USE OF VANADIUM HIGH-STRENGTH LOW-ALLOY STEELS IN TRAILERS

-

A case study

Jan Eckerlid[1], Mikael Åsell[1], Anders Ohlsson[1]

SUMMARY.

The trailer case study presented in this report shows that the implementation of High-Strength Low-Alloy Steel with Vanadium (HSLA-V Steel) offers advantages in terms of improved pay load and reduced manufacturing cost

By introducing HSLA-V Steel in the trailer chassis, the amount of steel can be reduced from 3200 kg to 2520 kg. This is corresponding to an overall weight reduction of 21%

The extra effort that may be needed to redesign critical areas is shown to be a good investment. The material cost for the steel sheets has actually potential to be reduced, if the weight reduction is more that the price increase of HSLA-V Steel, compared to Mild steel.

Welding cost has also potential to be reduced. The calculation example presented shows a potential reduction from 1770 Euro to 884 Euro. Assuming an annual transportation distance of 100.000 km, another example shows that 680 kg less weight results in reduction of diesel with 312 litres.

[1] THE STEEL COMPANY Tunnplåt AB, 781 84 Borlänge, Sweden

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INTRODUCTION

The use of high strength steels has grown over the years. The driving force is both technical and economical, where overall economy of the final product is of main significance. High strength steels create advantages such as reduced weight, reduced material cost and easier material handling. For applications that are transported during its lifecycle (e.g. vehicles), reduced weight means reduction of fuel consumption and / or increased payload. These secondary benefits may have a large impact on overall economy and life cycle cost (LCC).

The purpose of this study is to explore the possibility to use vanadium microalloyed extra high strength steels in trailers.

Aspects that are considered in the study are,

- Environmental
- Economical
- Manufacturing
- Technical

To get a better understanding of the product there are also a chapter that describes some of the different type of trailers that exist. What materials do they use, how are they designed and what are critical design aspects. To broaden the view, a number of other applications that use high strength steels are also described.

DESIGN OF TRAILERS TODAY

Trailer chassis can be divided in to two main designs, trailers with kingpin or pull rod. Those are the two most common designs of trailers and they will be described below. There are also other designs as interlinks. The trailer designs changes between different geographic markets.

Today’s trailers are mainly made of standard material, with yield strength of 235- 355 MPa. A few producers have upgraded their trailers to high strength material to save weight. Weight is the most important factor for end users since they turn weight reduction into extra payload. Producers, who have converted their trailers into high strength steel and lower weight, have invested a lot of FEA studies and redesigns in their trailers. It is possible to save a lot of weight by upgrading a existing trailer to high strength steel but a even larger saving can be done on a total redesign of the trailer.

KINGPIN DESIGN

A trailer with kingpin is designed with 2 main longitudinal beams normally with I-beam shape, (flanges welded to the web). The depth of the web is also changing to give space for the kingpin. Cross members are normally roll formed C- or I-beams. A kingpin design is showed in figure 1.

Figure 1, Kingpin design

PULLROD DESIGN

A trailer with pullrod is designed with 2 main longitudinal beams, normally with I-beam shape, (flanges welded to the web). The depth of the web is normally the constant along the length but can change depending of trailer application. Cross members are normally formed C- or I-beams. A pullrod design is showed in figure 2 .

Figure 2, Pullrod design

INTERLINK

Interlink is a combination of two kingpin trailers. The chassis design is the same as a kingpin design. Interlinks are more flexible on small roads or in cities compared to kingpin designs. An Interlink design is showed in figure 3.

Figure 3, Interlink design

BODY BUILDERS

This is another potential area for use of high strength material. Today normal mild steel with yield strength of 235-355 MPa is the most common material. The weight of the body is in most cases same or higher then the chassis it self. This makes it possible to save weight and/or costs by using high strength steel.

An example of body building is car transport trailer. A large body with a large potential of weight saving. A car transport trailer is showed in figure 4.

Figure 4, Car transport

MATERIAL PROPERTIES

BASIC PROPERTIES

High strength steels are not an unambiguous term. At THE STEEL COMPANY, the steels are divided in three groups depending on strength level. For hot rolled steels, the following division is normally used,

Mild steels: Yield stress up to 310 MPa

High strength steels: Yield stress from 310 MPa to 450 MPa

Extra high strength steels: Yield stress from 450 MPa to 700 MPa

Ultra high strength steels: Yield stress from 700 MPa

In this study we will use Domex 600 MC, a thermo mechanically extra high strength hot rolled cold forming steel. Minimum yield strength for this material is 600 MPa. The chemical composition is characterized by a low carbon content, an increased manganese level, reduced sulphur content and small additions of microalloying elements, see table 1.

Steel grade	C max	Si max	Mn max	P max	S max	Al max	Nb max	V max
Domex 600MC	0.12	0.10	1.90	0.025	0.010	0.015	0.09	0.20

Table 1, Chemical composition of Domex 600MC (wt.-%).

The microstructure consists mainly of a very fine grained polygonal ferrite with a small amount of pearlite. The fine grained microstructure which is positive for strength an impact toughness is a result of the microstructure in combination with thermo mechanical rolling in a hot strip mill.

Guaranteed mechanical properties and bendability for the material are shown in table 2. Typical bendability is normally below 1.0 x thickness. The low bending radius is achieved by reduction of pearlite together with elimination of elongated manganese-sulphides inclusions trough calcium treatment.

Steel grade	Yield strength [MPa]	Tensile strength [MPa]	Elongation A_5 % min	Bendability (min. recommended bend. radii)	
	min	min - max	t>3 mm	3<t<6 mm	t>6 mm
Domex 600MC	600	650-820	16	1,1xt	1,4xt

Table 2, Mechanical properties of Domex 600MC.

A typical engineering stress strain curve of Domex 600 MC in thickness 8.0 mm is presented in Figure 5. The tensile test specimen has been taken transverse from rolling direction according to the European standard for hot rolled cold forming steels EN 10149-2.

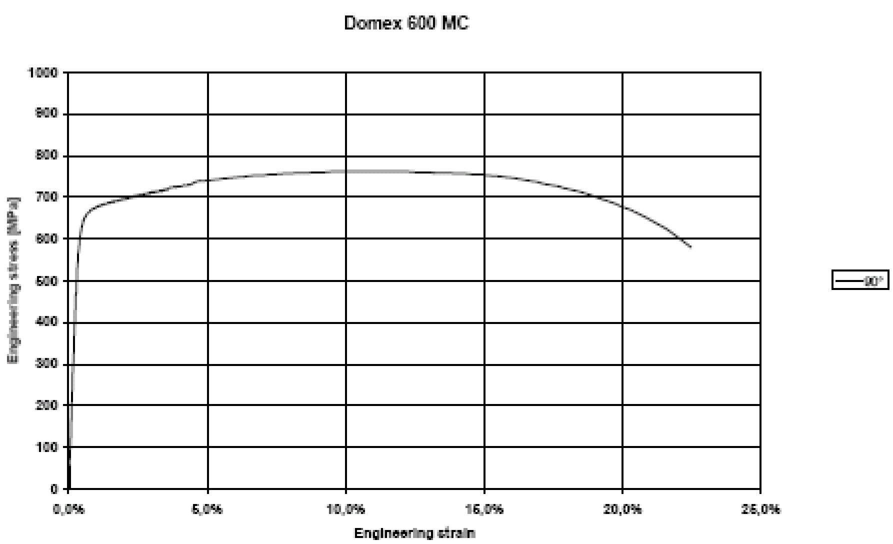


Figure 5, Typical stress strain curve for Domex 600 MC

The yield stress may vary 40-50 MPa depending on direction, where the highest properties always are found transverse rolling direction.

The impact toughness of the material is very good and can be supplied with Charpy V-notch guarantee (34 J/cm2, longitudinal) down to a temperature of –40 °C. The high impact toughness values in combination with the limited sheet thickness imply that the risk of brittle fracture in a real application is very small. The reason for the lower risk of brittle fracture in a thin sheet compared to a thicker plate is lower triaxial stress levels for the thin sheet.

WELDABILITY

All the conventional fusion welding methods can be used. The most common method is gas shielded arc welding (MAG), but manual metal arch (MMA), plasma welding and submerged arc welding are also often used. When discussing weldability of high strength steels in general some of the potential problems are,

1. Hot cracking
2. Hydrogen cracking
3. Lamellar tearing
4. Soft zones in the heat affected zones (HAZ)
5. Reduction of toughness

The risk of hot cracking is very small due to low contents of carbon, sulphur, phosphorus and niobium.

Hydrogen cracking does not occur for this steel and no preheating is needed. The reason is the lean chemical composition and the resulting microstructure in the HAZ after welding is not brittle enough. Table 3 shows the carbon equivalent values calculated according to some of the most common formulas (CE_{IIW} - International institute of welding 1940, P_{CM} – Ito-Bessyo 1968, CEN – Yurioka 1981, CE_{MW} – Duren 1981). As reference steel the standardized structural steel St 52-3 with a minimum yield stress of 355 MPa has been used.

Steel grade	CE_{IIW}	P_{CM}	CEN	CE_{MW}
Domex 600MC	0,40	0,19	0,29	0,19
St 52-3	0,39	0,24	0,37	0,24

Table 3, Carbon equivalent values for Domex 600 MC and St 52-3

Lamellar tearing is confined to plates with inadequate ductility in the trough thickness direction. Such steel may undergo tearing or cracking during welding since the ductility in the thickness direction is not sufficient to accommodate the welding contraction strains. Since the Domex steel grades have a very low amount of non-metallic inclusions and good sulphide shape control due to calcium treatment no problem with lamellar tearing exist.

Extra high strength microalloyed steels produced in hot strip mills always have a narrow zone in the HAZ which has lower hardness than the rest of the welded joint due to loss of precipitation hardening in the microstructure. If width of the zones is small, the strength of the welded joint is not affected and the fracture occurs in the base metal. Width of the soft zones depends mainly on heat input and plate thickness. It is therefore important to limit heat input when welding these steel grades. Figure 6 show tensile strength of a MAG welded joint versus heat input for Domex 650 MC. From the curve it can be seen that the strength requirement is fulfilled if the heat input is limited to 0,9 kJ/mm for the OK 13.29 wire and 1,0 kJ/mm for the TD-T90 wire. The final fracture of the tensile specimens were located in the base metal for the tests corresponding to the horizontal part of the curve and to the HAZ for the sloping part. For Domex 600 MC, a similar curve as in Figure 6 is expected (other values on the y-axis).

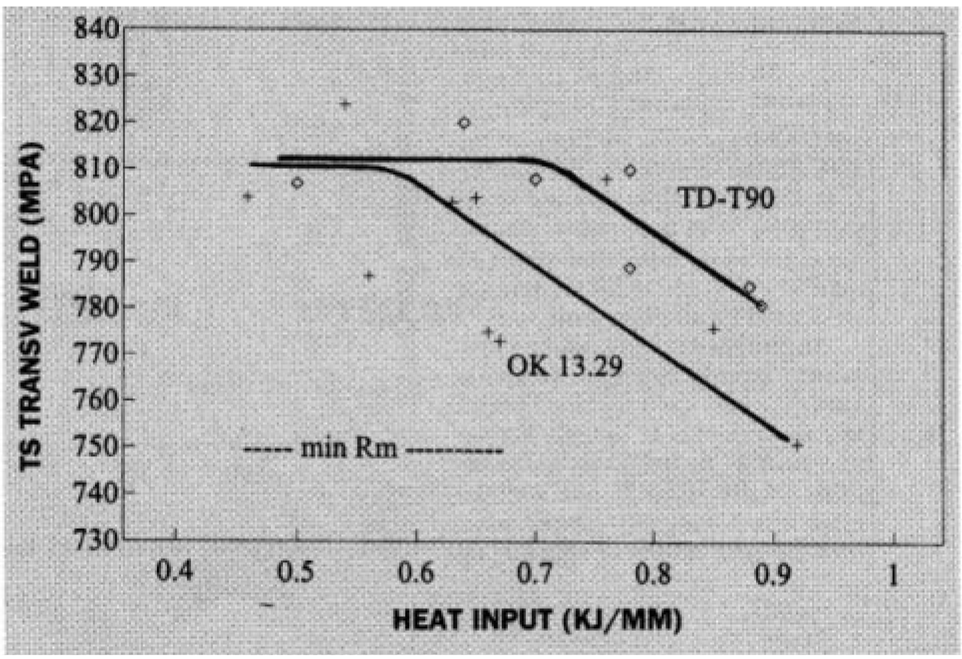


Figure 6, Tensile strength of MAG welded joints. One matching electrode OK 13.29 (tensile strength 820 MPa) was used.

It is important that the impact toughness is high in the final construction so brittle fracture can be avoided. The toughness in the weld metal and the HAZ should be at least as good as the toughness demands in the base metal. To obtain this, filler material with high toughness properties should be chosen. The microstructure in the HAZ varies depending on chemical composition of the steel and welds heat input and impact toughness changes corresponding to the microstructural change.

In the coarse grained zone near the fusion line the worst impact properties are normally obtained. An increased heat input results in a broader coarse-grained zone and this is detrimental for the impact toughness. For Domex HSLA-V Steels filler metals with a high amount of acicular ferrite in the weld metal is recommended. This assures a good combination of high strength and good impact toughness. Welding trials with such electrodes (for example OK 13.13, OK 13.29 and Spoolcord TD-T90) have shown that the most severe base metal requirements (34 J/cm^2 at –40 ^oC) can be fulfilled in the weld metal. Low heat input has to be used to get high toughness in the HAZ. For Domex 600 MC and with the most severe toughness requirement the cooling time $t_{8/5}$ must e maximized to approximately 15 seconds. This means that that the same toughness requirement as in the base metal can be fulfilled also in the weldment for the Domex HSLA-V Steels if filler metal with high toughness is used in combination with low welding heat input.

Details about weldability of the steel can be found in [1]

APPLICATIONS THAT USE EXTRA HIGH STRENGTH STEELS

TRAILERS

Trailord

Trailord PTY Ltd is a trailer producer in South Africa. Trailord has developed a new series of lightweight trailers. The whole chassis has been designed and produced in extra high strength steel with minimum yield strength of 700 MPa. A good design that has considered extra high strength steel and advanced production facilities has made this trailer to an excellent product. The trailer has following features,

- Interlink type
- The two main longitudinal chassis beams have flanges and webs made of extra high strength steel with minimum yield strength of 700 MPa
- Cross members are also made of extra high strength steel with minimum yield strength of 700 MPa
- The chassis has been designed with big smooth chapes to minimize stress concentrations and welds are placed to minimize fatigue problems.

This producer was the first in South Africa to use extra high strength steel in trailer chassis while the rest of the market were using normal mild steel. Trailord has been very successful with this design and that has resulted in a good position in the market. One of Trailords trailers is showed in figure 7.

Figure 7, Trailer from Trailord

Toptrailer

Toptrailer is a trailer and tipper trailer producer in South Africa. Toptrailer has developed all their tipper trailer buckets in extra high strength steel with typical tensile strength of 900 MPa. The use of material with high hardness in combination with good formability and weldability has resulted in a tipper bucket that can be produced at low cost, low weight but with a long life cycle. The whole bucket except the ribs is made of is made of extra high strength steel. The chassis is made of mild steel. These types of tipper trailers are designed for lighter type of wear. These tipper trailers are lighter then the tipper trailers made of mild steel but have a longer life cycle due to better wear and dent resistance. A Tipper trailer from Toptrailer is showed in figure 8.

Figure 8, Tipper trailer from Toptrailer

Kinnarp

Kinnarp AB is a producer of office furniture in Sweden. Kinnarp has developed its own transportation system in order to deliver its furniture all over Europe. Under many years they have developed a trailer to carry containers. The trailer has the following features,

- It is produced of two longitudinal C-profiles in same geometry as truck producers use (VOLVO, SCANIA). They are produced by roll forming or bending
- The beams are connected by two transversal beams that are bolted to the longitudinal beams
- Axles and suspension are same as for trucks in order to simplify maintenance and supply of spare parts
- Welding are minimized in order to reduce fatigue problems
- Extra high strength steels are used in the trailer to save weight create a robust design

In 2003 the third generation of trailer is designed. The trailer, shown in Figure 9 will be produced in extra high strength steel with minimum yield stress 650 MPa.

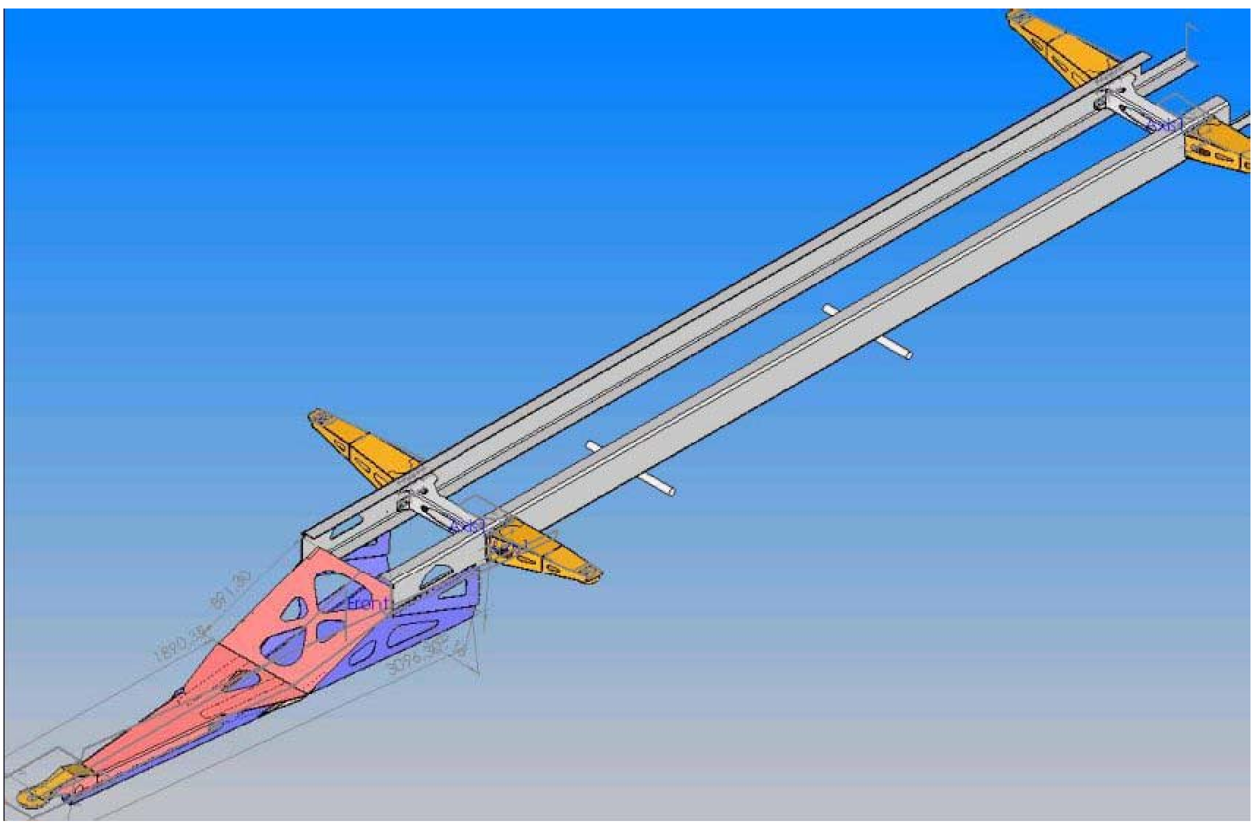


Figure 9, Trailer from Kinnarps

OTHER APPLICATIONS

Extension forks to a forklift truck

Norje Smidesfabrik in Sweden produces accessories for tractors, for example loading forks and buckets for tractors. The extension forks were previously using a steel with minimum yield strength 355 MPa. Just by changing material to Domex 650 MC, the thickness could be reduced between 20-50% depending on model. Replacing material from 355 to 650 MPa in the buckets made it possible to reduce thickness with 20%. One of the main benefits for the company is improved work environment since the amount of heavy lifting could be reduced because of lighter steel plates.

The extension forks were previously welded together using different types of steel. By using a steel with minimum yield 650 MPa, the forks can be made in one piece that is laser cut and bent to its final shape. Production time could be halved for open bottomed extension forks.

The buckets and extension forks are subjected to wear. Use of the extra high strength steel Domex 650 MC, wear resistance increased by 50%, which has led to a marked lifespan increase.

No major changes had to be done in the production stage. The material is very formable and easy to weld.

The extra high strength steel forks are shown in Figure 10.

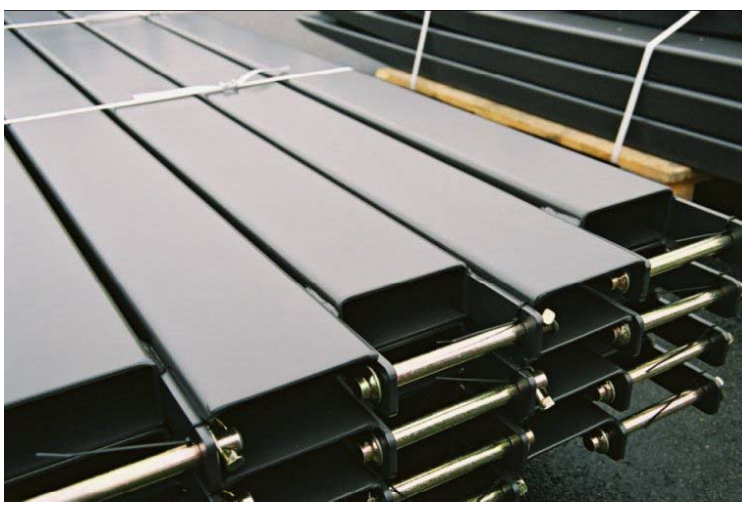


Figure 10, Extension forks

Container handling systems

Bromma Conquip, the leading producer of container spreaders is continuously developing the products by optimization of design and material grade. Low weight, high load capacity and reliability are key words for Bromma spreaders. Reduction of dead weight for some products with up to 40 % and increase of load capacity by 80 % for others has been achieved. This development has been possible by use of extra high strength steels and optimizing the design for the material.

Container spreaders are often subjected to collision damages. By using extra high strength steels, the spreaders are able to withstand impact loads to a greater extent. More information of Bromma Conquip can be found on internet at www.bromma.com. Figure 11 is an example of container spreader produced by Bromma.

Figure 11, Container spreader

Containers

The South Korean container producer Jindo has developed a new container in extra and ultra high strength steel which has a weight that are comparable of an aluminum container.

Jindo, one of the world's largest container producers constructs most of its containers in five sizes: 20, 40, 45, 48 and 53 feet. The 53 feet container is used for domestic freight transport in North America see Figure 12. It is carried both by road and rail, and is exposed to extreme wear and tear. In addition, it needs to withstand loads when several containers are stacked on each other.

The new 53-feet steel container has the same weight as an aluminum container, but production cost is 40 % less. Even more important is that maintenance cost has been cut by almost 70 % since the steel container is more robust.

Figure 12, 53 feet container for freight transport

Container Koudekerk is a Dutch container producer. The containers are used to handle recycled glass. The sidewalls in such a container are exposed to very high wear and impact loads. By replacing mild steel in thickness 4 mm in the sidewalls and 5 mm in the floor by un ultra high strength steel in thickness 2 mm both in the sidewalls and the floor are possible. The steel is a cold rolled martensitic AHSS (Advanced High Strength Steel) with minimum tensile strength 1400 MPa. Stiffeners has also been upgraded to extra high strength steels in thickness 3 mm. Minimum yield strength is 700 MPa.

Reduction of the dead weight is 45 %. In addition, the load capacity has increased from 15.000 to 25.000 kilos. The improved wear and impact resistance makes it possible to increase the maintenance interval and increased life span. This means both economical and environmental benefits. The container is shown in Figure 13.

Figure 13, Container for recycled glass

Truck frame rails

Truck producers such as VOLVO, SCANIA and DAF are using extra high strength cold forming steels in their frame rails. Since fatigue is of great concern, the design is advanced. The following techniques are used to increase fatigue resistance,

- Shot blasting of cut edges in order to introduce negative residual stresses
- Bolting instead of welding
- No joining in highly stressed areas

Example of frame rails in extra high strength is shown in Figure 14.

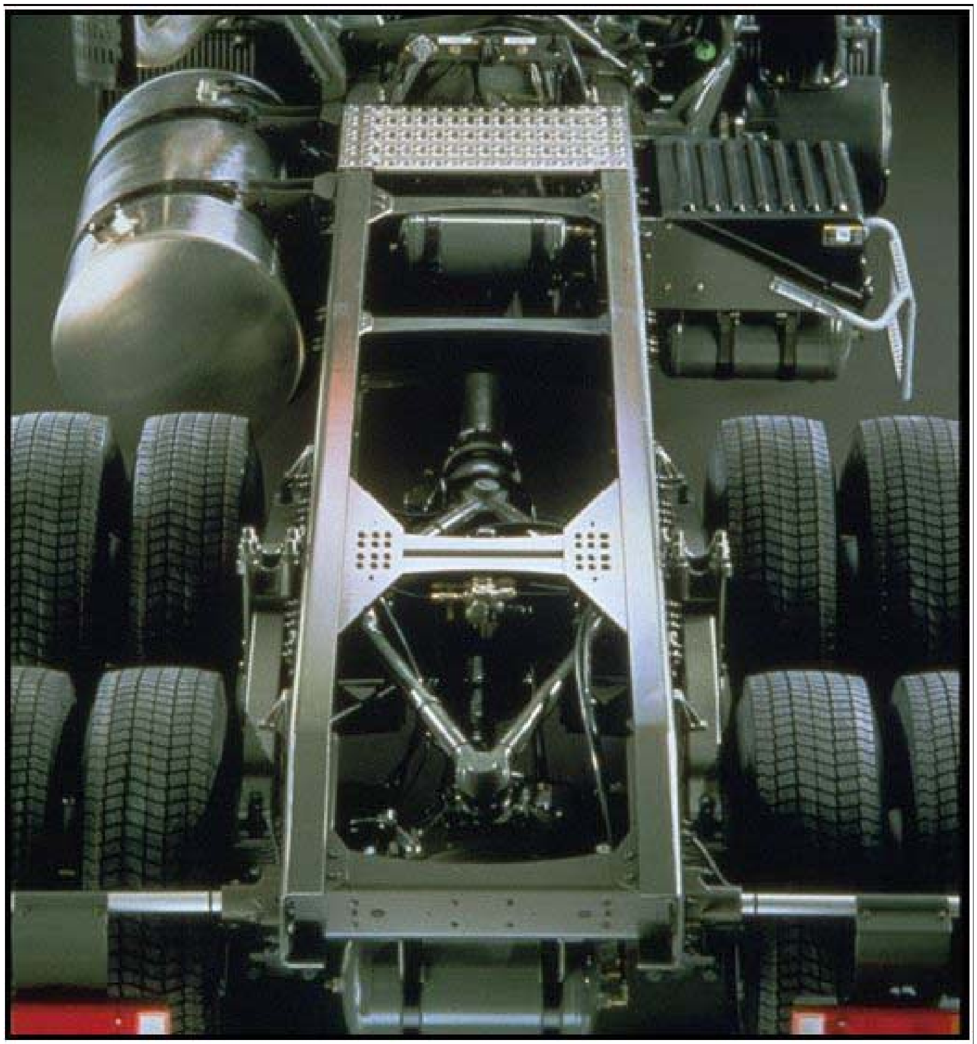


Figure 14, Truck frame rails in extra high strength steel

Dumptruck cab

When VOLVO Articulated Haulers AB developed its new generation of cabs year 2000, see Figure 15, extra high strength steels play an important role. The cab shall withstand a series of situations such as roll over and falling objects. The project team realized that a traditional approach with mild steels would require a patchwork quilt of reinforcements. By using laser cut cold formed steel components, considerable potential for weight and cost savings was indicated. The number of components was reduced from 352 parts to 110 by this approach. By using an extra high strength steel with minimum yield stress 420 MPa, energy absorbing capacity was doubled compared to earlier design.

Figure 15, New cab generation from Volvo Articulated Haulers

ENVIRONMENTAL ANALYSIS

Environmentally positive aspects are expected. They can be divided in three parts,

- Steel production
- Production of trailer
- Use of trailer

During steel production, less raw material has to be taken from the mines. Less material in the production process means less energy consumption and less transportation between the different production stages.

In the trailer production process, less material has to be transported from the steel mill to the trailer producer. When welding thinner material, less filler material is needed. Material handling is also improved, a working environment improvement.

The most obvious environmental effect comes from use of the trailer. The reduction of weight in the trailer body is used for increased load handling, which means less trips to transport the same load a given distance. As an example, reduction of weight with 100 kg causes reduced fuel consumption with 0.046 litres / 10 km [3]. Applied on the studied trailer reduction of fuel consumption will be 0.0312 litres / 10 km. Assuming an annual transportation distance of 100.000 km, reduction of diesel with 312 litres is achieved.

FINANCIAL CONSIDERATIONS

Cost savings is expected when using HSLA-V Steels in the trailer. The savings can be divided into two main groups, production of the trailer and increased load handling during its lifetime. In the chapter, weight reduction of the studied trailer is 680 kg . Technical details of weight reduction are found later in the report.

INCREASED LOAD HANDLING

The trailer is specified for 27 tones axle load (three axles) and 12 tonnes kingpin load. Tare weight of the trailer in original configuration is 7280 kg, which means that the payload is 31720 kg (27000+12000-7280). Use of Domex 600 MC makes it possible to reduce tare weight to 6600 kg. This reduction can be used to increase payload by 680 kg . A calculation example is presented below. It is based on values that are used by the transportation industry in middle Europe (Austria, Germany, France, Belgium, the Netherlands, Denmark).

Freight rate for one tonne per kilometer is 3,5 cent. 680 kg more payload at 100.000 km per year means 2376 Euro profit at 100% loading.

PRODUCTION OF THE TRAILER

Factors that may influence are material cost, material handling and production aspects such as forming, and joining (welding). In this study, material cost and welding is covered. Estimation of production aspects is dependent on present machines in the actual workshop. In general, no additional requirements are necessary due to use of HSLA-V Steels.

Material cost for Domex 600 MC is approximately 1.125 times cost for 355 material. Steel weight of the studied trailer body is 3200 kg. The upgraded version in Domex 600 MC weights 2520 kg. That means that material cost will be reduced by 11 %.

Welding of thinner material means,

- Less filler material
- Lower welding costs
- Reduced welding time

A comparison between the two alternatives is presented in table 4. Filler material OK Autrod 12.51 is undermatching for Domex 600 MC. However since fatigue is limiting the application, an undermatching wire may be used in a majority of the welds.

Base material	355, t=12 mm	Domex 600 MC, t=7 mm	Domex 600 MC, t=7 mm
Filler material	OK Autrod 12.51 4,72 Euro/kg	OK Autrod 12.51 4,72 Euro/kg	OK Autrod 13.31 13,50 Euro/kg
Gas	Mison 25 4,90 Euro/m3	Mison 25 4,90 Euro/m3	Mison 25 4,90 Euro/m3
Joint	V-60°	V-60°	V-60°
Intermittent [65%]	65	65	65
Current [A]	270	210	140
Welding time [minutes/meter]	8,03	4,37	6,11
Welder [Euro/hour]	22,50	22,50	22,50
Equipment [Euro/hour]	16,85	16,85	16,85
Total cost [Euro/meter]	11,80	5,89	9,96

A conservative estimation of weld length for the studied trailer is 150 m. If the undermatching wire is used for the HSLA-V Steel, the following welding cost is achieved:

Mild steel trailer: 1770 Euro

HSLA-V Steel trailer: 884 Euro

It has to be noted that the figures are approximate, since different welds have different leg lengths depending on thickness of the materials that are welded together. Most of the material that is welded together has different sheet thickness, and weld leg length has to be determined for each case. The comparison above may however serve as an indication of welding cost.

As a comparison, estimations made by a trailer producer in Germany [2] between a standard trailer (made in 355 material) and a trailer made of Domex 700 MC (65% Domex 700 MC and 35% 355 material) is presented in figure 16. In this study, a small increase in production cost is achieved. Factors such as material cost, transportation, welding and handling are covered.

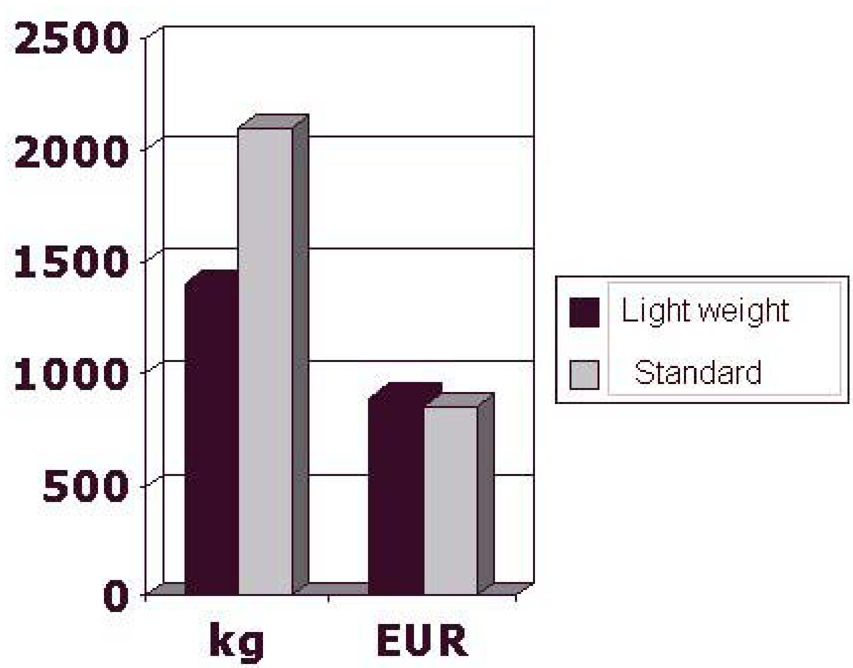


Figure 16, Comparison of weight and cost for standard trailer and a trailer in HSLA-V Steel.[2]

MANUFACTURING ASSESSMENT

There are no greater differences between high strength steels and mild steels when it comes to fabrication. This applies in particular to the new generation of high strength steels, HSLA that have good formability and low content of alloying elements. A comparison of high strength steels and mild steels shows:

- In size shearing, the cut edges of high strength steels are better if clearance is adapted to the strength and thickness. This in turn, places more stringent demands on the tool steel. When changing from mild steel to high strength steel the thickness is reduced. This reduction of thickness compensates the higher yield- and tensile strength so that the cutting force is remained on the same level.
- Thermal cutting as oxygen flame, plasma arc or laser beam are done the same way on mild steel as high strength steel due to low content of alloying elements. Cutting speed can often be raised on high strength steel thanks to thinner material thickness.
- High strength steels also have very good bending and forming characteristics. Particular attention must however be paid to the larger springback and lower deep drawing capacity.
- High strength steel can be welded without difficulty. Only minor adjustments on welding parameters may be necessary, mainly in resistance welding. Due to the low content of alloying elements, preheating is not necessary and risks of weld defects are limited.
- The surface treatment of high strength steel is not very different from the surface treatment of mild steels.

Small adjustments needs to be made in different machines and tooling but the must important is that the people in the workshop are aware of that they are working with a new material that behaves different compared to normal mild steel.

UPGRADING OF A TRAILER CHASSIS

UPGRADING FROM MILD STEEL TO EXTRA HIGH STRENGTH STEEL IN A TRAILER BODY

In a product development process, it's very common that Finite Element methods are used as a tool to investigate stresses and strains for single parts or assemblies in a construction. However, not all have the recourses to analyze a whole trailer chassis, since it is quite expensive and requires much time, knowledge and experience to interpret the results. The purpose of this case study has partly been to see what can be gained from a more advanced FE-simulation of a whole trailer chassis.

The objective is to make a survey of a typical trailer design and find out with more accuracy where EHS can be used and also pin point potential areas of problems, where some extra effort of redesigning should be made in order to better utilize the benefits with extra high strength steel. At the end, this deeper analysis will result in advantages, both from economical and technical point of view.

With the knowledge achieved by FE-analysis, a general upgrading process can start.

TRAILER CASE OBJECT

The trailer case object that is referred to throughout this report is best described as a typical multi purpose trailer of such type that is very common in European transport systems, see Figure 17.

Figure 17. Trailer case object

The trailer can be used for general cargo transport, but is also equipped with container locks for container handling. Using it as a container trailer, two 20 ft - or one single 40 ft ISO-container can be loaded, see Figure 18.

Figure 18. Container transport alternatives

The trailer was originally designed to be equipped with a 27 tonnes triple boogie with air-bellow suspension and a 12 tonnes kingpin, according to the former regulations within the Netherlands and Belgium.

Total weight of the trailer is **7280 kg**, indicating that this particular case study object is rather heavy for this trailer type. The weight is distributed with 5440 kg on the boogie and 1840 kg on the kingpin.

Trailer chassis assembly

The trailer chassis in Figure 19, (excluding axles, bakes and equipment) basically consists of five main sub-assemblies, for which the most of the steel is used.

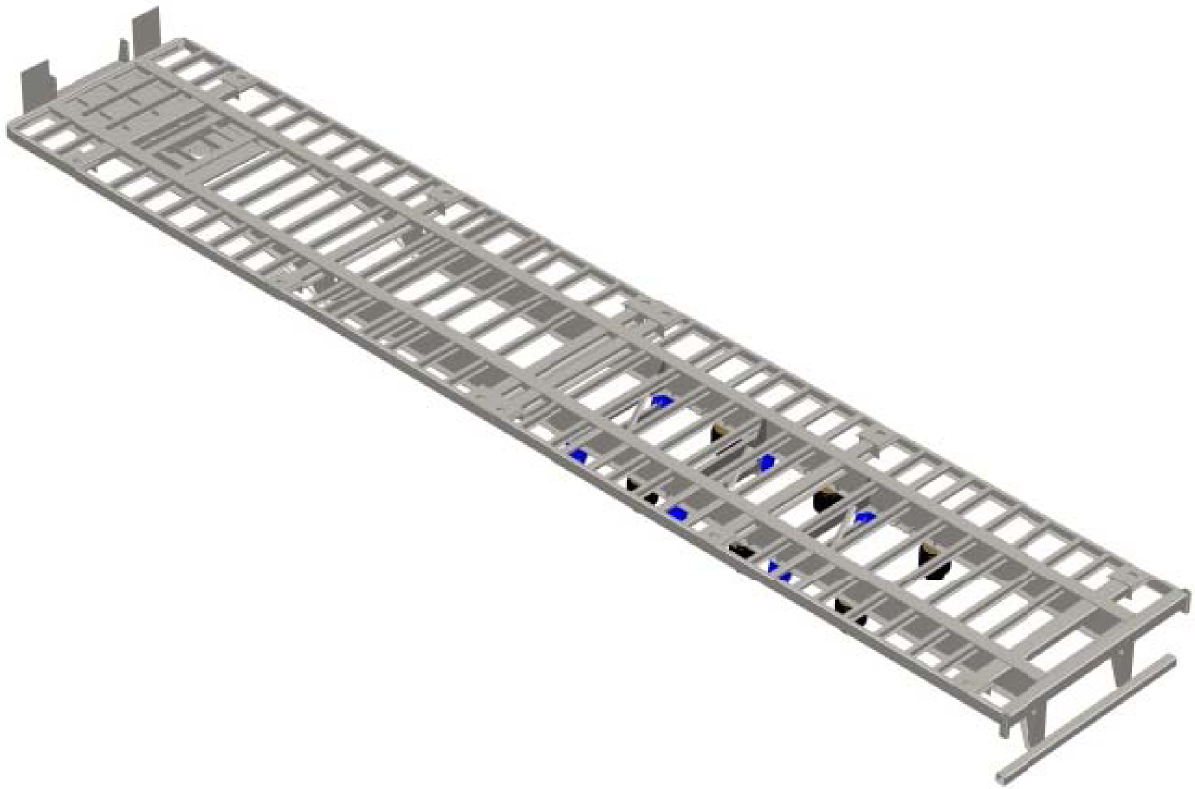


Figure 19. Trailer chassis

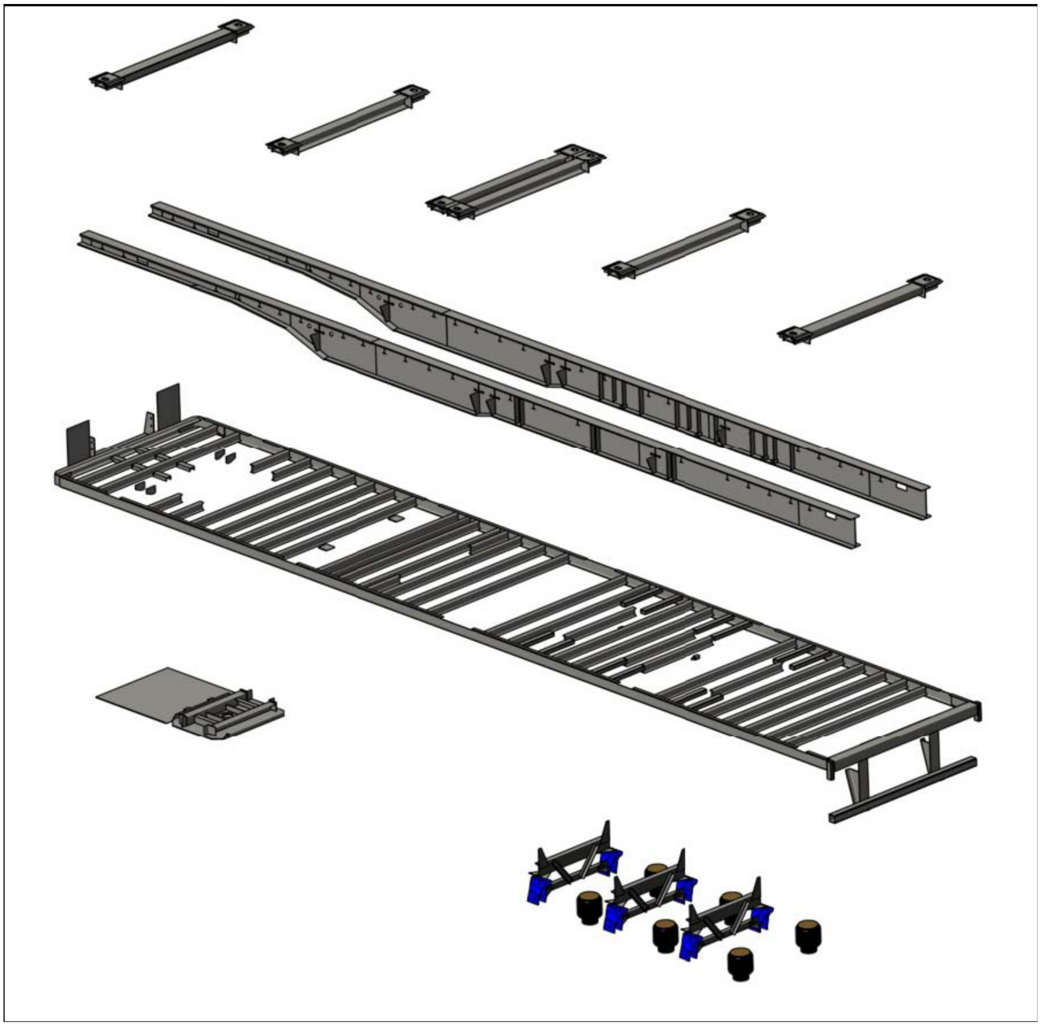


Figure 20. Trailer chassis assembly

The total amount of steel needed to manufacture the trailer chassis is approximately 3200 kg. Of this total weight, the components in Figure 20 stand for the majority of the steel consumption and they are of that reason the most interesting ones to upgrade. The amount of steel needed to build the trailer is divided into following;

1. Crossmembers – The cross members are produced from a hot rolled HEB140 profile. At each end of the cross member, container locks are mounted. During container transport the load is transferred to the rest of the trailer chassis through these cross members. Stiffness and strength is required from the cross member. Material used is S235JR and total weight for all of the cross members is 390 kg.

2. Side members – Manufactured by welding a number of plasma cut sheets together. For the web thickness 5.0 mm is used. For the rear flanges thickness 12.0 mm is used. In the front, where the side member has it's smallest cross section, thickness 20 mm is used for the flanges. Steel grade used for this component is S355J0 for all the parts. The total weight of the side members (excluding welds) is 1310 kg

3. Floor assembly - The floor is a steel frame mainly made of hot rolled 4'' SLS-profiles and hot rolled U-profiles. The steel grade is PROTENAX 36 (Re=235 MPa) for the SLS-profiles and S235JR for the U-profiles. The total weight of the floor assembly is 820 kg.

4. King-pin assembly –The connection between the truck and the trailer is subjected to tough loading. The kingpin attachment is reinforced by a framework construction using UNP-80 profiles and additional cut sheets. Steel grade is S235JR and weight equals 235 kg.

5. Suspension – The axles, the air-bellows and the axle hanger are mounted as a suspension unit onto the side member's lower flange. Normally, in order to withstand the transverse forces acting on the suspension unit, the frame has to be reinforced by a framework. In this case, the framework consists of UNP-65, 80, and 160 profiles in steel grade S235JR. Weight of this framework is 210 kg.

With this knowledge of weight distribution, we have decided to focus the work on introducing extra high strength steel to the first three components, where the potential is highest.

Regulations of transport within European Community

Transport on land is regulated by a number of directives. One of many of concern for trailers is directive 96/53 EG that states maximum dimensions and weight for international transport within the European community. However, this directive also states that each member state may adopt rules, which differs from 96/53, if the transport entirely is of domestic nature.

Regulations for international transport within the European community nowadays sets limit for the maximum boogie load to 24 tonnes and maximum kingpin load to 10 tonnes. Maximum total weight of a vehicle with at least five axles is 40 tonnes for general cargo transport or 44 tonnes for transport of a 40 ft ISO-container.

Directive 96/53 also states maximum weight of the truck:

Two axles truck – 18 tonnes
Three axles truck – 25 tonnes
Three axles truck with air suspension and double wheel axles or equivalent - 26 tonnes.
Four axles truck with double steering axles – 32 tonnes

Following the European regulations for international transport, the maximum load capacity for this particular trailer would then be:
10 + 24 - 7.3 = 26.7 tonnes.

National exceptions are however allowed and, as already mentioned, we have for this study decided to use the ones that the trailer was originally designed to follow. The Netherlands accepts 27 tonnes maximum boogie load and a maximum total weight of 50 tonnes for transport of a 40 ft ISO-container.

Using this specification, the maximum load capacity would be:

12 + 27 - 7.3 = **31.7 tonnes**

FE-MODEL OF TRAILER CASE OBJECT

The calculations are performed using I-DEAS Master Series 8.

The FE-model, see Figure 21, of the body is built with beam- and shell elements based on the Autocad files received from the manufacturer. The simulation is linear dependent, meaning that plasticity and local buckling is not accounted for. The shell element used considers warping effects.

The load is modeled as a 20 ft. ISO-container using beam elements and a mass element located at the center of gravity. Evenly distributed weight is also added so that total weight of the load is 31.7 tonnes. Typical dimensions of ISO-containers and max weight are given in Table 4.

20 ft ISO-container		40 ft ISO-container
Length mm	5890	12040
Width mm	2330	2330
Max.gross weight [kg]	24000	30480

Table 4. Dimensions and weight for ISO container

The suspension assembly is modeled as a balanced coupling system with rigid beams and links in order to resemble the function of the coupled air bellow system.

Coupled air suspension has the advantage of distributing the loads so that the axles always carry the same amount of load.

At the kingpin, translation in all three directions is prevented. At the wheels the model is restrained in vertical direction. One side of the trailer is restrained in horizontal direction as well, for all load cases except the marshalling load case. In the marshalling load case the middle wheel on one side is restrained in the horizontal direction.

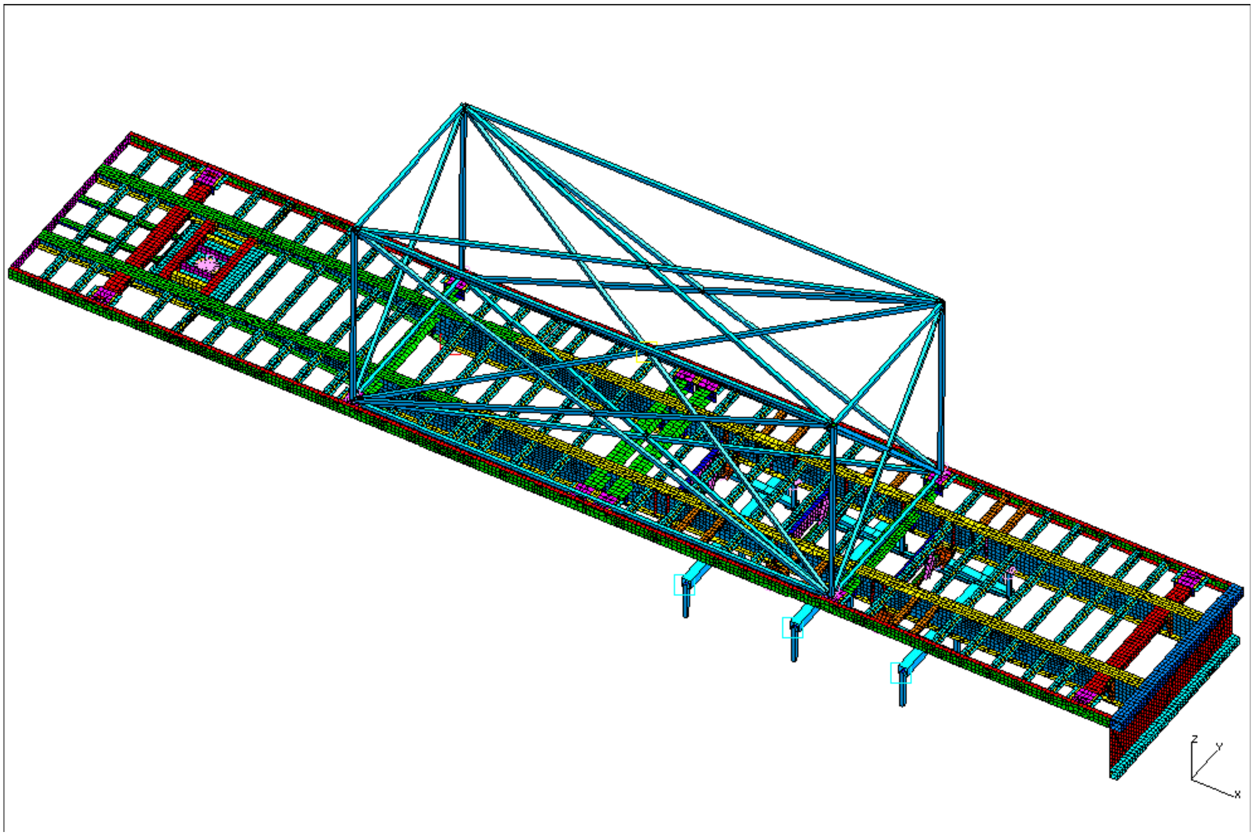


Figure 21. FE-model of trailer case study

The level of accuracy is usually proportional to the amount of work spent of modeling details. However, when using FEA as a tool to analyze stresses and strains in a complex welded structure, such as a trailer, one should be aware of the fact that a very detailed model, where also the welds have been modeled, requires new methods to evaluate the stresses and strains close to the welds. The main reason is that stresses in the close vicinity of the weld toe will increase to infinity as the element density increases, e.g. too dens mesh will give unrealistic values of the stresses close to the weld if not handled correct.

Methods such as the *hot spot method or effective notch method* handles the problem of finding reliable stresses close to a weld, but none of these methods are suitable to use for analyzing such a large complex welded structure as a trailer. The amount of work needed to model each weld is simply not reasonable. These methods are more suitable to use for sub-modeling of specific areas, after a first rough simulation have revealed the force distribution in the structure and critical areas.

For this case study, we have decided to evaluate the fatigue life using the widely known *nominal stress method* where nominal stresses far enough from any weld are used to calculate the fatigue life according to IIW's recommendation for welded structures. The advantage is that the welds need not to be modeled and a coarser mesh can be allowed. Even so, the FE-model of the trailer consists of roughly 500.000 D.O.F.

LOAD CASES FOR FE-SIMULATION

Finding relevant load cases is a difficult part when analyzing a whole trailer chassis with the use of FEA. Some help can be found in design codes that covers the design of trailers used for hazardous cargo transport and some information can be found in the design manual from the brake and suspension supplier. Unfortunately, not many design codes cover the whole design procedure of a general trailer steel frame. It is mostly up to the designer to set up the design criterion with stated load cases, which must be fulfilled.

Together with the trailer manufacturer and Epsilon High Tech Engineering, we have decided to analyze the load cases presented here. They may not be entirely correct in magnitude but they represent load conditions, which are realistic.

For this cases study, we have analyzed a five static load cases and five fatigue load cases

Maximum static load cases

M1. Vertical load, 1g ± 1.7g

"Extreme vertical ISO-container load"

This load case would best describe the transport of an ISO-tank container, which is considered stiff enough so that the load is transmitted only through the container locks without any contact with the upper flange of the main beams at all. The load represents the maximum peak as the trailer experience an acceleration of 1.7g added to it's own weight

M2. Lateral load, 1g vertical ±0.5g

"Roundabout load"

This load case is a combination of the trailers own weight and a 0.5g lateral acceleration. This load case resembles low speed cornering in a roundabout.

M3. Longitudinal load, 0.65g

"Emergency braking"

Maximum braking force is limited by friction between tire and road. The truck can generally generate more braking force than the trailer but we have chosen to apply a combined braking force of 0.65 g on the trailer through the kingpin and boogie.

M4. Marshalling

"Turning on the spot"

During positioning of the trailer at, for instance, a marshalling yard the trailer is often subjected to a turning-on-the-spot maneuver, which introduces a large lateral bending- and shear load on the chassis. Turning on the spot with a fully loaded trailer is considered as one of the toughest load cases to be fulfilled

M5. Distributed load, 2.7g (evenly distributed on trailer bed)

"Extreme vertical distributed load"

This is more or less the same load as M1, but with the exception that the maximum load is evenly distributed over the trailer floor and not only through the container locks.

Fatigue load cases

Evaluation of fatigue results also considers that the trailer not always transports the maximum allowed weight. Based on experience from recording real load spectra of similar vehicles, following in-service load profile has been used:

40 % Maximum loaded

30 % Partly loaded

30 % In-service weight

The design fatigue life has been set to 2E6 km or corresponding 10 years technical lifetime.

F1. Vertical load, 1.15g (±0.625g)

In a similar way as M1, this load case best describe the vertical fatigue load under transport of a stiff ISO-tank container, which transfers the load only through the container locks. The load represents transport under normal conditions. 1,15g when this load case was designed it was taken into account that the trailer is not fully loaded all the time.

F2. Lateral load, 0.5g (±0.25g)

Cornering left and right under normal conditions.

F3. Longitudinal load, 0.25g (0.05g acceleration-0.2g braking)

Fatigue load under normal acceleration and braking.

F4. Torsion load

This fatigue load case represents when the truck drives sideways up to a level higher or lower than the boogie of the trailer. Typical example is when the truck enters and leaves a gas station located somewhat higher than the road.

The torque along the trailer is created by applying the king pin force 450 mm to the left/right of the kingpin center.

F5. Distributed load, 1.15g (evenly distributed on trailer bed)

As F1, except that the load is evenly distributed over the trailer floor and not only through the container locks.

DESIGNING WITH RESPECT TO FATIGUE

When upgrading to extra high strength steel, the objective is often to combine this with a reduction of the sheet thickness. It is also common to apply this material change to an existing design without any further changes of geometry or dimensions. Under the same circumstances this will automatically result in higher stress, as expected.

If the construction is subjected to some kind of alternating load, as all vehicles are, the alternating stresses (or stress range) sooner or later call upon needs for designing with respect to fatigue.

Fatigue of base material

THE STEEL COMPANY has tested fatigue properties for all Domex steels. It’s shown that fatigue strength of steel is increased with increased static strength. See Figure 22.

Testing has been performed under constant amplitude load (R=0.1) and results presented in figure have 50% probability of survival.

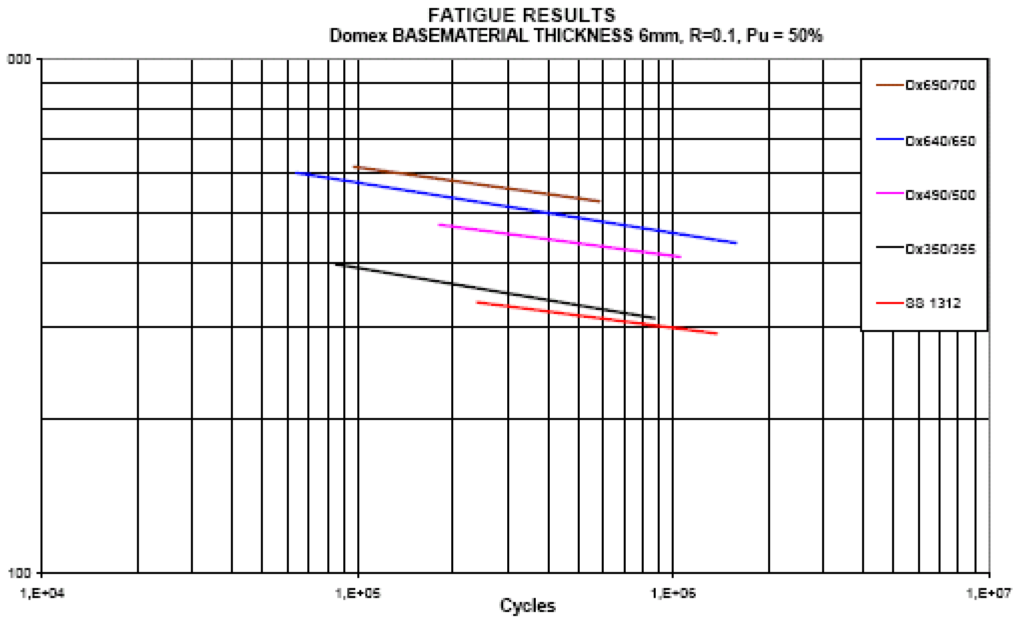


Figure 22. S-N diagram for Domex steels

Fatigue of edges

Shearing, punching or any kind of cutting have a negative effect on the material fatigue properties due to the formulation of micro cracks in the fracture surface. If these cracks are big enough and the stress range is sufficient to propagate the crack, they reduce the fatigue life of the material drastically. However, under normal circumstances cut edges experiences a material dependency and the fatigue life increase with increasing static strength of the material. From testing, it has been shown that laser- and plasma cutting are superior methods for achieving maximum fatigue performance of edges. Simplified, the better edge quality the better fatigue properties.

Fatigue of welds

Fatigue in welds is more or less independent of the base material strength due to macro- and micro geometrical effects.

First, the weld itself acts as a stress raiser due to the geometrical changes.

Secondly, small pre-existing cracks and cold laps can be found at the weld toe due to thermal shrinking and volumetric changes as the melted filer material solidifies.

Thirdly, in welds small inclusions as flaws, pores act like preexisting cracks and stress raisers.

In order to achieve good fatigue performance for welds, the welding quality is of most importance.

Sometimes it is clamed that the use of high strength steel, in highly fatigue loaded structures, is of less benefit since the welds under normal circumstances are the limiting factor for what stress range that can be allowed.

By redesigning joints and place welds in low-stressed areas, chose a joint type with better fatigue performance and aiming for good welding quality, high strength steels have been successfully used for reducing weight in though applications like dumpers, cranes, trailers and trucks for many years.

IIW design criteria for fatigue

We have used the IIW (International Institute of Welding) recommendation for calculating the fatigue life for welded structures rather than using any of the numerous national standards, which exists. The main reason for this is that IIW is a recognized independent organization not bounded to any national interest.

Our own experience is that designing after IIW recommendations best represent what can be expected from industrial welding in workshops where many of the national standards often is based on design codes for building and civil engineering, where the welding quality cannot be controlled in the same way as in a workshop.

For the fatigue load cases a safety factor of 1.2 have been used since the risk of failure is set to 50 %. Since the FE-model is rather rough, an allowable stress range for all welds is set to **90 MPa**. More detailed evaluation with respect to local design and welding procedure will give other allowable stress levels according to [4].

Improvement of fatigue properties of welds according to IIW

Sometime redesigning is not possible or the improvement is not enough. At critical areas it is possible to perform post-treatment of welds in order to increase fatigue performance. Since this often is a costly operation, it is still the best way to redesign the joint .

- TIG-dressing
- Shoot blasting
- Grinding
- Peening

FE-RESULTS FOR CASE STUDY

The results from the FE-analyses are separated in two parts; maximum and fatigue load cases. Contour plots over von Mises stresses are presented for each load case in Appendix 1 and 2.

It shall be noticed that the color bar to the right in the figures, which indicate the stress level in the structure, have different maximum values and interval steps of the scale for the maximum load cases and the fatigue load cases.

Maximum load cases

Six maximum load cases have been evaluated and the results indicate that the vertical load case is the most critical, see Figure 23. Hence, further discussions of the maximum load cases refer to the vertical load case.

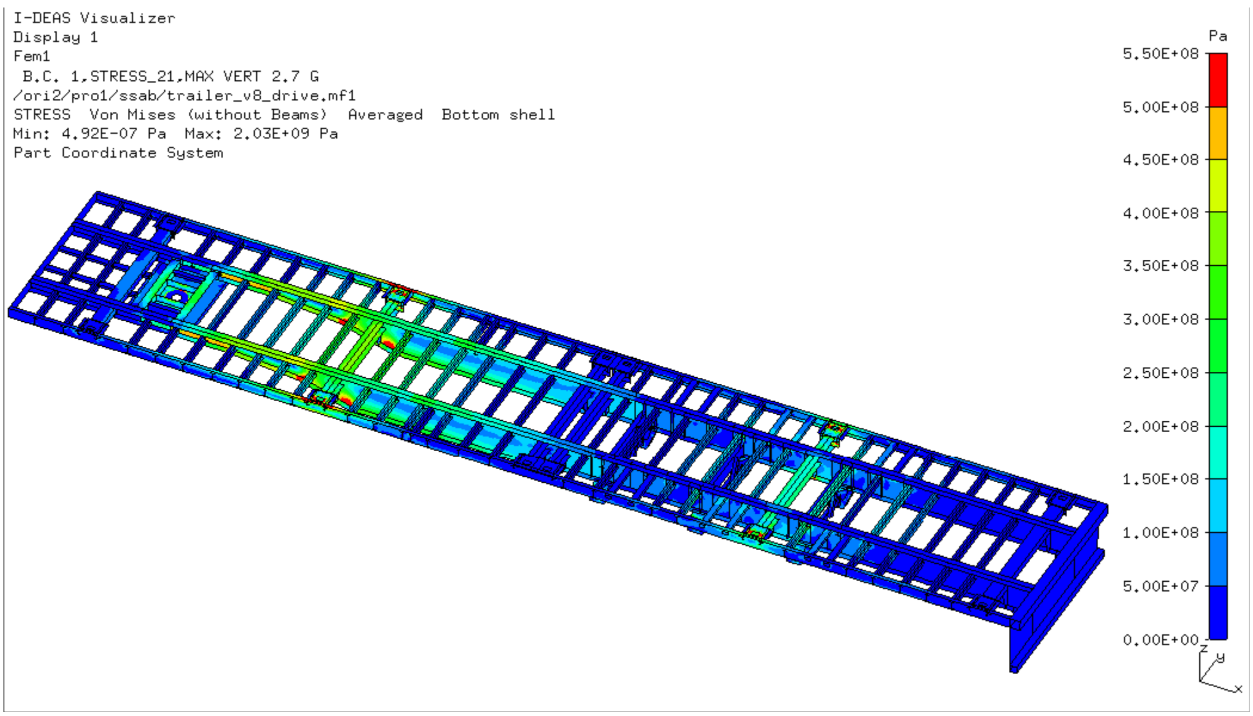


Figure 23. Von Mises stresses over max. vertical static loadcase

Vertical maximum load case gives the highest stress at the position where the side member changes cross section height. In this load case, we allow plasticity to develop and we can see that so must be the case since the stresses in this area is well above the yield stress for S235 material. Two of the major cross members take much of the load from the container and reaches stresses up to 350 MPa in the upper flange. Some of the minor reaches stresses up to approx 300 MPa, but many of them are low stressed. We also se that the rear part of the side member is less stresses and have no areas that need redesigning in order to implement EHS.

Figure 24. Von Mises stresses over max. Vertical static loadcase (magnified)

In Figure 24 it can be seen that the whole area is exposed to high stresses. Especially the inner longitudinal beam and the transverse beams are of great interest.

Fatigue load cases

Four different fatigue load cases have been evaluated; the results can be seen in Appendix 2. As for the maximum load cases, the vertical fatigue load case is the most severe and it is also the same area as before that is of interest, see Figure 25. We see that stress range perpendicular to the weld, located in the lower flange, is in the order of 300 MPa. For all fatigue load cases considered, this area is the most critical.

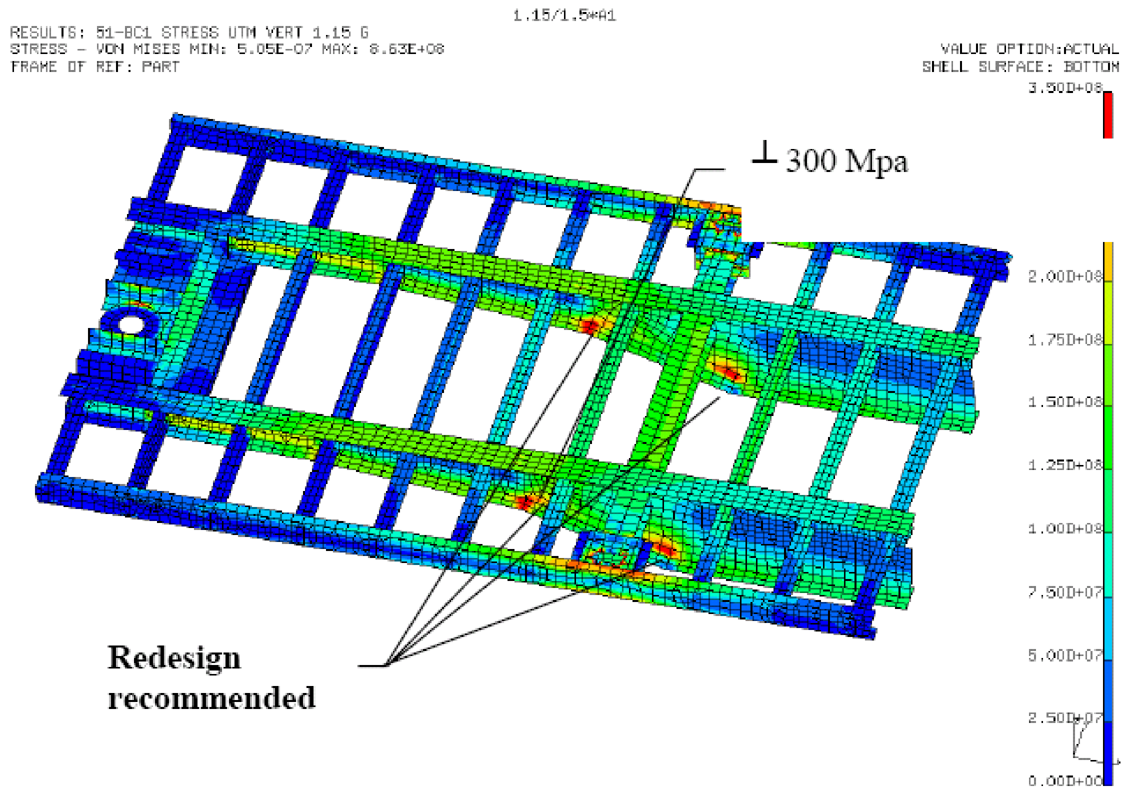


Figure 25. Von Mises stresses over max. Vertical fatigue loadcase

Modification of critical area

In order to benefit from using High Strength Steel, total redesign is recommended in this area. Some design changes are discussed further below. Following good design practice, there are two approaches that are recommended.

1. If possible, move and redesign the location of the weld.

2. Reduce stresses in the weld by adding web-stiffeners and / or increase sheet thickness in the web.

The effect of web stiffeners has been analyzed for load cases M1 and F1. These simple modifications show better results. See Figure 26 and Figure 27 for Von Mises stresses after modification. A more optimized geometry of the transition from full web height to the small web height would be most desirable for best fatigue performance, since introducing this web-stiffener also introduces more welds, which should be avoided if possible. However, this minor modification at least shows that the critical area can be improved.

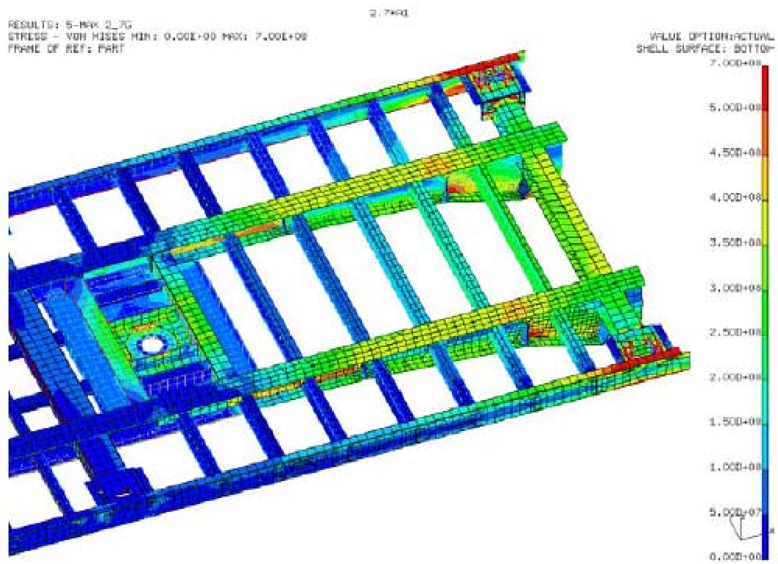


Figure 26. Von Mises stresses over max. Vertical static loadcase with stiffeners added.

Applying extra stiffeners in the transition area, results in a better distribution of the stresses. The magnitude of the stresses are somewhat reduced, but plasticity is still likely to occur.

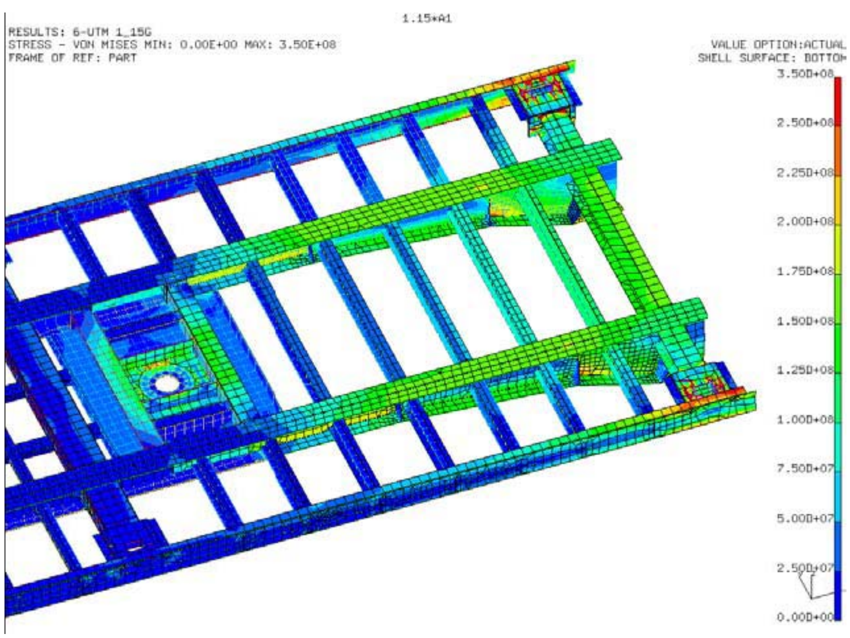


Figure 27. Von Mises stresses over max. Vertical fatigue loadcase with stiffeners added.

The stresses are reduced and distributed more evenly and are now in the order of 175 – 200 MPa. More work and innovative solutions would most likely further improve this critical area.

UPGRADING TO HIGH STRENGTH STEEL IN CASE OBJECT

With the knowledge achieved from all of the FE analysis, we see that High Strength Steel could be a benefit in the smaller cross members, the larger cross members and from the king pin to approx 1.0 m after the section where the side member has reached its full height. From the first results it can be seen that the container load case is the worst with the conditions established as the presumptions. With other loading conditions other parts of the trailer might be critical. To optimize this particular design of the trailer, the loading must be better known as the trailer will look different for container transport and transportation of other goods.

A closer look at the results from the modified trailer shows that the stresses are reduced by some small modifications. The results from the modifications shows that there is a possibility to decrease thickness and optimize the structure more if high strength steel is used and still keep the stresses at the same levels.

Method

The process of upgrading the case object have started with matching the static strength of each component with new alternatives made of extra high strength steel. For each member, cross sections at relevant positions have been taken out for static analysis.

Static strength were calculated using Do.Calc, especially in-house developed computer software, which is used for calculating bending-, shear- and torsion capacity for arbitrary thin sheet profiles, made of high strength steel. Do.Calc considers effects such as local buckling and plastic bending capacity.

The static strength of the original design is compared to a number of alternatives in high strength steel with thinner material and the design target is that the alternative shall have al least the same strength.

Static strength for the members is presented as bending- and shear capacity, together with bending resistance, stiffness and a weight index.

The term *capacity* includes the post-yield strength of steel and should be interpreted as the maximum load that can be applied to the member with the particular cross section analysed.

Upgrading of side member

The side member is made in different sheet thickness; 5.0 mm in the web, 12.0 mm and 20 mm for the flanges. Steel grade used is entirely S355J0. Static capacity has been calculated at two positions (Figure 29 and Figure 30) along the side member.

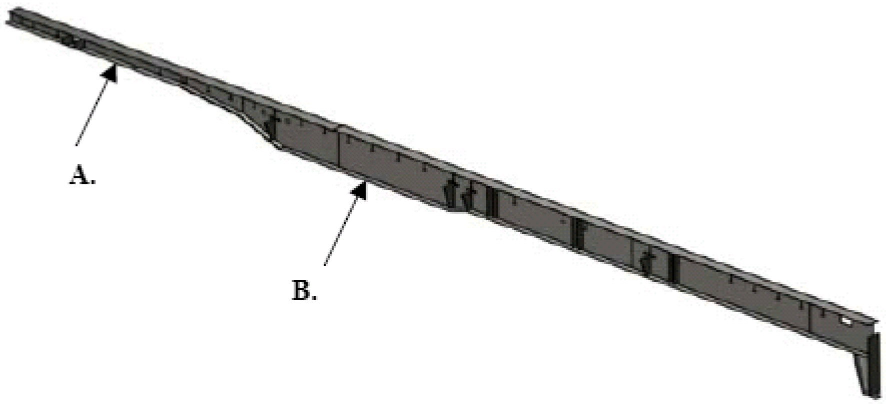


Figure 28. Side member

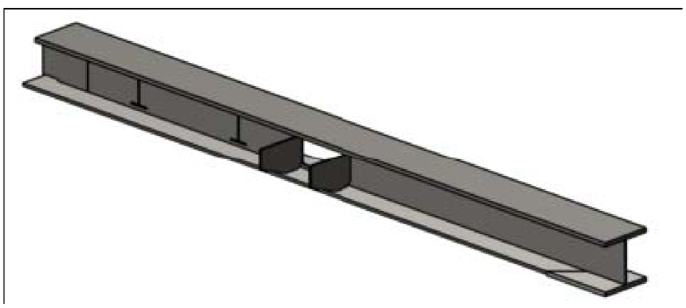


Figure 29. Section A of side member

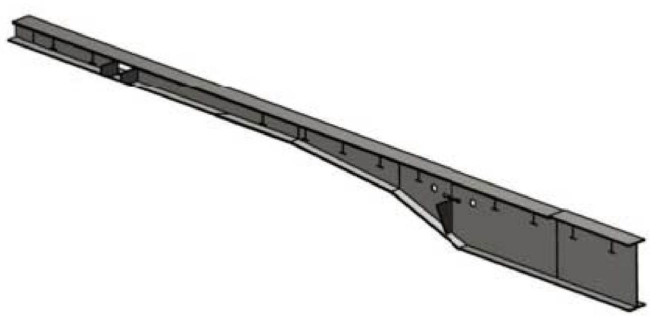


Figure 30. Section B of side member

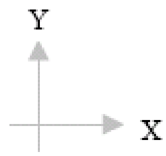
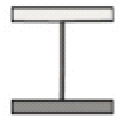
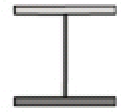
			
Material	**W.R.T**	**S355J0**	**WELDOX 700**
Thickness, flange[mm]		20	12
Material		**S355J0**	**Domex 600 MC**
Thickness, web[mm]		5.0	4.0
Bending resistance, W [mm^3]	**W_x**	3.8×10^5	2.6×10^5
	W_y	1.5×10^5	9.0×10^4
Bending capacity, M_d [Nmm]	**M_{dx}**	1.4×10^8	1.4×10^8
	M_{dy}	6.1×10^7	4.5×10^7
Shear capacity, T_d [N]	**T_{dx}**	1.3×10^5	2.3×10^5
	T_{dy}	1.3×10^6	1.2×10^6
Weight [kg / m]		52	33

Table 5. Bending resistance and cross section properties at section A for side member

The thickness of the flanges is 20 mm . Current steel production of Domex 600 MC in the hot strip has a limit of thickness 10 mm for this grade. For thicker material than 10 mm , THE STEEL COMPANY's high strength steel Weldox is a suitable alternative.

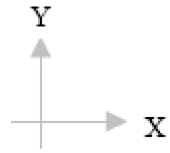
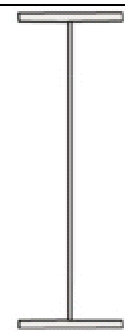
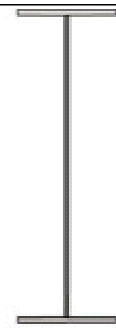
			
Material	**W.R.T**	**S355J0**	**DOMEX 600 MC**
Dimensions b x h ,[mm]		150 x 464	150 x 464
Thickness, flange[mm]		12	8.0
Thickness, web[mm]		5.0	4.0
Bending resistance,	W_x	1.0×10^6	6.1×10^5
W [mm^3]	W_y	9.0×10^4	6.0×10^4
Bending capacity,	M_{dx}	3.4×10^8	3.4×10^8
M_d [Nmm]	M_{dy}	2.9×10^7	3.2×10^7
Shear capacity,	T_{dx}	7.8×10^5	8.8×10^5
T_d [N]	T_{dy}	5.0×10^5	6.9×10^5
Weight [kg / m]		47	34

Table 6. Bending resistance and cross section properties at section B for side member

Using the suggested material and thickness, the amount of steel sheet needed for both side members can be reduced from 1310 kg to 935 kg, which is 375 kg less.

Based on an existing design, the first approximation of suitable sheet thickness in EHS-material, can be determined by a *relative design* study without the need to entirely modify the whole chassi frame.

Upgrading of floor using cold formed EHS-profiles

The floor is designed by using a number of 4 ‘’ SLS-hot rolled profiles, (Figure 31) which are welded to the web of two C-profiles and to the web of the side member. Results from FE-analysis revealed that many of the SLS-cross members were rather low stressed for most of the load cases.

4’’ SLS beam

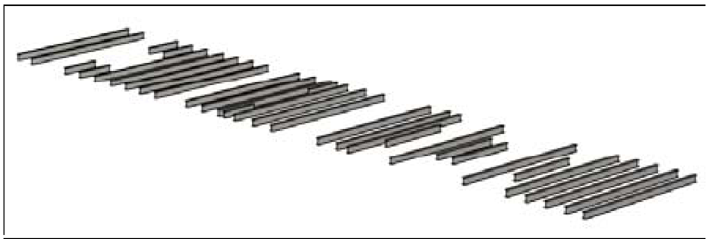
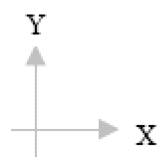
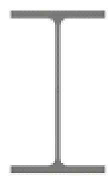
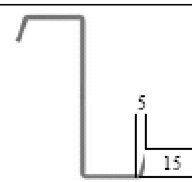


Figure 31. SLS beams in floor assembly

			
Material	**W.R.T**	**PROTENAX 35**	**Domex 600 MC**
Dimensions, b x h[mm]		4’’ x 2.25’’ (101 x 57 mm)	100 x 82
Thickness, flange[mm]		4.4	2.0
Thickness, web[mm]		2.8	
Bending resistance, W [mm^3]	**W_x**	2.7×10^4	1.1×10^4
	W_y	4.8×10^3	2.8×10^3
Bending capacity, M_d [Nmm]	**M_{dx}**	6.5×10^6	7.1×10^6
	M_{dy}	1.3×10^6	1.5×10^6
Shear capacity, T_d [N]	**T_{dx}**	7.2×10^5	5.6×10^4
	T_{dy}	3.7×10^5	6.8×10^4
Weight [kg / m]		6.0	2.9

An alternative to the 4´´SLS cross member is a Z-profile dimensions 100 x 82 mm made of Domex 600 MC in thickness 2.0 mm . With this alternative, bending capacity is increased by 24% even though the weight is reduced.

To build the trailer floor, it requires roughly 390 kg of the 4’’ SLS beam or

This same amount of alternative Z-profile requires approx. 240 kg, which is 150 kg less material.

C-profile

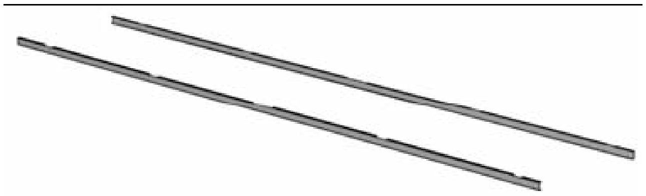
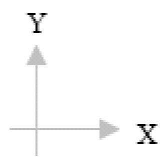
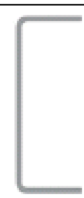
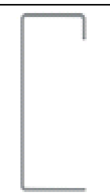


Figure 32. C-profiles in floor assembly

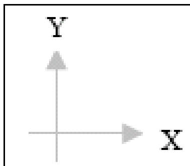
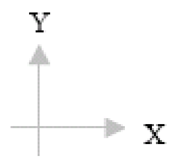
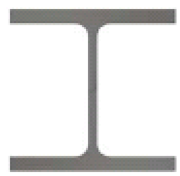
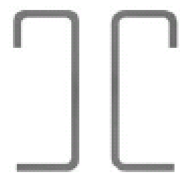
			
Material	**W.R.T**	**S235JG**	**Domex 600 MC**
Dimensions, b x h[mm]		50 x 140	50 x 140
Thickness, [mm]		4.0	2.0
Bending resistance, W [mm^3]	**W_x** **W_y**	3.6×10^4 1.67×10^4	2.2×10^4 5.8×10^3
Bending capacity, M_d [Nmm]	**M_{dx}** **M_{dy}**	8.9×10^6 1.4×10^6	1.1×10^7 2.1×10^6
Shear capacity, **T_d [N]**	**T_{dx}** **T_{dy}**	5.0×10^4 7.3×10^4	7.7×10^4 9.6×10^4
Weight [kg / m]		7.2	4.0

The alternative presented has the same dimensions except for a edge stiffener which is added to the upper flange in order to prevent local buckling. Using Domex 600 MC in thickness 2.0 mm it’s possible to reduce weight by up to 44 % and increase the bending capacity with 24%.

Upgrading of cross members

Using the HEB-140 profiles as a cross member gives a strong and stiff construction, but the design is also rather heavy for the purpose. From FE-analysis of load case F1, it is shown that the HEB-cross members are highly loaded and would also benefit from increased strength.

Figure 33. Cross members and container locks

			
Material	**W.R.T**	**S235JR**	**Domex 600 MC**
Dimensions b x h,[mm]		140 x 140	140 x 140
Thickness, flange[mm]		12	6.0
Thickness, web[mm]		7.0	
Bending resistance, W [mm^3]	**W_x** **W_y**	2.1×10^6 7.8×10^4	1.2×10^5 6.6×10^4
Bending capacity, M_d [Nmm]	**M_{dx}** **M_{dy}**	5.1×10^7 2.1×10^7	7.2×10^7 4.0×10^7
Shear capacity, **T_d [N]**	**T_{dx}** **T_{dy}**	4.8×10^5 1.2×10^5	4.1×10^5 5.1×10^5
Weight [kg / m]		33	24

Designing the alternative as a double C-profile in Domex 600 MC, thickness 6.0 mm it is possible to increase the bending resistance by 41% and still be able to reduce weight by 28 %. Some redesigning of connection points is of course needed, but total weight saving by at least 70 kg is possible using this alternative.

POTENTIAL WEIGHT REDUCTION

Using the alternatives presented here, we see that the potential weight reduction of each component is:

Side members: 375 kg

Cross members: 70 kg

Floor assembly: 235 kg

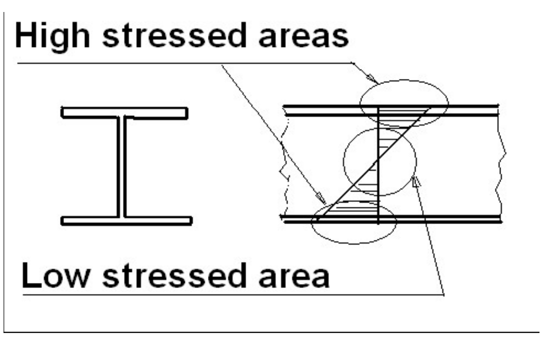
Total weight reduction: 680 kg

By introducing extra high strength steel in the trailer chassis, the amount of steel can be reduced from 3200 kg to 2520 kg. This is corresponding to an overall weight reduction of 21%

FIELD STUDY OF ATTACHMENTS AND CONNECTIONS

Below are examples from 2002-RAI Transport exhibition in Amsterdam. The aim is to give an idea of different design solution within the transport sector. Examples are taken from existing designs. We will try to give an idea of good and bad design solutions to avoid fatigue problems.

For components such as main beams of trailers, which are exposed for fatigue loading, a good design practice is to avoid welded attachments at high stressed areas.



Design examples on support legs for trailers

Figure 34,

Figure 35

Welding on flanges is not good from fatigue point. It's always good to move away welds from flanges. Support legs can often be found welded on to the flanges. Above are two examples how support legs can be welded to the main beams without welding on flanges.
Support legs on upper left picture are bolted to the main beams in low stressed area. Good design from fatigue point of view.
Support legs on upper right picture are bolted and welded to the main beam in low stressed area, good from fatigue point of view.

Figure 36

Above support legs are welded on to the flanges. The fatigue life depends on how high the stresses are in this area. Not a good design.

More design examples

Figure 37

Figure 38

Above are two examples of support mounted on the main beams. The top one is using a lot on welds around the support and welds are place both on top and bottom flanges. Bottom figure shows different solutions were all welds are removed from the flanges and the whole support is bolted to the web. The bottom design is much better from a fatigue point.

Below are examples of how to use the good formability of modern material to minimize welds on critical areas.

Figure 39

Above an example of how to change depth on a roll formed C-channel.

Figure 40

A rear axle pressed in high strength steel.

Design examples of cross member mounting on main beam

A common way of mounting cross members to main beams is to weld them together. If the cross member web is welded according to figure below, the connection will be very stiff and cause high local stresses on the main beam.

Figure 41

A better alternative connection is below. A hole is made in the main beam web and the cross member is only welded in the web. This is a less stiff connection and better from a fatigue point.

Figure 42

Other but more expansive ways are different kinds of bolt connections. See figures below.

Figure 43

Figure 44

Good design examples on cross members and main beams can be found on truck chassis. Below are a few examples of bolted connections with different design solutions.

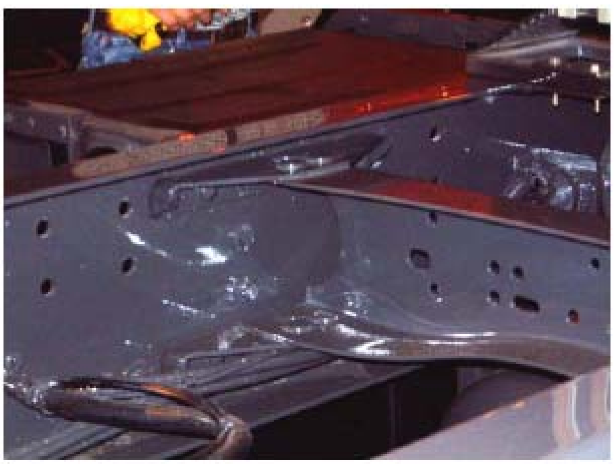


Figure 45

Figure 46

CONCLUSION AND DISCUSSION

With the trailer case study presented in this report it´s shown that the implementation of extra high strength steel offers big advantages in terms of improved pay load and reduce manufacturing cost. The weight of the trailer chassis has potential of being reduced by 680 kg.

From FE-analysis it is shown that most of the trailer is rather low stresses and changing material to thinner sheets should not encourage huge problems. For some areas, (e.g in the transition from full height side member to the kingpin position) it is recommended that modification and redesigns are made in order to improve the fatigue performances so that more can be gain from the benefits that offers with the use of EHS.

The extra effort and cost that may be needed to redesign critical areas and change material is shown to be a good investment. The material cost for the steel sheet has actually potential to be reduced, if the weight reduction is more that the price increase of EHS compared to mild steel. In this case we have assumed a price increase by 12.5 %, which should be compared to the potential weight reduction of 21%.

Welding cost have also potential to be reduced. The calculation example presented shows a reduction from 1770 Euro to 884 Euro. Assuming an annual transportation distance of 100.000 km, another example shows that the 680 kg less weight results in reduction of diesel with 312 litres.

ACKNOWLEDGEMENTS

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- The engineers at the trailer manufacturer for letting us use one of their trailers in the study, but also for valuable discussions of trailer design is general.
- The people at Epsilon High Tech Enginnering for their competence in FEA analyses of trailers.
- Prof. Rune Lagneborg for assistance.

REFERENCE LIST

(1) Nilsson T., Welding of Domex extra high strength cold forming steels.

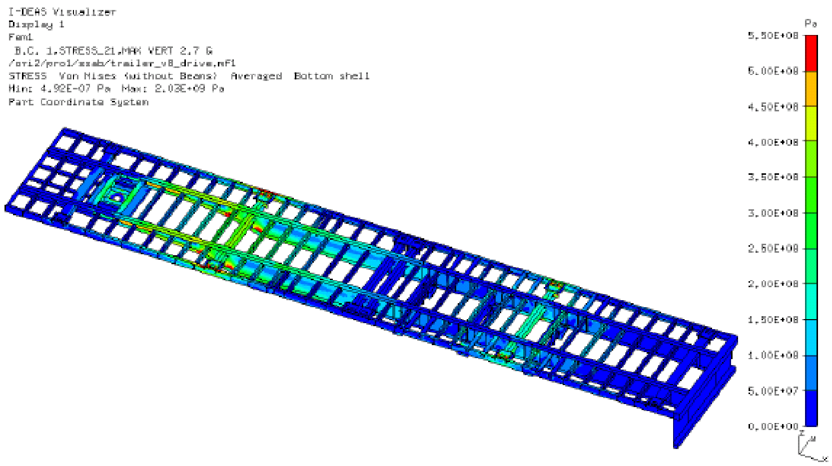
(2) Discussions with Mr. Schneide at THE STEEL COMPANY Tunnplåt AB in Germany who previously worked for a trailer producer.

(3) Discussions with Bernt von Brömssen at IVF (Institutet för Verkstadsteknisk Forskning)

(4) The International Institute of Welding. ISBN 1 85573 315 3

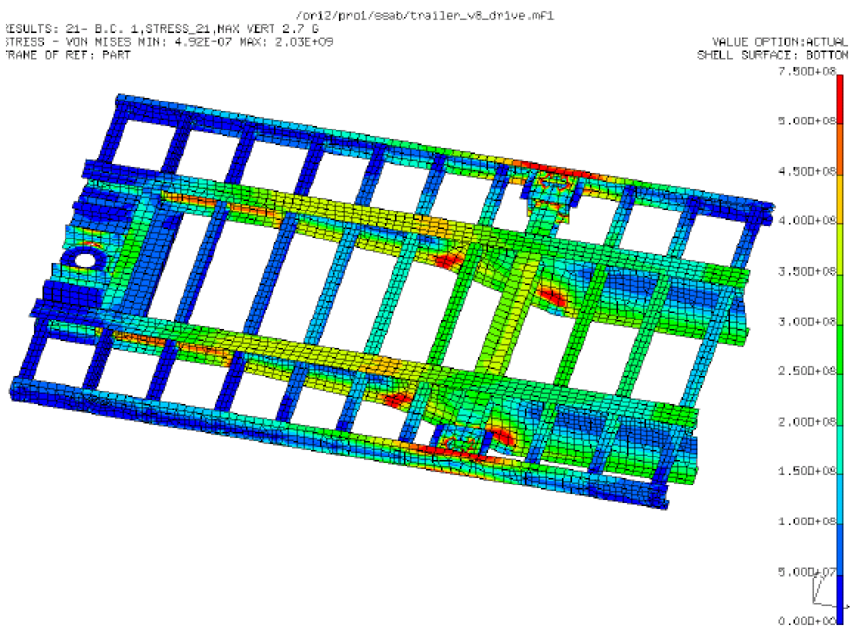
Appendix 1. FE-results from static load cases

Load case M1.



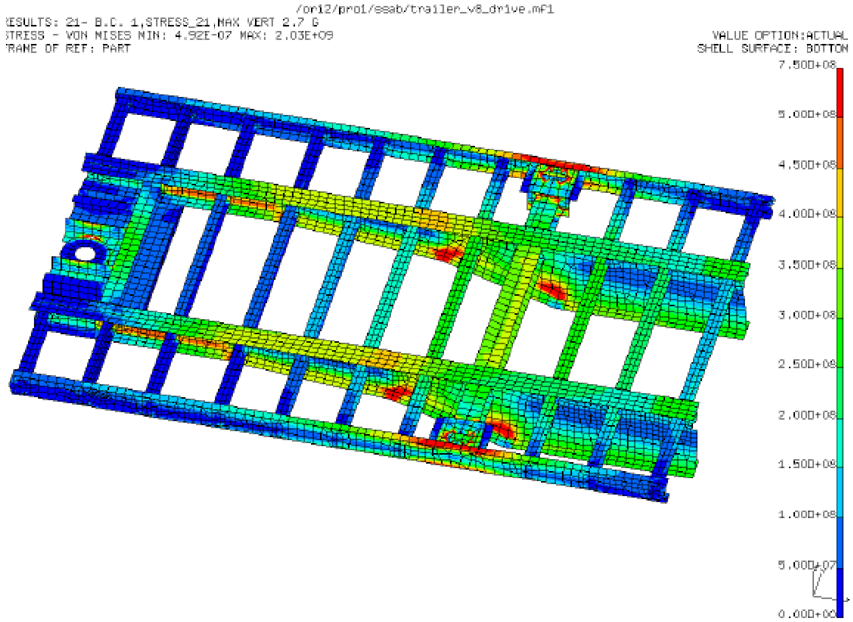
Results (von Mises stresses in Pa) for the vertical load case.

Load case M1.



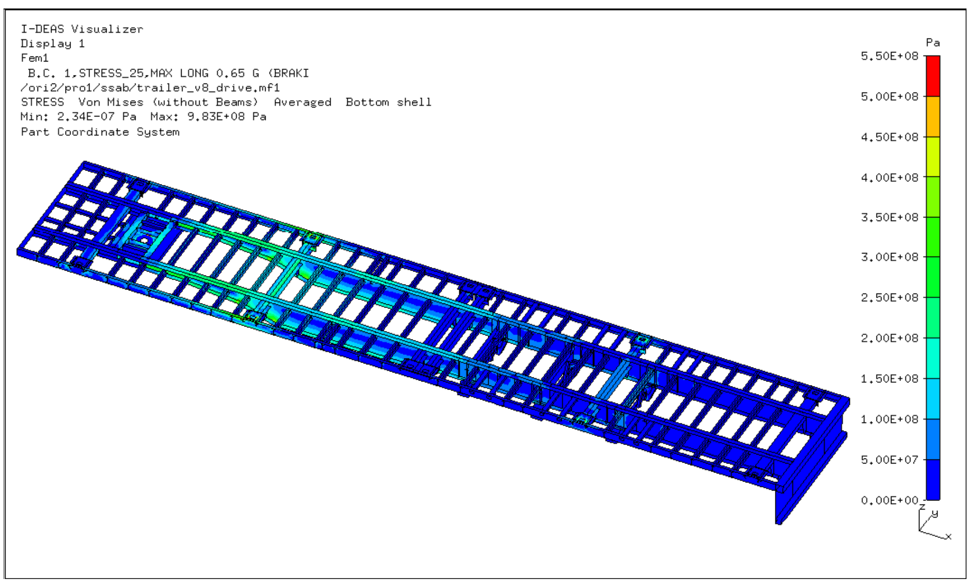
Results (von Mises stresses in Pa) for the vertical load case.

M2. Lateral maximum load case



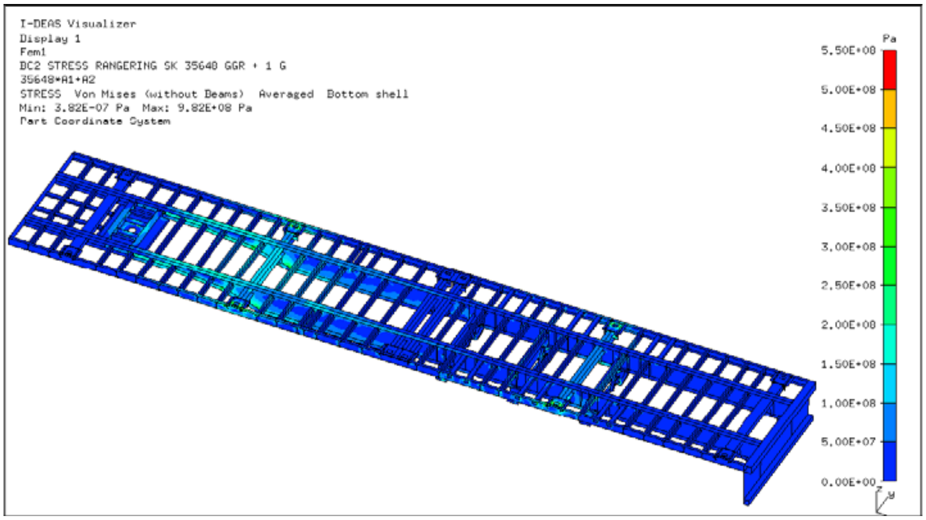
Results (von Mises stresses in Pa) for the lateral maximum load case.

M3. Longitudinal maximum load case



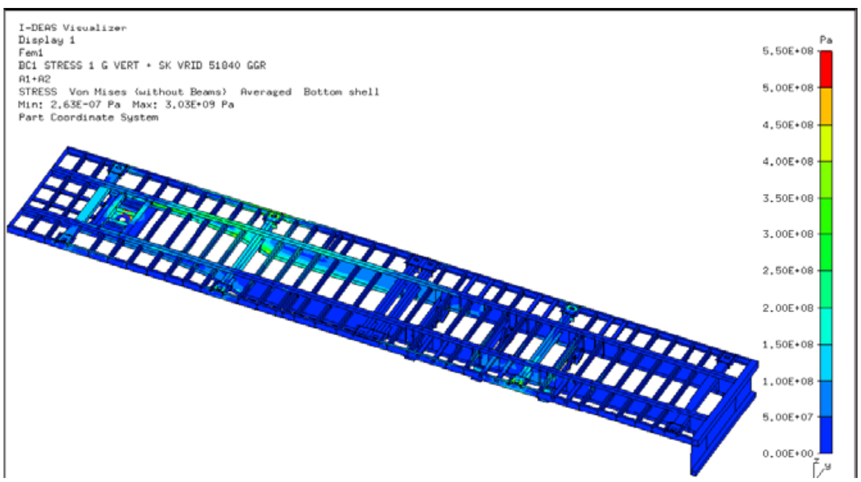
Results (von Mises stresses in Pa) for the longitudinal maximum load case.

M4. Marshalling maximum load case



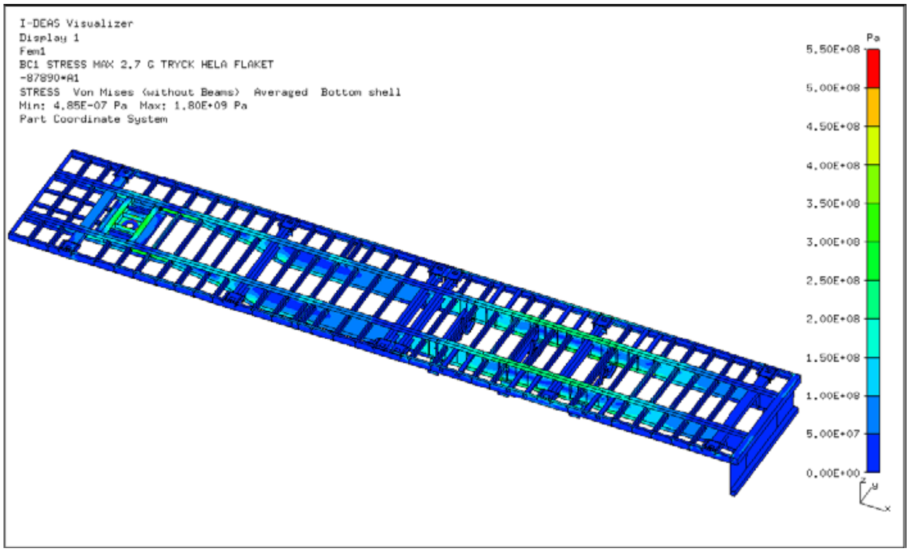
Results (von Mises stresses in Pa) for the marshalling maximum load case.

M5. Torsion load case



Results (von Mises stresses in Pa) for the torsion maximum load case.

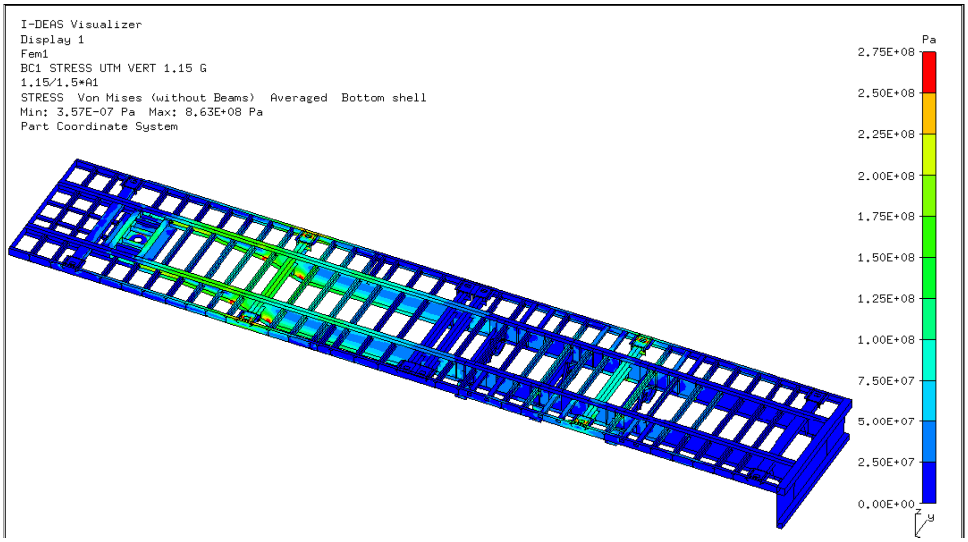
M6 Distributed load, 2.7g (evenly distributed on trailer bed)



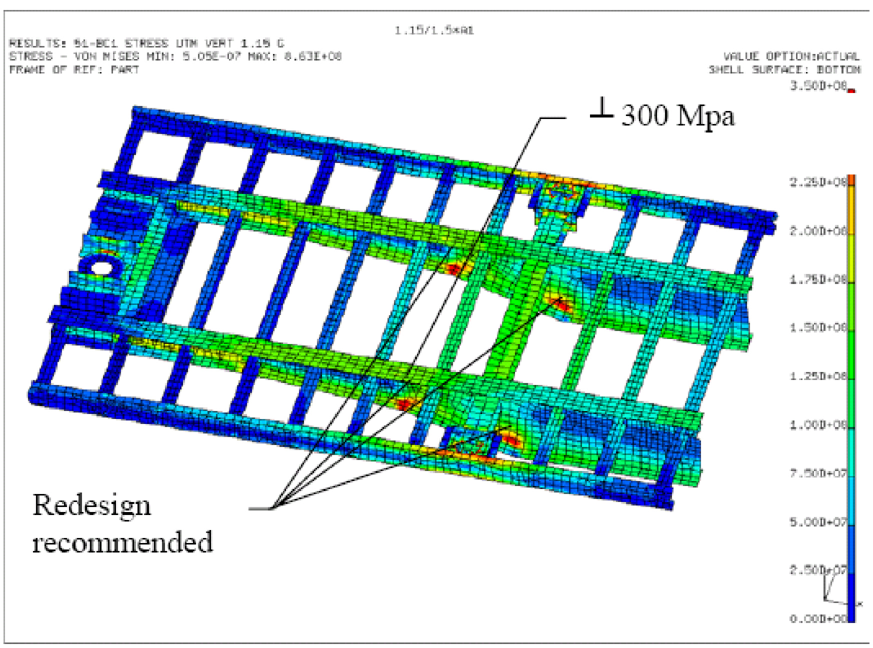
Results (von Mises stresses in Pa) for the distributed maximum load case.

Appendix 2. FE-results for fatigue load cases

F1 Vertical fatigue load case

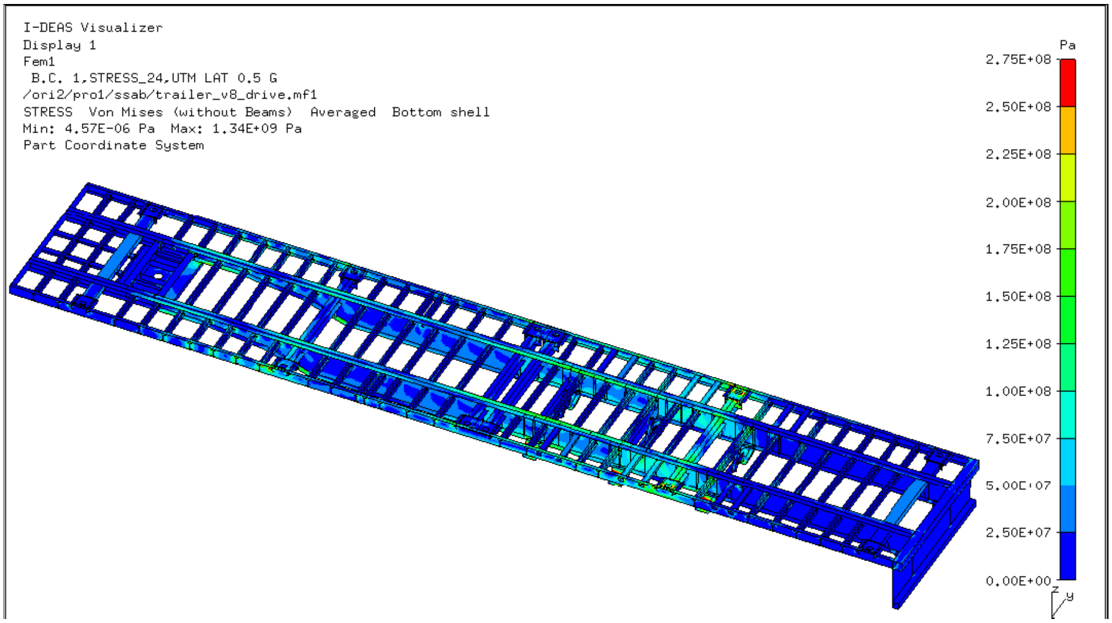


Results (von Mises stresses in Pa) for the vertical fatigue load case.



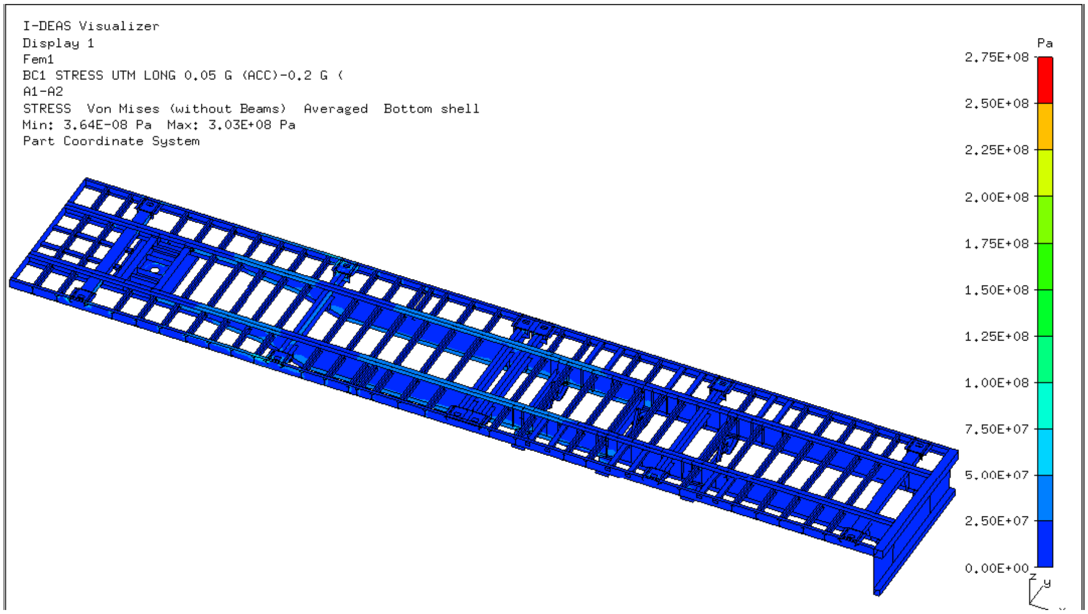
Results (von Mises stresses in Pa) for the vertical fatigue load case, front part of trailer seen from above.

F2 Lateral fatigue load case



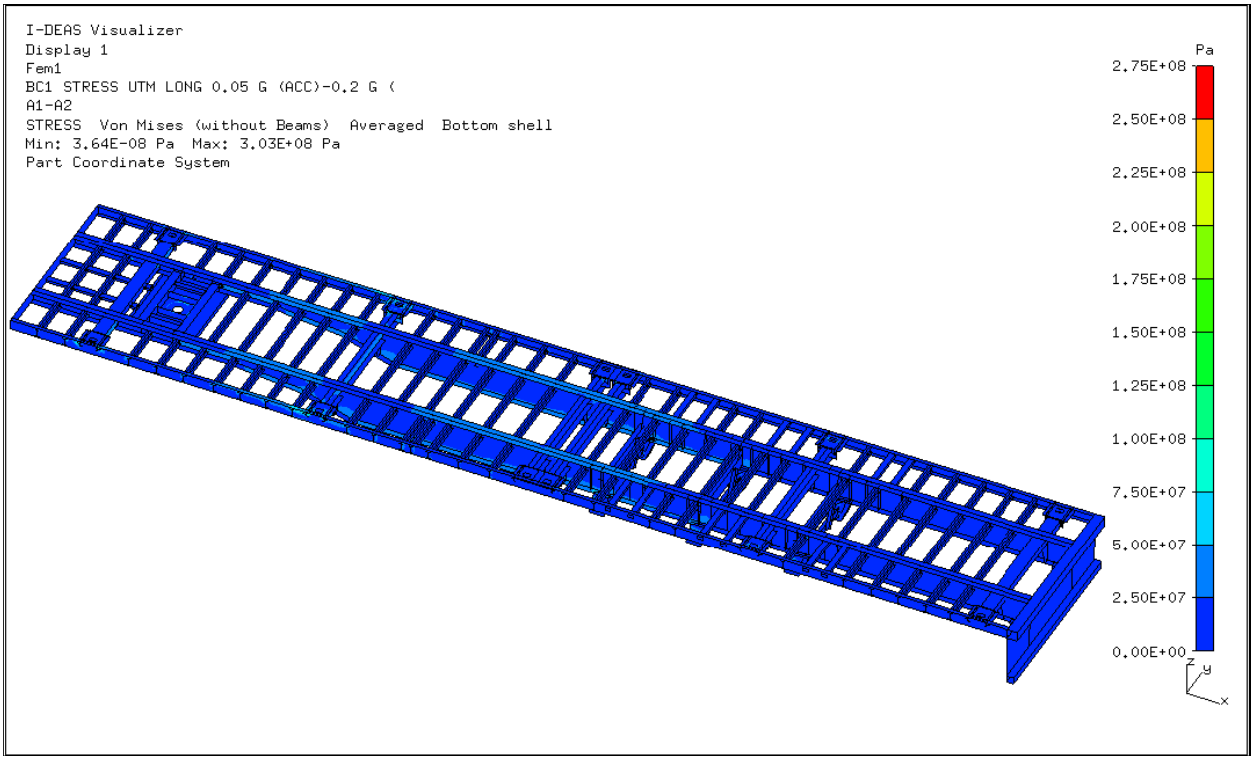
Results (von Mises stresses in Pa) for the lateral fatigue load case.

F3 Longitudinal fatigue load case



Results (von Mises stresses in Pa) for the longitudinal fatigue load case.

F4. Distributed fatigue load case



Results (von Mises stresses in Pa) for the distributed fatigue load case.