considered in this Rule as far as they need power from submarine systems and they are transmitting loads on the submarine.

7.4 Lighting

Each pressure hull compartment shall be adequately lighted, see Sec.12 [5].

7.5 Refuge compartment

7.5.1 Function

If required in the CONOPS a refuge compartment has to be installed within the pressure hull where the crew can remain in an emergency during the survival time even if other compartments of the submarine are flooded or have a contaminated atmosphere, compare also Sec.16 [3].

If the following requirements are met, the class notation **REF** may be issued, see also Sec.1 [1.2].

7.5.2 Structure

The structure of the walls surrounding this compartment has to withstand the collapse diving pressure *CDP*, if not otherwise defined by the naval administration.

The entrance and exit hatches (escape trunk to a mating system) shall be designed for 1.1 x *CDP*. The hatches shall be tightened by the surrounding water pressure.

7.5.3 Crossing arrangements

It shall be the aim that pipes, cables, etc., which have nothing to do with this compartment, don't pass through its walls. If pipes cannot be avoided, valves have to be installed within the compartment.

7.6 Floatable rescue sphere

7.6.1 Function

If required in the CONOPS a floatable rescue sphere has to be installed in a recess of the pressure hull and within the exostructure to carry the crew in an emergency and float up to the surface, compare Sec.16 [3].

If the following requirements and that in Sec.16 are met, the class notation **RES** may be issued, see also Sec.1 [1.2].

7.6.2 Structure

The walls of the sphere have to withstand the collapse diving pressure *CDP*, if not otherwise defined by the naval administration.

The entrance hatch(es) from the pressure hull and the exit hatch on the top shall be designed for 1.1 x *CDP*. The hatches shall be tightened by the surrounding water pressure.

7.6.3 Equipment

For floating elements and equipment see Sec.16 [3].

SECTION 6 EXOSTRUCTURE

1 General

1.1 Scope

The following requirements apply to the entire free flooding exostructure of the submarine including cladding, supporting structures and pressure hull fixtures.

1.2 Documents for approval

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

2 Materials

2.1

Materials shall be suitable for the intended application and manufacturing process and shall have been approved by the Society. Suitable proof shall be furnished of the characteristics of materials according to a DNV GL agreed material certificate.

2.2

The manufacture, processing and testing of steels are subject to SHIP Pt.2 Ch.1 – SHIP Pt.2 Ch.4.

2.3

If elements of the exostructure shall be made of fibre reinforced plastics App.C – Manufacture and Treatment of Fibre Reinforced Plastics (FRP) and Syntactic Foams has to be applied.

2.4

All other materials shall be manufactured and processed in accordance with recognized standards or to material manufacturer's specifications which have been examined and approved by the Society.

2.5

Materials for rigid regulating/compensating tanks shall be suitable for the proposed pressure and temperature ranges, shall have a low absorption factor and shall not suffer appreciable crushing under pressure.

2.6

The material for the exostructure shall be compatible with the material for the pressure hull, but the strength parameters may be different. If the materials and their electro-mechanical characteristics are different, corrosion protection may become necessary.

3 Principles for design and construction

3.1

The exostructure has to be designed in a streamlined form. Such a streamlined form has to achieve a low hydrodynamic resistance, a good steerability as well a reduced noise creation and sound radiation.

3.2

All free-flooding parts of submarines shall be designed and provided with openings in such a way that the spaces concerned can be fully flooded and vented. It shall be secured that those construction elements, which are not pressure-proof cannot get remarkable loads from the diving pressure and that no air bubbles remain in the construction after preparing the diving procedure.

3.3

When welding pressure hull fixtures such as diving tank mountings, operating equipment, stabilizing fins, rudders, etc., care shall be taken to minimize the resulting internal stresses in the pressure hull.

These fixtures, load bearing elements and other fixtures directly welded on the pressure hull have to be tested according to Sec.5 [3.3].

Stresses induced by the contraction of the pressure hull during diving shall be considered for the exostructure and its fixtures.

It shall be possible to inspect and preserve even those areas of the pressure hull adjoining fixtures.

The welding shop shall be approved by the Society, see also Sec.5 [3.2.1].

3.4

The exostructure of a submarine shall be so designed that parts of it can be crushed by collisions, etc. without damaging the pressure hull, and in addition steps shall be taken to exclude any likelihood of the submarine being caught up by parts of its exostructure.

3.5

Wherever possible, pressure hull penetrations for pipes, hoses and cables shall be protected against mechanical damage by pressure hull fixtures or cladding.

3.6

Buoyancy appliances mounted externally on the submarine shall be properly secured and protected.

3.7

All spaces of the exostructure shall be accessible with the possibility to walk in. The access shall be established by manholes which shall be gastight if they are located above the openings for flooding the diving/ballasting tanks.

The manholes shall be situated in recesses to protect their closing devices from mechanical damage. The manholes shall have plane sealing areas. If the access by manholes cannot be achieved, in free-flooding areas removable plates fixed with screws may be installed.

3.8

The exostructure shall be stiffened and supported by transverse and longitudinal frames and as far as necessary by web frames, middle and side stringers according to the design and strength requirements.

4 Calculations

4.1 Loads

4.1.1 The external loads which may effect the exostructure and which have to be considered for the computation, where applicable, are summarized in Sec.4 [2] and Sec.4 [3].

4.1.2 From equipment supported by the exostructure inertial forces created by submarine accelerations have to be considered by a factor of 2 to the weight of the equipment.

4.1.3 For safety under collision conditions, an acceleration of 3 g should be applied in the longitudinal direction ($g = 9.81\ m/s^2$) unless otherwise agreed by the naval administration. In these circumstances, the exostructure should be capable of deforming to absorb the impact energy without damage to the pressure hull.

4.2 Calculation procedure

4.2.1 Recognized calculation procedures shall be followed in performing calculations relating to components of the exostructure, see SHIP Pt.3 Ch.3. The dimensional design of the exostructure shall be such that, at the anticipated loads, the calculated stress is not greater than 0.6 times the yield strength.

For materials without definable yield strength, like copper, aluminium alloy, plastics, etc. the maximum allowable stress shall be agreed with the Society.

4.2.2 For the parts of the exostructure consisting of plate panels, proof of buckling strength shall be checked, see Pt.2 Ch.1 Sec.4 [6].

4.3 Corrosion protection and corrosion allowance

4.3.1 For corrosion protection of the exostructure see Sec.5 [6.1].

4.3.2 In general no corrosion allowance will be added for the exostructure.

5 Elements of the exostructure

The following requirements have to be considered for the design of the different elements of the exostructure.

5.1 Aft body

The aft body of the exostructure is the part behind the tower which is attached at the rear end of the pressure hull.

It has to support the shaft tube load and the loads of main ballast tanks as well as of the aft rudder and planes/rudders.

5.2 Shaft tube

The shaft tube in which the propeller shaft is situated shall be free flooding and has to be designed according to the requirements for the bearings of the propeller shaft. The shaft bearings shall be accessible in dry dock. It has to be avoided that forces from elastic deformation and vibrations of the aft body are transferred into the aft end of the pressure hull.

5.3 Fore body

The fore body of the exostructure is the part in front of the tower which is situated before the pressure hull.

It has to support the weight of supported equipment and the loads of main ballast tanks as well as of a forward steering system.

If a surfaced navigation in ice is intended, the requirements of RU SHIP Pt.6 Ch.6 Sec.1 have to be considered.

5.4 Keel

If a keel is arranged, it has to be designed to support the fixed ballast and to transmit the docking forces. Checking and corrosion protection of the pressure hull shall be guaranteed also in these areas.

5.5 Shell

The shell of the exostructure has to be carried out with a smooth surface. Connections of construction elements with steps in the shell have to be equalized if the course of flow will be influenced in negative way.

Because of safety reasons the shell has to be reinforced in the area of the diving/ballasting tanks. Screwed connections of shell elements are not permissible in the range of these tanks.

At openings for penetrations and at locations with additional loads the shell has also to be reinforced.

5.6 Frames and stiffeners

The exostructure has to be supported according to the design and strength requirements by transverse and longitudinal framing and as far as necessary by web frames, stringers, middle and side girders, etc.

5.7 Bulkheads

According to the design requirements transverse and longitudinal bulkheads for the subdivision of the spaces of the exostructure and ballast, trim and fuel tanks have to be provided. They have to be stiffened as far as necessary.

Not watertight bulkheads may have lightening holes. For penetrations through watertight or gastight bulkheads the sealing has to be designed to enable the possibility of checking and, if necessary, of maintenance works or even replacement.

If a bulkhead serves as boundary of ballast and trim tanks as well as support for torpedo tubes, the penetrations have to guarantee the two functions as tube bearing and tightening of the ballast and trim tanks. The connection between torpedo tube and supporting bulkhead has to consider the influence of manufacturing circumstances, like welding shrinkage, etc.

5.8 Fixed fins

According to the arrangement of depth control and side rudders fixed fore fins may be provided. They have to be dimensioned according to the requirements of manoeuvrability and dynamic stability of the steering characteristic of the submarine, compare Sec.11 [2.2].

If the fins are designed as free-flooding elements sufficient flooding and venting openings have to be provided.

5.9 Decks and platforms

As far as decks and platforms are needed for separation of the different spaces of the exostructure or for foundations of the various devices and equipment they may be used for stiffening of the exostructure at the same time.

5.10 Upper deck

5.10.1 If an upper deck is situated before and after the tower it has to be arranged in a streamlined form with sufficient flooding and venting openings. Where necessary, it has to be fitted with gratings or other measures to facilitate a safe, skid proof access to the submarine. All flaps have to be provided flush in the deck and shall be fastened in a shake proof way.

5.10.2 Further on the upper deck has to protect all devices and equipment situated in free spaces below, like containers with rescue equipment, rescue spheres, marker buoy and boatsman's equipment as fenders, ropes, etc.

5.10.3 A part of the deck area should be suitable for replenishment by helicopter. It shall be in save distance from the tower, but not too far from hatches.

5.11 Cladding

Cladding for e.g. detection and locating equipment and other extensions has to be designed according to the technical agreed spezification. As far as not the equipment demands special measures the covers have to be dimensioned for the loads defined in Sec.4.

5.12 Tower

In addition to the loads according to Sec.4 the exostructure forming the tower has to transmit the forces from the bearing of the periscopes, electronic masts, etc. and of the detection and location devices situated in the tower. Special requirements for the permissible dislocation of the bearings to guarantee the correct functioning of the liftable equipment have to be considered.

The supporting structural members have to be situated in line with bulkheads, web frames and frames of the pressure hull.

Accessibility to the spaces of the tower has to be enabled and sufficient flooding and venting openings shall be provided to guarantee free vertical flooding and empting. A low horizontal hydrodynamic resistance of the tower will also be an essential requirement.

SECTION 7 SEAMANSHIP EQUIPMENT

1 General

According to the area of operation and the mission of the submarine (CONOPS) the required seamanship equipment shall be provided.

2 Anchoring equipment

2.1

Anchoring equipment required by this section is intended of temporary mooring of a naval submarine within a harbour or sheltered area when the submarine is awaiting berth, tide, etc.

If required by the CONOPS also anchoring of the submerged submarine shall be possible.

2.2

Anchoring equipment is designed to hold a naval submarine in good holding ground in conditions such as to avoid dragging of the anchor. In poor holding ground the holding power of the anchors will be significantly reduced.

2.3

Therefore submarines are to be equipped with at least one suitable anchor including the necessary hoisting and lowering gear with a brake and indication device for the deployment length. The winch drum is normally to be situated in the exostructure, but the drive shall be located within the pressure hull. The driving power may be compressed air, hydraulic oil or an electric motor. Means shall be provided to lock the anchor in the desired position independent of motive power. Anchors are to be so arranged that, when stowed, they are flush with the exostructure.

2.4

Deployment, locking, recovery, abandonment shall be achievable without access to the exostructure.

2.5

It shall be possible to abandon anchor and chain in the event of motive power failure or fouling of the anchor.

2.6

The chain cable shall be stowed in a free flooded chain locker situated in the lower part of the exostructure.

2.7

For details of anchors and cables see Pt.3 Ch.1 Sec.18.

3 Mooring and towing gear

3.1 Mooring

3.1.1 The submarine shall be capable of being safely moored alongside a quay or another ship or even to buoys without using propulsion machinery.

3.1.2 Submarines are to be equipped with bollards, cleats, hawses or similar to enable a mooring of the submarine. The arrangement shall be chosen in a way to disturb the flow during underwater travel to a minimum. The aim should be to have the equipment flush with the exostructure when not being used.

3.1.3 The submarine shall be equipped with the necessary number and length of mooring lines. The exostructure has to include space for stowing of these lines.

Concerning the number and dimension of the mooring lines see Pt.3 Ch.1 Sec.18 [6].

3.1.4 For tensioning of the warping lines of bigger submarines (displacement $\Delta\downarrow$ > 1500 t) a winch shall be provided, which should have the controls in its direct vicinity.

3.2 Towing

3.2.1 Facilities shall be provided to allow the submarine to be towed at a speed to be agreed with the naval administration. It shall be possible that the towing connection can be broken by the submarine.

3.2.2 The strength of the equipment shall be based on the Safe Working Load (*SWL*) of the weakest element in the respective system.

3.2.3 If required by the CONOPS the submarine shall be provided with equipment for active towing of other ships or equipment.

3.3 Towing and mooring arrangement plan

3.3.1 A towing and mooring plan for the guidance of the commanding officer shall be available on board. It shall indicate the *SWL* of the lines and winches and describe the intended use for each shipboard fitting.

3.3.2 Also for submarines equipped for active towing establishing of a plan summarizing all locations, permissible loads, operating restrictions, etc. for the installed towing equipment is recommended.

4 Access to the deck

4.1 Guard rails

4.1.1 Depending on the size, the form and the accessibility of the upper deck it may be safety relevant, especially for works in the harbour or at the preparation of a diving mission, to provide guard rails at the upper deck. If the upper deck is rounded the stanchions are to be placed on the flat part on the deck.

4.1.2 The height shall be at least 1.0 m from the deck. The height below the lowest course is not to exceed 230 mm, The other courses are not to be spaced more than 380 mm apart. The guard rail shall be constructed according to DIN 81702, equivalent designs may be agreed by the Society.

4.1.3 As guard rails are disturbing during diving missions, it shall be possible to turn them down or draw them back.

4.2

As an alternative or as addition it may be recommendable to provide on upper deck a steel wire, a rail or a slot where the members of the crew can hang in their rescue belt/safety harness during the work on deck.

4.3

For replenishment by helicopter suitable means of earthing of persons and supplies have to be available. Marking of the area may be favourable.

4.4

For replenishment by boat, equipment for mooring and fendering of incoming boats as well as for facilitating to reach the deck from the boat shall be provided.

4.5

Suitable steps from the waterline to the deck are to be provided for safe excess at sea.

5 Retractable equipment

5.1 Masts

5.1.1 Masts for signal purposes, radar and sensor equipment respectively air pipes are normally retracted into the exostructure or turned down during diving journeys and are to be lifted/turned up for surface journeys. The required height and the scope of the devices to be mounted are to be agreed with the Society case by case.

5.1.2 For utilization of the mast for surface journeys the following loads are to be considered:

— wind forces according to Sec.4 [2.2.5].
— accelerations through movements of the submarine according to Sec.4 [2.2.2].

5.1.3 The flow resistance of the part of the mast in the water outside the exostructure has to be considered.

5.1.4 For the used material the limitation of deflection is in general the decisive criterion to secure a faultless and precise functioning of the devices.

5.1.5 If the bearings of the retractable masts are water lubricated, only materials which are completely corrosion-resistant against seawater are to be utilized.

For penetrating masts an adequate emergency sealing has to be provided.

5.1.6 For the lifting mechanism see DNV GL Standard for Certification No. 2.22 Lifting Appliances.

5.1.7 A retracting system for all pressure hull penetrating masts has to include:

— fast manual emergency retracting
— automatic retracting following certain design criteria like speed and depth.

5.2 Lights, signal shapes and sound signals

Submarines are to be equipped with lights, signal shapes and sound signals in accordance with the 1972 International Regulations for the Prevention of Collisions at Sea (COLREGS 1972). Requirements of the naval administration have to be observed in addition.

5.3 Position indicators, radio direction finders and navigation equipment

According to their mode of operation and application, submarines are to be provided with suitable equipment for locating the unit when travelling on the surface.

6 Lifting and hoisting devices

6.1

Lifting and hoisting devices including tackle and gear shall be available to transport torpedos, missiles, munitions, equipment and injured personnel to and from the submarine and on the submarine itself.

6.2

It shall not be possible to control a device from more than one operating position at the same time. As far as reasonably practicable, it shall be possible that the load can be viewed directly by the operator. If not, an effective means of communication shall be provided between the load area and the operating position.

6.3

The devices have to meet DNV GL CG-0377 and naval and national standards. Especially upon motive power failure the load shall remain in position and means are provided to safely move the load then to a pre-determined location.

6.4

Necessary instructions for assembly, testing, use and maintenance shall be present. Information including Safe Working Load (*SWL*) and expiry date shall be displayed on or adjacent to the equipment.

7 Ice protection

7.1

If surfaced operation of the submarine in ice-prone areas is required, at least the following design measures have to be provided:

7.1.1 Diving tanks and other buoyancy elements have to be strengthened.

7.1.2 Rudders and driving systems have to be strengthened.

7.1.3 If shielding as protection against drifting ice is planned in the bow area, the maximum possible forces at the connection points with the pressure hull are to be calculated.

7.2

The maximum ice thickness for safe operation shall be evaluated, considering the measures according to [7.1] and the existing propulsion power as well as hydrodynamic influences, etc.

SECTION 8 DIVING/BALLASTING/ COMPENSATING REGULATING AND TRIMMING SYSTEMS INCLUDING CONTROL

1 General

1.1

Naval submarines shall be fitted with systems for controlling depth, positive and negative buoyancy and trim and their associated components.

1.2

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

1.4

Pipes and pumps for these systems are treated in Sec.9. The requirements for rudders, planes and other manoeuvring systems are defined in Sec.11.

2 Principles of design and construction

2.1

For diving/surfacing may serve:

— diving/main ballast tanks
— compensating / regulating tanks
— trimming tanks as dynamic diving/surfacing assistance
— a combination of compensating and trimming systems
— rudders, planes as dynamic diving/surfacing assistance, see Sec.11
— propulsion systems as dynamic diving/surfacing assistance, see Sec.11
— hard ballast.

2.2

Diving/ballasting /compensating / regulating and trimming systems shall be so designed and arranged that the following conditions are satisfied (normal and emergency operation):

— the submarine shall be stable in every phase of operation esp. under all specified conditions of heeling and trim
— the systems shall remain functional even in situations of foreseeable damage where the pressure hull is not damaged
— it shall be possible to operate the submarine safely on the surface under the maximum permissible seaway conditions
— It has to be possible before initiating the diving procedure to check the necessary technical systems (Check “Ready for diving”).

— when submerged, it shall be possible to balance and trim the submarine at any depth up to or equal to its nominal diving depth NDD
— at periscope depth the submarine shall be enabled to keep this depth as required by the naval administration
— the submarine shall at all times be capable of returning safely to the surface
— in the event of failure of the regulating/compensating system the submarine shall be capable of surfacing by blowing of the diving/ballasting tanks and shall float on the surface in an upright stable position.

2.3

Flooding and bilge openings as well as vent valves shall be protected against obstruction respectively entrance of foreign matters by installation of e.g. suitable grids, filters.

3 Diving/ballasting system

3.1 Purpose

Diving/main ballast tanks shall serve for the diving of the submarine by filling with water and for surfacing by eliminating the water and filling with air. Thus the required buoyancy of the surfaced submarine has to be guaranteed.

3.2 Computation and materials

3.2.1 The materials, manufacture, design and calculation of diving tanks are to comply with the rules set out in Sec.5 and Sec.6, as far as applicable.

3.2.2 Diving/main ballast tanks shall be designed and fabricated to withstand the impact of waves, the internal static pressure and dynamic loads.

3.3 Arrangement

The diving/main ballast tanks are arranged normally outside of the pressure hull inside the exostructure in general in the fore and aft ship.

3.4 Filling and emptying

3.4.1 The volume of the diving/main ballast tanks has to be chosen in a way, that the submarine has enough freeboard in surfaced condition as well as that it owns enough reserve buoyancy, compare Sec.3 [2.1].

3.4.2 The filling shall normally be done by suitable flooding openings for water near the bottom of the tank, the venting at the same time through valves at the ceiling of the tank.

The emptying has to be done with closed venting valves by blowing with compressed air. For the layout of the air storage Sec.9 [4]. applies.

The minimum diving time will be determined by the naval administration in the CONOPS and the size of the diving/main ballast tanks as well as the free cross-sections of flooding and venting valves have to be determined accordingly.

For other concepts of diving/main ballast tanks eventual other deviating conditions shall be approved with the Society.

3.4.3 Diving/main ballast tanks shall be provided with vents enabling them to be completely flooded with water. The venting system shall be provided with a separate shut-off device for each individual tank. The vent valves shall be designed such as to prevent unintentional opening and should open against the pressure in the diving tank. Normally the vents are remotely operated, but manual emergency operation has to be possible.

The escaping air has to be safely guided through the exostructure and besides the tower.

3.4.4 Where diving/main ballast tanks or exostructure elements have flooding holes without means of closure, a shut-off device may be stipulated for the vent pipe.

Closing flaps may be desirable, if the signature of the submarine should be minimized! Such flaps have to be operated by remote control. If this drive fails, they have to open automatically.

3.4.5 Where diving/main ballast tanks are blown with compressed air, the blowing line for each tank has to be shut-off separately in case of emergency. It is necessary to ensure that blowing the tanks cannot cause an excessive overpressure, e.g. by installing a blow-out disk.

3.4.6 Where small diving/main ballast tanks shall be pumped out, the flooding holes shall be fitted with means of closure and steps shall be taken to ensure that the freeing of the tanks cannot cause an excessive underpressure. If freeing water is only possible with pumps, a standby bilge pumpshall be provided.

3.4.7 If several diving/main ballast tanks are provided which shall be applied for dynamic assistance of the diving/surfacing manoeuvres, each tank shall be controlled separately.

3.4.8 Emergency blowing

If required in the CONOPS an emergency blowing of the diving/main ballast tanks has to be installed.

3.4.8.1 This is a safety system for the submarine which shall in case of emergency bring the submarine to the surface within extremely short time (to be defined in CONOPS). At least the hatch on the tower has then to be free.

3.4.8.2 Blowing can be established by stored compressed air or by generators produced pressuring gas. The required compressed air has to be available at any time. The pressure gas system shall be independent from all other systems of the submarine.

3.4.8.3 To protect the tanks from the sudden pressure increase, burst flaps have to be installed at the low part of the tanks. They have to open at an overpressure below the design pressure of the tank.

3.4.8.4 The release of the blowing operation can be done manually from the central control station or from a limited number of remote control consoles in the different compartments. If required by the naval administration, an automatic release in case a certain diving depth is reached can be installed additionally.

3.4.8.5 It is recommended to install an emergency blowing flange for the main ballast tanks which shall be easily reachable from the exostructure.

3.5 Hard ballast

3.5.1 For equalization of weight changes during life time of the submarine, like keeping a design reserve or changing military loads or having different water density at various mission areas, hard ballast may become necessary to achieve neutral buoyancy.

3.5.2 The hard ballast shall consist of safely stored ballast weights.

3.5.3 At maximum ballast condition it shall be possible to create sufficient remaining positive buoyancy even in case of a failure.

4 Regulating/compensating system

4.1 Purpose

Normally compensating tanks shall be provided for a fine adjustment of the wanted depth and for balancing changes of buoyancy due to the consumption of provisions and supplies during the underwater operation, changes of the density of seawater, speed, taking-on or taking-off of military loads as well as effects of buoyancy/loss of buoyancy.

4.2 Computation and materials

4.2.1 The materials, manufacture, design and calculation of compensating tanks arranged outside or inside the pressure hull are to comply with Pt.2 Ch.5 Sec.16.

4.2.2 Pressure proof compensating tanks shall be designed for 1.1 times the collapse diving pressure *CDP*. If they change their filling condition with assistance of compressed air, a design pressure according to the maximum allowable working pressure of the compressed air system shall be considered.

4.2.3 Compensating tanks located within the pressure hull may be designed as gravity tanks provided that freeing is effected by pumps only.

4.3 Arrangement

The location of the compensating/regulating tanks should be chosen in a way that the floating condition of the submarine does not change significantly during filling and emptying.

4.4 Filling and emptying

4.4.1 The capacity of compensating/ regulating tanks has to be big enough to compensate for all the changes in buoyancy expected to arise during the planned diving operations plus a reserve capacity of at least 10%.

4.4.2 Regulating/compensating tanks may be freed by compressed air or by pumping. The quantity of water admitted during flooding and expelled during freeing has to be indicated. For that purpose regulating/ compensating tanks shall be fitted with content gauges, level indicators giving a continuous reading.

4.4.3 The vent pipes of regulating/compensating tanks shall be designed and arranged in such a way that water cannot penetrate into the submarine unnoticed. The section of the venting pipes shall be in accordance with the maximum rate of inflow/outflow.

4.4.4 The compensating tanks shall be safeguarded against excessive over- and underpressure.

4.4.5 Torpedo cells (compensating the weight of fired torpedos or missiles at a near centre of gravity) or diver lock-in/lock-out systems shall be flooded naturally via a flow limiting valve and to be emptied with the main bilge pump and compressed air.

4.4.6 The regulating pump has to transport water from the regulating/compensating tanks and other cells outboard via volume measuring devices. The pressure head of the pump shall meet at least test diving pressure *TDP*, the flow rate follows from the wanted regulating processes.

It is recommended that the pumps are designed for *CDP* of the pressure hull.

4.4.7 All pressure proven compensating tanks are designed for 1.1 x *CDP*.

5 Trimming system

5.1 Purpose

5.1.1 Trimming devices serve for producing a horizontal position of the submarine during a voyage at the same depth. The load cases defined in Sec.4 [6]. have all to be covered.

5.1.2 On the other hand an inclined position forward or astern can be adjusted with full intention to facilitate dynamic diving or surfacing.

5.2 Computation and materials

5.2.1 The materials, design and calculation of trimming tanks arranged outside of the pressure hull are to comply with Pt.3 Ch.5 Sec.16.

5.2.2 Trimming tanks located on the outside of the pressure hull in the exostructure of the submarine shall be designed to withstand an external load according to 1.1 times the collapse diving pressure *CDP*. If they change their filling condition with assistance of compressed air, a design pressure according to the maximum allowable working pressure of the compressed air system shall be considered.

5.2.3 Trimming tanks which are located inside the pressure hull and where the water is transferred by pumping may be designed as gravity tanks. If they change their degree of filling with the assistance of compressed air a design pressure according to the maximum allowable working pressure of the compressed air system shall be considered.

5.3 Arrangement of trimming tanks

To achieve a big leverage, trimming tanks shall be arranged as far as possible forward and aft on the submarine.

5.4 Filling and emptying of trimming tanks

5.4.1 The volume of the trimming tanks has to be chosen in a way that all planned trimming positions of the submarine can be adjusted by combined filling and emptying of the different tanks.

5.4.2 The transfer of water may be by compressed air and/or by pumping. A constraint circuitry shall ensure that the transfer always takes place in the desired direction. The quantities of water used for trimming shall be indicated.

5.4.3 If trimming tanks are arranged directly drainable for the emergency case, miss-switching in normal operationshall be avoided by suitable measures. The trim tanks shall be safe guarded against aggressive over/under pressure.

5.4.4 For trimming tanks outside the pressure hull (if applicable) ventilation into the pressure hull shall be provided with double shut-off devices. For combined compensating and trimming systems the overall system shall be agreed with the Society.

5.4.5 The trimming pump should be a pump with low noise level. To assist sucking of the pump the tanks should be set under pressure by compressed air while the different tanks are connected for pressure equalization by a pipe system.

5.4.6 A trim indicator (Inclinometer) and a redundant mechanical indication shall be provided at the central control stand and at emergency consoles. High accuracy is recommended especially at a minimum inclination range of +/- 10°.

5.5

The correct function of the trimming system shall be proven according to Sec.3 [5].

6 Control systems

6.1 Scope

The following requirements apply to all equipment for the static control of the depth, positive and negative buoyancy and trim of submarines.

6.2 General principles

6.2.1 All the remote operating units for controlling depth, positive and negative buoyancy and trim shall be grouped together at the diving control stand and shall be clearly marked.

6.2.2 The control station shall be equipped with indicating instruments which show continuously the position of the submarine, the state of depth and trim and the filling level of the diving/ballasting, regulating/ compensating and trimming tanks.

6.3 Systems and components

6.3.1 The design and construction of systems and components for the control of depth, positive and negative buoyancy and trim are to comply also with Sec.9.

6.3.2 Control and operating units and indicating instruments are subject to the rules set out in Sec.13.

6.4

For dynamic depth control see Sec.11.

SECTION 9 PIPING SYSTEMS, PUMPS AND COMPRESSORS

1 General

1.1

The following requirements apply to all piping systems, including valves, fittings, pumps and compressors, which are needed to operate the submarine. In addition, Pt.2 Ch.5 Sec.8 shall be observed, wherever applicable.

1.2

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

2 Principles of design and construction

2.1

All pipes, valves, fittings and pumps are to be dimensioned for a design pressure PR equal to the maximum allowable working pressure PB.

All such elements which can be loaded with the diving pressure are to be designed additionally for 1.1 times the collapse diving pressure *CDP* (according to the load case from outside or inside).

See also Sec.4 Table 2 with a summary for the different elements of the submarine.

2.2

Pipes which penetrate the pressure hull and which are loaded by diving pressure shall be fitted with two shut-off devices, one of which shall be located immediately at the pressure hull wall.

The type of shut-off devises, valves has to be approved under consideration of the specified external loads.

2.3

Gas pipes and electric cable conduits are to be routed separately wherever possible. Piping which may be susceptible to mechanical damage shall be adequately protected.

Piping passing through spaces inaccessible for maintenance shall consist of one piece.

2.4

Shutoff devices shall conform to a recognized standard. Valves and fittings with screw-down covers or spindles are to be safeguarded against unintentional unscrewing of the cover.

2.5

Safety relevant valves shall be operated manually also. Manual shut-off devices are to be closed by turning in the clockwise direction. Means have to be provided, that the valves can be operated and identified in an unmistakeable way, even in insufficient lighting condition.

2.6

The open and closed positions of all hull valves and essential shut-off valves shall be clearly indicated. If this is not practicable, equivalent procedures may be accepted.

2.7

All valves acting as sea connections shall be so designed that the tapered plug opens against the external pressure. Taper cocks shall not be used.

2.8

If hoses are used, the following has to be observed. Each hose shall be designed for the burst pressure, the minimum burst pressure is for liquids 4 times, for gases 5 times the maximum allowable working pressure.

3 Bilge pumping and ballast water equipment

3.1 Purpose

Submarines are to be equipped with a bilge system capable of freeing all the spaces inside the submarine from water due to condensation and leakage. Provisions of *MARPOL 73/78* have to be observed, if not otherwise defined by the naval administration.

3.2 Piping system

3.2.1 To prevent ballast water and seawater from penetrating inside the submarine through the bilge system, two non-return valves are to be mounted in front of the freeing connections. One of these non-return valves shall be placed in the pipe in front of each suction.

Locations of suctions shall be easily accessible.

3.2.2 All bilges are to be equipped with alarms at maximum water level.

3.2.3 The system shall be designed for remote control, only seldom used suction locations can be operated manually.

3.2.4 It is recommended to provide in the fore and aft submarine a coupling for connection of a fire fighting hose.

3.3 Interconnection with other systems

Where the bilge, seawater and ballast water systems are interconnected, the connecting pipes are to be fitted with valves in such a way that seawater is reliably prevented from penetrating inside the submarine through the bilge system even in the event of faulty switching of the valves or when the valves are in intermediate positions.

3.4 Bilge pumps

3.4.1 An electrically driven main bilge pump shall be provided. The pump shall be of the self-priming type and has to be able to transport water outboards at least down to test diving depth *TDD* or down to a depth defined in the CONOPS respectively into certain tanks. Priming shall be possible up to defined maximum trim angles.

If two pumps are provided, the piping system shall be so designed that each pump can also take over the tasks of the other pump.

3.4.2 Submarines with pressure tight bulkheads shall have at least one bilge pump in each compartment.

3.4.3 The bilge and ballast water system shall be provided with at least one standby pump. In case of interconnection of the bilge system with compensating and trimming systems the standby pump shall be able to serve all systems.

Where ballast and trim tanks are freed only by pumps, the standby pump shall be connected at minimum to two separated power sources.

3.4.4 The biggest pump of seawater cooling systems shall be connected to the bilge system as emergency bilge pump for minor diving depths.

3.4.5 Water entering during snorting operation has to be indicated via level indicator and shall be led into special snorting cells or in suitable bilges and pumped out automatically.

3.5 De-oiling system

3.5.1 From spaces, in which oily water may accumulate, the water has to pass a de-oiling system before transporting it outboards. The system shall be designed for continuous operation even if the submarine is submerged.

3.5.2 For the detailed requirements see Pt.2 Ch.5 Sec.8 [15].

4 Compressed air systems

4.1

Where air is used to blow diving/ballasting, regulating/compensating and trimming tanks, the supply of air carried on board shall be sufficient to blow the diving/ballasting tanks at least 4 times on surface and the regulating/compensating tanks at least 3 times at the nominal diving depth *NDD*. In normal operation, the compressed air receivers providing this supply may not be used for other purposes. In special cases deviation of this rule may be possible after agreement with the Society.

4.2

A compressor shall be provided for charging the compressed air receivers.

4.3

The compressed air supply shall be carried in at least 2 separate banks of receivers with the same total volume.

4.4

The compressed air systems are to be fitted, with valves in such a way that no unintentional pressure equalization can occur between different systems.

4.5

Where pressure-reducing valves are fitted, these are to be redundant via bypassing with manual control valves. In addition, a safety valve shall be fitted on the low pressure side of the pressure-reducing valve or an equivalent safety device shall be provided.

4.6

Compressed air systems are to be equipped with a sufficient number of pressure indicators.

4.7

Compressed air systems are to be equipped with an air dryer and a manual drain line.

4.8

Compressed air systems which come into contact with seawater are to be designed accordingly and are to be separated from other systems. In addition, measures are to be taken which as far as possible rule out the possibility of seawater penetrating into the compressed air system.

5 Hydraulic systems

5.1

All piping belonging to hydraulic systems which penetrate the pressure hull and which are necessary to the safety of the submarine shall be designed for the maximum allowable working pressure of the system (but min. *NDP* of the submarine). Wherever necessary, allowance shall be made for the possibility of a pressure rise due to the penetration of seawater into the system.

To protect the hydraulic system from over-pressurization, a safety valve shall be fitted and the discharged oil shall be returned into the system.

5.2

Hydraulic systems essential to the safety of the submarine are to be equipped with at least two power-driven pumps, one emergency pump with pneumatic drive and/or one hand-operated emergency pump.

5.3

In individual cases, hydraulic systems not designed for continuous operation may also be equipped with hand-operated pumps.

5.4

All valves and fittings, including hydraulic accumulators, which are fitted in submarines, are to be designed in accordance with [5.1]. Valves and fittings are to be placed in easily accessible positions.

5.5

Hydraulic systems are to be fitted with filters to keep hydraulic fluid clean. In addition, provision shall be made for venting and dewatering the system. Hydraulic fluid tanks are to be fitted with level indicators.

Wherever necessary, hydraulic systems are to be equipped with means of cooling the hydraulic fluid.

5.6

Hydraulic pipes should not be routed close to oxygen systems/pipes.

5.7

When selecting the hydraulic oil, allowance shall be made not only for the service conditions but also for the temperatures occurring during the commissioning or repair of the submarine.

5.8

Hydraulic systems are to be equipped with all the indicating devices necessary to the operation of the system.

5.9

Devices to avoid hydraulic shock are to be included.

6 Oxygen systems

6.1

Pipelines for mixed gases containing more than 25% oxygen are to be treated as pure oxygen lines.

6.2

All components and materials included in the system are to be suitable for oxygen in relation to their type and application and are to be carefully cleaned and degreased before putting into operation.

6.3

Manometers for oxygen or other mixed gases are to be marked as free of oil and grease.

6.4

In piping systems containing oxygen only spindle valves are permissible. As emergency shut-off quick-closing valves, like e.g. ball valves, may be provided at a suitable location, if these are adequately marked and secured against unintentional activation.

6.5

A easily accessible particle filter has to be installed near the gas storage.

6.6

Wherever possible, the pressure in oxygen lines shall be reduced at the gas storage facility to a pressure which is still compatible with an adequate gas supply.

6.7

Oxygen pipes are to be routed separately from oil pipes. Pipelines carrying oxygen under high pressure shall not be routed through accommodation spaces, engine rooms or similar compartments.

6.8

For oxygen lines with operating pressures above 40 bar high-alloyed Cr-Ni-steels with a content of Cr and Ni of together at least 22% or Cr-Si-steels with a Cr content of at least 22% shall be used.

6.9

Connection pieces for oxygen shall be designed to avoid burnout or shall be so arranged resp. to be protected that the personnel cannot be injured in case of burnout.

6.10

In the high pressure line of the oxygen system no quick closing devices, like ball valves, etc., shall be installed.

6.11

Spindle valves for oxygen with nominal diameters above 15 mm and operating pressures of more than 40 bar shall be so designed, that the spindle gear is outside the gas space.

6.12

Sealing materials which contain flammable elements and which come into contact with gases under pressure and oxygen influence may only be approved for connection parts if their suitability for pressures, temperature and type of mounting is proven.

6.13

For valves, fittings and connections for oxygen only lubricants are permissible, which are approved for the operating conditions.

6.14

Hoses shall be suitable for oxygen.

6.15

Concerning the requirements for oxygen plants in life support systems see Sec.14 [3.2.1].

7 System for ejecting of decoy flares

7.1 Purpose

7.1.1 By ejecting of decoy flares the submerged submarine may create a surface signal for exercises or in case of emergency.

7.1.2 By ejecting of fraud devices the submerged submarine may create an acoustic signal or gas bubbles in the water which would make detection more difficult.

7.2 Arrangement

The system is structured similar to a torpedo tube with pressure resisting outer muzzle door and end closure. These doors are blocked mechanically to each other so that they can never be opened at the same time.

7.3 Ejection

Ejecting may be done mechanically by a piston, with compressed air or water under pressure at minimum *TDD*.

8 System for ejecting galley waste

8.1 Purpose

For longer missions of submarines with a greater number of embarked persons, the galley waste has to be given outboards to avoid sanitary difficulties within the submarine. Consideration of environmental protection regulations in the actual operating area of the submarine is strongly recommended.

8.2 Arrangement

A pressure resisting lock of suitable size has to be installed in form of a strong tube with movable pressure resistant covers at the outside and the inner end. The opening of the covers shall be blocked mechanically to each other so that never both covers can be opened at the same time.

The outer cover can be combined with a streamlined flap to avoid disturbances of the water flow at the pressure hull.

8.3 Ejection

The ejecting of the waste can be arranged with compressed air or water under pressure at *NDD*.

9 Waste water system

9.1 Purpose

9.1.1 Grey water

The waste water from wash basins, showers and lavatories has to be gathered in a tank and given within due time outboards.

9.1.2 Black water

The waste water from toilets and hospital area has to be gathered in a black water tank. A special coupling for discharge shall be provided.

9.2 Arrangement

The gathering tank shall be pressure resistant up to *NDD* and located inside the pressure hull. A tank capacity for at least 24 hours service is recommended.

The feeding lines from each source to the tank shall be provided with shut-off valves and have to be blocked with the ejection line. The outboard line has to be provided with two valves in series situated directly at the pressure hull.

9.3 Ejection

The ejecting of the waste water shall be arranged with compressed air up to *NDD*.

Non-pressurised parts have to be suitably locked against overpressure from the ejecting line.

Consideration of environmental protection regulations in the actual operating area of the submarine is strongly recommended.

10 Drinking water system

Where existing, National Regulations and the Regulations of the naval administration shall be considered.

10.1 Drinking water tanks

10.1.1 Drinking water tanks shall be separated from tanks containing liquids other than potable water, ballast water, distillate or feed water.

10.1.2 In no case sanitary arrangement or corresponding piping shall be fitted directly above the potable water tanks.

10.1.3 Manholes arranged in the tank top are to have sills.

10.1.4 If pipes carrying liquids other than potable water shall be led through potable water tanks, they shall be fitted in a pipe tunnel.

10.1.5 On submarines with ice class **E** and higher drinking water tanks located at the submarine's side above the waterline shall be provided with means for tank heating to prevent freezing.

10.2 Drinking water tank connections

10.2.1 Filling connections shall be located sufficiently high above the waterline in surfaced condition and shall be fitted with two closing devices.

Filling connections are not to be fitted to air pipes.

10.2.2 Air/and overflow pipes shall be extended sufficiently high above the drinking water tank top within the pressure hull. For the protection of the tank safety valves or overflow pipes to the bilge shall be provided. The entry of insects has to be prevented by a fine mesh screen.

10.2.3 Sounding pipes are to terminate sufficiently high above drinking water tank top within the pressure hull. Easy sounding shall be possible and the sounding equipment to be easily desinfected.

10.3 Drinking water pipe lines

10.3.1 Drinking water pipe lines are not to be connected to pipe lines carrying other media.

10.3.2 Drinking water pipe lines are not to be laid through tanks which do not contain drinking water.

10.3.3 Drinking water supply to tanks which do not contain drinking water (e.g. expansion tanks of the fresh water cooling system) shall be made by means of an open funnel or with other means of preventing backflow. Less dead ends and easy cleaning are required.

10.3.4 The arrangement of the system shall allow easy cleaning.

10.4 Pressure water tanks/calorifiers

For design, equipment, installation and testing of pressure water tanks and calorifiers Sec.9 shall be observed.

10.5 Drinking water pumps

10.5.1 Separate drinking water pumps shall be provided for drinking water systems.

10.5.2 The pressure lines of the pumps shall be fitted with screw-down non-return valves.

10.6 Drinking water generation

Where the distillate produced by the submarine's own evaporator or reverse osmosis unit is used for the drinking water supply, the treatment of the distillate has to comply with current regulations of national health authorities or the naval administration.

11 Materials, manufacture and calculations

With regard to materials, manufacture and calculations:

11.1

For pipes, valves, fittings and pumps see Pt.2 Ch.5 Sec.8.

11.2

For compressors see Pt.3 Ch.5 Sec.6.

11.3

For hydraulic systems see Pt.3 Ch.5 Sec.14.

12 Operational media

12.1

Media such as hydraulic fluids, lubricants, etc. shall be selected in accordance with the proposed ambient conditions. They shall not tend to congeal or evaporate over the whole temperature range.

12.2

Hydraulic fluids, lubricants, etc. shall be so selected that water penetration or intermixture with seawater does not seriously impair the serviceability of the submarine.

12.3

Operational media shall not contain toxic ingredients which are liable to be hazardous to health through skin contact or when given off in fumes.

12.4

Operational media shall not be corrosive or attack other operating equipment (e.g. seals, hose lines, etc.).

12.5

The lubrication oil carried on board shall at least allow for one complete oil change of the diesel engines.

12.6

The provision of other essential operational media has to be agreed with the Society.

SECTION 10 PRESSURE VESSELS, HEAT EXCHANGERS AND FILTERS

1 General

1.1

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

1.2

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

1.3

The pressures on which the layout is to be based shall be taken from the relevant sections, especially Sec.4 [7] Table 2.

2 Pressure vessels and heat exchangers

2.1 Pressure vessels

Pressure vessels under internal and mainly external pressure are required in submarines among others for:

— pressure vessels for the operation, e.g. air groups, O_2 or mixed gases groups, H_2 storage, etc.
— compensating tanks
— trimming tanks
— fuel tanks
— equipment containers/housings, e.g. for rescue equipment, etc.
— pressure storages for hydraulic systems
— compression and diving chambers, lock-in/lock-out systems (see [3].)

2.2 Gas cylinders

— Gas cylinders for the purpose of these rules are bottles with a capacity ≤ 150 l, an outside diameter of ≤ 420 mm and length ≤ 2000 mm, which are charged with gases in filling stations.

2.2.2 On board of submarines gas cylinders are amongst others utilised for:

— compressed air for blowing tanks and bunkers
— breathing gases for the crew and persons aboard
— gases for drives, e.g. cyclic motors as well as fuel oil drives.

2.3 Lay out

2.3.1 Pressure vessels shall be designed under consideration of Sec.5 and to be tested according to Sec.2 [5].

2.3.2 For pressure vessels under internal pressure the requirements set out in the Pt.3 Ch.5 Sec.16.

2.3.3 For pressure vessels under external pressure normally Sec.5 has to be applied analogously and for the computation App.A shall be considered. The application of other recognized rules can be approved by the Society in individual cases. For this the requirements for products made of steel and titanium shall be considered according to Sec.5 [2.3] and for fibre reinforced plastics (FRP) the requirements according to App.C. shall be considered.

2.3.4 For pressure vessels located outside the pressure hull, the strength of which cannot be proven sufficiently by computation, a pressure test with a design pressure 1.1 x collapse diving pressure *CDP* has to be performed within a type test. Kind and scope of such a type test shall be agreed with the Society.

If it is guaranteed by suitable technical measures that at any time a defined internal pressure is existing, the test may be performed only with the differential pressure.

3 Compression and diving chambers

3.1 Purpose

If the CONOPS of a submarine requires the assignment of divers (as fighting special forces or for rescue operations, etc.) from the submerged submarine at considerable diving depth, the submarine has to be installed with a diver’s lock-out and a compression/decompression chamber.

For longer, complicated compression or decompression procedures it is recommended that via the diver‘s lock-out a mobile compression chamber can be docked on and the diver’s being transferred to a support vessel or to a landside hospital.

3.2 Design and construction

Compression and diving chambers in submarines shall be built and equipped in accordance with the DNV GL rules Underwater Technology UWT Pt.5.

SECTION 11 PROPULSION AND MANOEUVRING EQUIPMENT

1 General

1.1

The following requirements apply to all equipment for the propulsion and manoeuvring of submarines and to all steering gears, including dynamic depth control.

In addition, propulsion units are subject to the Pt.3 Ch.2 for Propulsion Plants and Pt.3 Ch.5 Sec.2 for steering gears.

1.2

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

2 Principles of design and construction

2.1 Propulsion units

2.1.1 Purpose

2.1.1.1 The motive power supply shall exhibit a level of redundancy, diversity and capacity to ensure that the propulsion and manoeuvring equipment remains operational and shall exhibit a level of continuity to ensure continuous operation according to the requirements defined in the CONOPS.

2.1.1.2 The propulsion and manoeuvring equipment shall fail safe and exhibit alternative modes of operation to fulfil the manoeuvring requirements during a failure condition.

2.1.2 Propulsion engines

2.1.2.1 Propulsion engines for submarines shall be designed for intermittent and continuous service as well as short time service with 110% power in manual operation mode. This time has to be defined in CONOPS.

2.1.2.2 Means shall be provided whereby normal operation of propulsion and manoeuvring equipment can be sustained or restored even though one of the auxiliary systems becomes inoperative.

2.1.3 Air-intake/exhaust outtake

2.1.3.1 When travelling on the surface, the air supply to internal combustion engines shall pass through an air/snorkel mast into the pressure hull via two pressure tight air flaps or the open tower hatch.

For the requirements to be met by the air/snorkel mast, see Sec.14 [3] and Sec.7 [5].

2.1.3.2 During surface operation exhaust gases shall be led out through the pressure hull via a double, pressure-tight shut-off flap or exhaust armatures.

At snorting operation the exhaust gases shall be led into the water via exhaust gas armatures protected by pressure switches.

If case too low pressure is created within the pressure hull, the diesel engines have to be stopped automatically. In this case and in any case of failures of the diesel engines, the underwater exhaust line has to be closed immediately.

If defined in the CONOPS, it is recommended to have silencers.

2.1.3.3 It has to be proven how the diving situation, the opening/closing of air-intake and exhaust gas outlet shall be controlled with the running/stopping of the diesel engines. If the top of the snorkel gets below the water surface, a suitable protection system has to close the snorkel. If the snorkel is below the surface for a longer time a low pressure controlled stopping system has to be activated.

2.1.3.4 The lay out has to consider the performance of the engines.

2.1.4 Fuel supply

2.1.4.1 Fuel supply arrangements from internal storage tanks shall be such that an amount of fuel is available without continuous transfer of fuel from external tanks and that means are provided to ensure that this reserve is of a suitable quality for use.

2.1.4.2 The weight of consumed fuel oil has to be compensated. In case of weight compensating by sea water, a water separating system has to be installed to protect the engines.

2.1.4.3 A connection flange for disposal of fuel compensating (sea) water shall be provided.

2.1.4.4 For the serial and parallel operation of fuel tanks a water trap shall be installed.

2.1.5 Electric propulsion

Electric propulsion motors shall be designed in accordance with the requirements stated in Sec.12.

2.1.6 Propeller/propeller shaft

2.1.6.1 The thrust bearing should be located in the same space as the propulsion engine.

2.1.6.2 Shaft penetrations through pressure hull walls shall be fitted with a gland of proven type designed to withstand the collapse diving pressure and has to be protected by an emergency gasket, e.g. pneumostop or stuffing box. For shaft penetration see also Sec.5 [3.7].

2.1.6.3 The lay-out of the propeller has normally to be done for submerged operation. Ducted propellers may be considered.

2.1.6.4 For details of propeller design see Pt.3 Ch.2 Sec.7.

2.1.7 Control locations

2.1.7.1 It shall be possible to operate the propulsion and manoeuvring equipment from a number of locations to be agreed with the naval administration. The operational status of the propulsion and manoeuvring equipment shall be clearly visible at each control station.

2.1.7.2 Devices for controlling the engine speed and/or the direction of rotation shall be so designed that the propulsion engine can be stopped should they fail. The propulsion engines shall also be capable to be controlled manually.

2.1.7.3 The propulsion equipment shall be fitted with a sufficient number of indicators and alarms to guarantee safe operation.

2.1.7.4 Effective means of communicating orders from the normal and emergency control locations to any position, from where the speed and direction of thrust of the propellers can be controlled, shall be provided.

2.1.8 Engine cooling system

2.1.8.1 A low pressure heat exchange system has to be provided with shut off valves in case of higher outside pressure.

2.1.8.2 Water cooled electric propulsion engines shall be equipped with water ingress sensors and a drain pump.

2.1.9 Space restrictions

Because of the restricted space conditions in a submarine an optimized arrangement of the devices has to be observed to guarantee the minimum required accessibility. It should be aimed at, as possible, that all devices can be mounted and dismounted via the existing hatches without opening of the pressure hull or at least using maintenance hatches, if provided.

2.2 Rudder / manoeuvring equipment

2.2.1 Purpose

2.2.1.1 Submarines shall be equipped with suitable devices to ensure that the submarine has the necessary manoeuvrability both on the surface and when submerged.

2.2.1.2 Horizontal and vertical rudders and planes shall be designed to withstand the maximum loads generated by the pitching motions of the submarine and the wash of the sea when surfaced and by the steering forces experienced when submerged.

2.2.2 Vertical rudders

2.2.2.1 With the submarine travelling at full speed, the steering gear shall be capable of putting the vertical rudder from 35° on one side to 35° on the other within the specified time values for surface and submerged condition. An emergency steering device shall be provided.

Note:

The time shall not be more than 28 seconds.

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2.2.3 Horizontal rudders/planes

2.2.3.1 Horizontal rudders or planes shall be so designed that, over the whole speed range and under all loading conditions, the desired depth can be maintained. But the hydrodynamic effects are not part of the classification procedure.

2.2.3.2 The classification however includes the integration of the system into the hull structure and the mechanical, electrical and hydraulic part.

2.2.3.3 For retractable rudders or planes a recess of sufficient size to harbor the complete rudder has to be provided in addition at the submarine's shell.

2.2.3.4 At the penetration of the rudder stock and at the slot of retractable rudders, the shell has to be strengthened in a sufficient way.

2.2.3.5 The watertight boundaries of the rudder recess, if applicable, and of the drive compartment have to be dimensioned according to Sec.5. Special attention has to be given to the transmission of the rudder support forces from the stock bearings into the submarine's structure. The local reinforcements and the overall transmission of the forces by girders, web frames, etc. have to be defined by direct calculations considering fatigue strength and have to be included in the hull drawings submitted.

2.2.3.6 The sealing arrangement at the penetration of the rudder shaft through the submarine's shell has to be either type approved or the appropriate drawings have to be submitted for approval.

2.2.3.7 The mechanical parts of the drive outside the pressure hull in the free floodable exostructure have to be protected against blocking by suitable devices.

2.2.3.8 The mechanical parts outside the pressure hull have to be equipped with a greasing line.

2.2.3.9 Shafts for rudders and planes have to be tested according to RU SHIP Pt.2.

2.2.4 Rudders

At the emergency steering control stand the individual position of each rudder has to be indicated.

2.2.5 Drive systems

2.2.5.1 The effective stress in the rudder stock shall not exceed 0.5 times the yield stress.

2.2.5.2 When non-retractable rudders or planes are not in use, the fins shall be kept in neutral position by hydraulically or preferably mechanical locking.

2.2.5.3 Retractable rudders or planes shall be retracted in the neutral position into the exostructure to prevent any damages. It shall not be possible to activate retractable rudders before they are completely unfolded out of the exostructure. The actual position shall be indicated.

2.2.5.4 Vertical and horizontal rudder systems or planes shall be equipped with an alternative hydraulic supply and emergency hand pump which meets the requirements of [2.2.1]. It shall be possible to switch from the main to the alternative hydraulic supply from the control station.

2.2.5.5 The main and emergency control stations shall be fitted with indicators showing the positions of vertical and horizontal rudders or planes. In addition, suitable indicators shall be fitted which signal any malfunction or failure of the steering gear.

2.2.5.6 For further details of the drive system the requirements for stabilizers defined in Pt.3 Ch.5 Sec.2 [3] to Pt.3 Ch.5 Sec.2 [10] shall be considered, as far as applicable.

2.3 Systems for safe navigation

For surface operation submarines have to be equipped with systems for safe navigation according to SOLAS Ch.V-1/7/02, as far as applicable.

For safe navigation at submerged operation the necessary systems shall be defined according to the requirements resulting from CONOPS.

3 Air independent power systems

3.1

The following types of non-nuclear Air Independent Power Systems (AIP) shall be considered:

- fuel cells
- stirling cycle engines
- closed cycle steam turbines
- closed cycle diesel engines.

These systems may be operated in single or hybrid mode.

3.2

For all types of AIP a risk analysis has to be performed.

3.3

Air independent power systems shall be installed in a separate space or a specially protected area.

3.4

The mechanical design has to guarantee silent and vibration-free operation. The required level has to be defined in CONOPS.

3.5

If special gases are involved, an appropriate gas detection system shall be installed in all involved compartments. If cycle gases are used which endanger human health, a warning system shall be provided.

To minimize the effect of failures in the processes, an alarm system and shut-off devices shall be provided.

3.6

The necessary consumption products of AIP systems have to be stored in redundant tanks in a safe area inside the pressure hull or outside well protected by the exostructure. Special attention shall be given to the refuelling procedure, where nearby presence of ignition sources have to be safely avoided.

3.7

High temperature AIP systems, like stirling cycle engines or closed cycle steam turbines shall be equipped with their own heat protection and fire extinguishing systems.

3.8

If fuel cell systems use metal hydride tanks for storage and transport of H_2 the maximum permissible elongation shall be agreed with the Society and to be checked regularly.

Pipes for fuel cell systems shall be separated from pipes and fittings for media containing oil.

3.9

If exhaust products/gases of the process are ejected into seawater, it has to be guaranteed, that no sea water penetrates the system at the diving depth defined in the CONOPS.

3.10

For further details concerning fuel cell systems see the requirements of SHIP Pt.6 Ch.2 Sec.3. In addition to these rules, the ventilation and emergency equipment of the fuel cell system has to consider special submarine conditions and shall be approved by the Society.

SECTION 12 ELECTRICAL EQUIPMENT

1 General

1.1

The electrical power supply is depending on:

— propulsion load
— safe navigation load
— relation between the submerged und surface operating time (capacity of batteries, charging performance)
— hotel load (for living conditions and environmental condition to be defined in CONOPS).

1.2

The documents to be submitted to the Society for approval are listed in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

2 Design principles

2.1 General principles

2.1.1 All electrical systems and equipment shall be constructed and installed in such a way that they are serviceable and perform satisfactorily under the design conditions specified for the submarine. The operating conditions of electrical equipment are to conform to the requirements stated in the Pt.3 Ch.3 Sec.1 [6], STANG 1008 or alternative naval administration requirements.

2.1.2 Essential equipment
The following items of electrical equipment on submarines shall be considered as essential/primary consumers:

2.1.2.1 Essential for submarine operation are all main propulsion plants.

2.1.2.2 Essential are the following auxiliary machinery and plants, which:

— are necessary for the propulsion and manoeuvrability of the submarine
— are necessary for the navigation of the submarine
— are required for maintaining submarine’s safety
— are required to maintain the safety of human life at sea
— battery charging equipment
— battery room ventilators
— acid circulation
— H_2 measuring device
— equipment for treating and monitoring breathing air
— bilge system
— as well as equipment according to special Characters of Classification and class notations.

2.1.3 Other equipment for safe navigation and habitability (hotel load)

The following items of electrical equipment have to be supplied with electrical power in addition to the power for propulsion:

Safe Navigation load:

- lighting external
- radio communication equipment
- hydraulic pumps
- locating equipment
- high pressure air compressors
- hull shut-offs
- monitoring and alarm system.

Hotel load:

- internal lighting
- life support system, e.g. equipment for breathable atmosphere
- monitoring and alarm equipment
- refrigeration, cooking and sanitary equipment
- heating/cooling systems and components
- ventilation systems including heating/cooling of spaces.

2.1.4 Power balance

2.1.4.1 The power requirements for essential equipment according to [2.1.2] and other equipment according to [2.1.3] have to be considered in the power balance of the submarine. Therefore the following parameters shall be calculated:

- power input
- voltage depending on battery capacity
- utility factor
- inrush/starting current and apparent power, if applicable
- simultanity factor.

For control of operation the following parameters have to be shown or recorded, if necessary:

- total voltage of battery and voltage of single cells
- temperature of battery
- currents of battery parts

2.2 Materials and insulation

2.2.1 The materials used in the construction of electrical machines, cables and appliances shall be resistant to moist and salty sea air, seawater and oil vapours. They may not be hygroscopic and shall be flame-retardant, self-extinguishing and halogen-free. The requirement that they should be flame-retardant does not apply to winding insulations.

2.2.2 Materials with high tracking resistance shall be used for the supports of live parts.

2.2.3 The creepage- and air distances shall be dimensioned as appropriate for the appliance in accordance with IEC. Generator circuit-breakers, pressure hull wall penetrations, under water plug connectors and appliances directly connected to the busbars shall be designed for the next higher nominal insulation rating.

2.2.4 Materials and insulations for electrical equipment used in water shall be agreed with the Society in each single case.

2.3 Supply systems

2.3.1 Approved supply systems are:

- Direct current and single-phase alternating current:
  - 2 conductors insulated from the submarine's hull
  - (2/PE)
- Three-phase alternating current:
  - 3 conductors insulated from the submarine's hull
  - (3/PE).

2.3.2 Networks with an earthed neutral are not permitted in submarines.

2.4 Voltages

The use of the following standard voltages and frequencies is recommended. The maximum permissible voltages except for propulsion purpose (these voltages may be agreed with the Society) are:

Above 500 V to be agreed between naval administration and the Society.

Up to 500 V:

- for permanently installed power systems
- for power systems connected by socket outlets, provided they do not need to be handled
- for heating and galley equipment
- for battery charging system
- for external power supply.

Up to 250 V:

- for lighting systems and sockets for direct current and single-phase alternating current
- mobile appliances with double insulation and/or protective isolating transformers
- machinery control and monitoring systems, submarine control systems and submarine safety systems
- for battery charging system
- for external power supply.

Up to 50 V (protective low voltage):

- for mobile appliances used in confined conditions in damp spaces, stores, machinery spaces and similar service spaces, where these appliances are not double insulated and/or fitted with protective isolating transformers

2.5 Protective measures

2.5.1 All electrical equipment shall be protected in accordance with the Pt.3 Ch.3 Sec.1 [10] unless otherwise stated below or agreed with the Society.

2.5.2 The minimum classes of protection stated in Table 1 shall be applied in submarines. The class of protection shall be maintained for the equipment as installed, even when in operation (heeling position). In this context, the provision of shielding at the point of installation is deemed to be a protective measure.

2.5.3 Protective conductors

The following points shall be observed in relation to the use of protective conductors:

- The protective conductors shall take the form of an additional cable, additional conductor or additional core in the connecting cable; the use of cable shields or sheaths as protective conductors has to be checked in every single case and shall be approved by the Society.
- The core marked green/yellow shall not be used as live conductor.
- The cross-section of the protective conductor shall be equal to at least half that of the principal conductors/outer conductors. However, with cross-sections of 16 mm^2, its cross-section shall be equal to that of the principal conductors/outer conductors. The minimum cross-section of separately laid protective conductors is 4 mm^2.

  The cross-section of the protective conductor shall at least comply with the factors shown in Table 2.

In the submarine's propulsion network, the dimensional design of the protective conductors shall be based on the maximum short-circuit currents of the equipment concerned, the maximum break times of the relevant protective elements and a maximum temperature rise of the protective conductor of 90 °C.

- Machines and appliances mounted on insulated vibration dampers shall be earthed with mobile cables or conductors or braided copper leads.
- The protective conductor shall be connected to the hull in a position where it can easily be checked.
- The exostructure or the hull of the submarine, as the case may be, shall be provided in an easily accessible position with means of connection in the form of a connecting plate with M 12 stud bolts to which protective conductors can be connected without the use of tools when the submarine is in harbour or in dock.
- The connection described also serves as a protective lightning conductor when in dock.

2.5.4 Electromagnetic compatibility

2.5.4.1 Electrical and electronic equipment shall not be impaired in its function by electromagnetic energy.

General measures shall include with equal importance:

2.5.4.1.1 Decoupling of the transmission path between the source of interference and equipment prone to interference

*2.5.4.1.2 R*eduction of the causes of interference sources, see also [4.5.7] for lying of cables and lines

2.5.4.1.3 Reduction of the susceptibility to interference

2.5.4.2 IEC publications 60533 and 60945 shall be observed for the bridge and the deck zone.

2.5.4.3 A reference for the required immunity to interference is provided by appliances and equipment components which have undergone a test to verify their immunity to electromagnetic interference.

2.5.4.4 Further requirements, which in particular result from military sensors, weapons and tactical command systems, shall be stipulated in the building specification and are not subject of these rules.

2.5.4.5 If above requirements are met class notation **EMC** can be assigned, see also Pt.3 Ch.3 Sec.12.

2.5.5 Radiation hazard (RADHAZ)

2.5.5.1 The radio and radar equipment of a submarine develops an electromagnetic frequency radiation environment which may cause hazards to

- personnel (significant internal heating occurs)
- ammunition and weapon systems embodying electro-explosive devices
- fuels, flammables
- safety critical electronic devices.

2.5.5.2 An exposure level of electromagnetic radiation that personnel and equipment can withstand without RADHAZ risk (Permissible Exposure Level - PEL) shall be evaluated.

2.5.5.3 For further details see Pt.3 Ch.3 Sec.1 [10.6].

2.5.6 Degaussing

2.5.6.1 Basic procedure

The signature requirements of a submarine will determine the special technical requirements for the degaussing system and its elements. This applies in particular to the determination of the geometry and the electrical dimensioning of the degaussing windings system.

The magnetic field induced by the degaussing system shall be capable of a real-time compensation of the permanent, the induced and the eddy-current generated magnetizations of the submarine's hull.

2.5.6.2 System elements

In general degaussing systems have to include the following system elements:

— central control unit
— winding amplifier
— winding system.

2.5.6.3 The detailed requirements for these elements are specified in Pt.3 Ch.3 Sec.12 [6].

2.5.6.4 If the submarine is equipped with an active degaussing system, the class notation **DEG** can be assigned, see also Sec.1 [1.2.7].

Table 1 Minimum degrees of protection against foreign bodies and water (in conformity with IEC 60529)

Type of equipment / *Where installed*	*Safety and measuring equipment*	*Generators, Motors, Transformers*	*Switchgear, Electronic Units, Recording equipment*	*Telecommunications Equipment, Input units, Signalling Equipment, Switches, Sockets, Junction boxes, Actuators*	*Heating Equipment, Heaters, Cooking equipment*	*Light fittings*
Control rooms, accommodation	--	IP 23	IP 23	IP 23	IP 44	IP 23
Machinery and sanitary spaces	IP 55	IP 44	IP 44	IP 55	IP 44	IP 44
Pipe tunnels, bilges	IP 56	--	--	IP 56	--	IP 55
Outside pressure hull	Watertightness under pressure in accordance with the submarine design criteria					

Table 2 Cross-sections for protective conductors

Cross-section of outer conductor [mm²]	*Minimum cross-section of earthing conductor*	
	in insulated cables [mm²]	*Separately laid [mm²]*
0.5 to 4	equal to cross-section of outer conductor	4
> 4 to 16	equal to cross-section of outer conductor	equal to cross-section of outer conductor
> 16 to 35	16	16
> 35 to < 120	equal to half the cross-section of the outer conductor	equal to half the cross-section of the outer conductor
> 120	70	70

3 Power supply

3.1 Power demand

3.1.1 Proof of adequate rating of the units for generation and storage of electrical power has to be furnished by a power balance.

3.1.2 The power demand shall be determined for the following operating conditions:

— normal operation (surface, snorting and diving operation),
— emergency operation.

3.1.3 In the power balance all consumers installed, including their power inputs, shall be considered for the required services and habitability requirements during all operational conditions.

3.1.4 The quality of power supply shall be agreed with the naval administration otherwise STANAG 1008 shall be considered.

3.2 Equipment for power supply

All electrical equipment essential for the safety of the submarine and its crew shall be connected to separated power sources, e.g. group of batteries or fuel cells. Other solutions that achieve equivalent safety may be accepted, they have to be agreed with the Society.

Note:

It is recommended to provide facilities to operate the submarine in surface mode only with diesel gensets without any battery backup.

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3.2.1 Electrical power supply

3.2.1.1 Each submarine shall be equipped with separated power sources of sufficient capacity, such as to ensurethat normal operation and the conditions of life as intended to prevail on board can be maintained for envisaged periods of service according to CONOPS.

3.2.1.2 The power source shall consist of at least two mutually independent, power supply systems, such as

— air independent power systems,
— battery groups,

— generator sets.

Exceptions may be permitted for submarines with restricted range of service and/or accompanied by support ships.

3.2.1.3 If started electrically, diesel generator sets shall be equipped with a starting device as per Pt.3 Ch.3 Sec.3.

3.2.2 Emergency power supply

3.2.2.1 Each power source group shall be capable of supplying the submarine with the energy required in emergencies.

All electrical equipment required for surfacing the submarine shall be adequately supplied with power. Apart from this, simultaneous supply of electrical power to at least the equipment listed below shall be ensured for a survival time defined by CONOPS:

- emergency lighting inside the submarine
- emergency communications equipment
- equipment for maintaining a breathable atmosphere
- important monitoring and alarm equipment, e.g. leakage monitoring system, fire alarm system, O_2-monitor and H_2-monitor
- locating equipment, signal lamps.

3.2.2.2 In addition, it shall be possible to supply electricity to the wireless equipment and important navigating equipment as defined by the naval administration, but at least for 18 hours of operation.

3.3 Charging and shore connection

3.3.1 Where socket connections are provided for charging and shore connection with a nominal current more than 16 A these shall be blocked such as to preclude both insertion and withdrawal of the plug, with the contact sleeves of the sockets being alive.

3.3.2 On the main switchboard an indicator shall be fitted showing whether the shore connection line is alive.

3.4 Batteries and battery charging facilities

3.4.1 Batteries, general

3.4.1.1 Batteries shall be rated such as to be capable of supplying the consumers during the period specified in accordance with the power balance, when charged to 80% of their rated capacity.

3.4.1.2 At the end of the supply period the voltage in the storage battery and/or in the consumers shall at least reach the values quoted in the Pt.3 Ch.3 Sec.1 [6] and Pt.3 Ch.3 Sec.3 [3].

The minimum allowable discharge voltage shall be defined according to battery type.

3.4.1.3 Accepted batteries are lead-acid batteries with diluted sulphuric acid as electrolyte and steel storage batteries with nickel-cadmium cells and diluted potassium hydroxide as electrolyte.

Other types of batteries may be accepted, if suitability for submarine use is proven.

3.4.1.4 Further types of batteries may be approved under consideration and test of the following points:

- resistance to short circuits
- fuse elements at occurring short circuits
- electrical monitoring elements

— battery management system
— fire risk/fire behaviour including consequences on adjacent cells or components
— special requirements for the installation location
— suitability of the used belonging electrical components
— integration in the electrical plant including switch gears
— charging devices and automation system for charging.

An adequate risk analysis has to be provided.

3.4.1.5 If not otherwise stated, batteries shall be designed such as to retain their rated capacity at inclinations of up to 22.5° and such that inclinations of up to 45° electrolyte will not leak. Cells without cover are not admissible.

3.4.1.6 The casing shall be resistant to electrolytes, mineral oils and cleaning agents, as well as to corrosion due to salt mist. Glass and readily flammable materials are not approved as materials for casings.

3.4.1.7 In the case of batteries containing liquid electrolyte it shall be possible to check the electrolyte level. The maximum admissible electrolyte level has to be marked.

3.4.1.8 Lead and alkaline batteries may not be accommodated in the same space or be placed in direct proximity to each other.

3.4.1.9 Where the installed battery capacity is 1000 Ah or more, the battery shall be divided into battery units so that restricted operation of the submarine is still possible in the event of a fault.

3.4.1.10 It shall be possible to bridge damaged cells with measures on board. The use of rigid interconnection links between batteries shall be avoided.

3.4.1.11 The rating data of the storage batteries shall be indicated on rating plates.

3.4.1.12 Storage batteries shall be serviced and operated in accordance with manufacturer´s instructions.

3.4.2 Batteries, installation, ventilation and monitoring

3.4.2.1 Batteries providing the source of electrical energy for electric propeller drives and/or the submarine's power network should be located in special battery spaces. It is necessary to ensure that the batteries are accessible for cell replacement, for repairs and maintenance.

3.4.2.2 Measures shall be taken to ensure that neither the crew nor the operational equipment can be endangered by emissions of electrolyte fumes.

3.4.2.3 A sign shall be mounted at the entrance of battery spaces pointing out that only insulated tools shall be used inside and conductive objects like keys, ballpoint pens, watches with conductive watch straps have to be taken off.

Attention shall be drawn to the explosion hazard.

3.4.2.4 Storage batteries shall be installed in such a way that mechanical damage is as far as possible excluded. Safe operation under the environmental conditions stated in Sec.4 [2]. shall be ensured and the discharge of electrolyte shall be prevented.

Suitable measures, e.g. provision of plastic trays or flexible rubber bags, shall be taken to prevent, wherever possible, electrolyte from entering the battery space bilges in the event of mechanical damage to individual battery cells.

3.4.2.5 Special requirements for lead acid batteries

3.4.2.5.1 Battery spaces shall be arranged and ventilated to prevent the accumulation of ignitable gas mixtures.

3.4.2.5.2 The quantity of air to be aspirated and exhausted during charging shall be so calculated, as to exclude any possibility of exceeding the lower explosion limit for a hydrogen air mixture. H_2-monitors permanently mounted at suitable points shall measure the gas concentration in the battery space, the exhaust system and, where necessary, in other spaces within the submarine.

If the gas concentration reaches and exceeds a level equivalent to 25% of the lower explosion limit (LEL), this shall automatically release a visual and audible alarm at a central monitoring station. At a level equivalent of 30% the charging has to be stopped.

3.4.2.5.3 Battery spaces shall contain no other electrical appliances apart from the batteries themselves. Lighting fixtures as well as monitoring equipment for H_2 concentration may be installed, if they are in compliance with the hazardous area requirements for H_2 atmosphere (see IEC 60079 recommendation).

3.4.3 Charging facilities

3.4.3.1 The charging facilities, usually the diesel gensets, including the control device have to meet the requirements of the batteries. The maximum admissible charging currents shall not be exceeded, compare Figure 1.

3.4.3.2 If during charging simultaneously consumers are fed, the maximum charging voltage shall not exceed 120% of the rated voltage.

3.4.3.3 The battery chargers shall be rated such that the tolerances of the limited characteristics and constant characteristics respectively are adhered to irrespective of external disturbance effects. Preferably chargers with IU or IUI characteristics should be employed. See example for lead acid batteries in Figure 1.

3.4.3.4 The charging process shall cut out automatically in case of

— failure of the battery space ventilation (if an ignitable gas mixture may be created)
— over temperature of charging generator/battery charger
— excessive H_2 – concentration
— over temperature of the electrolyte (if a temperature control of the cells is provided)

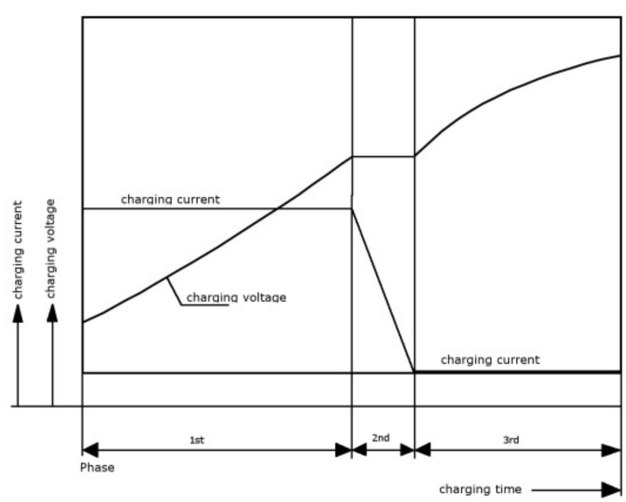

Figure 1 Characteristic charging curves for lead acid batteries

4 Power distribution

4.1 Distribution and switchgear

4.1.1 Electrical distribution systems shall be so designed that a fault or failure in one circuit cannot impair the operation of other circuits or the power supply.

Redundant supplies have to be provided in minimum for all essential consumers e. g. supply from each part battery.

In surface operation supply of all essential consumers should be possible without any battery.

4.1.2 Type and configuration of the distribution system for the ship and machinery platform system shall be agreed by the naval administration.

Distribution for other systems like sensors, weapons shall be agreed up to a certain interface which has to be coordinated with the naval administration.

4.1.3 The distribution system shall be designed and arranged with a high level of integrity and availability.

4.1.4 Switchboards shall be so placed as to minimize the length of the cables from the batteries to the switchboard. These cables shall be laid as far as their respective circuit breakers in separate cable runs and shall be protected against mechanical damage.

4.1.5 Effective measures shall be taken to prevent the occurrence of vagabond voltages inside switchgear. Circuits at protective low voltage shall not be routed with circuits at higher voltage in a joint conductor bundle or cable duct.

Terminals for different voltage levels shall be arranged separately and shall be clearly identified.

4.1.6 Switches and fuses for different voltage systems shall be spatially separated inside the switchboard.

4.2 Switching and protective devices

4.2.1 Each circuit shall be protected against overload and short-circuit.

4.2.2 All consumer circuits shall be fitted with switches. The switching action shall be on all poles.

4.2.3 Fuses in distribution panels may be used for overload protection to a rated current of 100 A. The use of greater fuses, e.g. in the main switchboard has to be agreed with the Society.

4.2.4 A continuously operating insulation monitoring system shall be installed.

An alarm has to be available at a continuously manned operation station if the insulation value drops below a present limit (in general: 50 Ω per 1 V)

4.3 Enclosures for electrical equipment

Pressure tight enclosures which are arranged outside the pressure hull and are exposed to diving pressure shall be designed according to Sec.4 [3.3] and shall be tested according to Sec.2 [5].

Where the strength of enclosures and electrical components situated outside of the pressure hull cannot sufficiently be proven by computation, a pressure test with a layout pressure equal to 1.1 x collapse diving pressure *CDP* has to be performed as a type test or routine test.

4.4 Earthing

The earthing of electrical systems and equipment on submarines is subject to the requirements stated in the Pt.3 Ch.3.

4.5 Cables and lines

4.5.1 Cables and lines for submarines shall be suitable for the proposed application. Their use is subject to approval by the Society.

4.5.2 The selection, dimensions and installation of cables and lines shall comply on Pt.3 Ch.3 Sec.11 and Pt.3 Ch.3 Sec.15 [7] or according to naval administration requirements.

4.5.3 Only halogen-free materials shall be used as insulating sleeves, protective coverings, sheaths and fillers of cables used in submarines.

4.5.4 Underwater cables and lines shall be radially or longitudinally watertight and designed for an external hydrostatic pressure equal to 1.1 times the collapse diving pressure *CDP* and minimum 2 x *NDP*.

The pressure resistance shall be verified by pressure testing for each cable (connectors fitted).

4.5.5 In cables for winding on drums, no mechanical forces may be transmitted via conductors of the cable and their insulation.

4.5.6 Cables shall be installed such that the risk of injury to persons or damage to the system is minimised when equipment is operating in foreseeable or under fault conditions.

4.5.7 Installation of cables shall not cause mutual interference between systems. Also electrical and electronic equipment shall not be impaired in its function by electromagnetic energy. Electromagnetic Compatibility (**EMC**) shall be achieved according to the requirements of the naval administration.

4.6 Busbars bare or painted

Where busbars are used for connecting equipment only sealed or insulated systems may be used. Exceptions to this Rule are switchboards and enclosed electrical service spaces.

4.6.1 General

4.6.1.1 Busbars shall be made of copper, aluminium with copper sheathing or corrosion resistant aluminium. Further busbar materials shall be agreed with the Society and have to be checked for the load case in accordance with Pt.3 Ch.3 Sec.12 [5].

The loading of busbars shall be designed according to Table 3. On continuous load, the busbar temperature shall not exceed 100°C.

For frequencies above 60 Hz special considerations have to be made.

4.6.1.2 Parallel-run busbars of the same phase shall be installed not less than one bar thickness apart. Earth conductors, neutral conductors of three-phase mains and equalization lines between compound-wound generators shall have at least the half cross section of the phase conductor.

4.6.2 Connections to equipment

Cross-sections of connection bars and wires to equipment shall be of such size as to avoid thermal overloading of the equipment at rated load as well as in the event of a short circuit.

4.6.3 Busbar carriers

Busbars shall be mounted in such a way that they withstand the dynamic loads caused by short-circuit currents and maintain the required clearance and creepage distances relative to other voltage carrying or earthed components.

Busbars shall be adequately isolated from the pressure hull.

4.6.4 Clearance and creepage distances

Clearance and creepage distances shall be designed for the specific equipment according to IEC.

4.6.4.1 Where busbars are used for connecting equipment only sealed or insulated systems may be employed.

Exceptions to this rule are switchboards and enclosed electrical service spaces.

4.6.4.2 The busbar system shall be so constructed that neither the connected equipment nor the busbar system itself can be damaged by movement of the busbars, temperature rises or external mechanical influences.

It is recommended that expansion links should be fitted.

Prior to the installation of busbar systems, proof is required of mechanical strength under short-circuit conditions considering the effects of the electrical heating produced by the short-circuit current.

Table 3 Maximum permissible loading [A] for DC and AC up to 60 Hz

	Maximum permissible loading [A] with 50/60 Hz							
	painted (matt-black)				*bare*			
Width × Thickness	*Number of bars*				*Number of bars*			
[mm]	*1* |	*2* | |	*3* | | |	*4* | | | |	*1* |	*2* | |	*3* | | |	*4* | | | |
15 × 3	230	390	470	–	200	350	445	–
20 × 3	290	485	560	–	250	430	535	–
20 × 5	395	690	900	–	340	620	855	–
20 × 10	615	1145	1635	–	530	1020	1460	–
25 × 3	355	580	650	–	300	510	615	–
25 × 5	475	820	1040	–	405	725	985	–
30 × 3	415	670	735	–	350	590	700	–
30 × 5	555	940	1170	–	470	830	1110	–
30 × 10	835	1485	2070	–	710	1310	1835	–
40 × 5	710	1180	1410	–	595	1035	1350	–
40 × 10	1050	1820	2480	3195	885	1600	2195	2825
50 × 5	860	1410	1645	2490	720	1230	1560	2380
50 × 10	1260	2130	2875	3655	1055	1870	2530	3220
60 × 5	1020	1645	1870	2860	850	1425	1785	2740
60 × 10	1460	2430	3235	4075	1220	2130	2850	3595

	Maximum permissible loading [A] with 50/60 Hz							
	painted (matt-black)				bare			
Width × Thickness	Number of bars				Number of bars			
[mm]	1 |	2 | |	3 | | |	4 | | | |	1 |	2 | |	3 | | |	4 | | | |
80 × 5	1320	2080	2265	3505	1095	1795	2170	3370
80 × 10	1860	2985	3930	4870	1535	2615	3460	4275
100 × 10	2240	3530	4610	5615	1845	3075	4040	4935
120 × 10	2615	4060	5290	6360	2155	3545	4635	5580
160 × 10	3348	5121	6646	7836	2752	4451	5803	6857
200 × 10	4079	6162	7973	9287	3335	5344	6956	8109
Note:The maximum permissible loading applies to switchboards not closed at the rear. In the case of fully enclosed switchboards adequate ventilation shall be ensured, or a temperature rise task according IEC-Pub. 60439-001 has to be performed.								

4.7 Electrical penetrations in pressure hull walls

4.7.1 Lay out

For the lay out the following shall be considered:

4.7.1.1 General

— The lay out has to be done for 1.1 times the collapse diving pressure *CDP*.
— Pressure hull penetrations shall be gas and watertight. Their tightness shall be guaranteed even should the connected cables be damaged or shorn off.

4.7.1.2 Penetration with cables

— radially watertight
— longitudinally watertightness to be agreed with naval administration
— sufficiently protected against damage before and afterwards

4.7.1.3 Penetration with conductors of solid material

— longitudinally watertight
— The positive and the negative conductors from a power source are not to pass through the same penetrating device at the pressure hull wall, e.g. charging connectors of external power supply connectors.

4.7.2 Type approvals

Electrical pressure hull penetrations shall be type approved. This type approval allows the manufacturing of pressure hull penetrations with identical finish without permanently accompanying construction and function tests by the Society.

Type-testing is performed, on application, at the manufacturer's works and comprises at least the following individual tests:

— Hydraulic pressure test

For this test the test pressure shall be equal to twice the nominal pressure P_N. The test shall be conducted in accordance with the test pressure/time curve shown in Figure 2, the changes in pressure being applied as quickly as possible.

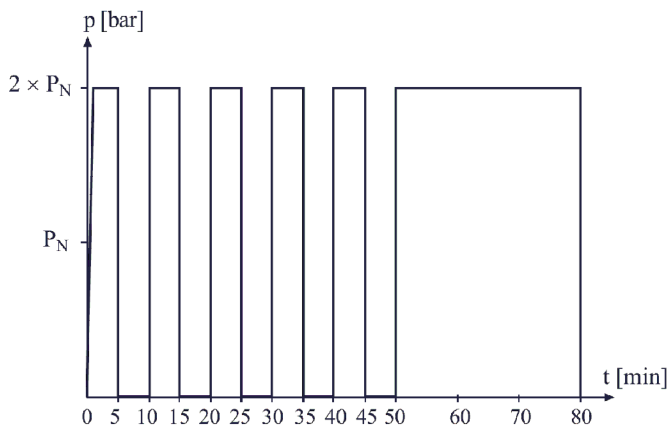

Figure 2 Test pressure/time curve for type approval

— Gastightness test with shorn, open cable ends.

This test may be performed under air or alternatively under helium. The test pressure shall be 2 times the nominal pressure of the component P_N for air and 1.5 times the nominal pressure of the component P_N for helium. The leakage rate shall be specified by the manufacturer and to be approved by the Society.

In all pressure and tightness tests on pressure hull wall penetrations, the pressure shall in each case be applied from the pressure side of the wall penetration.

During the pressure and tightness test, the penetration shall be loaded with the rated current in all conductors.

— High voltage test according to Table 4. The duration of the test is one minute in each case.

Table 4 Test voltage for high voltage test

Rated insulation voltage *U_i* *DC and AC* *[V]*	*Test voltage* *(AC)* *(r.m.s)* *[V]*
$U_i \leq 60$	1000
$60 < U_i \leq 300$	2000
$300 < U_i \leq 690$	2500
$690 < U_i \leq 800$	3000

Rated insulation voltage U_i DC and AC [V]	Test voltage (AC) (r.m.s) [V]
$800 < U_i \leq 1000$	3500

— Measurement of insulation resistance

The minimum value of the insulation resistance between the conductors mutually and between the conductors and the casing shall be 5 MOhm for the type test, for periodic Classification surveys the minimum value shall be 2 MOhm.

The insulation resistance shall be measured with an instrument using 500 V DC.

With wet plug connections, the minimum insulation resistance is also to be measured after the connection has been made once in saltwater.

— Visual check against manufacturer's documentation
— Type approved pressure hull penetrations have to be pressure tested after installation with a test pressure according to Sec.4 Table 2.
— The Society reserves the right to execute individual tests as spot check.
— The number of the pressure hull penetrations shall be minimised and approved by the Society.

4.7.3 Individual test after the manufacturing (Routine Test)

All electrical pressure hull wall penetrations and all plug connections, which are not type approved, shall be subjected to routine inspection after manufacturing by the manufacturer under the survey of the Society.

This inspection comprises the following tests:

— hydraulic pressure test at the manufacturer in accordance with Figure 3 at 1.5 times the nominal pressure of the component P_N and at the overall test with test diving pressure *TDP*, if applicable.
— high-voltage test according to Table 4
— measurement of insulation resistance

A Manufacturer Inspection Certificate/Works Certificate shall be issued covering the inspection.

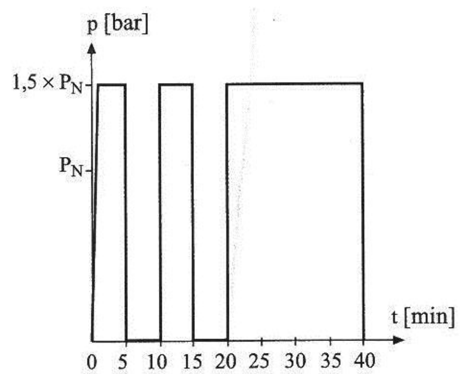

Figure 3 Test pressure/time curve for routine tests

4.7.4 A functional testing of all pressure hull penetrations shall be performed separately at the different phases of testing (fabrication acceptance, harbour acceptance, sea trials).

5 Electrical equipment

5.1 Electrical machines

5.1.1 Electrical machines shall comply with Pt.3 Ch.3 Sec.14.

5.1.2 Generators with an output of ≥ 100 kVA and all electric propeller motors rated at over 100 kW shall be equipped with a standstill heating system.

5.1.3 Machines for electric propeller drives rated at more than 100 kW shall be equipped with monitoring devices in accordance with the Pt.3 Ch.3 Sec.12 [8].

If direct current motors are used, energizing current circuits where the failure may endanger the operation are only to be protected against short circuit.

5.1.4 At least isolation class F shall be provided.

5.1.5 An automatic limitation of the performance of the driving motors has to secure that the board main is not overloaded.

The reverse power for reversing, reduction and shut-off shall be considered and shall be limited to permissible maximum values.

5.1.6 For water cooled propeller motors sensors for indicating water ingress and a dewatering system shall be installed.

5.1.7 In addition to the tests stipulated in Pt.3 Ch.3 Sec.14 [2.4] the following electrical machines shall be tested in the presence of a surveyor:

— generators and motors for electric propeller drives
— motors for steering gear drives and windlasses
— all other motors driving machines and equipment necessary to the safety and manoeuvrability of the submarine.

5.1.8 All electrical equipment shall be suitably protected against damage to itself under fault conditions (e.g. arc flash) and to prevent injury to persons. All electrical equipment shall be suitably protected against damage to itself under fault conditions and to prevent injury to personnel.

5.1.9 Exposed metal parts of electrical machines or equipment which is not intended to be live, but which are liable under fault conditions to become live shall be earthed. Exposed metal parts of electrical machines or equipment which are not intended to be live but which are liable under fault conditions to become live shall be earthed.

5.1.10 Suitable security arrangements to prevent unauthorised access to live electrical connections and electrical control shall be provided.

5.1.11 Electrical equipment and distribution systems shall be suitably protected from mechanical damage.

5.2 Interior lighting

5.2.1 Service and work spaces, safety and control stations, accommodation spaces and day rooms shall be equipped in minimum with normal and emergency lighting. Emergency lights shall be marked as such to facilitate easy identification.

5.2.2 The lighting shall be so designed and arranged that all important instruments and markings can be read and any necessary operations can be safely performed.

As far as possible, the interior lighting shall be arranged glare-free.

5.2.3 All lighting fixtures shall be so mounted that combustible parts are not ignited by the generated heat and they themselves are not exposed to damage.

5.2.4 The emergency lighting has to be independent from the normal lighting. This applies to the power supply as well as to the cable/distribution network.

5.2.5 The emergency lighting has to be automatically switched on in case of failure of the main lighting. Switches for emergency lighting shall switch-off only partial areas, e.g. in the control stand.

5.2.6 Additional lighting systems are to permit the submarine to be operated in accordance with CONOPS.

5.3 Spare parts

The amount of spare parts has to be agreed with the naval administration, see Sec.2 [7].

SECTION 13 AUTOMATION, COMMUNICATION AND NAVIGATION EQUIPMENT

1 General

1.1

The following requirements supplement the Pt.3 Ch.3 and Pt.3 Ch.4 far as applicable and shall be applied to the construction and use of control, monitoring, open and closed loop control and communication equipment in submarines as well as to that of navigating and locating equipment in submarines built under the survey and in accordance with the DNV GL rules.

In submarines with a diver's lockout, for automation, control, monitoring and communications equipment in the area of the diver's lockout the requirements of UWT Pt.5 Ch.1 are to be considered.

1.2

The documents to be submitted to the Society are listed in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

2 Automation equipment

2.1 Design principles

2.1.1 General principles

2.1.1.1 All automatic, monitoring and open and closed loop control of a submarine's operating parameters shall be designed and constructed so that it works properly under the design and environmental conditions specified for the submarine.

2.1.1.2 Computer-aided operating systems for the navigation and/or for the control and monitoring of the submarine will be accepted.

Details of the scope and redundancy requirements of these systems shall be agreed with the Society.

The systems are subject to preferred DNV GL-type approval. Such type-approval relates both to the hardware and to the software. Other approval may be accepted by the Society.

2.1.1.3 The automation equipment on board submarines shall be constructed in accordance with Pt.3 Ch.4 – Automation as far as applicable. Apart from this, the following shall be observed.

2.1.1.4 All items of automation equipment shall be clearly inscribed and identified.

2.1.1.5 Indicating instruments and synoptic displays shall be designed and inscribed in such a way that they can be read quickly and clearly.

2.1.1.6 Probable faults or failures which may occur in the control and monitoring system shall not provoke a critical operating condition.

2.1.1.7 As far as possible, automation equipment shall be safeguarded against faulty operation.

2.1.1.8 Automation equipment shall be capable of maintaining the submarine's assigned operating parameters.

2.1.1.9 Any specified inadmissible variations in the operating parameters/conditions shall actuate an (visual and audible) alarm at the control station. The same shall also occur in the event of automatic switching operations in the gas and power supply systems or faults in the automation system.

Acknowledging of the acoustic alarms is only permissible for this actual failure case. A general suppression of alarms is not allowed.

2.1.1.10 In addition to electronic open and closed loop control and monitoring equipment, independent safety devices shall be fitted which prevent a fault in one system from provoking an improper response in another system.

2.1.1.11 Automatic monitoring and open and closed loop control equipment shall be capable of being switched to manual operation.

2.1.1.12 The response values of automation equipment shall be so coordinated with each other that, when a threshold is reached, a warning is initiated, followed, after a certain warning period or if the process variable continues to change at a present speed, by the actuation of safety devices. The limit value for the warning shall be defined in a way that for reaching this limit value still no actual endangerment occurs.

2.1.1.13 The integral operation of automation systems shall be designed to take account of the lags and time constants of the units and elements making up the system (e.g. by allowing for the length and cross-section of piping systems and the response time of gas analyzers).

2.1.1.14 The criterion for the freedom from interference of electronic systems shall be IEC 60533 (Electromagnetic compatibility of electric and electronic installations in ships).

2.1.1.15 The functioning of essential indicating lamps has to be checkable during operation.

2.1.2 Construction

2.1.2.1 Automation systems shall comprise easily replaceable assemblies, of the plug-in type wherever possible. Standardization of units is recommended and the number of assembly types shall be kept small in order to minimize the spare parts inventory.

2.1.2.2 Plug-in cards shall be clearly marked or coded to prevent inadvertent confusion.

2.1.2.3 Measures shall be taken to prevent condensation inside electronic units, even when switched off.

Standstill heating is recommended.

2.1.2.4 Wherever possible, automation equipment shall be capable of operation without forced ventilation.

Any cooling system used shall be monitored.

2.1.2.5 Components shall be effectively secured. Any mechanical loading of wires and soldered connections due to vibration or jolting shall be reduced to a minimum.

2.1.2.6 The construction of systems and units shall be simple and straightforward. Good accessibility shall be ensured to facilitate measurements and repairs.

2.1.2.7 Input equipment such as limit switches, transducers, transformers and reading-in machines, as well as control elements, fire alarm systems, remote control devices for propulsion systems, engine alarm systems as well as combined equipment for the recording of measurement data and interferences requires to be type-approved in line with SHIP Pt.4 Ch.8 Sec.1 [2.3].

2.1.3 Circuitry

2.1.3.1 Automation equipment for monitoring and open and closed loop control systems with a safety function shall be designed on the fail-safe principle, i.e. faults due to short-circuit, earthing or circuit breaks shall not be capable of provoking situations hazardous to personnel and/or the system. In this respect, it shall be assumed that faults occur singly.

The failure of one unit, e.g. due to short-circuit, shall not result in damage to other units.

2.1.3.2 Alarm systems shall be designed on the closed-circuit or the monitored open-circuit principle.

Equivalent monitoring principles are permitted.

2.1.3.3 In stored-program control (PLC) systems, the electrical characteristics of the signal transmitters shall conform to the safety requirements for instruction and control devices. This means principally:

— activation at H level, i.e. by energization across NO contacts
— deactivation at L level, i.e. by energization across NC contacts.

The requirements of [2.1.3.1] are unaffected.

2.1.3.4 Instruction and control units for safety functions, e.g. emergency stop buttons, shall be independent of stored-program control systems and shall act directly on the output unit, e.g. the STOP solenoid. They shall be safeguarded against unintended operation.

2.1.3.5 Stored-program control systems should be reactionless and, in case of fault, should cause no malfunctions in program-independent safety interlocks or stepped safety circuits for fixed subroutines.

2.1.3.6 Freely accessible potentiometers and other units for equipment trimming or operating point settings shall be capable of being locked in the operating position.

2.1.3.7 Interfaces with mechanical switchgear shall be so designed that the operation of the system is not adversely affected by contact chatter.

2.1.3.8 Printed conductors forming part of circuits extending outside the enclosure containing the printed circuit boards shall be conditionally short-circuit proof, i.e. in the event of an extreme short-circuit only the protective devices provided may respond without destroying the printed conductors.

2.1.3.9 The equipment shall not be damaged by brief overvoltages in the unit's power supply, due for example to switching operations.

Where systems are supplied by static converters, it may be necessary to make allowance for periodic voltage pulses. The size of the pulse amplitude depends on the converter type and shall be investigated in each case.

An overvoltage protection adjusted to the system is recommended.

2.1.4 Power supply

Regarding the power supply to control, monitoring and ship safety equipment the requirements as per Pt.3 Ch.3 Sec.9 shall be observed, as is the following:

2.1.4.1 Power supply units for automation equipment shall at least have short circuit and overload protection, if no unsafe operation conditions of the vehicle may be created.

2.1.4.2 The energy supply shall be monitored and failure shall be alarmed.

2.1.4.3 The equipment shall be supplied via separate power circuits. Selective circuit opening of each of these in the event of short-circuit shall be ensured.

2.1.4.4 For power supply to systems which require remaining operational in the event of failure of the power supply system common mains backed up by storage battery may be provided. For this mains, two power supply alternatives shall be available, compare Pt.3 Ch.3 Sec.4.

2.1.4.5 The automation equipment shall be capable of being safely operated in the event of voltage and frequency variations referred to in the Pt.3 Ch.3 Sec.1 [6].

2.1.5 Tests

Automation equipment shall be approved by the Society. Preferably type-approved components shall be used.

The nature and scope of the test will be determined by the Society in each single case, see also Sec.2 [5.11].

Type tests shall be in line with the SHIP Pt.4 Ch.8 Sec.1 [2.3].

2.2 Navigation and manoeuvring

Principally the regulations of the flag state respectively of the competent authorities shall be considered.

2.2.1 Control station

2.2.1.1 For the control and monitoring of the submarine a control station shall be provided which shall be equipped with indicators displaying all essential information about the submarine, its internal conditions and the operating states of the auxiliary systems and with all the control devices needed to operate the submarine including its communication equipment.

2.2.1.2 The grouping and arrangement at the control station of the instruments for the control, monitoring and operation of the submarine shall conform to the principles of safety technology and ergonomics.

2.2.1.3 As far as feasible and rational, initiated control functions shall be indicated on the console or switchboards respectively.

2.2.1.4 No units or equipment liable to impair the control or monitoring of the submarine may be installed in the area of the control station.

2.2.2 Control station equipment

2.2.2.1 For each of the functions to be performed on the control station of the submarine the following monitoring equipment shall be provided:

2.2.2.2 Navigation

— navigational radarscope
— position indication system (e.g. GPS)
— obstruction signalling device (if fitted)
— optical surveillance (e.g. TV, periscope)
— external communication system (e.g. VHF)
— internal communication system
— navigation and signal lamp monitor
— chronometer.

2.2.2.3 Steering:

— gyro compass
— depth indicators

  2 depth indicators which work independently of each other and are not connected to the same pressure hull penetration.

The scales of the depth indicators shall be suitable for all operational conditions including test diving depth *TDD*.

- heeling and trim angle indicator
- speed and distance indicator
- rudder angle indicators (vertical and horizontal rudders)
- indicator showing speed and direction of rotation of main driving propeller
- thrust direction indicator for other propulsion units (if fitted)
- level indicators for regulating/compensating and trimming tanks.

2.2.2.4 Submarine atmosphere

- The indicators and alarms specified in Sec.14 for monitoring the submarine atmosphere.

2.2.2.5 Electrical equipment

- generator current and voltage indicators
- battery capacity, current and voltage indicators
- If a capacity indication for the batteries has to be provided will be defined by the Society in each single case.
- current consumption indicators of propeller motors and essential electric drives
- power supply/distribution indicators
- insulation monitor displays.

2.2.2.6 Alarm equipment and indicators

- machinery alarm systems
- fire detection and fire alarm system
- leakage alarm
- bilge alarm
- general alarm system
- pressure gauge for all compressed-air receivers
- pressure gauge for all oxygen storage tanks
- pressure gauge for all hydrogen storage tanks, if applicable
- pressure gauges for hydraulic system(s).

2.2.3 Control equipment

2.2.3.1 The control station or another suitable place of the submarine shall be equipped to control at least the following:

- control of pressure, temperature and humidity (if necessary) of the submarine atmosphere plus the oxygen metering and air renewal rates
- propulsion plant
- autopilot
- vertical and horizontal steering gears
- diving/ballasting systems
- trimming system
- regulating/compensating systems
- power distribution
- auxiliary systems
- emergency stopping devices (e.g. combustion engines, shut-off hull valves).

2.2.3.2 Navigation and control functions are, wherever possible and expedient, to be indicated by displays on monitors and/or dead-front circuit diagrams on the control console.

2.3 Sensors and actuators

All devices for registering the operating conditions of submarine shall be approved by the Society and should be type-approved.

2.4 Computer systems

2.4.1 Computer systems shall fulfil the requirements of the process under normal and abnormal operating conditions. The following shall be considered:

— danger to persons
— environmental impact
— endangering of technical equipment
— usability of computer systems
— operability of all equipment and systems in the process.

2.4.2 If process times for important functions of the system to be supervised are shorter than the reaction times of a supervisor and therefore damage cannot be prevented by manual intervention, means of automatic intervention shall be provided.

2.4.3 Computer systems shall be designed in such a way that they can be used without special computer knowledge. Otherwise, appropriate assistance shall be provided for the user.

2.4.4 For detailed requirements see Pt.3 Ch.3 Sec.10, as far as applicable for submarines.

2.5 Integrated systems

The integrity of essential machinery or systems, during normal operation and fault conditions shall be demonstrated. A test program shall be submitted to the naval administration.

2.5.1 The integration of functions of independent equipment shall not decrease the reliability of the single equipment.

2.5.2 The required independence of monitoring, conventional alarm, control and safety functions shall be secured by other sufficient measures where two or more of those functions are integrated in one system.

Such measures may be:

— coupling of otherwise autonomous systems, involving an exchange of information and data correction
— multichannel technology
— fault-tolerant systems
— These measures have to be documented and suitable proofs have to be furnished.

2.5.3 The interruption of the transfer of data between connected autarkic sub-systems shall not impair their independent functions.

2.5.4 Operation of essential equipment shall be possible independently of integrated systems.

2.5.5 Networks shall be designed according to an international standard.

2.5.6 The creation and configuration of a network with regard to the use of the

— transmission media
— topologies
— access methods

— access speeds
— network systems
— interfaces
— any redundancy which may be required.

shall comply with the system requirement in each case.

2.5.7 Standard interfaces shall be used to ensure the exchange of data between different systems.

2.5.8 If an autopilot for submerged operation is required, the following parameters shall at least be integrated:

— depth
— speed
— buoyancy
— density of sea water
— trim angle
— rudder or plane positions.

2.5.9 For detailed requirements see Pt.3 Ch.4 Sec.7, as far as applicable for submarines.

3 Communication equipment

3.1 General

3.1.1 Regardless of their type, size and function or range of service, submarines shall be equipped with various means of internal and external communication.

3.1.2 Antennae and transducers shall be permanently installed and so arranged as to preclude mutual interference.

3.2 Internal communications equipment

3.2.1 Compartments, rooms and control stations shall be equipped with a two-way communications system.

3.2.2 A telephone link independent of the submarines power supply system shall be provided between the control station and the steering gear compartment and between the control station and the propulsion machinery space.

3.2.3 A main broadcast system has to be provided in all compartments, rooms and control stations.

3.3 Surface communications

3.3.1 Submarines shall be equipped with at least one two-channel transmitter/receiver, one of the channels of which shall operate on safety channel 16-VHF, while the other is used as a "working channel" for communication.

3.3.2 Submarines are also to be equipped with an additional radiotelephone.

3.4 Underwater communications

3.4.1 Submarines shall be equipped with a two-channel side-band UT system, if not otherwise defined by the naval administration. The UT system should have a minimum range equivalent to twice the nominal diving depth *NDD* of the submarine, but at least 1 nautical mile.

3.4.2 For submarines with a diver's lockout suitable means and procedures of communication shall be provided between the diver(s) in the water and the diver(s) in the lockout and that between the diver's lockout and the submarine's control stand shall meet the requirements set out in UWT Pt.5 Ch.1 Sec.8.

3.5 Emergency communications equipment

3.5.1 Submarines shall be equipped with radiotelephones connected to at least two alternative power supplies and capable of both surface and snorkelling operation. The emergency radiotelephone equipment should include at least one VHF transmitter / receiver operating on safety channel 16. The standby UT system should have a minimum range equivalent to twice the nominal diving depth *NDD* of the submarine.

4 Navigation equipment

4.1

All electrically operated items of navigation equipment necessary to the safety of the submarine and its crew shall be connected to at least two of the submarine's alternative power supplies. The availability of the equipment for service and its current operating status shall be indicated at the control station.

4.2

Wherever necessary, the official regulations of the naval administration shall be observed when fitting out the submarine with navigation equipment. The minimum equipment to be provided should include the relevant items specified in Sec.7 [5] and Sec.16 [3].

5 Machinery Control

5.1

Provisions shall be made to ensure a continuous power supply to the essential machinery/systems control system. An audible and visual alert shall be initiated in the event of the failure on any of the power supply.

The control system shall operate essential machinery and systems in a safe, controlled and stable manner throughout the machinery's/systems defined operational limits and shall recover automatically in a safe manner after a loss of power supply.

5.2

It shall only be possible to control machinery/systems from one location at a time, with clear indication showing the location of the control. The hierarchy of control stations shall be agreed by the naval administration. Transfer between control stations without altering the control set points shall be provided. Transfer of control location will be indicated with visual and audible indication.

5.3

Appropriate indication and feedback shall be provided at each control station to confirm that the system has responded to operator demands. The status of automatic control systems shall be indicated.

5.4

It shall be possible to disable the automatic or remote control operation of essential machinery and systems to allow inspection and maintenance tasks to be safely performed on the machinery and systems.

5.5

Indications of impending slow-down / shut-down of essential machinery and systems shall be provided at applicable locations with provision to take alternative actions if approved.

5.6

Automated control systems which utilise stored energy to start essential machinery shall be configured not to exhaust the stored energy completely and to provide an alert when the stored energy is below a critical limit.

5.7

The monitoring system for system parameters is to have integrity appropriate for its intended purpose.

5.8

For unattended machinery spaces, a machinery control and alarm position shall be provided.

5.9

Failure of the external control systems for essential safety functions shall initiate an audible and visual alert at the relevant control stations. It shall be possible to override the control system to regain control of the machinery or system.

5.10

The control system shall fail safe. Consideration shall be given whether this means maintain the last position or some other known state, and a justification shall be provided to the Society.

5.11

Operators shall have an independent, high integrity method to disconnect all energy sources that shall put machinery for essential safety functions into a known safe state.

SECTION 14 LIFE SUPPORT SYSTEMS

1 General

1.1

The following requirements apply to all those plant components and parts which are needed to ensure life support and a safe environment for the crew of the submarine.

1.2

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

1.4

For breathing gas systems the Pt.3 Ch.5 Sec.18 have to be observed as far as applicable.

2 Design principles

2.1

Submarines shall be fitted with equipment for providing, maintaining and monitoring life support conditions. The equipment shall be so designed that the necessary conditions can be maintained for the survival time defined by CONOPS in excess of the maximum intended duty period of the submarine.

For submarines equipped with a diver's lockout, the space of the lockout is to comply with the requirements set out in UWT Pt.5 Ch.1.

2.2

Equipment shall be installed for the circulation and treatment of the atmosphere in the submarine such that the oxygen partial pressure can be maintained within the range 0.18 – 0.24 bar and the CO_2 partial pressure can be kept below 0.008 bar in the various spaces. In addition, air purifying and conditioning units shall be installed. The limit values for the permissible atmospheric impurities shall be agreed with the Society in each case. The following note may be useful for design:

Note:

Parameters for the design of life support systems (at 20°C and 1013 m bar):

— O_2 demand per person: 15 l/h (resting); 40 l/h (working); 26 l/h (average)

— CO_2 production per person : 22 l/h (average);

— Humidity: 50 +/-20%

— Heat production per person: 265 kJ/h.

---e-n-d---of---n-o-t-e---

Smoking, fire and open flames have to be avoided by relevant notices and organisational measures.

2.3

Facilities shall be provided for supplying the whole crew with food and water and for disposing of waste and effluent during the period stated in [2.1].

2.4

Suitable equipment shall be fitted for monitoring the environmental conditions inside the submarine. The crew shall be warned by an automatic alarm in the event of inadmissible deviations from the O_2 and CO_2 partial pressures stated in [2.2].

3 Air supply

3.1 Air supply and gas exhaust system

3.1.1 When travelling on the surface or at snorting depth, it shall be possible to ventilate the submarine via an air/snorkel mast which shall be designed and arranged to prevent the penetration of spray and swell water. See also Sec.7 [5.1] and Sec.9 [3.4.5].

3.1.2 For spaces where air can be contaminated, gas exhaust systems have to be provided.

A power-driven extractor fan shall be provided for expelling the battery gases during the charging of the batteries, as well as during the required time before and afterwards, from the battery spaces in the pressure hull.

The venting of battery spaces shall be separated from other ventilation systems as far as applicable.

3.2 Air renewal

3.2.1 Oxygen system

3.2.1.1 An oxygen system shall be installed to replace the oxygen consumed from the atmosphere in the submarine.

3.2.1.2 The oxygen supply system shall be designed on the basis of a consumption average consumption rate of at least 25 l/h per person, see also [2.2].

3.2.1.3 The oxygen partial pressure for breathable atmosphere shall be maintained within the range of 0.19 to 0.23 bar. In case of emergency the value of the O_2 partial pressure has to beagreed by the Society and naval administration.

The oxygen shall be stored in at least two separate units/groups of bottles, if possible outside the pressure hull. In case of internal installation each bottle has to be equipped with a head valve.

For the storage of the oxygen bottles within the pressure hull the volume of each bottle shall be restricted in such a way that the pressure does not exceed by 1 atmosphere and the O_2 content does not exceed 25% by volume if the complete content of one bottle escapes. If this cannot be achieved, the bottles shall be arranged outside the pressure hull.

3.2.1.4 Each unit/group of oxygen bottles shall be connected to the manifold inside of the submarine by a separate line.

3.2.1.5 All pipes and components used in oxygen systems shall be carefully cleaned and degreased before being put into service.

3.2.1.6 Manually operated oxygen dosing units shall be equipped with a shut-off valve on the pressure side and a device for controlling the flow-rate. A flow-rate indicator has to be fitted.

3.2.1.7 Dosing units shall be equipped with a manually operated bypass.

3.2.2 CO_2 absorption

3.2.2.1 For regenerating the breathing air a CO_2 absorption unit shall be provided which shall be capable of keeping the CO_2 partial pressure in the range 0.005 – 0.008 bar. In addition, it shall be possible to maintain a CO_2 partial pressure within the submarine of not more than 0.020 bar at the end of the survival time.

In case of emergency the value of the CO_2 partial pressure has to be agreed by the Society and naval administration.

3.2.2.2 The design of the CO_2 absorption unit shall be based on a CO_2 production according to [2.2].

3.2.2.3 The CO_2 absorption unit shall be fitted with a dust filter of non-combustible material.

3.2.3 Humidity

The relative humidity of the air during operation shall be kept by suitable measures within boundaries comfortable for the crew, compare the note given in [2.2].

3.3 Internal temperature

For maintaining an optimum temperature in the working areas and living quarters of the crew, a system for temperature control (e.g. combination of heating and cooling systems) shall be provided. Hereby also the operation area of the submarine according to CONOPS shall be considered.

3.4 Emergency breathing air/ gas supply

3.4.1 Emergency breathing air systems/appliances shall be designed to ensure that in an emergency every person on board has sufficient breathing air/gas while the submarine is rising or being brought, to the surface, subject to a minimum time of one hour.

The emergency breathing air masks are to have a gastight eye protection.

3.4.2 The emergency breathing air appliances shall be so designed and arranged that in an emergency every person on board can very quickly reach a breathing appliance.

Embarked persons shall be in the position to move around to execute their duties and being able to sit or lay down. A short interruption of breathing gas supply is permissible.

Finally they shall be able to reach the exit of the submarine without first having to remove the breathing mask.

3.4.3 In case of increasing the atmospheric pressure inside the pressure hull, the breathing air /gas pressure shall be increased simultaneously.

In case of different emergency breathing air/ gases it has to be secured that a mixing of the different gases can safely be avoided.

3.4.4 An emergency breathing air/ gas appliance shall be provided for each person on board. naval administration will decide about the number of additional appliances, but the minimum should be additional 20%.

3.4.5 If compressors are used for filling of breathing air / gas, the quality of the produced compressed air/ gas shall be proven according to EN 12021.

3.5 H_2 monitoring

3.5.1 If development of H_2 has to be expected, the hydrogen content shall be monitored continuously in the battery spaces and, if applicable in other spaces. The position of the measuring points shall be selected considering the local conditions.

3.5.2 If a gas concentration of 35% of the lower explosion limit is exceeded, it shall be signalled optically and acoustically to the control station.

If a value of 50% of the lower explosion limit is reached, all charging or discharging processes of the batteries have to be interrupted automatically.

If the H_2 concentration is still rising after the switch-off, e.g. from finish gassing of the batteries, immediately surfacing shall be initiated and forced ventilation shall be applied.

3.5.3 The request for immediate surfacing shall be signalled optically and acoustically at the control station. Reset of the optical signal shall be possible only after surfacing and after sufficient fresh air has been supplied.

3.5.4 The measuring and assessing equipment for monitoring of the H_2 concentration shall be approved by the Society.

3.5.5 The hydrogen measuring system shall also be supplied by an alternative power supply.

4 Monitoring equipment

4.1

The control station of the submarine according to Sec.13 [2.2] shall be fitted with indicating instruments for monitoring at least the following environmental conditions inside the submarine:

- pressure
- temperature
- humidity, if applicable
- oxygen partial pressure / content
- oxygen flow meter
- CO_2 partial pressure / content
- H_2
- pressure of connected breathing air/ gas bottles
- further monitoring in case of use of health endangering gases.

The readings of the pressure gauges shall be accurate to at least 1% of the complete indicating range. The use of mercury pressure gauges and thermometers is not permitted.

For oxygen and CO_2 pressure gauges see [4.5] and [4.6].

4.2

Each section of the submarine which can be separated should be provided with facilities for measuring the room temperature and the O_2 and CO_2 partial pressures.

4.3

A permanent gauge and a standby indicator shall be provided for monitoring both the O_2 and CO_2 partial pressure. Test tubes may be recognized as standby indicators.

4.4

The system for the analysis of oxygen shall have a minimum indicating accuracy of ± 0.015 bar oxygen partial pressure.

4.5

The CO_2 analysis system shall have a minimum indicating accuracy of ± 0.001 bar CO_2 partial pressure.

4.6

A system of analysis shall be provided for determining atmospheric impurities such as CO, NO, NO_x and hydrocarbons. Test tubes may be accepted for this purpose.

5 Pressure equalization

Measures shall be provided to transfer the higher or lower pressure eventually built up within the pressure hull in a controlled manner to atmospheric pressure before the access hatches are opened.

SECTION 15 FIRE PROTECTION AND FIRE EXTINGUISHING

1 General

1.1

The requirements of this section apply to the fire protection and fire extinguishing systems of submarines and shall be applied in conjunction with Pt.3 Ch.1 Sec.20 and Pt.3 Ch.5 Sec.9, where applicable, see also SOLAS requirements Pt. C, Regulation 7 as far as applicable.

1.2

The documents to be submitted to the Society for approval are stated in Sec.2 [3].

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

1.4

A fire safety policy shall be defined for the submarine and be in accordance with CONOPS.

2 Fire protection

2.1 Structure

2.1.1 The submarine shall be subdivided by thermal and structural boundaries as far as applicable. The fire integrity shall be maintained at openings and penetrations of these boundaries.

2.1.2 As far as possible, only non-combustible materials or materials which are at least flame-retardant shall be used inside submarines. All loadbearing components and insulations shall be made of non-combustible materials.

2.1.3 Sources of ignition shall be avoided wherever possible. Electrical heating appliances and heaters shall be fitted with protection against overheating.

2.1.4 Components and materials shall be selected with a view to minimize the accumulation of electrostatic charges.

2.1.5 Where combustible materials are installed in closed cabinets, the latter shall be so designed that effective extinguishing action can be taken from outside.

2.1.6 Fire resistant boundaries shall be designed to withstand the instantaneous pressure differences that may result from a fire and any pressure effects from the application of extinguishers. If safe evacuation is required through the boundary, the boundary shall be equipped with a pressure relief.

2.1.7 Fittings that preserve external watertight integrity shall remain effective during and after a fire.

2.1.8 Every construction shall be designed with the consideration that it may be exposed to a fire.

2.1.9 Fire boundaries, openings and penetrations as well as materials shall be demonstrated fire safe in accordance with a recognized standard.

2.2 Risk of ignition

2.2.1 Ignition sources shall be restricted.

2.2.2 Flammable liquids and gases shall be stored in dedicated spaces or tanks. See also [6.5.3.6].

2.2.3 Where petrol products with a flash point below 60°C are required e.g. for special operation, they have to be stored outside the pressure hull in single, independent containers. Their fixing arrangements shall allow to jettison the containers overboard in surfaced condition.

3 Fire detection and alarm system

3.1 General

3.1.1 Effective means of detecting and locating fires and alerting the continuously manned control station and fire teams shall be provided.

3.1.2 The operational readiness of the systems has to be indicated at the control stand.

3.1.3 The systems have to be connected to at least two independent sources of power.

3.1.4 The fire detection and fire alarm systems shall be functional for both a manned and an unmanned submarine in the harbour.

3.1.5 The fire detection and fire alarm systems shall be designed in accordance with a recognised standard and shall be tested periodically according to a recognized procedure.

3.1.6 The design and arrangement of fire detection and alarm systems shall conform to Pt.3 Ch.3 Sec.9 [4.3] and Pt.3 Ch.4 Sec.11 [8], as applicable.

3.2 Fire detection systems

3.2.1 Fire detection systems including central fire detection stations, fire detectors and the wiring of the detection loops require the approval of the Society.

3.2.2 Fire detection systems shall be so constructed that any fault, e.g. supply failure, short-circuit or wire breakage in the detection loops, or the removal of a detector from its base triggers a visual and audible signal at the central fire detection station.

3.3 Fire alarm systems

3.3.1 The fire alarm shall be actuated manually from the control station or other effectively placed call points in the different compartments or automatically by the fire detection system.

3.3.2 The alarm shall be sounded in the central control station and in every compartment of the submarine.

In machinery spaces an adequate visual alarm has to be provided additionally.

Silent fire alarms shall give a clear visual signal that a fire has been detected.

3.3.3 The fire alarm is to sound the submarine's general alarm if not responded to within a defined timescale.

3.4 Other alarm systems

For extinguishing systems with toxical or safety relevant gases an additional suitable detecting system has to be installed to detect leaking. The type and place of installation has to be agreed by the Society.

4 Fire extinguishing systems

4.1 Design

4.1.1 Each compartment of the pressure hull shall be equipped with suitable means for extinguishing a fire in the interior by providing for the rapid and efficient distribution of the extinguishing agent to any part of the space.

4.1.2 The fire extinguishing systems shall be designed and constructed in such a way that they can safely deal with every conceivable outbreak of fire under the environmental conditions stated in Sec.4.

4.1.3 Fire extinguishing systems and appliances shall be designed in accordance with a recognized standard and shall be tested periodically.

4.2 Extinguishing agents

The following principle requirements shall be complied with for extinguishing agents.

4.2.1 Extinguishing agents with a toxic or narcotic effect are not permitted. Choking hazards of extinguishing systems shall be considered. For gaseous extinguishing agents an alarm circuit shall be provided in advance to their application.

4.2.2 In general salt water is not permissible as extinguishing agent.

4.2.3 Actuation of a fire extinguishing system may not cause any unacceptable pressure change in the space concerned.

4.3 Types of fire extinguishing systems

Extinguishing systems include portable extinguishers or permanently installed extinguishing appliances.

4.3.1 Portable fire extinguishers

4.3.1.1 Fire extinguishing agents that may be utilized:

— distilled water
— dry powder
— foam
— CO_2 for local application at electrical systems and switchboards; not to be used as space protection as the critical concentration to endanger human beings shall not be reached (net weight 10 kg maximum).

4.3.1.2 In each closed space of the pressure hull portable fire extinguishers shall be available.

The total number and distribution of the different extinguishers shall be agreed with the Society.

4.3.1.3 Wherever possible, potable extinguishers shall be mounted where they are easily accessible.

4.3.2 Fixed installed systems

4.3.2.1 Extinguishing agents that may be utilized:

- NOVEC-1230
- FM 200 or comparable gases
- water fog
- nitrogen or other inert gases/gas mixtures
  (e.g. inergen)

Extinguishing agents with a toxic, stifling or narcotic effect are not permitted. Other solutions shall be agreed with the Society.

4.3.2.2 In case that for separated compartments carbon dioxide only be used as extinguishing agent with acceptance of the naval administration special procedures shall be defined and trained to guarantee the safety of the personal on board.

4.3.2.3 Suitable means shall be provided to ensure that in any space the quantity of extinguishing agent ejected does not exceed the amount required to extinguish the fire.

4.3.2.4 Fixed installed extinguishing systems shall only be capable of manual actuation and shall, as far as possible, be safeguarded against improper and accidental operation. The systems shall be actuated from outside the space to be protected and only after an alarm has been given in the space which has then been evacuated from all present crew members.

4.3.3 Water fire extinguishing systems

If all other extinguishing media have been used up, water extinguishing may be applied.

4.3.3.1 Connections from ballast water system to supply fire hoses in the fore and aft part of the submarine shall be provided.

4.3.3.2 Water from firefighting efforts shall be drained without unnecessarily contaminating any equipment. Drainage installations shall be provided especially in areas with electrical equipment for the purpose of minimizing damage.

4.3.3.3 Hydrostatic buoyancy constraints will restrict the quantities of water that can be used for firefighting and cooling.

4.3.3.4 Firefighting shall not result in a loss of depth control or in trim instability.

5 Handling of smoke

5.1 Smoke generation and toxity

Smoke and toxic products released from materials exposed to the effect of fire shall be limited to materials installed and demonstrated to be in accordance with relevant standards (e.g. FTP Code).

5.2 Control of smoke spread

5.2.1 The submarine shall be capable of expelling smoke from within the pressure hull, in both surfaced and snorkelling conditions.

5.2.2 Smoke clearance shall be provided for all compartments.

5.2.3 The atmosphere on the clear side of a smoke boundary shall be monitored in terms of toxic combustion products using portable and/or fixed instruments.

5.2.4 Where possible, the ventilation system shall be designed such that smoke clearance after the fire is extinguished, will be possible from every compartment without contaminating other areas.

5.2.5 The risk of smoke spread by the battery ventilation system shall be minimized.

5.2.6 Special measures shall be made to keep the control station free from smoke to allow the equipment contained therein to be operated effectively.

6 Carriage of dangerous materiel

6.1 General requirements

6.1.1 Arrangements for dangerous materiel to be applied in submarines and defined herein shall allow a safe storage, distribution and use of these products.

6.1.2 Arrangements with dangerous materiel shall be in accordance with the requirements of SOLAS and IMDG Code, as far as applicable to submarines.

6.1.3 The requirements herein apply directly to all spaces and systems in which dangerous material are stowed, maintained, handled or used and to those adjacent spaces containing items that might produce an unacceptable risk of incident. The list of affected spaces and equipment shall be agreed with the Society.

6.1.4 A Dangerous Materiel Safety Management System specific to the dangerous materials shall be operated and independently assured.

6.1.5 Access to dangerous materiel by unauthorized persons shall be prevented.

6.2 Special measures for explosives

6.2.1 This section does not apply to explosives (class 1) which are permanent components of a submarine weapon system and are stored within their launching mechanism. Once equipment containing explosives is removed from its host system, it is subject to this section.

6.2.2 Explosives have to be stowed in separate spaces with structural metal walls and shall be protected from vibrations, heat and radiation hazard, see also [6.5.3.5]. Such spaces shall be floodable.

6.3 Special measures for gaseous products

6.3.1 If gaseous products have to be stored on board in pressurized form, the pressure of the product and therefore the environment, especially surrounding temperature, ventilation, etc., have to be kept continuously under control and within a certain range.

6.3.2 Compressed, non-flammable gases like CO_2, Inergen, FM-200, etc. (class 2.2) shall be stored in pressure vessels/bottles which have to be installed in special spaces, securely anchored and connected to a manifold. The temperature in these spaces has to be controlled and ventilation provided.

6.3.3 If hydrogen has to be applied on board, e.g. for an Air Independent Power Supply (class 2.1) it has to be stored pressurized in steel pressure vessels which may be situated outside or inside the pressure hull. If the tanks are located inside the pressure hull, the requirements according to [6.3]. have to be met - if the tanks are located outside, they have to be integrated into the exostructure and protected at least against direct solar radiation.

6.3.4 If oxygen has to be applied on board, e.g. for submarine atmosphere or for an Air Independent Power Supply (class 5.1) it has to be stored in pressure vessels inside the pressure hull.

6.4 Special measures for miscellaneous materials

6.4.1 The functioning and use of the materials shall only be possible if the airtight sealing is broken.

6.4.2 Oxygen candles (class 5.1) for delivering oxygen to the submarine's atmosphere in case of emergency shall be stored in a sealed way in steel containers.

The places of operation of oxygen candles have to be protected against overheating.

6.4.3 Materials like LiOH or lime (class 8) for the absorption of CO_2 from the submarine's atmosphere in case of emergency shall be distributed over the different spaces of the submarine and sealed airtight.

6.4.4 Cleaning fluids (class 9) and paints (Classes 3 or 8) have to be carried in limited amounts only. They have to be contained in closed bottles or containers and kept in paint lockers. Such lockers have to be protected against fire from outside. They have to be contained in closed bottles or containers in a safe area. A ventilation system should be considered.

6.4.5 Corrosive liquids like corrosive hydraulic oils or other liquids have to be stored in special tanks which have to be provided with suitable transfer devices.

6.4.6 Low flashpoint fuels have to be stored outside the pressure hull in speared containers of limited size, well protected in the exostructure.

6.5 Dangerous material

6.5.1 Structural

6.5.1.1 The submarine structure shall support safety and a Safety Management System shall be operated.

6.5.1.2 Safety factors of structures associated with handling and operating equipment shall be appropriate for the hazard classification of the dangerous materiel.

6.5.1.3 Temporary or portable submarine structures or fittings associated with the carriage and use of dangerous materiel shall be designed, built, assembled and tested commensurate with the risk associated with the dangerous materiel.

6.5.1.4 Structural fixings of items within dangerous materiel stowage areas shall ensure that items remain fixed in all foreseeable operating conditions.

6.5.2 Electrical

6.5.2.1 Electrical items shall be approved and certified safe for operation in dangerous materiel stowage areas or in the vicinity of dangerous material or their associated safety systems.

6.5.2.2 Electrical items under normal, overload and fault conditions shall not create a source of ignition.

6.5.2.3 Submarine arrangements shall maintain the electromagnetic conditions within safe limits wherever and whenever dangerous material is present.

6.5.3 Fire protection

6.5.3.1 Materials at spaces with dangerous materiel shall be selected to minimise the fire risk they present. Systems passing through such spaces shall be avoided where failure of the system presents a fire risk.

6.5.3.2 A fire detection and alarm system shall be established and shall be commensurate with the type of hazard presented by the dangerous materiel. The operation of the fire protection system shall be monitored at all times at a continually manned space.

6.5.3.3 Fire protection arrangements shall provide the rapid and direct distribution of appropriate fire suppressant or cooling media. The fully automatic or manually operated system shall be controllable from outside the space.

6.5.3.4 Ventilation control shall ensure the effectiveness of the fire protection system.

6.5.3.5 Fire protection arrangements shall facilitate the testing of the systems to ensure their availability and reliability are maintained whilst the dangerous materiel is present. Failure modes and suitable mitigation measures shall be considered.

6.5.3.6 Battery rooms and all fuel tanks have to be protected by an isolating coating to avoid electrostatic charging.

6.6 Qualification and emergency procedures

6.6.1 All persons managing the safety of dangerous material shall be suitably qualified and experienced. A formal process of assessing, validating and recording evidence of qualification, experience and training shall be in place.

6.6.2 All planned activities involving the use of dangerous materiel shall be identified with a safe system of work defined for each activity.

6.6.3 Emergency planning shall be conducted to identify and prioritise all foreseeable emergency situations.

6.6.4 Incidents involving dangerous materiel or associated safety systems shall be reported, investigated and, where appropriate, arrangements shall be amended to maintain or improve safety levels.

SECTION 16 RESCUE SYSTEM

1 General

1.1

The following rules apply to all the systems for Submarine Escape, Rescue, Abandonment and Survival (SMERAS) of the crew and other embarked persons.

1.2

The documents as stated in Sec.2 [3] and the rescue procedures are to be submitted to the Society.

1.3

The necessary tests and markings are as stated in Sec.2 [5] and Sec.2 [6].

1.4

A rescue concept has to be established, demonstrated and to be agreed by the naval administration and the Society.

2 Measures inside the pressure hull

2.1 Evacuation routes

2.1.1 Evacuation routes shall be designed to enable the movement of embarked persons from any compartment within the submarine to another compartment as quickly and safely as possible.

2.1.2 The routes shall be direct, redundant, remain functional during fire, flooding, heel, trim and shall not contribute to spread of fire, flood, smoke as reasonably practical.

2.1.3 The layout shall also consider the number and distribution of embarked persons, transport of incapacitated persons, level of risk in individual compartments and personal protective equipment to be worn.

2.2 Way finding system

2.2.1 If required by naval administration a way finding system to allow embarked persons to safely, quickly and effectively locate any compartment and evacuation routes.

2.2.2 The system shall lead from all compartments to the rescue locations and shall take into account hazards such as fire, smoke and flood water.

2.3 SMERAS lighting

2.3.1 Lighting systems shall provide sufficient illumination to conduct any SMERAS activity during an emergency.

2.3.2 The lighting system shall operate for a period of time necessary to complete all SMERAS activities.

2.3.3 The lighting system shall have minimised susceptibility to damage and the cabling from the energy source to the SMERAS lighting fixtures shall be specially protected.

2.3.4 SMERAS lighting can be a part of emergency lighting, see Sec.12 [5.2].

2.4 Emergency breathing system

2.4.1 If the atmosphere in the submarine is not safe for breathing, the embarked persons shall have access to emergency breathable air.

2.4.2 The requirements for the emergency breathing air supply are defined in Sec.14 [3.4].

2.5 Emergency life support stores (ELSS)

2.5.1 The SMERAS storages shall protect SMERAS equipment and provisions and ensure that these are readily accessible.

2.5.2 The stored elements shall be protected from heat, fire, smoke or hazardous gasses. Regular inspection shall be carried out.

2.5.3 If applicable, the storages shall be distributed over the different compartments of the submarine.

2.6 Personal hygiene and clean sanitary conditions

2.6.1 Purpose

For the embarked persons in a DISSUB, personal hygiene and sanitary facilities shall be provided for the duration of the survival time.

2.6.2 Liquid and solid waste

2.6.2.1 For normal see Sec.8 and Sec.9.

2.6.2.2 In case of an emergency it shall be possible to use an emergency toilet which needs no power. The produced human waste in liquid and solid form shall be disinfected as far as possible and stored in sealed bags, containers or tanks.

Other waste shall not endanger the atmosphere in the submarine and may be gathered and sealed in bags.

2.6.3 Personal hygiene

The embarked persons shall be able to perform minimum personal hygiene and maintaining the hygiene of the basic facilities e.g. galley, sanitary.

3 The elements of the rescue system

3.1 Scope

For the purposes of these rules, rescue appliances include all systems and equipment for recovering the submarine and rescuing its crew, including in particular:

- emergency personal protection equipment, see [4].
- air trapping device
- escape trunk
- inflatable liferafts

- emergency gas supply for blowing the ballast tanks by e.g. additional supply of compressed air or hydrazine generators, if installed.
- marker buoy, if applicable
- signal ejector
- refuge compartment, if installed
- mating flange for external submarine rescue systems (if not installed, an additional risk analysis has to be developed and approved by the Society)
- floatable rescue sphere, if installed
- emergency communication equipment, see Sec.13 [3]
- medical equipment

Additionally see also systems for breathable atmosphere control and monitoring according to Sec.14.

3.2 Air trapping device under exit hatches

3.2.1 If there is a leakage in the pressure hull and there are no pressure resistant bulkheads, the crew will get under diving pressure and the remaining air will build up an air bubble in the upper part of the pressure hull. The crew may use the emergency breathing air supply, see Sec.14 [3.4], and gather under the exit hatch.

3.2.2 To avoid the escape of the air bubble if pressure equalization outside and inside the submarine is achieved and the hatch cover is opened, a mobile air trapping hose has to be lowered from the underside of the hatch down below the water level. Then the crew members may individually leave the submarine using their emergency personal protection equipment.

3.3 Escape trunk

If an escape trunk for evacuation of persons is provided, the following requirements have to be fulfilled:

3.3.1 Pressure resistant components are to be designed for 1.1 x *CDP* of the pressure hull.

3.3.2 All operating elements are to be marked clearly with:

- element number
- designation of function
- indicator for position (open/closed)

3.3.3 Openings for flooding and emptying are to be protected against impurities, e.g. by grids.

3.3.4 The flooding time of the escape trunk is to be adjusted to the actual diving depth, e.g. by inserted disks into the flooding line.

3.3.5 A communication system between operating desk and escape trunk is to be established. For emergency communication a signal hammer is to be provided in the escape trunk.

3.3.6 The position of the exit hatch (open/closed) has to be shown at the operating desk.

3.3.7 Internal lighting has to be installed in the escape trunk.

3.3.8 Two breathing air connections are to be installed within the escape trunk.

3.3.9 For the requirements of escape trunks and their exit hatches see Sec.5 [3.6].

3.4 Inflatable liferafts

Such inflatable liferafts may be used if the submarine is on the surface or sunken to the bottom of the sea with the possibility to escape from the submarine.

The necessary number of liferafts is to be packed in containers which are stowed in pressure resistant spaces or in pressure tight cases within the exostructure. A sensor for intrusion of water is to be built in. The covers of these spaces are to be opened remotely from inside the submarine.

3.4.1 After releasing the liferafts and their containers they shall develop uplift to reach the surface and shall automatically unfold at adequate outside pressure. They shall remain in connection with the sunken submarine by an unspooled line with pull linkage.

3.4.2 The liferafts – and other life saving appliances - have to be in accordance with international and national regulations. Their design and testing will be separately evaluated by the Society, but is not part of the Classification of the submarine. In any way their storage, activation as well as resulting forces, if applicable, are to be considered within the frame work of the overall design.

3.5 Emergency blowing of the diving tanks

3.5.1 If required in the CONOPS an emergency system for the emergency blowing of the diving/ballasting tanks has to be provided. A calculation which shows the required volume and blow pressure for safe emergency surfacing of the submarine is to be submitted to the Society. The requirements have to be agreed with the naval administration and the Society.

3.5.2 For further requirements see Sec.8 [3.4.8].

3.6 Marker buoy

3.6.1 Submarines are to be equipped with a marker buoy, which can be released in emergency from inside the submarine. The buoy has to be pressure tight assuming a layout pressure of 1.1 times the collapse diving pressure *CDP*.

3.6.2 The marker buoy is to be equipped with an automatic emergency call transmitter.

Instead of the marker buoy also inflatable liferafts equipped with an automatic emergency call transmitter may be used.

3.6.3 For low diving depths, the marker buoy shall remain connected with the submarine by a rolling-off cable. If possible, the marker buoy shall also be usable as telephone connection with arrived rescue forces.

3.6.4 As the buoy and the related mechanism are in general arranged in the free flooded exostructure, all elements of the release system, the cable drum, etc. shall be made of stainless material to guarantee a faultless functioning under all circumstances.

3.6.5 If for high diving depths a connection of the marker buoy to the submarine is not possible anymore, it shall be equipped with a drag anchor, to remain as close as possible to the position of the submarine.

3.7 Signal ejector

3.7.1 The ejector for decoy flares as described in Sec.9 [7] can also be used for signal elements.

3.7.2 The ejected signal elements have to have enough buoyancy to safely reach the sea surface.

3.7.3 In general red flares and/or coloured water marker may be used as signal elements.

3.8 Refuge compartment

3.8.1 General

If required in the CONOPS a refuge compartment has to be installed within the pressure hull. For the structure see Sec.5 [7.5].

3.8.2 Equipment

The following equipment resp. provisions have to be provided within the compartment to be applied for the full survival time or otherwise defined by the naval administration:

— atmosphere control (oxygen supply and elimination of dangerous gases)
— sanitary equipment (chemical toilet)
— provisions (liquids and emergency rations)
— survival equipment
— a possibility to release the marker buoy, signal ejector and life rafts
— emergency communication

3.9 Mating flange

3.9.1 Where the submarine is provided with mating flanges for an external submarine rescue system or a rescue bell, the relevant design parameters and calculations are to be agreed with the Society in each case.

3.9.2 Number and location of access/exit hatches for crew and other persons are to be defined bearing in mind the total length of the submarine, the length of the pressure hull, number of persons on board as well as conditions of operation and rescue facilities.

The number of the hatches shall not be increased beyond the necessary minimum.

3.9.3 Exit hatches and their mating flanges have to meet international sizes and standards to allow for rescue operations by different naval organisations.

The minimum net width shall be as defined in Sec.5 [3.6.4].

3.9.4 The complete exit arrangement shall be designed to allow also the transport of incapacitated persons on stretchers. Therefore it has to be checked, if the minimum net widths as defined of Sec.5 [3.6.4] have to be increased.

3.9.5 The outer hatch shall be operable from inside and outside to allow access to the submarine.

3.9.6 The hatch has to be equipped with the possibility for a pressure equalization with the rescue system.

3.9.7 The mating flange has to be clearly marked.

3.9.8 Measures for a power independent communication with the submarine rescue system (e.g. signal hammer and signal table) shall be provided.

3.10 Floatable rescue sphere

3.10.1 The size of the rescue sphere has to be fitted to the number of the crew and has to be suitable for a safe and quick surfacing procedure.

3.10.2 For design of the pressure resisting structure see Sec.5 [7.6].

3.10.3 The upper part of the sphere shall be surrounded by a buoyancy body which has to deliver the necessary uplift for surfacing after watering the gap between pressure hull and sphere and after releasing of the connection with the pressure hull.

3.10.4 It shall only be possible to activate the release from inside the rescue sphere if the access hatches are closed.

3.10.5 In surfaced condition the rescue sphere shall float in a stable position with the exit hatch at the top and with sufficient freeboard to the water surface.

If necessary the freeboard may be increased by a buoyancy tank which empties itself at the water surface.

3.10.6 The rescue sphere has to be provided with the necessary survival equipment, which is required for the stay of the crew over a time period to be agreed with the Society depending on the rescue plan to be submitted.

3.11 Medical equipment

3.11.1 Medical equipment shall contain first aid and preventive pharmaceutical materials.

3.11.2 For the transport of incapacitated persons in horizontal and vertical direction special equipment, e.g. stretchers and lifting gear, shall be provided.

4 Emergency personal protection equipment

4.1

For each crew member submarines are to be equipped with sufficient emergency personal protection equipment (PPE) even in an emergency for the duration of the survival time.

4.2

Such equipment shall meet the following requirements:

— be designed to provide protection from the effect of severe environmental conditions (e.g. cold shock and hypothermia);
— accommodate the full range of anthropometrical characteristics of embarked persons
— be unpacked and donned easily, swiftly and without assistance
— not hinder the person wearing it to conduct SMERAS activities
— remain functional during the SMERAS process
— not hinder the person wearing it to don a life jacket, if not combined in a PPE
— not hinder the person wearing it to swim a short distance through the water and board a life raft

5 Means for survival on the sea surface

5.1 Safe assembly on the upper deck of the exostructure

5.1.1 The persons, who have been evacuated from inside the surfaced submarine, shall be able to assemble safely on the upper deck before abandonment of the submarine.

5.1.2 There shall be sufficient space for the evacuated persons on the upper deck without a high risk of being thrown overboard.

5.1.3 For protecting elements, like guard rails see Sec.7 [4].

5.2 Safe embarkation into life rafts

5.2.1 A safe method for transfer of embarked persons on the upper deck into life rafts shall be available.

5.2.2 It shall also be possible to transfer incapacitated persons with stretchers, etc.

5.2.3 See also Sec.7 [4.4].

5.3 Rescue by helicopter

5.3.1 It shall be possible for persons, who have been evacuated from the surfaced submarine and are on the upper deck (or in the surrounding sea) to be rescued by helicopter.

5.3.2 One or more places shall be available on the upper deck, where evacuated persons, including incapacitated persons can be air lifted by helicopter.

5.3.3 See also Sec.7 [4.3].

5.4 Man overboard equipment

The submarine has to be equipped with a special buoy to assist the person over board during the recovering manoeuvre.

This buoy shall be easy to handle, have a signal colour and be provided with a swimming rope for recovering.

For these buoy a suitable place of storage easily reachable for the crew shall be provided.

SECTION 17 SPECIAL PURPOSE SYSTEMS

1 General

This section summarizes the main systems of submarines, vehicles and devices which can be designed to effectively assist the different missions of naval divers.

In addition the deviating criteria for rescue submarines and rescue equipment as well as for mine transport are summarized.

The basic requirements have to be defined in a Concept of Operations (CONOPS), which leads to the selection of the system type to be applied.

2 Diver transport submarine

2.1 Purpose

In a diver transport submarine the divers are carried in a dry compartment under environmental control and are not exposed to the water and diving pressure during transport. Therefore long range missions for a greater number of divers can be performed.

Internationally also known as Advanced Seal Delivery System (ASDS) or Autonomous Swimmer Delivery Vehicle (ASDV).

2.2 Design principles

The following design principles are recommended:

— control of the submarine by crew members independent from the divers
— Control and machinery spaces separated from diver transport compartment by pressure resistant bulkheads, thus the diver compartment may also be used as compression/decompression chamber
— lock-in/lock-out chamber with entrances from diver compartment and control room of the crew
— mainly designed for underwater operation
— possibility for anchoring underwater
— electric drive, power from batteries or AIP
— communication and navigation systems
— reduced signature level for undetected approach
— military equipment according to CONOPS
— transport of diver propulsion devices, if required

2.3 Detailed requirements

For detailed requirements Sec.1 to Sec.16 of these rules have to be considered as far as applicable. For special systems the Society's rules for Underwater Technology for diving systems UWT Pt.5 Ch.1- UWT Pt.5 Ch.2 and for manned submersibles UWT Pt.5 Ch.5 are to be applied.

3 Diver delivery vehicle

3.1 Purpose

With a diver delivery vehicle the divers are transported outside in their diver’s suits and are exposed to the water. Therefore only missions with medium and short range for a limited number of divers can be performed.

Internationally also known as Seal Delivery Vehicle or Swimmer Delivery Vehicle (SDV).

3.2 Design principles

The following design principles are recommended:

— control of the vehicle by one or two crew members or directly by a diver
— only designed for underwater operation in limited depths
— breathing from the vehicle's compressed air supply or diver's own Scuba gear
— electric drive, power from batteries
— only basic location system
— reduced signature level for undetected approach
— military load, if applicable

3.3 Detailed requirements

For detailed requirements Sec.1 to Sec.16 of these rules have to be considered as far as applicable. For special systems the Society's rules for Underwater Technology for manned submersibles UWT Pt.5 Ch.4 have to be applied.

4 Diver propulsion device

4.1 Purpose

With a diver propulsion device the diver is towed behind in his diver's suits and controls the device with his hands. Therefore only missions with short range for one or two divers can be performed.

Internationally also known as Diver Propulsion Vehicle (DPV) or underwater scooters.

4.2 Design principles

The following design principles are recommended:

— control of the vehicle directly by one or two divers
— only designed for underwater operation in limited depths
— breathing from the diver's own Scuba gear
— electric drive, power from batteries
— reduced signature level for undetected approach
— The device is not to be started accidentally and must not run away from the diver (dead man's handle to be provided)
— neutrally buoyant under all conditions
— propeller shall be caged to create no harm to divers
— to be designed electrically safe
— no military equipment

4.3 Detailed requirements

The fulfillment of aforementioned design principles has to be demonstrated to the Society.

5 Rescue submarines and equipment

5.1 Purpose

Submarine Rescue Submarines are manned submarines designed for the only duty to save crews of distressed submarines from the sea bottom by docking-on and taking over the crew during several diving missions. Rescue submarines may be able to keep the saved crew under the pressure occurring in the distressed submarine or not.

5.2 Types of rescue submarines

The following types of rescue submarines have to be distinguished:

— independant with no connection to the rescue mother ship
— dependent with umbilical connection to the mother ship for establishing of communication and supplies

5.3 Other elements of rescue systems

Despite of the manned rescue vehicle, the following elements of a complete rescue system have to be considered:

— *Mother submarines* which are able to carry the rescue submarine on their (rear) deck and be locked to the rescue submarine by access hatch and mating flange. This type of submarine is treated essentially in Sec.1 to Sec.16.
— Naval or commercial *surface vessels of opportunity* (VOO) which are able to act as motherships (MOSHIP) for the handling system for launch and recovery of the submarine, the decompression system, if applicable and the necessary auxiliary systems.
— Candidate vessels of opportunity may be Offshore Service Vessels, Offshore Platform Support Vessels or Anchor Handling Tugs and Supply Vessels or Multi-Purpose Ships. The requirements for these ship types are defined in the DNV GL rules for Offshore Service Vessels.
— *Launch and recovery system* with or without coil-up/coil-off mechanism for umbilicals. The requirements for these systems are defined in the Society's rules for Underwater Technology UWT Pt.5 Ch.6 Sec.11, for umbilicals UWT Pt.4 Ch 5.
— For the *decompression system*, if applicable, requirements are defined in the Society's rules for Underwater Technology UWT Pt.5 Ch.1.
— For reconnaissance and preparation works during the salvage mission an *unmanned submersible* (ROV, AUV) may become part of the system. The requirements are defined in the Society's rules for Underwater Technology UWT Pt.5 Ch.5 and UWT Pt.5 Ch.6.

5.4 Special requirements for independent rescue submarines

In comparison to the naval submarines treated in Sec.1 to Sec.16 the following special requirements have to be considered:

5.4.1 Pressure hull

— designed for nominal diving pressure *NDD* as usual in Sec.5

5.4.2 Transport compartment

— mating flange to be adjusted for inclined positions of the distressed sub
— mating flange and mating arrangements shall be physically secured by locking mechanism which exclude unintentional opening

- lock to the internal part of the rescue submersible, if there is no pressurized transport compartment which can itself be the lock
- pressure equalization of the lock before opening the hatch
- transport compartment also to be used as compression chamber for rescued crew by increasing its internal pressure
- connection to a decompression system of a mother ship out of the water shall be possible
- for communication between the rescue crew and the distressed submarine a standard emergency communication tapping code table and signal hammer shall be provided

5.4.3 Propulsion

- main propulsion and/or thrusters for movement in all directions with fine adjusting (dynamic positioning at least under water)
- only electric drives
- energy stored in batteries, recharging only from outside

5.4.4 Control

- control stand separated pressure tight from transport compartment, if this can be used for decompression
- precise navigation system for the near range (e.g. ultrasonic beacon at the mating flange of DISSUB)

5.4.5 Crew

For the crew is at least recommended:

- Pilot
- Navigator
- Lock and Decompression Operator
- Medical Person

6 Additional mine transport systems

6.1 Purpose

Besides the possibilities to carry mines in special mine ducts within the pressure hull or in the torpedo tubes instead of torpedos a « mine belt » installed occasionally at the sides of the submarine may be considered.

6.2 Design principles

The following design principles are recommended:

- the pressure hull shall be designed and prepared with connection elements to carry the additional loads of belt and mines
- the additional weight has to be compensated by buoyancy elements or the adjustment of fixed installed hard ballast respectively blowing of ballast tanks of the submarine
- the safety of the submarine must not be endangered with mines and without mines
- the remote control of minelaying has to be possible from inside the pressure hull
- it has to be secured that the mines do not get into active condition as long as they are connected to the submarine
- any changes of weight have to be submitted and approved by the Society

7 Torpedo handling and storage systems

7.1 Purpose

The torpedo handling and storage system serves to load, transport and storage torpedo's from outside and within the pressure hull.

7.2 Design principles

The following design principles are recommended:

— the pressure hull shall be designed and prepared with connection elements to carry the additional loads of the torpedo handling and storage system
— the structure and safety arrangements are to be designed and tested according to DNV GL CG-0378, further requirements and tests have to be agreed by the Society
— integration, load and function test for each system on board of the submarine is required
— the torpedo weight has to be submitted by the naval administration

SECTION 18 CONSIDERATION OF THE NAVAL SUBMARINE CODE

1 Introduction to the naval submarine code (NSubC)

1.1 Publishing organisation

The Naval Submarine Code (NSubC) is a non-classified Code of the North Atlantic Treaty Organisation (NATO) published as ANEP

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1.2 Aim

The overall aim of the NSubC is to provide an internationally accepted baseline against which a submarine can be demonstrated to be safe to operate, recognizing the risk arising from their unique operational requirements, through a process covering design, manufacture and maintenance, against a defined scope and operational envelope.

1.3 Scope

1.3.1 The NSubC is applicable to submarines, which insofar as the Navies wish it to apply to their own submarines, including submarines belonging to or operated by the armed forces, coastguard or other protection and security department or agency of a State.

1.3.2 The NSubC shall not to be applied to the following types of submarines:

— Swimmer Delivery Vehicles (SDV)
— Unmanned Underwater Vehicles (UUV)
— Submarine Rescue Systems (SRS)
— Submarine Rescue Vehicles (SRV)
— Submarine Rescue Chambers (SRC)
— Nuclear Submarines

1.3.3 The scope of NSubC is divided in three parts and includes the following chapters and annexes:

Parts:

Part.1 – Tiers 1-3	Goals, Functional Objectives and Performance Requirements
Part.2 – Tier 4	Solutions
Part.3 – Tier 5	Justification and Guidance

In this section only **Part.1** is considered in detail. For **Part.2** the general standard Solutions are repeated in [3.2.7] and [3.2.8] of this section. **Part.3** seems mainly of interest for the INSA Working Group and is therefore not considered in this section.

Chapters:

Chapter I:	General Provisions
Chapter II:	Structure
Chapter III:	Buoyancy, Stability and Controllability
Chapter IV:	Engineering Systems

Chapter V:	Seamanship Systems
Chapter VI:	Fire Safety
Chapter VII:	Submarine Escape, Rescue, Abandonment and Survival
Chapter VIII:	Communications
Chapter IX:	Navigation
Chapter X:	Dangerous Goods
Chapter XI:	Integration of Platform, Combat and Navigation Systems
Chapter XII:	Atmosphere Control
Chapter XIII:	Nuclear Power Generation

Annexes:

Part.1 Chapter I, Annex A:	Concept of Operations Statement
Part.1 Chapter I, Annex B:	Standards Plan
Part.1 Chapter I, Annex C:	Model words for the Authorisation of Recognised Organisations
Part.1 Chapter I, Annex D:	Form of Certificates
Part.1 Chapter I, Annex E:	Definitions and Abbreviations

For the Annexes A to E it is recommended to take the information directly from the NSubC.

1.3.4 The NSubC is based on and benchmarked against IMO conventions and resolutions, it therefore contains safety issues that correspond in scope to that which is covered by IMO publications but which reflect the fundamental nature of submarines.

1.4 Principles of application

1.4.1 Navies who adopt the Naval Submarine Code and all parties involved in application shall recognise that implementation of the provisions of the Naval Submarine Code is a matter for each party.

1.4.2 The International Naval Safety Association (INSA) assumes no responsibility and will not be liable to any person for any loss, damage or expense caused by reliance on the information or advice in this document or howsoever provided.

1.5 Organisation and areas of responsibility

The main organisations involved in a submarine project during definition of the Concept of Operations (CONOPS), design, construction, survey and testing as well as operation are as described below:

1.5.1 Owner - The organisation which is responsible for submarine safety and for ensuring that design, material and equipment selection, construction and in-service operation and maintenance are carried out and demonstrating that this is undertaken correctly in accordance with standards agreed with the naval administration in the Concept of Operations Statement.

The Owner is normally the nominated Department of Government of the State. This responsibility may be delegated to a number of organisations, in which case a nominated lead is to be identified. This can be split up in 3 duty holders: material, operational control and commanding officer.

1.5.2 Naval administration - The Department of Government of the State responsible for providing safety regulations and suitable standards for naval submarines. The naval administration is also responsible for ensuring the Owner has access to verification of compliance and issue certification against the submarine role, operating and maintenance philosophy, environmental conditions, survivability and principle standards set out in the Concept of Operation Statement.

The naval administration may be assisted or supported by other governmental departments or Recognised Organisations who, by mutual agreement of the naval administration and the department or agency concerned, have agreed to enact this Code for specified submarines of that department or agency.

1.5.3 The Recognized Organization - The organisation authorized to undertake certain activities on behalf of the naval administration, e.g. a Classification Society (like DNV GL) or other competent organisations. The Recognized Organisation may also be called upon by the naval administration to assist in the development of safety assurance arrangements that supplement the Recognised Organisation's own standards.

The scope of work and the nomination of Recognized Organizations have to be defined and documented with forms recommended in App.C.

1.6 Compliance with the code

1.6.1 Ideally a naval submarine will comply in all respects with the agreed standards throughout its seagoing life. However, there will inevitably be some aspects of the submarine design, material, equipment or construction that fall short of the agreed standards. It is the responsibility of the naval administration (or the recognised organisation on behalf of the naval administration) to manage these.

1.6.2 There are a number of alternatives to how Non-Compliances can be managed:

1.6.2.1 Minor Non-Compliances - These can be generally demonstrated to either not affect the submarine safety, or offer an equivalent solution that achieves at least the same level of safety. In these cases, the certifying organisation will record these as a Memorandum Item to capture the agreement for future reference.

1.6.2.2 Major Non-Compliances -These are of such a nature that submarine safety is compromised. They will require rectification and the certifying organisation will need to agree a date by which the rectification work shall be complete, and the aspect of concern re-surveyed or re-assessed. In some cases, it may be necessary to issue temporary operating restrictions or instructions to control the extent of the hazard.

1.6.2.3 Refusal or Withdrawal of Certification - Ultimately, if the Non-Compliance is of a significant nature, the certifying organisation may refuse to issue or withdraw certification until the Non-Compliance has been rectified by the Owner to the satisfaction of the certifying organisation.

1.7 Impact of the NSubC on the rules for naval submarines of the Society

1.7.1 For the application of the NSubC the Society would have the role as Recognised Organisation, which is autorised by the relevant naval administration and confirms verification of compliance and issues Certificates.

1.7.2 For the classification of a naval submarine in the frame work of the Classification and Construction rules of the Society the full or partly use of the NSubC can be established by assigning the class notation **NSubC(Chapter)**. This notation makes clear that performance requirements of the defined Chapter(s) of NSubC are fulfilled.

1.7.3 The text of the NSubC is not directly included in the main text of the the Society's rules for naval submarines because a direct integration of NSubC structure and wording would have required a massive change in the Society's existing and proven rule structure.

1.7.4 To offer the ability to check the performance requirements of NSubC against the the Society's rules, the relevant performance requirements of NSubC are summarized in the following under [3]. Alternatively there is stated for each Chapter:

— reference to the exact position in the the Society's rules where this Regulation is treated
— definition of measures to fulfil the NSubC performance requirement in view of the Society

If the class notation **NSubC(Chapter)** is assigned, the performance requirements of NSubC can be included in the the Society Classification procedure.

2 Structure of NSubC (Introduction, 9 – 13)

2.1

The Naval Submarine Code adopts a goal based approach. The basic principle of a goal based approach is that the goals should represent the top tiers of the framework, against which submarines are verified both at design and construction stages, and during operation. This approach has several advantages over more traditional prescriptive standards:

2.1.1 The goal based approach permits innovation by allowing alternative arrangements to be justified as complying with the higher level requirements.

2.1.2 The Naval Submarine Code can become prescriptive if appropriate for the subject, or alternatively, remain at a high level with reference to other standards and their assurance processes.

2.1.3 Non-Compliances against specific design standards or codes can be managed in a more controlled manner by referring to the higher level intent.

2.2

For the development of the Naval Submarine Code, a hierarchy of tiers has been adopted as shown in Figure 1. The increasing width of the triangle as the Naval Submarine Code descends through the tiers implies an increasing level of detail.

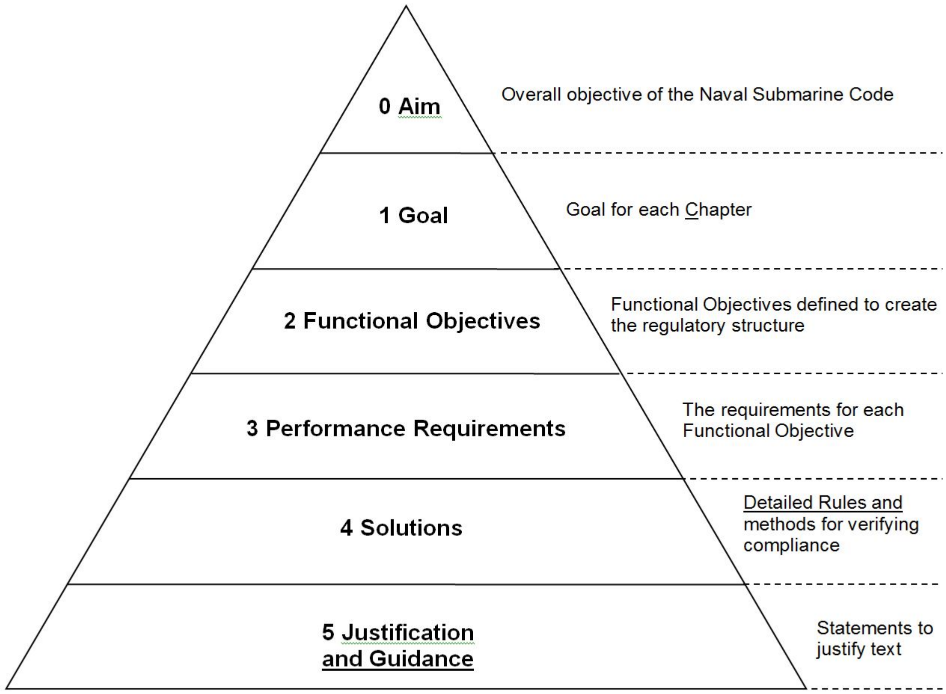

Figure 1 Goal based approach to the developing the Naval Submarine Code

2.3 Application

The principles of application of the tier levels are detailed below, including an example for atmosphere control of submarines.

2.3.1 Tier 1 – Goal

2.3.1.1 The Tier 1 Goals are not intended to set prescriptive requirements or to give specific solutions. However, they should be clear, demonstrable, verifiable and long standing and capable of adapting to changes in technology. Goals should be stated in terms that are potentially measurable, even if the precise measurement scale is not specified. Thus, goals may be stated in terms of impact on crew, general public, property of the environment, capability interruption/reduction, or combination of these. Goals should address the primary concern of the document.

2.3.2 For example, the goal for chapter VII submarine escape, rescue, abandonment and survival may include the statement:

"Provide effective escape for all embarked persons from all manned spaces to a place of safety in the event of foreseeable accidents and emergencies."

2.3.3 Tier 2 - Functional objectives (regulations)

2.3.3.1 For each NSubC Chapter there will be a number of factors which can contribute to achieving the Tier 1 Goal. These are identified as the Functional Objectives and are used to establish the Regulatory framework for the Chapter.

2.3.3.2 Risk assessment techniques to identify hazards may be used to establish the Functional Objectives. Multitude of risk assessment methodologies is available which will assist the Study Groups through this and subsequent tiers. These can include HAZID (Hazard Identification Study), SWIFTS (Structured What If Technique), Fault Tree Analysis, etc. Recently IMO have investigated and applied the Formal Safety Assessment (FSA) process, an outline of this is held by the INSA secretariat for guidance of Study Groups as required. The method shall be suitable for the subject being covered in the NSubC Chapter.

2.3.3.3 Once the Functional Objectives have been identified, these need to be grouped into a logical Regulatory framework – a set of Regulations.

2.3.3.4 One Functional Objective may be Built in Breathing Systems. Functional Objectives can then be defined as a lower level goal such as:

“If the atmosphere in the submarine is not anymore in the right composition for human breathing, the embarked persons shall be delivered with suitable breathing air individually.”

2.3.4 Tier 3 - Performance requirements

2.3.4.1 At the third tier, for each Regulation, the Working Group is to define a set of requirements relevant to the Functional Objective which are to be complied with and verified during design, construction and operation, to meet the aforementioned aim, philosophies and goals.

2.3.4.2 The performance requirements are independent of the technical or operational solution and have a qualitative character. This will allow for future alternative technical or operational solutions, which were not available at the time of development of the Naval Submarine Code text.

2.3.4.3 A performance requirement for Built in Breathing Systems may be:

“The Built in Breathing System shall allow complete separate operation from the general atmosphere control and allow the embarked persons to move around to execute their remaining duties and have partially some rest. During moving the air connection may be interrupted shortly.”

2.3.5 Tier 4 - Solutions

2.3.5.1 Tier 4 describes the solution but also identifies activities for verification or solutions. The fourth tier will begin with a statement describing how it will be verified that the Performance Requirements are to be met. In some cases within the text there are specific activities prescribed. E.g. a survey and plan approval, document review or a test, a detailed standard or verification procedures.

2.3.5.2 Users are to note that prescription presents minimum risk, i.e. risk of failure is greatly reduced once prescriptive criteria or standards selected. A performance based solution (e.g. first principles calculations, risk assessment techniques, statistical analysis) is likely to be both expensive to apply and defers risk reduction until the full demonstration is complete. As such, performance based solutions should be avoided if possible.

2.3.5.3 A Solution for Built in Breathing Systems could include:

“The Built in Breathing System shall consist of:

- independent preparation of breathing air;
- piping system for air distribution through all manned spaces;
- connecting valves to this piping system at short distances;
- connection hoses and full face masks with slight overpressure and integrated communication
- membrane for every embarked person.”

2.3.6 Tier 5 – Justification

Tier 5 requires a statement justifying how the NSubC text for Tier 3 – performance Requirements and Tier 4 – Solutions satisfies the Tier 1 – Goal for the chapter and ultimately the Tier 0 – Aim of the NSubC.

This statement is essential for configuration control of the NSubC and has to capture the context, hazards identified, minimum controls required and all the key arguments and issues exposed during the course of developing the NSubC text.

2.3.6.1 For some chapters it may be considered sufficient to establish requirements for tiers 1 - 3 only. Tier 4 being included where appropriate.

3 Application to the different chapters of NSubC

Original elements of NSubC are written in bold letters, remarks to this and the Society's rules are written in upright letters.

3.1 Chapter I – General Provisions

Part 1 Goals, functional objectives and performance requirements

3.1.1 Regulations 0 and 1 – Goal and principles

The purpose of the NSubC is to provide a regulatory safety framework for submarines that recognises their operational usage and the needs of Navies. The philosophy behind this Code is based on the management of risk.

The Society's rules for classification and construction constitute the basis for the Classification of naval submarines with non-nuclear propulsion.

3.1.2 Regulation 2 - Application

The NSubC shall not be applied to the types of submarines defined in [1.3.2].

The Society's rules define requirements for the majority of these submarine types in Sec.17 of this Code.

3.1.3 Regulation 3 - Concept of operations

The Owner shall define and document the manner in which the submarine is to be operated in a Concept of Operations Statement (ConOpS) including but not limited to the contents of the template included at App.A to this Chapter.

The Society's rules define in Sec.2 [1.2]: Submarines and their components are to be designed to meet the service conditions stated in the Concept of Operations by the naval administration.

In the Concept of Operations Statement all main parameters for military tasks, external and internal hazards to cope with, limitations of operation, survey and maintenance philosophy, etc. shall be well defined and documented as the basis for each actual submarine project.

3.1.4 Regulation 4 - Exceptions

This Code, unless expressly provided otherwise, does not apply to the types of submarines defined in [1.3.2] and to submarines where the naval administration has accepted an alternative regulatory regime as offering an equivalent level of safety.

For submarines, which are not built according to rules of the Society a Certification can be applied, see Sec.1 [4.3].

3.1.5 Regulation 5 - Exemptions

The naval administration may exempt a submarine from complying with the requirements of this Code:

— in exceptional circumstances, if it is required to undertake a single international voyage
— if it embodies features of a novel kind
— if it is required to engage in activities which are not defined in the Concept of Operations Statement provided that it complies with safety arrangements which are appropriate for the activity.

Survey by special agreement will be performed by the Society on request in accordance with the relevant provisions, see Sec.1 [3.1].

3.1.6 Regulation 6 - Deviations

Where this Code requires that a particular structure, fitting, material, appliance, apparatus, software, software, etc. shall be fitted or carried in a submarine, or that any particular provision shall be made, the naval administration may allow any other substitution to be made in that submarine, if it is satisfied by trial thereof or otherwise that such substitution is at least as effective as that required by this Code.

Naval ships deviating from the Society's rules in their type, equipment or in some of their parts may be classed, provided that their structures or equipment are found to be equivalent to the Society's requirements for the respective Class, compare Sec.1 [1.1.9].

3.1.7 Regulation 7 – Alternative design and arrangement

3.1.7.1 Designs and arrangements may deviate from solutions of the Code, provided that the design and arrangements meet the goals and performance requirements of the Code and are agreed by the naval administration.

3.1.7.2 When designs or arrangements deviate from the solutions to this Code, engineering analysis, evaluation and approval by the naval administration of the alternative design and arrangements shall be carried out in accordance with this regulation.

Hull and machinery installations which have been developed on novel principles and/or which have not yet be sufficiently tested in shipboard services require the Society’s special approval, compare Sec.1 [1.1.10].

3.1.8 Regulation 8 – Operator testing and inspection

3.1.8.1 Safety of critical structures, equipment and systems, the sudden operational failure of which may result in hazardous situations, shall be identified.

3.1.8.2 The Operator shall conduct periodic routine tests and inspections to provide the command with the assurance that all safety critical structures, equipment and systems will operate satisfactorily as and when required.

3.1.8.3 A test and inspection regime shall be defined for all safety critical structures, equipment and systems specifying the inspection or test procedures, acceptance criteria and the frequency of testing/inspection.

3.1.8.4 Appropriate records of the conduct of the tests and inspections shall be maintained. These records are to include the results of the tests and inspections to assure safe operation and to inform maintenance activities.

A complete maintenance program including spare parts administration is to be established and the crew/owner has to perform their part regularly. After maintenance an inspection and testing by the crew/owner shall take place. For more information see Sec.2 [8].

3.1.9 Regulation 9 - Inspection and survey

3.1.9.1 The inspection and survey of submarines, so far as regards the enforcement of the provisions of this Code and the granting of exemptions therefrom, shall be carried out by the naval administration. The naval administration may, however, entrust the inspections and surveys to organisations recognised by it.

3.1.9.2 A naval administration recognising organisations to conduct inspections and surveys as set forth in paragraph [3.1.3.1.9.1] shall formally empower any Recognised Organisation to the extent considered appropriate. The naval administration is encouraged to share with other naval administrations the specific responsibilities and conditions of the authority delegated to Recognised Organisations.

The Society is ready to be nominated as Recognized Organisation by naval administrations and execute Inspections and Surveys for Classification, but also for Certification, see Sec.1 [2], Sec.1 [3] and Sec.1 [4].

3.1.10 Regulation 10 – Verification

Verification activities are to be undertaken to provide assurance that the submarine complies in all respects with the provisions of this Code and remains compliant throughout its life.

3.1.10.1 The naval administration or its Recognised Organisation shall undertake an assessment of the design of the submarine and systems to verify compliance with the Tier 4 Solutions.

3.1.10.2 Verification activities shall be conducted at a periodicity appropriate to the design, construction, material state and usage of the submarine at intervals aligned with those required by the naval administration.

3.1.10.3 A programme of re-validation of certificates, in-line with the maintenance cycles, shall be developed and implemented.

Regular verification of the technical condition of the submarine will be done by the Society within the surveys for classification, compare Sec.1 [2].

3.1.11 Regulation 11 – Survey of a submarine to national and international conventions and regulations

Where adoption of national and/or international conventions is required, the naval administration is to agree procedures with the Flag State Administration.

The application of other construction rules and Maritime Regulations is defined in the Society's rules for Naval Ship rules Pt.1 Ch.1 Sec.2 [2.2] and Pt.1 Ch.1 Sec.2[2.3].

3.1.12 Regulation 12 – Maintenance of submarine and equipment after survey

3.1.12.1 The condition of the submarine and its equipment shall be maintained to ensure that the submarine in all respects will remain fit to operate in accordance with the Concept of Operations Statement without danger to the submarine or embarked persons.

See the Society's rules Sec.2 [8].

3.1.12.2 After any survey of the submarine has been completed, no change shall be made without approval of the naval administration.

Whenever a defect or deviation is discovered, the commanding officer shall report at the earliest opportunity to the naval administration.

Submarines are required to carry a log book in which details of repairs, etc. are entered. The log book is to be presented to the surveyor on request, compare Sec.1 [1.1.8].

3.1.13 Regulation 13 – Issue and endorsement of certificates

A Certificate/s or Statement of Compliance shall be issued to a submarine after an initial, intermediate, renewal or extraordinary survey which complies with the relevant requirements of this Code. The scope of each certificate shall be in accordance with requirements determined by the naval administration. naval administrations are encouraged to share the particulars and reasons for their certification arrangements with other naval administrations for their information.

After completion and successful testing of the submarine a Submarine Certificate will be issued by the Society. For this and other Certificates see Sec.1 [4].

3.1.14 Regulation 14 – Form, duration, validity and availability of certificates

3.1.14.1 Certificates shall be issued for a period specified by the naval administration in accordance with this Code,

The Society has its own standards for the form of Certificates, for validity see Pt.1 Ch.1 Sec.2 [4].

3.1.14.2 The certificates or authenticated copies of the certificates shall be readily available on board for examination at all times.

The Certificates issued by the Society are to be kept on board, compare Sec.1 [1.1.6].

3.1.15 Not used

3.1.16 Regulation 16 - Casualities and other incidents

3.1.16.1 The naval administration shall ensure that an investigation is undertaken of any near misses, casualty or incident endangering the submarine or the safety of the embarked persons. The investigation shall determine what changes to the present regulations, submarine design, operation and support may be required.

3.1.16.2 A management system shall exist to ensure that incidents and accidents are recognised, reported, investigated and lessons learnt are fed back to allow design, maintenance and operating procedures to be improved.

3.1.16.3 Each naval administration is encouraged to supply other naval administrations and/or INSA with pertinent information concerning the findings of such investigations, where such information can be released.

3.1.17 Regulation 17 - Disposal and recycling

The submarine shall be designed and maintained to enable its safe disposal and/or recycling in accordance with national policy at the end of its service life to protect those involved in the dismantling process.

The requirements for the process of disposal are contained in Sec.1 [6].

Part 2 Tier 4 : NSubC Solutions

No requirements!

3.2 Chapter II – Structures

Part 1 Goals, functional objectives and performance requirements

3.2.1 Regulations 0 and 1 – Goal and general

The structure shall be designed, constructed and maintained in order to provide in all operational conditions and in the event of all foreseeable emergencies and accidents.

See the Society's rules Sec.5 for pressure hull and Sec.6 for exostructure.

3.2.2 Regulation 2 - Materials

NSubC defines the main characteristics of materials suitable for the intended application and manufacturing process in general form.

With the Society's rules this is treated in Sec.5 [2] and Table 1 summarizes the different types of approved materials.

3.2.3 Regulation 3 – Loads and load cases

The loads relevant to the structural design shall be thoroughly defined and combined within load cases that meet the requirements of the Owner’s defined Concept of Operations Statement.

NSubC summarizes the loads to be expected and combines them to five main Load Cases.

The Society's rules offers a special Sec.4 for Design Loads with seven main Load Cases. Sec.4 Table 2 summarizes the pressures to be considered for the different elements of the submarine for design and testing.

3.2.4 Regulation 4 – Structural design of the pressure hull

The structural design of the pressure hull shall serve as the primary means of meeting the Goals of this chapter and shall provide for accessibility during operations and maintenance.

NSubC provides only some rough aspects for design; practically a classification society's rules will become necessary for verification.

The Society's rules offer in Sec.5 [3] extensive Principles of Manufacture and Construction and in Sec.5 [4] the Calculation Principles. App.A describes the calculation procedure in detail.

3.2.5 Regulation 5 – Structural design of other structures

3.2.5.1 The exostructure surrounding the pressure hull shall allow for the location and protection of systems and arrangements outside the pressure hull, for improvement of flow and resistance characteristics, and for practical seamanship on deck.

3.2.5.2 Structures internal to the pressure hull (e.g. decks, platforms, tank structures, watertight and non-watertight partitions, etc.) shall provide subdivision of the submarine's internal spaces and provide locating and securing of all systems and equipment.

3.2.5.3 Accessibility during operations and maintenance as well as repairability considerations shall be integral to the structural design of these structures.

The Society's rules offer for the outside structure the Sec.6 – Exostructure which gives instructions for all elements of it. Advice is also given for Materials and special Design and Construction principles. The interior facilities are treated in Sec.5 [7].

3.2.6 Regulation 6 - Construction

3.2.6.1 The quality of construction is to be consistent with structural design requirements, material, welding and Non Destructive Testing (NDT) and shall meet the Goals of this Chapter. In addition requirements for Welding and Non Destructive Testing are defined.

3.2.6.2 Objective quality evidence shall be retained for the life of the submarine demonstrating verifiable achievement against this Chapter.

The Society's rules define the welding requirements in Sec.5 [3.2] and the non-destructive tests in Sec.5 [2.3.3].

Part 2 Tier 4 : NSubC Solutions

3.2.7 Regulations 0 and 1 – Goal and general

Verification that the submarine complies with this chapter shall be by the naval administration. Provision of evidence to support verification shall be by the owner. All decisions that affect compliance with the requirements of this chapter shall be recorded at all stages from Concept to Disposal and these records shall be maintained throughout the life of the submarine.

If a submarine will be classified by the Society the submitted documents become binding for execution. Any subsequent modifications have to be clearly documented and require the Society's consent before they are implemented, compare Sec.2 [3.1].

3.2.8 Regulations 2 to 6 – Materials to construction

Following naval administration agreement, the submarine, systems and equipment are to comply with, and be approved in accordance with justified classification society's rules or other suitable justified standard to facilitate verification of the performance requirements.

See Sec.1 to Sec.17.

3.3 Chapter III – Buoyancy and controllability

Part 1 Goals, functional objectives and performance requirements

3.3.1 Regulations 0 and 1 - Goal and general

The buoyancy, freeboard, sub-division, stability and manoeuvring & control characteristics of the submarine shall be designed, constructed and maintained.

Adequate reserve of buoyancy and stability shall be provided to safeguard life and property at sea whilst maintaining freedom of manoeuvre.

The Society's rules state that the submarine will be assigned class only after it has been demonstrated that their buoyancy and their static and dynamic stability in intact condition is adequate for the service intended, compare Sec.3 [1].

3.3.2 Regulation 2 - Watertight integrity

The submarines shall have watertight boundaries that prevent the uncontrollable ingress of water in all Foreseeable Operating Conditions.

Requirements for watertight boundaries, openings, closures, penetrations as well as for a liquid leakage detection and liquid removal system are also given.

The Society's rules defines principles, cut-outs and penetrations, pipe connection and flanges, as well as hatches, doors and access ports in Sec.5 [3]. For bilge pumping see also Sec.9 [3].

3.3.3 Regulation 3 – Reserve of buoyancy and freeboard

3.3.3.1 The submarine on the surface shall have sufficient buoyancy and freeboard to prevent excessive shipping of green seas, in accordance with the conditions defined in the Concept of Operations Statement.

3.3.3.2 The submarine shall have sufficient reserve of buoyancy in all foreseeable intact and damaged conditions to safeguard life and property at sea whilst maintaining the freedom to manoeuvre.

The buoyancy reserve required by the Society is at least 10 % of the pressure tight volume of the submarine in surfaced condition, compare Sec.3 [2.1].

3.3.3.3 Reserve of buoyancy and freeboard (based on approved lightship weight and centre of gravity) shall be approved by the naval administration at the end of construction and through life at intervals acceptable to the naval administration to ensure the agreed level of performance is maintained. Any standards, models (numerical or physical), calculations, tests, trials or procedures used to determine the reserve of buoyancy and freeboard shall be justified to and approved by the naval administration.

NSubC requires surveys during construction and during lifetime, inclining tests on the surface and submerged as well as a trim dive. The Society's rules define the necessary diving, trimming and heeling tests in Sec.3 [5].

3.3.4 Regulation 4 – Static control

The submarine shall be able to accommodate all foreseeable changes in sea water density, deadweight (excluding Trim & Compensation tank contents) mass and corresponding longitudinal centre of gravity, by achieving both weight/buoyancy balance and longitudinal moment balance using the internal Trim & Compensation tanks only.

The Society's rules require also a Trimming diagram in form of a Polygon line in Sec.3 [3.5.4]. It has to be proven that the displacement due to additional loads can be compensated by changing the filling of the compensating tanks as well as the trim by filling the trimming tanks.

3.3.5 Regulation 5 – Reserve of stability

The submarine shall have adequate resistance to inclination to prevent capsize when disturbed and adequate restoring energy to return to upright once the disturbance is removed in all Foreseeable Operating Conditions.

The Society's rules recommend to check the intact stability for ten different load cases and define the contributions of the different heeling and righting levers. Finally the minimum values of the remaining levers for submarines are given in dived and surfaced condition in Sec.3 [3.1] - Sec.3 [3.5].

3.3.6 Regulation 6 – Controllability

3.3.6.1 In all Foreseeable Operating Conditions and all foreseeable intact and damaged conditions, the submarine shall have adequate controllability to maintain and change speed, depth and heading in order to avoid normal shipping hazards.

3.3.6.2 The manoeuvring performance and directional stability of the submarine shall be approved by the naval administration at the end of construction and through life at intervals acceptable to the naval administration to ensure the agreed level of performance is maintained. Any standards, models (numerical or physical), calculations, tests, trials or procedures used to determine the manoeuvring performance and directional stability shall be justified to and approved by the naval administration.

NSubC requires at least crash stop, turning circle, initial turning, depth and pitch changing manoeuvring trials to be documented in an Operator Guidance. A Safe Operating Envelop and a Manoeuvring Limitation Diagram shall be developed.

The Society's rules define the rudder/manoeuvring equipment in Sec.11 [2.2]. General requirements for tests and trials are defined in Sec.2 [5].

3.3.7 Regulation 7 – Safety of embarked persons

3.3.7.1 The behaviour of the submarine shall be optimised considering the stability requirements and the safety of embarked persons, at the surface in heavy weather and submerged accounting for any wave action while manoeuvring in all 6 degrees of freedom.

3.3.7.2 The submarine shall have acceptable Motion Induced Interruptions, Motion Sickness Incidence, and other measures to permit embarked persons to undertake their duties safely. Appropriate methods shall be used to determine the limitations of safe operation and impact of motions on essential safety functions.

The Society requires dynamic stability to be investigated in any case. The Society is able to offer for such a case special advice and relevant computation procedures, compare Sec.3 [3.5.5].

3.3.8 Regulation 8 – Provision of operational guidance

Information required by the submarine’s crew, pertaining to the watertight integrity, buoyancy and freeboard, static control, stability and controllability of the submarine, shall be provided and maintained with the submarine to facilitate its safe operation in all Foreseeable Operating Conditions and for escape, evacuation and rescue.

The Society's rules define the documents of approval in Sec.2 [3.2.6] to Sec.2 [3.2.8].

Part 2 Tier 4 : NSubC Solutions

See Ch.II [3.2.7] and Ch.II [3.2.8] of this section.

3.4 Chapter IV – Engineering systems

Part 1 Goals, functional objectives and performance requirements

3.4.1 Regulations 0 and 1 - Goal and general

Engineering systems shall be designed and constructed to operate in all Foreseeable Operating Conditions.

For general principles of the Society's rules see Sec.2 [1].

3.4.2 Regulation 2 - Concept of operations statement

The Concept of Operations Statement is the Owner's vision of how the engineering systems of the submarine are to be operated and maintained throughout the life of the submarine and shall be shared by the naval administration. The scope of the information to be provided is defined in AnnexA of Chapter I of the Code.

In the Concept of Operations Statement all main parameters for military tasks, external and internal hazards to cope with, limitations of operation, duty period, survival time, survey and maintenance philosophy, etc. shall be well defined and documented as the basis for each actual submarine project, compare Sec.2 [1].

Regulation 3 – Provision of Operational Information

Operators shall be provided with adequate information and instructions for the safe operation and maintenance of all machinery and systems.

A summary of all necessary documentation is contained in the Society's rules in Sec.2 [3].

3.4.3 Regulation 4 – Propulsion and manoeuvring

The propulsion and manoeuvring equipment shall enable the submarine to manoeuvre as and when required by the Command but still remain within the designed or imposed limitations.

Sec.11 of the Society's rules defines the requirements for propulsion and manoeuvring equipment. Some principles for Air Independent Power Systems are defined in [3].

3.4.4 Regulation 5 – Pressure and piping systems

Pressure vessels, tanks and piping systems and fittings shall be of a design and construction adequate to safely contain and convey media, taking account of the anticipated pressure and temperature profiles and services for which they are intended.

The requirements for pressure vessels, heat exchangers and filters are summarized in the Society's rules in Sec.10 and for piping systems, pumps and compressors in Sec.9.

3.4.5 Regulation 6 – Control of depth, buoyancy and trim

The submarine shall have the ability to operate safely at the surface, at various depths and under various, definite buoyancy and trim conditions.

In the Society's rules the requirements for diving/ballasting, regulating/compensating and trimming systems including control are defined in Sec.8.

3.4.6 Regulation 7 – Other essential safety functions

Continuous supply of energy, a high pressure sea water service, bilge pumping arrangements, continuous removal of heat as well as storage, use and safe disposal of low-flashpoint fuels are required.

In the DNV GL rules the requirements for safety functions like power demand and electrical power supply are defined in Sec.12 [3], for propulsion engines in Sec.11 [2.1.2] , bilge pumping in Sec.9 [3] and engine cooling system in Sec.11 [2.1.8]. Low-flashpoint fuels in submarines (e.g. for outborders) would need special approval from the Society. compare Sec.15 [6.4.6].

3.4.7 Regulation 8 – Electrical generation and power supplies

Sufficient electrical power is to be supplied for required services, essential safety systems and habitability requirements. Continuous supply is required for equipment where a supply interruption is unacceptable.

In the Society's rules Sec.12 [3] describes the measures to establish electrical power supply. Each power source group shall be capable of supplying the submarine with the energy required. In addition it shall be possible to supply wireless equipment and important navigation equipment at least for 18 hours of operation.

3.4.8 Regulation 9 – Battery system and battery charging

The electrical power produced on board shall be stored for flexible operation of the submarine in times with no or insufficient power generation.

In the Society's rules comprehensive requirements for batteries are defined in Sec.12 [3.4] including charging facilities in [3.4.3]. The criteria for approving different types of batteries are put together in 3.4.1.

3.4.9 Regulation 10 – Air independent power supplies

Additional power supply with limited performance, but without air consumption from outside the submarine shall be subject to special consideration by the naval administration.

Some more principles for Air Independent Power Systems are defined in Sec.11 [3]. See also [3.4.4].

3.4.10 Regulation 11- Electrical distribution and equipment

Electrical power shall be safely distributed to consumers and shall meet a greater number of quality requirements.

In the Society's rules all aspects of power distribution including switchgear, cabling, busbars and hull penetrations, etc. are summarized in Sec.12 [4].

3.4.11 Regulation 12 - Lighting

Illumination shall be provided, appropriate for location and operational requirements both in normal and emergency conditions.

Sec.12 [5.2] considers interior lighting including the measures for emergencies.

3.4.12 Regulation 13 – Electrical protection arrangements

All electrical equipment shall be suitably protected against damage to itself under fault conditions and to prevent injury to personnel. A greater number of detailed requirements has to be met.

Protective measures including the design details for protective conductors are defined in Sec.12 [2.5].

3.4.13 Regulation 14 – Machinery control

Machinery and systems essential for propulsion, manoeuvring and safety of the submarine shall be provided with effective means for its operation and control during all submarine operational conditions.

In Sec.13 [5] practically the same criteria as for NSubC are applied.

3.4.14 Regulation 15 – Alerts and safety systems

3.4.14.1 The alert system shall inform operators as soon as reasonably practicable of deviations from normal operation of essential machinery and systems during all submarine operations.

3.4.14.2 A safety system shall be installed to ensure that any serious malfunctions of machinery or system which present an immediate danger shall initiate a corrective action where appropriate to remove the risk of danger.

Alarm and control equipment at the control station is summarized in Sec.13 [2.2].

3.4.15 Regulation 16 – Programmable Electronic Systems (PES)

Additional hazards shall not be introduced by the application of programmable electronic systems. The defined greater number of requirements apply in addition to Regulation 14 - Machinery Control and Regulation 15 - Alerts and Safety Systems as well as the requirements specified within Regulation 17 Systems Integration shall be met.

The requirements for computer systems are defined in Sec.13 [2.4].

3.4.16 Regulation 17 – Systems integration

Essential safety functions shall be designed such that risks of harm to personnel, damage to the platform or the environment are reduced to a level acceptable to the naval administration, both in normal operation and under fault conditions. Functions shall be designed to fail safe.

The integrity of essential machinery or systems during normal operation and fault conditions shall be demonstrated.

In Sec.13 [2.5] a comprehensive list of criteria to establish integrated systems is shown.

3.4.17 Regulation 18 – Human element

The layout of different equipment and local control facilities shall be such that human operation is logical and can be performed without unintended mistakes.

Physical arrangements for machinery and equipment shall not pose a risk to embarked persons.

In Sec.13 [2.2] is stated that the grouping and arrangement of the instruments for the control, monitoring and operation shall conform to the principles of safety technology and ergonomics.

3.4.18 Regulation 19 - Hazardous areas

Machinery and systems located in hazardous areas shall not create an additional fire or explosion risk. The risks to persons associated with hazardous areas shall be minimised.

Sec.12 [2] - Design Principles shows the required electrical measures. The requirements for carriage of dangerous materials are listed in Sec.15 [6]. The handling of special gases for air independent power generation is treated in Sec.11 [3].

3.4.19 Regulation 20 – Heating, Ventilation and Air Conditioning (HVAC)

Ambient conditions for machinery requirement, crew habitability and ventilation of hazardous areas shall be provided. (To be read in conjunction with Ch.XII.)

In Sec.14 [3] – Air Supply, the aspects of air renewal, CO_2 absorption, humidity, internal temperature, H_2 monitoring and emergency supply are given in detail.

3.4.20 Regulation 21 – Tanks

Bulk fluids, required for machinery systems and crew habitability, shall be safely stored.

The requirements for diving/main ballast tanks, compensating tanks and trimming tanks are defined in Sec.8 [2] – Sec.8 [5]. Fuel tanks are treated in Sec.11 [2].

3.4.21 Regulation 22 – Maintain crew health

The submarine’s machinery, outfit and systems shall provide services essential to maintain the health of all embarked persons for the required period of endurance.

Aspects of fresh water, food storage, food preparation, sanitary facilities and waste storage or disposal are summarized in this Regulation.

The requirements for the drinking water system are defined in Sec.9 [10]. The requirements for waste water and galley waste are summarized in Sec.9 [9] and Sec.9 [8].

Measures to maintain health in an emergency are required as described in Sec.16 [2.6].

For equipment and interior facilities see also Sec.5 [7].

Part 2 Tier 4 : NSubC Solutions

See Ch II,[3.2.7] and [3.2.8] of this section.

3.5 Chapter V – Seamanship systems

Part 1 Goals, functional objectives and performance requirements

3.5.1 Regulations 0 – Goal and 1 - General

Seamanship systems are to be designed and constructed to operate in all environmental conditions as defined in CONOPS and by keeping essential safety functions. Maintenance has to take place safely.

According to Sec.7 [1] seamanship equipment is to be provided considering CONOPS.

3.5.2 Regulation 2 – Concept of operations statement

The Concept of Operations Statement is the Owner's vision of how the seamanship systems of the submarine are to be operated and maintained throughout the life of the submarine and shall be shared by the naval administration.

DNV GL rules define in Sec.2 [1.2].: Submarines and their components are to be designed to meet the service conditions stated in the Concept of Operations by the naval administration.

In the Concept of Operations Statement all main parameters for military tasks, external and internal hazards to cope with, limitations of operation, survey and maintenance philosophy, etc. shall be well defined and documented as the basis for each actual submarine project.

3.5.3 Regulation 3 – Provision of operational information

Operators shall be provided with adequate information and instructions for the safe operation and maintenance of all seamanship systems.

A summary of all necessary documentation is contained in DNV GL rules in Sec.2 [3].

3.5.4 Regulation 4 – Access to the casing and work on the casing

The accessibility to the casing and the deck space itself shall enable the crew to safely and effectively fulfil their tasks as and when required by the Command but still remain within the designed or imposed limitations. A greater number of detailed requirements is summarized.

The safety measures for working on the deck are defined in Sec.7 [4.1].

3.5.5 Regulation 5 – Man overboard recovery

The Submarine's crew shall be able to safely recover a person if they have fallen overboard. There shall be a means of visually marking the position, alert the crew, proving continuous observation, keeping swimmers free from machinery and deliver assistance.

The man overboard equipment are treated in Sec.16 [5.4].

3.5.6 Regulation 6 - Mooring

A submarine shall be capable of being secured in position alongside or to a buoy without the use of propulsion machinery.

The mooring requirements are treated in Sec.7 [3.1].

3.5.7 Regulation 7 - Anchoring

A Submarine shall be capable of being secured in position and/or heading without use of propulsion machinery at sea in limited water depths, consistent with the areas of operation as defined in the Concept of Operations Statement.

The anchoring equipment is treated in Sec.7 [2].

3.5.8 Regulation 8 – Towing equipment

Facilities shall be provided to allow the submarine to be towed or to tow another ship, another submarine or equipment, if required.

The towing equipment is treated in Sec.7 [3.2].

3.5.9 Regulation 9 – Lifting and hoisting appliances

Lifting and hoisting appliances shall be designed, constructed, maintained and operated to minimise danger to embarked persons, the lifting equipment and the submarine in all Foreseeable Operating Conditions.

The requirements for lifting and hoisting devices are defined in Sec.7 [6].

3.5.10 Regulation 10 – Helicopter and boat transfers

Submarines shall be provided with means to safely execute helicopter and boat transfers whilst underway.

The provisions for transfers are defined in Sec.7 [4.3] and Sec.7 [4.4], Sec.7 [4.5]. Further on requirements on the deck for replenishment by helicopter are defined in Sec.6 [5.10.3].

3.5.11 Regulation 11 – Pilot transfer arrangements

For safe excess to the deck see Sec.7 [4.5].

3.5.12 Regulation 12 – Operations other than war

Submarines shall be capable, where required, of safely accommodating leisure activities of the crew on the casing and, where required, of safely facilitating (guided tours for) visitors.

Such requirements are to be defined by naval administration.

Part 2 Tier 4 : NSubC Solutions

See Ch II, [3.2.7] and [3.2.8] of this section.

3.6 Chapter VI – Fire safety

Part 1 Goals, functional objectives and performance requirements

3.6.1 Regulations 0 – Goal and 1 - General

For effective fire safety, the submarine and its arrangements are to be designed, constructed, maintained and operated in such a way that as far as it is practicable, fire can be prevented, detected, contained and extinguished whilst maintaining essential safety functions during and after the outbreak of a fire.

The requirements for protection, detection, extinguishing of fire and smoke handling are defined in Sec.15.

3.6.2 Regulation 2 – Structural integrity

Structural integrity of the submarine shall be maintained preventing partial or whole collapse of the submarine structures due to strength deterioration by heat consistent with the Concept of Operations for the submarine.

The submarine shall be subdivided by thermal and structural boundaries as far as applicable, see Sec.15 [2.1].

3.6.3 Regulation 3 – Risk of ignition

The ignition of combustible materials or flammable liquids, gases and vapours shall be prevented.

Requirements as used by the NSubC are defined in Sec.15 [2.2].

3.6.4 Regulation 4 – Fire growth potential

The fire growth potential shall be limited in every space of the submarine.

For use of non-combustible materials and avoidance of sources of ignition see Sec.15 [2.1].

3.6.5 Regulation 5 - Smoke generation and toxicity

The hazard to life shall be reduced in spaces where persons work, live and may have regular access, from smoke and toxic products generated during a fire from spaces that contain the fire or adjacent to the fire.

In Sec.15 [5.1]. also reference is made to the FTP Code.

3.6.6 Regulation 6 – Control of smoke spread
The spread of smoke in and the removal of smoke out of the submarine shall be controlled in order to minimize hazards from smoke.

Requirements as used by the NSubC are also used in Sec.15 [5.2].

3.6.7 Regulation 7 – Detection and alarm
To detect a fire in the space of origin and to provide an alarm to allow for the safe evacuation from a compartment and for the start of the fire-fighting activities.

The requirements for fire detection and fire alarm systems are defined in Sec.15 [3.2] resp. Sec.15 [3.3].

3.6.8 Regulation 8 – Containment of fire
A fire shall be contained in the space of origin and therefore the submarine shall be subdivided by thermal and structural boundaries or equivalent.

These requirements are included in requirements for structure in Sec.15 [2.1].

3.6.9 Regulation 9 – Fire fighting
Suppression and quick extinction of fires shall be effective within the space of origin. For all foreseeable fire hazards there shall be defined effective and proportionate means of extinguishing each such fire.

In Sec.15 [4]. the requirements for extinguishing agents, portable fire extinguishers, fixed installed systems and finally operated water extinguishing systems are defined.

3.6.10 Regulation 10 – Maintain capability
In case of Fire, the capability of essential safety functions and other defined services shall be maintained and/or recovered to a minimum level as specified in this regulation or to a specified level consistent with the Concept of Operations Statement, whichever is the most strict.

The requirements for fire protection in Sec.15 [2] contribute to maintaining of capability.

3.6.11 Regulation 11 – Provision of operational information
Information shall be provided to address operational effectiveness, readiness und training of crew for the installed fire safety arrangements.

A summary of all necessary documentation is contained in DNV GL rules in Sec.2 [3] and esp. in Sec.2 [3.13].

3.6.12 Regulation 12 – Special requirements
Any special features of the submarine shall be consistent with the fire safety goal and other functional objectives of this Chapter.

Requirements for carrying dangerous materials, location of power sources and draining out of water from firefighting efforts without unnecessarily contaminating equipment, etc. are summarized in this Regulation.

See Sec.15 [6] for dangerous materials.

Water from firefighting efforts shall be drained out according to Sec.15 [4.3.3.2].

3.6.13 Regulation 13 – Carriage of low flash point fuels
Safe storage of low flash point fuel shall be provided where this is required by the Concept of Operations Statement. Low flash point fuel shall never be taken inside the pressure hull.

To reduce the risk of ignition petrol products have to be stored outside the pressure hull and arranged to jettison the containers overboard in surfaced condition, see Sec.15 [2.2.3].

Part 2 Tier 4 : NSubC Solutions

See Ch II,[3.2.7] and [3.2.8] of this section.

3.7 Chapter VII – Submarine escape, rescue, abandonment and survival

Part 1 Goals, functional objectives and performance requirements

3.7.1 Regulations 0 and 1 – Goal and general

The arrangements for the Submarine Escape, Rescue, Abandonment and Survival (SMERAS) of embarked persons shall be designed, constructed and maintained to provide effective evacuation for all embarked persons from all manned spaces to a place of safety in the event of foreseeable accidents and emergencies at least until the threat has receded.

Rescue Systems are treated in Sec.16.

3.7.2 Regulation 2 - Compartments in the submarine

According to the tasks defined in CONOPS, a submarine may be divided in different watertight and/or non-watertight compartments and decks. Hatches and doors shall be able to be manually operated by one person from either side at all expected angles of heel and trim.

For pressure tight bulkheads see Sec.5 [3.8], for hatches and doors see Sec.5 [3.6].

3.7.3 Regulation 3 – Evacuation routes

Evacuation routes shall enable the movement of embarked persons from any compartment within the submarine to another compartment and/or the muster stations as quickly and as safely as possible.

Requirements are defined in Sec.16 [2.1].

3.7.4 Regulation 4 – Access hatches

Each hatch on the casing or in the conning tower shall allow safe entry and exit into and safe exit from the submarine.

All requirements for hatches are defined in Sec.5 [3.6].

3.7.5 Regulation 5 – Way finding system

A way-finding system shall allow embarked persons to safely and effectively locate muster stations, and as far as reasonably practicable take into account hazards caused by fire, smoke and flood water.

The requirements are defined in Sec.16 [2.2].

3.7.6 Regulation 6 - SMERAS lighting

SMERAS lighting systems shall provide sufficient illumination to conduct any SMERAS activity during an emergency and shall be independent of the submarine's own power.

SMERAS lighting as a part of emergency lighting is defined in Sec.16 [2.3].

3.7.7 Regulation 7 – Emergency breathing system

Embarked persons shall have access to breathable air if the atmosphere in the submarine exceeds permitted criteria as agreed by the naval administration. The system shall be operated separately from the general atmosphere control system.

For emergency breathing system see Sec.16 [2.4] and Sec.14 [3.3].

3.7.8 Regulation 8 – Provision of operational information

On board documentation shall provide information, plans and procedures for the conduct of effective SMERAS activities.

For documentation see Sec.2 [3] especially Sec.2 [3.14].

3.7.9 Regulation 9 – General emergency alarm system

A General Emergency Alarm System shall enable the notification of all embarked persons in a timely manner that an emergency situation exists.

For communication see Sec.13 [3].

3.7.10 Regulation 10 – Main broadcast system

A Main Broadcast system shall enable verbal announcements from strategic positions to all embarked persons.

For communication see Sec.13 [3.2].

3.7.11 Regulation 11 – On board two-way communication

On board communication systems shall enable effective two-way communication between embarked persons to support SMERAS activities.

For internal communication see Sec.13 [3.2].

3.7.12 Regulation 12 – External communication equipment

External Communication equipment shall enable communication to other ships, submarines, aircraft or to shore during normal and SMERAS operations.

For external communication see Sec.13 [3.3] and Sec.13 [3.4].

3.7.13 Regulation 13 – Power supply to SMERAS systems

The power supply to SMERAS systems shall provide sufficient power necessary to conduct any combination of those SMERAS activities during an emergency.

For emergency power supply see Sec.12 [3.2.2].

3.7.14 Regulation 14 - Life-jackets

Life jackets shall provide effective flotation assistance for persons over board.

Compare Sec.16 [4].

3.7.15 Regulation 15 – Submarine Escape and Surface Survival Personnel Equipment

Submarine Escape and Surface Survival Personnel Equipment (SESSPE) shall help persons to escape from a DISSUB (Distressed Submarine).

Compare Sec.16 [4].

3.7.16 Regulation 16 – Incapacitated persons

Persons who are incapacitated shall be evacuated by CASEVAC equipment, which shall enable horizontal and vertical transport throughout the submarine, be compatible for helicopter pick-up and consider anthropometrical characteristics of embarked persons and escape routes in the submarine.

The rescue aspects – as far a Classification Society is concerned – are contained in Sec.16. For helicopter pick-up see also Sec.7 [4.3].

3.7.17 Regulation 17 – SMERAS Analysis and demonstration

A SMERAS Analysis and Demonstration shall ensure that the effectiveness of SMERAS measures are optimised.

To be organized by naval administration.

3.7.18 Regulation 18 – Training and drills

Training and drill procedures shall ensure that all embarked persons have sufficient skills to undertake SMERAS tasks.

To be organized by naval administration.

3.7.19 Regulation 19 – SMERAS Emergency Life Support Stores (ELSS)

For the embarked persons in a DISSAUB Emergency Life Support Stores (ELSS) shall be maintained for the defined survival time as agreed by the naval administration.

To be organized by the naval administration. For storages see Sec.16 [2.5].

3.7.20 Regulation 20 – Inspection and maintenance

Inspection and maintenance procedures shall ensure that any SMERAS arrangement or equipment has an availability which is as high as reasonably practicable.

Inspection and maintenance procedures are to be organized by the naval administration as far as Classification surveys according to Sec.2 [2]. are not concerned.

3.7.21 Regulation 21 – Safe embarkation into life raft(s)

A save method of transfer of embarked persons from the submarine into life raft(s) shall be available.

Means for save embarkation and survival on the sea surface are defined in Sec.16 [5].

3.7.22 Regulation 22 - Survival until recovery from sea

The survival of embarked persons who have abandoned the submarine, shall be achieved without external support whilst awaiting recovery.

Means for this duty are defined in Sec.16 [4] and Sec.16 [5].

3.7.23 Regulation 23 – Providing breathable atmosphere

The atmosphere in a DISSUB shall be suitable for breathing during the defined survival time as agreed by the naval administration.

Requirements for emergency breathing air supply are defined under Life Support in Sec.14 [3].

3.7.24 Regulation 24 – Maintaining personal hygiene and clean sanitary conditions

For the embarked persons in a DISSUB minimum personal hygiene and sanitary facilities shall be provided.

Requirements for hygiene and sanitary conditions are defined in Sec.16 [2.6].

3.7.25 Regulation 25 – Means for rescue

A dry transfer rescue from a DISSUB into a Submarine Rescue System shall be possible.

Requirements for a mating flange for an external submarine rescue system are given in Sec.16 [3.9] Rescue submarines and equipment are treated in Sec.17 [5].

3.7.26 Regulation 26 – Means for escape

A means of individual escape from a DISSUB down to a depth as agreed by the naval administration shall be provided.

Requirements for exit hatches and the air trapping device under it are given in Sec.5 [3.6] and Sec.16 [3.2].

Part 2 Tier 4 : NSubC Solutions

See Chapter II,[3.2.7] and [3.2.8] of this section.

3.8 Chapter VIII – Communications

Part 1 Goals, functional objectives and performance requirements

3.8.1 Regulations 0 and 1 – Goal and general

The different types of required transmitting and receiving equipment are summarized.

The communications systems shall provide the capability to facilitate all submarine safety communications, including but not limited to SUBLOOK, SUBMISS and SUBSUNK procedures through the Global Maritime Distress and Safety System (GMDSS) and/or the military internal and external communications fit.

In Sec.13 [6] the requirements of equipment for internal, surface, underwater and emergency equipment are defined.

3.8.2 Regulations 2/3/5 – GMDSS/Availability of GMDSS and other safety communication equipment/position updates

GMDSS and other safety communications equipment shall be continuously available at sea.

Electronic position information shall be available to both the GMDSS equipment and any fitted supplementary submarine emergency communications and location equipment.

Not subject to Classification.

3.8.3 Regulation 4 – Communications sources of energy

A suitable source of power shall be available for all critical internal and external communication systems at all times and during all foreseeable events.

A suitable source of power has to be available at all times and during all foreseeable events.

For emergency communication, radiotelephones shall be connected to at least two alternative sources of power supply, compare Sec.13 [3.5].

3.8.4 Regulations 6/7 – Internal communication/main broadcast

Internal communication and a main broadcast system shall enable verbal and audio communication to all embarked persons of an emergency incident and the actions to be taken.

Main broadcast and Two-way communication systems between compartments, rooms and control stations are defined in Sec.13 [3.2].

3.8.5 Regulation 8 – Portable radio communications

Portable Radio communication systems shall enable effective two-way communication between crew members.

To be defined by naval administration.

3.8.6 Regulation 9 – Survival craft radio equipment

External communication equipment used in survival craft shall enable communication to other vessels, or to shore during emergencies.

To be defined by naval administration.

3.8.7 Regulation 10 – Sea air radio communications

A sea-to-air two-way radio communications system shall be fitted to enable communication with overflying aircraft during emergencies.

To be determined by naval administration!

3.8.8 Regulations 11/12/13 – Radio personnel, radio watches, radio records

Requirements for qualification of operators, monitoring of equipment at sea and maintaining of records are to be defined.

These requirements are not subject to Classification.

3.8.9 Regulation 14 – Installation, testing, maintenance and repairs

The location and submarine installation of all safety communication equipment shall enable it's operation, maintenance, testing and repair.

This is a general requirement for types of equipment, compare Sec.2 [1] - General principles and scope.

3.8.10 Regulation 15 – Operational audit and compliance validity

Safety communication equipment shall be surveyed at regular intervals.

As defined in surveys for classification the communication system is to be surveyed annually, see Sec.1 [2.2.1.11].

Part 2 Tier 4 : NSubC Solutions

See Chapter II, [3.2.7] and [3.2.8] of this section.

3.9 Chapter IX – Navigation

Part 1 Goals, functional objectives and performance requirements

3.9.1 Regulations 0 to 9 – Goal to training of personnel

The official regulations and detailed requirements for navigation have to be defined by the naval administration.

The following basic statements are included in the Society's rules:

— According to their mode of operation and application, submarines are to be provided with suitable equipment (position indicators, radio direction finders, navigation equipment, etc.) for locating the unit when travelling on the surface, compare Sec.7 [5.3].
— All electrically operated items of navigation equipment necessary to the safety of the submarine and its crew are to be connected to at least two of the alternative power supplies, compare Sec.13 [4].
— The availability of the equipment for service and its current operating status are to be indicated at the control station.

Part 2 Tier 4 : NSubC Solutions

See Chapter II, [3.2.7] and [3.2.8] of this section.

3.10 Chapter X – Dangerous goods

Part 1 Goals, functional objectives and performance requirements

The requirements for the carriage of dangerous materiel are summarized in Sec.15 [6].

3.10.1 Regulations 0 and 1 – Goal and general

The submarine arrangements for the carriage and use of dangerous goods shall minimise the risk of an incident associated with this materiel.

The dangerous goods in packaged form for which safety measures regarding the electrical equipment are required are committed in *SOLAS*, Chapters II-2 Reg.19, IMDG Code and they are divided into Classes 1 to 9. A detailed definition of these classes for goods in packaged form is given in Pt.3 Ch.5 Sec.9 [14.1.4].

Engineering requirements for the transport of dangerous materiel are defined in Pt.3 Ch.5 Sec.9 [14].

Additional rules for electrical equipment are defined in Pt.3 Ch.3 Sec.16.

3.10.2 Regulation 2 – Layout and services

Submarine arrangements for the location within the submarine, layout of spaces and the provision of supporting services shall maintain the inherent safety of the dangerous goods and manage incidents.

According to Pt.3 Ch.5 Sec.9 [14.1]. the requirements depend on the type of cargo space, the dangerous materiel class and the special properties of the materiel/goods to be carried. These requirements shall be applied as far as possible for naval submarines.

3.10.3 Regulation 3 – Structural protection

Submarine arrangements shall provide appropriate structural integrity to support dangerous goods and their associated safety systems.

See Sec.15 [6.5.1]. Requirements for machinery space boundaries are given in Pt.3 Ch.5 Sec.9 [14.10].

3.10.4 Regulation 4 – Fire protection

Submarine arrangements shall manage to an acceptable level, the risk of fire incidents initiated by dangerous goods or that threaten dangerous goods.

See Sec.15 [6.5.3]. Requirements for fire protection and fire extinguishing are defined in Sec.15. Special requirements are contained in Pt.3 Ch.5 Sec.9 [14.2].

3.10.5 Regulation 5 – Electrical fittings

The submarine arrangements shall protect dangerous goods from electric conditions that could lead to an incident.

See Sec.15 [6.5.2]. Additional rules for electrical equipment within hazardous areas because of dangerous materials are defined in Pt.3 Ch.3 Sec.16. Explosion-protection measures are required in these areas.

3.10.6 Regulation 6 – Stowage and handling

The submarine arrangements shall provide safe and secure stowage, handling, movement, relocation and transfer of dangerous goods.

The requirements for naval surface ships defined in Pt.3 Ch.5 Sec.9 [14] shall be applied as far as applicable to naval submarines.

Requirements for personnel protection (clothing, breathing apparatus) are defined in Pt.3 Ch.5 Sec.9 [14.8].

3.10.7 Regulation 7 - Security

Submarine arrangements shall prevent malicious or unintended interference with the dangerous goods or their safety management system.

Access to dangerous materiel by unauthorized persons shall be prevented, see Sec.15 [6.1]. To be organized by naval administration.

3.10.8 Regulation 8 – Incident reporting

Incidents involving dangerous goods or associated safety systems shall be reported, investigated and, where appropriate, submarine arrangements amended to maintain or improve safety levels.

See Sec.15 [6.6]. To be organized by the naval administration and reported to surveyors as far as necessary.

3.10.9 Regulation 9 – Training and personnel competence

All persons directly or indirectly responsible for or affected by the safe carriage and use of dangerous goods shall be demonstrably competent to discharge their duties.

To be organised and followed by the naval administration.

3.10.10 Regulation 10 – Use of dangerous goods

Submarine Arrangements shall control the safety risk associated with use of dangerous goods

Activity planning to be done by naval administration, the Society to be informed.

3.10.11 Regulation 11 – Emergency procedures

Submarine Arrangements shall control the consequences associated with dangerous goods, arising from foreseeable emergency situations.

See Sec.15 [6.6]. Procedures are to be defined by naval administration, the Society is to be informed for approval.

Part 2 Tier 4 : NSubC Solutions

See Chapter II, [3.2.7] and [3.2.8] of this section.

3.11 Chapter XI – Integration of platform, combat and navigation systems

Part 1 Goals, functional objectives and performance requirements

3.11.1 Regulations 0 and 1 – Goal and general

The integration shall be designed, constructed, operated and maintained to enable operation in all foreseeable conditions, minimise unintended danger, minimise risk of fire, support the persons on board, enable adequate level of information and enable maintenance and repair, etc.

Requirements for integrated systems are summarised in Sec.13 [2.5].

3.11.2 Regulation 2 – Concept of operations statement

The Concept of Operations Statement is the Owner’s vision of how the Integration of Platform, Combat and Navigation Systems of the submarine are to be operated and maintained throughout the life of the submarine and is to be shared by the naval administration.

See [3.1.3] and Sec.2 [1.2].

3.11.3 Regulation 3 – Provision of operational information

Operators shall be provided with adequate information and instructions for the safe operation and maintenance of all Integration of Platform, Combat and Navigation Systems.

A summary of all necessary documentation is contained in Sec.2 [3].

3.11.4 Regulation 4 – Safe design

The Integration of Platform, Combat and Navigation Systems shall be designed, installed, operated and maintained to minimize danger to an ALARP (as low as reasonably practicable) level of safety to personnel in all foreseeable conditions.

Requirements for integrated systems are summarised in Sec.13 [2.5].

3.11.5 Regulation 5 – Network

The integration of Platform, Combat and Navigation Systems shall be designed to ensure that malfunction of one system will not influence the safe function of the network or other systems using the same network.

Requirements for integrated systems are summarised in Sec.13 [2.5].

3.11.6 Regulation 6 – Output information robustness

Sensors and sensor systems used for combined functionality in both navigations systems and CWCS shall be designed, installed and maintained to provide high reliability and shall have built-in-redundancy or have redundant systems to ensure the safe operation and navigation of the submarine in all foreseeable operating conditions.

Requirements for integrated systems are summarised in Sec.13 [2.5].

3.11.7 Regulation 7 – Radiation safety

The Integration of Platform, Combat and Navigation Systems shall be designed, installed, operated and maintained without causing interference or hazardous radiation of any kind to personnel and systems on the submarine itself or unintentionally to persons, ships or systems in its proximity.

Requirements to avoid radiation hazard (RADHAZ) are defined in Sec.12 [2.5.5].

Part 2 Tier 4 : NSubC Solutions

See Chapter II, [3.2.7] and [3.2.8] of this section.

3.12 Chapter XII – Atmosphere control

Part 1 Goals, functional objectives and performance requirements

3.12.1 Regulations 0 and 1 – Goal and general

To preserve life and promote well-being and long-term health by providing and maintaining a safe breathable atmosphere within the pressure hull which does no harm to embarked persons or the fabric of the submarine.

All aspects to ensure life support and safe environment for the crew are treated in Sec.14.

3.12.2 Regulation 2 – Provision of oxygen

Oxygen shall be provided to all parts of the enclosed volume of the submarine in sufficient quantity within the pressure hull which does no harm to embarked persons or the fabric of the submarine.

The detailed requirements for the oxygen system are defined in Sec.14 [3.2.1].

3.12.3 Regulation 3 – Removal of carbon dioxide

Carbon dioxide shall be maintained throughout the enclosed volume of the submarine at level which does not affect the capacity of the crew members and special personnel to perform their tasks in support of the Concept of Operations Statement.

The detailed requirements for CO_2 absorption are defined in Sec.14 [3.2.2]

3.12.4 Regulation 4 – Removal of hydrogen, carbon monoxide and other contaminants

Means shall be provided for the removal of all identified types of gaseous and vaporous contaminants from the submarine’s atmosphere.

H_2 monitoring and control is defined in Sec.14 [3.5]. A system of analysis is to be provided for determining atmospheric impurities, such as CO, NO, NO_x and hydrocarbons according to Sec.14 [4.7].

3.12.5 Regulation 5 – Preserve nitrogen balance

The naval administration shall provide the crew with guidance on the management of nitrogen in the submarine's atmosphere when the volume of nitrogen carried, at Normal, Temperature and Pressure (NTP), if fully released from its storage containers presents a threat to the maintenance of a safe breathable atmosphere within the enclosed volume of the submarine.

Sec.14 [4.7] and compare Sec.15 [4].

3.12.6 Regulation 6 – Maintenance of temperature, humidity and pressure

A means of maintaining temperature and humidity, and regulating internal pressure in the pressure hull within the operating patterns of the submarine shall be established.

The range of internal temperature, humidity and pressure shall be maintained within the limits defined by the naval administration.

Parameters for the life support systems are recommended in Sec.14 [2.2]. For humidity see also Sec.14 [3.2.3]. For partial pressure of oxygen and CO_2 see also Sec.14 [2.2].

3.12.7 Regulation 7 – Circulation of air

Air shall be circulated throughout the compartments and spaces of the submarine to distribute oxygen and to encourage mixing of the air to ensure that the atmosphere does not present a hazard to the embarked persons. Temperature, humidity and oxygen of the enclosed volume shall remain within prescribed limits.

The requirements for air supply and renewal are treated in Sec.14 [3].

3.12.8 Regulation 8 – Monitor the internal atmosphere

To provide a means of monitoring the constituents of the internal atmosphere of the submarine at all times.

The environmental parameters and the monitoring equipment is defined in Sec.14 [4].

3.12.9 Regulation 9 – Continuously monitoring and recording of specified gases

There shall be a means of continuously monitoring and recording the atmosphere inside the enclosed volume of the submarine.

See Sec.14 [4].

3.12.10 Regulation 10/11 – Recording and reporting the condition of the submarine's atmosphere/assessment and feedback of the records

Provide a means of recording and reporting the condition of the submarine's atmosphere and provide assessment and feedback of the records by qualified and experienced personnel ashore.

These operational duties are to be organised by the naval administration.

3.12.11 Regulation 12 – Assessment of materials

A means of assessment of materials contained within or introduced to the enclosed volume of the submarine for their effect on the submarine atmosphere, crew members or other equipment in normal and abnormal conditions shall be provided.

Sec.5 [7.1] requires that for interior facilities use may only be made of those materials and media which do not release any toxic or severe irritant gases.

3.12.12 Regulation 13 - Infrastructure

To provide the infrastructure to assess, select, support and dispose of atmosphere control equipment and consumables.

For monitoring equipment see Sec.14 [4]. Also very much an operating problem to be solved by naval administration!

3.12.13 Regulation 14 – Provide emergency breathing air

Provide and distribute a safe and breathable supply of air throughout the submarine for use by the crew (every person on board) when the submarine’s internal atmosphere is out of specified limits.

The requirements for emergency breathing air supply are defined in Sec.14 [3.4].

Part 2 Tier 4 : NSubC Solutions

See Chapter II, [3.2.7] and [3.2.8] of this section.

3.13 Chapter XIII – Nuclear power generation

Note:

If the submarine has a nuclear steam raising plant, the safety arrangements shall be to the satisfaction of the naval administration to meet national defence nuclear safety regulations.

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Nuclear Power submarines are not covered by the Society's rules.

APPENDIX A CALCULATION OF THE PRESSURE HULL

1 General

1.1 Introduction

1.1.1 In the following a calculation method is described which investigates the stress and stability situation in the pressure hull for the load cases II, III and IV with the pressures:

— nominal diving pressure *NDP* (load case II according to Sec.4 [6])
— collapse diving pressure *CDP* (load case III)
— test diving pressure *TDP* (load case IV).

In the following the method of calculation for stiffened cylindrical shells is presented. For unstiffened cylindrical shells with dished ends the calculations are analogously performed for the sectional area of the stiffening ring $A_{eff} = A_F = 0$, whereas the buckling length is limited by the dished ends. If the buckling length is limited by dished ends, 40% of the curve depth shall be added for each dished end to the cylindrical length.

The method of calculation presented takes account of manufacturing related deviations from the ideal form of the shell (e.g. out-off-roundness). The manufacturing tolerances defined in App.B have to be applied for the calculation.

1.1.2 Conical shells are calculated in sections, each of which is treated like cylindrical shells.

1.1.3 The overall collapse of the construction is regarded as buckling of the pressure hull between bulkheads, web frames and dished ends.

For the states of stability described, proof is required of sufficient safety in respect to the particular form of damage concerned.

1.1.4 When using the method of calculation it is to observe, that both elastic and elastic-plastic behavior can occur in the materials of the shell structure and the frames.

It is generally the case that:

— at nominal diving pressure, the stress is within the purely elastic range of the material
— at test diving pressure, the stress may lie at the commencement of the elastic-plastic range of the material
— but for calculation against exceeding of the permissible stress elastic material behavior of the material can be assumed
— at collapse diving pressure, the stress may lie in the elastic or the elastic-plastic range of the material.

1.1.5 When calculating a pressure hull the calculation data shall be introduced according to the planned operating conditions under consideration of Sec.5 [4].

1.1.6 Pressure hulls subjected to internal overpressure shall be calculated in addition according to Pt.3 Ch.5 Sec.16.

1.2 Longitudinal strength

For the longitudinal strength of the pressure hull the longitudinal bending moments and shear forces shall be considered. It shall be checked only on request of the Society.

1.3 Vessels similar to the pressure hull

For vessels which are partly or totally arranged like the pressure hull and from which the safety of the submersible depends in the same way, like e.g. entrance trunk, containers for rescue equipment, etc., the same proofs have to be carried out as for the pressure hull.

1.4 Acrylic windows

The requirements for design and manufacturing of acrylic windows are defined in UWT Pt.4 Ch.7 Sec.3.

2 Fatigue strength

2.1

Proof of fatigue strength has to be carried out for load case II determined by nominal diving pressure *NDP* according to Sec.4 [3.2.1].

2.2

The proof of stresses shall be based on the nominal geometry.

2.3

For the calculation of the stresses in the pressure hull, the following influences have to be considered with sufficient accuracy:

- increase of stress at frames, web frames, bulkheads and tripping/transition rings
- increase of stress at penetrations
- disturbances of the state of stress because of connection with pressure-proof extensions.

3 Stresses at nominal diving pressure

3.1

Proof of stress has to be carried out for load case II characterized by nominal diving pressure *NDP* according to Sec.4 [3.2.1].

3.2

For the calculation of the stresses in the pressure hull the stress limits are defined in Sec.5 [4.3].

3.3

The proof of stress has to be performed using the methods in [6.1], [6.6.2], [6.4.4] Equation (59), [6.7.2] and [6.7.4].

4 Stresses at test diving pressure

4.1

Proof of stresses has to be carried out for load case IV characterized by test diving pressure *TDP* according to Sec.4 [3.2.2].

4.2

For the calculation of the stresses in the pressure hull the stress limits are defined in Sec.5 [4.3].

4.3

For nominal diving pressures of at least 10 bar proof of strength for load case IV can be omitted.

4.4

The proof of stress has to be performed using, the methods in [6.1], [6.6.2], [6.4.4] Equation (59), [6.7.2] and [6.7.4].

5 Proof of ultimate strength at collapse diving pressure

5.1

The proof of ultimate strength has to be carried out for load case III characterized by the collapse diving pressure *CDP* according to Sec.4 [3.2.3] as proof of stability and stress.

For the following types of failure it has to be proven that the pressures for a failure are greater or equal to the collapse diving procedure:

— symmetric buckling between the frames
— asymmetric buckling between the frames
— general instability under consideration of the partial effect of the web frames
— tilting of the frames
— buckling of the dished ends and spheres
— local yielding in the area of discontinuities.

5.2

For the calculation of the stresses in the pressure hull the stress limits are defined in Sec.5 [4.3].

5.3

The proof of stress has to be performed using the methods in [6.1], [6.6.2], [6.4.4], [6.5.3], [6.7.2] and [6.7.4].

6 Calculation

6.1 Calculation of stresses in a uniformly stiffened cylinder or cone as a basis for the calculation of the collapse pressure

6.1.1 The geometrical situation is defined in Figure 1 and a summary of the stresses is given in Table 1.

Designations in Figure 1:

R_m = mean radius of the cylindrical shell
R = internal radius of the cylindrical shell
s = nominal wall thickness of the cylindrical shell after deduction of corrosion allowance c
h_w = web height of the frame
s_w = web thickness of the frame
b_f = flange width
s_f = flange thickness
L_F = frame spacing
A_F = cross sectional area of the frame
R_C = radius to the center of gravity of the frame cross section
R_f = inner radius to the flange of frame

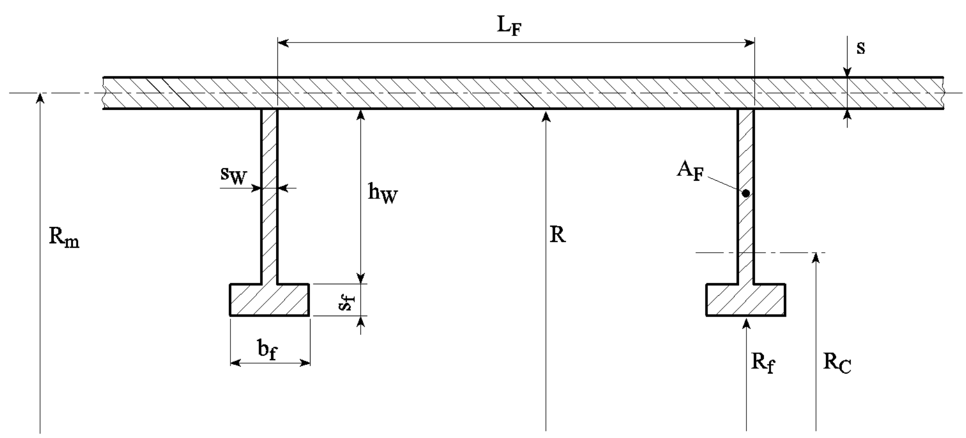

Figure 1 Geometrical situation of frames stiffening the pressure hull

Table 1 Summary of stresses in a stiffened cylindrical shell

Types of stresses	*Stresses in the cylindrical shell*					
	At the frame			*In the middle of the field*		
	Circum-ferential	*Equivalent*	*Axial*	*Circum-ferential*	*Equivalent*	*Axial*
Membrane stress	$\sigma^m_{\varphi,F}$ (A19)		$\sigma^m_{x,F}$ (A17)	$\sigma^m_{\varphi,M}$ (A18)		$\sigma^m_{x,M}$ (A17)
Membrane equivalent stress		$\sigma^m_{v,F}$ (A14)			$\sigma^m_{v,M}$ (A14)	
Bending stresses	$\sigma^b_{\varphi,F}$ (A23)		$\sigma^b_{x,F}$ (A21)	$\sigma^b_{\varphi,M}$ (A22)		$\sigma^b_{x,M}$ (A20)
Normal stress outside	$\sigma^m_{\varphi,F} + \sigma^b_{\varphi,F}$ (A19) + (A23)		$\sigma^m_{x,F} + \sigma^b_{x,F}$ (A17) + (A21)	$\sigma^m_{\varphi,M} + \sigma^b_{\varphi,M}$ (A18) + (A22)		$\sigma^m_{x,M} + \sigma^b_{x,M}$ (A17) + (A20)
Equivalent normal stress outside		$\sigma^{m+b}_{v,F,o}$ (A14)			$\sigma^{m+b}_{v,M,o}$ (A14)	
Normal stress inside	$\sigma^m_{\varphi,F} - \sigma^b_{\varphi,F}$ (A19) - (A23)		$\sigma^m_{x,F} - \sigma^b_{x,F}$ (A17) - (A21)	$\sigma^m_{\varphi,M} - \sigma^b_{\varphi,M}$ (A18) - (A22)		$\sigma^m_{x,M} - \sigma^b_{x,M}$ (A17) - (A20)
Equivalent normal stress inside		$\sigma^{m+b}_{v,F,i}$ (A14)			$\sigma^{m+b}_{v,M,i}$ (A14)	
Remark: The numbers in brackets represent the numbers of the equations to be applied.						

6.1.2 Calculation of factors and basic equations

$$F_1 = \frac{4}{\theta}\left\{\frac{\cosh^2\eta_1\theta - cos^2\eta_2\theta}{\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cosh\eta_2\theta\cdot\sinh\eta_2\theta}{\eta_2}}\right\} \tag{1}$$

$$F_2 = \frac{\frac{\cosh\eta_1\theta\cdot\sin\eta_2\theta}{\eta_2} + \frac{\sinh\eta_1\theta\cdot\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}} \tag{2}$$

$$F_3 = \sqrt{\frac{3}{1-v^2}}\left\{\frac{-\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}}{\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}}\right\} \tag{3}$$

$$F_4 = \sqrt{\frac{3}{1-v^2}}\left\{\frac{\frac{\cosh\eta_1\theta\cdot\sin\eta_2\theta}{\eta_2} - \frac{\sinh\eta_1\theta\cdot\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}}\right\} \tag{4}$$

$$p^* = \frac{2\cdot E\cdot s^2}{R_m^2\sqrt{3(1-v^2)}} \tag{5}$$

E = modulus of elasticity
= 2.06 · 105 N/mm^2 for ferritic steel
= adequate values for other materials to be agreed

ν = Poisson ratio in elastic range
= 0.3 for steel

ν_p = Poisson ratio in elastic-plastic range (see Equation (35))

$$\gamma = \frac{p}{p^*} \tag{6}$$

p = calculation pressure
= alternatively *NDP*, *TDP* and *CDP*

$$\eta_1 = \frac{1}{2}\sqrt{1-\gamma} \quad (7)$$

$$\eta_2 = \frac{1}{2}\sqrt{1+\gamma} \quad (8)$$

$$L = L_F - S_w \quad (9)$$

$$L_{eff} = \frac{2}{\sqrt[4]{3(1-\nu^2)}}\sqrt{R_m \cdot s} \quad (10)$$

$$A_{eff} = A_F \frac{R_m}{R_C} \quad (11)$$

$$\theta = \frac{2 \cdot L}{L_{eff}} \quad (12)$$

For the stress designations the following indices are valid:

0 = reference value
m = membrane stress
b = bending stress
v = equivalent stress
x = longitudinal direction
φ = circumferential direction
r = radial direction
t = tangential direction
o = outer side
i = inner side
F = at the frame
D = at the web frame
F/D = at the frame/ at the web frame
M = in the middle of the field
f = in the flange of the frame
w = in the web of the frame
C = at the centre of gravity of the frame cross section
c = in the crown of the dished ends

The reference stress is the circumferential stress in the unstiffened cylindrical pressure hull:

$$\sigma_o = -\frac{p \cdot R_m}{s} \tag{13}$$

The equivalent stresses are composed of the single stresses in longitudinal and circumferential direction:

$$\sigma_v = \sqrt{{\sigma_x}^2 + {\sigma_\varphi}^2 - \sigma_x \cdot \sigma_\varphi} \tag{14}$$

The radial displacement in the middle between the frames w_M:

$$w_M = -\frac{p \cdot {R_m}^2}{E \cdot s}\left(1 - \frac{\nu}{2}\right)\left\{1 - \frac{A_{eff} \cdot F_2}{A_{eff} + s_w \cdot s + L \cdot s \cdot F_1}\right\} \tag{15}$$

(The radial displacement at the frames w_F:

$$w_M = -\frac{p \cdot {R_m}^2}{E \cdot s}\left(1 - \frac{\nu}{2}\right)\left\{1 - \frac{A_{eff} \cdot F_2}{A_{eff} + s_w \cdot s + L \cdot s \cdot F_1} \cdot \left[\cosh \eta_1 \theta \cdot \cos \eta_2 \theta + \frac{\sqrt{\frac{1-\nu^2}{3}\frac{F_4}{F_3} + \gamma}}{4 \cdot \eta_1 \cdot \eta_2} \sinh \eta_1 \theta \cdot \sin \eta_2 \theta\right]\right\} \tag{16}$$

Average membrane stress in longitudinal direction (independent of the longitudinal coordinate x):

$$\sigma_x^m = -\frac{p \cdot R_m}{2 \cdot s} \tag{17}$$

Membrane stress in circumferential direction in the middle between the frames:

$$\sigma_{\varphi,M}^m = E\frac{w_M}{R_m} + \nu \cdot \sigma_x^m \tag{18}$$

and at the frames:

$$\sigma_{\varphi,F}^m = E\frac{w_F}{R_m} + \nu \cdot \sigma_x^m \tag{19}$$

Bending stresses in longitudinal direction in the middle between the frames:

$$\sigma^{b}_{x,M} = \pm\sigma_o\left(1-\frac{\nu}{2}\right)F_4\,\frac{A_{eff}}{A_{eff}+s_w\cdot s+L\cdot s\cdot F_1} \qquad (20)$$

and at the frames:

$$\sigma^{b}_{x,F} = \pm\left(\sigma_o-\sigma^{m}_{\varphi,F}\right)F_3 \qquad (21)$$

The positive sign is valid for the outside of the cylindrical shell, the negative preceding sign for the inner side.

Bending stresses in circumferential direction in the middle between the frames:

$$\sigma^{b}_{\varphi,M} = \nu\cdot\sigma^{b}_{x,M} \qquad (22)$$

and at the frames:

$$\sigma^{b}_{\varphi,F} = \nu\cdot\sigma^{b}_{x,F} \qquad (23)$$

The circumferential stress follows from the radial displacement to:

$$\sigma^{m}_{\varphi,Fw} = E\,\frac{w_F}{R} \qquad (24)$$

in the frame foot, respectively

$$\sigma^{m}_{\varphi,Ff} = E\,\frac{w_F}{R_f} \qquad (25)$$

in the frame flange.

The equivalent stresses as well as the circumferential stresses in the frame summarized in Table 1 shall be limited with the value of the permissible stresses $\sigma_{zul,NDP}$, $\sigma_{zul,TDP}$ resp. $\sigma_{zul,CDP}$ belonging to each load case according to Sec.5 [4.3].

6.1.3 Calculation of the stresses for a conical pressure hull

The equations given above are also applicable to stiffened conical shells.

The relevant equations have to be modified using the half apex angle α. For this, the mean radius yields to:

$$R_{m,eqv} = R_m / \cos\alpha \tag{26}$$

and the equivalent frame spacing turns to:

$$\begin{aligned} L_{F,eqv} &= L_F / \cos\alpha, \text{ resp.} \\ L_{eqv} &= L / \cos\alpha. \end{aligned} \tag{27}$$

R_m = radius midway between the frames of the area under consideration

The calculation has to be carried out for both frames of the bay under evaluation. The dimensions of the frames have to be multiplied by the radius ratio $R_m/R_{m,F}$. For the following calculation of the collapse pressures the (absolutely) greatest value is decisive.

6.2 Calculation of the collapse pressure for the asymmetric interstiffener buckling of the shell in uniformly stiffened sections of the pressure hull

6.2.1 For conical pressure hulls the same values as defined for the stress calculation above shall be used.

For calculation of the minimum buckling pressure which depends on the number of circumferential lobes, the following approximation may be used:

6.2.2 Elastic buckling pressure

$$p_{cr}^{el} = \frac{2 \cdot \pi^2 \cdot E \cdot f}{3 \cdot \Phi \cdot \left(1 - \nu^2\right)} \cdot \left(\frac{s}{R_m}\right)^2 \cdot \frac{\frac{R_m \cdot s}{L^2}}{3 - 2 \cdot \Phi \cdot (1 - f)} \tag{28}$$

Theoretical elastic-plastic pressure:

$$p_{cr}^{i} = p_{cr}^{el} \cdot \frac{1 - \nu^2}{1 - \nu_p^2} \cdot \left\{ \frac{E_t}{E} \cdot \left(1 - \frac{3\Phi}{4}\right) + \frac{E_s}{E} \cdot \frac{3\Phi}{4} \right\} \tag{29}$$

with:

$$\Phi = 1{,}23 \frac{\sqrt{R_m \cdot s}}{L} \tag{30}$$

$$f = \frac{\sigma_x^m}{\sigma_{\varphi,M}^m} \tag{31}$$

$$\sigma_v = \sqrt{\left(\sigma_{\varphi,M}^m\right)^2 + \left(\sigma_x^m\right)^2 - \sigma_{\varphi,M}^m \cdot \sigma_x^m} \tag{32}$$

For secant module:

$$E_s = \frac{\sigma_v}{\varepsilon_v} \tag{33}$$

For tangential module:

$$E_t = \frac{d\sigma_v}{d\varepsilon_v} \tag{34}$$

For elastic-plastic Poisson's ratio:

$$\nu_p = 0.5 - (0.5 - \nu)\frac{E_s}{E} \tag{35}$$

f, σ_v, E_s, E_t are functions of the elastic-plastic buckling pressure p'_{cr} to be determined. For the iterative evaluation of p'_{cr} the value f can be computed for the calculation pressure *CDP* and be assumed as constant in the following calculation. σ_v can be determined by linear extrapolation starting from the value of the calculation pressure *CDP*.

6.2.3 Secant module and tangential module of steels

For various types of steel is valid:

$$Z = \frac{\sigma_e}{\sigma_{0.2}} \tag{36}$$

σ_e = limit of proportional extension
$\sigma_{0.2}$ = 0.2 % yield strength, R_{eH}
z = 0.8 for ferritic steel

= 0.6 for austenitic steel (see also [6.2.4])

If $\sigma_v > \sigma_e$ the equations defined in [6.2.3.1] and [6.2.3.2] are valid.

For $\sigma_v \le \sigma_e$ is valid:

$$E_s = E_t = E \tag{37}$$

6.2.3.1 Modules for z ≥ 0.8

$$E_t = E \cdot \left\{ 1 - \left(\frac{\sigma_v - z \cdot \sigma_{0.2}}{(1-z) \cdot \sigma_{0.2}} \right)^2 \right\} \tag{38}$$

$$E_s = E \cdot \frac{\sigma_v}{\sigma_{0.2} \left(z + (1-z) \operatorname{arc\,tanh} \frac{\sigma_v - z \cdot \sigma_{0.2}}{(1-z) \cdot \sigma_{0.2}} \right)} \tag{39}$$

6.2.3.2 Modules for z < 0.8

$$E_t = E \cdot \left\{ 1 - \left(\frac{\sigma_v - z \cdot \sigma_{0.2}}{(1-z) \cdot \sigma_{0.2}} \right)^2 \right\} \tag{40}$$

$$E_s = E \cdot \frac{\sigma_v}{z \cdot \sigma_{0.2} - \frac{1}{k}(1-z) \cdot \sigma_{0.2} \ln \left(1 - k \frac{\sigma_v - z \cdot \sigma_{0.2}}{(1-z) \cdot \sigma_{0.2}} \right)} \tag{41}$$

k has to be calculated from the condition:

$$\sigma_{0.2} + 0.002 \cdot E = z \cdot \sigma_{0.2} - \frac{1}{k}(1-z) \cdot \sigma_{0.2} \cdot \ln(1-k) \tag{42}$$

at least with the accuracy of four decimals.

6.2.4 Secant modules and tangent modules for other metallic materials

For other metallic materials z and the applicable material formulation shall be agreed. For various aluminium and austenitic steel alloys the Ramberg-Osgood stress-strain relationship is recommended.

6.2.5 It has to be proven, that the collapse pressure, which is the theoretical elastic-plastic buckling pressure p'_{cr} multiplied by the reduction factor r, is at least equal to the calculation pressure CDP of the pressure hull.

With the reduction factor:

$$r = 1 - 0.25 \cdot e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1\right)} \quad (43)$$

6.3 Calculation of the collapse pressure for the symmetric interstiffener buckling of the shell in uniformly stiffened sections of the pressure hull

6.3.1 For conical pressure hulls the equivalent values as defined for the stress calculation above have to be used.

6.3.2 Elastic buckling pressure:

$$p_{cr}^{el} = \frac{2}{\sqrt{3(1-\nu^2)}} \cdot E \cdot \frac{s^2}{R_m^2} \left\{ \left[\frac{2 \cdot L}{\pi \cdot L_{eff}}\right]^2 + \frac{1}{4}\left[\frac{\pi \cdot L_{eff}}{2 \cdot L}\right]^2 \right\} \quad (44)$$

Theoretical elastic-plastic buckling pressure:

$$p_{cr}^{i} = \frac{2}{\sqrt{3(1-\nu^2)}} \cdot E_s \cdot \frac{s^2}{R_m^2} \cdot C \cdot \left\{ \left[\frac{\alpha \cdot L}{\pi}\right]^2 + \frac{1}{4}\left[\frac{\pi}{\alpha \cdot L}\right]^2 \right\} \quad (45)$$

with:

$$\alpha = \sqrt[4]{\frac{3\left(\frac{A_2}{A_1} - \nu_p^2 \frac{A_{12}^{\;2}}{A_1^2}\right)}{R_m^2 \cdot s^2}} \quad (46)$$

$$C = \sqrt{\frac{A_1 \cdot A_2 - \nu_p^{\;2} \cdot A_{12}^2}{1 - \nu_p^2}} \quad (47)$$

$$\nu_p = \frac{1}{2} - \frac{E_s}{E}\left(\frac{1}{2} - \nu\right) \quad (48)$$

$$A_1 = 1 - \frac{1 - E_t / E_s}{4\,(1-\nu_p^2)\,K^2 \cdot H}\left[(2-\nu_p) - (1 - 2\cdot\nu_p)\,k\right]^2 \tag{49}$$

$$A_2 = 1 - \frac{1 - E_t / E_s}{4\,(1-\nu_p^2)\,K^2 \cdot H}\left[(1 - 2\cdot\nu_p) - (2-\nu_p)\,k\right]^2 \tag{50}$$

$$A_{12} = 1 + \frac{1 - E_t / E_s}{4\nu_p\,(1-\nu_p^2)K^2 \cdot H}\left[(2-\nu_p) - (1 - 2\cdot\nu_p)\,k\right]\cdot\left[(1 - 2\cdot\nu_p) - (2-\nu_p)\,k\right] \tag{51}$$

$$H = 1 + \frac{1 - E_t / E_s}{4\left(1-\nu_p^2\right)K^2}\left\{\left[\left(2-\nu_p\right) - \left(1 - 2\cdot\nu_p\right)k\right]^2 - 3\left(1-\nu_p^2\right)\right\} \tag{52}$$

$$k = \frac{\sigma_{\varphi,M}^m}{\sigma_x^m} \tag{53}$$

$$K^2 = 1 - k + k^2 \tag{54}$$

The procedure for the evaluation of the theoretical elastic-plastic buckling pressure is analogous to that described for asymmetric buckling.

6.3.3 It has to be proven, that the collapse pressure, which is the theoretical elastic-plastic buckling pressure $p_{cr}^{'}$ multiplied by the reduction factor r, is at least equal to the calculation pressure *CDP* of the pressure hull.

With the reduction factor:

$$r = 1 - 0.25\,e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1\right)} \tag{55}$$

6.4 Proof of the collapse pressure for the general instability under consideration of the web frames

6.4.1 The proof of the general instability has to be done on the basis of a stress calculation which meets the equilibrium criteria in a deformed state. As predeformation, the out-of-roundness of the frames has to be considered. It has to be proven, that the out-of-roundness permissible according to App.B cannot lead to a global collapse.

6.4.2 Consideration of the stress-strain behaviour

For austenitic steels and other materials, for which $\sigma_{0.01} < 0.8 \cdot \sigma_{0.2}$ is valid, the actual stress-strain behaviour has to be considered by adequate calculation. The pressure hull, pre-deformed to the permissible out-of-roundness and inclinations of the frames, has to be incrementally pressure loaded. For the calculation of the increasing elastic displacement and stresses, the deformations in equilibrium condition and the actual, local material behaviour have to be considered.

For materials with $\sigma_{0.01} > 0.8 \cdot \sigma_{0.2}$ a linear elastic behaviour can be assumed for a stress calculation according to a theory of 2nd order. In this case the following stress limits (without consideration of local weaknesses) have to be met:

— The sum of basic stress and stress due to out-of-roundness in the frame flange shall not exceed $\sigma_{0.2}$.
— The sum of basic stress and stress due to out-of-roundness in the web frame flange shall not exceed 80% of $\sigma_{0.2}$.

6.4.3 The calculation procedure is described in the following:

Definitions:

p	=	collapse diving pressure of the pressure hull *CDP*
$n \geq 2$	=	number of circumferential lobes of out-of-roundness
w_0	=	maximum permissible out-of-roundness of the pressure hull according to App.B
R_m	=	mean radius of the pressure hull in the considered field
$R_{m,F/D}$	=	mean radius of the pressure hull at particular frame or web frame
e	=	distance from the centroid of the frame or web frame plus the effective length of shell to the furthest surface of the flange (see Figure 2). For conical shells e' =e/cos α is valid.
R_C	=	radius to the centroid of the frame or web frame cross section
L_D	=	length of the generating shell line at the considered area of the web frame
$L_{D,r}$, $L_{D,l}$	=	length of the generating shell line of the left hand or the right hand adjacent field, depending on the field boundary for which the proof is made (see Figure 3)
L_B	=	distance between bulkheads

$$\beta_D = \frac{\pi \cdot R_m}{L_D}; \quad \beta_B = \frac{\pi \cdot R_m}{L_B} \qquad (56)\ (57)$$

α	=	half apex angle (see Figure 2)

Generally the apex angle is not constant, neither in the actual web frame field nor in the adjacent field. Which angle is decisive will be described in the following for each particular case.

I, I_D = area moment of inertia of frame respectively web frame including effective length of pressure hull shell, to be assumed always parallel to the axis of the pressure hull

The effective length is:

$$L_{eff} = \frac{2}{\sqrt[4]{3\left(1-\nu^2\right)}}\sqrt{R_{m,F} \cdot s / \cos\alpha} \qquad (58)$$

but not greater than the average value of both adjacent frame distances.

α_{Dl}, α_{Dr} = the local half apex angle at the adjacent web frame, right or left

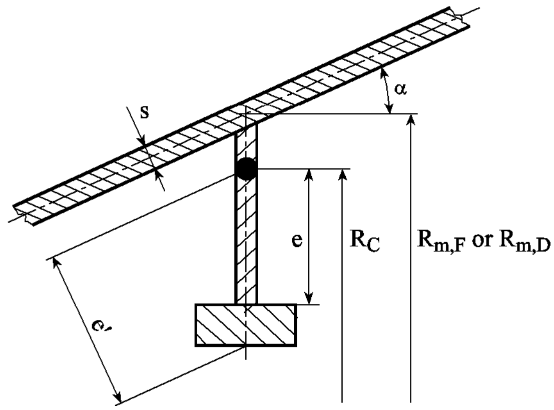

Figure 2 Situation at a frame or web frame

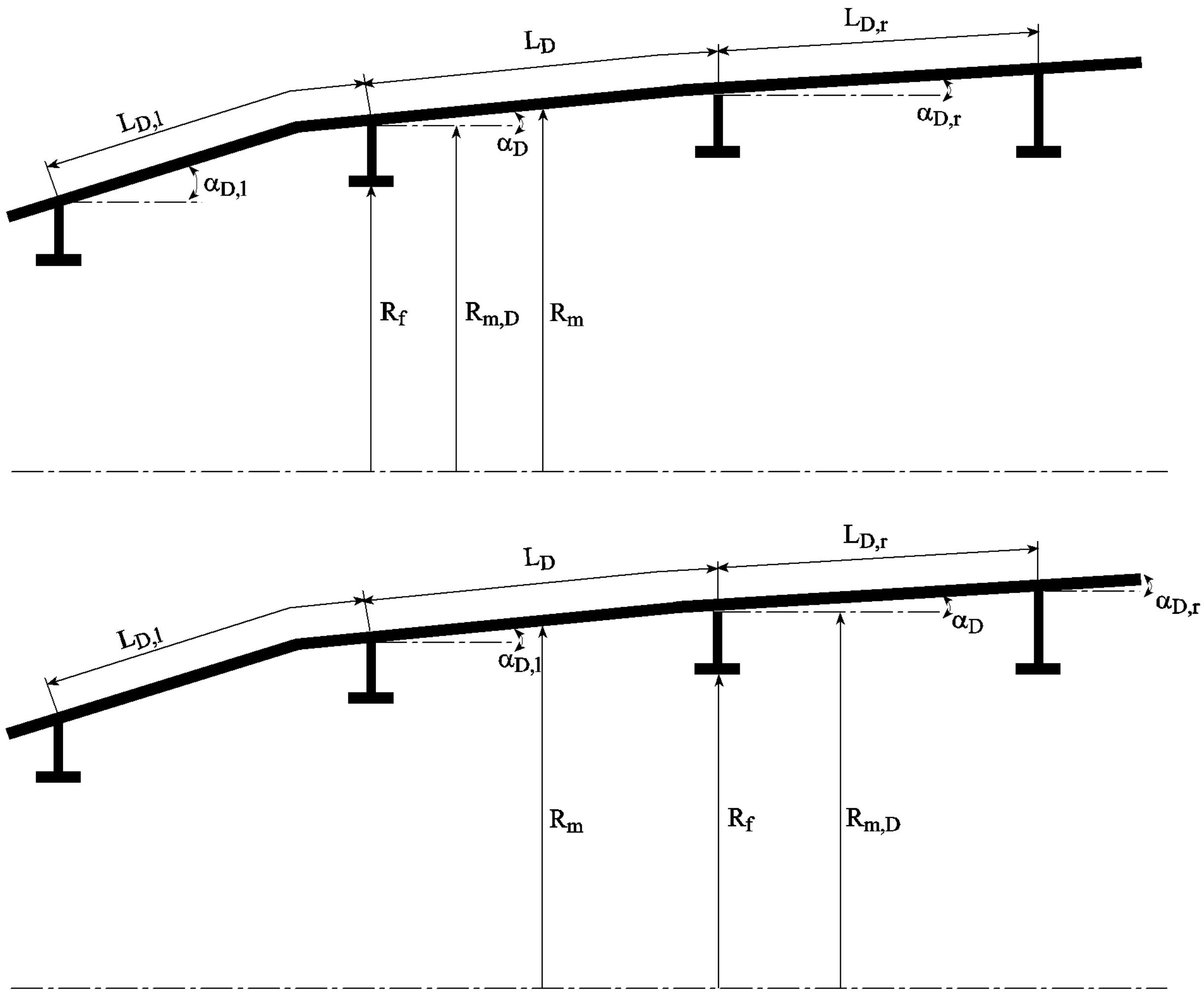

Figure 3 General stability – both calculation cases for a conical pressure hull

The area moment of inertia has to be converted to the radius R_m of the actual field by multiplying them by the ratio $(R_m/R_{m,F})^4$.

The proof has to be done for each section of the pressure hull, bounded by web frames, bulkheads or dished ends. Dished ends shall be considered as bulkheads.

A pressure hull section relevant for general instability may be limited by two web frames, followed by two adjacent web frame (or bulkhead) fields at each end, compare Figure 3. The calculation has to be performed for both relevant, adjacent fields in question. The most unfavourable case is decisive.

6.4.4 Basic stress in the frames and in the web frames

The basic stress in a frame flange has to be calculated according to [6.1.2], Equation (25) for $R = R_f$.

The effect of the half apex angle α is explicitly considered in the following equations.

The basic stress in a deep frame can be conservatively evaluated according to the following equations:

$$\sigma_{\varphi,D} = -\frac{p \cdot R_m \cdot L_{eff}\,(1-\nu/2)\dfrac{R_m}{R_f}}{A_D\dfrac{R_m}{R_D} + L_{eff}\cdot s}\,\frac{1}{\cos\alpha} \tag{59}$$

R_f = radius of the flange

$$L_{eff} = \frac{2}{\sqrt[4]{3\,(1-\nu^2)}}\sqrt{R_m \cdot s/\cos\alpha} \tag{60}$$

It has to be observed that A_D is the sole section area of the web frame and R_D the corresponding radius. For the thickness of the shell s the locally reinforced shell thickness at the web frame has to be used, if applicable.

The bending stress in the frame respectively web frame is:

$$\sigma_{\varphi,D} = \pm w_{el} \cdot E \cdot e\,\frac{n^2-1}{{R_C}^2} \tag{61}$$

R_C = see Figure 2

The elastic deflection w_{el} for the frames reads:

$$w_{el} = w_0\,\frac{p}{p_g^n - p} \tag{62}$$

and for web frames:

$$w_{el} = w_0\,\frac{p}{p_g^n - p}\;\frac{p_m}{p_m + p_D} \tag{63}$$

with the membrane part:

$$p_m = \frac{E \cdot s}{R_m}\cos^3\alpha\,\frac{\beta^4}{(n^2 - 1 + \beta^2/2)\,(n^2 + \beta^2)^2} \tag{64}$$

α is the average half apex angle and s the average cylinder shell thickness in the considered field.

And with the web frame part p_D:

$$p_D = \frac{2(n^2-1)E \cdot I_D \cdot \cos^3\alpha}{R_{C,D}^2[R_m - 4(R_m - R_{C,D})](L_D + L_{D,l/r})} \cdot \frac{n^2-1}{n^2-1+\beta_B^2/2} \quad (65)$$

α is the maximum half apex angle along the pressure hull section starting at the middle of the field under consideration and ending at the middle of the adjacent field:

$\alpha_{max} = \max(\alpha;\ \alpha_{Dl})$ resp. $\alpha_{max} = \max(\alpha;\ \alpha_{Dr})$

see Figure 3

$R_{C,D}$ applies to web frames.

The total instability pressure p_g^n has to be evaluated as follows:

$$p_g^n = p_F + \frac{p_m \cdot p_D}{p_m + p_D} + p_B \quad (A66)$$

using p_m and p_D as described above, and the frame part p_F as well as the bulkhead part p_B as follows:

$$p_F = \frac{(n^2-1)E \cdot I_F}{R_{C,F}^3 \cdot L_F}\cos^4\alpha \frac{n^2-1}{n^2-1+\beta^2 \frac{1}{2}\frac{p_D}{p_D+p_m}} \quad (67)$$

$R_{C,F}$ applies to frames

$$p_B = \frac{E \cdot s}{R_m}\cos^3\alpha \frac{{\beta_B}^4}{(n^2-1+{\beta_B}^2/2)\,(n^2+{\beta_B}^2)^2} \quad (68)$$

α is here to be understood as the average half apex angle in the field considered.

The frame part has to be calculated with the dimensions of an equivalent frame including equivalent frame spacing. Generally these are the dimensions of the frame closest to the midway point of the field under evaluation, which have to be converted to the average field radius in a manner described in [6.1.3].

The following condition has to be met:

For each frame of the considered field the permissible out-of-roundness has to be calculated for n = 5, assuming for p_g^5 an infinitive field length (β_D = 0). The arithmetic average of the out-of-roundness values evaluated in this way for three adjacent frames divided by the related frame radius shall not be less than the out-of-roundness for the equivalent frame evaluated in analogous way.

6.5 Proof of the collapse pressure for tripping of frames

6.5.1 Stability against tripping

The proof of the tripping stability has to be done for frames and web frames on the basis of a stress calculation, which fulfils the status of equilibrium in deformed condition. As pre-deformations the tolerances of the frames as defined in App.B may be considered.

Concerning the consideration of the stress-strain behaviour the rules defined in [6.4.2] are valid.

For materials with $\sigma_{0.01} \geq 0.8 \cdot \sigma_{0.2}$ linear elastic behaviour can be assumed for a stress calculation according to 2nd order theory. The following stress limits have to be observed (disregarding local material weakening):

— The equivalent stress in frame web shall not exceed $\sigma_{0.2}$.
— The circumferential stress in frame flange shall not exceed $\sigma_{0.2}$.

The effects to be considered in this procedure are defined further on.

6.5.2 Additional stresses caused by frame imperfections

The additional stresses caused by imperfections of the frame cross section have to be evaluated for internal frames according to the following equations. See also Figure 4.

The imperfections "inclination of web to plane of frame Θ", "eccentricity of flange to web u_{ex}" and "misalignment of frame heel to frame plane d" are defined in App.B [3.2.5] to App.B [3.2.7].

$$h'_w = h_w + \frac{s_f}{2} \quad (69)$$

$$\beta = \frac{h'_w}{R} \quad (70a)$$

$$R'_f = R_f + \frac{s_f}{2} \quad (70b)$$

$$\beta_f = \frac{h'_w}{R'_f} \quad (71)$$

$$A'_f = b_f\, s_f - \frac{s_f \cdot s_w}{2} \quad (72)$$

$$I_f = \frac{b_f^3 \cdot s_f}{12} \quad (73)$$

$$J_f = \frac{b_f \cdot s_f^3}{6\,(1+\nu)} \quad (74)$$

$$A'_w = h'_w \cdot s_w \quad (75)$$

$$D = \frac{E \cdot s_w^3}{12\,(1-\nu^2)} \quad (76)$$

$$L_0 = \frac{\sigma_0 \cdot A_F}{R} \quad (77)$$

$$F_f = \sigma_0 \cdot A'_f \quad (78)$$

σ_0 = basic stress in flange according to [6.5.3]/[6.5.4]

$$\lambda = \frac{A'_w}{A_F} \quad (79)$$

n = number of circumferential lobes of imperfections; the calculation has to be performed for n = 3.

$$e = \frac{h'^2_w \cdot L_0}{D} - 2 \cdot n^2 \cdot \beta^2 \quad (80)$$

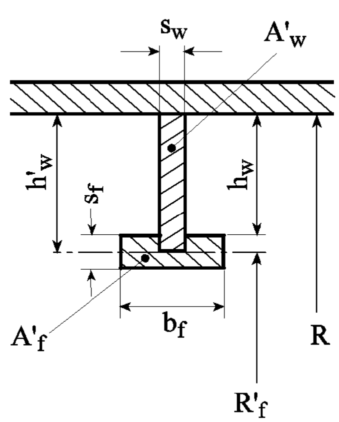

Figure 4 Local situation at the frame

$$\varepsilon = \lambda \frac{h_w'^2 \cdot L_0}{D} \tag{81}$$

$$g = n^2 \cdot \beta \left(\lambda \frac{h_w'^2 \cdot L_0}{D} - n^2 \cdot \beta^3 \right) \tag{82}$$

$$k_{11} = 12 - 1.2 \cdot e + 0.6 \cdot \varepsilon - \frac{13}{35} g \tag{83}$$

$$k_{12} = 6 - 0.1 \cdot e - \frac{11}{210} g + \nu \cdot n^2 \cdot \beta^2 \tag{84}$$

$$k_{22} = 4 - \frac{2}{15} e + 0.1 \cdot \varepsilon - \frac{g}{105} \tag{85}$$

$$k_{31} = 6 - 0.1 \cdot e + 0.1 \cdot \varepsilon + \frac{13}{420} g \tag{86}$$

$$k_{32} = 2 + \frac{e}{30} - \frac{\varepsilon}{60} + \frac{g}{140} \tag{87}$$

$$A_{11} = \frac{n^2 E}{R_f^4} \left(n^2 \cdot I_f + J_f \right) + \frac{D}{h_w'^3} k_{11} - n^2 \frac{F_f}{R_f^2} \tag{88}$$

$$A_{12} = \frac{n^2 \cdot E}{R_f^3} \left(I_f + J_f \right) - \frac{D}{h_w'^2} k_{12} \tag{89}$$

$$A_{22} = \frac{E}{R_f^2} \left(I_f + n^2 \cdot J_f \right) + \frac{D}{h_w'} k_{22} \tag{90}$$

Amplitudes of the elastic displacement u and twist ω of the connection web-flange:

$$u = \frac{1}{Det}\left(B_1 \cdot A_{22} - B_2 \cdot A_{12}\right) \quad (91)$$

$$\omega = \frac{1}{Det}\left(B_2 \cdot A_{11} - B_1 \cdot A_{12}\right) \quad (92)$$

with

$$Det = A_{11} \cdot A_{22} - A_{12}^2 \quad (93)$$

$$B_1 = \theta\left[\frac{F_f}{R_f}\left(1+n^2\cdot\beta_f\right) - L_0\cdot\lambda\cdot k_{1,\theta}\right] + u_{ex}\frac{F_f}{R_f\cdot h_w^{'}}\cdot n^2\cdot\beta_f + d\frac{L_0\cdot n^2\cdot\beta_f}{h_w^{'}}\left[\left(1-\lambda\right)\frac{R}{R_f} - \lambda\cdot k_{1,d}\right] \quad (94)$$

$$B_2 = -\theta\cdot L_0\cdot\lambda\cdot h_w^{'}\cdot k_{2,\theta} + u_{ex}\frac{F_f}{R_f} - d\cdot L_0\cdot\lambda\cdot n^2\cdot\beta_f\cdot k_{2,d} \quad (95)$$

where:

$$k_{1,\theta} = \frac{1}{2}\left(-1 - \frac{\varepsilon}{420} + 0.013\cdot g + 0.015\cdot e^2 - 0.025\cdot e\cdot\varepsilon - 0.7\cdot n^2\cdot\beta\right) \quad (96)$$

$$k_{1,d} = \frac{1}{2}\left(-1 - \frac{\varepsilon}{420} + 0.013\cdot g + 0.015\cdot e^2 - 0.025\cdot e\cdot\varepsilon\right) \quad (97)$$

$$k_{2,\theta} = \frac{1}{12}\left[1 + \frac{e}{60} - \frac{\varepsilon}{105} - \frac{g}{140} - 0.008\cdot e^2 + 0.013\cdot e\cdot\varepsilon + 0.6\cdot n^2\cdot\beta\left(1 + \frac{19\cdot e}{1260} + \frac{25\cdot\varepsilon}{336}\right)\right] \quad (98)$$

$$k_{2,d} = \frac{1}{12}\left(1 + \frac{e}{60} - \frac{\varepsilon}{105} - \frac{g}{140} - 0.008\cdot e^2 + 0.013\cdot e\cdot\varepsilon\right) \quad (99)$$

Stresses in the flange are as follows:

$$\sigma^{b}_{r,F/Df} = \pm \frac{E \cdot b_f}{2 \cdot R_f^2} \left(n^2 \cdot u + R_f \cdot \omega \right) \qquad (100)$$

Bending stress around radial axis, and

$$\tau_{t,F/Df} = \frac{n \cdot E \cdot s_f}{2(1+\nu) R_f^2} \left(u + R_f \cdot \omega \right) \qquad (101)$$

Torsion around the tangential axis, which is phase-shifted against $\sigma^{b}_{r,F/Df}$ by a quarter period.

The bending stress at the toe of the web is:

$$\sigma^{b}_{r,F/Dw} = \pm \frac{6}{s_w^2} \left[\frac{D}{h'^2_w} \left(k_{31} \cdot u - k_{32} \cdot h'_w \cdot \omega \right) + \lambda L_0 \left(k_{3,\theta} \cdot h'_w \cdot \theta + k_{3,d} \cdot n^2 \cdot \beta \cdot d \right) \right] \qquad (102)$$

with

$$k_{3,\theta} = \frac{1}{12} \left(1 + \frac{e}{60} - \frac{\varepsilon}{140} + 0.4 \cdot n^2 \cdot \beta \cdot \left(1 + 0.019 \cdot e - 0.009 \cdot \varepsilon \right) \right) \qquad (103)$$

$$k_{3,d} = \frac{1}{12} \left(1 + \frac{e}{60} - \frac{\varepsilon}{140} \right) \qquad (104)$$

The stresses resulting from imperfections of the frames shall be checked for frames and web frames, using different procedures.

6.5.3 Frames

For the stress σ_0 always $\sigma_{0.2}$ of the frame material has to be used.
The bending rigidity of the flange has to be neglected, i.e. set to zero ($I_f = 0$).
The equivalent stress at the web toe has to be evaluated with the calculation pressure for both signs of the bending stress $\sigma^{b}_{r,Fw}$ according to Equation (102).

Circumferential stress:

$$\sigma^{m+b}_{\varphi,F} = \sigma^{m}_{\varphi,Fw} + \frac{e_2}{e_1} \cdot \sigma_{O/R} \pm \nu \cdot \sigma^{b}_{r,Fw} \qquad (105)$$

with $\sigma^{m}_{\varphi,Fw}$ according to [6.1.2] Equation (24), compare Figure 5 and

$$\sigma_{O/R} = \sigma_{0,2} + \sigma^{m}_{\varphi,Ff} \tag{106}$$

with $\sigma^{m}_{\varphi,Fw}$ according to [6.1.2], Equation (25)

Radial stress:

$$\sigma_r = -\frac{L_0}{s_w} \pm \sigma^{b}_{r,Fw} \tag{107}$$

The equivalent stress:

$$\sigma_v = \sqrt{\sigma_\varphi{}^2 + \sigma_r{}^2 - \sigma_\varphi \cdot \sigma_r} \tag{108}$$

shall not exceed $\sigma_{0.2}$.

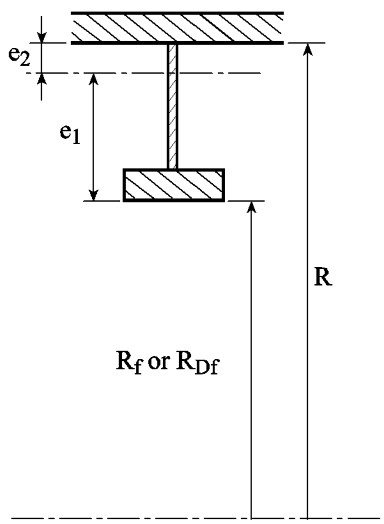

Figure 5 Situation of the frame in relation to the axis of the pressure hull

6.5.4 Web frames

For the basic stress in the flange σ_0 the absolute value of the circumferential stress $|\sigma_{\varphi,D}|$ according to Equation (59) has to be taken, as obtained for the half value of the permissible out-of-roundness resulting from the general instability proof performed for n = 2 circumferential lobes according to [6.4].

It has to be proven that:

a) $\sigma_0 + \left|\sigma^{b}_{r,Df}\right| \le \sigma_{0.2}$ (109)

b) $\sqrt{\sigma_0^2 + 3 \cdot \tau_{t,Df}^2} \le \sigma_{0.2}$ (110)

With $\sigma^{b}_{r,Df}$ according to Equation (100) and $\tau_{t,Df}$ according to Equation (101) considering the relevant dimensions of the web frames and the equivalent stress at the web toe

$$\sigma_v = \sqrt{\sigma_\varphi^2 + \sigma_r^2 - \sigma_\varphi \cdot \sigma_r} \le \sigma_{0.2} \quad (111)$$

The circumferential stress σ_φ is the sum of the basic stress $\sigma_{\varphi,D}$ obtained with the Equation (59) in [6.4.4] and v-times the web bending stress $\sigma^{b}_{r,Dw}$ according to Equation (102):

$$\sigma_\varphi = \sigma_{\varphi,D} + \nu \cdot \sigma^{b}_{r,Dw} \quad (112)$$

The radial stress is:

$$\sigma_r = \frac{-A_f \cdot \sigma_0 + A_w \cdot \sigma_D}{R_D \cdot s_w} \pm \sigma^{b}_{r,Dw} \quad (113)$$

For calculation of σ_0 the following simplified equation can be used:

$$\sigma_0 = \frac{1}{2}\left|\sigma_{\varphi,D}\right| + 0.4 \cdot \sigma_{0.2} \quad (114)$$

6.5.5 Modifications for frames arranged outside

For frames arranged outside all radii (R, R_f, R_{Df}) have to be applied as negative values.

6.6 Spherical shells and dished ends

6.6.1 General

Spherical shells and dished ends shall be investigated for the load cases defined in Sec.4 [6] against exceeding stresses and buckling. For dished ends the stresses in the crown and the knuckle shall be investigated. Spheres shall be treated like the crown area of dished ends.

6.6.2 Stresses

For the crown area the stress results from Equation (118). For the knuckle area the stress can be evaluated by Equation (119). The coefficients β can be evaluated directly with assistance of the following equations:

For torispherical ends:

$$\beta = 0.6148 - 1.6589 \cdot x - 0.5206 \cdot x^2 - 0.0571 \cdot x^3 \tag{115}$$

And for semi-ellipsoidal ends:

$$\beta = 1.3282 - 0.3637 \cdot x - 0.1293 \cdot x^2 - 0.0171 \cdot x^3 \tag{116}$$

$$\text{with } x = \ln\left(\frac{s}{D_a}\right)$$
$$\text{for range of validity } 0.001 \le \frac{s}{D_a} \le 0.1 \tag{117}$$

D_a = outside diameter of the dished end

In the range $0.5 \cdot (s \cdot R)^{0.5}$ besides the transition to the cylinder the coefficient β= 1.1 for hemispherical ends.

Under the assumption that deviations in the form of dished ends stay within the permissible tolerances, the stresses can be calculated with the following equations. If the tolerances are exceeded, a separate proof of stress shall be performed.

$$\sigma = -\frac{R_{c,o,l}^{\,2} \cdot p}{2 \cdot R_{c,m,l} \cdot s} \tag{118}$$

$R_{c,o,l}$ = local outside radius of sphere crown of the dished end

$R_{c,m,l}$ = local radius of the sphere crown of the dished end at half thickness of the shell

$$\sigma = -\frac{p \cdot D_a \cdot 1.2 \cdot \beta}{4 \cdot s} \tag{119}$$

For p *NDP*, *TDP* and *CDP* shall be introduced respectively.

The proof has been made if the permissible stresses according to Sec.5 [4.3] are not exceeded.

6.6.3 Calculation of the collapse pressure

The calculations are based on the local thickness and curvature of the shell and they are considering an out-of-roundness of the shell in the sense of a local flattening up to maximum $u = 0.218 \cdot s_l / R_o$. This is valid for pressed spherical shells and is adequate to a local outside curvature radius of $R_{o,l} = 1.3 \cdot R_o$ of the outer nominal radius.

The out-of-roundness and herewith the local radius shall be evaluated with a bridge gauge as described in App.B [5]. There a measuring length $L_{cr,l}$ according to Equation (120) has to be used. The out-of-roundness defined in this way shall be understood as local flattening from the theoretical form of the sphere within the diameter $L_{cr,l}$. For the lay out a local radius of 1.3 times the nominal radius and a nominal thickness of the shell (eventually reduced by the corrosion addition) shall be assumed. The corrosion addition shall be considered by keeping the outside radius.

If other tolerances are provided or another out-of-roundness is resulting from the measurement checks according to App.B [5.3] or App.B [5.4], then a recalculation of the permissible pressure according App.B [5.5] is required.

For mechanically machined spherical shells local radii less than 1.05 · R_o are reachable from point of manufacturing. The more favourable geometrical condition of the shell can be introduced in the calculation with at minimum $R_{o,l}$ = 1.05 · R_o under the assumption that the measurement procedure, as described in App.B, has proven a maximum permissible local flattening of u = 0.035 · s_1 / R_o with an accuracy of at least 0.001 · s.

6.6.4 Definitions

The following definitions are valid:

R_o = Outer nominal radius of the sphere

$R_{m,l}$ = maximum local mean radius of curvature of the sphere at shell half thickness
$R_{o.1}$ = maximum local outside radius of curvature of the sphere
s = nominal thickness of the shell
s_1 = local average shell thickness

Critical arc length or diameter of the measuring circle to be used for measuring the deviations from the perfect form of the sphere according to App.B [5.3] and App.B [5.4]:

$$L_{cr,l} = \frac{2,2}{\sqrt[4]{\frac{3}{4} \cdot (1 - \nu^2)}} \cdot \sqrt{R_{o,l} \cdot s_l} \qquad (120)$$

Elastic buckling pressure of the sphere:

$$p_{cr}^{el} = \frac{1,4}{\sqrt{3 \cdot (1 - \nu^2)}} \cdot E \cdot \left(\frac{s_l}{R_{o,l}} \right)^2 \qquad (121)$$

Theoretical elastic-plastic buckling pressure of the sphere:

$$p_{cr}^{i} = p_{cr}^{el} \cdot \frac{\sqrt{E_t \cdot E_s}}{E} \qquad (122)$$

$$p_{0,2} = \frac{2 \cdot \sigma_{0,2} \cdot s_l \cdot R_{m,l}}{R_{o,l}^2} \qquad (123)$$

6.6.5 Spherical ends made of ferritic steel

For spherical ends made of ferritic steel grade GLM550 or similar material p_{cr} can be calculated as follows:

6.6.5.1 For spherical ends which are not stress relieved the following is valid:

$$p_{cr} = p_{cr}^{el} \text{ if } \frac{p_{cr}^{el}}{p_{0.2}} \leq 0.47 \quad (124)$$

$$p_{cr} = p_{0.2}\left(0.38 + 0.195\frac{p_{cr}^{el}}{p_{0.2}}\right) \text{ if } 0.47 < \frac{p_{cr}^{el}}{p_{0.2}} \leq 3.18 \quad (125)$$

$$p_{cr} = p_{0.2} \text{ if } \frac{p_{cr}^{el}}{p_{0.2}} > 3.18 \quad (126)$$

6.6.5.2 For stress relieved spherical ends (tempered and stress relieved) the following is valid:

$$p_{cr} = p_{cr}^{el} \text{ if } \frac{p_{cr}^{el}}{p_{0.2}} \leq 0.595 \quad (127)$$

$$p_{cr} = p_{0.2}\left(0.475 + 0.195\frac{p_{cr}^{el}}{p_{0.2}}\right) \text{ if } 0.595 < \frac{p_{cr}^{el}}{p_{0.2}} \leq 2.7 \quad (128)$$

$$p_{cr} = p_{0.2} \text{ if } \frac{p_{cr}^{el}}{p_{0.2}} > 2.7 \quad (129)$$

The fabrication of ends by welding of stress relieved segments and the welding of the penetrations into the shell after stress relieving is permitted.

The calculated collapse pressure p_{cr} shall be at least equal to the collapse diving pressure *CDP* of the pressure hull.

6.6.6 Spherical shells of other materials

For spherical ends made of other steel materials the elastic-plastic buckling pressure p_{cr}' which has been evaluated according to the equations described above has to be multiplied by the reduction factor k defined in Figure 6. The reduction factor k is also summarized in tabular form in Table 2. Intermediate values can be defined by linear interpolation.

For the application of non-iron metal materials the reduction factors shall be evaluated in accordance with the Society by model tests.

6.7 Penetrations of the pressure hull and discontinuities

6.7.1 Discontinuities

Discontinuities like

— connections of cylinders and conical segments
— transition rings (tripping rings)
— flanges for the attachment of dome shaped windows.

shall be subjected for the load cases nominal diving pressure and test diving pressure to an analysis of the stress and elongation behaviour similar to /10/[1] and /11/[1] The equivalent stress follows from Equation (14).

Sufficient safety is given, if the permissible stresses according to Sec.5 [4.3] are not exceeded. If stiffeners are interrupted by penetrations, suitable reinforcements shall be provided.

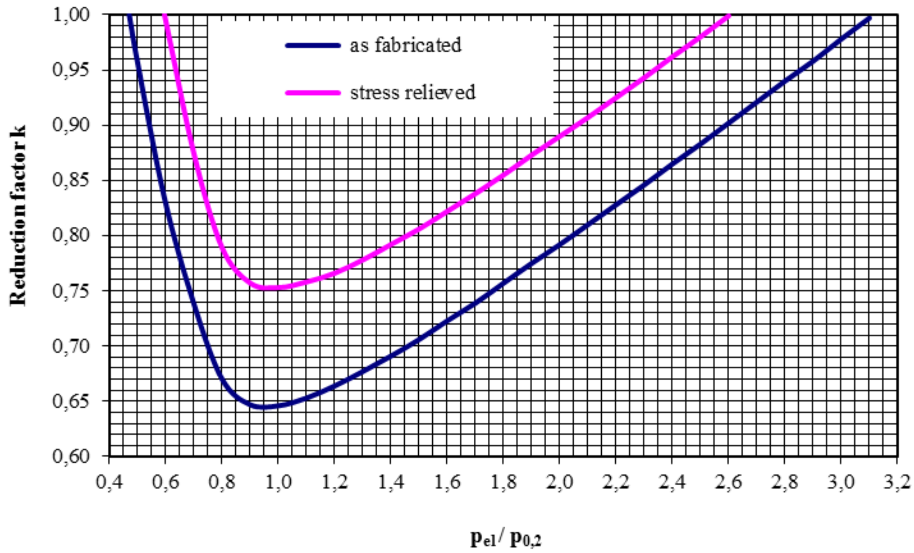

Figure 6 Reduction factor "k" for different kinds of steel treatment

6.7.2 Penetrations in the cylindrical or conical part of the pressure hull - area comparison principle

Penetrations in cylinders shall be preferably evaluated according to Pt.3 Ch.5 Sec.15 [4.2.3.4] with a design pressure p_c for which *NDP*, *TDP* resp. *CDP* shall be inserted alternatively. There is:

$D_i = 2 \cdot R$

and

s_A = necessary wall thickness at the penetration boundary (including existing reinforcement) which shall be evaluated by iteration.

The following rules for dimensioning are valid under the assumption that the material strength is the same for the shell of the pressure hull and for the reinforcement of the penetration boundary.

For different material characteristics the rules have to be modified in an analogous way.

6.7.3 Penetrations in the cylindrical or conical part of the pressure hull – cross sectional area substitution principle

After approval by the Society the required reinforcement of the penetration boundary can be evaluated also with the cross sectional area substitution principle.

These rules for dimensioning are valid under the assumption that the material strength is the same for the shell of the pressure hull and for the reinforcement of the penetration boundary.

For different material strength the rules have to be modified in an analogous way.

6.7.3.1 Small penetrations which do not interrupt frames

6.7.3.1.1 Circular penetrations in radial direction

The situation is characterised by Figure 7 where for the calculation one half of the nozzle is considered.

Designations in Figure 7:

s = thickness of the shell of the pressure hull after deduction of corrosion allowance
s_v = thickness of the shell of the pressure hull in the reinforcement vicinity
R = internal radius of the pressure hull
d_a = external diameter of the nozzle
ℓ_s, ℓ'_s = excess lengths of the nozzle
ℓ_{min} = min (ℓ_s, ℓ'_s)
= smaller excess length of the nozzle
ℓ_{max} = max (ℓ_s, ℓ'_s)
= bigger excess length of the nozzle
s_s = wall thickness of nozzle
A = cross sectional area to be substituted
A_{eff} = effective substitutive cross sectional area
l_{eff} = effective length of the nozzle

$$l^* = \frac{\sqrt{0.5(d_a - s_s) \cdot s_s}}{\sqrt[4]{3(1 - v^2)}} \quad (130)$$

$$r_m = 0.5 \cdot (d_a - s_s) \quad (131)$$

Table 2 Reduction factor "k" for different kinds of steel treatment

Pressure relation	*Reduction factor k*	
$p_{el}/p_{0,2}$	*As fabricated*	*Stress relieved*
0.470	1.000	1.000
0.495	0.963	1.000
0.595	0.834	1.000
0.700	0.738	0.874
0.800	0.670	0.789
0.900	0.647	0.757
1.000	0.646	0.753
1.100	0.653	0.758
1.200	0.664	0.766
1.300	0.677	0.778
1.400	0.691	0.792
1.500	0.706	0.806
1.600	0.723	0.822
1.700	0.739	0.838

Pressure relation	*Reduction factor k*	
$p_{el}/p_{0,2}$	*As fabricated*	*Stress relieved*
1.800	0.757	0.855
1.900	0.775	0.873
2.000	0.792	0.890
2.100	0.810	0.907
2.200	0.828	0.925
2.300	0.846	0.943
2.400	0.865	0.962
2.500	0.883	0.980
2.600	0.902	0.999
2.700	0.921	1.000
2.800	0.940	1.000
2.900	0.958	1.000
3.000	0.978	1.000
3.100	0.997	1.000
3.200	1.000	1.000

It has to be proven that the effective substitutive cross sectional area of the boundary reinforcement A_{eff} of the penetration is at least equal to the cross sectional area A cut out of the shell which shall be substituted.

The area to be substituted is

$$A = 0.5 \cdot d_a \cdot s \quad (132)$$

For penetrations, which are designed in the form shown in Figure 7 the effective substituted cross sectional area can be calculated according to the following equation:

$$A_{eff} = b_{min} \cdot (s_v - s) + s_s \cdot \ell_{eff} \quad (133)$$

$$B_{min} = 0.78 \cdot \sqrt{R \cdot s_v}$$

Effective length of the nozzle:

Case 1:

$$\ell_{eff} = 2 \cdot \ell^* + s_v \text{ for} \quad (134)$$

$$\ell_s \geq \ell^*;\ \ell_s^{'} \geq \ell^* \tag{135}$$

Case 2:

$$\ell_{eff} = 2 \cdot \ell_{min} + s_v \tag{136}$$

$$\frac{\ell^*}{2} \leq \ell_{min} \leq \ell^* \tag{137}$$

Case 3:

$$\ell_{eff} = \ell_{min} + \min\left(a, \frac{\ell^*}{2}\right) + s_v \tag{138}$$

$$\ell_{min} < \frac{\ell^*}{2};\quad \ell_{max} > \frac{\ell^*}{2} \tag{139}$$

$$a = \ell_{max}\left(0.4 + 0.6\frac{\ell_{min}^2}{\ell_{max}^2}\right) \tag{140}$$

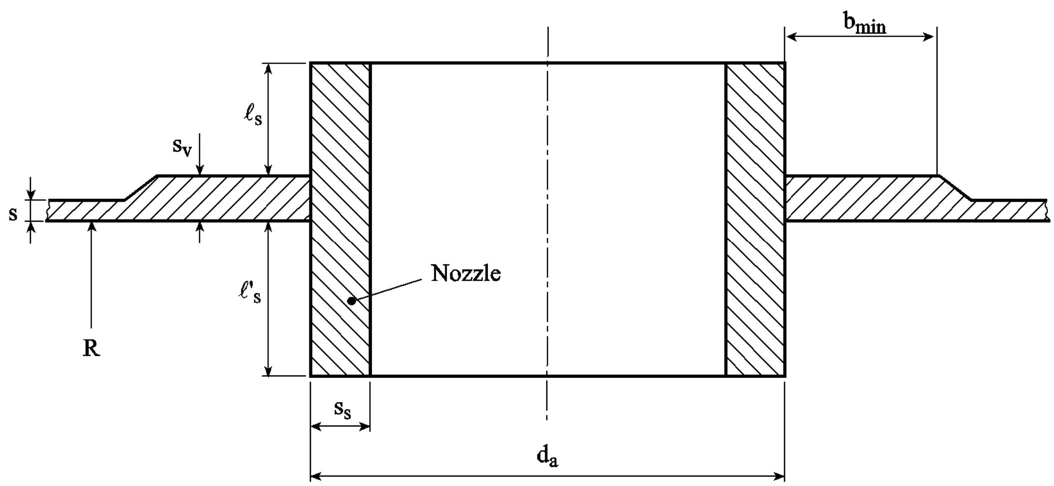

Figure 7 Penetration through the enforced shell

6.7.4 Flush form of circular penetrations in radial direction

Penetrations in flush form of the pressure hull ($\ell_s = 0$), may have in the penetration area a cut out to include a zinc ring, see Figure 8.

In this case ℓ_{eff} can be evaluated with the equations given above. In addition the strength of the cross section A-A has to be proven.

In the case that the wall of the pressure hull is not reinforced, the following condition has to be met:

$$c > \sqrt{4 \cdot \frac{s \cdot d_a \left(g - \frac{s}{2}\right) - c \cdot g^2}{d_a - c} + c_\tau^2} \qquad (141)$$

$$c_\tau = \sqrt{3} \cdot \frac{s \cdot d_a - 2 \cdot c \cdot g}{d_a - c} \qquad (142)$$

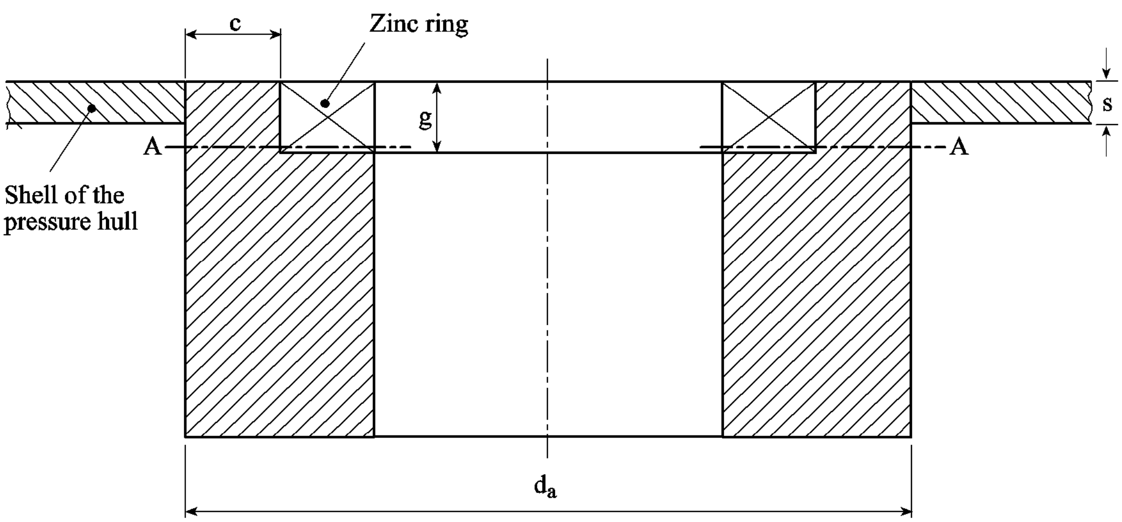

Figure 8 Penetration in flush form

6.7.5 Non-circular penetrations or penetrations not in radial direction to the shell

If the penetration is not circular or does not cut the shell of the pressure hull in radial direction the diameter d_a has to be replaced by:

$$d_a = \max\left(L_x, L_\varphi \cdot \frac{\sigma_x^m}{\sigma_\varphi^m}\right) \qquad (143)$$

L_x = width of the penetration line in longitudinal direction

L_φ = width of the penetration line in circumferential direction
$\sigma_x{}^m$ = membrane stress in the pressure hull in longitudinal direction
$\sigma_\varphi{}^m$ = membrane stress in the pressure hull in circumferential direction

In special cases, if the rules can only be utilized in limited way, the strength has to be proven by numerical computation.

6.7.5.1 Big penetrations interrupting frames

For preliminary dimensioning the following procedure can be used:

The effective border reinforcement for the penetration has, in a similar way as for the small penetrations, to substitute the area cut out. The cross sections of the interrupted frame webs shall be considered additionally. The effective substitutive cross sectional area has to be evaluated in analogous way as for small penetrations. Compact reinforcement rings are fully load carrying if they are located directly in the penetration line.

The construction in the flange plane of the frame has to be designed in such a way that the maximal permissible forces in the flange ($A_f \cdot \sigma_{zul}$) can be transmitted further. For σ_{zul} the value of the permissible stress belonging to the individual load case acc. to Sec.5 [4.3] shall be inserted.

Big penetrations have to be proven by numerical computation.

6.7.6 Penetrations of spherical shells

Penetrations in spherical shells shall be evaluated according to Pt.3 Ch.5 Sec.15 [4.4.3.3] with a design pressure p_c for which 1.2 · *NDP*, 1.2 · *TDP* resp. 1.2 · *CDP* shall be inserted alternatively. There is:

$D_i = 2 \cdot R$

and

s_A = necessary wall thickness at the penetration boundary (including existing reinforcement) which shall be evaluated by iteration.

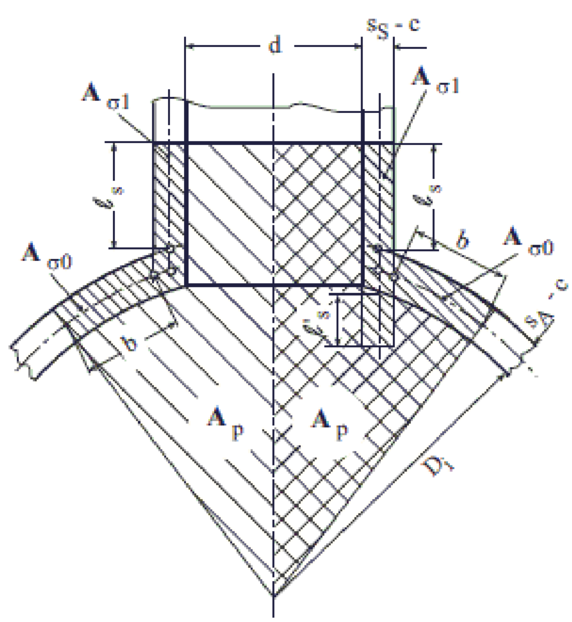

Figure 9 Penetrations of spherical shells

After approval by the Society the cross sectional area substitution principle as described in [6.7.3] may be applied analogously. For this R is the internal radius of the sphere.

In cases, where area comparison respectively cross sectional area substitution principle are not fulfilled, a numerical proof has to be done. For this the local radius of the spherical shell according to [6.6.3] shall be chosen adequately in the vicinity of the penetration. The achieved failure pressure is then to be reduced like the elastic-plastic buckling pressure, which has been evaluated for undisturbed dished ends, see Figure 6.

7 Literature

/1/ DNV GL Rules SHIP Pt.4

/2/ AD 2000 Regelwerk, Merkblätter Reihe B, *Berechnung von Druckbehältern*, Herausgeber: Arbeitsgemeinschaft Druckbehälter

/3/ The *Stress Analysis of Pressure Vessels and Pressure Vessel Compartments,* Herausgeber: S.S. Gill, Pergamon Press, 1970

/4/ John C. Pulos und Vito L. Salerno: *Axisymmetric Elastic Deformations and Stresses in a Ring-Stiffened, Perfectly Circular Cylindrical Shell under External Hydrostatic Pressure*, DTMB-Report No. 1497

/5/ *Development in Pressure Vessel Technology*, Herausgeber: R. W. Nichols, Applied Science Publishers, 1983

/6/ *European Recommendations for Steel Construction*: Buckling of Shells, Herausgeber: ECCS-CECM-EKS, Brüssel, 1984

/7/ DIN 4114, Blatt 2: *Stabilitätsfälle (Knickung, Kippung, Beulung)*, Ausgabe 2.53

/8/ Myron E. Lunchick: P*lastic Axisymmetric Buckling of Ring-Stiffened Cylindrical Shells Fabricated from Strainhardening Materials and Subjected to External Hydrostatic Pressure*, DTMB-Report No. 1393

/9/ Krenske, Martin A. und Kierman, Thomas J.: *The Effect of Initial Imperfections on the Collapse Strength of Sherical Shells,* DTMB Report No. 1757

/10/ ASME Boiler and Pressure Vessel Code, Section VIII, Division 2

/11/ Raymond J. Roark and Warren C. Young: *Formulas for Stress and Strain,* Mc Graw - Hill Book Company

/12/ William F. Blumenberg: *The Effect of Intermediate Heavy Frames on the Elastic General-Instability Strength of Ring-Stiffened Cylinders Under External Hydrostatic Pressure*, DTMB-Report No. 1844

/13/ Thomas E. Reynolds: *Inelastic Lobar Buckling of Cylindrical Shells Under External Hydrostatic* Pressure, DTMB-Report No. 1392.

APPENDIX B MANUFACTURING TOLERANCES FOR THE PRESSURE HULL

1 General

1.1

This App. describes the permissible manufacturing tolerances for the pressure hull as prerequisite for the application of the strength calculations defined in App.A.

1.2

All tests shall be performed by the manufacturer in presence of a surveyor and a measurement report has to be sent by the manufacturer to the Society.

1.3

The required checks defined in the following are only to be performed, if no following changes of the measurement values shall be expected. Areas with welding seams which have been worked over in the mean time because of impermissible defects have to be measured again.

The component to be investigated shall be cooled down to ambient temperature and is so to be relieved from any tensions by means of installation aids in order to prevent falsification of the measurement results.

2 Dimensions of the pressure hull

2.1 General

2.1.1 As far as not defined otherwise in these rules the following tolerances are valid.

2.1.2 All longitudinal and circumferential seams in the pressure hull plating shall be inspected for edge offset, weld sinkage, undercuts and hollow grinding. This shall also be valid for the welding connection of the plating with the tripping / transition ring. The inner and outer surface of the plates shall be inspected for damage.

2.2 Dimensions of the cylindrical and conical parts

2.2.1 Diameter

The actual mean outside diameter of cylindrical respectively conical pressure hulls shall, calculated from the circumference, deviate not more than ± 0.5% from the outside diameter on which the calculation is based. The measurements shall be performed in distances of maximum $(3 \cdot R \cdot s)^{1/2}$ over the complete length of the component.

s = nominal shell thickness [mm]

R = internal radius of the shell [mm]

2.2.2 Generating line

The deviation of the theoretical generating line from the straight line shall not exceed ± 0.2% of the length of the straight forward part of a cylinder resp. cone over three adjacent measuring points, which are given by web frames, bulkheads and connections of cones and dished ends. If web frames, cones and bulkheads are not provided, only between dished ends shall be measured. The deviation shall be measured at minimum 8 positions equally distributed over the circumference.

2.2.3 Length

The length of the pressure hull rings in manufacturing shall be measured at minimum 4 positions equally distributed over the circumference and to be averaged.

The allowable tolerance of the length of the pressure hull ring shall not be bigger than the sum of the existing deviations of the frame distances within this ring. If no frames are provided, the tolerance is ± 1% of the nominal length, but not more than 15 mm.

2.3 Dimensions of spherical shells and dished ends

2.3.1 Radius of spherical shells and crown of dished ends

For determination of the spherical form of the spherical shell the outside radius shall be evaluated according to [5.3].

The spherical form of the spherical shell has to remain within a tolerance of ± 1% of the nominal outside radius.

2.3.2 Course of theoretical geometry lines of dished ends (knuckle/crown radius)

The tolerances shall be defined by the manufacturer according to recognized regulations and deviations from it shall be approved by the Society, compare [5.2].

2.4 Component thickness

Tolerances for components of the pressure hull: −0/+t

Tolerance value t according to material delivery specifications (if the material delivery standard allows minus tolerances, these shall be considered for the calculations).

2.5 Edge offset and weld sinkage

2.5.1 The radial deviations x_1 and x_2 are the basis for the determination of weld sinkage and edge offset of sheet metal surfaces with regard to their nominal positions next to a welding seam, compare Figure 1.

They are measured at a distance $y = s_{max} + 20$ mm on both sides centred over the welding seam. s_{max} is the larger value of the adjacent wall thicknesses.

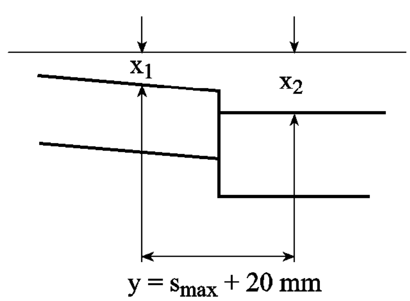

Figure 1 Radial deviation of the sheet metal surface of the pressure hull

2.5.2 The tolerances for the discontinuity in the theoretical centre line at the transition between both plates shall be documented in the manufacturing protocols and to be checked.

2.5.3 Edge offset for cylindrical and conical parts

The edge offset of both plates which is determined by the difference of the measuring values $|x_2 - x_1|$, compare Figure 1.

For circumferential seams the edge offset shall not exceed 5% of the nominal thickness of the thinner plate, but maximum 2 mm.

For longitudinal seams the edge offset shall not exceed 10% of the nominal thickness of the thinner plate, but maximum 3 mm.

2.5.4 Edge offset for spherical shells and dished ends

For butt joints within these shells and dished ends the edge offset shall not exceed 10% of the nominal thickness of the thinner plate, but maximum 3 mm.

2.5.5 Weld sagging, notches, undercuts and concavities

The imperfections shall not exceed 0,5 mm. For details please refer to App.A or DIN EN ISO 5817 considering quality level B.

2.5.6 Weld sinkage for spherical shells and dished ends

For butt joints within these shells and dished ends the weld sinkage shall not exceed $h = 1/6 \cdot s$, but maximum 3 mm.

2.6 Damages to the component surface

Damage to the surface, such as scores, scratches, arc strikes, indentation pits, etc. shall be thoroughly smoothed and inspected for surface cracks. The flaws treated in this way are permissible without proof of strength, if the following requirements are met:

— The depth shall be at maximum $0.05 \cdot s$ or 3 mm, the smaller value is decisive.
— The area of the undercut of the thickness shall be within a circular area with $2 \cdot s$ as diameter or 60 mm, the smaller value is decisive.
— The distance between two areas of thickness undercut and the distance from points of disturbance, like e.g. penetrations, shall be at least $(2 \cdot R \cdot s)^{1/2}$.

Deeper flaws shall be treated specially in agreement with the Society.

2.7 Evaluation of the welding seams

The evaluation of other imperfections on welding seams as defined under 2.5 shall be performed according to the SHIP Pt.2 Ch.4 Sec.7 – Non destructive testing of welds.

All detected imperfections have to evaluated and the result reported to the Society for approval.

3 Pressure hull frames

3.1 Measurements

The following measurements shall be carried out on every frame of the pressure hull at eight measuring points uniformly distributed around the circumference:

— flange width
— flange thickness
— web thickness
— frame spacing (measured at frame heel)
— frame height at frame moulding edge
— eccentricity flange to web
— web tilt to plane of frame.

The spacing k of the frame heel from a reference plane shall be determined by direct measurement, see Figure 2. The location of the frame heel is shown as detail "A" in this Figure. For cylindrical pressure hull parts this measurement shall be carried out on a minimum of one frame per ring (with a ring length of up to a maximum of 8 pressure hull frames) and for conical pressure hull parts on every frame at 16 points uniformly distributed around the circumference.

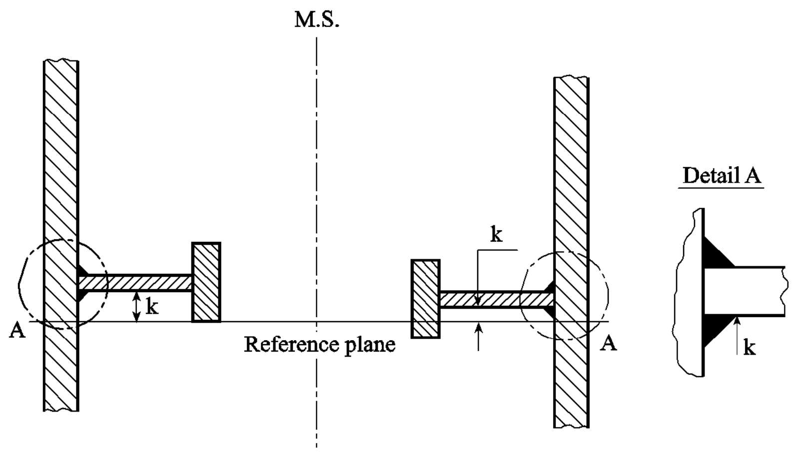

Figure 2 Definition of the reference plane of a frame

3.2 Tolerances

3.2.1 The following tolerances are maximum values and shall not be exceeded. The tolerances calculated from percentages may be rounded up to half of a millimeter.

Flange width:	0% to + 4.5%
Flange thickness:	0 mm to + 3 mm
Web thickness:	0 mm to + 3 mm

3.2.3 With regard to the flange width resp. flange thickness the nominal cross sectional area of the flange is considered to be a permissible acceptance criteria. Height tolerances of 0.2 + 0.04 · s ≤ 1 mm (s = material thickness in mm) due to flat grinding of nicks may be exceeded locally, however, the nominal cross section of the flange or web shall not be reduced to more than 90%.

3.2.4 Frame spacing: generally ± 1%

At circumferential seams +1% to −3%

3.2.5 Frame height at frame moulding edge: 0% to + 5%

Tolerances up to −2% are allowed locally if the mean value of the 8 measuring points reaches nominal value.

3.2.6 Eccentricity of flange to web: 2% of frame height

3.2.7 Inclination of web to reference plane of frame: ± 2°

3.2.8 Misalignment of frame heel to reference plane: + 4 mm for frames

± 6 mm for web frames

If the maximum difference of determined spacings (k_{max} – k_{min}) is larger than 8 mm for frames and 12 mm for web frames, the real deviations of h shall be determined by evaluation according to the following equation:

$$h_i = k_i - k_0 - \Delta k_x \cdot \sin\varphi_i - \Delta k_y \cdot \cos\varphi_i \quad (1)$$

$$k_0 = \frac{1}{J} \cdot \left(k_1 + k_2 + k_3 + \cdots + k_J\right) \quad (2)$$

$$\Delta k_x = \frac{2}{J}\left(k_1 \cdot \sin\varphi_1 + k_2 \cdot \sin\varphi_2 + k_3 \cdot \sin\varphi_3 + \cdots + k_J \cdot \sin\varphi_J\right) \quad (3)$$

$$\Delta k_y = \frac{2}{J}\left(k_1 \cdot \cos\varphi_1 + k_2 \cdot \cos\varphi_2 + k_3 \cdot \cos\varphi_3 + \cdots + k_J \cdot \cos\varphi_J\right) \quad (4)$$

φ_i = 360° · i /J
h_i = deviation of the frame heel from the actual plane of frame at measuring point i
k_i = measured distance of frame heel from the reference plane of measuring point i
J = number of measuring points

3.3 Transition rings and strengthening of pressure hull

Transition rings, strengthenings of cut-outs and other strengthenings of the pressure hull shall not be applied with tolerances which weaken the components.

4 Out-of roundness of the cylindrical resp. conical pressure hull

4.1

The out-of-roundness shall be measured at each frame and also at each transition ring. The measurements shall be conducted with a maximum distance according to $(3 \cdot R \cdot s)^{1/2}$ over the complete length of the component. For frame spacings above $(3 \cdot R \cdot s)^{1/2}$ the out-of-roundness shall be determined also at the shell between the frames considering this measuring distance.

Moreover the course of the theoretical geometry lines at the transition ring shall be determined.

4.2

The following requirements shall be met prior to conducting out-of-roundness measurements:

- The required tests shall only be carried out when no subsequent changes of measured values shall be expected.
- The section shall be cooled down to ambient temperature and relieved from any tension by means of appropriate aids in order to prevent falsification of measurement results.

4.3

The measurement of the pressure hull can be carried out from outside or from inside. In principle the measurement of out-of-roundness shall be carried out at 24 points distributed as uniformly as possible around the circumference. It can be conducted with the help of a circular template, callipers, a two point bridge gage (see Figure 4), photogrammetry or theodolite methods, in which case access has to be provided by appropriate means. If the measuring of individual values is not possible due to constructional reasons (e.g. in the area of larger openings), it shall be supplemented as far as practically possible (in general by linear interpolation). The measurement shall not be impaired by welding seams (e.g. weld reinforcement) or local imperfections on the surface.

4.4

The results of the evaluation shall be presented to the Society as tables and graphs.

4.5

The maximum permissible out-of-roundness is ± 0.5% of the nominal pressure hull radius unless otherwise agreed by the Society.

4.6 Measuring method 1: direct measurement of the radii and their deviation from constant radius; from inside or from outside

The measurement can be performed from inside - measurement of the radii, and from outside – measurement of the deviations from the constant, mean radius by rotating the pressure hull around an assumed axis (centre). The assumed centre shall be as near to the true centre as possible, compare Figure 3.

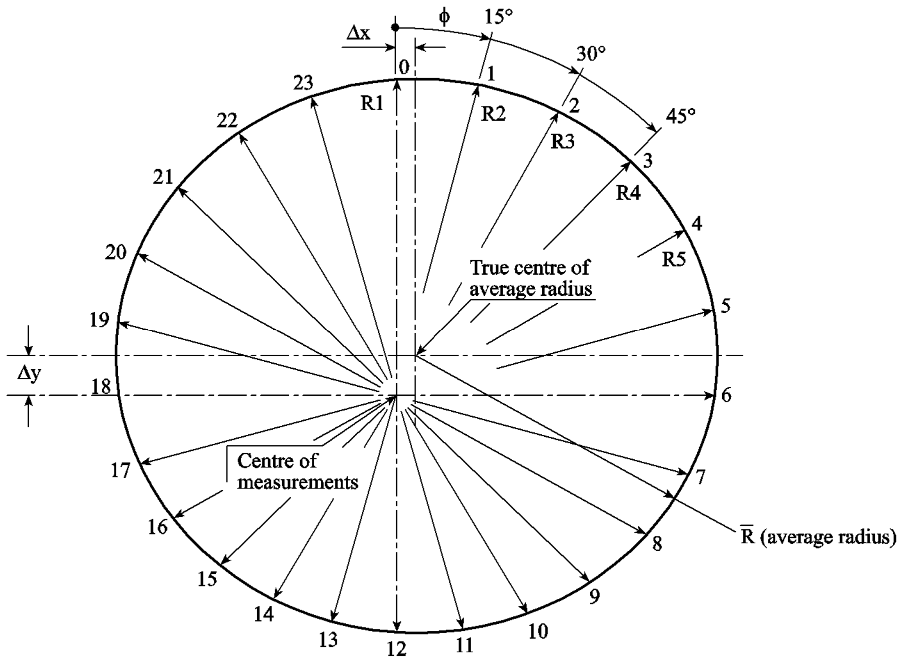

Figure 3 Measurement of the out-of-roundness at the cylinder; measuring method 1, explanation of symbols

The following equations apply to J = 24 measuring points distributed uniformly around the circumference:

$$u_i = R_i - \bar{R} - \Delta x \cdot \sin\varphi_i - \Delta y \cdot \cos\varphi_i \tag{5}$$

$$\bar{R} = \frac{1}{J}\left(R_1 + R_2 + R_3 + \cdots + R_J\right) \tag{6}$$

$$\Delta x = \frac{2}{J}\left(R_1 \cdot \sin\varphi_1 + R_2 \cdot \sin\varphi_2 + R_3 \cdot \sin\varphi_3 + \cdots + R_J \cdot \sin\varphi_J\right) \tag{7}$$

$$\Delta y = \frac{2}{J}\left(R_1 \cdot \cos\varphi_1 + R_2 \cdot \cos\varphi_2 + R_3 \cdot \cos\varphi_3 + \cdots + R_J \cdot \cos\varphi_J\right) \tag{8}$$

i = measuring points 1 to J (for above equation J = 24)
R_i = radial measuring value at the curve shape at measuring point i; measured from assumed centre
$\bar{R}$ = average calculated radius
Δx = deviation of measurement, horizontal

Δy = deviation of measurement, vertical

u_i = calculated out-of-roundness of the pressure hull at the measuring point i

φ_i = angle of the measuring point, see [3.2.7]

The calculation procedure shall be documented according to Table 1.

Table 1 Protocol and calculation table for evaluation of the out-of-roundness according to method 1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i	R_i[mm]	φ_i [°]	$\sin\varphi_i$	$\cos\varphi_i$	$R_i \cdot \sin\varphi_i$	$R_i \cdot \cos\varphi_i$	$\Delta x \cdot \sin\varphi_i$	$\Delta y \cdot \cos\varphi_i$	(7) + (8)	(9)+ $\bar{R}$	u_i=(1)-(10)
1		15	0.2588	0.9659							
2		30	0.5000	0.8660							
3		45	0.7071	0.7071							
4		60	0.8660	0.5000							
5		75	0.9659	0.2588							
6		90	1.0000	0.0000							
7		105	0.9659	−0.2588							
8		120	0.8660	−0.5000							
9		135	0.7071	−0.7071							
10		150	0.5000	−0.8660							
11		165	0.2588	−0.9659							
12		180	0.0000	−1.0000							
13		195	−0.2588	−0.9659							
14		210	−0.5000	−0.8660							
15		225	−0.7071	−0.7071							
16		240	−0.8660	−0.5000							
17		255	−0.9659	−0.2588							
18		270	−1.0000	0.0000							
19		285	−0.9659	0.2588							
20		300	−0.8660	0.5000							
21		315	−0.7071	0.7071							
22		330	−0.5000	0.8660							
23		345	−0.2588	0.9659							
24		360	0.0000	1.0000							

4.7 Measuring method 1: Non-uniformly distributed measuring points

In case of non-uniformly distributed measuring points and angular separation of measuring points ≤ 18° the following equations apply:

$$u_i = R_i - \bar{R}' - \Delta x' \cdot \sin\varphi_i - \Delta y' \cdot \cos\varphi_i \quad (9)$$

$$\bar{R}' = \left[\frac{1}{(2 \cdot \pi \cdot D)}\right]\left[R_1 \cdot x_2 + R_2(x_3 - x_1) + R_3(x_4 - x_2) + \cdots + R_J\left(x_1 - x_{J-1} + \pi \cdot D\right)\right] \quad (10)$$

$$\Delta x' = \left[\frac{1}{(\pi \cdot D)}\right]\left[R_1 \cdot \sin\varphi_1 \cdot x_2 + R_2 \cdot \sin\varphi_2\,(x_3 - x_1) + R_3 \cdot \sin\varphi_3\,(x_4 - x_2) + \cdots + R_J \cdot \sin\varphi_J\,\left(x_1 - x_{J-1} + \pi \cdot D\right)\right] \quad (11)$$

$$\Delta y' = \left[\frac{1}{(\pi \cdot D)}\right]\left[R_1 \cdot \cos\varphi_1 \cdot x_2 + R_2 \cdot \cos\varphi_2\,(x_3 - x_1) + R_3 \cdot \cos\varphi_3\,(x_4 - x_2) + \cdots + R_J \cdot \cos\varphi_J\,\left(x_1 - x_{J-1} + \pi \cdot D\right)\right] \quad (12)$$

i = measuring points 1 to J (for above equation J = 24)
J = actual number of measuring points
R_i = see definition in [4.6].
R' = average calculated radius *R quer Strich* =
$\Delta x'$ = deviation of measurement, horizontal
$\Delta y'$ = deviation of measurement, vertical
u_i = see definition in [4.6].
D = diameter of the measuring circuit
x_i = circumferential coordinate at measuring point i (measuring distance from starting point $x_J = x_0 = 0$)
φ_i = angle at measuring point
= $360 \cdot x_i / (\pi \cdot D)$

4.8 Measuring method 2: Indirect measurement of the deviation from the average arc height of the measuring bridge; from outside

The number of planes used for measuring the out-of-roundness of cylindrical pressure vessels shall be agreed with the Society. For each measuring plane, at least J = 24 measuring points shall be provided and evenly distributed round the circumference. The height of arc x (j) is measured with a bridge extending over a string length $L_s = 4 \cdot \pi \cdot R / J$ (see Figure 4). From the values x (j) and the influence coefficients C, the out-of-roundness values can be calculated by applying Equation (13). Table 2 gives the influence coefficients C where J = 24. The values of the local flattening U (j) measured in this way shall not exceed the maximum permissible values defined in [4.5].

R_0 means here the outer radius of the cylindrical shell.

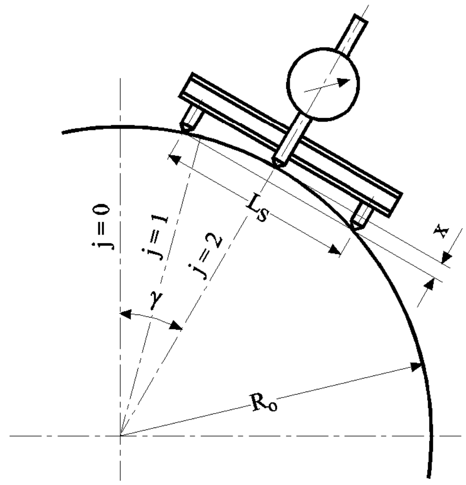

Figure 4 Measuring the out-of-roundness of a cylindrical shell, measuring method 2

$$U_j = \sum_{i=0}^{J-1} x_i \cdot C_{|i-j|} \qquad (13)$$

Example for local flattening U at the point j = 2 for J = 24:

$$U_2 = x_0 \cdot C_2 + x_1 \cdot C_1 + x_2 \cdot C_0 + x_3 \cdot C_1 + \cdots + x_{21} \cdot C_{19} + x_{22} \cdot C_{20} + x_{23} \cdot C_{21} \qquad (14)$$

Table 2 Influence factors C_i for J = 24

$i = j$	$C\|i - j\|$	$i = j$	$C\|i - j\|$
0	1.76100	12	0.60124
1	0.85587	13	0.54051
2	0.12834	14	0.36793
3	−0.38800	15	0.11136
4	−0.68359	16	−0.18614
5	−0.77160	17	−0.47097
6	−0.68487	18	−0.68487
7	−0.47097	19	−0.77160
8	−0.18614	20	−0.68359
9	0.11136	21	−0.38800

i = j	C|i − j|	i = j	C|i − j|
10	0.36793	22	0.12834
11	0.54051	23	0.85587

5 Spherical shells and dished ends

5.1

The following measurements shall be performed for spherical shells and dished ends:

— course of the theoretical geometry lines at the transition ring (tripping ring)
— out of roundness, circumference and inclined position of the cylindrical attachment of dished ends
— out of roundness of the spherical shell (local flattening)
— spherical form of the shell.

5.2

For dished ends with torispherical resp. semielliptical shape the tolerances according to recognized standards, e.g. DIN 28011 resp. DIN 28013 shall be kept. But for the deviations in shape:

— local flattening
— out of roundness of the cylindrical attachment.

the tolerances defined in this App.are valid, compare [4] resp. [4.5].

5.3

A permissible spherical form is a shell which keeps a defined radius with a defined tolerance. For evaluation of the spherical form of the shell the outside radii shall be measured in 6 equally distributed (i.e. displaced by 30°) planes cutting a joint axis (Figure 5). For spherical segments an analogous procedure shall be established.

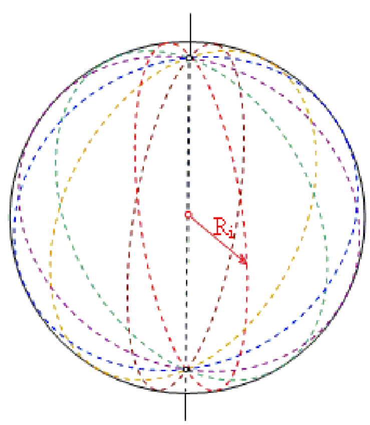

Figure 5 Measurement planes of a spherical shell - measuring method 1

The values for the out-of-roundness measured in this way shall not exceed ± 1% of the nominal outer radius. If smaller local radii as 1.3 times the nominal outer radius are agreed for local flattenings, a less permissible out-of-roundness of the spherical shell is of advantage. The permissible value of the out-of-roundness shall be agreed with the Society.

5.4 Measurement of the local flattening at spherical shells

The measurement shall not be impaired by welding seams (e.g. seam reinforcement) or local imperfections of the surface.

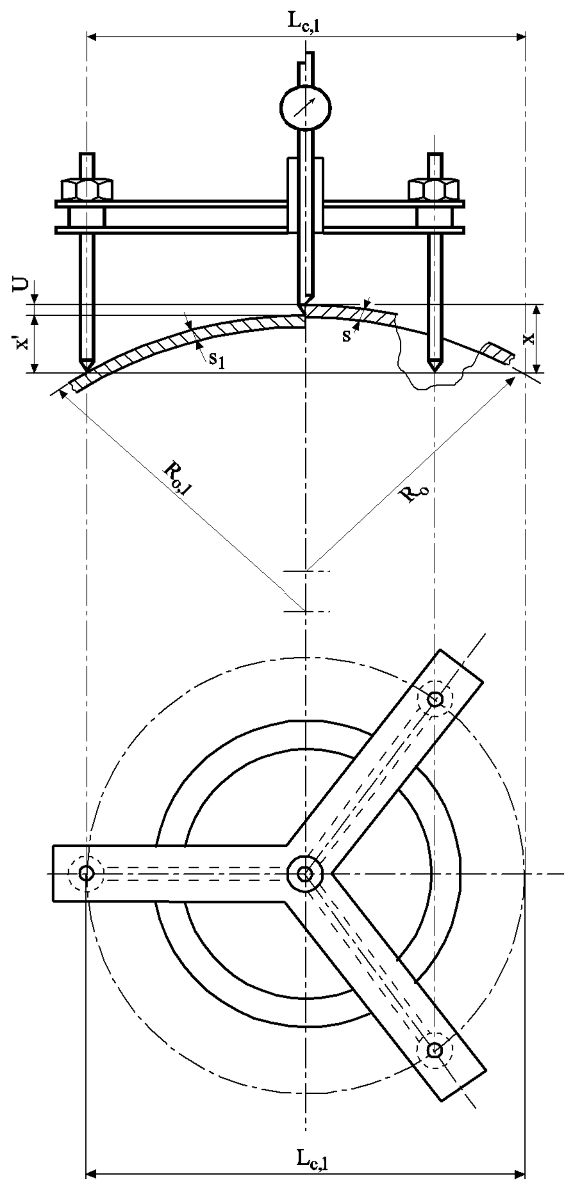

Figure 6 Measuring the out-of-roundness of a sphere (Change drawing: R_0 is outer radius!!!!)

The height of arch x' is measured with a 3 point bridge gauge (see Figure 6), where the measuring diameter $L_{c,1}$ shall be calculated with Equation (15). The out-of-roundness of the spherical shell follows from the local flattening U according to Equation (17). The maximum permissible value of the local flattening, on the basis of a local radius $R_{0,1}$ = 1.3 · R_0 is u = 0.218 · s_1/R_0. Consequently the maximum permissible local flattening U of the spherical shell from the theoretical spherical form is 21.8% of the plate thickness s_l (average value of the measured thickness in the measuring area). If a deviating local radius for the layout of the pressure hull is agreed, a corrected collapsing pressure p_{cr}' and a corrected permissible local flattening shall be evaluated according to [5.5].

$$L_{c,1} = \frac{2.2}{\sqrt[4]{\frac{3}{4} \cdot (1 - v^2)}} \cdot \sqrt{R_{o,1} \cdot s_1} \tag{15}$$

$$x = R_o - \sqrt{R_o^2 - \frac{L_{c,1}^2}{4}} \tag{16}$$

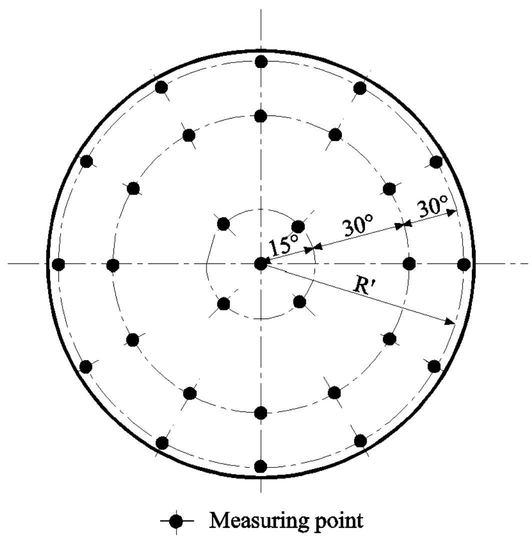

Figure 7 Distribution of the measuring points over a hemisphere

$$U = x - x' = u \cdot R_o \tag{17}$$

$L_{c,1}$ = critical arch length (diameter of measuring circle)
R_o = outer radius of the sphere
$R_{o,1}$ = local outer radius of the sphere
s_1 = local average shell thickness
x = arch height at nominal shell radius R_o

x' = measured arch height
ν = Poisson's ratio in elastic range
= 0.3 for steel
U = local flattening of the spherical shell within diameter $L_{c,1}$
u = local flattening, related to the nominal radius R_o

The distribution of the measuring points is defined in Figure 7. In each measuring point two measurements shall be made: once in a plane through the middle axis and once vertical to it.

5.5 Calculation of the failure pressure for spherical shells with a deviating out-of-roundness ($u \neq 0.218 \cdot s/R_0$)

The corrected maximum permissible out-of-roundness can be evaluated with the aid of Table 3.

The corrected elastic-plastic buckling pressure $p_{cr}^{i}{}'$ shall be evaluated with Equation (18) using the correction factor c_p under consideration of the actually existing local curvature radius $R_{o,1}$ (relation $R_{o,1}$ / R_o). The local curvature radius shall be calculated with Equation (19). The thus evaluated elastic-plastic buckling pressure $p_{cr}^{i}{}'$ shall be multiplied with the reduction factor k according to App.A [6.6.6]. Local radii larger than two times the nominal radius shall be avoided. For radii less than 1.3 times the nominal radius the definitions in App.A [6.6.3] shall be observed.

$$p_{cr}^{i}{}' = \frac{p_{cr}^{i}}{c_p} \tag{18}$$

$$R_{o,1} = \frac{x'}{2} + \frac{L_{c,1}^2}{8 \cdot x'} \tag{19}$$

The corrected failure pressure p_{cr}' which is evaluated in this way shall at least be equal to the collapse diving pressure *CDP* of the pressure hull:

$$p_{cr}' = \frac{p_{cr}^{i}{}'}{c_p} \cdot k \geq \boldsymbol{CPD} \tag{20}$$

Table 3 Maximum permissible local flattening for deviating local radius

Relation	*Maximum local flattening*	*Corrected diameter of the measuring circle **	*Correction factor for the elastic-plastic buckling pressure $p^i_{cr}{}'$*
$\frac{R_{o,1}}{R_o}$	$U = \frac{L_{c,1}^2}{8} \cdot \left(\frac{1}{R_o} - \frac{1}{R_{o,1}}\right)$	$L_{c,1} = \frac{2.2}{\sqrt[4]{\frac{3}{4} \cdot (1-\nu^2)}} \cdot \sqrt{R_o \cdot s_1}$	$c_p = \left(\frac{R_{o,1}}{1.3 \cdot R_o}\right)^{1.07}$
1.3	$0.218 \cdot s_1$	$2.759 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.000
1.4	$0.290 \cdot s_1$	$2.863 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.083
1.5	$0.363 \cdot s_1$	$2.964 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.165
1.6	$0.435 \cdot s_1$	$3.061 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.249
1.7	$0.508 \cdot s_1$	$3.155 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.332
1.8	$0.580 \cdot s_1$	$3.247 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.417
1.9	$0.653 \cdot s_1$	$3.336 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.501
2.0	$0.725 \cdot s_1$	$3.422 \cdot \sqrt{R_{o,1} \cdot s_1}$	1.586

* $L_{c,1} = \frac{2.2}{\sqrt[4]{\frac{3}{4} \cdot (1-\nu^2)}} \cdot \sqrt{\frac{R_{o,1}}{R_o}} \cdot \sqrt{R_o \cdot s_1}$

Table 3 is valid for a wall thickness ratio $\frac{s}{R_o} \geq 0.02$ and for materials with yield strength $\sigma_{0.2} \leq 550$ MPa.

6 Literature

Concerning literature reference is made to App.A [7].

APPENDIX C MANUFACTURE AND TREATMENT OF FIBRE REINFORCED PLASTICS (FRP) AND SYNTACTIC FOAMS

Fibre reinforced plastics are treated in [1] to [3], the requirements for syntactic foam are defined in [4].

1 General

1.1 Definition

Fibre reinforced plastics are heterogeneous materials, consisting of a thermosetting resin as the matrix and an embedded fibrous reinforcing material.

1.2 Scope of application

For submarines fibre reinforced plastics are mainly used for the following components:

— exostructure
— rudder and propeller
— pressure vessels.

2 Requirements for the materials and their processing

2.1 Materials

2.1.1 Approval

2.1.1.1 The materials used for the manufacturing of components from FRP shall be assessed and approved by the Society.

2.1.1.2 The approval refers only to the approved material. The applicability of this material in connection with other materials shall be demonstrated independently by the manufacturer or the user in a suitable manner.

2.1.2 Quality assurance

2.1.2.1 A constant material quality shall be secured by the manufacturer through constant quality assurance measures.

2.1.2.2 The Society reserves the right to demand resp. carry out spot tests of the material properties during the duration of the material approval.

2.1.3 Types of materials

For the construction of submarines in general the following materials shall be considered:

— laminated resins, e.g. cold-setting or hot-setting unsaturated polyester (UP) resins and cold setting epoxy (EP) resins
— reinforcing materials, e.g. fibre reinforcements made of glass and carbon
— prepregs as reinforcing materials, which are preimpregnated with a thermosetting resin and which can be processed without any further addition of resin or hardener
— core materials, e.g. rigid foams with adequate compressive strength
— adhesives, e.g. cold- and hot-setting thermosetting adhesives and hot-melt adhesives
— flame retardant laminates produced by additives to the resin system, whereby the viscosity of the resin or the mechanical properties of the manufactured laminates not be changed essentially.

Other materials may be approved in agreement with the Society.

2.2 Manufacturing

2.2.1 Approval

2.2.1.1 Manufacture of FRP-components shall only be performed by workshops which are approved by the Society for the manufacture of components made from fibre-reinforced thermosetting resins.

2.2.1.2 The manufacture of FRP-components shall only be carried out by persons with professional knowledge. This professional knowledge shall in general be verified by certificates of the corresponding training courses.

2.2.1.3 All manufacturing facilities, store-rooms and their operational equipment shall fulfil the requirements of the responsible authorities. The manufacturer is alone responsible for compliance with these requirements.

2.2.2 Store rooms and laminating workshops

The danger of contamination of laminating materials shall be minimized through separation of production facilities from store rooms.

2.2.3 Guidelines for processing

2.2.3.1 As a matter of principle, only materials approved by the Society shall be used. In addition to the choice of suitable and approved materials, special care shall be taken when working with them because of the great influence on the properties of the product.

2.2.3.2 For the preparation and processing of the resin compounds and reinforcing material, beside the DNV GL rules, the instructions issued by the material manufacturers and the regulations of the competent authorities shall be observed.

2.2.4 Manufacturing surveillance

For components made of FRP, manufacturing surveillance has to consist of the quality control of the basic materials, production surveillance and the quality inspection of the finished components.

2.2.5 Repair of components

2.2.5.1 Repairs of structural FRP-components shall only be performed by workshops which are approved by the Society.

2.2.5.2 For the approval of a repair, all design and repair drawings needed to assess the repair of the relevant components shall be submitted to the Society. The repair plan shall be examined and approved by the Society.

2.2.5.3 A report shall be established for each repair which has to be signed by the head of the repair team.

2.2.5.4 If the materials and laminates used for the repair are not identical to those employed when the component was manufactured, equivalence of the combination of materials shall be verified with respect to their properties.

2.3 Detailed requirements

The detailed requirements for the areas pointed out are defined in the SHIP Pt.2 Ch.3 Sec.2 – *Composite Materials* and UWT Pt.2 Ch.5 Sec.5.

3 Requirements for the design

3.1 Design data

The mechanical properties and the nominal thickness of the laminate as well as weight, type and portion of the reinforcement layers, which can be individually used, shall be defined on the design drawings.

3.2 Design measures

For the design of components the following measures shall be considered:

3.2.1 Changes in the laminate thickness shall be established with a smooth transition of 25 mm per 600 g/m². In the transition area from a sandwich design to massive laminate the core material shall be gradually tapered (at least 3 : 1).

3.2.2 In general frame and stiffening sections shall be built up by layer and layer on the laminate, as far as the last layer is not yet cured. Where internal structural members are crossing each other, special care shall be taken that the load-bearing capacity remains unchanged.

3.2.3 Closed hollow spaces in the structure which may be subjected to external pressure shall be avoided.

3.2.4 If core materials are used in areas which may be subjected to external pressure, pressure-proof materials like e.g. rigid foams shall be used.

3.2.5 Stress concentrations, peaks in stiffness and discontinuities shall be avoided. It has to be ensured, that because of cut-outs, openings in load carrying elements and the connection of fittings the strength of the component is not impaired.

3.2.6 If various components which have been produced in different moulds shall be connected with each other, then the connecting laminates have to be finished before curing of the components. If components of FRP are bolted which each other or with components of other materials, the connecting elements (bolts, nuts, washers) shall be of seawater resistant material. Bolted connections shall be dimensioned according to the occurring forces.

3.2.7 In areas with local force introduction (e.g. connecting elements of the exostructure, bitts, cleats) sole pieces and/or shims of adequate strength shall be situated. The strength, e.g. bearing strength shall be proven in a suitable way. The connecting area of these sole pieces shall be prepared in a suitable way and shall be free of contamination.

3.2.8 Metallic materials used in the design, like e.g. steel or aluminium alloys have to be suitable for the intended purpose and shall not impair the curing of the laminating resins.

Local reinforcements of metallic materials shall be cleaned and degreased carefully and, if possible, shall be shot blasted or roughened up to achieve a toothing effect.

3.2.9 For sandwich laminates in way of bolted connections and fittings, inserts of a material, which can withstand the compression and the design loads, shall be provided. The inserts shall be connected with the core material and the laminate layers in the best way.

3.2.10 Laminate edges and holes shall be sealed.

3.2.11 Further design measures which are recommendable for different shipbuilding components made of plastics are contained in SHIP Pt.3.

3.3 Definition

Syntactic hard foams are manufactured using a thermosetting plastic matrix, in which glass microspheres are dispersed. The wall thickness of the glass microspheres (microscopic glass particles completely enclosing a void) in conjunction with the formation of the matrix results in a hydrostatically resistant, low density material.

3.4 Scope of application

For submarines syntactic foams are mainly used for:

— buoyancy elements in the exostructure if the specific weight is considerably lower than 1 kg/dm³
— to be used as heeling correction only in exceptional cases!
— to be used for trim correction only up to +/- 2° inclination
— noise absorbing material.

3.5 Requirements for the material and its testing

3.5.1 Approval

The materials used shall be assessed and approved by the Society.

3.5.2 Tests

The following characteristics have to evaluated:

— density (e.g. according to EN ISO 845)
— uniaxial compressive strength (e.g. according to ASTM D695-02a)
— buoyancy variation
— seawater intake (e.g. according to ASTM D2735)
— hydrostatic crush pressure.

The tests have to be made with different specimen of different fabrication batches to be applied for the actual submarine project.

3.5.3 Longterm check

A cube of 1 dm³ volume shall be installed with the other foam elements of the submarine in the exostructure and its condition has to be proven at least at the occasion of class renewal survey.

3.6 Aspects for submarine design

The application for submarines has to consider the following aspects:

— the foam elements shall be accessible for inspection
— safe fixing to pressure hull and exostructure
— dismountable if fixing directly on pressure hull
— coating recommendable to avoid any seawater intake
— for greater foam elements a supporting construction shall be provided to discharge the fixing points from the buoyancy forces
— the crush pressure shall be suitable for the collapse diving pressure *CDP*.