Diploma Thesis

Static Calculations for Electric Train

According to Norms

DIN EN 12663 and ERRI B 12/RP 60

Inda Balagić

Statische FE Berechnungen
für E-Zug nach
DIN EN 12663 und ERRI B 12/RP 60 Normen

Diplomarbeit

zur Erlangung des akademischen Grades einer Diplom-Ingenieurin

Studienrichtung: Maschienenbau

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November, 2010.

Diese Arbeit ist in englischer Sprache verfasst.

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for obtaining the academic degree of Diplom-Engineer

Field od study: Mechanical Engineering

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Deutsche Fassung:

Beschluss der Curricula-Kommission für Bachelor-, Master- und Diplomstudien vom 10.11.2008 Genehmigung des Senates am 1.12.2008

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Abstract

Safety is one of the decisive factors in traffic. The safety of rail traffic is statistically better, compared to other means of transport. Therefore is important to strive towards preservation and improvement of theese benefits.

In the traffic generally, there are passive and active measures that can be used to improve traffic safety. The active safety includes all measures which are trying to prevent accidents and thereby reduce their frequency. Passive safety is dealing with the consequences of accidents, with aim of reducing theese concequences, and thereby reducing the potential injuries to all participants.

During construction, every vehicles manufacturer has to satisfy the wishes of customer, and at the same time fulfill all the norms (passive safety standards), which are regulated by the legislation.

According to given intensivity of exploitation of the infrastructure, where the risk of collisions with road vehicles is really great, performance of the whole vehicle must comply standards that include "anti-crash" provisions (EN12663 and ERRI B 12/RP 60).

This work refers to the segment of testing the construction strength of the "anti-crash" provisions.

There are two basic ways to test security of the construction. The first possibility is an experiment, the crash test. This method is very expensive, primarily because it requires laboratory and all necessary equipment to carry out an experiment. Most companies can not afford it. The second possibility is much more approachable, and it refers to the software calculation of strength of the construction.

The idea is that CAD model, in real size, simulates the default situation, and on the basis of the entire series of given parameters (material, load, types of elements, etc.) tries to obtain realistic results. This way of obtaining the desired result is accepted in all standards.

This thesis is using this method of checking strength of construction of the electric train.

Kurzfassung

Sicherheit ist einer der entscheidenden Faktoren im Verkehr. Sicherheit im Schienenverkehr ist statistisch gesehen höher als bei anderen Verkehrsarten, und es gilt sie zu erhalten und womöglich noch zu erhöhen.

Es gibt generell zwei Arten von Maßnahmen, um die Sicherheit im Verkehr zu erhöhen – die passiven und die aktiven Maßnahmen. Die aktive Sicherheit schließt alle Maßnahmen ein, durch die versucht wird den Unfällen vorzubeugen, und dadurch ihre Häufigkeit zu reduzieren. Die passive Sicherheit bezieht sich auf die Folgen von den Unfällen – es wird versucht diese zu mildern, bzw. die potentiellen Verletzungen aller Teilnehmer im Verkehr zu minimieren.

Jeder Hersteller muss bei der Konstruktion der Schienenfahrzeuge die Wünsche der Konsumenten erfüllen, und gleichzeitig die rechtlich festgelegten Sicherheitnormen (passive Sicherheit Normen) einhalten.

Wegen der intensiven Nutzung der Infrastruktur, die zu einem erhöhten Risiko des Aufpralls mit den Straßenfahrzeugen führt, müssen bei der Konstruktion der Fahrerkabinen die Vorschriften eingehalten warden, die die “anti-crash” Maßnahmen (EN12663 und ERRIB 12/ RP 60) einschließen. Diese Arbeit bezieht sich auf das Segment der Prüfung Festigkeit der Konstruktion von “Anti-Crash”-Bestimmungen.

Es gibt zwei grundsätzliche Möglichkeiten die Sicherheit der Konstruktion zu prüfen.

Die erste Möglichkeit ist ein Experiment – der Aufpralltest. Diese Methode ist allerdings sehr kostspielig, weil sie ein Labor und alle für die Durchführung des Experiments notwendigen technischen Einrichtungen benötigt, die sich die meißten Unternehmen nicht leisten können. Die andere Möglichkeit ist viel zugänglicher, und sie bezieht sich auf die Software-Streßberechnung der Konstruktion.

Die Idee ist, dass das CAD-Modell die Standardsituation in der realen Große simuliert, und auf der Basis einer ganzen Reihe gegebener Parameter (Material, Last, Typen von Elementen usw.), die gegebenen Resultate die realistische Ergebnisse versucht zu erhalten. Diese Art der Erlangung der Resultate ist in allen Normen akzeptiert.

Dieser Arbeit wurde diese Methode der Streßberechnung für den elektrischen Zug verwendet.

Contents

1	Introduction	9
2	Methodology and structure of the working	11
3	Analysis and Selection of Standards	13
3.1	Loads - EN 12663	14
3.1.1	Vehicle masses	14
3.1.2	Structural requirements	15
3.1.4	Static strength and structural stability	16
3.1.5	Load cases	19
3.2	Stress - ERRI B12/RP 60	30
3.2.1	Definition of welded joints categories	30
4	Geometry analysis	34
5	CAD Model construction	35
6	FE Model construction	36
6.1	Algor software	37
6.1.1	Type of analysis - Static Stress with Linear Material Models	37
6.1.2	Analysis Parameters Information	37
6.1.3	Element Information	49
7	Visual results	59
7.1	Compressive forces in buffer and/or coupling area	59
7.1.1	Loads FEA Object : -750kN	59
7.1.2	Constraints FEA Object	59
7.1.3	Results	60
7.2	Tensile force in coupler area	63
7.2.1	Loads FEA Object : -400kN	63
7.2.2	Constraints FEA Object	63
7.2.3	Results	64
7.3	Compressive force 150 mm above the top of the structural floor at head stock	67
7.3.1	Loads FEA Object : -200kN	67
7.3.2	Constraints FEA Object	67
7.3.3	Results	68
7.4	Compressive force at the level of the waistrail (window sill)	71

7.4.1 Loads FEA Object : -150 kN 71
7.4.2 Constraints FEA Object 71
7.4.3 Results 72
7.5 Compressive force at the level of the waistrail (window sill) 75
7.5.1 Loads FEA Object : -150 kN 75
7.5.2 Constraints FEA Object 75
7.5.3 Results 76
7.6 Compressive force at the level of the cant rail 79
7.6.1 Loads FEA Object : -150 kN 79
7.6.2 Constraints FEA Object 79
7.6.3 Results 80
7.7 Compressive force at the level of the cant rail 83
7.7.1 Loads FEA Object : -75 kN 83
7.7.2 Constraints FEA Object 83
7.7.3 Results 84
7.8 Lifting at one end of the vehicle at the specified 87
lifting positions 87
7.8.1 Loads FEA Object: $1,1 \times g \times (m_1+m_3)$ 87
7.8.2 Constraints FEA Object 87
7.8.3 Results 88
7.9 Lifting the whole vehicle at the specified lifting positions 91
7.9.1 Loads FEA Object: $1,1 \times g \times (m_1+2m_3)$ 91
7.9.2 Constraints FEA Object 91
7.9.3 Results 92
7.10 Compressive force and vertical load 95
7.10.1 Loads FEA Object: $gx(m_1+m_2)$ 95
7.10.2 Constraints FEA Object 95
7.10.3 Results 96
7.11 Compressive force and vertical load 101
7.11.1 Loads FEA Object: $g \times m_1$ 101
7.11.2 Constraints FEA Object 101
7.11.3 Results 102
8 Conclusion 105
9 Bibliography 106

1 Introduction

Safety is one of the decisive factors in traffic. The safety of rail traffic is statistically better, compared to other means of transport. Therefore is important to strive towards preservation and improvement of theese benefits.

In the traffic generally, there are passive and active measures that can be used to improve traffic safety. The active safety includes all measures which are trying to prevent accidents and thereby reduce their frequency. Passive safety is dealing with the consequences of accidents, with aim of reducing theese concequences, and thereby reducing the potential injuries to all participants. Passive safety defines all the requirements for the design of vehicles that must be adhered during construction. Passive safety is prescribed with norms. Requirements are changing with time and tend to achieve maximal security.

During construction, every vehicles manufacturer has to satisfy the wishes of customer, and at the same time fulfill all the norms (passive safety standards), which are regulated by the legislation.

In the case of Electric train (ET) customer is a Croatian railway, and their requests are explicitly stated in the Technical conditions. According to the requirements, the train is designed for passenger transport in the wide area of the city of Zagreb. Individual travel time is about 60 minutes between the average length of 50 km, and with pausing after every 1-5 km the route crossed.

According to given intensivity of exploitation of the infrastructure, where the risk of collisions with road vehicles is really great, performance of the whole vehicle must comply standards that include "anti-crash" provisions (EN12663 and ERRI B 12/RP 60).

This work refers to the segment of testing the construction strength of the "anti-crash" provisions.

There are two basic ways to test security of the construction. The first possibility is an experiment, the crash test. This method is very expensive, primarily because it requires laboratory and all necessary equipment to carry out an experiment. Most companies can not afford it. The second possibility is much more approachable, and it refers to the software calculation of strength of the construction.

The idea is that CAD model, in real size, simulates the default situation, and on the basis of the entire series of given parameters (material, load, types of elements, etc.) tries to obtain realistic results. This way of obtaining the desired result is accepted in all standards.
The accuracy of results depends on the whole series of arguments and never shows the full real condition but with the help of various simplification can be obtained about the exact solution that meets. This way of obtaining the desired result is accepted in all standards.
This thesis is using this method of checking strength of construction of the electric train.

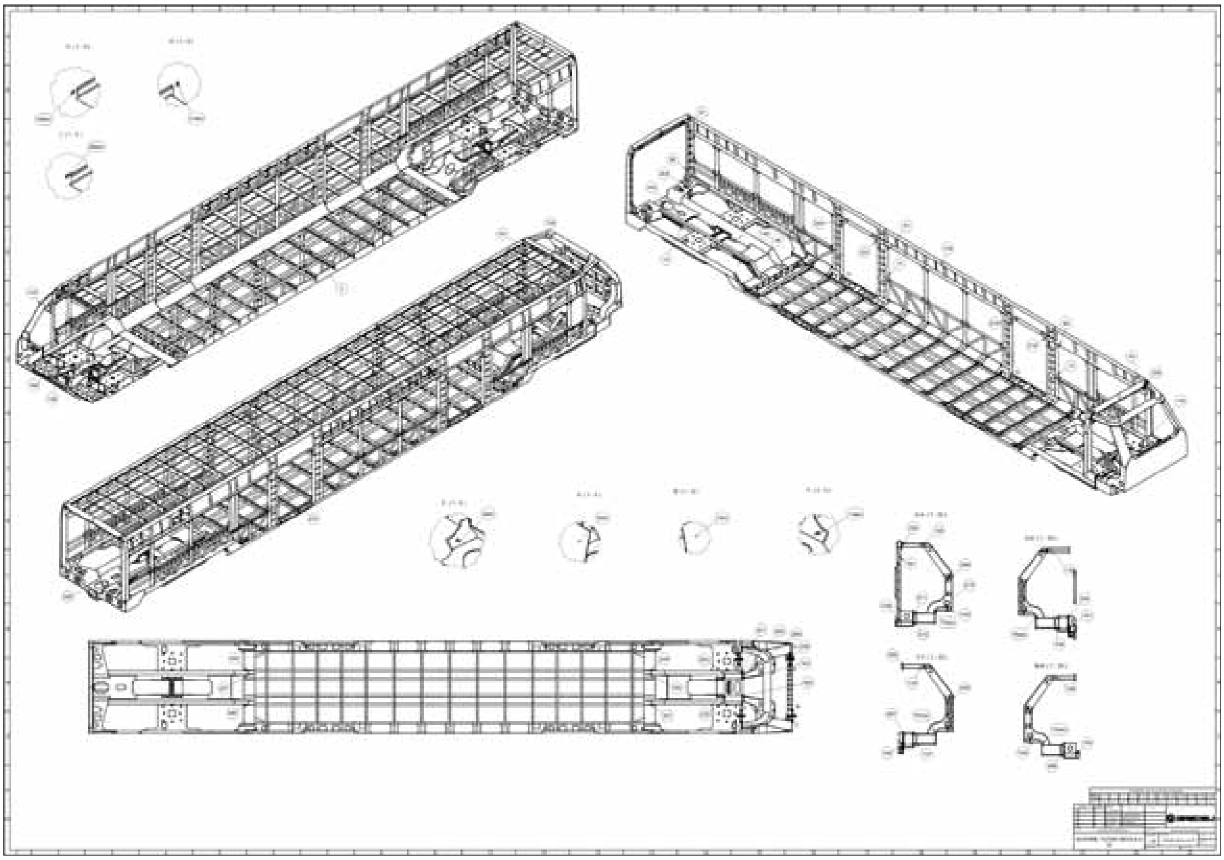


Image 1: Construction model of electric train

2 Methodology and structure of the working

The first step in the calculation of the any construction is introducing to the prototype itself. The model I got was made in scale 1:1. After consultation with the designer engineers I divided the model of train into segments (floor, site, roof, portal, driver cabin, bogie carrier) and studied certain materials, parts, connections between components.
Prototype CAD model of Electric train is designed as a steel constructions that should satisfy all the safety conditions and hold on all the load that it is exposed during use (the weight of equipment, a bogie, passengers, etc.).

After that I started with analysis of standards that include security testing strength of rail vehicle, I made a selection of standards that meet client's demands. Choice of standards was relatively easy because it was given by the technical specification of buyer.
By detaild studying of norms I determined the individual load cases and boundary conditions that apply to construction. It required a lot of time.

Strength of construction can be examineted whit finite element simulation method using a appropriate software packages. I have been used Algor software package.
FE software packages provide the option of direct construction of a desired model as well as importing model from compatible Cad software package. Because of the complexity of construction for me was easier first to made a Cad model in Cad software package, in this case - Autodesk Inventor, and model as such, in shall and plate elements, imported into Algor.
By the requests that are indicated in the European standard DIN EN 12663 and ERRIB 12/RP 60, the static analysis has been made for the CAD model of Electric train for regional transport.

Respecting the original design (made by dipl.ing.P.Kovač, dip.ing.I.Bobinac) I created three-dimensional model of ET, performed in a scale 1:1 with smaller disparities-simplification for easier adjustment to the FE software. Deviations are taken into account in the budget and are negligible in comparison to the whole construction.

The model is by using STEP-translatora transferred to Algor software package. In Algor software were finite element network made, were given boundary conditions and at the end were calculated stress and strain of the construction.

Because of complexity and symmetry of the whole construction around the longitudinal axis in the analysis is half of the entire model made.

Used materials respect the Technical requirements for steel given by Croatian railway. It has expected durability of 50 years and was selected by the designers of the construction dipl. ing. P. Kovač and dipl.ing. I. Bobinac (S355J2G3C).

Model mass depends on the selection of the material (also limited by Technical requirements) and the standards.

After calculating all cases of loading, the data that I become, I put in the form of tables and figures.
I compared the obtained results with the standards, and for each case I made conclusion of any difference.

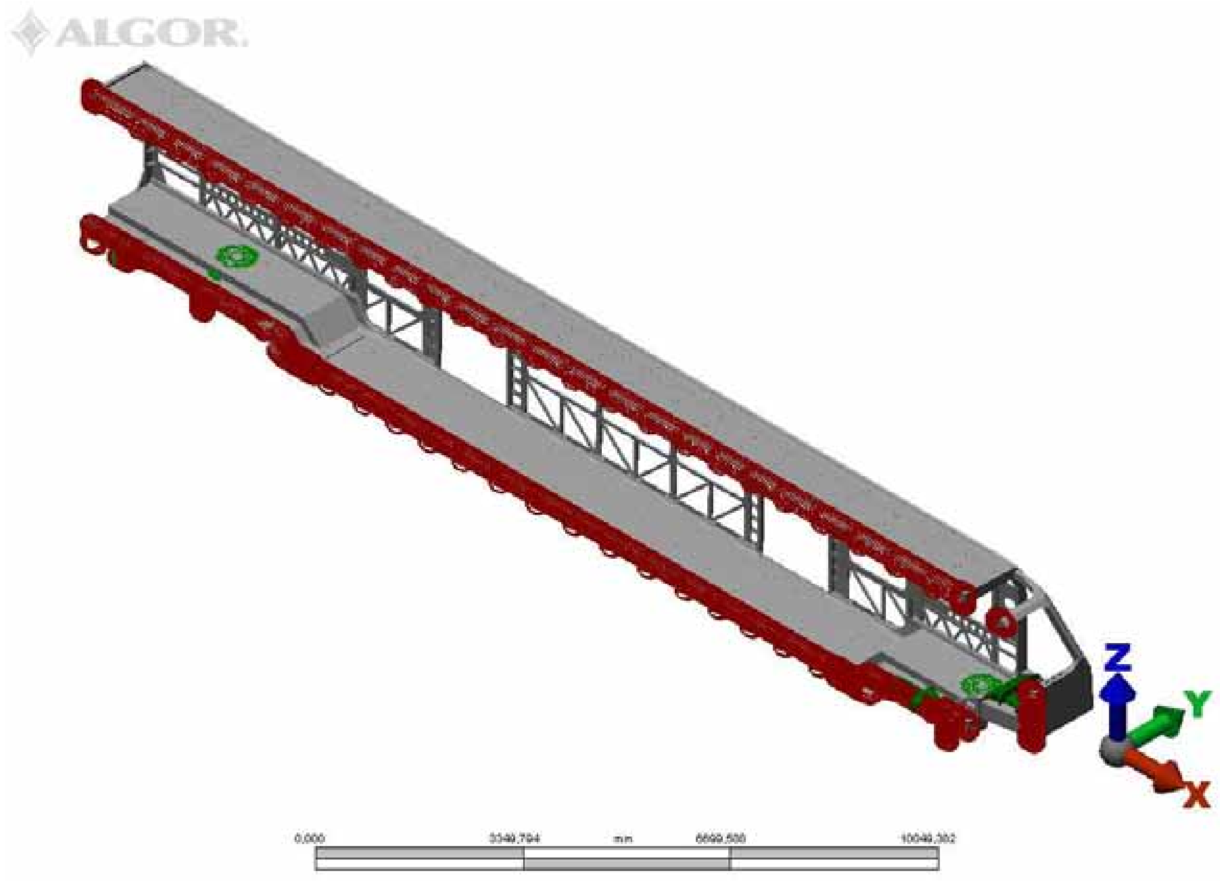


Image 2: FE model of electric train

3 Analysis and Selection of Standards

Depending on individual states and different associations in the market there is a whole range of standards that are referred to the "anti-crash" requirements.
So there are:
EN - norms and standards developed by the European Committee for Standardization,
DIN - norms issued by the German DIN institute,
ISO - norms and standards issued by the International Organization for Standardization,
UIC –norms issued by the worldwide international organisation of the railway sector,
ERRI – norms issued by European Rail Research Institute.

By the study of individual standards with the help of the Institute for Standardization Croatian, Gredelj engineers and Prof. Moser I came to the specific standards related to my problem. And these are for:

a) Loads
EN 5560 - Rail vehicles - Longitudinal strength of bodies of light railway vehicles,
EN 12663 - Railway applications - Structural requirements of railway vehicle bodies,
EN 15227 - Railway applications - Crashworthiness requirements for railway vehicle bodies,
DIN 5550-3- Testing as to running behaviour and acceptance of railway vehicles;
general rules for testing of driving safety and running behaviour,
UIC 518 - Testing and approval of railway vehicles from the point of view of their
dynamic behaviour - Safety - Track fatigue - Ride quality,
UIC 566 - Loadings of coach bodies and their components,
UIC 651 - Layout of driver's cabs in locomotives, railcars, multiple-unit trains and
driving trailers;

b) Stress
DIN 15018 - Cranes; steel structures; principles of design and construction,
IIW - International Institute of Welding (by ISO),
UNI EN 1993 Euro code 3 - Design of steel structures (Design of joints, Fatigue strength),
DVS 1612 - Design and fatigue testing of welded steel joints,
DS 952 - Quality of welds in rail vehicle construction (DB),
ERRI B 12/RP 60 - Regulation for proof tests and maximum permissible stresses.

3.1 Loads - EN 12663

Selected standard by which conducts the test is EN 12663.
This standard is specified in the Technical conditions given by the client.

This European Standard defines minimum structural requirements for railway vehicle bodies. It specifies the loads vehicle bodies shall be capable of sustaining, identifies how material data shall be used and presents the principles to be used for design verification by analysis and testing.
The railway vehicles are divided into categories which are defined only with respect to the structural requirements of the vehicle bodies.

ET belongs to the category of vehicles P-III (Passenger vehicles - Underground and rapid transit vehicles), while the front end of segments (drivers cabin area, gang) sized by category P-II (Passenger vehicles - Fixed units).

The standard applies to all railway vehicles within the EU and EFTA territories. The specified requirements assume operating conditions and circumstances such as are prevalent in these countries.

3.1.1 Vehicle masses

3.1.1.1 Mass of the vehicle body in working order m_1

The mass in working order m_1 consists of the completely assembled vehicle body with all mounted parts. This includes the full operating reserves of water, sand, fuel, foodstuffs etc. and the overall weight of staff.

3.1.1.2 Maximum payload m_2

The maximum payload m_2 is determined dependent on the type of vehicle. For passenger rolling stock, it depends on the number of seats for passengers and on the number of passengers per m_2 in the standing areas.
Typical weights for passengers:
- commuter/suburban - 70 kg per passenger.

Typical passenger densities in standing areas :

- commuter/suburban - 5 to 10 passengers per m^2.

Typical luggage area loading - 300 kg per m^2.

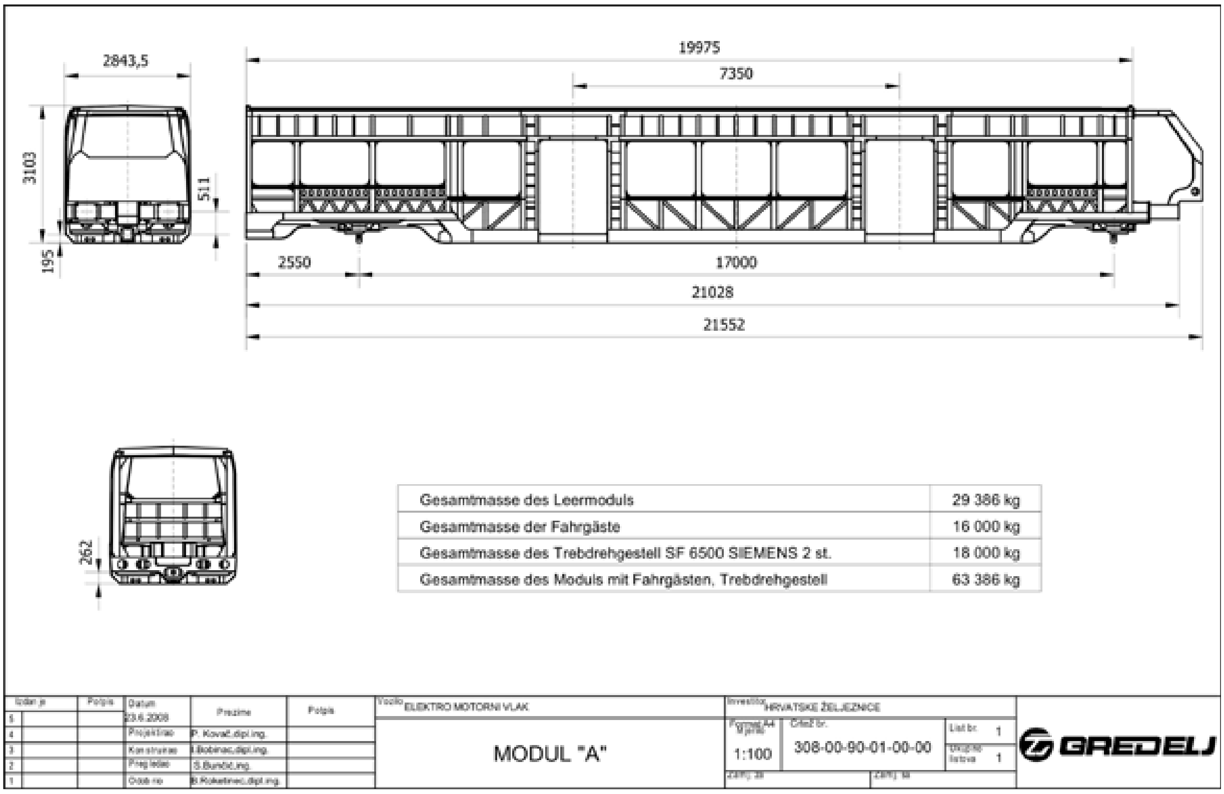


Image 3: Vehicle masses

3.1.2 Structural requirements

Railway vehicle bodies shall withstand the maximum loads consistent with their operational requirements and achieve the required service life under normal operating conditions with an adequate probability of survival.

The capability of the railway vehicle body to not sustain permanent deformation and fracture shall be demonstrated by calculation and/or testing. The assessment shall be based on the following criteria:

a)Exceptional loading defining the maximum loading which shall be sustained and a full operational condition maintained;

b) Acceptable margin of safety, such that if the exceptional load is exceeded, catastrophic fracture or collapse will not occur;

c) Stiffness, such that the deformation under load and the natural frequencies of the struc-

ture meet limits as determined by the operational requirements;
d) Service or cyclic loads being sustained for the specified life without detriment to the structural safety.

All formal parameters are expressed as SI basic units and units derived from SI basic units. The gravitational acceleration g is -9,81 m/s^2.

3.1.3 Material

In technical conditions client is demanding the steel S355J2G3.

S355J2G3 is calcium treated steel for inclusion modification. Contains soft, deformable calcium aluminates encapsulated in manganese sulphide rather than hard alumina oxide inclusions.
It has low carbon for weldability and the grain size is 5 or finer.
Chemical composition is C - 0.23, Si - 0.60,Mn - 1.70, P - 0.045,S - 0.045, Al - 0.05, V - 0.08.

3.1.4 Static strength and structural stability

It shall be demonstrated by calculation and/or testing, that no permanent deformation or fracture of the structure as a whole, or of any individual element, will occur under the prescribed design load cases.

3.1.4.1 Strength

Strength of materials refers to various methods of calculating stresses in structural members.
Stress is expressed by
where F is the force [N] acting on an area A [m^2].

$$\sigma = \frac{F}{A}$$

Compressive stress is the stress applied to materials resulting in their compaction (decrease of volume). When a material is subjected to compressive stress, then this material is under compression.

Tensile stress is a loading that tends to produce stretching of a material by the application of axially directed pulling forces. Any material which falls into the "elastic" category can generally tolerate mild tensile stresses. If a material is stressed beyond its limits, it will fail. The failure mode, either ductile or brittle, is based mostly on the microstructure of the material. Shear stress is caused when a force is applied to produce a sliding failure of a material along a plane that is parallel to the direction of the applied force.

Depending on the given load cases, on the construction are reported all three types of loads.

3.1.4.2 Yield

The yield strength of a material is defined as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed some fraction of the deformation will be permanent and non-reversible. In the three-dimensional space of the principal stresses (σ_1,σ_2,σ_3), an infinite number of yield points form together a yield surface.

Typical yield behavior for non-ferrous alloys:

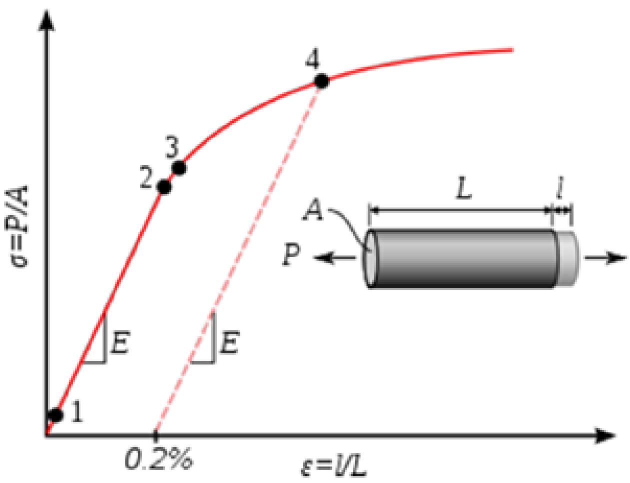


Image 4: Stress–strain curve

1 - True elastic limit

The lowest stress at which dislocations move. This definition is rarely used, since dislocations move at very low stresses, and detecting such movement is very difficult.

2 - Proportionality limit

Up to this amount of stress, stress is proportional to strain (Hooke's law - strain is directly proportional to stress), so the stress-strain graph is a straight line, and the gradient will be equal to the elastic modulus of the material.

3 - Elastic limit (yield strength)

Beyond the elastic limit, permanent deformation will occur. The lowest stress at which permanent deformation can be measured. This requires a manual load-unload procedure, and the accuracy is critically dependent on equipment and operator skill.

4 - Offset yield strength (proof stress)

This is the most widely used strength measure of metals, and is found from the stress-strain curve as shown in the figure to the right. A plastic strain of 0.2% is usually used to define the offset yield stress, although other values may be used depending on the material and the application. The offset value is given as a subscript, e.g., $R_{p0.2}$=310 MPa.

Area of interest of this work is proportionality limit with a prescribed safety.

3.1.4.3 Proof strength

The calculation is prescribed by the standard taking into account the calculated values of stresses and material properties.

Because design is verified only by calculation, S_1 is 1,15 for each individual load case. S_1 may be taken as 1,0 and than it is subject of agreement between designer and operator.

Under the static load cases, the ratio of permissible stress to calculated stress shall be greater than or equal to S_1.

$$\frac{R}{\sigma_c} \geq S_1$$

where:

R is the material yield (R_{el}) or 0,2% proof stress, (R_{p02}) in N/mm²

σ_c is the calculated stress, in N/mm².

In determining the stress levels in ductile materials, it is not necessary to take into account features producing local stress concentration. If the analysis does incorporate local stress concentrations, then it is permissible for the theoretical stress to exceed the material yield or 0,2% proof limit. The areas of local plastic deformation associated with stress concentrations shall be sufficiently small so as not to cause any significant permanent deformation when the load is removed.

3.1.5 Load cases

3.1.5.1 Longitudinal static loads for the vehicle body

a) Compressive forces in buffer and/or coupling area

Passenger rolling stock Category P-II - 1500kN

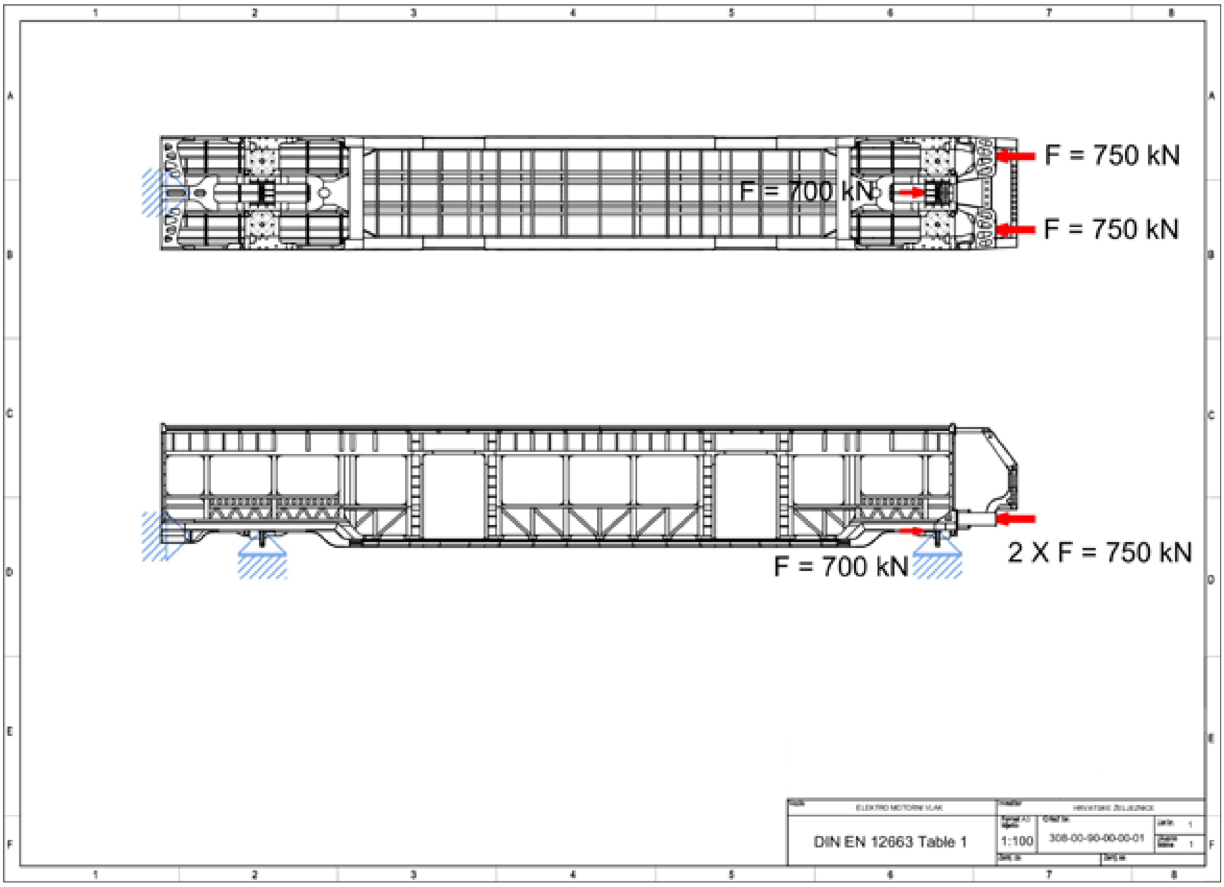


Image 5: Compressive forces in buffer and/or coupling area

b) Tensile force in coupler area

Passenger rolling stock Category P-II - 800kN

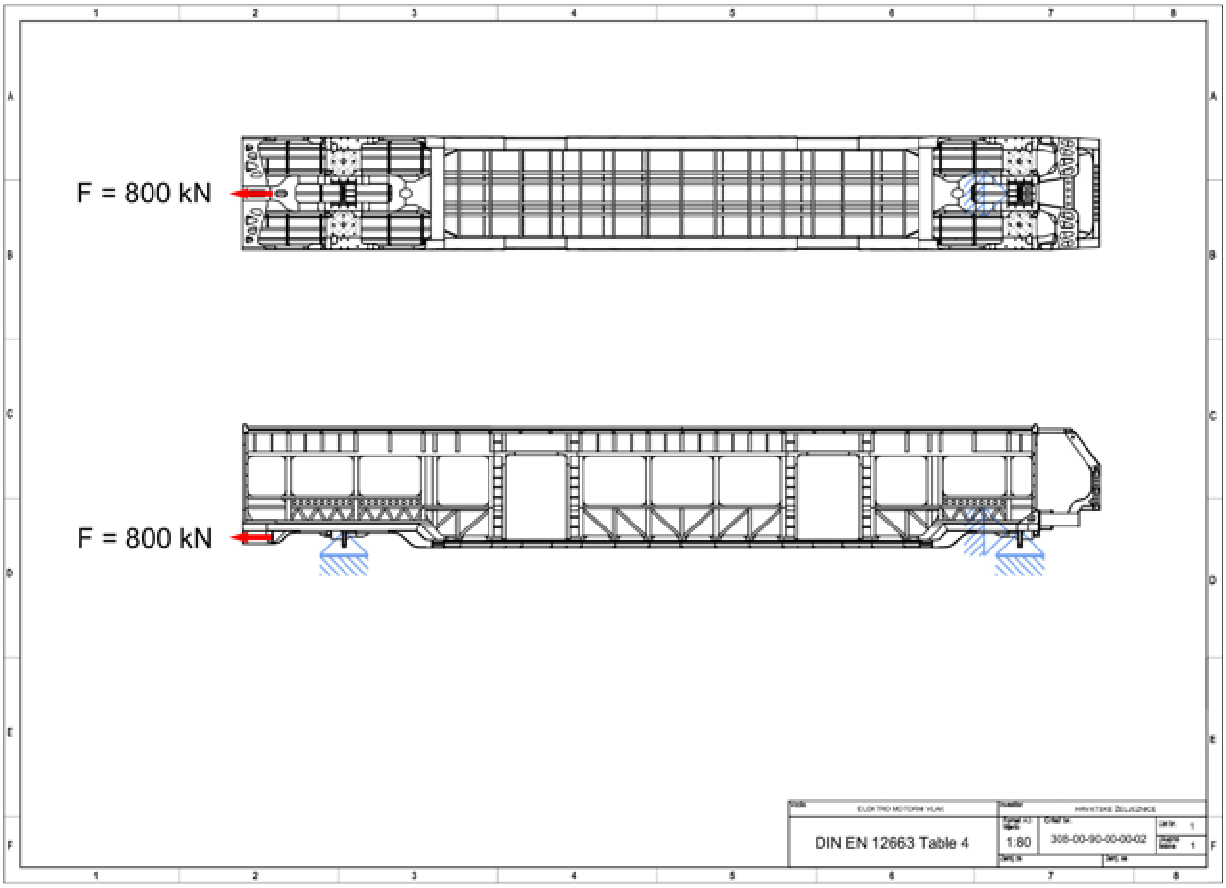


Image 6: Tensile force in coupler area

3.1.5.2 Compressive forces in end wall area

a) Compressive force 150 mm above the top of the structural floor at head stock

Passenger rolling stock Category P-II - 400kN

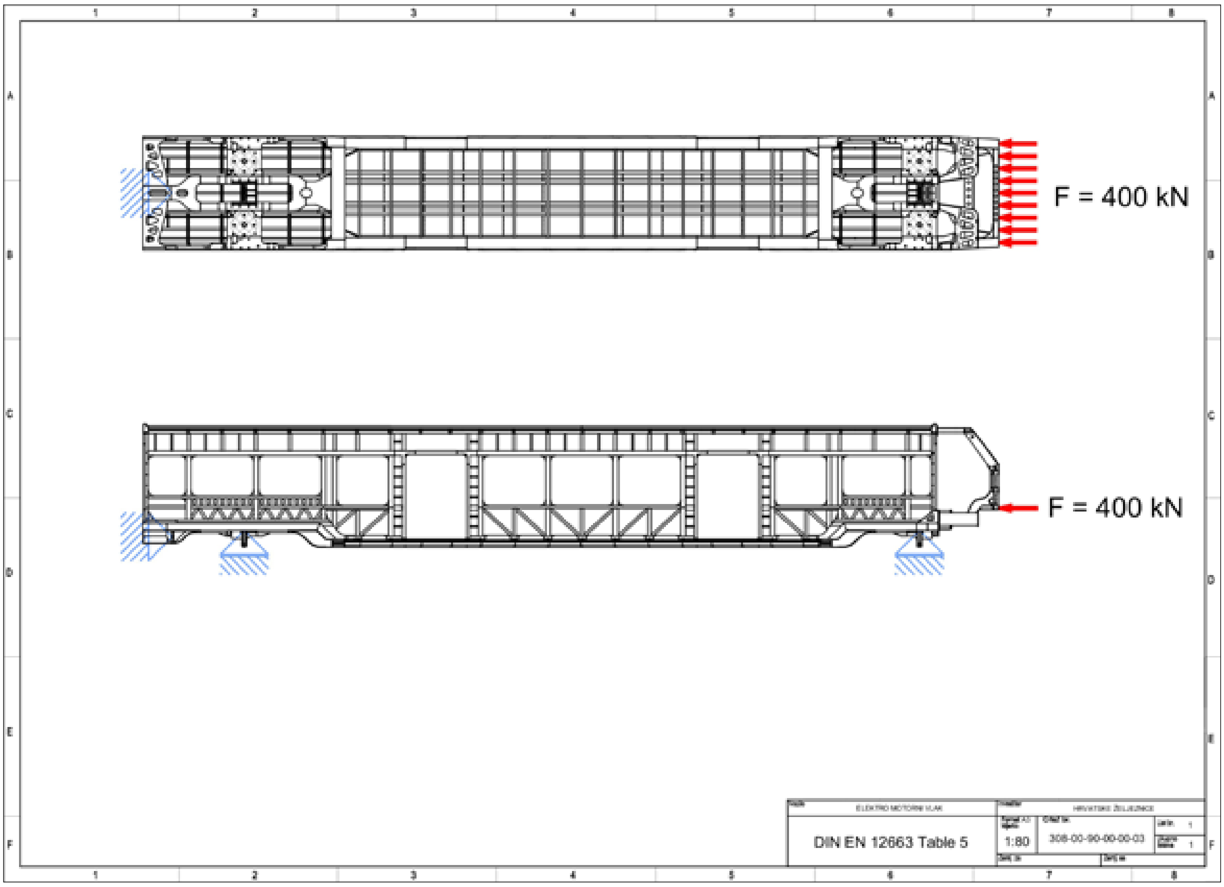


Image 7: Compressive force 150 mm above the top of the structural floor at head stock

b) Compressive force at the level of the waistrail (window sill)

Passenger rolling stock Category P-II - 300kN

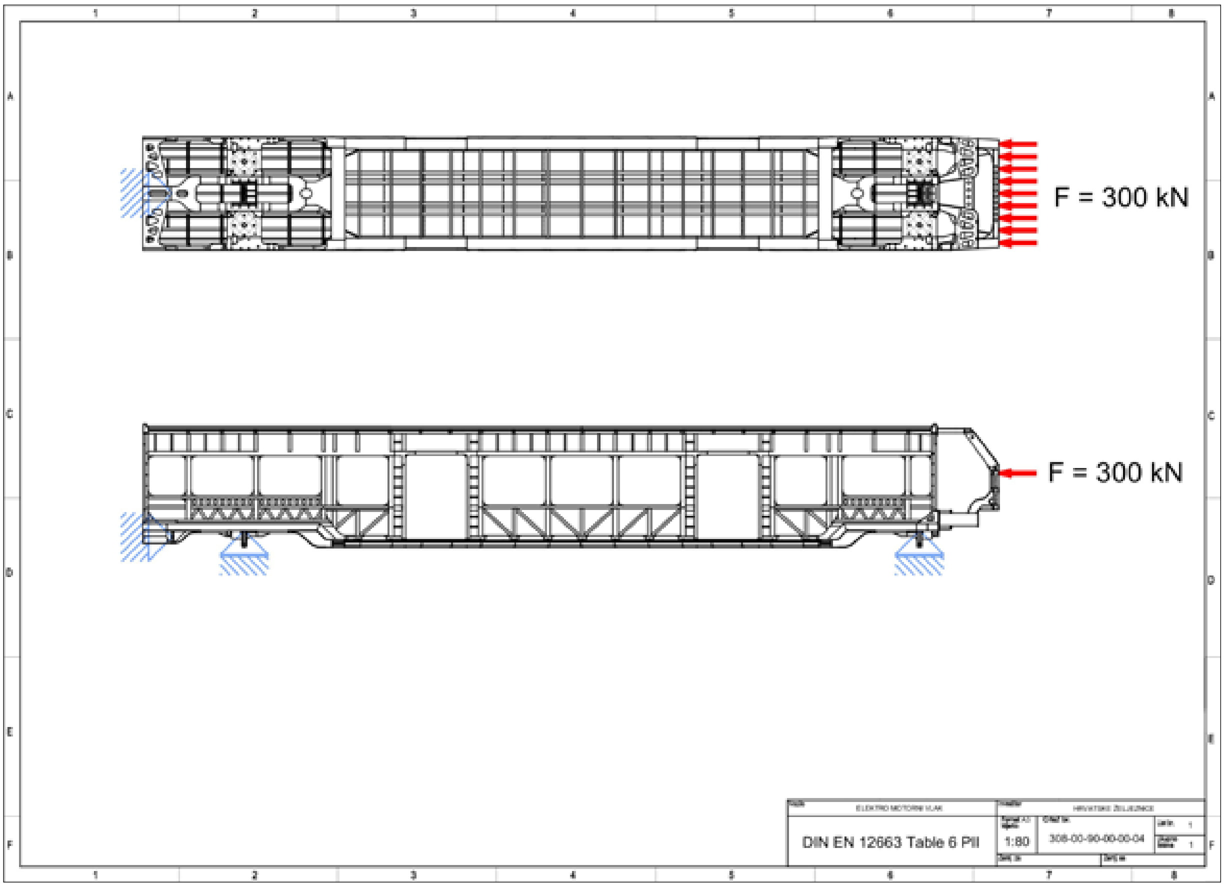


Image 8: Compressive force at the level of the waistrail (window sill)

c) Compressive force at the level of the waistrail (window sill)

Passenger rolling stock Category P-III - 300kN

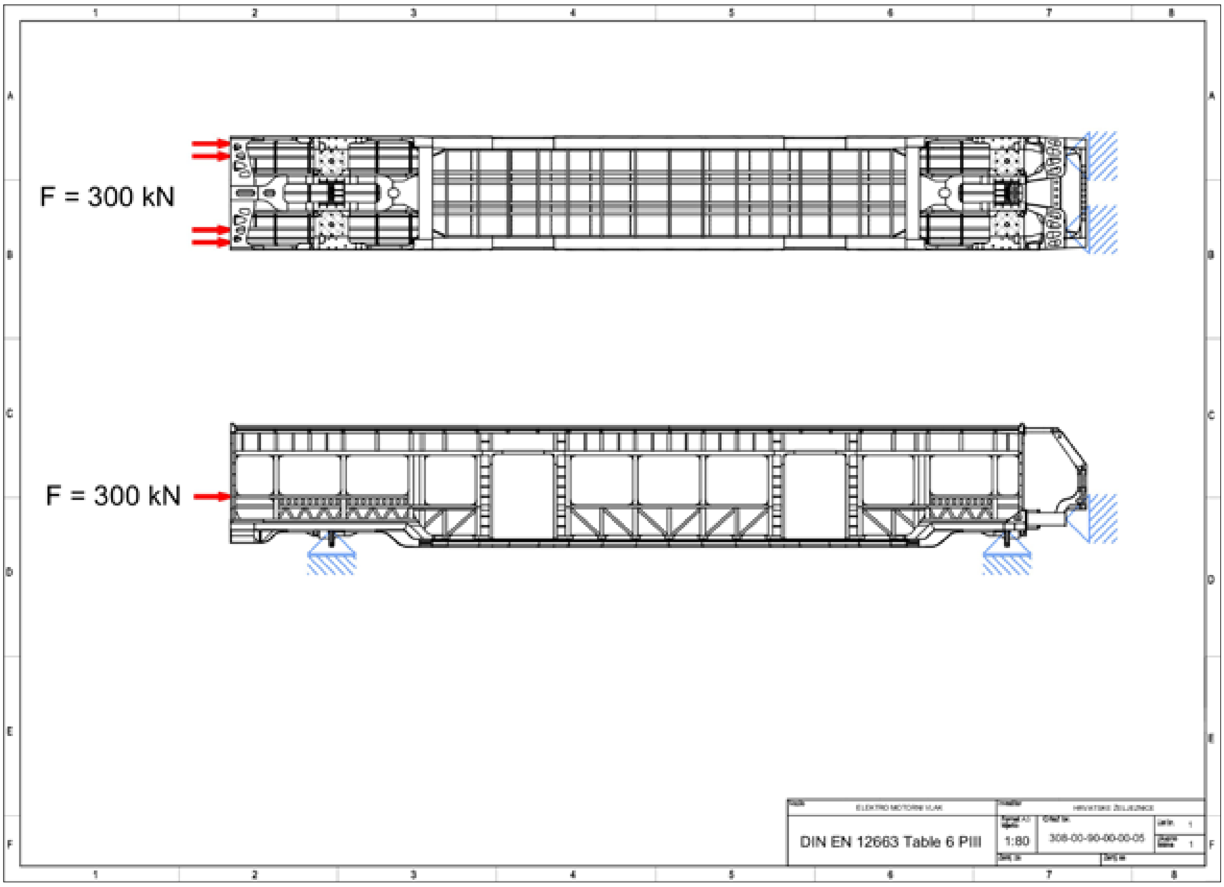


Image 9: Compressive force at the level of the waistrail (window sill)

d) Compressive force at the level of the cant rail

Passenger rolling stock Category P-II - 300kN

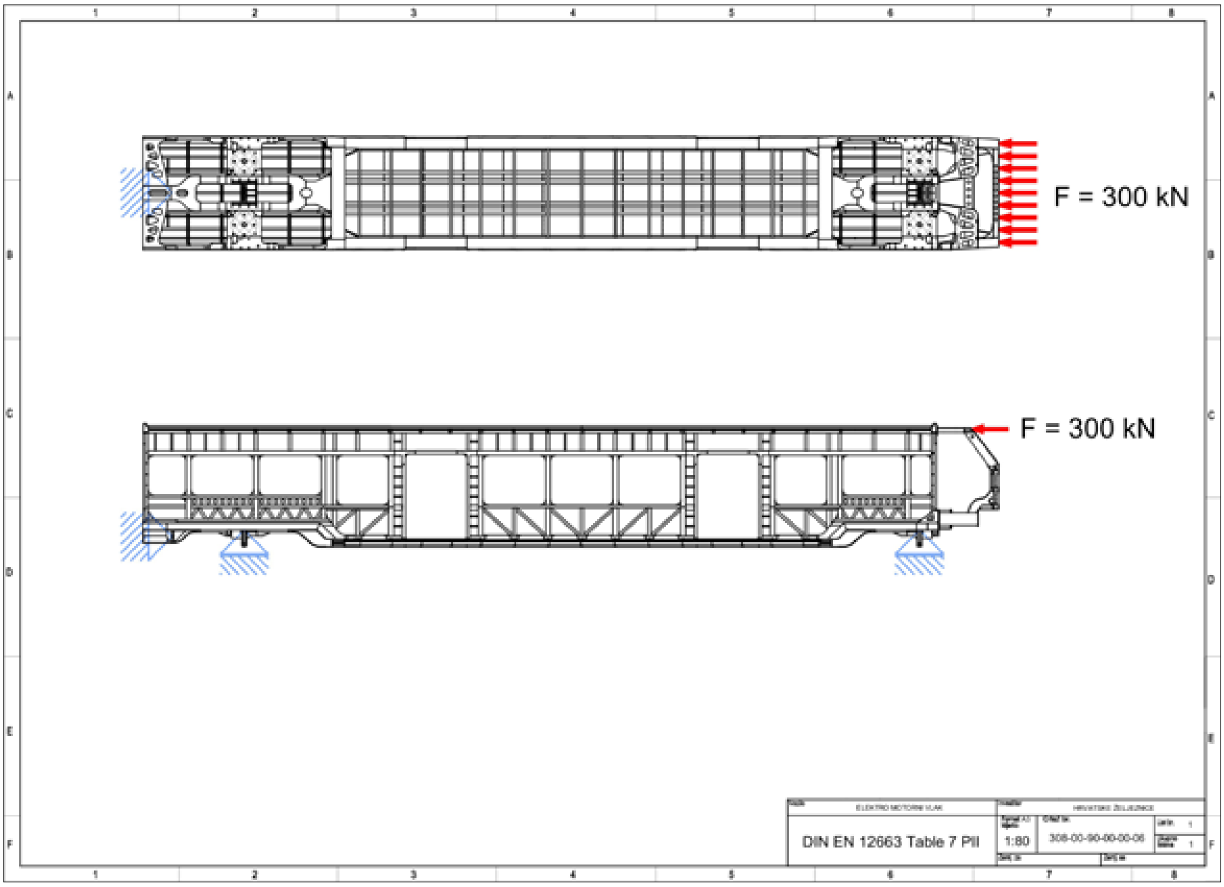


Image 10: Compressive force at the level of the cant rail

e) Compressive force at the level of the cant rail

Passenger rolling stock Category P-III - 300kN

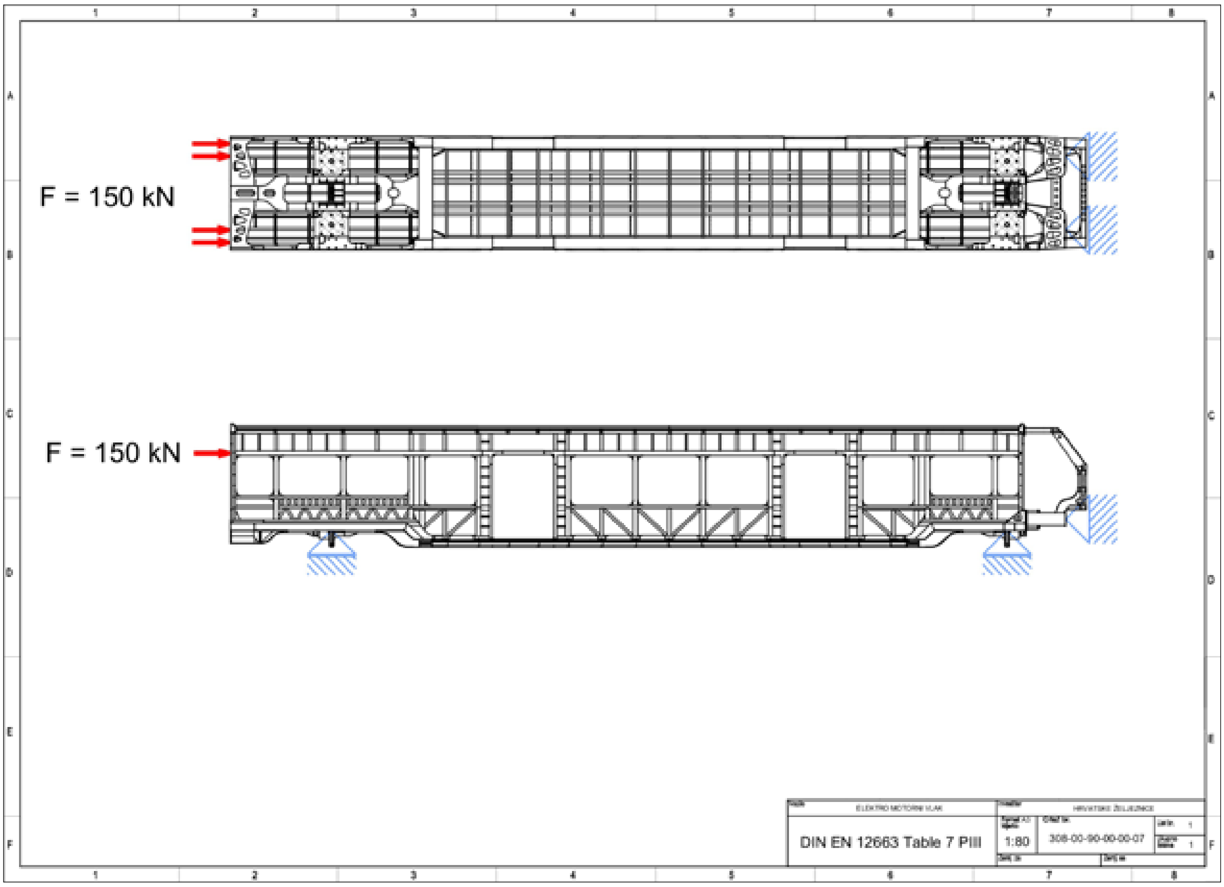


Image 11: Compressive force at the level of the cant rail

3.1.5.3 Lifting

a) Lifting at one end of the vehicle at the specified lifting positions

Passenger rolling stock Category P-II - $1,1xgx(m_1+m_3)$

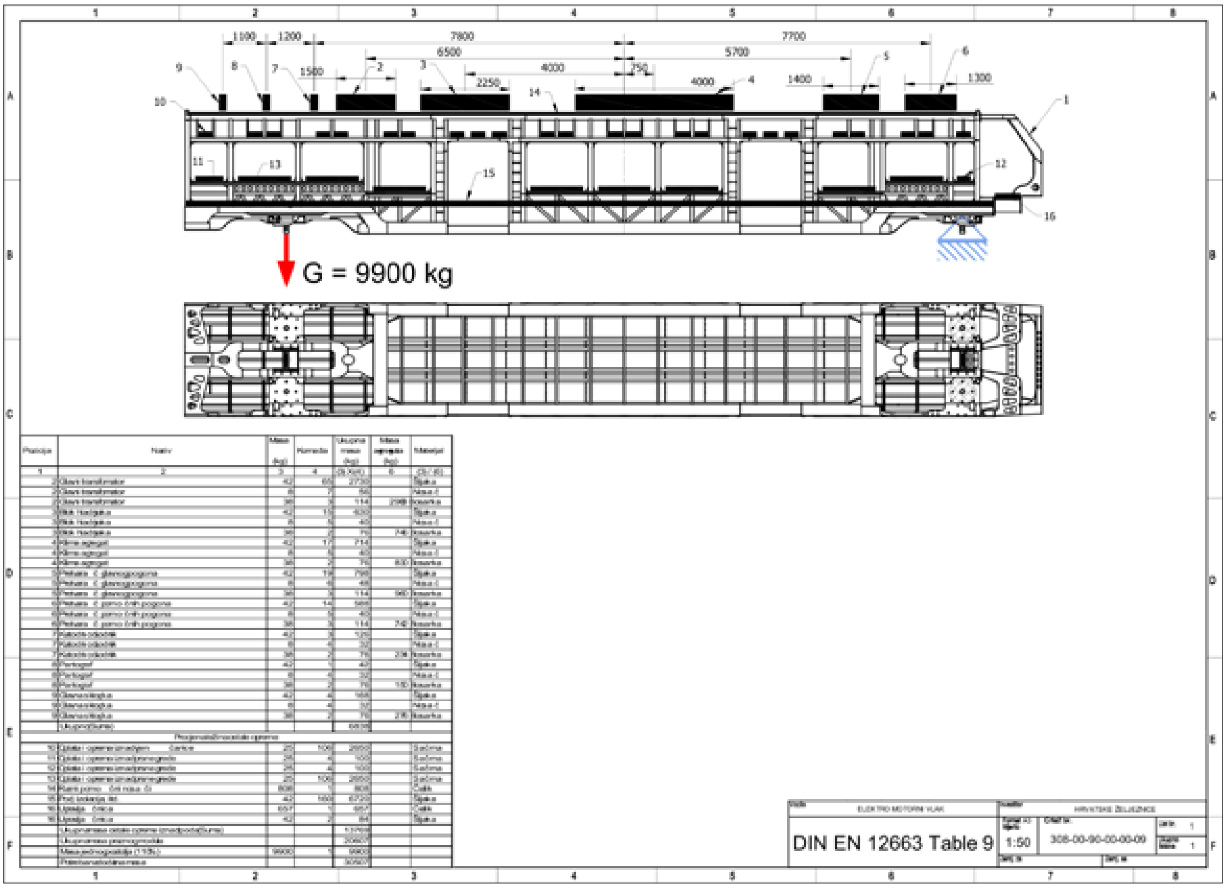


Image 12: Lifting at one end of the vehicle at the specified lifting positions

b) Lifting the whole vehicle at the specified lifting positions

Passenger rolling stock Category P-II - $1{,}1xgx(m_1+2xm_3)$

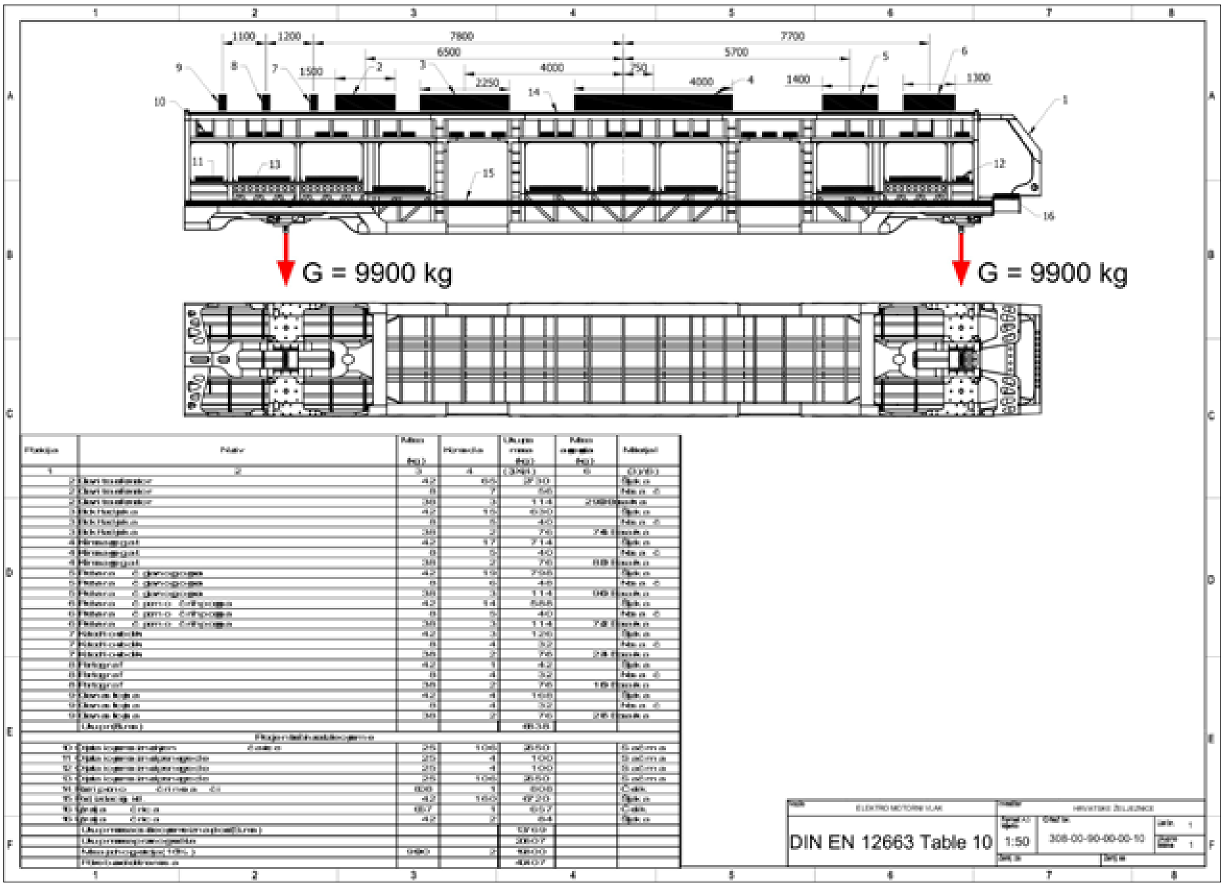
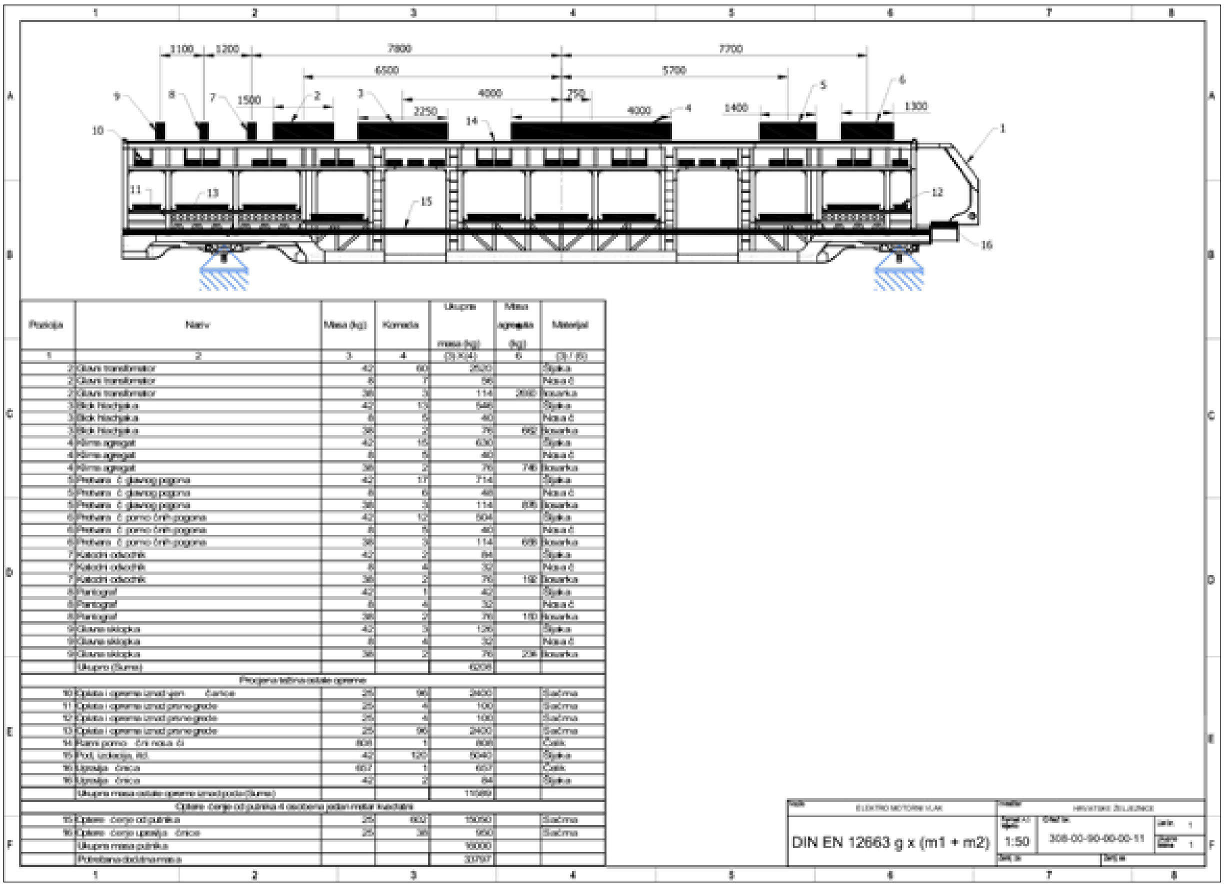


Image 13: Lifting the whole vehicle at the specified lifting positions

3.1.5.4 Superposition of static load cases for the vehicle body

a) Compressive force and vertical load

Passenger rolling stock Category P-II $gx(m_1+m_2)$

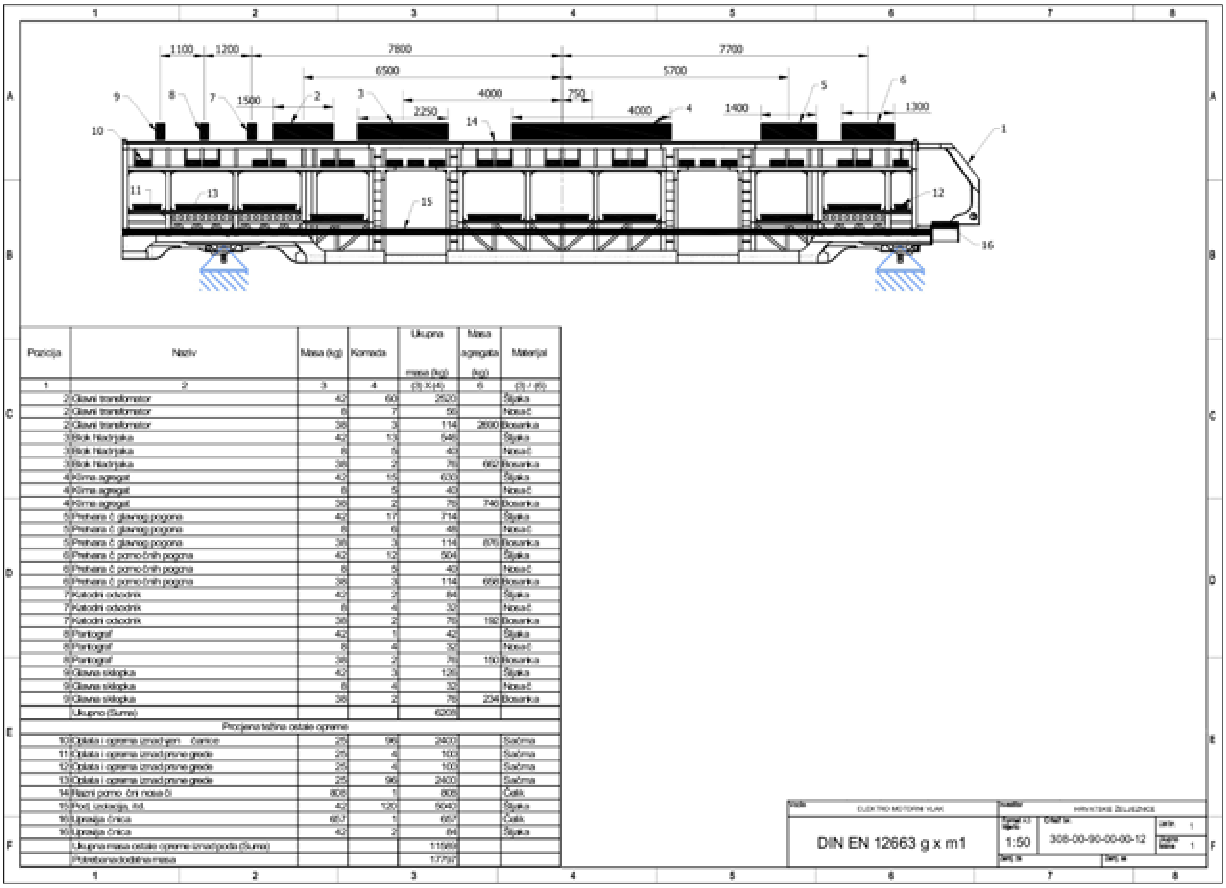


Pozicija	Naziv	Masa (kg)	Komada	Ukupna masa (kg)	Masa agregata (kg)	Materijal
1	2	3	4	(3) X (4)	6	(3) / (6)
2	Glavni transformator	42	60	2520		Šipka
2	Glavni transformator	8	7	56		Nosač
2	Glavni transformator	38	3	114	2690	Bosarka
3	Blok hladnjaka	42	13	546		Šipka
3	Blok hladnjaka	8	5	40		Nosač
3	Blok hladnjaka	38	2	76	662	Bosarka
4	Klima agregat	42	15	630		Šipka
4	Klima agregat	8	5	40		Nosač
4	Klima agregat	38	2	76	746	Bosarka
5	Pretvarač glavnog pogona	42	17	714		Šipka
5	Pretvarač glavnog pogona	8	6	48		Nosač
5	Pretvarač glavnog pogona	38	3	114	876	Bosarka
6	Pretvarač pomoćnih pogona	42	12	504		Šipka
6	Pretvarač pomoćnih pogona	8	5	40		Nosač
6	Pretvarač pomoćnih pogona	38	3	114	658	Bosarka
7	Katodni odvodnik	42	2	84		Šipka
7	Katodni odvodnik	8	4	32		Nosač
7	Katodni odvodnik	38	2	76	192	Bosarka
8	Pantograf	42	1	42		Šipka
8	Pantograf	8	4	32		Nosač
8	Pantograf	38	2	76	150	Bosarka
9	Glavna sklopka	42	3	126		Šipka
9	Glavna sklopka	8	4	32		Nosač
9	Glavna sklopka	38	2	76	234	Bosarka
	Ukupno (Suma)			6208		
Procjena težina ostale opreme						
10	Oplata i oprema iznad vjetrobranskog čanice	25	96	2400		Saćma
11	Oplata i oprema iznad prsne grede	25	4	100		Saćma
12	Oplata i oprema iznad prsne grede	25	4	100		Saćma
13	Oplata i oprema iznad prsne grede	25	96	2400		Saćma
14	Rami pomoćni nosač	808	1	808		Čelik
15	Pod, izolacija, itd.	42	120	5040		Šipka
16	Upravljačnica	657	1	657		Čelik
16	Upravljačnica	42	2	84		Šipka
	Ukupna masa ostale opreme iznad poda (Suma)			11589		
Opterećenje od putnika 4 osobe na jedan metar kvadratni						
15	Opterećenje od putnika	25	602	15050		Saćma
16	Opterećenje upravljačnica	25	38	950		Saćma
	Ukupna masa putnika			16000		
	Potrebna dodatna masa			33797		

Image 14: Compressive force and vertical load

b) Compressive force and min. vertical load

Passenger rolling stock Category P-II gxm_1



Pozicija	Naziv	Masa (kg)	Komada	Ukupna masa (kg)	Masa agregata (kg)	Materijal
1	2	3	4	(3) X (4)	6	(3) / (6)
2	Glavni transformator	42	60	2520		Šipka
2	Glavni transformator	8	7	56		Nosač
2	Glavni transformator	38	3	114	2690	Bosanka
3	Blok hladnjaka	42	13	546		Šipka
3	Blok hladnjaka	8	5	40		Nosač
3	Blok hladnjaka	38	2	76	662	Bosanka
4	Klima agregat	42	15	630		Šipka
4	Klima agregat	8	5	40		Nosač
4	Klima agregat	38	2	76	746	Bosanka
5	Pretvarač glavnog pogona	42	17	714		Šipka
5	Pretvarač glavnog pogona	8	6	48		Nosač
5	Pretvarač glavnog pogona	38	3	114	876	Bosanka
6	Pretvarač pomoćnih pogona	42	12	504		Šipka
6	Pretvarač pomoćnih pogona	8	5	40		Nosač
6	Pretvarač pomoćnih pogona	38	3	114	658	Bosanka
7	Katodni odvodnik	42	2	84		Šipka
7	Katodni odvodnik	8	4	32		Nosač
7	Katodni odvodnik	38	2	76	192	Bosanka
8	Pantograf	42	1	42		Šipka
8	Pantograf	8	4	32		Nosač
8	Pantograf	38	2	76	150	Bosanka
9	Glavna sklopka	42	3	126		Šipka
9	Glavna sklopka	8	4	32		Nosač
9	Glavna sklopka	38	2	76	234	Bosanka
	Ukupno (Suma)			6208		
	Procjena težina ostale opreme					
10	Oplata i oprema između ... čanice	25	96	2400		Sačma
11	Oplata i oprema između prvne grede	25	4	100		Sačma
12	Oplata i oprema između prvne grede	25	4	100		Sačma
13	Oplata i oprema između prvne grede	25	96	2400		Sačma
14	Razni pomoćni nosači	808	1	808		Čelik
15	Pod, izolacija, itd.	42	120	5040		Šipka
16	Upravljačnica	657	1	657		Čelik
16	Upravljačnica	42	2	84		Šipka
	Ukupna masa ostale opreme između poda (Suma)			11589		
	Potrebna dodatna masa			17797		

Image 15: Compressive force and min. vertical load

3.2 Stress - ERRI B12/RP 60

This standard is also given by technical conditions and refers to allowable limits for the detection od carbody fatigue stiffness.

3.2.1 Definition of welded joints categories

The marginal strain, which is for the tests on carbodies of passenger and freight wagons used, is for three types of steel with a minimum of 370, 420 and 520 MPa and for five weld categories defined.

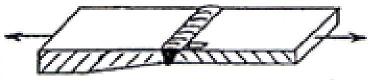
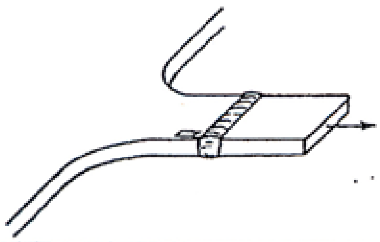
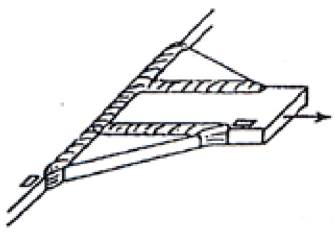
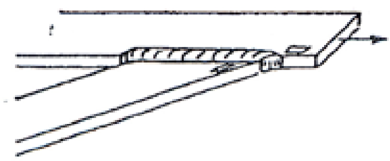
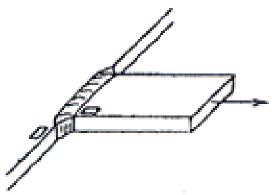
Five weld categorys are generally defined with:
Case A: full part,
Case B: butt joints - equal
Case C: butt joints - unequal,
Case D: tee joints,
Case E: lap joints

These five weld categories don't cover the diversity of structures is fully, and in practice it must be for each tested welding area the most appropriate weld category selected.

To make the choice, to simplify and unify contains in Table 3-1 are presented practical examples of welded joints, which often in the structures of car bodies and bogie frames occur.

3.2.1.1 Carbodies for passenger wagons

For passenger wagons carbody , according to UIC 566, is a dynamic load coefficient K of 0.2. During the testing of these carbodies are the ultimate tension σ_{max} (under normal tension load multiplied by 1.2) determined. The values are included in the table below.

Fall	Konstruktions-einzelheiten	Beschreibung	Bemerkungen
A		Vollmetall	Vollmetall
		Bearbeiteter Stumpf-anschluss	Bearbeitete Stumpf-naht
B		Stumpfanschluss	Stumpfnaht
		Stumpfanschluss mit Abschrägung	
B		Bearbeitete Schweiss-verbindung	
C		Eckverbindung mit Knoten-blechen	Stumpfnaht mit Winkelbildung
C		Schrägverbindung	
D		Eckverbindung	Stumpfnaht mit Anschluss bei 90^{0}

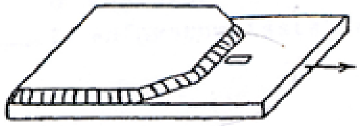
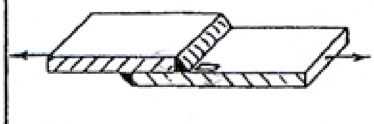
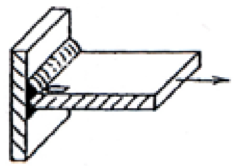
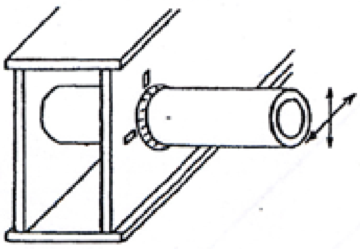
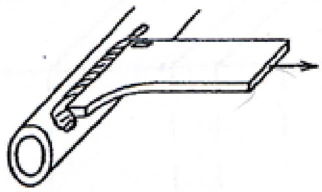
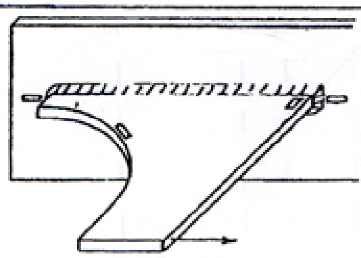
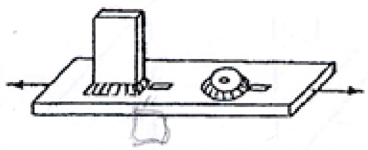
Fall	Konstruktions-einzelheiten	Beschreibung	Bemerkungen
D		Verstärkungsflansch	Uberlappt-verbindungen
D		Stumpfanschluss mit Uberlappung	
D		Eckanschluss	Kehlnaht
D		Anschluss Rohr - Längs-träger	
D		Anschluss Flansch - Rohr	
D		Anschluss Flansch - Steg	
E		Angeschweisste Anschlussteile	

Table 3-1: Weld joints categories

	$2\sigma_{Alim}$ [N/mm²]			σ_{mlim} [N/mm²]						σ_{maxlim} [N/mm²]					
Stahl 1)				K = 0,2			K = 0,3			K = 0,2			K = 0,3		
	370	420	520	370	420	520	370	420	520	370	420	520	370	420	520
Kerb-fall										S235	S275	S355			
A	110	118	166	200 2)	233 2)	300 2)	183	197	277	240 2)	280 2)	360 2)	238	256	360
B	90	90	90	182 2)	213 2)	225	150	150	150	218 2)	255 2)	270	195	195	195
C	80	80	80	182 2)	200	200	133	133	133	218 2)	240	240	173	173	173
D	66	66	66	165	165	165	110	110	110	198	198	198	143	143	143
E	54	54	54	135	135	135	90	90	90	162	162	162	117	117	117

1) Kennzeichnende Zugfestigkeit R_m nach Werkstoffnorm
2) Spannung ist durch die Elastizitätsgrenze R_p bzw. R_p' festgelegt

Table 3-2: Tension values

4 Geometry analysis

During the design process of ET prototype model are created different variants of the construction. Each of the variants are carefully studied and with eliminating possible errors is the final selection of the model made. This model was made in the 3D view in M 1:1 and as such after the strength analysis goes into production.

The very construction consists several major segments developed by special working groups (floor, roof, site, drivers cabin, ect.). All the elements of groups are different by the geometry (thickness is a very important factor), material (quality welded structural steel (S355J2G3C)) and the connections which they are associated to.

Due to the reduced capacity of the existing hardware in a detailed analysis of the geometry places of a minor loads are simplified. Simplifications I have worked in consultation with the head designer who has a lot of experience, knowledge and can provide evetualne critical stresses point.

The actual construction I divided into working groups and each I had to specifically give her name. Standard DIN 25 001 applies to terminology and give detailed description indicated to a certain parts of the structure. It is in this part of the job that demanded the most time.

Demanding part of the work was the study of boundarie conditions between individual parts. All connections were welded. Because of the simplification, I had (in agreement with the head designer) to bring all the welding into a several standard thickness.

The last stage was each element applying its properties. In this particular case it is referred to the type of material.

5 CAD Model construction

According to the obtained prototype Cad model in Invetor and its analysis I made ET Cad model suitable for simulation (also as Inventor file). I simplified complexesed model (as agreed with the chief engineer) and adapted it to FE software package Algor. The model was created in the actual dimensions of the scale of 1:1.

The actual construction is symmetrical along the longitudinal axis and in the feature I was also used this condition when creating model. Because of that conditions I constructed only one part of the symmetrical structure. This symmetry accelerated my analysis and provided that available hardware does make simulation.

It is made in shall and plate elements which were added default thickness later in Algor. Shall and plate elements coincide the simplified structure completely. This was necessary because of hardware limitations which are available for creating these simulations.

Connections between elements are defined as welded. Software (Algor later) is by creating these connections used the maximum simplification.
Minor radius, which are obtained when bending profiles used for construction, I ignored and simplified it for simulations. It has also been necessary because of the complexity and size of model.

6 FE Model construction

Cad model in shall and plate elements is by using Step translator imported in FE software package Algor. When importing model, it is allocated unit system, in this case SI, and type of analysis, in this case static stress analysis.
After that, to the model for analysis is allocated the kind of material (the default, given by technical conditions), the type of elements (shall, plate) and the thickness of elements (varies depending on construction).
The implementation of the first step have performed a variety of errors. Errors were usually related to the connection between the part and demanded the re-adjustment model of Inventor for Algor software equirements. This phase of work took unexpectedly long time and slowed down the whole calculation, because every little mistake on such a large construction for Algor software was a problem that it did not automatically solved.

The next step in the drafting of the model is meshing . This is the process of creating a finite element. Shape and density elements are also set and depend on the requirements of the design and support capabilities of hardwer. In this case shall – plate elements are set to defaults values which software genrate and the length of elements in this case are 6.5 mm.
After the process of meshing in some places where large loads which were seeking for more precise value (for the drivers cabin, entrance doors, etc.).There I have to manually increase the network elements decrease their length to 4 mm.
The problems that I met during the process of meshing were often related to not properly connected elements. Such elements I had to connect manually. The manual linking has also taken a lot of time.

After a successful model meshing it has been set the conditions symmetry along the Y axis. It is a condition of symmetry that I used when I create shall / plate model as the major advantage for reducing production time.
The last step in creating the model for the simulation is to saddle model whit given load forces. All load cases are given in selected standard and each case requires individual simulation.

6.1 Algor software

6.1.1 Type of analysis - Static Stress with Linear Material Models

Static stress with linear material models is used in cases where all applied loads are static and all material strains are expected to be in the linear elastic range.
Static stress with linear material models analysis, enables the study of stress, strain, displacement and shear and axial forces that result from static loading.
When performing a static stress with linear material models analysis, it is apply static loads (forces, moments, pressures, gravity or displacements) to a finite element model. The model is constrained with boundary conditions and the material properties are define. Static forces are assumed to be constant for an infinite period of time, while resulting strain, movement, and deformation are small. It is assume that the material will not deform beyond its elastic limit and any resulting dynamic effects from the loading are insignificant.

6.1.2 Analysis Parameters Information

6.1.2.1 Load Case Multipliers

Static Stress with Linear Material Models may have multiple load cases. This allows a model to be analyzed with multiple loads while solving the equations a single time.

A force can be applied to a node, edge or surface.
An edge force will apply nodal forces to each node along the edge. The magnitudes of the nodal forces will be calculated so that the force will be evenly distributed along the edge.A surface force will apply an equivalent pressure to the selected surface. A force can be applied in any direction specified by a vector. A surface force can also be applied normal to the surface.

The force will cause a displacement of the node to which it is applied. The amount of displacement will depend on the geometry and material properties of the model. The equation $\{ F \} = [k]\{ x \}$ is used to solve for the displacements, x, with the forces, F, and the stiffness, k, known. The stiffness of a model is dependent on the geometry and material properties.
The displacement of the node that the force is applied to will cause the nodes connected to it to also displace. Through these interactions, the force will affect the entire model.

The data entered for the force will be applied to each object selected. Nodal and edge forces will be applied to a load case.

An gravity or acceleration load will apply a constant acceleration value to any part that has a mass density defined.

A displacement boundary element will cause a node to translate or rotate a specified distance in a specified direction.
The displacement boundary element will act like a spring using the equation F=kx. A large stiffness value, k, will cause the node on the model to move the same amount as the new node. A low stiffness value will cause the displacement boundary element itself to deflect and therefore absorb some of the displacement.

6.1.2.2 Gravity Information

The following lists the values used if acceleration or gravity was included in the analysis.
The Acceleration/Gravity direction multiplier is multiplied by the Acceleration Due To Body Force which is then multiplied by the Acceleration/Gravity load case multiplier.
Acceleration Due To Body Force = 9814.56 mm/s^2

Acceleration/Gravity X Multiplier	Acceleration/Gravity Y Multiplier	Acceleration/Gravity Z Multiplier
0	0	-1

Table 6-1: Gravity Information

6.1.2.3 Boundary Condition

A boundary condition can be applied to nodes, edges or surfaces of a model. A edge or surface boundary condition will apply nodal boundary conditions to each node on the edge or surface.

In this case used the symmetry condition along the Y axis. And below is the table that describes this condition.

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 6-2 : Y Symmetrie - Nodal Boundary Condition

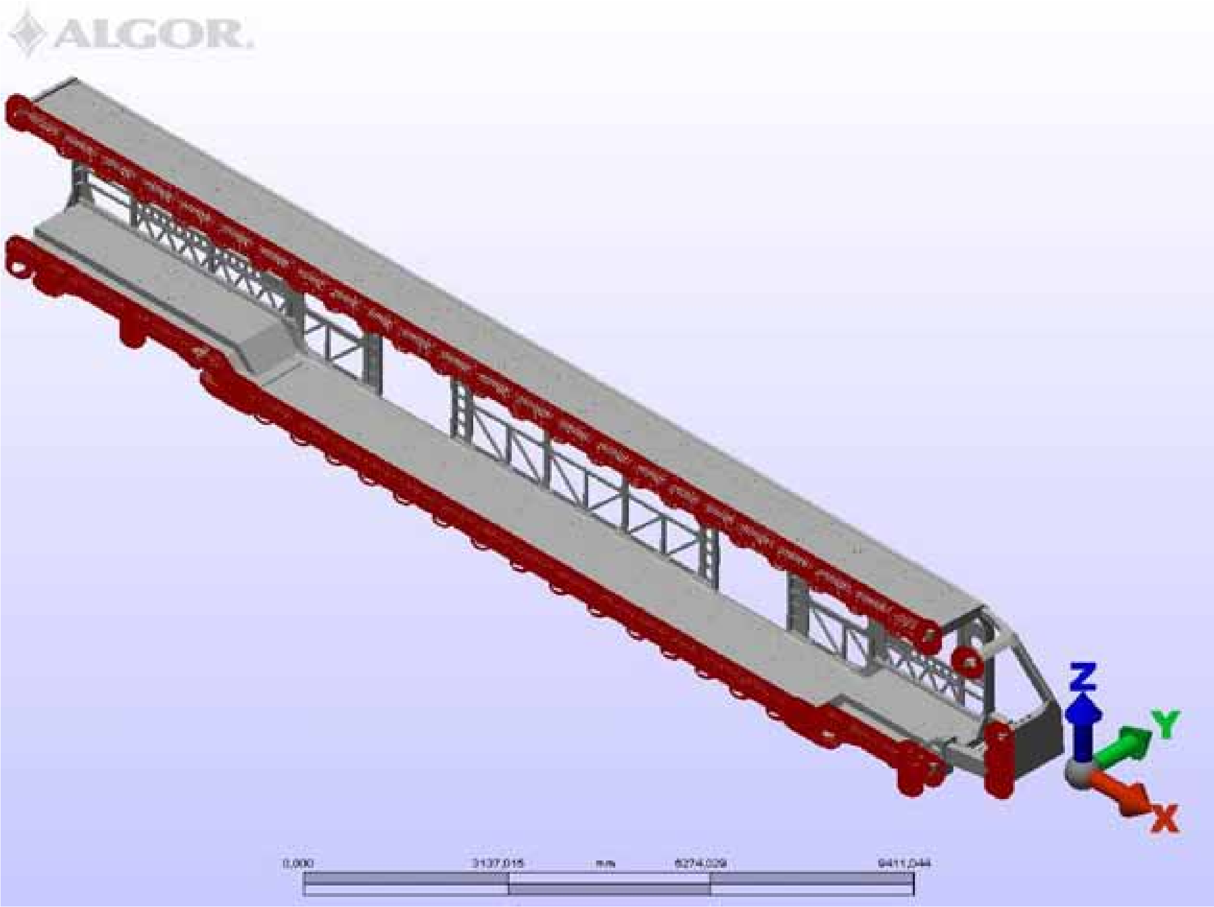


Image 16: Y Symmetrie - Nodal Boundary Condition - Side

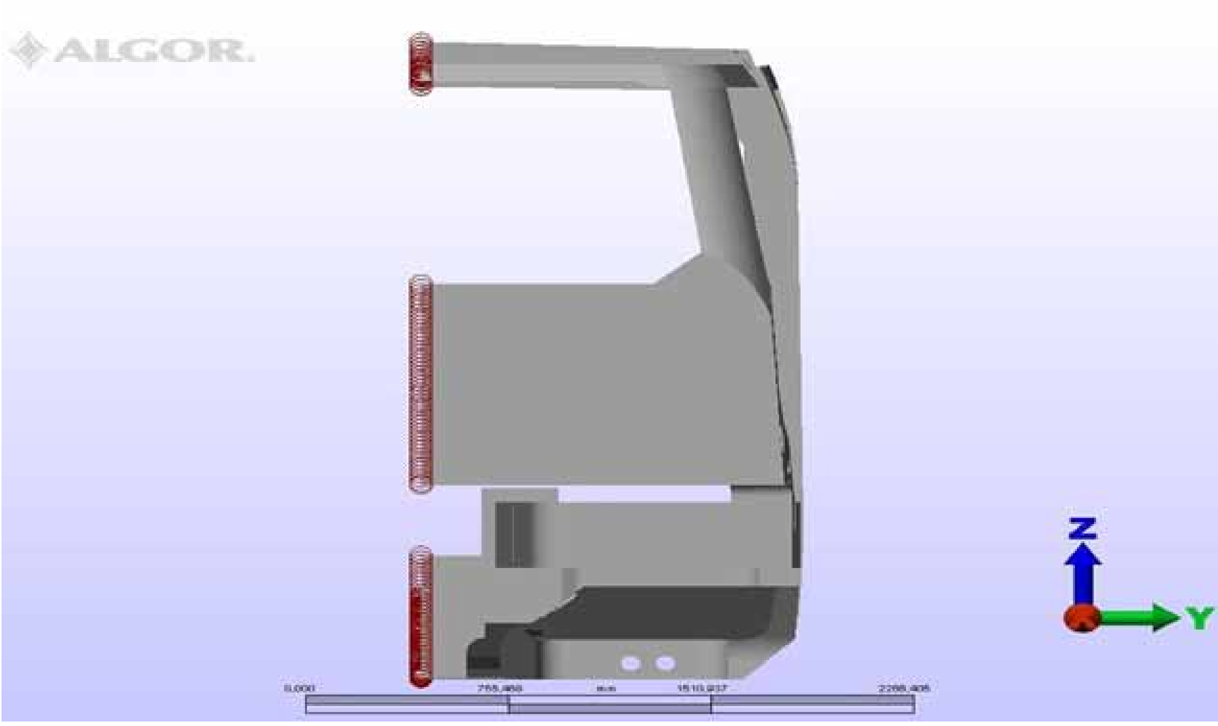


Image 17: Y Symmetrie - Nodal Boundary Condition - Front

6.1.2.4 Processor Information

Types of Solvers

In one form or another, Finite Element Analysis (FEA) comes down to solving a set of equations. Take the simple two spring model shown below, where F_1 and F_2 are the applied loads, K1 and K2 are the stiffness of the springs, and X_1 and X_2 are the deflections of each end. Keep in mind that either of the applied loads can be zero, but each one is a known value. The force developed in each spring due to elongation is unknown, but it can be calculated from the direct formula F = k*x. Considering that spring 1 elongates by the amount X_1 and spring 2 elongates by the amount (X_2-X_1), we can write the equation for the sum of the forces at each node:

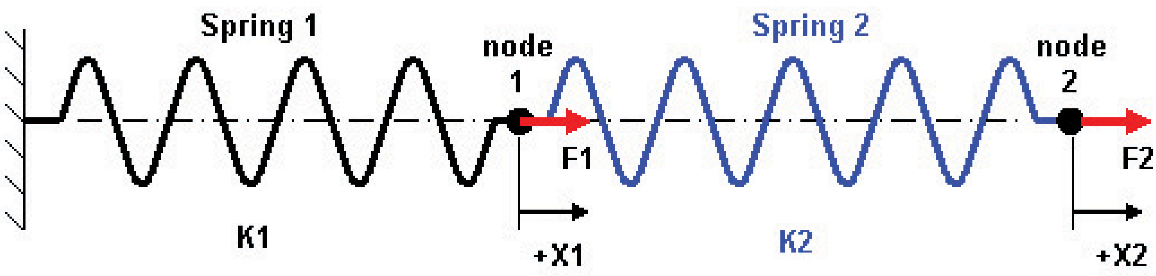


Table 6-3: Nodes forces

F1 - K1*X1 + K2*(X2-X1) = 0   node 1

F2 - K2*(X2-X1) = 0   node 2

Rearranging the equations gives:

F1 = (K1 + K2)*X1 - K2*X2   node 1

F2 = -K2*X1 + K2*X2   node 2

These equations can be expressed in matrix form as follows:

$$\begin{Bmatrix} F1 \\ F2 \end{Bmatrix} = \begin{bmatrix} (K1+K2) & -K2 \\ -K2 & +K2 \end{bmatrix} \begin{Bmatrix} X1 \\ X2 \end{Bmatrix}$$

or in shorthand notation, {F} = [K]{X}.

How the matrix of equations is solved in FEA is the task of the solver. As computer hardware and computational techniques evolve, new solvers are added to the software. Each analysis type has various solvers to choose from. In many cases, the default option is "Automatic", in which case the software chooses the solver best suited for the analysis (usually based on the size of the model; that is, the number of equations). The discussion below gives the general methodology of each type of solver.

Next, the solution to the set of equations will determine how long the analysis requires. There are direct solution methods that are guaranteed to give a solution — provided the model is set up properly (static stress model is properly constrained, steady state heat transfer model has a source of heat and way to remove the heat, and so on). Techniques such as Gauss Elimination and matrix inversion are simple examples of direct solution methods. Then there are indirect solution methods in which the solution is assumed. By substituting the assumed solution into the system of equations, a better estimate is obtained for each unknown. This process is repeated until the solution no longer changes; hence, these techniques are known as iterative solution.

Finally, the stiffness matrix is generally symmetric in FEA. In these cases, only the terms on and above the diagonal need to be stored. This reduces the memory requirements and number of operations to solve the matrix. When an effect is included which causes the matrix to be unsymmetric (such as body-to-body radiation in a heat transfer analysis, or an actuator element in a Mechanical Event Simulation), the entire matrix needs to be stored and operated upon. The solution will be longer in such cases.

Sparse Solver

Provides a direct solution to the matrix.
The bandwidth is not optimized, so time that would be spent performing this operation is saved.
Instead of storing the entire matrix, only the nonzero terms are stored. (This is where the terminology of "Sparse" solver comes from.)
Although fewer terms from the stiffness matrix are stored, more variables are required to store the position of the nonzero terms. Thus, the sparse solver requires more memory than the other solvers.

The sparse solver is the fastest solution for midsize models.

Reaction Forces

Displays the internal force reaction at each node. Note that this is NOT the support reactions. It can either have the magnitude of the reaction force displayed or the individual components along the global axes.

Type of Solver	Sparse
Calculate Reaction Forces	Yes
Invoke Banded Solver	Yes
Avoid Bandwidth Minimization	No
Stop After Stiffness Calculations	No
Displacement Data in Output File	No
Stress Data in Output File	No
Equation Numbers Data in Output File	No
Nodal Input Data in Output File	No

Table 6-4: Type of solver

6.1.2.5 Part Information

Plate Elements

Plate elements are three- or four-node elements formulated in three-dimensional space. These elements are used to model and analyze objects such as pressure vessels, or structures such as automobile body parts.
For applying surface-based loads, the highest surface number among the lines that define an element determines the surface number of that element.
Nodal forces, nodal moments (except when about an axis normal to the element face), pressures (normal to the element face), acceleration/gravity, centrifugal and thermal loads are supported.

Plate Element Parameters

By using plate elements, it must be define the thickness of the part. The element is drawn at the midplane of the plate element. Therefore, half of the entered value for thickness will be on top of the element while the other half will below the midplane. The average thickness of each element – based on the thickness of each corner – will be used.

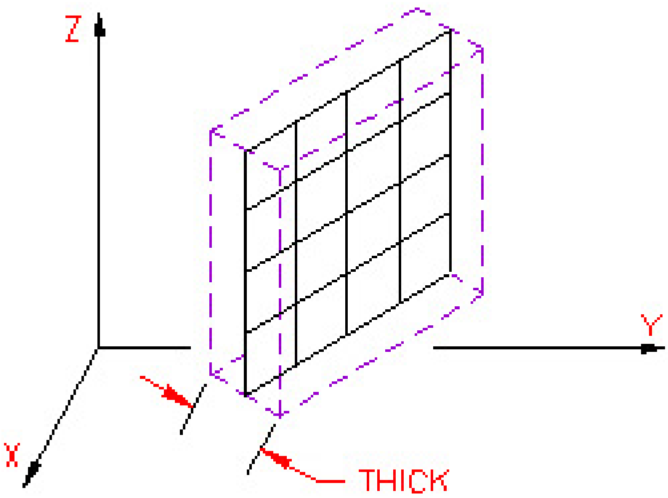


Image 18: Thickness of a Plate Element

Material

Materials are isotropic if the properties are not dependent on the direction. The isotropic material properties are listed below.

The mass density of a material is its mass per unit volume. Mass density is applicable to all linear elements.
The modulus of elasticity is the slope of the stress versus strain curve of a material until the proportionality limit, or yield stress. It is also referred to as the Young's modulus of a material.
Poisson's ratio is found by taking the negative lateral strain and dividing it by the axial strain for an axially loaded member. Typical values for Poisson's ratio range from 0.0 to 0.5.
The yield strength of a material is the point on the stress versus strain curve where the material initially starts to go into plastic strain. After yielding once, the new yield stress depends on the type of hardening and the loading history. The Yield Strength is used with beam elements in linear stress for code checking as a parameter for the allowable stress. Otherwise, the yield stress has no effect on the results in a linear analysis. That is, plasticity effects are not included.

The thermal coefficient of expansion is based on the contraction and expansion of the material due to a temperature difference.
The shear modulus of elasticity is the slope of the shear stress versus shear strain of a material until the proportionality limit. This is also referred to as the modulus of rigidity.

S355J2G3C –Plate

Material Model	Standard
Material Source	Moji materijali
Material Source File	C:\Program Files\ALGOR\21.01\matlibs\Moji materijali.mlb
Date Last Updated	2008/05/30-12:05:11
Material Description	None
Mass Density	0.00000000785 $N \cdot s^2/mm/mm^3$
Modulus of Elasticity	210000 N/mm^2
Poisson's Ratio	0.3
Thermal Coefficient of Expansion	0.0000148 1/°C
Shear Modulus of Elasticity	80769.2 N/mm^2

Table 6-5: Type of material

Part ID	Part Name	Element Type	Material Name
1	Untergestell_Lengtrager vollst	Plate	S355J2G3C
2	Untergestell_Versteifung	Plate	S355J2G3C
3	Kastenrohbau_Trager	Plate	S355J2G3C
4	Kastenrohbau_Turfeldtrager	Plate	S355J2G3C
5	Untergestell_Versteifung	Plate	S355J2G3C
6	Unergestell_Quertrager	Plate	S355J2G3C
7	Untergestell_Lengtrager	Plate	S355J2G3C
8	Stirnwand_Bekleidung	Plate	S355J2G3C
9	Stirnwand_Bekleidung	Plate	S355J2G3C
10	Stirnwand_Versteifung	Plate	S355J2G3C
11	Stirnwand_Versteifung	Plate	S355J2G3C
12	Stirnwand_Versteifung	Plate	S355J2G3C
13	Stirnwand_Versteifung	Plate	S355J2G3C
14	Stirnwand_Versteifung	Plate	S355J2G3C
15	Stirnwand_Dachklappenbekleidung	Plate	S355J2G3C
16	Stirnwand_Versteifung	Plate	S355J2G3C
17	Pfette	Plate	S355J2G3C
18	Pfette	Plate	S355J2G3C

19	Pfette	Plate	S355J2G3C
20	Dachgerippe	Plate	S355J2G3C
21	Seitenwandgrippe_Fenstersaule	Plate	S355J2G3C
22	Seitenwandgrippe_Fenstersaule	Plate	S355J2G3C
23	Seitenwand_Pfette	Plate	S355J2G3C
24	Seitenwand_Fensterversteifung	Plate	S355J2G3C
25	Seitenwandgerippe_Brustungsgurt	Plate	S355J2G3C
26	SeitenwandPfette	Plate	S355J2G3C
27	Seitenwandgerippe_Riegel	Plate	S355J2G3C
28	Sietenwand_Spriegel	Plate	S355J2G3C
29	Seitenwandrippe_Strebe	Plate	S355J2G3C
30	Seitenwand_Taschenwandsaule	Plate	S355J2G3C
31	Seitenwandrippe_Strebe	Plate	S355J2G3C
32	Seitenwandrippe_Strebe	Plate	S355J2G3C
33	Seitenwand_Versteifung	Plate	S355J2G3C
34	Seitenwand_Knotenblech	Plate	S355J2G3C
35	Seitenwandgrippe_Fenstersaule	Plate	S355J2G3C
36	Seitenwandgrippe_Fenstersaule	Plate	S355J2G3C
37	Seitenwand_Fensterecke	Plate	S355J2G3C
38	Seitenwand_Versteifungsblech	Plate	S355J2G3C
39	Seitenwand_Versteifungsblech	Plate	S355J2G3C
40	Seitenwand_Turversteifung	Plate	S355J2G3C
41	Seitenwandgrippe_Fenstersaule_Versteifung	Plate	S355J2G3C
42	Seitenwandgrippe_Fenstersaule_Versteifung	Plate	S355J2G3C
43	Seitenwand_Knotenblech	Plate	S355J2G3C
44	Seitenwand_Knotenblech	Plate	S355J2G3C
45	Seitenwand_Knotenblech	Brick	S355J2G3C
46	Seitenwand_Knotenblech	Brick	S355J2G3C
47	Seitenwand_Fensterversteifung	Plate	S355J2G3C
48	Seitenwand_Versteifung	Plate	S355J2G3C
49	Seitenwand_Versteifung	Plate	S355J2G3C
50	Untergestell_Kopfstuck	Plate	S355J2G3C
51	Untergestell_Kopfstuck	Plate	S355J2G3C
52	Untergestell_Kopfstuck	Plate	S355J2G3C
53	Untergestell_Kopfstuck	Plate	S355J2G3C
54	Untergestell_Kopfstuck_Versteifung	Plate	S355J2G3C
55	Untergestell_Kopfstuck	Plate	S355J2G3C
56	Untergestell_Kopfstuck	Plate	S355J2G3C

57	Untergestell_Knautschel. mittler	Plate	S355J2G3C
58	Untergestell_Knautschel. seiten	Plate	S355J2G3C
59	Untergestell_Knautschel. seiten	Plate	S355J2G3C
60	Untergestell_Hauptquertreger_Drehzapf-enauflage	Plate	S355J2G3C
61	Untergestell_Hauptquertreger_Drehzapf-enauflage	Plate	S355J2G3C
62	Untergestell_Hauptquertreger_Drehzapf-enauflage	Plate	S355J2G3C
63	Untergestell_Ruckteil	Plate	S355J2G3C
64	Untergestell_Ruckteil	Plate	S355J2G3C
65	Untergestell_Ruckteil	Plate	S355J2G3C
66	Untergestell_Ruckteil	Plate	S355J2G3C
67	Untergestell_Hauptquertreger	Brick	S355J2G3C
68	Untergestell_Hauptquertreger	Plate	S355J2G3C
69	Untergestell_Hauptquertreger	Plate	S355J2G3C
70	Untergestell_Hauptquertreger	Plate	S355J2G3C
71	Untergestell_Hauptquertreger	Plate	S355J2G3C
72	Untergestell_Hauptquertreger	Plate	S355J2G3C
73	Untergestell_Hauptquertreger	Plate	S355J2G3C
74	Untergestell_Hauptquertreger	Plate	S355J2G3C
75	Untergestell_Kopfstuck	Plate	S355J2G3C
76	Untergestell_Hauptquertreger	Plate	S355J2G3C
77	Untergestell_Hauptquertreger	Plate	S355J2G3C
78	Untergestell_Hauptquertreger	Plate	S355J2G3C
79	Untergestelle_Knautschel	Plate	S355J2G3C
80	Untergestell_Hauptquertreger_Drehzapf-enauflage	Plate	S355J2G3C
81	Untergestell_Hauptquertreger	Plate	S355J2G3C
82	Untergestell_Hauptquertreger	Plate	S355J2G3C
83	Untergestell_Hauptquertreger	Plate	S355J2G3C
84	Untergestell_Ruckteil	Plate	S355J2G3C
85	Untergestell_Ruckteil	Plate	S355J2G3C
86	Untergestell_Ruckteil	Plate	S355J2G3C
87	Untergestell_Ruckteil	Plate	S355J2G3C
88	Untergestell_Ruckteil	Plate	S355J2G3C
89	Untergestell_Ruckteil	Plate	S355J2G3C
90	Untergestell_Ruckteil	Plate	S355J2G3C

91	Untergestell_Ruckteil	Plate	S355J2G3C
92	Untergestell_Ruckteil	Plate	S355J2G3C
93	Untergestell_Ruckteil	Plate	S355J2G3C
94	Untergestell_Ruckteil	Plate	S355J2G3C
95	Untergestell_Ruckteil	Plate	S355J2G3C
96	Untergestell_Ruckteil	Plate	S355J2G3C
97	Untergestell_Ruckteil	Plate	S355J2G3C
98	Untergestell_Ruckteil	Plate	S355J2G3C
99	Untergestell_Ruckteil	Plate	S355J2G3C
100	Untergestell_Ruckteil	Plate	S355J2G3C
101	Untergestell_Hauptquertreger	Plate	S355J2G3C
102	Untergestell_Hauptquertreger_Versteifung	Plate	S355J2G3C
103	Untergestell_Hauptquertreger_Versteifung	Plate	S355J2G3C
104	Untergestell_Hauptquertreger	Plate	S355J2G3C
105	Untergestell_Kopfstuck	Plate	S355J2G3C
106	Untergestell_Kopfstuck	Plate	S355J2G3C
107	Untergestell_Kopfstuck	Plate	S355J2G3C
108	Untergestell_Kopfstuck_Versteifung	Plate	S355J2G3C
109	Untergestell_Kopfstuck_Versteifung	Plate	S355J2G3C
110	Untergestell_Kopfstuck_Versteifung	Plate	S355J2G3C
111	Untergestell_Kopfstuck_Versteifung	Plate	S355J2G3C
112	Unterstell_Kopfstuck	Plate	S355J2G3C
113	Untergestell_Kopfstuck	Plate	S355J2G3C
114	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
115	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
116	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
117	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
118	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
119	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
120	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
121	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
122	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
123	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
124	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
125	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
126	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
127	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
128	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C

129	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
130	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
131	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
132	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
133	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
134	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
135	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
136	Voredewrbekleidung	Plate	S355J2G3C
137	Vorderbekleidung	Plate	S355J2G3C
138	Kopfstuck	Plate	S355J2G3C
140	Kopfstuck	Plate	S355J2G3C
141	Kopfstuck	Plate	S355J2G3C
142	Kopfstuck	Plate	S355J2G3C
143	Kopfstuck	Plate	S355J2G3C
144	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
145	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
146	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
147	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
148	Seitenwandgerippe fur Fuhrerraum	Plate	S355J2G3C
149	Kopfstuck	Plate	S355J2G3C
159	Pod	Plate	S355J2G3C
160	Krov	Plate	S355J2G3C

Table 6-6: Type of elements

6.1.3 Element Information

6.1.3.1 Element Properties used for:

Elements:

Untergestell_Lengtrager vollst

Kastenrohbau_Trager

Kastenrohbau_Turfeldtrager

Untergestell_Versteifung

Seitenwand_Versteifung

Seitenwand_Versteifungsblech

Untergestell_Kopfstuck_Versteifung

Untergestell_Kopfstuck_Versteifung

Untergestell_Kopfstuck_Versteifung

Untergestell_Kopfstuck_Versteifung

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Voredewrbekleidung

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Element Type	Plate
Material Model	Isotropic
Thickness	6 mm

Table 6-7: Element Properties - 6mm

6.1.3.2 Element Properties used for:

Elements:

Untergestell_Versteifung

Stirnwand_Versteifung

Stirnwand_Versteifung

Stirnwand_Versteifung

Seitenwand_Versteifungsblech

Seitenwandgerippe fur Fuhrerraum

Element Type	Plate
Material Model	Isotropic
Thickness	5 mm

Table 6-8: Element Properties - 5mm

6.1.3.3 Element Properties used for:

Elements:

Unergestell_Quertrager

Pfette

Dachgerippe

Seitenwand_Turversteifung

Element Type	Plate
Material Model	Isotropic
Thickness	3 mm

Table 6-9: Element Properties - 3mm

6.1.3.4 Element Properties used for:

Elements:

Untergestell_Lengtrager

Untergestell_Ruckteil

Element Type	Plate
Material Model	Isotropic
Thickness	3 mm

Table 6-10: Element Properties - 3mm

6.1.3.5 Element Properties used for:

Elements:

Stirnwand_Bekleidung

Stirnwand_Bekleidung

Stirnwand_Versteifung

Stirnwand_Versteifung

Stirnwand_Dachklappenbekleidung

Pfette

Pfette

Seitenwandgrippe_Fenstersaule

Seitenwandgrippe_Fenstersaule

Seitenwand_Pfette

Seitenwand_Fensterversteifung

Seitenwandgerippe_Brustungsgurt

SeitenwandPfette

Seitenwandgerippe_Riegel

Sietenwand_Spriegel

Seitenwandrippe_Strebe

Seitenwand_Taschenwandsaule

Seitenwandrippe_Strebe

Seitenwandrippe_Strebe

Seitenwandgrippe_Fenstersaule

Seitenwandgrippe_Fenstersaule

Seitenwand_Fensterecke

Seitenwandgrippe_Fenstersaule_Versteifung

Seitenwandgrippe_Fenstersaule_Versteifung

Seitenwand_Versteifung

Seitenwand_Versteifung

Untergestell_Hauptquertreger

Element Type	Plate
Material Model	Isotropic
Thickness	4 mm

Table 6-11: Element Properties - 4mm

6.1.3.6 Element Properties used for:

Element:

Stirnwand_Versteifung

Element Type	Plate
Material Model	Isotropic
Thickness	3 mm

Table 6-12: Element Properties - 3mm

6.1.3.7 Element Properties used for:

Elements:

Seitenwand_Knotenblech

Untergestell_Hauptquertreger_Drehzapfenauflage

Untergestell_Hauptquertreger

Element Type	Plate
Material Model	Isotropic
Thickness	20 mm

Table 6-13: Element Properties - 20mm

6.1.3.8 Element Properties used for:

Elements:

Seitenwand_Knotenblech

Seitenwand_Knotenblech

Seitenwand_Fensterversteifung

Untergestell_Kopfstuck

Untergestell_Kopfstuck_Versteifung

Untergestell_Kopfstuck

Untergestell_Knautschel. mittler

Untergestell_Knautschel. seiten

Untergestell_Hauptquertreger_Drehzapfenauflage

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Hauptquertreger

Untergestell_Hauptquertreger

Untergestell_Hauptquertreger

Untergestell_Hauptquertreger

Untergestell_Hauptquertreger

Untergestell_Hauptquertreger

Untergestell_Kopfstuck

Untergestell_Hauptquertreger_Drehzapfenauflage

Untergestell_Hauptquertreger

Untergestell_Hauptquertreger

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Hauptquertreger

Untergestell_Hauptquertreger_Versteifung

Untergestell_Hauptquertreger_Versteifung

Untergestell_Hauptquertreger

Untergestell_Kopfstuck

Untergestell_Kopfstuck

Untergestell_Kopfstuck

Seitenwandgerippe fur Fuhrerraum

Kopfstuck

Kopfstuck

Element Type	Plate
Material Model	Isotropic
Thickness	8 mm

Table 6-14: Element Properties - 8mm

6.1.3.9 Element Properties used for:

Elements:

Untergestell_Kopfstuck

Untergestell_Kopfstuck

Untergestell_Knautschel. seiten

Untergestell_Hauptquertreger

Untergestelle_Knautschel

Untergestell_Hauptquertreger

Untergestell_Ruckteil

Untergestell_Ruckteil

Untergestell_Ruckteil

Unterstell_Kopfstuck

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Seitenwandgerippe fur Fuhrerraum

Element Type	Plate
Material Model	Isotropic
Thickness	10 mm

Table 6-15: Element Properties - 10mm

6.1.3.10 Element Properties used for:

Element:

Untergestell_Kopfstuck

Element Type	Plate
Material Model	Isotropic
Thickness	50 mm

Table 6-16: Element Properties - 50mm

6.1.3.11 Element Properties used for:

Element:

Untergestell_Kopfstuck

Element Type	Plate
Material Model	Isotropic
Thickness	80 mm

Table 6-17: Element Properties - 80mm

6.1.3.12 Element Properties used for:

Element:

Untergestell_Hauptquertreger_Drehzapfenauflage

Element Type	Plate
Material Model	Isotropic
Thickness	35 mm

Table 6-18: Element Properties - 35mm

6.1.3.13 Element Properties used for:

Element:

Untergestell_Ruckteil

Element Type	Plate
Material Model	Isotropic
Thickness	14 mm

Table 6-19: Element Properties - 14mm

6.1.3.14 Element Properties used for:

Element:

Untergestell_Hauptquertreger

Element Type	Plate
Material Model	Isotropic
Thickness	6 mm

Table 6-20: Element Properties - 6mm

6.1.3.15 Element Properties used for:

Elements:

Untergestell_Ruckteil

Untergestell_Kopfstuck

Element Type	Plate
Material Model	Isotropic
Thickness	18 mm

Table 6-21: Element Properties - 18mm

6.1.3.16 Element Properties used for:

Element:

Vorderbekleidung

Element Type	Plate
Material Model	Isotropic
Thickness	16 mm

Table 6-22: Element Properties - 16mm

6.1.3.17 Element Properties used for:

Element:

Kopfstuck

Element Type	Plate
Material Model	Isotropic
Thickness	15 mm

Table 6-23: Element Properties - 15mm

6.1.3.18 Element Properties used for:

Elements:

Kopfstuck

Kopfstuck

Seitenwandgerippe fur Fuhrerraum

Element Type	Plate
Material Model	Isotropic
Thickness	40 mm

Table 6-24: Element Properties - 40mm

6.1.3.19 Element Properties used for:

Element:

Kopfstuck

Element Type	Plate
Material Model	Isotropic
Thickness	12 mm

Table 6-25: Element Properties - 12mm

7 Visual results

7.1 Compressive forces in buffer and/or coupling area

7.1.1 Loads FEA Object : -750kN

Magnitude	Vx	Vy	Vz
-750000,000000	1,000000	0,000000	0,000000

Table 7-1: Surface Force

7.1.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-2: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-3: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-4: Fix - Surface Boundary Condition

7.1.3 Results

7.1.3.1 Displacement

Image 19: Displacement

7.1.3.2 Stress

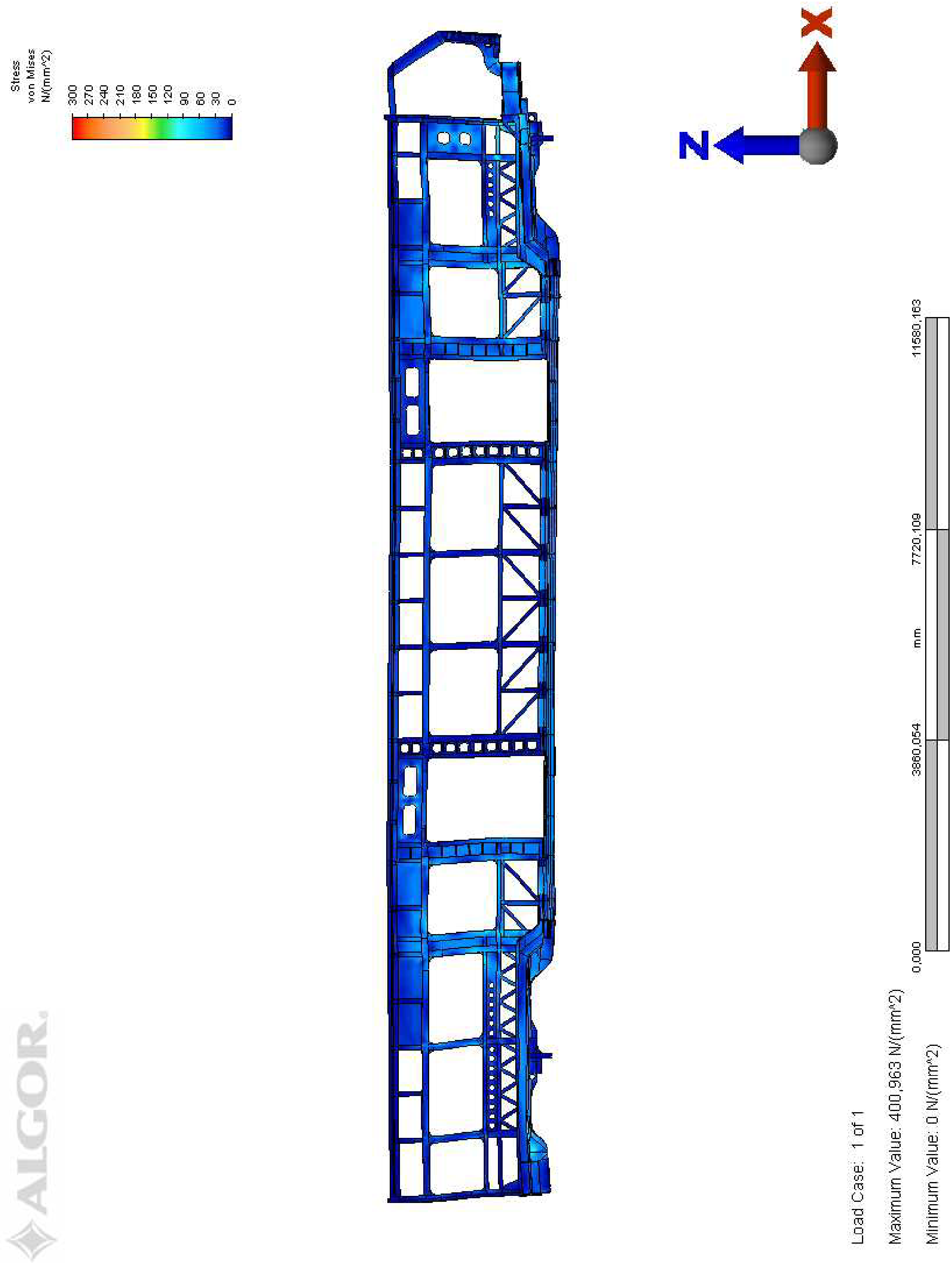


Image 20: Stress

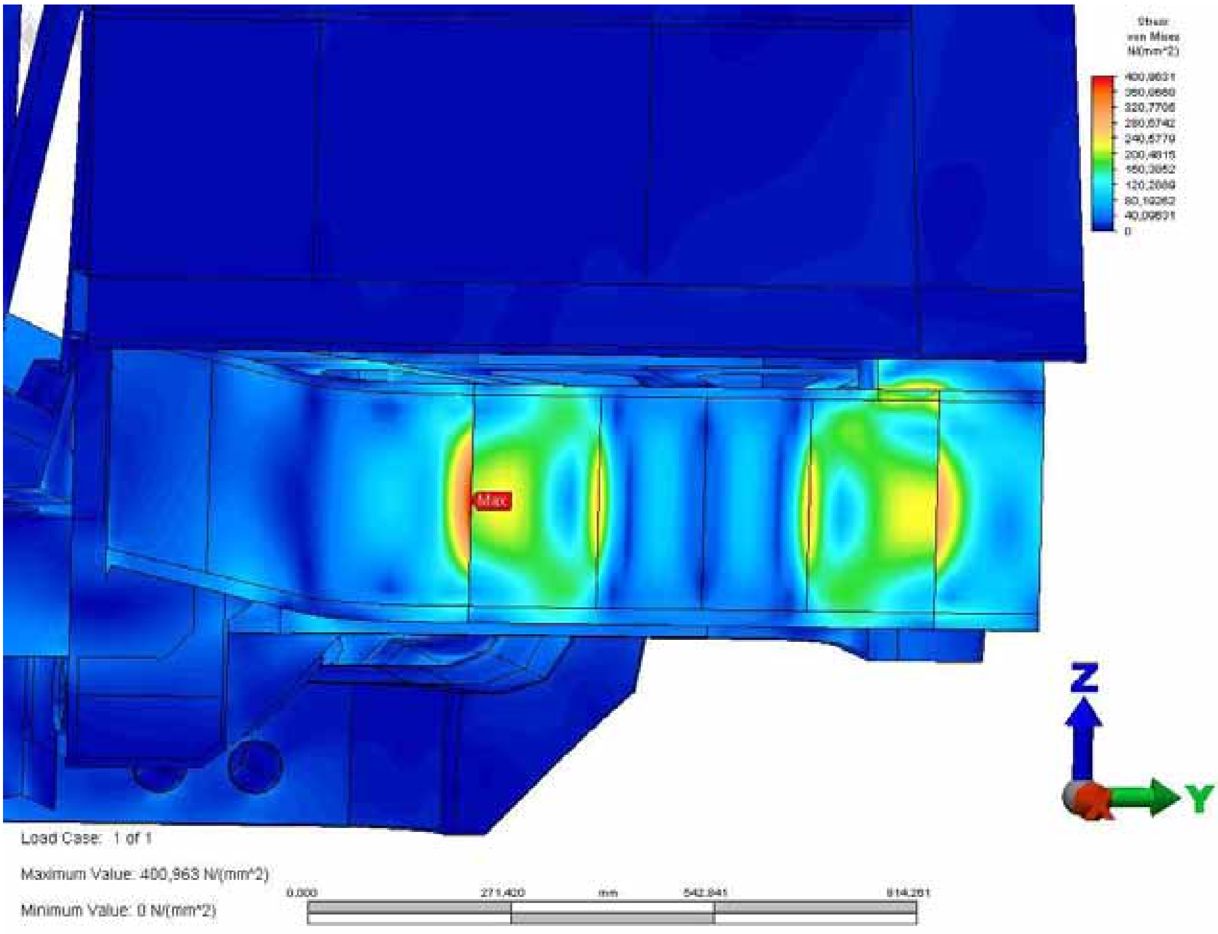


Image 21: Detail - Stress

$\sigma_1 = 400$ N/mm²

$\sigma_2 = 321$ N/mm²

	$\sigma_{\max\, lin}\left[N/m^{2}\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-5: Weldcategory - Allowed stress

7.2 Tensile force in coupler area

7.2.1 Loads FEA Object : -400kN

Magnitude	Vx	Vy	Vz
-400000,000000	1,000000	0,000000	0,000000

Table 7-6: Surface Force (N)

7.2.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-7: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-8: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-9: Fix - Surface Boundary Condition

7.2.3 Results

7.2.3.1 Displacement

Image 22: Displacement

7.2.3.2 Stress

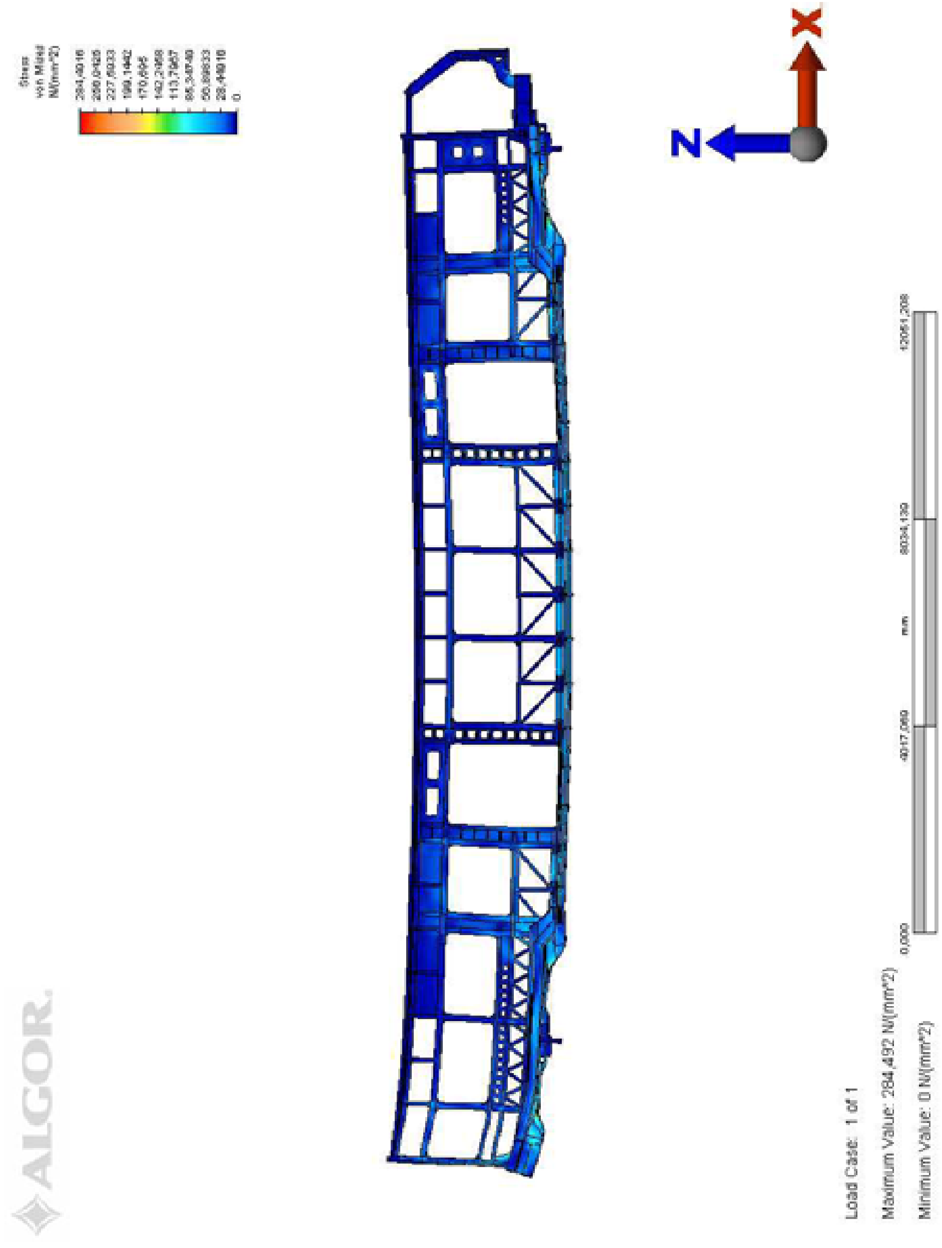


Image 23: Stress

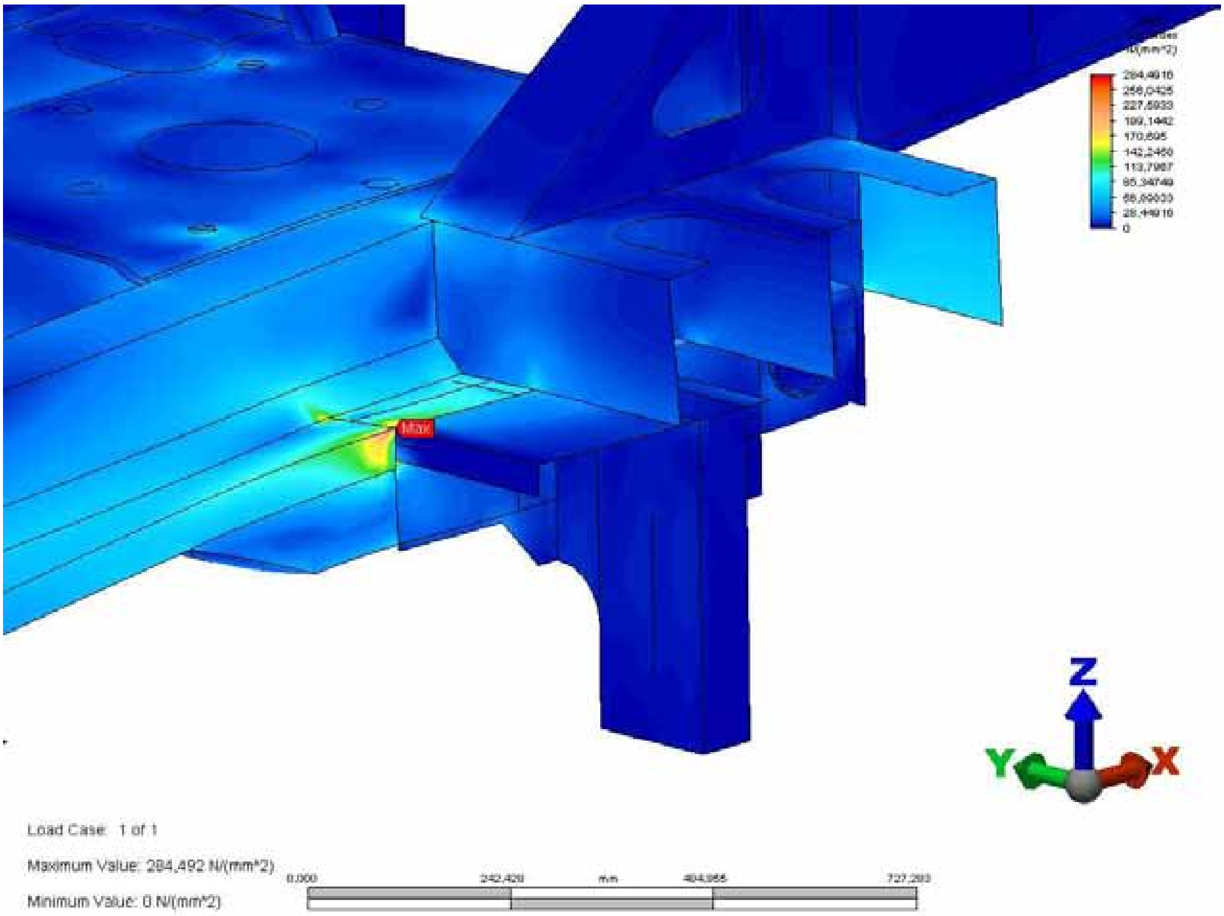


Image 24: Detail - Stress

$\sigma_1 = 284\ N/mm^2$

	$\sigma_{\max lin} \left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-10: Weldcategory - Allowed stress

7.3 Compressive force 150 mm above the top of the structural floor at head stock

7.3.1 Loads FEA Object : -200kN

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	-598,802395

Table 7-11: Nodal Force (N)

7.3.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-12: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-13: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-14: Fix - Surface Boundary Condition

7.3.3 Results

7.3.3.1 Displacement

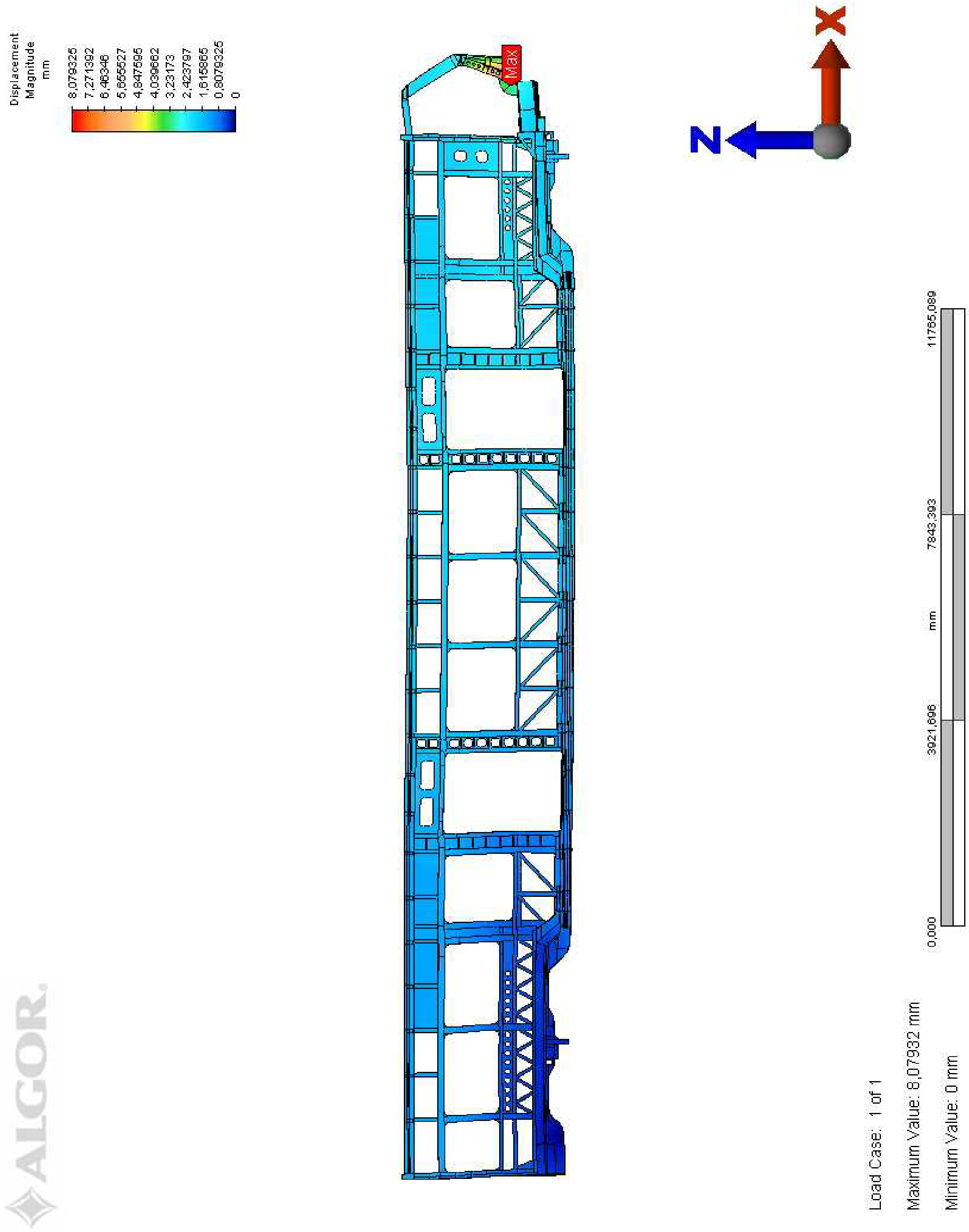


Image 25: Displacement

7.3.3.2 Stress

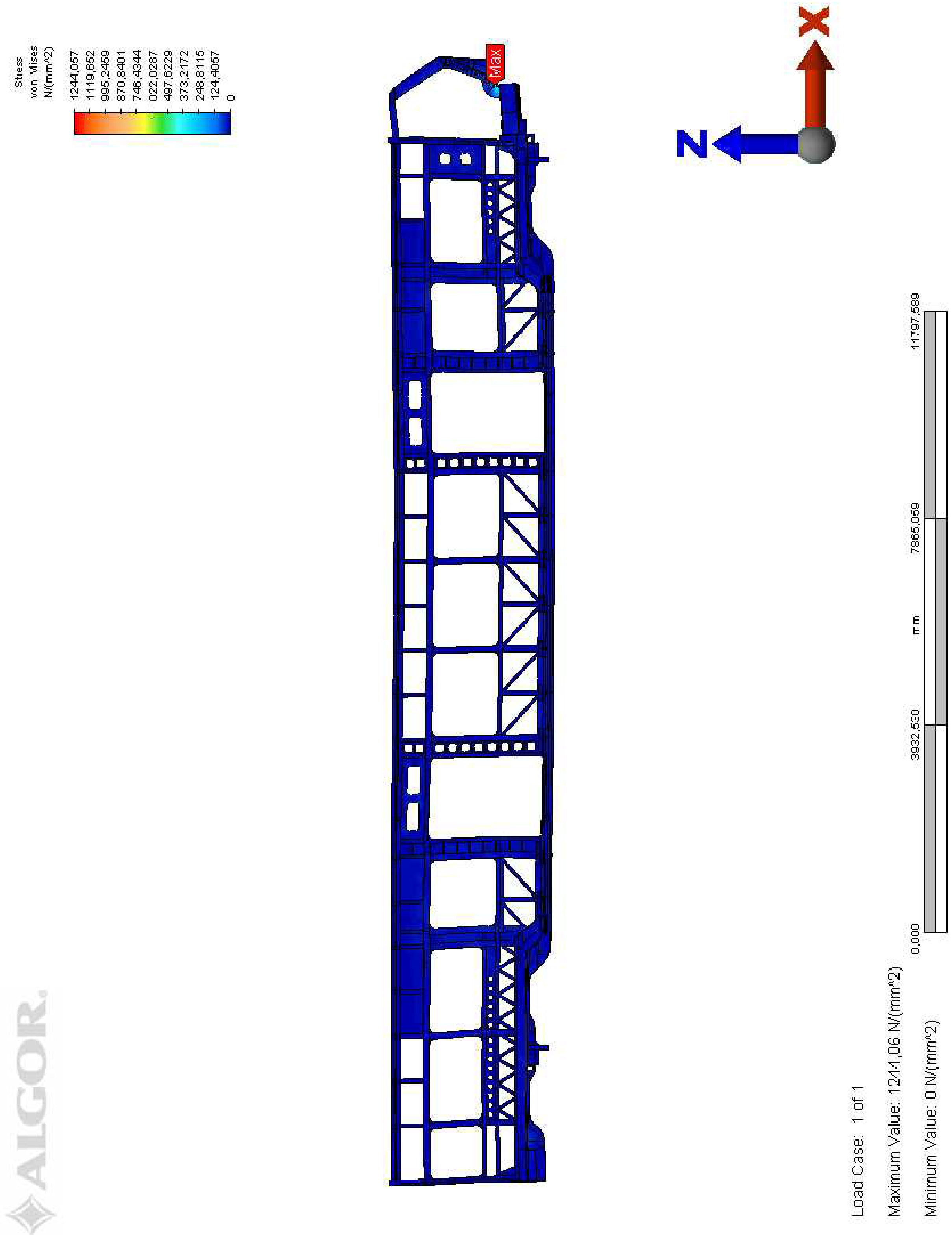


Image 26: Stress

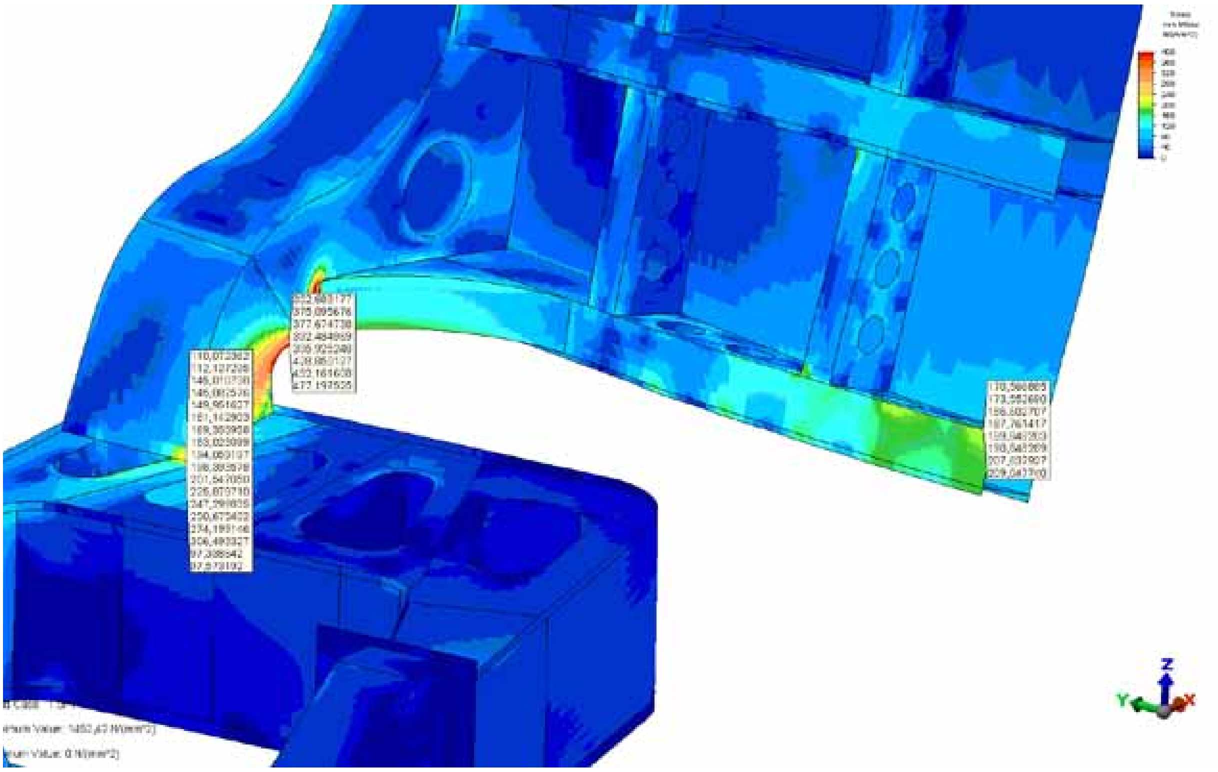


Image 27: Detail - Stress

$\sigma_1 = 1244\ N/mm^2$

$\sigma_2 = 1452\ N/mm^2$

$\sigma_3 = 477\ N/mm^2$

	$\sigma_{\max lin}\left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-15: Weldcategory - Allowed stress

7.4 Compressive force at the level of the waistrail (window sill)

7.4.1 Loads FEA Object : -150 kN

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	-541,516245

Table 7-16: Nodal Force (N)

7.4.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-17: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-18: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-19: Fix - Surface Boundary Condition

7.4.3 Results

7.4.3.1 Displacement

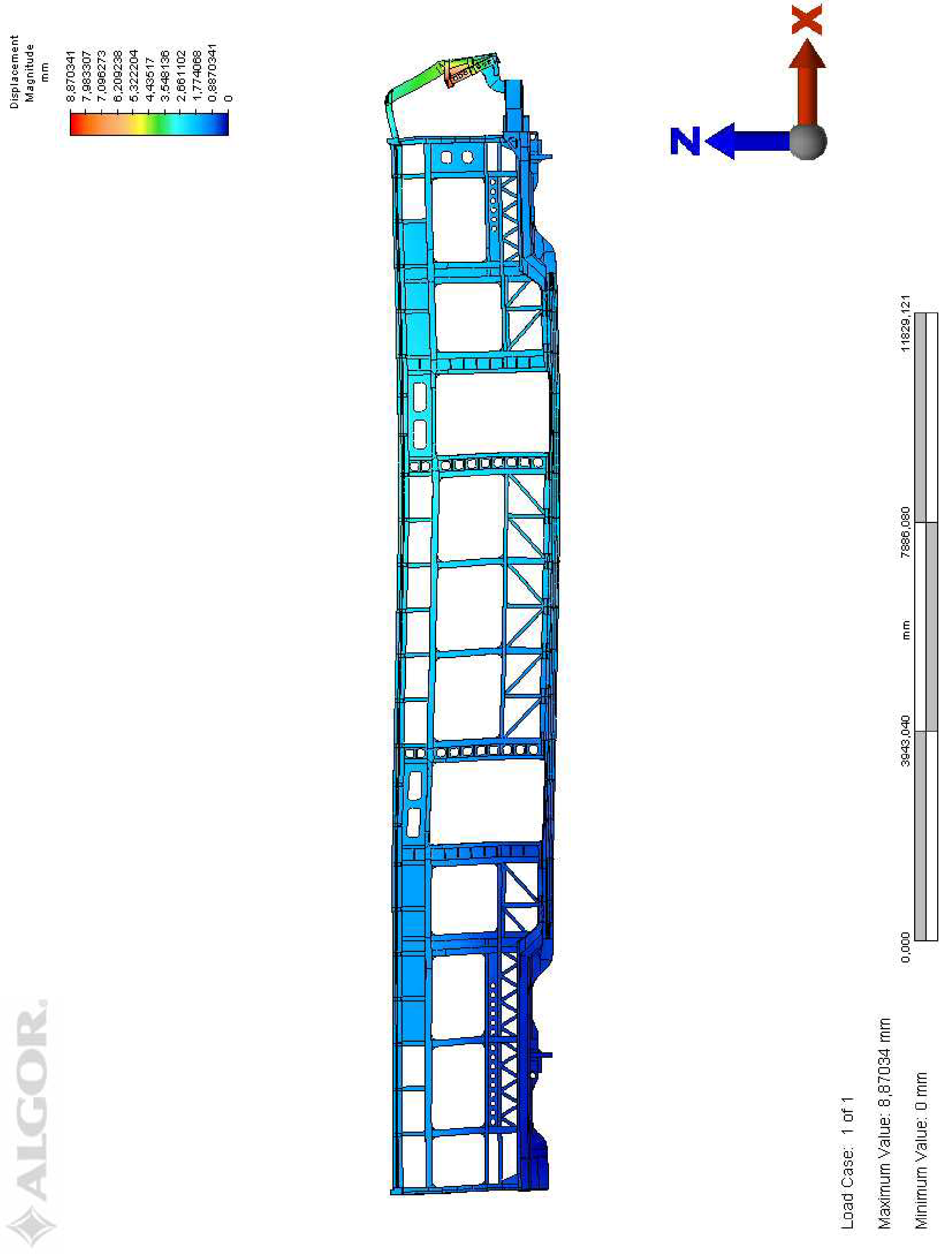


Image 28: Displacement

7.4.3.2 Stress

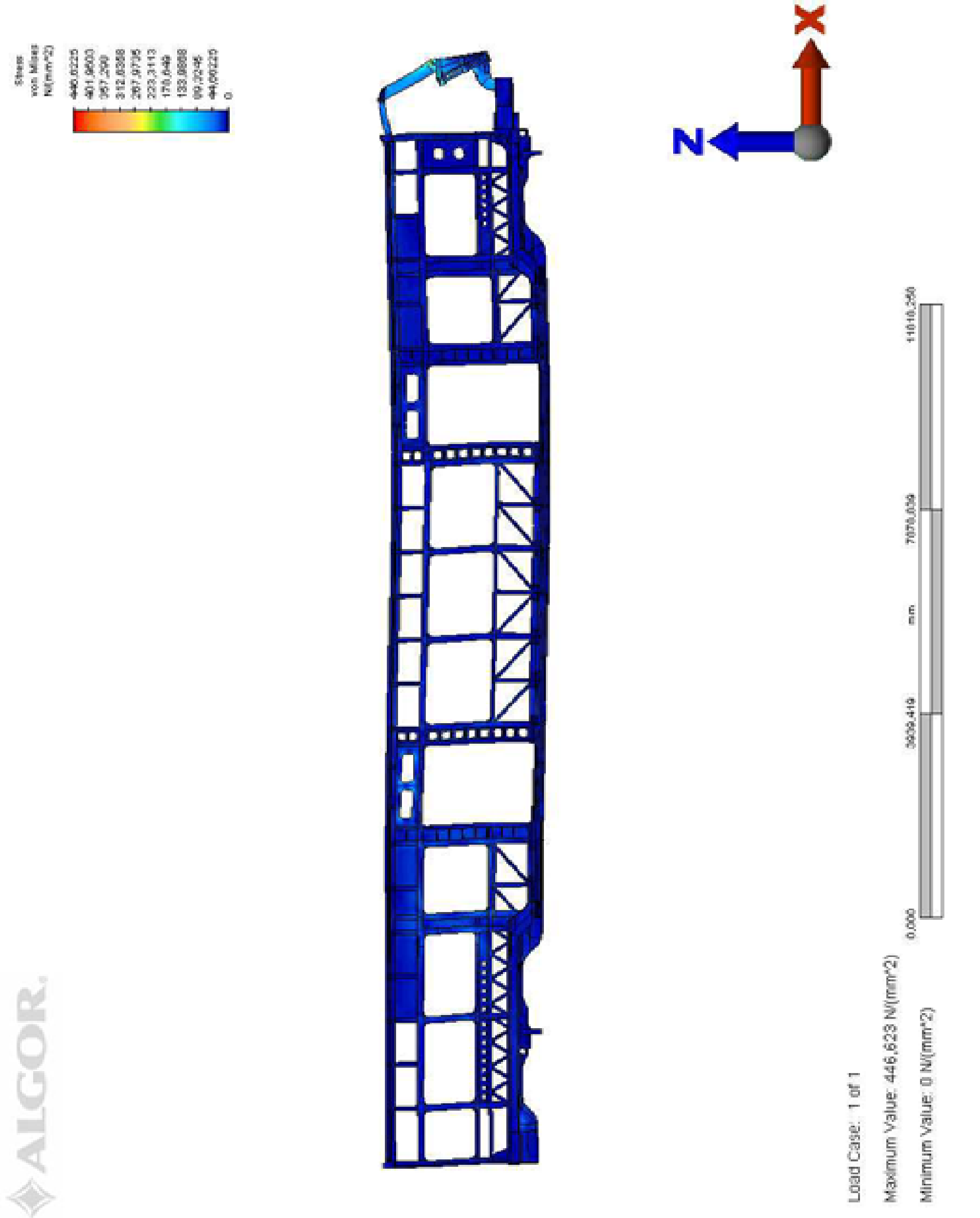


Image 29: Stress

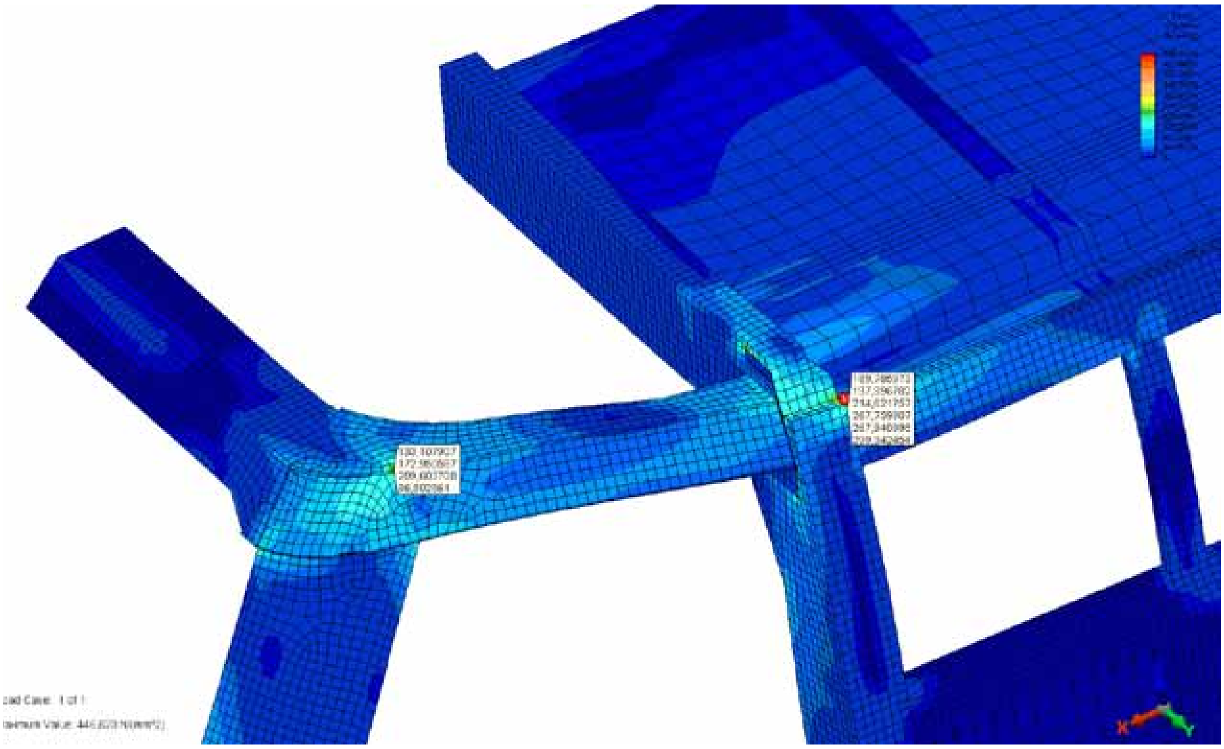


Image 30: Detail - Stress

$\sigma_1 = 446\ N/mm^2$

$\sigma_2 = 299\ N/mm^2$

	$\sigma_{\max lin}\,[N/m^2]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-20: Weldcategory - Allowed stress

7.5 Compressive force at the level of the waistrail (window sill)

7.5.1 Loads FEA Object : -150 kN

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	1785,714286

Table 7-21: Nodal Force (N)

7.5.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-22: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-23: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-24: Fix - Surface Boundary Condition

7.5.3 Results

7.5.3.1 Displacement

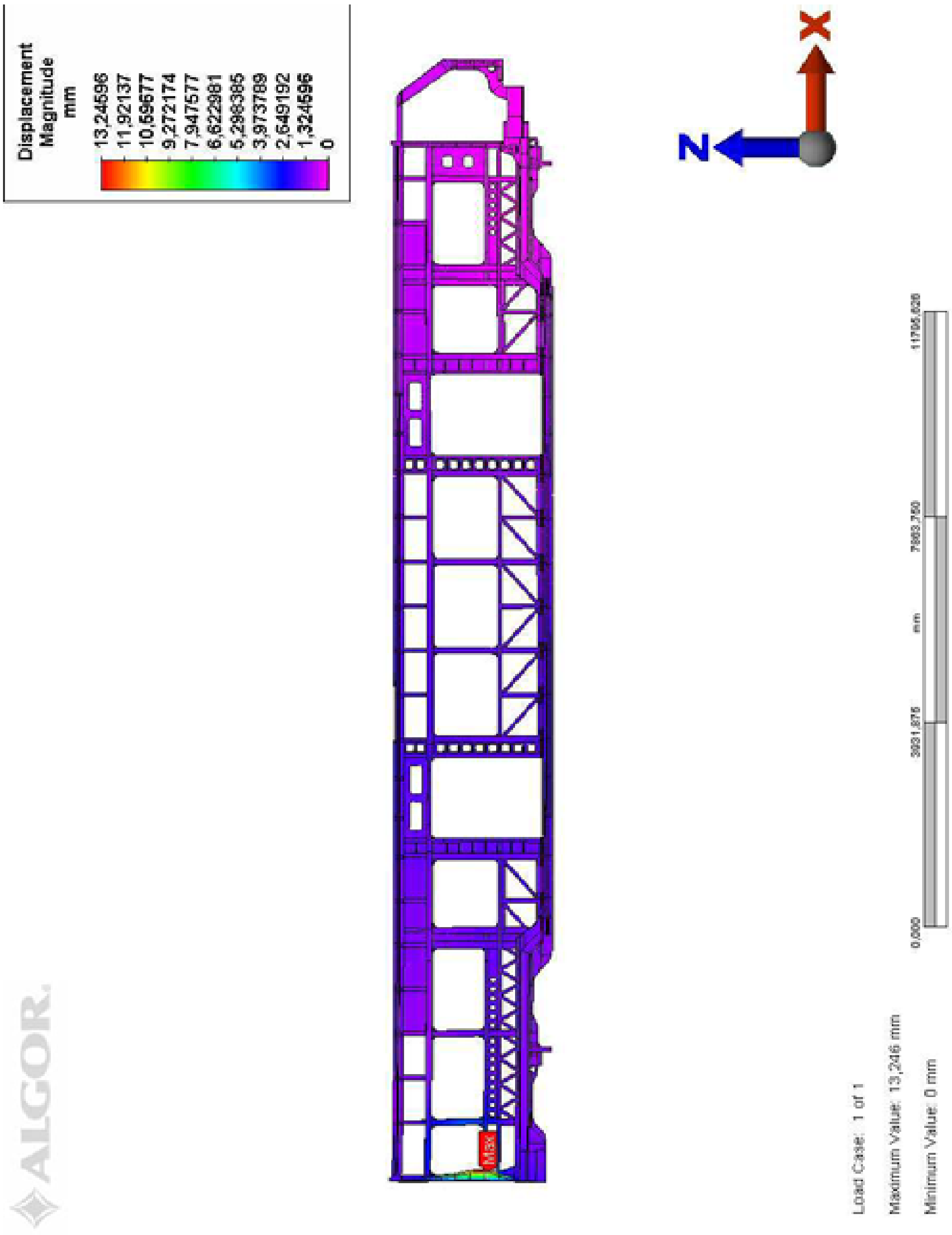


Image 31: Displacement

7.5.3.2 Stress

Image 32: Stress

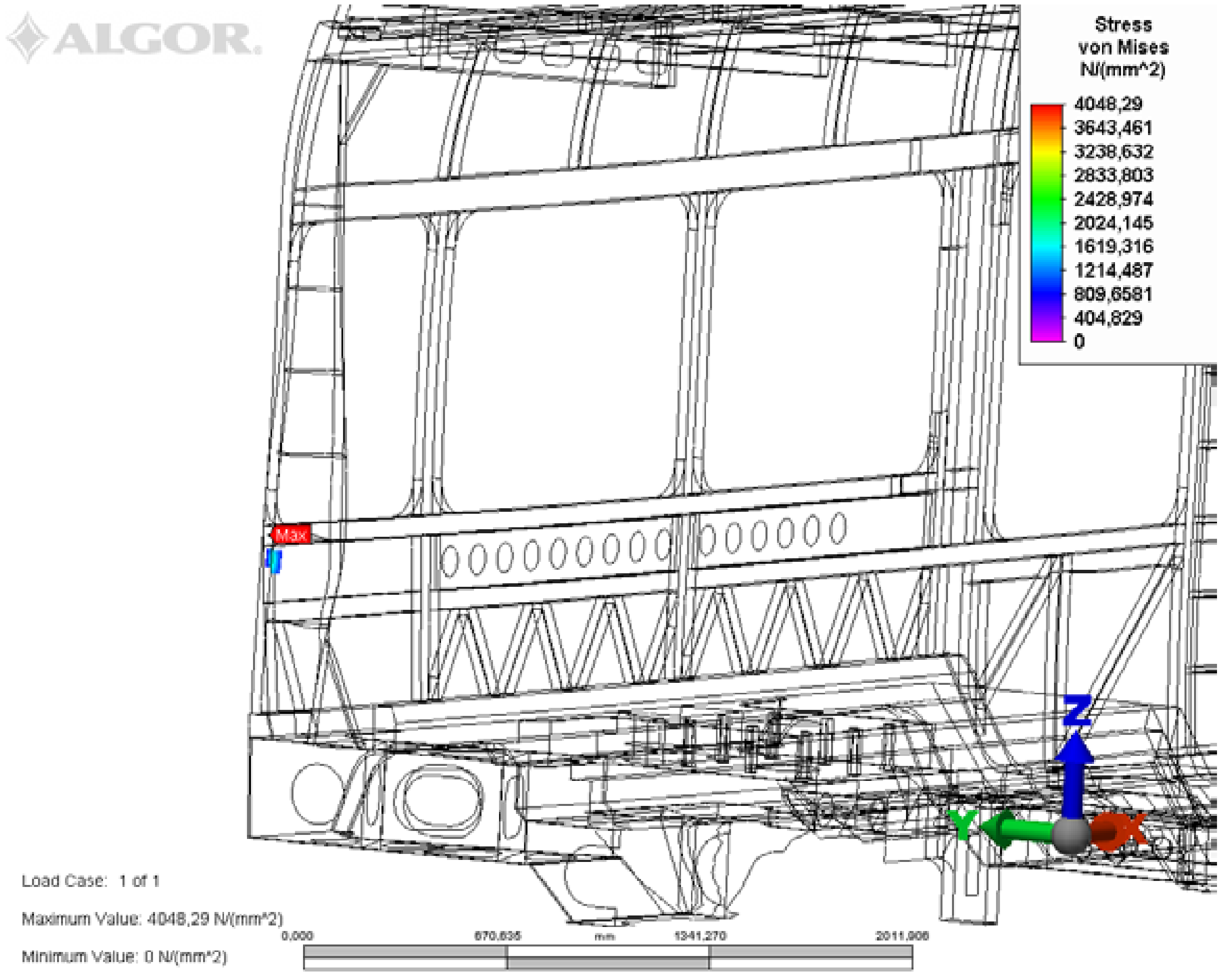


Image 33: Detail - Stress

σ_1 = 4048,29 N/mm²

	$\sigma_{\max lin} \left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-25: Weldcategory - Allowed stress

7.6 Compressive force at the level of the cant rail

7.6.1 Loads FEA Object : -150 kN

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	-50000,000000

Table 7-26: Nodal Force (N)

7.6.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-27: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-28: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-29: Fix - Surface Boundary Condition

7.6.3 Results

7.6.3.1 Displacment

Image 34: Displacement

7.6.3.2 Stress

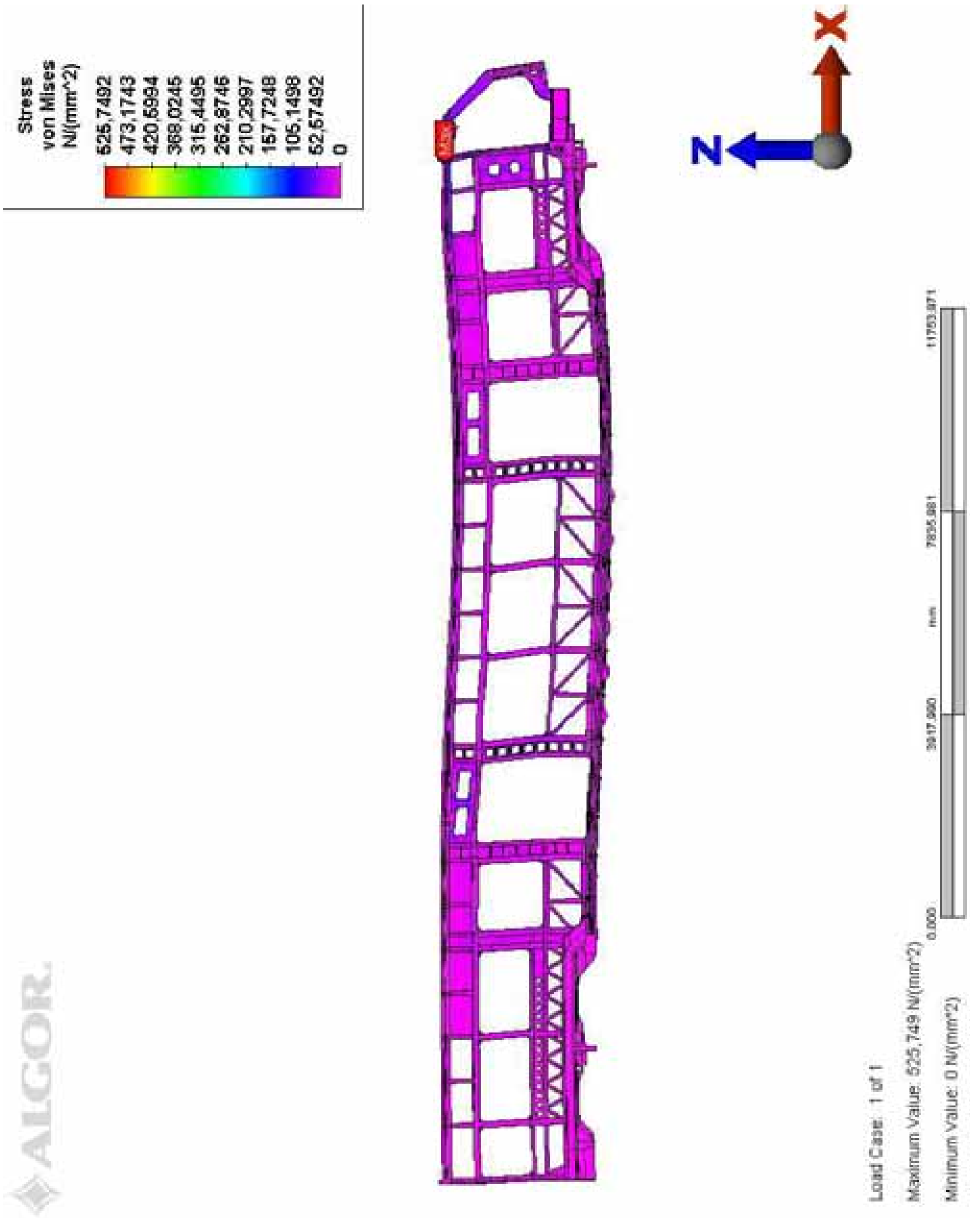


Image 35: Stress

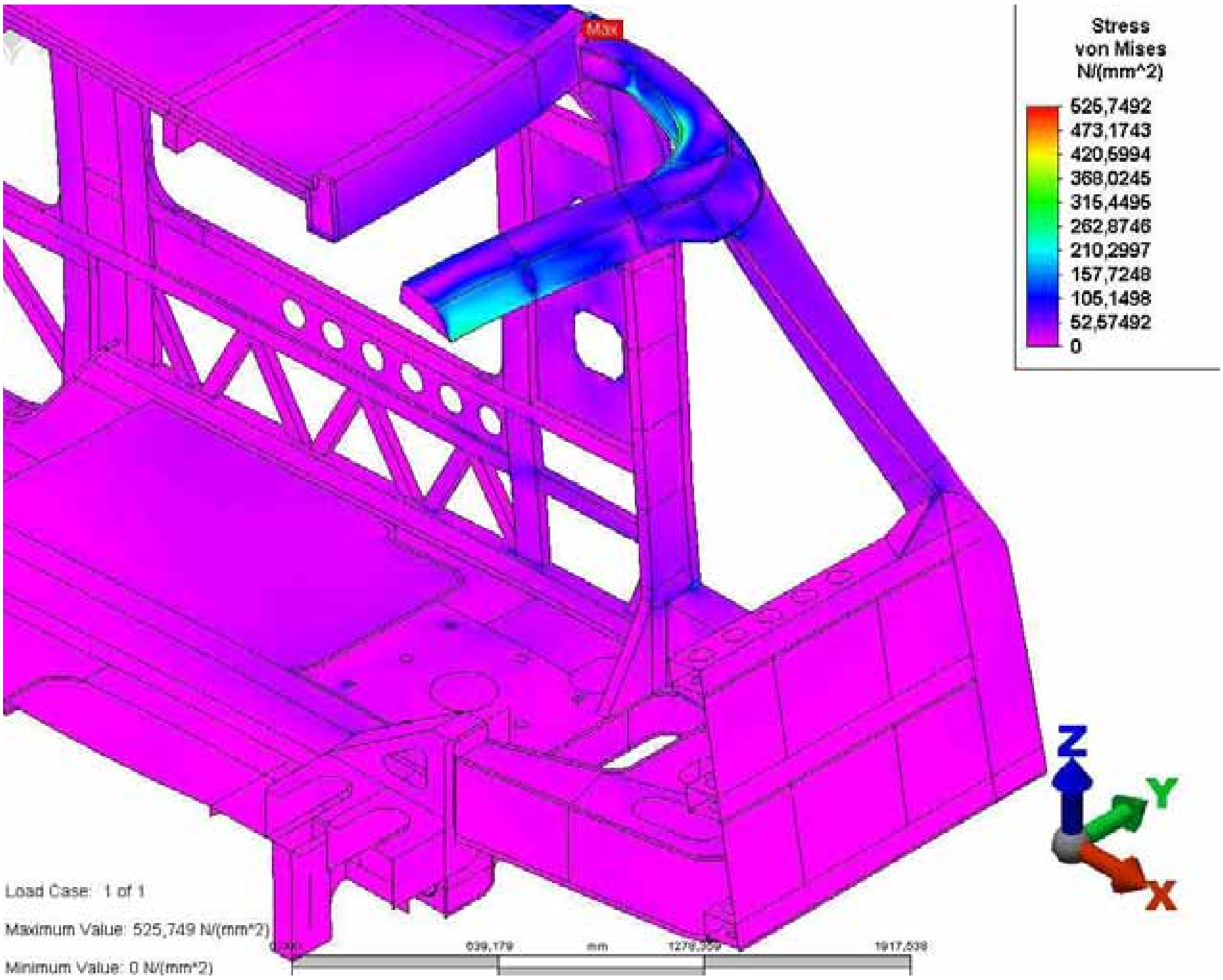


Image 36: Detail - Stress

σ_1 = 525,75 N/mm²

	$\sigma_{\max lin} [N/m^2]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-30: Weldcategory - Allowed stress

7.7 Compressive force at the level of the cant rail

7.7.1 Loads FEA Object : -75 kN

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	914,634146

Table 7-31: Nodal Force (N)

7.7.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-32: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-33: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-34: Fix - Surface Boundary Condition

7.7.3 Results

7.7.3.1 Displacment

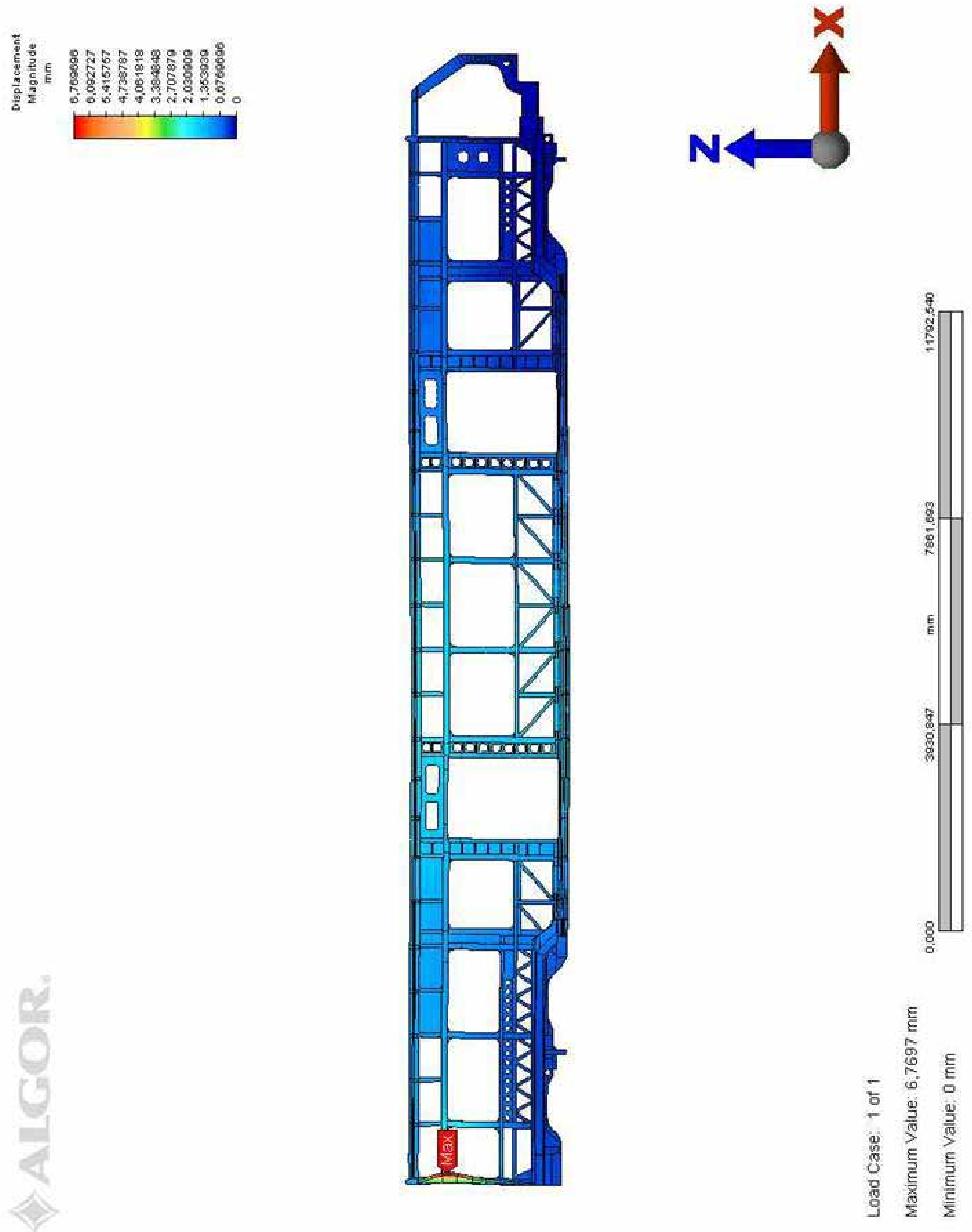


Image 37: Displacement

7.7.3.2 Stress

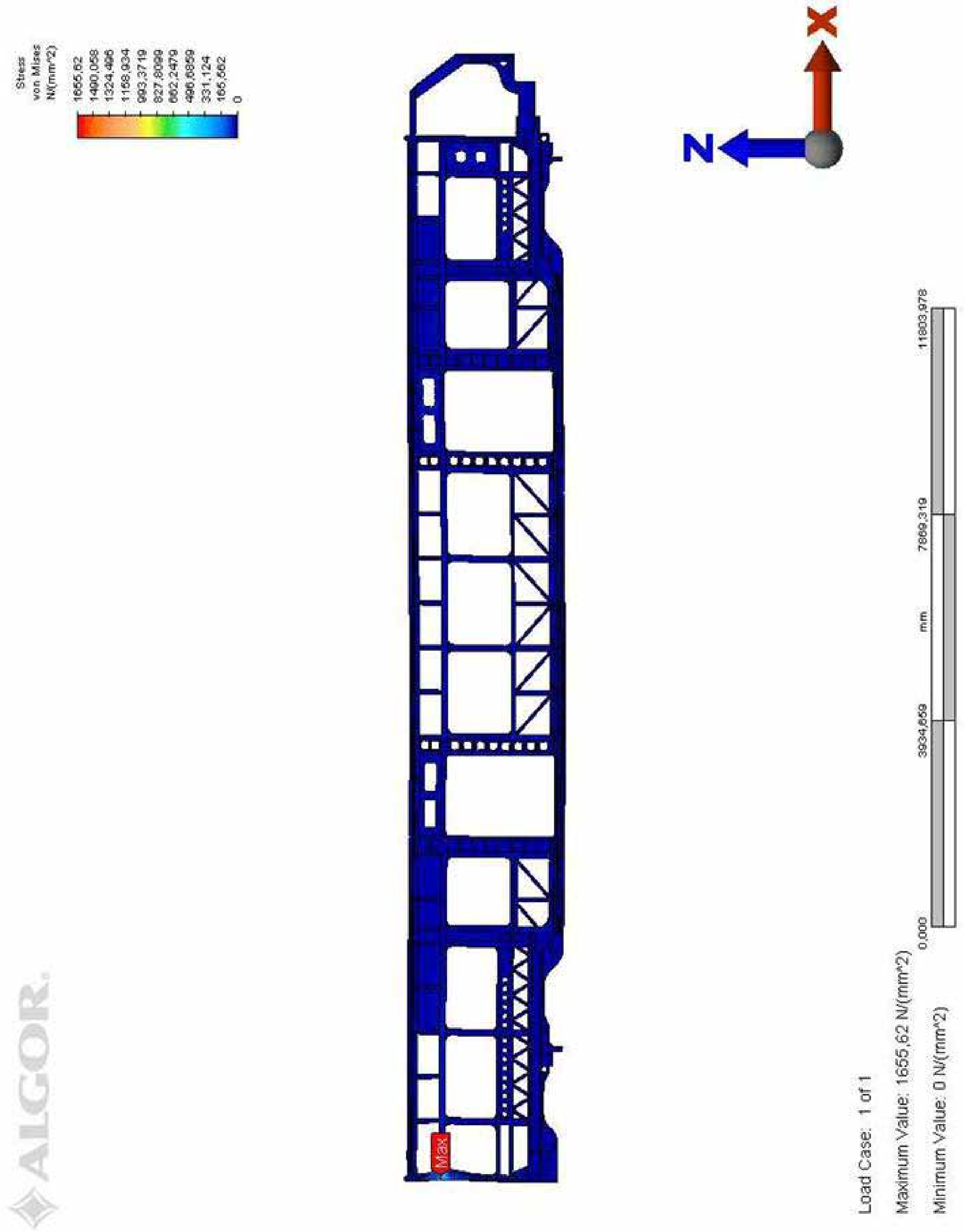


Image 38: Stress

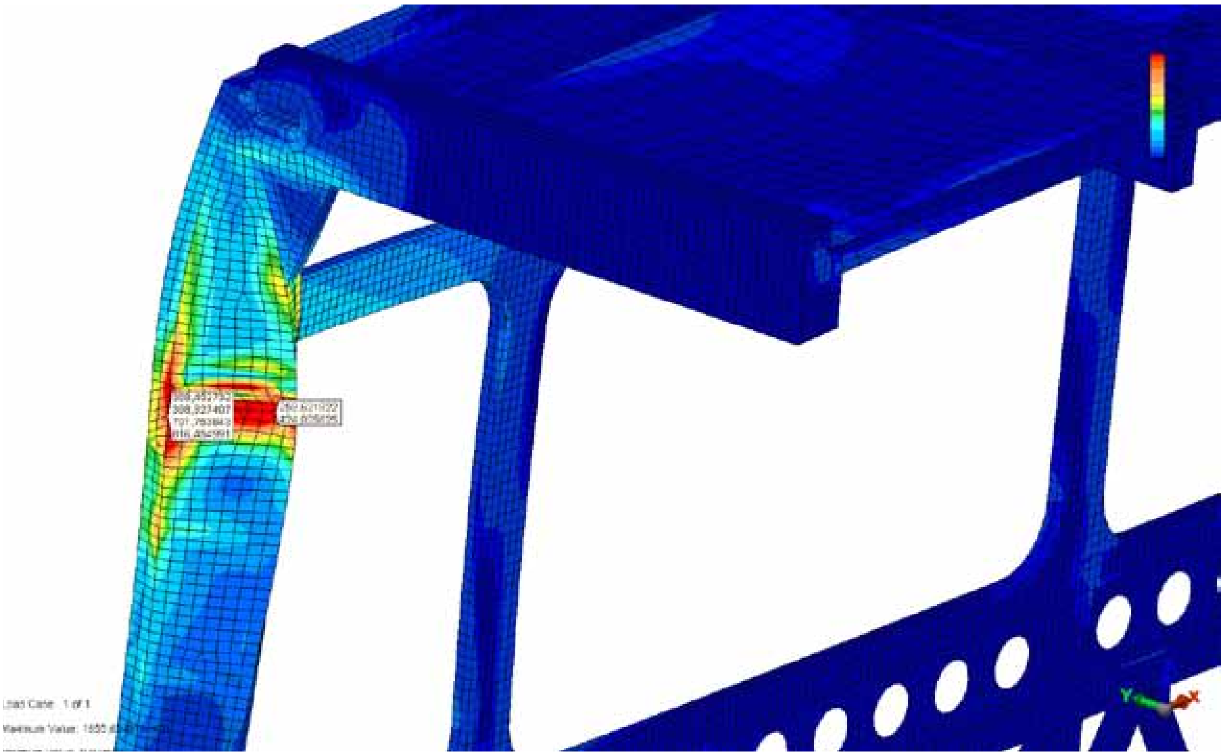


Image 39: Detail - Stress

$\sigma_1 = 1655,62\ N/mm^2$

$\sigma_2 = 816,455\ N/mm^2$

	$\sigma_{\max lin}\left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-35: Weldcategory - Allowed stress

7.8 Lifting at one end of the vehicle at the specified lifting positions

7.8.1 Loads FEA Object: 1,1 × g × (m_1+m_3)

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	-1865,384615

Table 7-36: Nodal Force (N)

7.8.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-37: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-38: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-39: Fix - Surface Boundary Condition

7.8.3 Results

7.8.3.1 Displacment

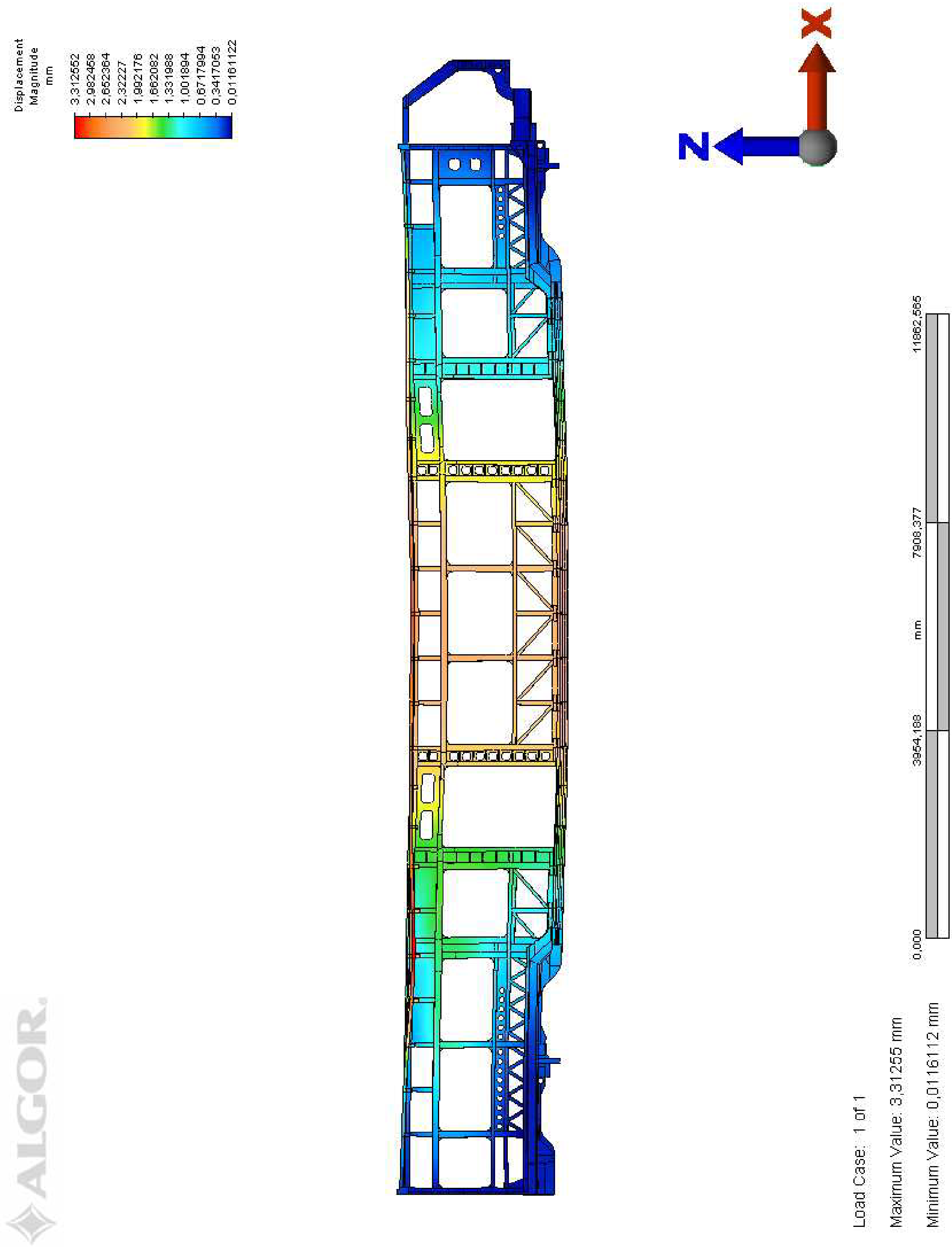


Image 40: Displacement

7.8.3.2 Stress

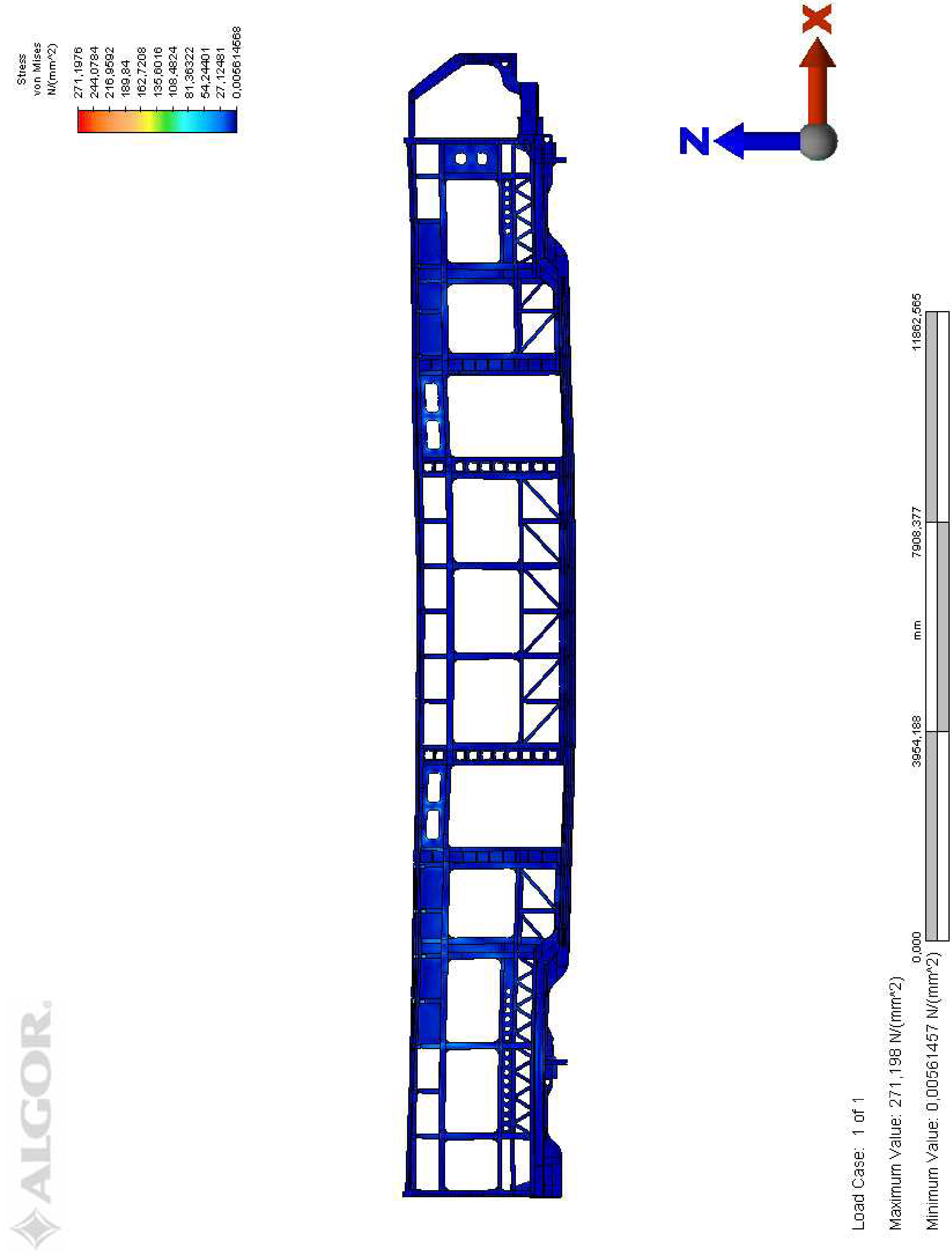


Image 41: Stress

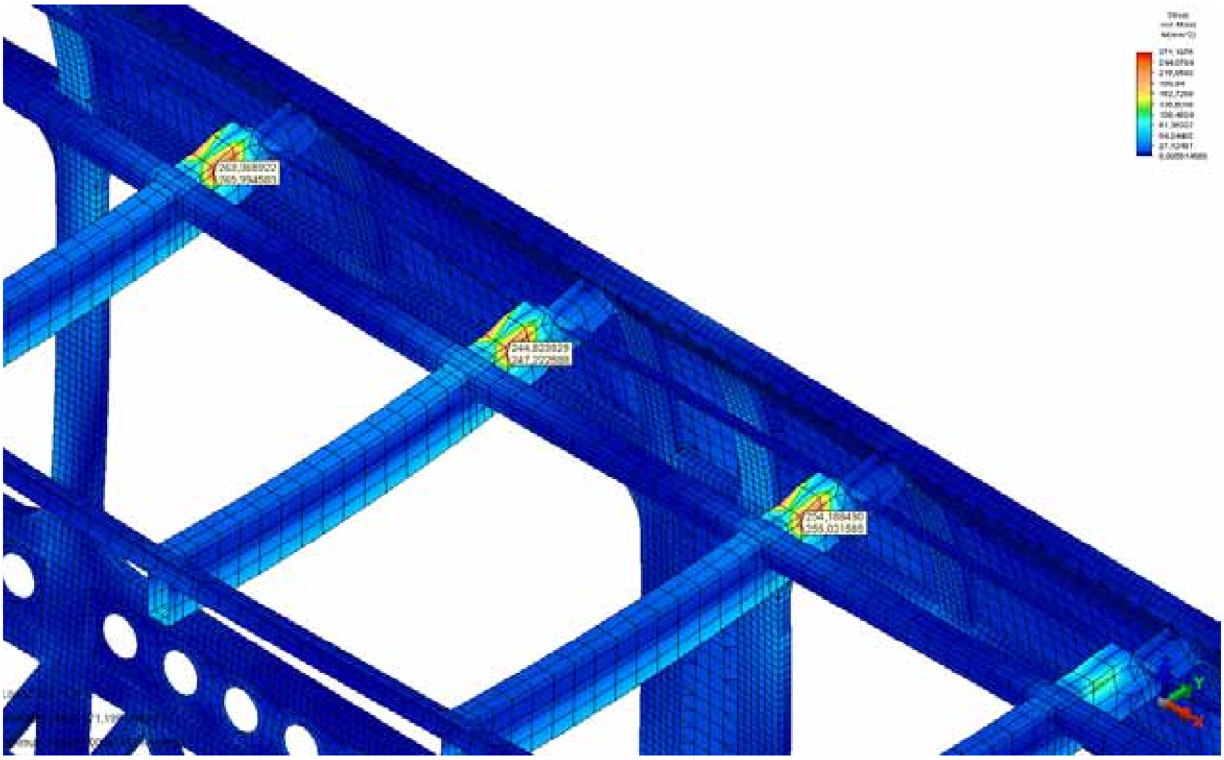


Image 42: Detail - Stress

$\sigma_1 = 271\ N/mm^2$

$\sigma_2 = 255\ N/mm^2$

$\sigma_3 = 265\ N/mm^2$

	$\sigma_{\max lin}\left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-40: Weldcategory - Allowed stress

7.9 Lifting the whole vehicle at the specified lifting positions

7.9.1 Loads FEA Object: $1{,}1 \times g \times (m_1+2m_3)$

Object Group 6 and 7: -45,8 kN

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	-1865,384615

Table 7-41: Nodal Force (N) – Group 6

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	-1865,384615

Table 7-42: Nodal Force (N) – Group 7

7.9.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-43: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-44: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-45: Fix - Surface Boundary Condition

7.9.3 Results

7.9.3.1 Displacment

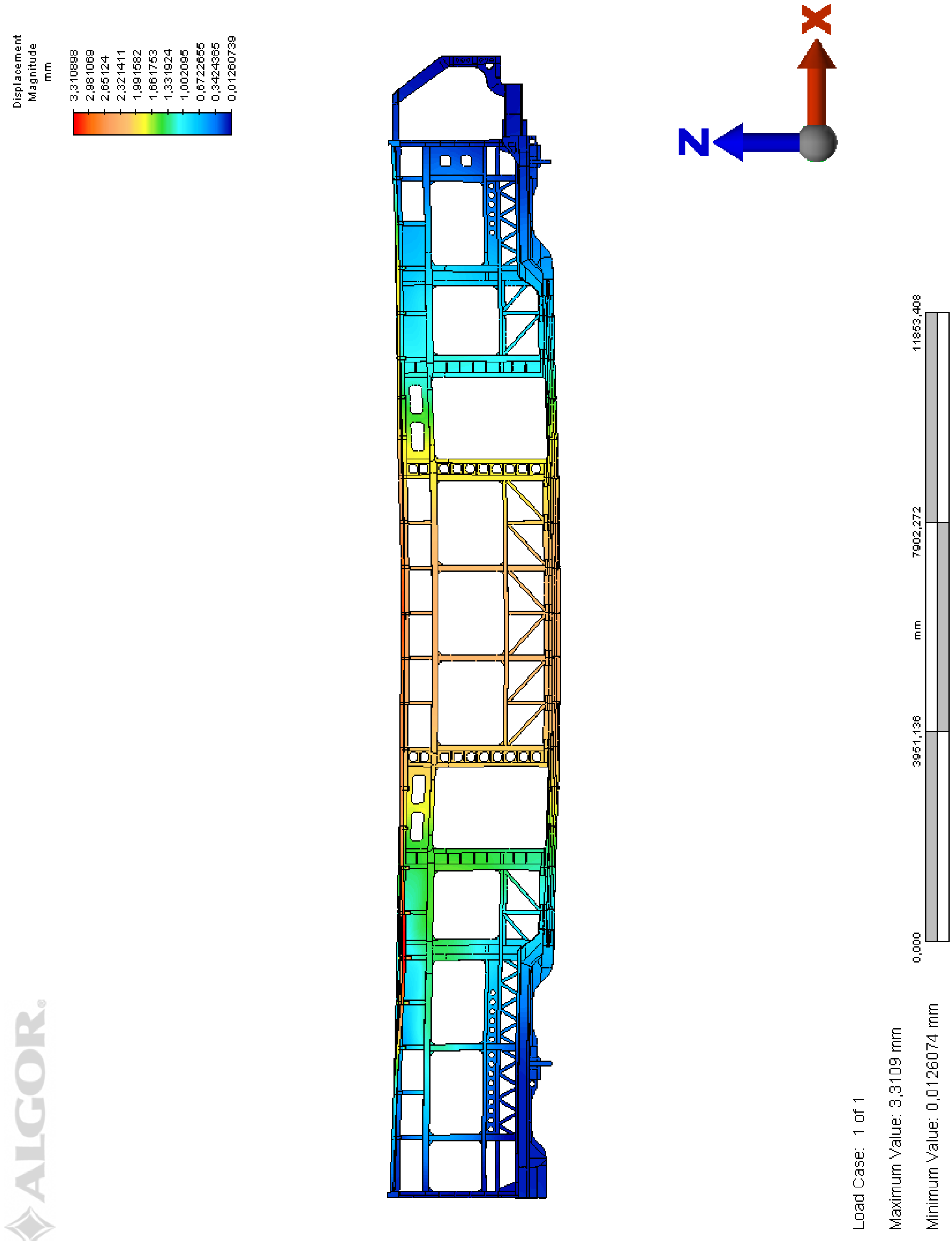


Image 43: Displacement

7.9.3.2 Stress

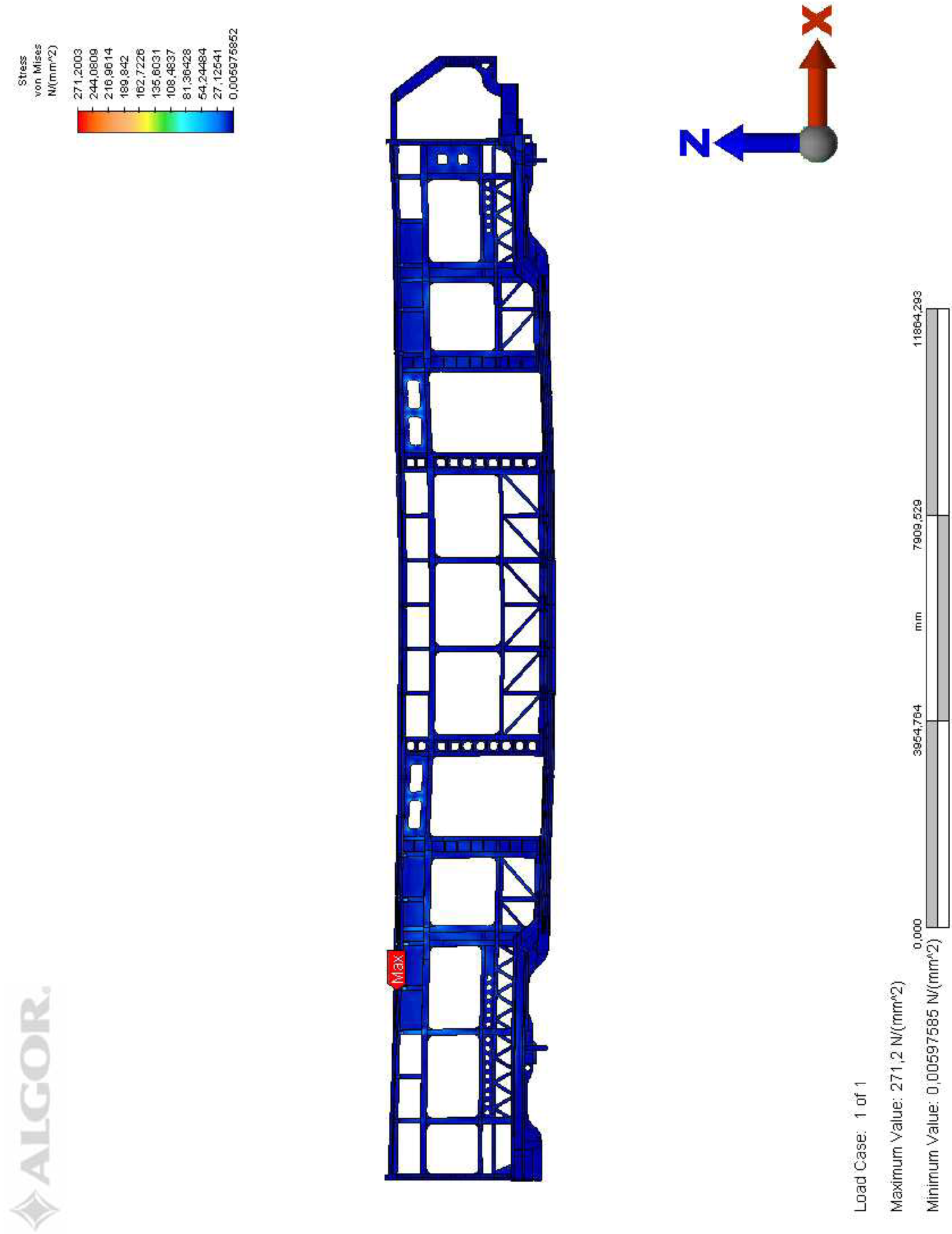


Image 44: Stress

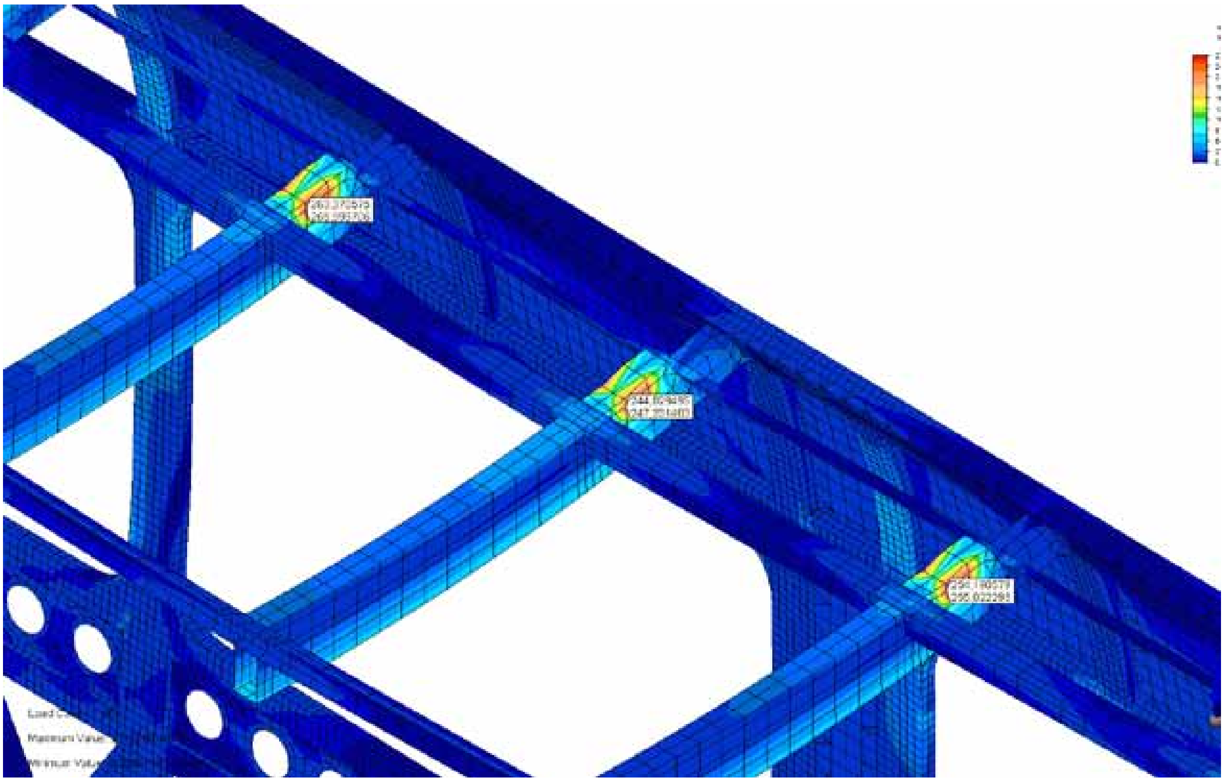


Image 45: Detail - Stress

$\sigma_1 = 271 \ N/mm^2$

$\sigma_2 = 255 \ N/mm^2$

$\sigma_3 = 265 \ N/mm^2$

	$\sigma_{\max lin} [N/m^2]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-46: Weldcategory - Allowed stress

7.10 Compressive force and vertical load

7.10.1 Loads FEA Object: $gx(m_1+m_2)$

Vx	Vy	Vz	Magnitude
1,000000	0,000000	0,000000	-78480,000000

Table 7-47: Nodal Force (N)

7.10.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-48: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-49: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-50: Fix - Surface Boundary Condition

7.10.3 Results

7.10.3.1 Displacment

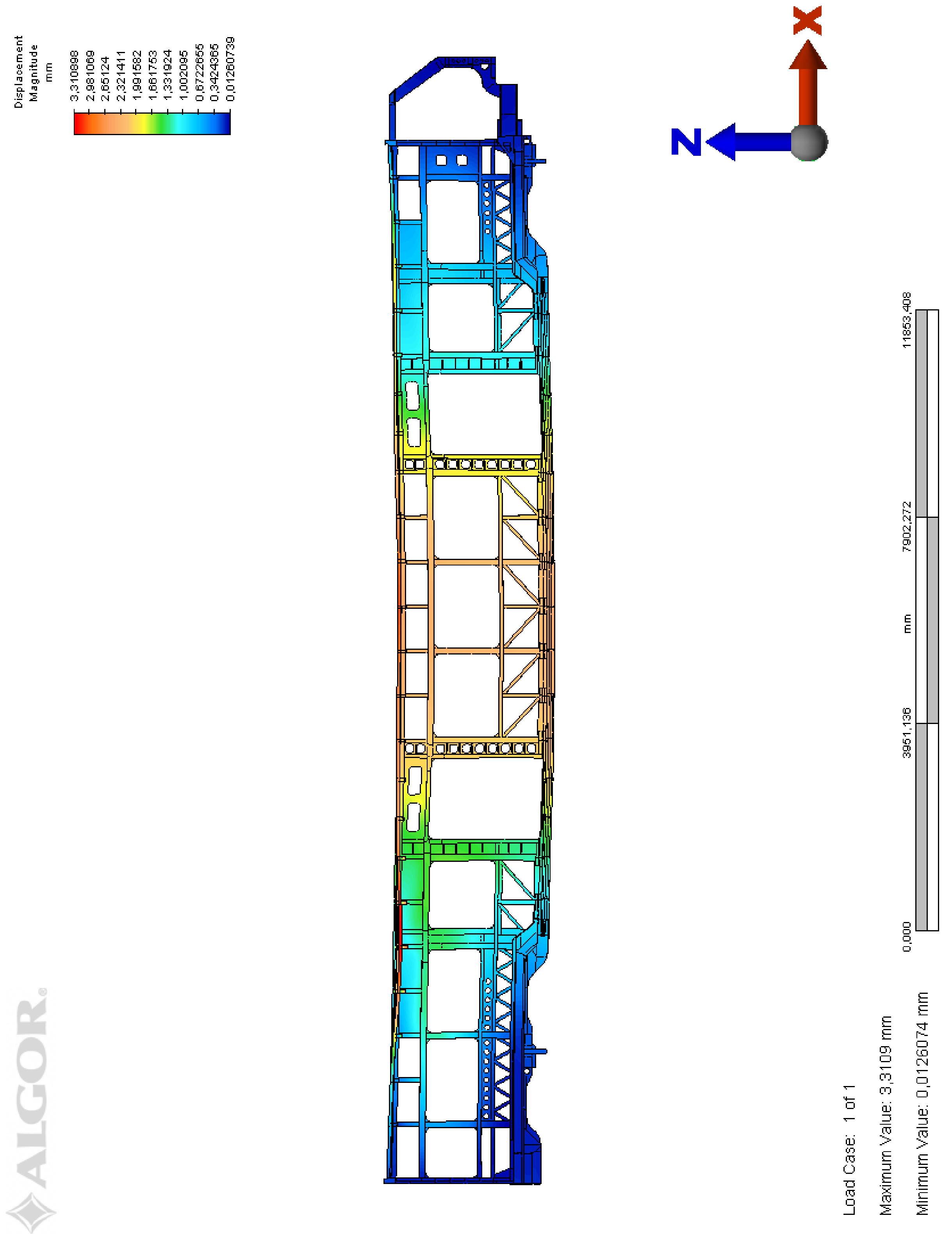


Image 46: Displacement

7.10.3.2 Stress

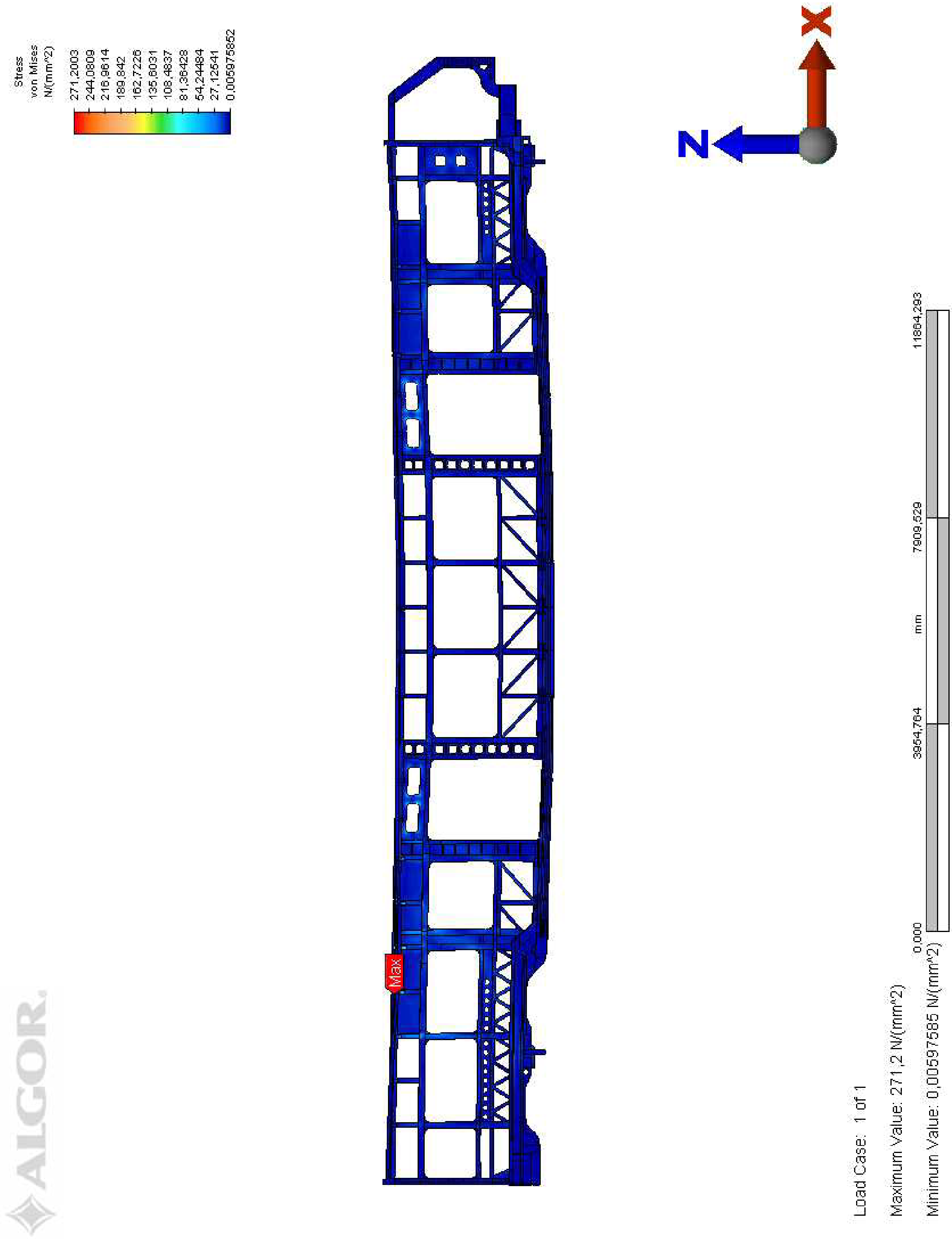


Image 47: Stress

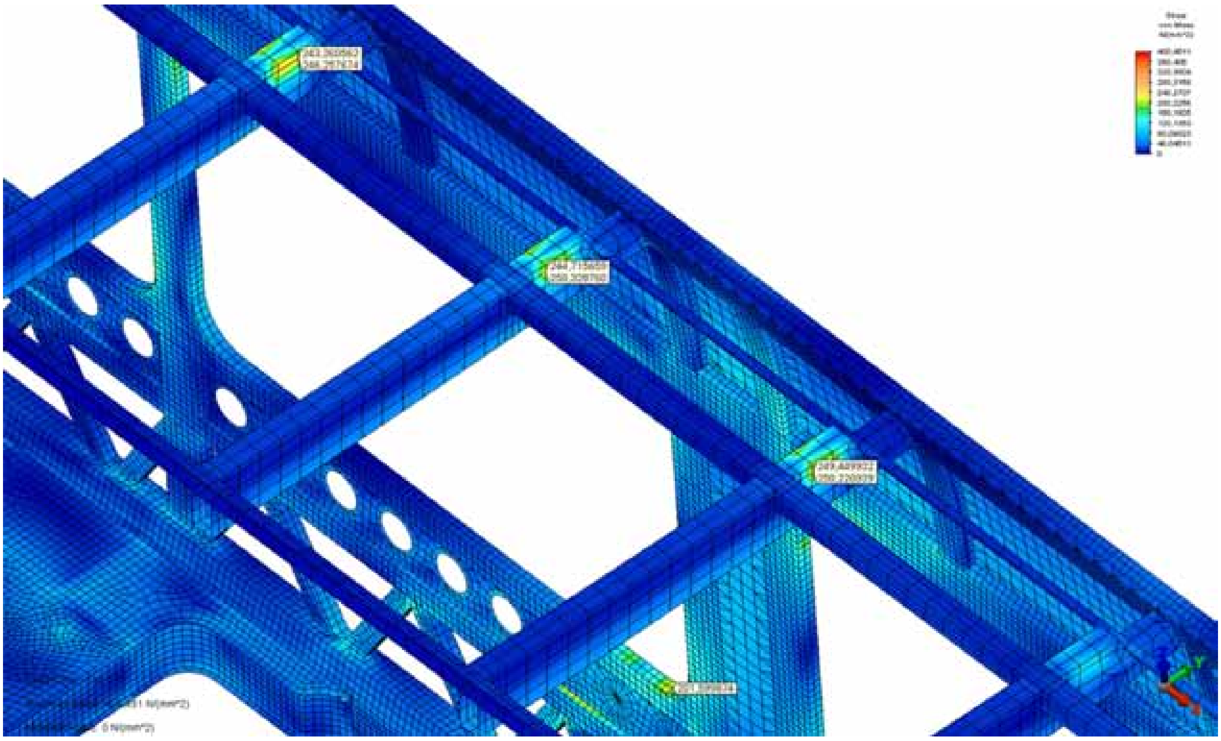


Image 48: Detail - Stress

$\sigma_1 = 250\ N/mm^2$

$\sigma_2 = 249\ N/mm^2$

	$\sigma_{max\,lin}\left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-51: Weldcategory - Allowed stress

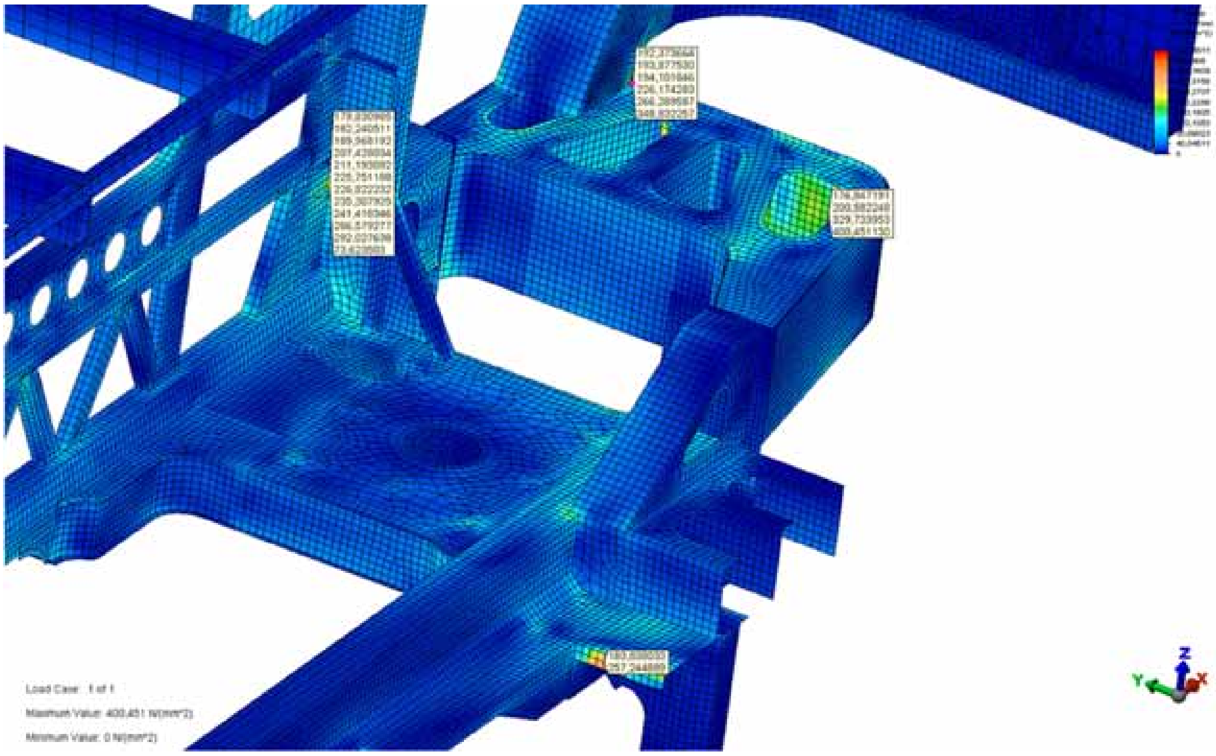


Image 49: Detail - Stress

$\sigma_1 = 400\ N/mm^2$

$\sigma_2 = 348\ N/mm^2$

	$\sigma_{\max lin}\left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-52: Weldcategory - Allowed stress

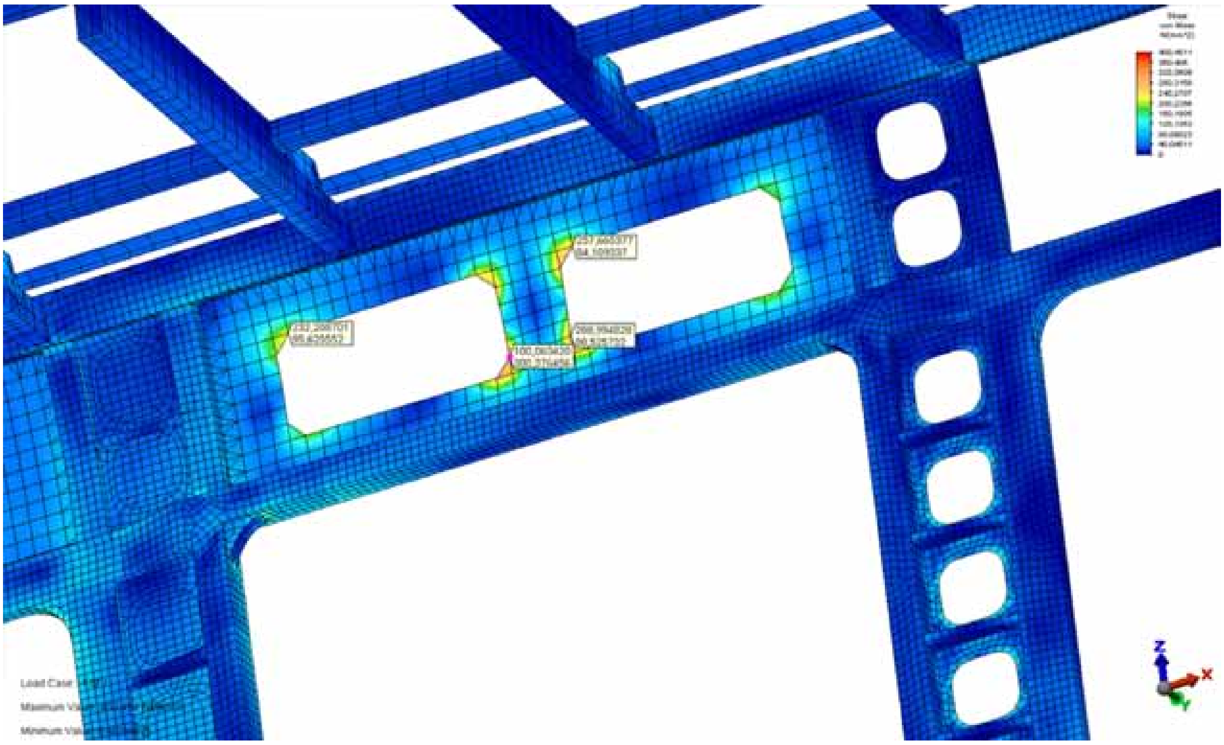


Image 50: Detail - Stress

$\sigma_1 = 288\ N/mm^2$

$\sigma_2 = 257\ N/mm^2$

	$\sigma_{\max lin} [N/m^2]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-53: Weldcategory - Allowed stress

7.11 Compressive force and vertical load

7.11.1 Loads FEA Object: $g \times m_1$

Vx	Vy	Vz	Magnitude
0,000000	0,000000	1,000000	-78480,000000

Table 7-54: Nodal Force (N)

7.11.2 Constraints FEA Object :

Tx	Ty	Tz	Rx	Ry	Rz
No	Yes	No	Yes	No	Yes

Table 7-55: Y Symmetrie - Nodal Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
No	No	Yes	No	No	No

Table 7-56: Tz fix - Surface Boundary Condition

Tx	Ty	Tz	Rx	Ry	Rz
Yes	Yes	Yes	Yes	Yes	Yes

Table 7-57: Fix - Surface Boundary Condition

7.11.3 Results

7.11.3.1 Displacment

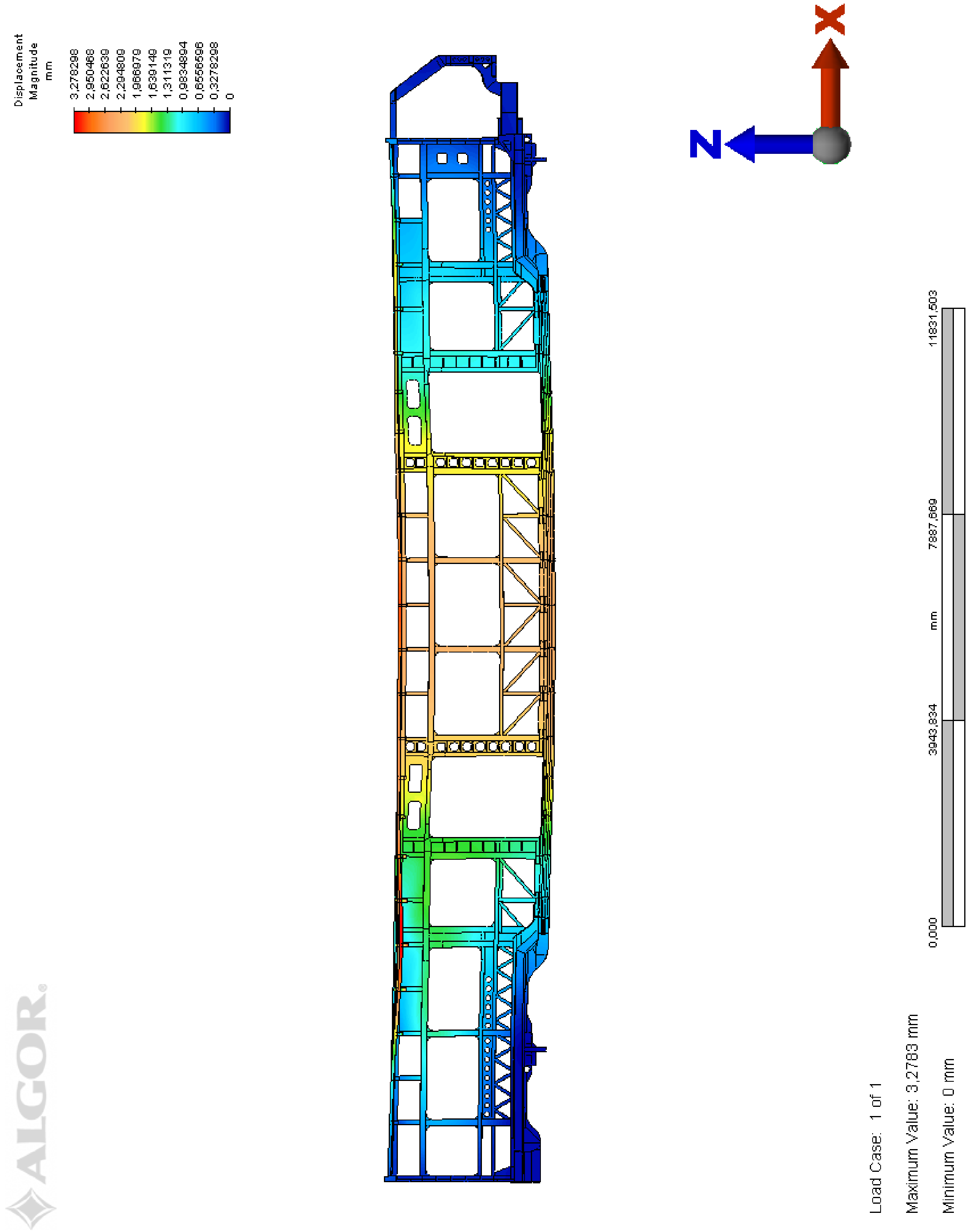


Image 51: Displacement

7.11.3.2 Stress

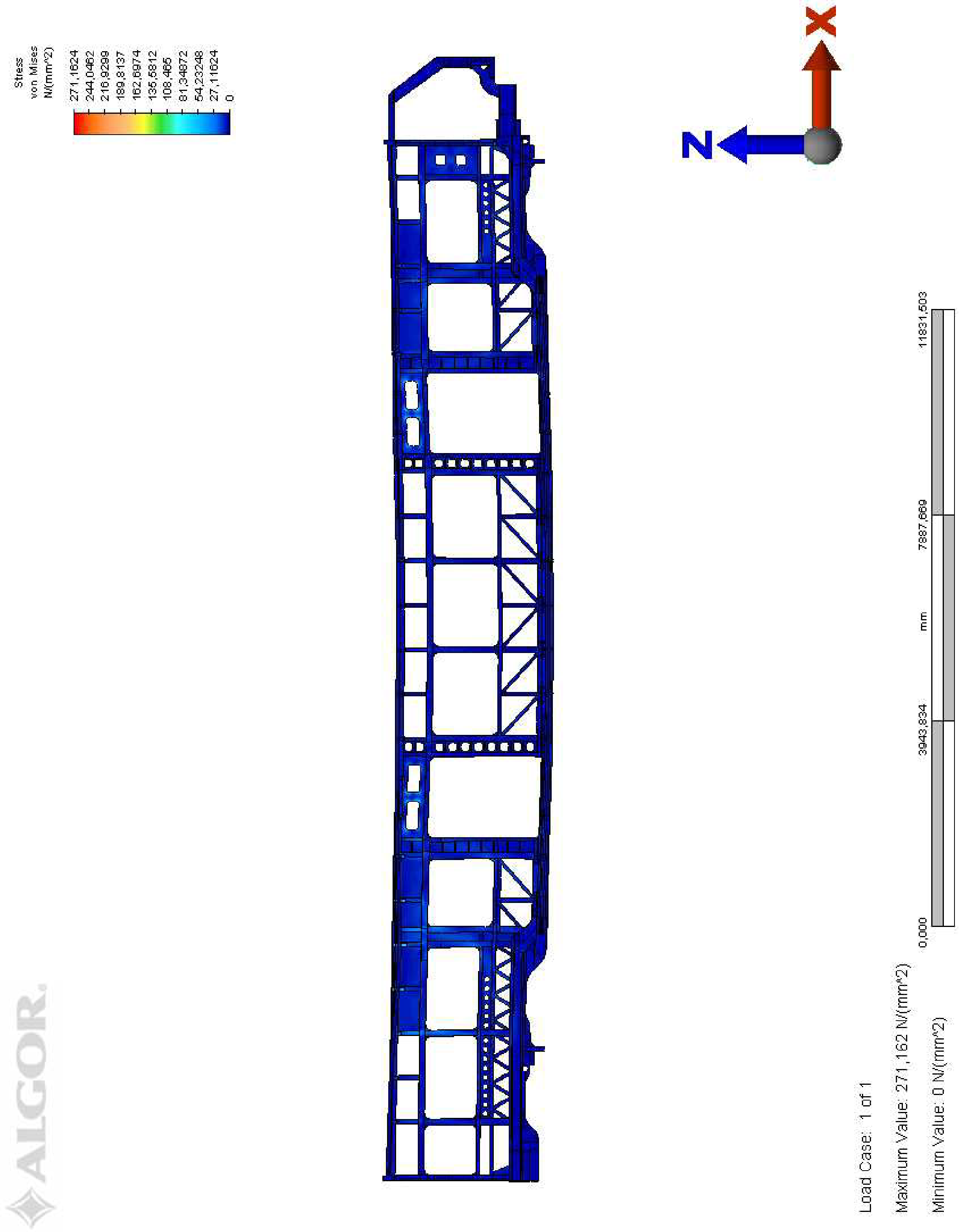


Image 52: Stress

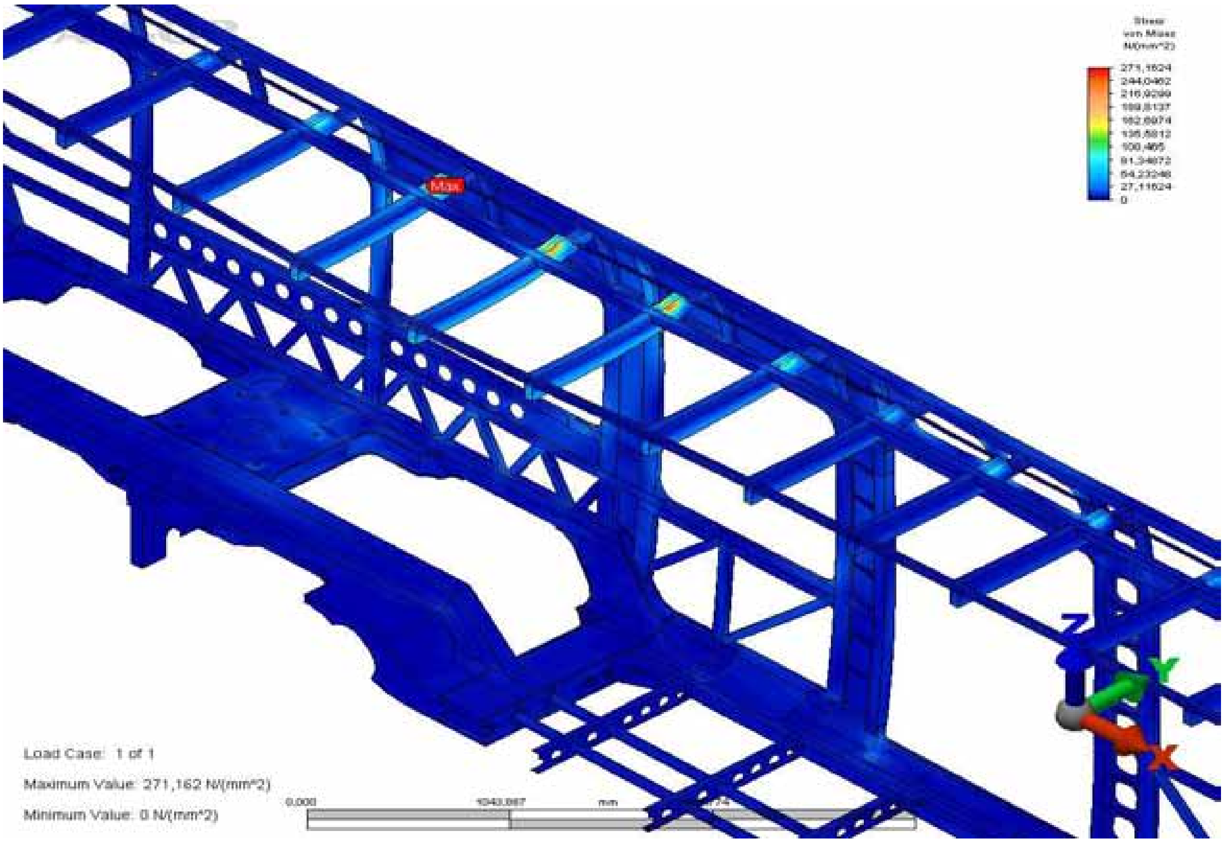


Image 53: Detail - Stress

$\sigma_1 = 250\ N/mm^2$

$\sigma_2 = 246\ N/mm^2$

$\sigma_3 = 271\ N/mm^2$

	$\sigma_{\max lin}\left[N/m^2\right]$		
Steel	K=0.2		
	S235	S275	S355
Weldcategory			
A	240	280	360
B	218	255	270
C	218	240	240
D	198	198	198
E	162	162	162

Table 7-58: Weldcategory - Allowed stress

8 Conclusion

After all performed calculations obtained results are sorted into tables according to individual load cases. Visual results (images) give the best insight into the possible critical areas of the construction. These areas are almost always places of connectivity (welded areas) of two or more parts, what was be expected. With very easy comparison of results obtained with the standard ERRI B 12/RP 60 it could be concluded that the given construction does not meet the necessary requirements for strength.

Problems have appear in the expected areas of drivers cab in front of the whole cabin. The upper part of the cabin was to weak constructed compared to the lower area of cabin. Major modifications were needed to be done in structural terms in upper part of the construction. The next big problem in calculation was ocured in the area around doors and windows. Upper and lower bounds of windows and doors compare to the rest of the structure (roof or floor in particular) showed weakness and did not meet the required conditions. These areas are also required to be improved. Following problem appeared in the area of the portal (which has the function of connecting structure to remain of modules) and requests to be carefully designed and specially solid. The area around the upper and lower bounds with a window showed large defects (more than 1000N/mm^2). And the last two load cases showed that during the lifting of the construction, on one or on both ends, critical areas of excessive strain appear in the roof. Only the last two load cases are closely within permitted limits of stress according to the given standards.

Due to construction problems that calculation showed the main engineers have decided to do also experimental approach to check the strength security of the construction. It was made a Project of measuring stress and displacement with DMS Sensors on a prototype construction according to the same standard. The resaults of measurements showed a great similarity with the obtained calculation results.

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10 List of images and tables

10.1 List of images

Image 1: Construction model of electric train 10
Image 2: FE model of electric train 12
Image 3: Vehicle masses 16
Image 4: Stress–strain curve 18
Image 5: Compressive forces in buffer and/or coupling area 20
Image 6: Tensile force in coupler area 21
Image 7: Compressive force 150 mm above the top of the structural floor at head stock 22
Image 8: Compressive force at the level of the waistrail (window sill) 23
Image 9: Compressive force at the level of the waistrail (window sill) 24
Image 10: Compressive force at the level of the cant rail 25
Image 11: Compressive force at the level of the cant rail 26
Image 12: Lifting at one end of the vehicle at the specified lifting positions 27
Image 13: Lifting the whole vehicle at the specified lifting positions 28
Image 14: Compressive force and vertical load 29
Image 15: Compressive force and min. vertical load 30
Image 16: Y Symmetrie - Nodal Boundary Condition - Side 40
Image 17: Y Symmetrie - Nodal Boundary Condition - Front 41
Image 18: Thickness of a Plate Element 45
Image 19: Displacement 45
Image 20: Stress 62
Image 21: Detail - Stress 63
Image 22: Displacement 65
Image 23: Stress 66
Image 24: Detail - Stress 67
Image 25: Displacement 69
Image 26: Stress 70
Image 27: Detail - Stress 71
Image 28: Displacement 73
Image 29: Stress 74
Image 30: Detail - Stress 75
Image 31: Displacement 77
Image 32: Stress 78
Image 33: Detail - Stress 79
Image 34: Displacement 81
Image 35: Stress 82
Image 36: Detail - Stress 83
Image 37: Displacement 85
Image 38: Stress 86
Image 39: Detail - Stress 87
Image 40: Displacement 89
Image 41: Stress 90
Image 42: Detail - Stress 91
Image 43: Displacement 93
Image 44: Stress 94
Image 45: Detail - Stress 95
Image 46: Displacement 97
Image 47: Stress 98
Image 48: Detail - Stress 99

Image 49: Detail - Stress 100
Image 50: Detail - Stress 101
Image 51: Displacement 103
Image 52: Stress 104
Image 53: Detail - Stress 105

10.2 List of tables

Table 3-1: Weld joints categories 33
Table 3-2: Tension values 34
Table 6-1: Gravity Information 39
Table 6-2 : Y Symmetrie - Nodal Boundary Condition 40
Table 6-3: Nodes forces 42
Table 6-4: Type of solver 44
Table 6-5: Type of material 46
Table 6-6: Type of elements 50
Table 6-7: Element Properties - 6mm 51
Table 6-9: Element Properties - 3mm 52
Table 6-10: Element Properties - 3mm 52
Table 6-11: Element Properties - 4mm 53
Table 6-12: Element Properties - 3mm 53
Table 6-13: Element Properties - 20mm 54
Table 6-14: Element Properties - 8mm 55
Table 6-15: Element Properties - 10mm 56
Table 6-16: Element Properties - 50mm 56
Table 6-17: Element Properties - 80mm 57
Table 6-18: Element Properties - 35mm 57
Table 6-19: Element Properties - 14mm 57
Table 6-20: Element Properties - 6mm 57
Table 6-21: Element Properties - 18mm 58
Table 6-22: Element Properties - 16mm 58
Table 6-23: Element Properties - 15mm 58
Table 6-24: Element Properties - 40mm 59
Table 6-25: Element Properties - 12mm 59
Table 7-1: Surface Force 60
Table 7-2: Y Symmetrie - Nodal Boundary Condition 60
Table 7-3: Tz fix - Surface Boundary Condition 60
Table 7-4: Fix - Surface Boundary Condition 60
Table 7-5: Weldcategory - Allowed stress 63
Table 7-6: Surface Force (N) 64
Table 7-7: Y Symmetrie - Nodal Boundary Condition 64
Table 7-8: Tz fix - Surface Boundary Condition 64
Table 7-9: Fix - Surface Boundary Condition 64
Table 7-10: Weldcategory - Allowed stress 67
Table 7-11: Nodal Force (N) 68
Table 7-12: Y Symmetrie - Nodal Boundary Condition 68
Table 7-13: Tz fix - Surface Boundary Condition 68
Table 7-14: Fix - Surface Boundary Condition 68
Table 7-15: Weldcategory - Allowed stress 71
Table 7-16: Nodal Force (N) 72
Table 7-17: Y Symmetrie - Nodal Boundary Condition 72
Table 7-18: Tz fix - Surface Boundary Condition 72

Table 7-19: Fix - Surface Boundary Condition 72
Table 7-20: Weldcategory - Allowed stress 75
Table 7-21: Nodal Force (N) 76
Table 7-22: Y Symmetrie - Nodal Boundary Condition 76
Table 7-23: Tz fix - Surface Boundary Condition 76
Table 7-24: Fix - Surface Boundary Condition 76
Table 7-25: Weldcategory - Allowed stress 79
Table 7-26: Nodal Force (N) 80
Table 7-27: Y Symmetrie - Nodal Boundary Condition 80
Table 7-28: Tz fix - Surface Boundary Condition 80
Table 7-29: Fix - Surface Boundary Condition 80
Table 7-30: Weldcategory - Allowed stress 83
Table 7-31: Nodal Force (N) 84
Table 7-32: Y Symmetrie - Nodal Boundary Condition 84
Table 7-33: Tz fix - Surface Boundary Condition 84
Table 7-34: Fix - Surface Boundary Condition 84
Table 7-35: Weldcategory - Allowed stress 87
Table 7-36: Nodal Force (N) 88
Table 7-37: Y Symmetrie - Nodal Boundary Condition 88
Table 7-38: Tz fix - Surface Boundary Condition 88
Table 7-39: Fix - Surface Boundary Condition 88
Table 7-40: Weldcategory - Allowed stress 91
Table 7-41: Nodal Force (N) – Group 6 92
Table 7-42: Nodal Force (N) – Group 7 92
Table 7-43: Y Symmetrie - Nodal Boundary Condition 92
Table 7-44: Tz fix - Surface Boundary Condition 92
Table 7-45: Fix - Surface Boundary Condition 92
Table 7-46: Weldcategory - Allowed stress 95
Table 7-47: Nodal Force (N) 96
Table 7-48: Y Symmetrie - Nodal Boundary Condition 96
Table 7-49: Tz fix - Surface Boundary Condition 96
Table 7-50: Fix - Surface Boundary Condition 96
Table 7-51: Weldcategory - Allowed stress 99
Table 7-52: Weldcategory - Allowed stress 100
Table 7-53: Weldcategory - Allowed stress 101
Table 7-54: Nodal Force (N) 102
Table 7-55: Y Symmetrie - Nodal Boundary Condition 102
Table 7-56: Tz fix - Surface Boundary Condition 102
Table 7-57: Fix - Surface Boundary Condition 102
Table 7-58: Weldcategory - Allowed stress 105