Buoyancy and Floating Structure Calculation for Paraxylene Storage Tanks (TK-2090 A/B)	
Document No.: A238-PV-00-CSH-218	Rev.: 01

APPROVED WITH MINOR COMMENTS
Comments made and reviews performed on vendor prints shall not relieve vendor from its responsibilities under purchase order
HEDCO By: Sohrabi.Navid MD Department 1:33 pm, May 22, 2022 www.hedcoint.com

See comments on page#16

Hint:
Considering general comments on REV-0 of this document, it seems that contractor has carried out its own cutting plan and reached selected dimension and QTY. for bulk heads, pontoon lower/upper plates and outer rim plate.
It shall be clarified that contractor will be held responsible for any possible wast of purchased sheet plates. for instance, by the selected dimension for bulk head in this document, only on bulk head can be cut from a 6[m] x 1.5[m] sheet plate while 49% of sheet plate remains intact. Please see attached DWG.

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Rev.	Status	Prepared	Checked	Approved	Date

Tabulation of Revised Pages

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1	X	X									
2	X	X									
3	X	X									
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5	X										
6	X										
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12	X	X									
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1- Introduction

All requirements and committal of API 650 code for design of internal floating roof Tank No.TK-2090 A/B are presented at this calculation notebook, that shall be applied for material selection, shop drawing and construction methods of tanks. All used units at this manual are in metric system.

2- Project summary and abbreviation

Project	Storage Terminal Development Plan
Owner	Farasakou Assaluyeh
Purchaser	HEDCO
Vendor	N.A.
Site	Assaluyeh, Iran
H.H.L. L	High High Liquid Level
H.L. L	High Liquid Level
L.L. L	Low Liquid Level
L.L.L.L	Low Low Liquid Leve
D.L.L	Design Liquid Level
E	Elastic Module = 200 (GPa)
ρ	Specific Gravity of Steel =8.60 (gr/Cm3)
g	Ground Acceleration = 9.81 (m/s^2)

3 References

Mechanical Datasheet for TK-2090 A/B - Tankage area	-
Process Datasheet for Paraxylene Storage and Pumping	2134F-PR-20-PFD-111
Welded Steel Tanks for Oil Storage	API 650 (2018) - (12 th Ed.)
American Institute of Steel Construction	AISC STANDARD
Job Specification for Storage Tanks Field Erected	-

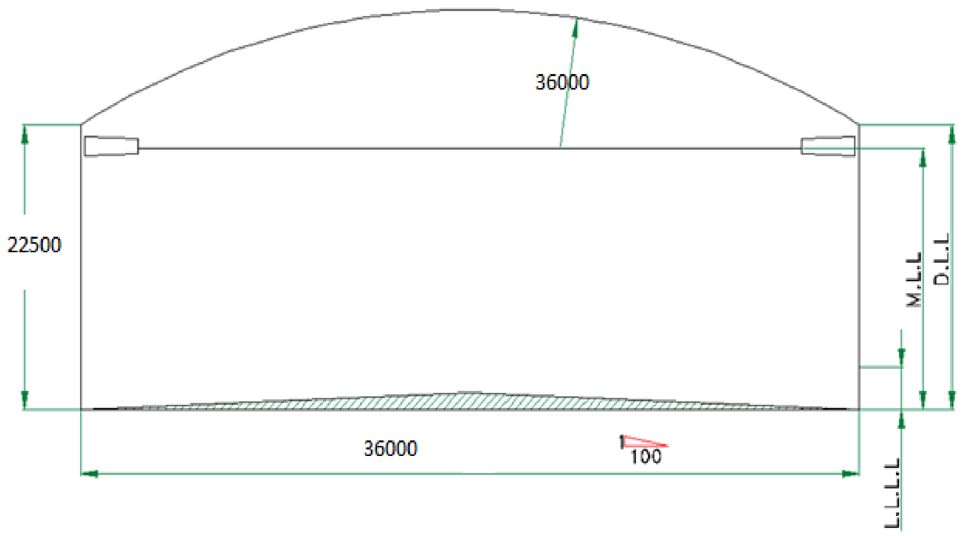
4- Tank Design Data

Tank No.		TK-2090 A/B	
Number Required		2	
Geometric Capacity		22,891	(m^3)
Nominal Capacity		22,204	(m^3)
Net Work Capacity		20,000	(m^3)
Tank Inside Diameter (ID)		36	(m)
Tank Height		22.5	(m)
Design Liquid Level	(D.L.L)	20.9	(m)
Max.Liquid Level	(M.L.L.)	20.9	(m)
Low Liquid Level	(L.L.L.)	0.91	(m)
Min. Liquid Level	(L.L.L.L)	0.61	(m)
Contents	Name	Paraxylene	
	Flash Point	27	(°c)
	Max.Oper. Temp.	52	(°c)
	Specific Gravity	0.860	
	I.B.P	HOLD	(°c)
Gravity of hydrostatic test water .		1.0	
Design Code		API 650, 12TH EDITION, 2018	
Operating Pressure		0.5	kpa
Design Metal Temperature		5	(°c)
Design Pressure (Pi)		1.5	kpa
Vaccum Pressure (Pe)		0.5	kpa
Design Temprature (Dt)		85	(°c)
Pumping Rate	IN	147	(m^3/hr)
	OUT	1200	(m^3/hr)
Corrosion Allowance			
	FLOATING ROOF EXPOSING TO PRODUCT	1.5	(mm)
	FLOATING ROOF EXPOSED TO VAPOR	0	mm (For vapor part)

MATERIAL :

A283-C σ_y =	205	S_d =	137	S_t =	154	

5- Tank Capacities



D=	36 m	BOTTOM SLOP=	1/100
H=	22.5 m	Hb=	0.18 (m)
D.L.L.=	20.9 m	N.F.L =	20.9 (m)
M.L.L.=	20.9 m		
L.L.L.=	0.91 m		
L.L.L.L.=	0.61 m		

GEOMETRIC CAPACITY (V_G) :

$V_G = \pi/4 * D^2 * H$ = 22902 (m^3)

NOMINAL CAPACITY (V_N) :

$V_N=\pi/4*D^2*(D.L.L)$ = 21274 (m^3)

DEAD CAPACITY (V_d) :

$V_{dC}=\pi/4*D^2*(L.L.L.L)$ = 621 (m^3)

NET WORK CAPACITY (V_N) :

$V_N = \pi/4 * D^2 * (N.F.L - L.L.L)$ = 20347 (m^3)

MAX. STORAGE CAPACITY (V_M) :

$V_M = \pi/4*D^2*(M.L.L.)-\pi/12D^2*H_b$ = 21213 (m^3)

* Shall be specifyed by operator .

6- buoyancy calcualtion

t min = 4.8 As per API 650

t_1 = C.A(product) + t_{min} = 6.3 mm

$t_{1\ actual}$ = 7 mm For deck and outer rim and bottom pantoon

t_2 = C.A(vapor) + t_{min} = 4.8 mm

$t_{2\ actual}$ = 5 mm For upper pantoon

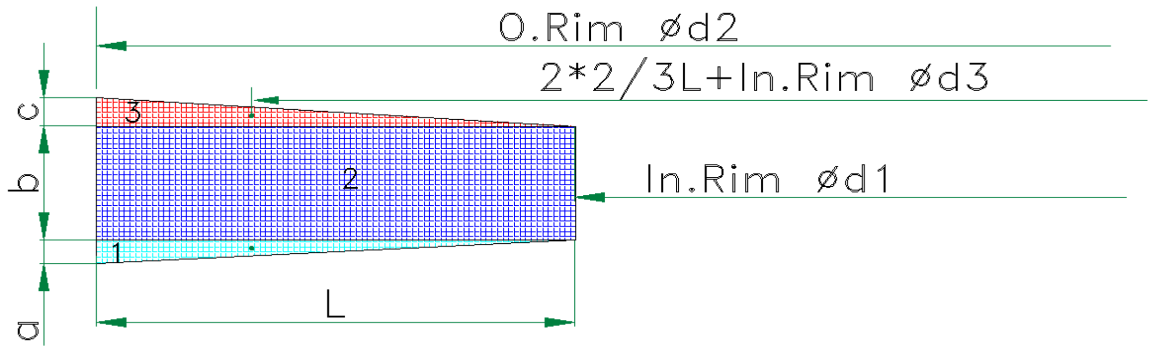
t_{inner} = 20 mm

WEIGHT CALCULATION (Kg)			
		Un-Corrodded	Corrodded
Deck Plate	=	24,830	19,509
Deck Legs	~=	5,000	4,250
Deck Miscellaneous	~=	5,000	4,250
Total deck	=	**34,830**	**28,009**
Top pontoon	=	23,847	23,847
Bottom pontoon	=	33,386	26,232
Inner rim	=	7,789	7,205
outer rim	=	5,675	4,459
compart	~=	3,000	3,000
Pontoon legs	=	2,500	2,125
Trusses	=	3,500	3,500
Pontoon Miscellaneous	~=	10,000	8,500
Friction Force of Sealing System	=	1,131	1,131
Total pontoon	=	**89,697**	**78,868**
		124,527	106,877

$\rho_{product}$ = 700 Kg/m^3

ρ_{steel} = 7850 Kg/m^3

ρ_{water} = 1000 Kg/m^3



GAP RIM	=	0.2	m	
ID	=	36	m	
L	=	5.96	m	
a	=	0	m	
b	=	0.65	m	
c	=	0.25	m	
d_1	=	23.68	m	~= Center Deck O.D.
d_2	=	35.6	m	
d_3	=	31.6	m	

V_3	=	74.02	m^3
V_2	=	360.735	m^3
V_1	=	0.0	m^3

Total pontoon volume	434.8	m^3

⚠1

6-1- Floating in water

Deck floating depth = $= \dfrac{\text{Total deck weight}}{\rho\text{ (water) x A\_deck}}$

Deck floating depth = 79.1 mm

$V_{displacement}$ (pontoon) = $\dfrac{\text{Total Pontoon Weight}}{\rho\text{ (water)}}$ = 89.7 m^3

$H_{displacement}$ (pontoon) = $\dfrac{\text{Vdisplacement-Vbackslope}}{\text{Pontoon cross area in volume 2}}$ = 161.6 mm

H_{DECK}-$H_{PONTOON}$ = 82.5 mm

Total volume displaced by roof = $\dfrac{\text{Roof total weight}}{\rho\text{ (water)}}$ = 124.5 m^3

6-2- Floating in product

$$\text{Deck floating depth} = \frac{\text{Total deck weight}}{\rho\ (\text{product}) \times \text{A\_deck}} * t_1$$

Deck floating depth = **113.0** mm

$$V_{displacement}\ (\text{pontoon}) = \frac{\text{Pontoon weight}}{\rho\ (\text{product})} = 128.1\ m^3$$

$$H_{displacement}\ (\text{pontoon}) = \frac{\text{Vdisplacement-Vbackslope}}{\text{Pontoon cross area in volume 2}} = 230.9\ \text{mm}$$

H_{DECK}-$H_{PONTOON}$ = 117.9 mm ⚠1

$$\text{Total volume displaced by roof} = \frac{\text{Roof total weight}}{\rho\ (\text{product})} = 177.90\ m^3$$

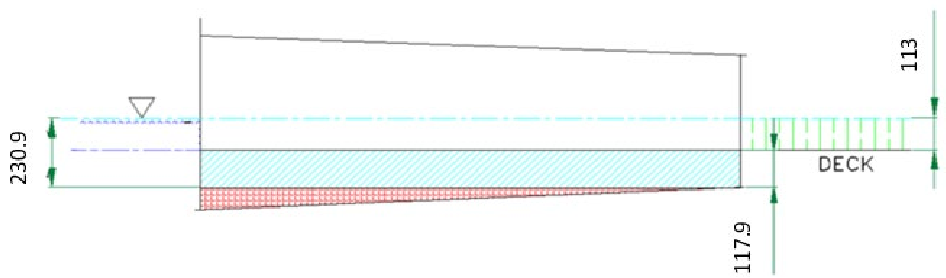
Free board available above deck level and top outer corner of pontoon = 782 mm

Total volume displaced by roof =

Volume1 + partial volume displaced in pontoon under deck + Volume displaced by deck & pontoon

===> 177.9 = 0.00 + 65.4 + 995.38 * H

===> H = 0.1130 m ===> **H = 112.98 mm**



6-3- Consider the effect of two punctured pontoons and Centre Deck on the stability of the Floating Roof △1

Volume available with two out of 12 compartments punctured = 362.3 m3

Min. volume required to meet design requirements = 177.9 m3

As 362.30 > 177.90 Available volume is sufficient

Product liquid level above the deck is found as follows:

177.90 = 0.00 + 554.98 H'

=> H' = 0.32 m

Free board of Pontoon above the product level for the punctured condition is : 0.58

Level of product above the deck = 320.55 mm

6-4- Checking of Buoyancy as per API-650 cl. H.4.2.1.2 △1

Pontoon Total Volume : V1 + V2 + V3 = 434.76 m^3

Roof Total Weight : 124,527 kg

$$S.F. = \frac{\rho\ (\text{product}) \times (V1 + V2 + V3)}{2 \times \text{Roof total weight}} = 1.2219 > 1 \quad \text{OK}$$

7- Checking the stresses and deflection in the center deck

△1

- Data

t	Thickness of plate (deck plate)	=	7	mm
E	Modulus of Elasricity	=	200,000	Mpa
α	Outer radius of deck plate, mm	=	11,840	mm
q	Unit lateral pressure on deck (equiv.weight of deck that float on product) $t * (\rho_{plate} - \rho_{product})$	=	0.00049	Mpa
v	poisson ratio	=	0.3	
y	Maximum deflection, mm			
σ	Maximum stress due to flexure and diaphragm tension combined			
σ_b	Bending stress			
σ_d	Diaphragm stress			

K constants are determined in the Roark's Formula for Stress and Strain for different cases and edge condition

$K_1 = \frac{5.33}{1-v^2}$ = 5.86

$K_2 = \frac{2.6}{1-v^2}$ = 2.86

At center :

$K_3 = \frac{2}{1-v}$ = 2.86

K4 = 0.98

At edge :

$K_3 = \frac{4}{1-v^2}$ = 4.4

K4 = 1.73

In the large deflection of the thin plate, the plate is stiffer than indicated by the ordinary theory and the load-deflection and load-stress relation become non-linear. For circular plates, where the maximum deflection exceeded half the thickness, the below formula shall be used for more accurate and precise result [Roark, 2002].

$$\frac{q\alpha^4}{Et^4} = K_1 \frac{y}{t} + K_2 \left(\frac{y}{t}\right)^3 \qquad \frac{\sigma\alpha^2}{Et^2} = K_3 \frac{y}{t} + K_4 \left(\frac{y}{t}\right)^2$$

$\frac{q\alpha^4}{Et^4} =$ 20,094 = $5.86\frac{y}{7} + 2.86(\frac{y}{7})^3$ = 20,094 ==> **y = 133.82** mm

At center :

$K_3\frac{y}{t} + K_4(\frac{y}{t})^2$ = 413 = $\frac{\sigma\alpha^2}{Et^2}$	===>	σ_{total}	=	28.86	Mpa
$K3\frac{y}{t}$ = 54.6		$\sigma_{bending}$	=	3.82	Mpa
$K4(\frac{y}{t})^2$ = 358.2		$\sigma_{diaphgram}$	=	25.04	Mpa

At edge :

$K_3\frac{y}{t} + K_4(\frac{y}{t})^2$ = 716 = $\frac{\sigma\alpha^2}{Et^2}$	===>	σ_{total}	=	50.07	Mpa
$K3\frac{y}{t}$ = 84.0		$\sigma_{bending}$	=	5.87	Mpa
$K4(\frac{y}{t})^2$ = 632.3		$\sigma_{diaphgram}$	=	44.20	Mpa

The abobe calculation will be repeated for corrodded condition as following:

t	Thickness of plate (deck plate)	=	5.5	mm
q	Unit lateral pressure on deck (equiv.weight of deck that float on product) $t * (\rho_{plate} - \rho_{product})$	=	0.00039	Mpa

$\frac{q\alpha^4}{Et^4} =$ 41,425 = $5.86\frac{y}{7} + 2.86(\frac{y}{7})^3$ = 41,425 ==> **y = 170.437**

At center :

$$K_3 \frac{y}{t} + K_4 \left(\frac{y}{t}\right)^2 = 1030 = \frac{\sigma a^2}{E t^2} \implies$$

$$K_3 \frac{y}{t} = 88.5$$

$$K_4 \left(\frac{y}{t}\right)^2 = 941.1$$

σ_{total}	=	44.44	Mpa
$\sigma_{bending}$	=	3.82	Mpa
$\sigma_{diaphgram}$	=	40.61	Mpa

At edge :

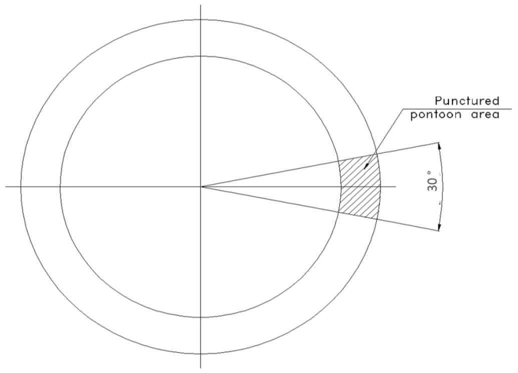
$$K_3 \frac{y}{t} + K_4 \left(\frac{y}{t}\right)^2 = 1798 = \frac{\sigma a^2}{E t^2} \implies$$

$$K_3 \frac{y}{t} = 136.2$$

$$K_4 \left(\frac{y}{t}\right)^2 = 1661.3$$

σ_{total}	=	77.58	Mpa
$\sigma_{bending}$	=	5.88	Mpa
$\sigma_{diaphgram}$	=	71.70	Mpa

7-2- Consider the effect of two punctured pontoons and Centre Deck on the stability of the Floating Roof △1



Area of pontoon : $\frac{\pi}{4}(OD^2 - ID^2)$ = 555.0 m^3

Punctured pontoon area: 60.0 = 1.047 rad

Remaining Pontoon area= Area of pontoon * $\frac{\text{360-Punctured pontoon area}}{360}$ = 462.5 m^3

$$Z = \frac{2\sin\phi/2\left(R^3 - r^3\right)}{3\times A_{rem}} = \quad 2.868559 \quad m$$

Moment of Inertia of remaining pontoon area :

$$I_{yy} = \frac{\left(R^4 - r^4\right)}{8}\left[2\pi - \left(\phi/180\times\pi\right) - \sin\phi\right] \quad = \quad 10092$$

Iyy = 61581.2 m^4

Ixx = (Iyy + Arem*Z^2) = 65386.8 m^4

listening moment = Weight of roof "W"* Z = 357212.4 Kg.m

Compare to actual eccentric loads :

Deck :	68,730	Kg.m	Total =	290,282	Kg.m
Pontoons :	221552	Kg.m			

As	290,282	<	357,212	Roof is Ok

Additional submersion on punctured side:

$$d' = \frac{ML\left(R+Z\right)}{Ixx\times s.g.} = \quad 0.161 \quad m$$

$$d'' = \frac{ML\left(R-Z\right)}{Ixx\times s.g.} = \quad 0.117 \quad m$$

Nominal floatation depth is 320.5 mm, above deck

Max. Submersion 0.482 m < 0.782 m the roof still floats

Min. Submersion = 0.204 m

Angle of Roof = 0.519 deg

8- Deck support design

- Data

Pipe 3" sch xs is adopted as Leg

	Material :		A53-B	
Fy	Yeild stress of material	=	240	Mpa
d :	Outside diameter	=	88.9	mm
Id :	inide diameter	=	73.66	mm
t :	Wall thickness	=	7.62	mm
L :	Max length of deck support	=	3,000	mm
C.A :	Corrosion allowance	=	1.5	mm
$I_{corroded}$:	Second moment of inertia	=	1,419,185	mm^4
$A_{corroded}$	Section Area	=	1562.7	Mm2
r :	Radius of gyration	=	30.1	mm
E :	Modulus of Elasricity	=	200,000	Mpa
Rde	R deck	=	11,840	mm
Rout	R outer rim	=	17,800	mm
P :	Design live load (As per api 650) = 1.2 Kpa	=	1,200	N/m^2
W_{deck} :	Deck Weight	=	341,678	N
$W_{poonton}$	Poonton and attachment Weight	=	896,972	N
A :	Tota area of deck	=	440	m^2
	Unit unifrom load per deck		**4,013**	N/m^2

Leg Series	QTY	Radius (m)	Ri (m)	Ro (m)	Deck area supported by legs (m^2)	Area per leg (m^2)	P load per leg (N)	Fc (Mpa)	Fa (Mpa)
1st	3	2.0	0.00	3.5	38.485	12.83	51,473	32.9	89
2nd	6	5.0	3.50	6.5	94.248	15.71	63,028	40	89
3rd	9	8.0	6.50	9.5	150.796	16.76	67,230	43	89
4th	12	11.0	9.50	12.5	207.345	17.28	69,331	44	89
5th	15	14.0	12.50	15.50	263.894	17.59	70,592	45	80
6th	15	17.0	15.50	17.0	153.153	10.21	40,969	26	80
7th	6	17.5	17.00	17.5	54.192	9.03	36,241	23	80

Please clarify why 6 additional leg supports are considered with 0.5[m] radial distance from the 6th sets of leg supports?

Please recheck

L_{deck} :	Maximum length of deck support in deck	=	2,000	mm
$L_{poonton}$:	Maximum length of deck support in pontoons	=	3,000	mm

As per AISC standard :

On the gross section of axially loaded compression members whose cross sec-tions meet the provisions of Table 5.1, when Kl/r, the largest effective slender-ness ratio of any unbraced segment is less than Cc, the allowable stress is:

As per AISC standard Table C-C2.1 K=1

$$F_a = \frac{\left[1 - \frac{(Kl/r)^2}{2C_c^2}\right] F_y}{\frac{5}{3} + \frac{3(Kl/r)}{8C_c} - \frac{(Kl/r)^3}{8C_c^3}}$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}}$$ ===> Cc = 128.25

In deck :	KL/r =	66.37	<	128.25	===>
In poonton :	KL/r =	99.55	<	128.25	

For Fa deck support :

$2*C^2c =$ 32899 $(L/r)^2 =$ 4405 $1-\frac{(L/r)^2}{2.C^2c} =$ 0.866

$\frac{5}{3}+\frac{3(L/r)}{8.Cc} =$ 1.861 $\frac{(L/r)^3}{8.C^3c} =$ 0.0173 $1.6-\frac{L}{200.r} =$ 1.2682

Therefore : **Fa $_{Deck}$ = 88.9 Mpa** △1

For Fa poonton support :

$2*C^2c =$ 32899 $(L/r)^2 =$ 9910 $1-\frac{(L/r)^2}{2.C^2c} =$ 0.699

$\frac{5}{3}+\frac{3(L/r)}{8.Cc} =$ 1.958 $\frac{(L/r)^3}{8.C^3c} =$ 0.0585 $1.6-\frac{L}{200.r} =$ 1.1022

Therefore : **Fa$_{Poonton}$ = 80.1 Mpa** △1

For deck :

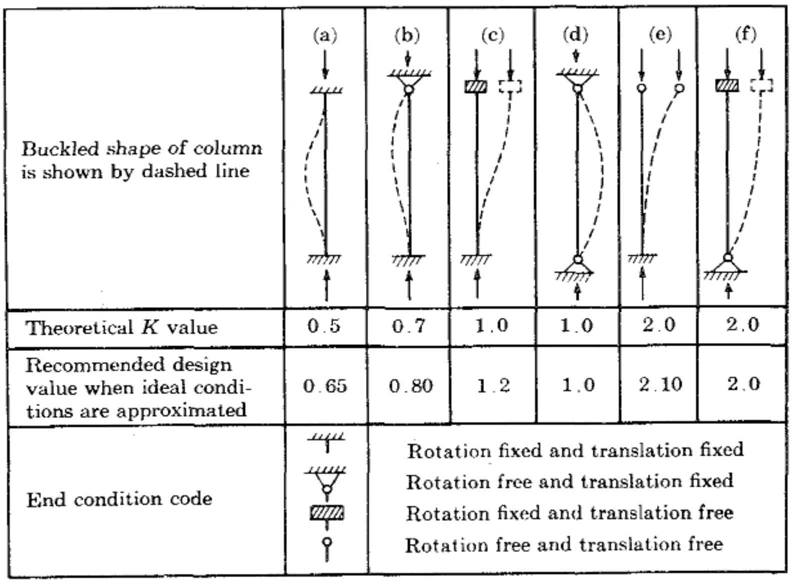
Deck support : PIPE 3" SCH.80 & SLEEVE : PIPE 4" SCH.STD

For pontoon :

Pontoon support : PIPE 3" SCH.80 & SLEEVE : PIPE 4" SCH.80

K = 1

Table C-C2.1



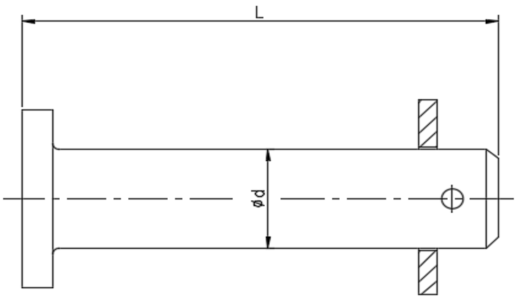
	(a)	(b)	(c)	(d)	(e)	(f)
Buckled shape of column is shown by dashed line						
Theoretical *K* value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0

End condition code	
	Rotation fixed and translation fixed
	Rotation free and translation fixed
	Rotation fixed and translation free
	Rotation free and translation free

9-1- Sections for pontoon trusses

SEE DWG.

9-2- Pin Design ⚠1



Max P load per leg (N) = 70591.9 N

Pin Material = A-36 or Eq.

Fy = Pin Yield Strength = 250 Mpa

τ = Pin Shear Allowable Stress = 0.5 x (2 / 3) x Fy = 83.33 Mpa

d = Pin dia. = ((P / 2 τ) x 4 / π) ^ 0.5 = 23.2225 mm

Therefore, selected Pin dia. Is equal to 35 mm

9-1- Sleeve Design

Sleeve : PIPE 4" SCH.80, Wall Thk. = 8.56 mm O.D. = 114.3 mm

Support : PIPE 3" SCH.80, Wall Thk. = 5.49 mm O.D. = 88.9 mm

Material : A 53-Gr.B Yield Strength = 225 Mpa

Allowable Stress = 202.5 Mpa

Length = 1000 mm (min)

σb-1=bearing stress for leg support=P/2/(pin bore diam.X leg support thk.) = 183.69 Mpa Acceptable

σb-s=bearing stress for leg support=P/2/(pin bore diam.X leg sleeve thk.) = 117.81 Mpa Acceptable

σb-1=bearing stress for leg support=P/2/(pin bore diam.X leg support thk.) =