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Preface

This master thesis is written as my final project of my Master´s degree in constructions and materials at the University of Stavanger, Faculty of Science and Technology, Norway. The research has been carried out during the spring semester of 2021.

I wish to express my sincere gratitude to my supervisor at the University of Stavanger, Nirosha D. Adasooriya for assistance throughout the duration of the thesis. Her advice and support of the research, as well as the guidance regarding the structural analysis and calculations in relation to the case study has been extremely helpful and highly appreciated.

I also want to thank my family and friends for their continuous support and encouragement throughout my work of the thesis, especially considering the ongoing pandemic.

Stavanger, July 2021
Julie Sofie Stave Sandviknes

Abstract

The purpose of this thesis is to propose a framework/methodology based on a recently proposed fatigue strength curve of corroded steel to assess the life of an existing steel bridge exposed to environment-assisted fatigue. A fatigue assessment using damage accumulation method is performed on an ageing steel bridge located in a marine environment in Sri Lanka. The assessment is performed using both the newly proposed method and conventional approaches covered in the framework. The difference of the estimated fatigue lives emphasizes the importance of considering the interactions of corrosion and fatigue mechanisms.

The newly proposed method includes a formula and corresponding S-N curves to predict fatigue strength of corroded structural elements of steel structures. Parameters of the S-N curve for both marine and urban environments are provided for detail categories in the Eurocode and the DNV-GL code. The formula does not require any other material parameters than the fatigue curves given in the codes. The applicability and significance of this method is discussed by comparison of the fatigue lives obtained by both the conventional method from the Eurocode and proposed method.

Prior to the fatigue assessment, a thorough literature review regarding forms of corrosion on steel bridges, their effects and causes are first studied. Environment-assisted cracking (EAC) and how it affects the structural integrity of steel bridges are introduced. Research gaps and shortcomings in the literature regarding the issue are investigated.

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Abbreviations

CF	Corrosion fatigue
COV	Coefficient of variation
EAC	Environment-assisted cracking
FLS	Fatigue limit state
HE	Hydrogen embrittlement
MIC	Microbiologically influenced corrosion
NDT	Non-destructive damage inspection techniques
SCC	Stress corrosion cracking
VHCF	Very high cyclic fatigue

Symbols

b	Basquin´s exponent
m	Negative inverse slope of the S-N curve
A	Cross-sectional area
D	Damage accumulation factor
N	Number of stress cycles
N_f	Number of cycles to fatigue failure
$N_{f,FL}$	Endurance number of cycles
$N_{f,LCF}$	Number of cycles to fatigue failure of the uncorroded materials at yield strength
$N_{f,CAFL}$	Number of cycles at constant amplitude fatigue limit
$N_{f,VAFL}$	Number of cycles at variable amplitude fatigue limit
N_R	Number of cycles to fatigue failure
γ_{Ff}	Partial factor for equivalent constant amplitude stress ranges
γ_{Mf}	Partial factor for fatigue strength
$\Delta\sigma$	Stress range
$\Delta\sigma_C$	Reference value of fatigue strength
$\Delta\sigma_{cor}$	Fatigue strength range of corroded constructional detail
$\Delta\sigma_D$	Stress range at constant amplitude fatigue limit
$\Delta\sigma_{D,cor}$	Stress range at intersecting points of two slopes
$\Delta\sigma_L$	Stress range at variable amplitude fatigue limit
$\Delta\sigma_{L,cor}$	Stress range at number of cycles at variable amplitude fatigue limit
$\Delta\sigma_R$	Direct stress range
$\sigma_{a,cor}$	Fatigue strength of corroded material
σ_y	Yield strength
σ'_f	Fatigue strength coefficient
σ_∞	Endurance limit
$\sigma_{\infty,cor}$	Endurance limit for corroded material

1. Introduction

1.1 Background

Bridge authorities are paying significant attention to the ageing issues of bridges, as bulk of bridges are subjected to environment-assisted damages and replacement of all these is not economical. Environment-assisted cracking (EAC) is one of the main deterioration processes that affect the integrity of bridges. Steel bridges exposed to an aggressive environment are subjected to loss of protective coating, thus a loss of material due to corrosion [1, s. 4]. These bridges suffer a change of stiffness and structural behaviour, causing a reduction of the remaining fatigue life.

Detailed provisions and frameworks are not available for assessment of structural integrity due to EAC [1, s. 2]. Three main types of EAC affects the structural integrity of bridges, including corrosion fatigue (CF), stress corrosion cracking (SCC) and hydrogen embrittlement (HE). The environment-assisted fatigue damages are quite significant, and presence of reliable methodologies/theories are essential. Well known failures of steel bridges due to EAC such as the collapse of Silver Bridge in 1967 and Mianus River Bridge in 1990 illustrates that such corrosion mechanisms cannot be ignored.

1.2 Problem description

Recently proposed S-N curve for constructional details in corrosive environment is applied to estimate the fatigue life of a steel bridge. The results are compared with conventional approaches. The applicability and significance of the proposed curve are to be confirmed. Hence, a conceptual framework/guideline will be proposed.

1.3 Methodology

A literature review on existing guidelines and methods used to estimate fatigue assessment of steel bridges is carried out to investigate shortcomings, doubts and research gaps. This is then compared to a recent research done to overcome above shortcomings or research gaps. A critical analysis of the methodologies will be done to identify the most suitable and accurate method. This is done by the applying proposed method on a case study.

The case study will include an identification of environmental conditions, current state and critical details of a steel bridge in a corrosive environment. A structural analysis of the bridge will be carried out, and checked for design limit states, by simulating the current state. Lastly, the case study will include a fatigue assessment, remaining life calculation by using both the conventional approach and the proposed method.

1.4 Limitations of the thesis

Only fatigue effects from traffic loads and dead load are taken into consideration for the fatigue assessment of the case study. As no information regarding the traffic loading is available, the traffic model are assumed to be "standard traffic mix".

1.5 Outline of the thesis

Including this introduction, the thesis is divided into eight chapters. The approach of the problem objective is illustrated in figure 1.

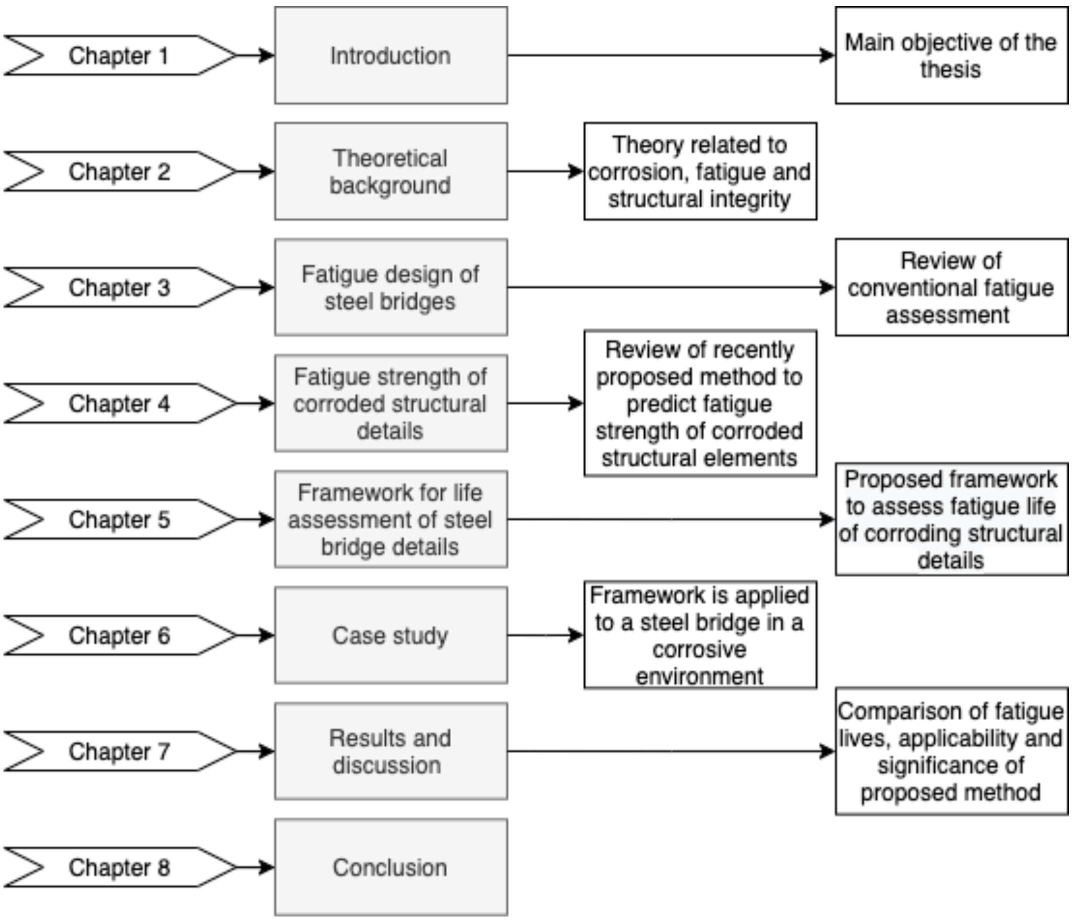


Figure 1 Organization of the thesis

2. Theoretical background

This chapter introduces relevant theory that is important to understand prior to the fatigue life assessment. Forms of corrosion common for steel bridges, as well as their causes, effects and preventative measures will be reviewed. Furthermore, the concept of EAC will be introduced, including its mechanisms, causes and effects on steel bridges.

2.1 Steel as a structural material for bridges

The construction of steel bridges began more than a 100 years ago. Eads bridge (pictured in figure 2), a three span arch bridge over the Mississippi river, was opened in 1874. It is named a National Historic Civil Engineering Landmark, and is one of the 19th century´s most well-known bridges. The arches being made of steel, made the bridge the first major building constructions with steel as the structural material. At this time, wrought iron was more commonly used in bridge construction, replacing the use of cast iron and wood [2, s. 18-19].

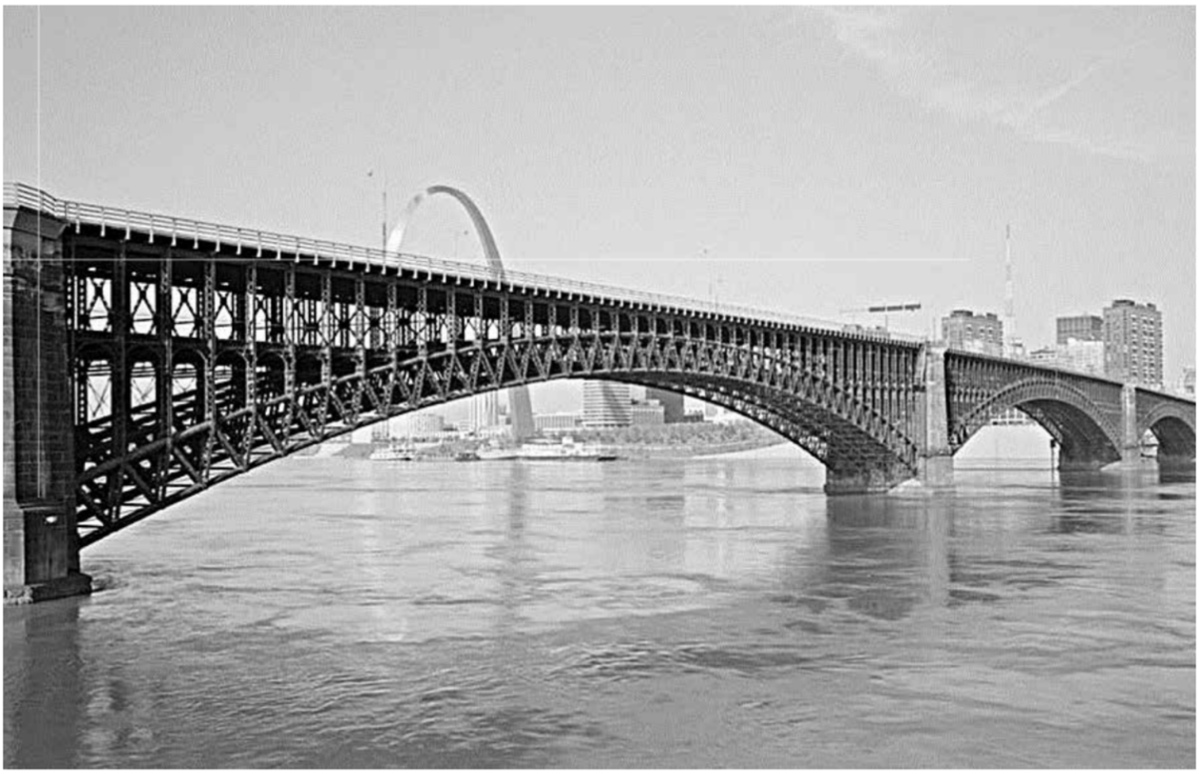


Figure 2 Eads bridge [2, s. 18]

Today, structural steel is widely used as a bridge construction material around the world. As a bridge construction material, steel is commonly used as wires, cables, plates, bares, rolled-shapes and built-up shapes. Common steel shapes can be I girders, box girders and truss members. Structural beams are often made as rolled shapes, e.g. I beams, while columns are made as various shapes, often I-shapes with straight or tapered flange thickness [3, p. 229].

2.2 Corrosion

Corrosion is one of the major deterioration mechanisms affecting steel bridges. The phenomenon can range from a progressive weakening of the structure over time to a sudden collapse of the structure [4, s. 1]. It is degrading to the structure in a way that it causes loss of material which again results in reduction of structural load-carrying capacity. This deterioration process is difficult to predict due to its nonuniform corrosive rate [5, s. 53]. The uncertainty regarding the structural performance of corroding bridges is why it may eventually cause catastrophic failures.

The primary method for detecting damage of steel bridges is non-destructive damage inspection techniques (NDT). This includes visual inspection, eddy current method, radiographic method, ultra-sonic testing, infra-red thermography, laser technology, etc. One of the main issues with NDT, is that even though they can determine surface damage such as corrosion, they cannot detect sub-surface damage including EAC [6, s. 1]. A weakening of the structure due to corrosion damage may occur gradually over time, which eventually can cause a sudden collapse. A few examples of well-known bridge collapses due to corrosion are listed below, and should be a reminder of the importance of studying corrosion damages to avoid it happening again.

<u>Silver bridge</u>

Silver bridge, known for its silvery aluminium paint, was built in 1928 and spanned Ohio River between Ohio and West Virginia. Originally it was designed using conventional wire cables, but eyebar chain design was used as a cheaper alternative. In 1967, the 1460 foot (about 450 m) bridge collapsed without warning, taking with it 46 victims. The cause of the collapse were determined a few years later – fracture in the lower limb of the eye of the eyebar. The fracture were a result of the joint action of stress corrosion and corrosion fatigue, and were not detectable by visual inspection [7].

Mianus river bridge

Mianus river bridge crossed Mianus river in Cos Cob, Greenwich, Connecticut. Built in 1958, the bridge collapsed in 1983 due to built-up corrosion product over a long period of time from an underlying washer, caused a misalignment of a pin-and-hanger assembly. This misalignment increased the stress range in the pin, which eventually caused a fatigue crack leading to failure of the pin [4, s. 4].

2.2.1 Costs due to corrosion

Three main costs related to the importance of corrosion are [8, s. 2]:

1. Finances
2. Conservation of natural resources
3. Safety

Economic factors is an important influence regarding the study of corrosion. A study conducted to estimate the financial costs directly connected to corrosion, showed that total costs due to corrosion for the US is 3.1% of the Gross Domestic Product. This amounts to approximately 276 billion dollars. Similarly, for other industrialized countries mentioned in the study, this results in 3-4% of the Gross Domestic Product. It is stated in the study that around 25-30% of these costs could be avoided if available corrosion technology were efficiently applied [8, s. 3]. Corrosion engineers and corrosion scientists aim to reduce the loss of materials and their associated costs. This includes [9, s. 5-8]:

1. Loss of product during shutdown or failure
2. Maintenance costs
3. Consideration of environmental and consumer costs
4. Costs as a result of leakage from corroded pipes
5. Increased labour requirements

These financial costs show the importance of the investigation and to minimize corrosion problems. These costs also illustrate the costs related to conservation of natural resources. It is a waste of the material that are replaced, and also the energy and water involved in the production and fabrication of the structural elements. In addition, the human effort involved in the process of replacement and maintenance should be taken into consideration [8, s. 2].

Furthermore, safety is a critical consideration when designing bridges, primarily to avoid such catastrophic failures described in chapter 2.2.

2.3 Causes and effects of corrosion

The impacts that corrosion have on conservation of natural resources, the economy and especially safety has now been covered. For a better understanding of why corrosion has such an impact on the integrity of a structure, this subchapter will cover the many causes of corrosion, and the effects it has on steel bridges.

2.3.1 Electrochemical mechanism of corroding structural steel

Corrosion processes are mainly electrochemical, consisting of a metal, an electrolyte and current flow. The corrosion process is illustrated as a corrosion cell, pictured in figure 3. Corrosion exists between a metal with high tendency to corrode (anode) and a metal with a lower tendency to corrode (cathode). Additionally, an electrolyte allowing current flow must be in contact with the anode and the cathode for the process to occur. For bridges, this electrolyte is most likely water [4, s. 5].

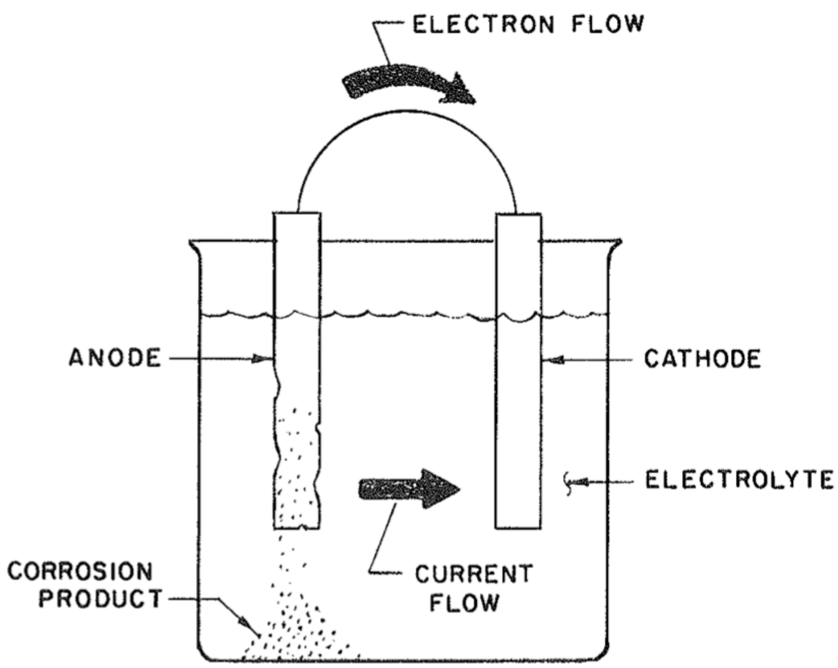


Figure 3 Corrosion cell illustrating the simplified corrosion process [4, s. 5]

Negatively electrons flows from the base of the anode to the cathode. Positively charged ions from the anode are released into the electrolyte. These ions may react with other materials, forming corrosion product. This material loss occurs at the anode, while the cathode appears undamaged [4, s. 5].

The corrosion cell illustrates the general electrochemical mechanism which can occur for different metals. The corrosion process of structural steel occurs in stages, and is described below [10, s. 1-2]. Iron ions reacts with oxygen in water, forming the corrosion product rust. The presence of water and oxygen is crucial for the reaction to occur. Any absence of the reactants, and the corrosion process will not occur.

1. At the anode, ferrous ions goes into solution, according to the following equation:

$$Fe \rightarrow Fe^{2+} + 2e^{-} \tag{2.1}$$

2. Here, electrons are released and moved through the metallic surface to the cathode where they are combined with oxygen and water to form hydroxyl ions, shown as follows:

$$2O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \tag{2.2}$$

3. Finally, the hydroxyl ions will react with the ferrous ions from the anode to produce ferrous hydroxide. These will continue to oxide in air and as a result produce hydrated ferric oxide, also known as rust. This reaction is presented as the chemical reaction given in equation 2.3.

$$4Fe + 3O_2 + 2H_2O = 2Fe_2O_3H_2O \tag{2.3}$$

2.3.2 Aqueous environments

A bridge construction´s ability to resist corrosion is affected by the surrounding environment. As mentioned, the reaction resulting in corrosion is completely dependent on the presence of water and oxygen. Furthermore, other factors from the surrounding environment will contribute to the rate of corrosion.

Microbiologically influenced corrosion

Microbiologically influenced corrosion (MIC) is corrosion that occurs by presence and activity from microorganisms such as microalgae, bacteria and fungi [8, s. 118]. MIC can take place in both sea water and fresh water, and can form various forms of localized corrosion. This includes stress corrosion cracking and hydrogen embrittlement, which is also considered as types of EAC.

Temperature

The corrosion rate increases with temperature up to 80 ºC. For higher temperatures, the solubility of oxygen in water will drastically be reduced, and the corrosion rate falls to a low value [8, s. 120].

pH values

The corrosion rate is independent of pH for values within the range of pH 4-10, and is only dependent on how rapidly oxygen diffuses to the metal surface. For acidic values, pH < 4, the corrosion rate increases as the ferrous oxide film is dissolved, resulting in a decreasing surface pH. Iron is therefore in direct connect with the acidic aqueous environment, and the corrosion rate increases. On the contrary, for pH > 10 there is an increase in alkalinity of the environment which will raise the pH value of the iron surface. The corrosion rate will as follows decrease, as the iron becomes increasingly passive in the presence of alkalis and dissolved oxygen [8, s. 121-122].

Dissolved salts

The corrosion rate is also affected by sodium chloride concentration (NaCl). The corrosion rate will increase until the salt concentration reaches sea water concentration at about 3% and then start decreasing. This is because the oxygen solubility in water decreases continuously with the NaCl concentration, and the corrosion rate will therefore be lower in higher NaCl concentrations [8, s. 131].

2.3.3 Metallurgical factors

As understood by the previous subchapter, the corrosion rate of iron and steel in natural water is governed by diffusion of oxygen to the metal surface. The corrosion rate are mainly affected by its surrounding environment, however, there are also metallurgical factors that should be taken into consideration.

The composition of iron and steel within the normal commercial limits of carbon and low-alloy steels does not have an effect on the corrosion rate in natural water. However, a slight increase of corrosion rate has been seen in seawater due to hydrogen evolution reaction in chloride solution. In acids, the corrosion rate depends on both composition and the structure of steel, and it will increase with higher carbon and nitrogen content [8, s. 138-139].

2.3.4 Corrosion effects

Built-up corrosion wastage can cause a change of the overall stiffness and structural behaviour of the structure. Typically, this will lead to a reduced remaining fatigue life of ageing steel bridges [11, s. 605]. To categorize how corrosion affects steel structures, four main categories are identified as [4, s. 7]:

1. Section loss
2. Stress concentration
3. Unintentional fixity
4. Unintended movement

Section loss

Thickness of structural members are reduced due to corrosion. This could lead to a weakness of the structural capacity of the metal such as lower bending, axial and shear capacity [4, s. 7]. Additionally, a loss of material will lead to different geometrical properties, e.g. effective cross-sectional area, moment of inertia, torsional and warping constants, etc. [11, s. 604]

Stress concentration

The creation of pits and notches due to corrosion will generate stress concentration which can eventually initiate cracking [4, s. 7].

Unintentional fixity

Built-up corrosion wastage can prevent hinges and bearing mechanisms from moving. The structure will therefore behave different than it was designed to, and structural members can therefore experience an increase of stress [4, s. 7].

Unintended movement

The wastage can also create a pressure in areas of the structure resulting in movement and bending causing damaging effects [4, s. 7].

2.4 Corrosion damage on steel bridges

The electrochemical mechanism of corrosion is as mentioned a degrading mechanism. Steel bridges can be subjected to several types of corrosion damages, such as:

Uniform attack

Also known as general corrosion, and is the type of corrosion one usually think of when talking about corrosion. This corrosion type generally appears evenly distributed over the entire surface of the material, at the approximately same corrosion rate. This type of corrosion is predictable, and also easily detectable, and therefore rarely leads to catastrophic failure. In many cases, uniform corrosion is often seen as only an issue in form of appearance. This can be specified in terms of an acceptable corrosion rate, measured in millimetres penetration per year, classified into three groups listed in table 1 [8, s. 16]:

Table 1 Rates of corrosion [8, s. 16]

Corrosion rate [mm/year]	Application
< 0.15	Satisfactory for critical parts.
0.15 – 1.5	Satisfactory for parts where higher rates of corrosion can be tolerated.
> 1.5	Not satisfactory.

Pitting

Compared to uniform corrosion which appears evenly at the whole surface of the material, pitting corrosion is a localized attack. Pitting is generally more critical than uniform corrosion, as it is harder to detect and predict. It is characterized as deep and narrow penetration into the steel surface, occurring when the steel is exposed to chemical or physical changes. This can for example be flaws in the metallurgy of the steel and paint protection imperfections. Commonly for steel bridges, pitting is often found due to moisture on the surface from dirt, trash and bird excrement. Foreign particles such as salts either from the marine environment, or from de-icing is also a common accelerator of pitting. Pitting usually takes place under these various deposits, and can be detected through visual inspection [4, s. 9].

Galvanic corrosion

Galvanic corrosion occurs when metals of different compositions are in contact with an electrolyte. Due to their difference in corrosive potential they will produce an electron flow, and one metal will act as an anode while the other acts as a cathode. The corrosion damage from galvanic corrosion can be detected visually. The corrosion rate depends on the difference in corrosion potential between the metals and the ratio of the exposed area of the metals. Galvanic corrosion typically occurs for steel bridges with aluminium detailing. Insulating materials are therefore used to prevent these materials to be in contact with each other [4, s. 8].

Crevice corrosion

Crevice corrosion is a variant of localized corrosion, which occurs at confined locations where easy access to the outside environment is prevented. It is one of the most common forms of corrosion that damages steel bridges, and can appear in closely spaced gaps between surfaces and structural details such as bracing members and eyebars. Crevice corrosion occurs due to differences between the environments inside and outside of the crevice. These differences are typically caused by oxygen cells, metal ion cells or the presence of chloride ions [4, s. 8].

Intergranular corrosion

Intergranular corrosion rapidly attacks the grain boundaries of a metal due to tensile stresses, and penetrates deep into the metal. This leads to a loss of strength and ductility, and is one of the corrosion types often causes catastrophic failures. The corrosion is typically seen in the welds and for weld decay. This type of corrosion can be detected by visual inspection, but often requires a microscopic examination [4, s. 9].

2.4.1 Corrosion prevention

It is now clear that structural details may fail by several numbers of corrosion mechanisms. There are various techniques available for preventing structural details on bridges from corroding. Each bridge and its structural members should be considered individually, as the corrosion rate varies with respect to environmental conditions, structural details and maintenance considerations such as cleaning and coatings of the bridge [4, s. 26]. These corrosion prevention and repair methods will shortly be reviewed below.

Structural details

When inspecting bridges, certain structural details require particular attention and maintenance. Generally, members should not be able to accumulate water, hence shall have the possibility of rapid drying after wetting. Advantageously, the members are therefore open or given proper drainage mechanisms. The maintenance of joints and details that are subjected to movement or rotation should be inspected carefully, and protected against "freezing" - as discussed in chapter 2.3.4 regarding unintentional fixity [4, s. 26].

Cleaning

Bridge cleaning is an effective and affordable method to reduce build-up causing corrosion. This includes salt, atmospheric pollution, bird droppings and other corrosive deposits that would initially lead to an increased corrosion rate [4, s. 27].

Bridge coating

One of the foremost corrosion preventions is bridge coating. The condition of the coating should be checked at every bridge inspection. When choosing an appropriate coating, several factors should be taken into consideration. This includes corrosion resistance, cost, resistance to wear including cleaning, availability, etc. Particularly exposed areas might need special protection, e.g. corrosion resisting material or cathodic protection [4, s. 27].

Repair

Despite the bridge and its structural elements being maintained, some bridge elements may need further repair due to corrosion damage. The damaged members is then repaired to its original cross-sectional area, and kept by a certain standard to avoid further corrosion damage [4, s. 27].

2.5 Environment-assisted cracking

Cracking caused by impacts of the environment, primarily from a corrosive environment, is termed environment-assisted cracking (EAC). EAC may cause damage that is not easily detectible, and can lead to unexpected failures. Detailed provisions and frameworks for assessment of structural integrity when a structure is subjected to EAC is not available in codes of practises [12, s. 1200].

The development of EAC is dependent on three conditions [13, s. 1]:

1. Environment
2. Stress
3. Material

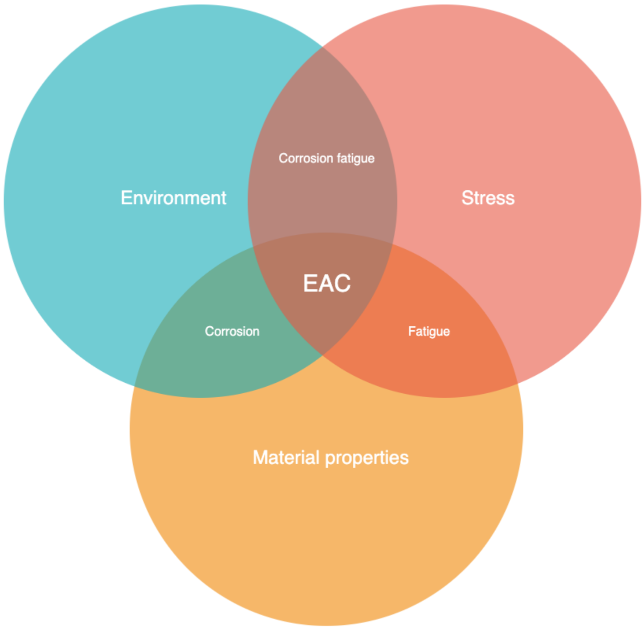


Figure 4 Main components for EAC to occur

These main contributions are necessary for the occurrence of cracking, and are illustrated in figure 4. However, within these three parameters, there is a large range of variables that make EAC a complex phenomenon to predict [13, s. 4]. Examples of these variables are listed below in table 2. These contributions illustrate the underlying mechanism of the crack initiation and growth of cracks in aqueous environments, and shows the importance of establishment of simplified methods to predict EAC.

Table 2 Parameters influencing the initiation of EAC [13, s. 4]

Environment	Temperature
	Pressure
	Solute species
	Solute concentration and activity

	pH
	Electrode potential
	Solution viscosity
	Stirring or mixing
	Radiation
Stress	Primary loading/applied stress
	Secondary loading/residual stress
	Stress intensity factor
	Mode of loading at the crack tip (tension/torsion)
	Plane stress or plane strain conditions
	Length, width, aspect ratio of the crack
	Crack opening and crack tip closure
Microstructure properties	Mechanical properties (yield stress/ultimate tensile strength, fracture toughness)
	Second phases present in the matrix and at the grain boundaries
	Composition of phases
	Grain size
	Surface finish
	Irradiation effects (e.g. grain boundary segregation, radiation swelling, radiation hardening, creep relaxation)

Another factor worth mentioning, is time-dependence. This factor is often neglected, or at least under-recognised especially for SCC, and should be taken into account [13, s. 1].

EAC covers several types of corrosion, including the following:

- Corrosion fatigue (CF)
- Stress corrosion cracking (SCC)
- Hydrogen embrittlement (HE)

CF is described as cracking of metal caused by repeated or fluctuating applied stresses in corrosive environments. For steel bridges, it typically occurs for fatigue-sensitive members [4, s. 10]. The phenomena will more thoroughly be reviewed in chapter 2.7.

SCC is defined as cracking caused by simultaneous occurrence of tensile stresses, either residual or applied, in a corrosive environment. SCC is observed for bridges in both industrial and marine environments, and causes reduced ductility of the steel. Corrosion will cause initiation of discontinuities in a metal, acting as stress raisers leading to cracking. The cracks from SCC can be transgranular, intergranular or a combination of both, but it´s often perpendicular to the stress of the member. SCC can appear in structural members under tension, such as bolts, wires, strands and the main cables of suspension bridges. [4, s. 10]. Tension stress can either be residual or applied. The residual stresses is typically induced by fabrication, welding, bolting, or riveting [1, s. 7]. The damage occur as brittle damage in a ductile metal, and needs a microscopic inspection for identification as the metal surface necessarily doesn't show any visual corrosion damage [4, s. 10].

A loss of ductility of a metal resulting from absorption of hydrogen is known as HE. Cracking resulting from HE is caused by hydrogen atoms diffusing the metal when it is cathodically polarized or exposed to a corrosive media. Cracking occurs under high applied or residual tensile stress [8, s. 167]. Hydrogen can either pre-exist in the material matrix, so-called internal hydrogen embrittlement, or it can be picked from the environment, known as hydrogen environment embrittlement [1, s. 2].

2.6 Fatigue

Fatigue is defined as failure at relatively low stress levels of structures that are subjected to fluctuating and cyclic stresses. This type of failure is the single largest cause of failure in metals, and is typical for bridges, aircraft and machine components. Fatigue failure can be catastrophic as it occurs suddenly and without warning. It initiate and propagate as cracks, and the fracture surface is typically perpendicular to the direction of an applied tensile stress. [14, s. 270]

Table 3 presents the main damage causes of existing bridges, where failure due to fatigue represents 38,3 % of total failures. It is based on a study by P. Oehme, considering different types of steel structures and their causes of failure [15, s. 125]. Among the structures most often damaged were bridges, including both railway and road bridges. A total of 128 of the considered damaged steel structures were bridges, as seen in the table.

Table 3 Damage causes of existing steel bridges [15, s. 125]

Damage cause	Bridges	
	No.	%
Fatigue	49	38.3
Environment	41	32.0
Static strength	19	14.8
Local or global stability	11	8.6
Brittle fracture	5	3.9
Rigid body movement	2	1.6
Elastic deformation	1	0.8
Thermal loads	0	0
Others	0	0
Total	128	100

According to the study, approximately 98 % of the damages occurred between 1955 and 1984, meaning that most of these steel bridges were riveted. A further study confirmed that fatigue are the major cause of failure of steel riveted bridges [15, s. 125].

2.6.1 Initiation and propagation of cracking

The process of failure due to fatigue can be described in three steps [14, s. 276-277]:

1. Initiation
2. Propagation
3. Failure

Cracking due to fatigue initiate on the metal surface due to stress concentration, and will cause damages such as scratches, sharp fillets, dents, etc. Besides the surface flaws, microscopic surface discontinuities, resulting from dislocation slip steps caused by cyclic loading, will act as stress raises and therefore initiate cracking. During crack propagation, localized plastic deformation at the crack tips is formed, despite the applied stress the object is exposed to in each stress cycles being lower than the yield strength of the metal. The applied stress is amplified at the crack tips until the local stress levels exceed the yield strength of the metal, causing a final fatigue failure [14, s. 277-278].

2.6.2 S-N curve

The fatigue performance of a material is typically characterised by a S-N curve. The S-N curve is a plot of the magnitude of the stress *S* versus the logarithmic of the number of cycles to failure *N*. The data from the S-N curve is collected from a series of laboratory tests by subjecting a specimen to stress cycling at a relatively large maximum stress, and the number of cycles to failure is then recorded. The procedure is then repeated with progressively decreasing stress levels. A S-N curve will also have a fatigue limit, also called the endurance limit, where no fatigue will occur at stress levels below this limit. [14, s. 272]

2.7 Corrosion fatigue

If a metal is present in a corrosive environment, and additionally exposed to alternating cyclic stresses, it is said to be subjected by corrosion fatigue (CF). The damage from corrosion fatigue is almost always greater than the damage from fatigue and corrosion individually. The cracks are transgranular surface cracks, and often branches with several smaller cracks in addition to the major crack that caused failure. CF must not be confused by stress corrosion cracking, since CF can occur at any given point without the occurrence of pitting [8, s. 173-174].

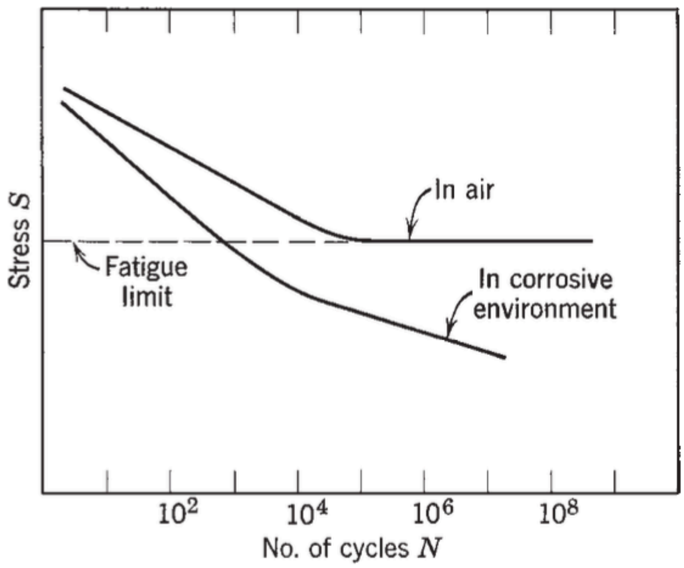


Figure 5 S-N curve for steels in air and in corrosive environment [8, s. 174]

Figure 5 illustrates the S-N curve for steels present in air and in a corrosive environment. The fatigue limit does not exist in a corrosive environment, and the failure caused by CF therefore occurs regardless of how low the stresses are.

2.7.1 Mechanism of corrosion fatigue

CF cracks are transgranular and initiates at an early stage of fatigue life. Slip lines subjected to plastic deformation and corrosion simultaneous, will under stress repetitions expose fresh metal from the surface, and this active site becomes anodic. Where no slip occurs, the site becomes cathodic. Hence, a local electrochemical cell is created. Corrosion pits are then generated by anodic dissolution, leading to a reduction in fatigue strength. [16, s. 346]

To summarize, the mechanism of the slip dissolution process behind corrosion fatigue can be explained as [8, s. 180]:

- Diffusion of the active species to the crack tip
- Protective film rupture at the slip step
- Dissolution of the exposed surface
- Nucleation and growth of the protective film on the bare surface

However, CF may also occur without the formation of corrosion pits. This is seen on non-passive metals, such as carbon steels and can happen in any corrosive medias. There is a need for generalized method for predicting life of steel structural details without cracks or pits in the literature [12, s. 1-2].

2.7.2 Corrosion fatigue prevention

Correct maintenance of the structure is important for corrosion related damages. It requires a scientific understanding on what causes corrosion, as well as ways of preventing or minimizing the effect. One can either reduce the corrosiveness, or minimize the probability of fatigue failure. The most common way to protect steel structures against damage from corrosion fatigue, is to apply a protective coating system. Sacrificial coatings, e.g. zinc or cadmium electrodeposited on steel, are effective coatings since they cathodically protect the base of the metal at defects in the coating [8, s. 178]. Other remedial measures includes cathodic protection, inhibitors, electrodeposits of tin, lead, copper or silver on steel and shot peening of the metal surface [8, s. 178-179].

3. Fatigue design of steel bridges

Bridges are primarily exposed to fatigue under the action of heavy vehicles, such as lorries and trains. Determining the load effects caused by traffic is a complex process, and requires an understanding of the load spectrum which illustrates the load variation of each load level during the design life of the structure [17, s. 335]. Load spectrum for bridges are therefore replaced by equivalent load models, which will be introduced in this chapter.

The study of fatigue load models is crucial to the fatigue life assessment. Two principal methods defined by the Eurocode are used to assess fatigue design of bridges:

- λ-coefficient method
- Cumulative damage method

This chapter will focus on the cumulative damage method applied to railway bridges. The method will be applied as the conventional method for fatigue assessment of the case study in chapter 6.

3.1 Eurocodes for bridges

The guidelines in this chapter are based on relevant parts of the Eurocode. The different parts of the Eurocode that are applicable for fatigue analysis of steel bridges are presented in figure 6, and the codes used for the fatigue assessment in this thesis are described below [18, s. 1].

<u>EN 1993-2:2006 Eurocode 3: Design of steel structures – Part 2: Steel Bridges</u>

EN 1993-2 gives a general basis of the structural design of steel bridges and steel parts of composite bridges.

<u>EN 1993-1-9:2005 Eurocode 3: Design of steel structures – Part 1-9 Fatigue</u>

This code includes fatigue assessment methods for resistance of members, connections and joints subjected to fatigue. Structural steels used in design of steel bridges should be protected against corrosion, as discussed in chapter 2.7.2. Structures in a mildly corrosive environment are covered in EN 1993-1-9:2005. [18, s. 3]

EN 1991-2:2003 Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges

This code presents imposed loads associated with road traffic, pedestrians and rail traffic. This includes relevant dynamic effects and centrifugal, braking and accelerating actions for accidental design situations [19, s. 15]. The fatigue assessment in this thesis is carried out using the traffic mixes given in Annex D of this code.

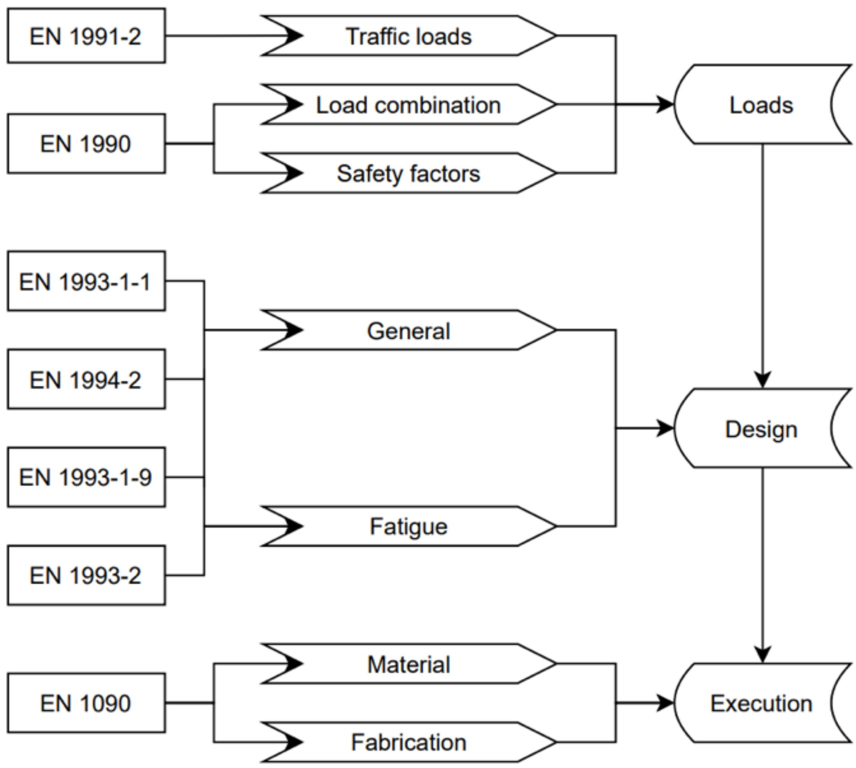


Figure 6 Eurocodes used for the fatigue analysis [18, s. 2]

3.2 Assessment methods

Methods for fatigue assessment are carried out by using either:

- Damage tolerant method
- Safe life method

The methods are defined according to chapter 3 of EN 1993-1-9.

3.3 Fatigue load models

Bridges are exposed to fatigue when lorries and trains continuously crosses them. These load effects are generally very complex, and are expressed by a so-called load spectrum. The load spectrum is given as either a histogram, function graph or table and expresses the load variation or number of recurrences of each load level during the structure´s lifetime. For bridges, the load spectrum is commonly replaced by simpler load spectra, e.g. equivalent load models. These are suitable sets of standardized lorries or trains with given properties including frequency, number of axles, axle loads, distance between axles deduced from relevant traffic measurements [17, s. 335].

The principles for the derivation of the fatigue load models in the Eurocode is described as follows [18, s. 5]:

1. Typical bridges are selected to simulate the bridge responses to traffic flow.
2. Typical structural details are selected for fatigue analysis along with their fatigue resistance curve.
3. Simulation of bridge response to obtain the stress history relevant for fatigue design of the structural detail by using the measured traffic data and the influence line for each detail.
4. Use an appropriate cycle counting method to transform the stress history into a stress histogram with a number of constant amplitude stress ranges.
5. By applying damage accumulation rule, also known as Palmgren-Miner rule, obtain an equivalent stress range, $\Delta\sigma$, which causes the same damage factor as the stress histogram generated in the traffic simulation.
6. Derive damage-equivalent fatigue load models, which generate a comparable damage to that caused by $\Delta\sigma$.

Fatigue load models are specified in EN 1991-2 for both road bridges and railway bridges. The recommended load models for railway bridges are reviewed in the next subchapter. These will then be applied for the case study in chapter 6.

3.3.1 Railway bridges

The fatigue load models recommended in EN 1991-2 are derived to be applied for standard track gauge and wide track gauge for European mainline network. This means that the load models are not applicable for the railways listed below. Loading and characteristic values of these railways should be defined for the individual project [19, s. 66].

- Narrow-gauge railways
- Tramways and other light railways
- Preservation railways
- Rack and pinion railways
- Funicular railways

The fatigue life assessment for railway bridges are performed using the "safe life method" to assure that the structure will perform satisfactorily throughout its design life, without being dependent of regular in-service inspection for fatigue damage. The safe life method is applied for cases where local formation of cracks in components could rapidly lead to failure of the structural element or structure. [20, s. 10]

Both λ-coefficient method and the cumulative damage method can be used in the fatigue verification, with associated load models. This thesis will continue with the cumulative damage method.

3.3.2 Fatigue load models for the cumulative damage method

Three standard mixes of rail traffic are given in Annex D of EN 1991-2 for calculation of fatigue life of structures. The so-called "traffic mixes" are composed of wagons with predefined axle loads and axle spacings, and are defined in the next subchapters. Additionally, a traffic volume per year is defined to be 25 million tonnes per year for each traffic mix [18, s. 20].

3.3.2.1 Standard traffic mix

"Standard traffic mix" with axles < 225 t, which equals to 225 kN, is shown in table 4. The traffic mix consists of 8 types of trains, totalling 67 train passages a day.

Table 4 Standard traffic mix [19, s. 140]

Train type	Number of trains [/day]	Mass of train [t]	Traffic volume [10^6 t/year]
1	12	663	2.90
2	12	530	2.32
3	5	940	1.72
4	5	510	0.93
5	7	2160	5.52
6	12	1431	6.27
7	8	1035	3.02
8	6	1035	2.27
Total	67		24.95

3.3.2.2 Heavy traffic mix

"Heavy traffic mix" with axle loads of 250 kN, consisting of 4 types of trains, totalling 51 passages of trains a day is shown in table 5.

Table 5 Heavy traffic mix [19, s. 140]

Train type	Number of trains [/day]	Mass of train [t]	Traffic volume [10^6 t/year]
5	6	2160	4.73
6	13	4131	6.79
11	16	1135	6.63
12	16	1135	6.63
Total	51		24.78

3.3.2.3 Light traffic mix

"Light traffic mix" with axles up to 22.5 tons, equalling 225 kN is shown in table 6. The traffic mix contains 4 types of trains, with a total of 67 passages of trains a day.

Table 6 Light traffic mix [19, s. 140]

Train type	Number of trains [/day]	Mass of train [t]	Traffic volume [10^6 t/year]
1	10	663	2.4
2	5	530	1.0
5	2	2160	1.4
9	190	296	20.5
Total	67		25.3

3.4 Fatigue design

As mentioned earlier, there are two methods for fatigue design of bridges: the λ-coefficient method and the general cumulative damage method. The latter method will be applied after choosing the fatigue load model, as illustrated in figure 7.

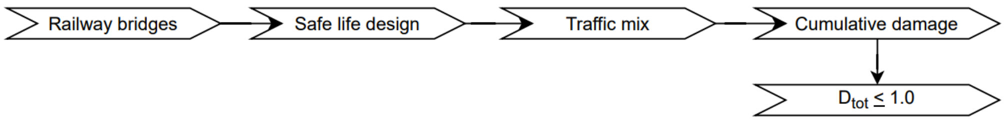


Figure 7 Summary the cumulative damage method for fatigue design

However, generating traffic loads on bridges are a complex process. The loads generates stress ranges of variable amplitudes which are difficult to process in a design situation. The fatigue load effects caused by the actual variable amplitude loading is therefore represented in terms of “equivalent constant amplitude load effects”. This can be treated in the following steps [18, s. 25]:

1. Transform the variable amplitude into a representative constant amplitude loading. This can be done by a “cyclic counting method”.
2. Use the new set of representative constant amplitude loading to perform the fatigue design or analysis. This can be done by two methods:
    - Palmgren-Miner damage accumulation rule
        - This method will be applied in the case study and therefore reviewed in the next subchapter.
    - Equivalent stress range concept

3.4.1 Palmgren-Miner damage accumulation rule

A given structural detail with a certain fatigue strength represented by an S-N curve fails after N cycles of a stress range $\Delta\sigma$. The total fatigue damage in the detail at failure, $n = N$, will be 100%, e.g. $D = 1,0$. If the detail is loaded with a number of cycles $n < N$ at the same stress range, the fatigue damage equals:

$$D = \frac{n}{N} \tag{3.1}$$

Resulting in:

$$D = 1,0 \; when \; n = N$$

$$D < 1,0 \; when \; n < N$$

A general formula can be obtained when the detail is subjected to a number i of loading blocks, each with constant amplitude stresses $\Delta\sigma_i$, which is repeated n_i number of times. The total fatigue damage accumulated in the structural detail is given as the sum of the damage caused by each individual loading block:

$$D_{total} = \sum_i D_i = \sum_i \frac{n_i}{N_i} \tag{3.2}$$

Number of cycles causing failure at each stress range $\Delta\sigma_i$ can be found from:

$$N_i = 5 \cdot 10^6 \left(\frac{\Delta\sigma_D / \gamma_{Mf}}{\gamma_{Ff} \cdot \Delta\sigma_i} \right)^m \tag{3.3}$$

Slope of the fatigue strength curve m, equals 3 or 5 depending on the level of stress.

3.4.2 Application of the Damage Accumulation method to railway bridges

Verification of the fatigue strength by using the Damage Accumulation method can be done by the following steps [18, s. 75]:

1. Determine the stress history of each detail by moving each train model individually over the influence line for the relevant load effect governing the fatigue life of the detail.
2. Construct a stress histogram by using Rain-flow counting method including all train models with their number of occurrence per day.
3. Calculate the damage caused by individual stress blocks in the stress histogram, and summarize all damage components to obtain total damage.
4. Verify damage by checking:

$$D_{total} \leq 1.0 \tag{3.4}$$

4. Fatigue strength of corroded structural details

This chapter will cover the shortcomings and research gaps regarding assessing structural integrity due to EAC. Moreover, a recent study proposing a generalized S-N curve formula for structural details of bridges exposed to a corrosive environment is reviewed.

4.1 Shortcomings and research gaps

Detailed provisions and frameworks are not available for assessing structural integrity due to EAC [21, s. 4]. Bridge assessment for existing steel bridges to detect loss of material and stress concentration due to corrosion are specified by codes and standards, and are only provided in some nations. There is a request to generalize these guidelines to apply for the whole of Europe Hence, a simplified assessment procedure of existing bridges was proposed based on past studies [22, s. 1]. However, this assessment procedure concentrates on visual inspections and NDT. Internal damages such as cracking and defects due to EAC cannot be detected by these techniques, which is an essential concept that should be included in the guidelines [21, s. 4].

Lack of detailed guidelines for assessing structural integrity due to EAC and the need of generalized S-N curves for structural details exposed to corrosive environments has been covered in a study by Adasooriya et al [21]. A generalized formula of S-N curve for corroded structural details has been proposed to predict the fatigue life of steel bridge members exposed to corrosive environments [21, s. 20-24]. The following subchapters will cover the research outcomes from this study.

4.2 S-N curve formula for corroded steel structural details

The S-N curve formula for corroded steel is shown in equation 4.1 [23, s. 3].

$$\sigma_{a.cor} = \left(\sigma'_f N_{f,LCF}^{c}\right) N_f^{(b-c)} \; where \; c = \left. \log\left[\frac{\sigma_\infty}{\sigma_{\infty,cor}}\right] \middle/ \log\left[\frac{N_{f,FL}}{N_{f,LCF}}\right] \right. \tag{4.1}$$

$\sigma_{a.cor}$ is the fatigue strength of corroded material, corresponding to the number of cycles to fatigue failure, N_f. Parameter σ'_f is the fatigue strength coefficient, b is the Basquin's exponent. σ_∞ is the endurance limit, while $\sigma_{\infty,cor}$ is the endurance limit of the corroded material, corresponding to the specified number of cycles $N_{f,FL}$. $N_{f,LCF}$ is the number of cycles to fatigue failure of the uncorroded material when the stress amplitude is the yield strength, σ_y.

The parameters σ'_f, b, σ_∞, $N_{f,FL}$ and $N_{f,LCF}$ can be found from the S-N curve. $\sigma_{\infty,cor}$ is determined by fatigue testing in the very high cyclic fatigue (VHCF) region, which is a complex and time-consuming process. As a result, values for structural steels in both urban and marine environments are estimated and presented in table 7 and 8.

Table 7 Parameters used in proposed S-N curve for constructional details in Eurocode [23, s. 8]

Parameter	Constructional details in Eurocode			
$N_{f,LCF}$	10^4			
$N_{f,CAFL}$	5×10^6			
$N_{f,VAFL}$	10^8			
$\frac{\Delta\sigma_L}{\Delta\sigma_D}$	0.549			
Corrosion parameters	**Marine environment**		**Urban environment**	
	Mean value	**Conservative value**	**Mean value**	**Conservative value**
$\frac{\Delta\sigma_{D,cor}}{\Delta\sigma_D}$	0.497	0.308	0.641	0.536
$\frac{\Delta\sigma_{L,cor}}{\Delta\sigma_L}$	0.356	0.175	0.518	0.40

Table 8 Parameters used in proposed S-N curve for constructional details in DNV-GL code [23, s. 8]

Parameter	Constructional details in DNV-GL code			
$N_{f,LCF}$	10^4			
$N_{f,CAFL}$	10^7			
$N_{f,VAFL}$	10^8			
$\frac{\Delta\sigma_L}{\Delta\sigma_D}$	0.631			
Corrosion parameters	**Marine environment**		**Urban environment**	
	Mean value	**Conservative value**	**Mean value**	**Conservative value**

$\frac{\Delta\sigma_{D,cor}}{\Delta\sigma_D}$	0.46	0.27	0.61	0.50
$\frac{\Delta\sigma_{L,cor}}{\Delta\sigma_L}$	0.356	0.175	0.518	0.40

The mean value for the $\sigma_{\infty,cor}/\sigma_{\infty}$ ratio is 0.61 and the coefficient of variation (COV) is 0.1 for steel in natural water (i.e. urban environment). Considering 5% failure probability, the conservative value is set to be 0.5. For steel in sea water (i.e. marine environment), the mean value is 0.46 while the COV is 0.59. The conservative value is set to be 0.27 [23, s. 4].

4.3 Proposed S-N curve of structural details in corrosive environments

Based on the formula 4.1, figure 8 presents the generalized S-N curve of riveted structural details exposed to a corrosive environment. European standards have defined two detail categories for riveted structural details – detail category 71 given in Eurocode and WI-rivet detail in the UK railway assessment code. The proposed S-N curve has been obtained by modifying both detail categories.

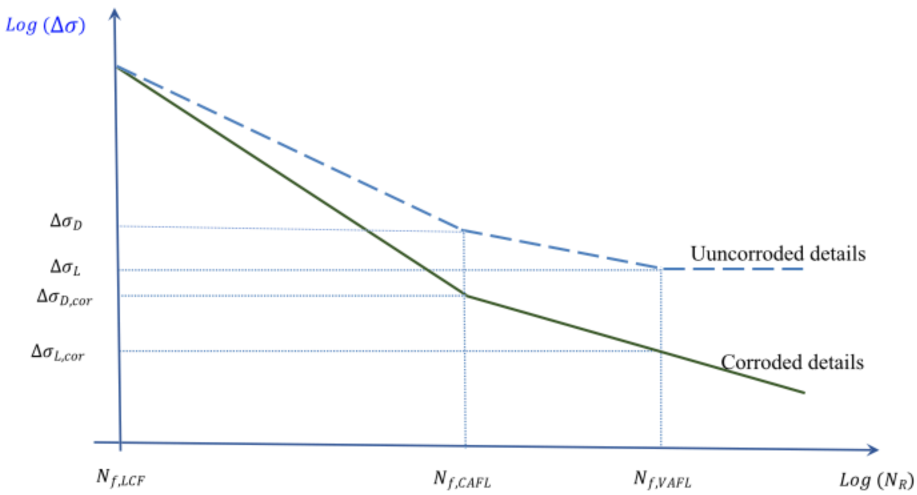


Figure 8 Trilinear fatigue strength curve for corroded and uncorroded constructional detail [23, s. 7]

Values $\Delta\sigma_D$, $\Delta\sigma_L$, m, $N_{f,LCF}$, $N_{f,CAFL}$ and $N_{f,VAFL}$ can be found in the code providing fatigue strength of constructional details testing in air. $\Delta\sigma_{D,cor}$ and $\Delta\sigma_{L,cor}$ are respectively the corrosive state and the environment-dependent parameters of the structural detail.

The fatigue strength range of structural details in corrosive environments, $\Delta\sigma_{cor}$, and corresponding number of cycles to fatigue failure, can be found as [23, s. 6]:

If $\Delta\sigma_{cor} \geq \Delta\sigma_{D,cor}$

$$\Delta\sigma_{cor} = \Delta\sigma_D \left[N_{f,LCF}^{c} N_{f,CAFL}^{1/m}\right] N_R^{(-c-1/m)} \; where\; c = {\log\left[\frac{\Delta\sigma_D}{\Delta\sigma_{D,cor}}\right]} \Big/ {\log\left[\frac{N_{f,CAFL}}{N_{f,LCF}}\right]} \tag{4.2}$$

The constant amplitude fatigue limit, $\Delta\sigma_D$, is the stress range at the fatigue curve slope changing point, corresponding to the $N_{f,CAFL}$ cycles. $-1/m$ is the slope of the fatigue strength curve, where m is equal to 3 when $\Delta\sigma \geq \Delta\sigma_D$, equal to 5 when $\Delta\sigma_D \geq \Delta\sigma > \Delta\sigma_L$ and infinite when $\Delta\sigma \leq \Delta\sigma_L$, where $\Delta\sigma_L$ is the fatigue endurance limit of the detail corresponding to $N_{f,VAFL}$. $N_{f,LCF}$ is the number of cycles to fatigue failure of the details when stress range transits from high cyclic fatigue to low cyclic fatigue region. $\Delta\sigma_{D,cor}$ is the stress range at intersecting points of two slopes of fatigue curve of the details, exposed to corrosive environments, corresponding to $N_{f,CAFL}$ cycles. $\Delta\sigma_{L,cor}$ is the stress range corresponding to $N_{f,VAFL}$ cycles of the details, exposed to corrosive environments.

If $\Delta\sigma_{cor} \leq \Delta\sigma_{D,cor}$

$$\Delta\sigma_{cor} = \Delta\sigma_{D,cor}\left[N_{f,CAFL}^{-\acute{c}}\right] N_R^{\acute{c}} \; where\; \acute{c} = {\log\left[\frac{\Delta\sigma_{D,cor}}{\Delta\sigma_{L,cor}}\right]} \Big/ {\log\left[\frac{N_{f,CAFL}}{N_{f,VAFL}}\right]} \tag{4.3}$$

5. Framework for life assessment of steel bridge details

Based on the recent research presented in chapter 4, together with existing guideline presented in chapter 3, this chapter will present a methodology to assess the life of existing steel bridge details exposed to environment-assisted fatigue. The method will be applied for the case study of an existing steel bridge in chapter 6.

5.1 Proposed conceptual framework

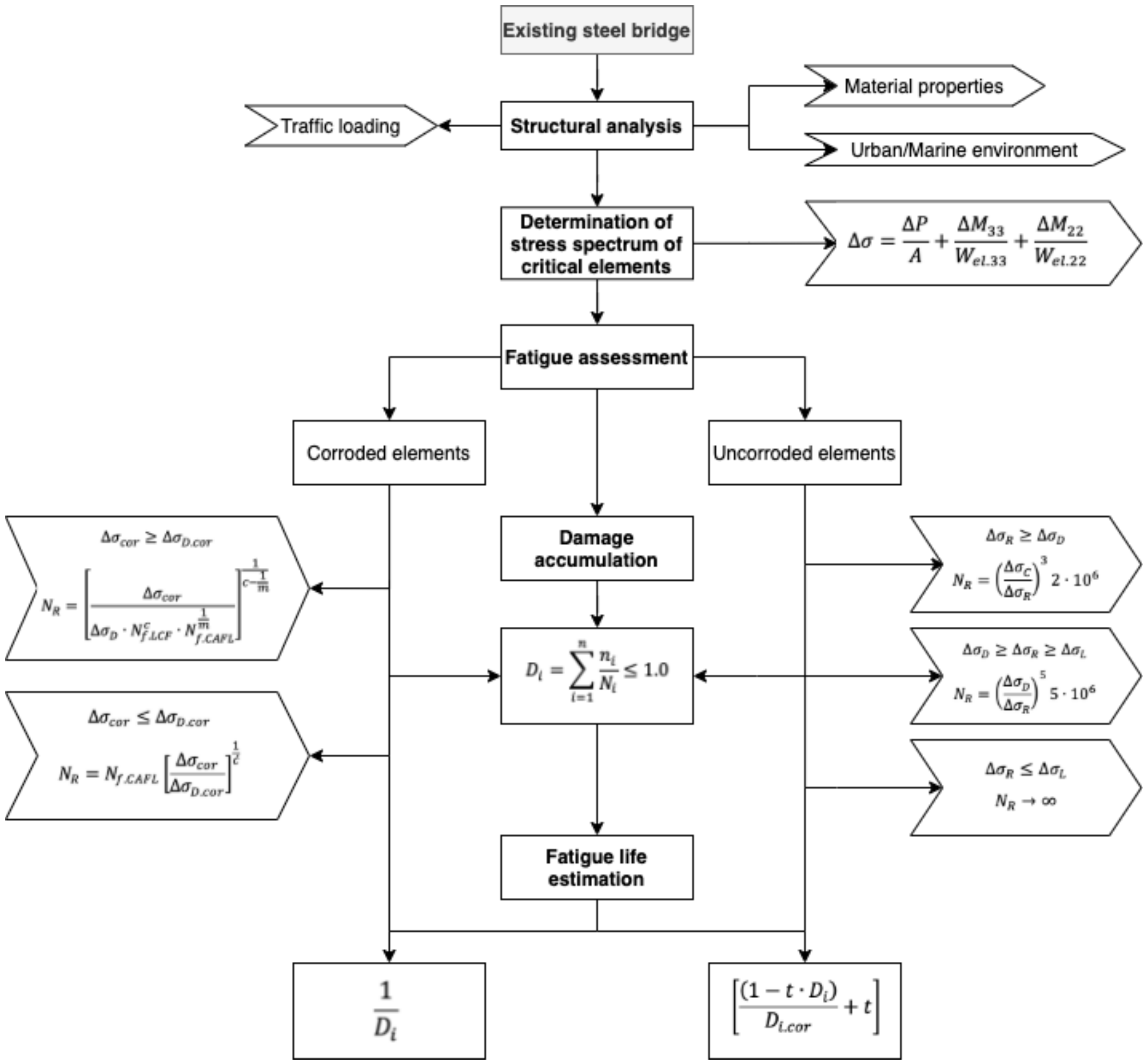


Figure 9 Conceptual framework for estimating fatigue life of corroded structural members

A conceptual framework for fatigue life estimation is presented in figure 9. Determination of fatigue life of both corroded and uncorroded is included in the framework. The methods are based on damage accumulation from the Eurocode and newly proposed method for estimating life of members subjected to corrosion and EAC. The framework may be applied to ageing, existing steel bridges in an urban or marine environment.

The framework considers five primary steps. First, a structural analysis is performed to simulate the currents state of the bridge, hence identify the critical elements. Following, the next step is to determine the stress spectrum of the identified critical elements. These are then included in the remaining life calculation using both conventional approach and the newly proposed method.

6. Case study: Steel bridge in corrosive environment

The methodology presented in the previous chapter will be applied to a steel bridge in a corrosive environment. Firstly, the environmental conditions, current state and critical details of the bridge will be identified. A structural analysis to simulate the current state of the bridge will then be done to check for design limit state, hence evaluating the state of stress histories. Lastly a fatigue assessment will be carried out to calculate remaining life using both conventual approach and proposed method.

6.1 Considered bridge and its current status

A railway bridge in a marine corrosive environment is to be considered for fatigue life estimation. The considered bridge (figure 10) is a Warren truss girder bridge. It is located in Sri Lanka, and constructed in 2007. The bridge consists of about ten different cross-sections, which will be considered in the fatigue assessment. The structural members and their material properties are collected from the detail drawing in Appendix A.

Figure 10 Considered railway bridge

6.2 SAP2000

SAP2000, hereby referred as SAP, is a civil-engineering software for structural analysis and design, ranging from simple 2D structures to more complex 3D structures. The program was introduced by CSI (Computers and Structures inc.) over 45 years ago. The software offers a customizable graphical user interface to perform modelling, design, analysis and reporting. The user has the ability to create any type of model, with a variety of structural components included in the software [24].

6.3 Structural analysis

The bridge has been modelled in SAP2000 based on provided structural details and drawings, given in Appendix A. Only the structural elements relevant to the fatigue assessment is included in the model, e.g. girders and bracings. The structure has fixed bearings in one end, and longitudinal free bearings in the other end according to the drawing. The riveted connection are assumed to be fully-fixed. The three-dimensional (3D) model, shown in figure 11, is analysed under loading to determine the stress histories of critical members.

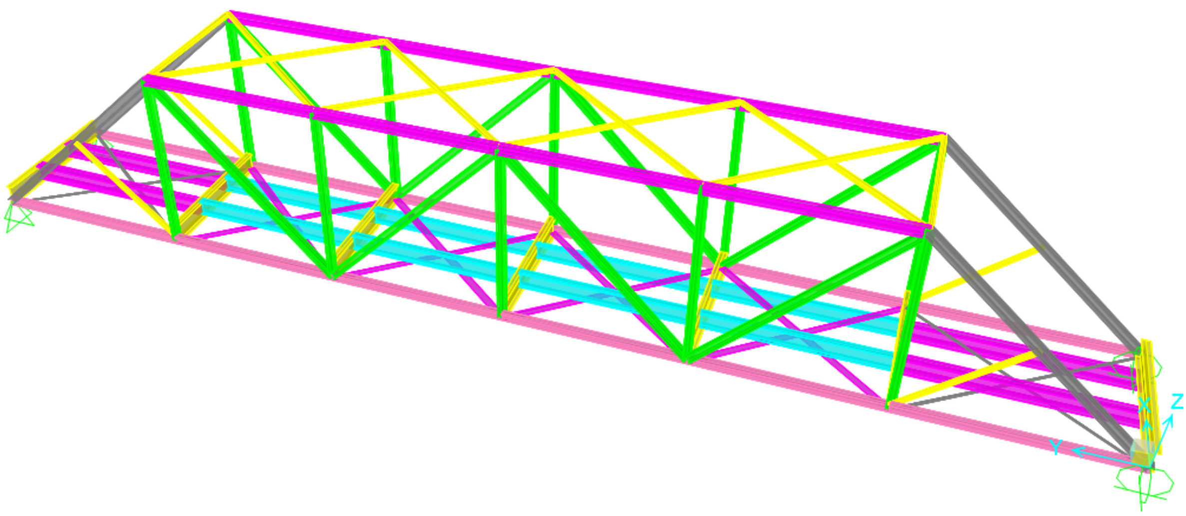


Figure 11 Structural model of considered bridge in SAP2000

6.3.1 Environmental factors

Except for the detail drawings of the considered railway bridge, there are no information available regarding inspections of the bridge, and therefore its current status. Photo of the bridge (figure 10) reveals surface corrosion on the bottom and top chord, as well as the diagonals of the bridge. The bridge is located in a marine environment, and referring to the types of corrosion discussed in chapter 2.4, it is likely that it is subjected to pitting and crevice corrosion due to presence of chloride and salt ions.

6.3.2 Material properties

It is known that the bridge has been constructed according to the Eurocode. Detail drawing of the bridge (Appendix A) provides relevant cross-sections used for the bridge details. Plates and girders relevant for the fatigue analysis are S355 steel.

6.3.3 Load cases

Chapter 9.2 in EN-1993-2, defines loading relevant to fatigue analysis. Paragraph 9.2.1 states that the loading relevant to fatigue is as follow [19, s. 35]:

(1) The fatigue loading from traffic should be obtained from EN 1991-2.
(2) The fatigue loads on slender elements due to wind excitations should be obtained from EN 1991-1-4.

As the bridge is a truss structure, the effect of wind is relatively small compared to vehicle load due to the many openings. The wind load is therefore relatively small in comparison, and will thus be disregarded in this case study.

6.3.3.1 Traffic loads for fatigue

As discussed in chapter 3.3.2, Traffic mix representing the rail traffic is provided in Annex D.3 in EN 1991-2. For this case study, "Standard traffic mix with axles ≤ 22,5 t (225 kN)", referring to table 4 of chapter 3.3.2.1. is chosen. This traffic mix covers train type 1-8, and is reproduced in Appendix B of this thesis.

Annual traffic tonnage of 25 000 000 tonnes passing over the bridge on each track, according to EN 1991-2, 6.9 (4)

6.4 Design limit state

Limit states are classified into four categories: serviceability limit states (SLS), ultimate limit states (ULS), fatigue limit states (FLS) and accidental limit states (ALS).

6.4.1 Fatigue limit state

Failure due to fatigue is associated with cumulative damage caused by a repeated application of stress, and fatigue design therefore requires to be checked by FLS. Even though FLS is an ultimate limit state, the stresses needs to be based on an elastic stress analysis, with no plastic redistribution, and to consider shear lag and geometrical configurations leading to stress concentrations. FLS is therefore more suitable, as fatigue life depends on the stresses at positions where attachments are made or where the shape of the members changes, not on the general strength of the structural element [25].

6.5 Stress evaluation

Members of the bridge which gives the maximum stress range and may therefore suffer fatigue damage, are selected from each cross-sectional group. The described traffic loading establishes a spectrum of stress ranges $\Delta\sigma$, consisting of a series of stresses generated of each train model, $\Delta\sigma_{VEH1} - \Delta\sigma_{VEH8}$ for each member. Element forces, i.e. maximum and minimum bending moments of both strong and weak axis, as well as the axial force of each detail are obtained from the analysis in SAP. The moment range ΔM_{22} and ΔM_{33} are divided by associated section modulus $W_{el.33}$ and $W_{el.22}$. The axial force range ΔP are divided by the area A. As a result, the stress range can be found from the following formula:

$$\Delta\sigma = \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}} \tag{6.1}$$

Calculations of the stress ranges of the critical members of each cross-sectionals are found in Appendix C. The stress ranges has been calculated at the end points of each member for truss members and at mid span for cross girders, where the maximum stress range are selected and will be used in the fatigue assessment.

6.6 Critical constructional details and detail categories

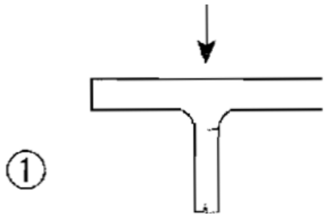
Stated in the previous subchapter, the critical constructional details generates the maximum stress ranges. The fatigue assessment will be performed for the critical element of each cross-sectional group, as presented in table 9. HEAA120, Plate 80x8 and Plate 220x8 (highlighted in table 9) are considered secondary structural members and the fatigue life is not considered in the design. The members therefore has infinite fatigue life. The stresses of the members generated large stresses and the fatigue lives were calculated improbably high values and are shall not be included in fatigue life estimation.

Table 9 Critical constructional elements

Cross-sectional group	Critical constructional element	Detail category
HEA220	Diagonal	90
HEA240	Bottom chord	90
HEA260	Diagonal	90
HEA550	Stringer	90
HEAA120*	Diagonal/Top lateral bracing	90
HEB260	Top chord	90
IPE550	Stringer	90
Plate 80x8	Bottom lateral bracing	90
Plate 220x8	Bottom lateral bracing	90
UB686/284/125	Floor beam	160
* HEAA120 generated no stresses in SAP and the calculations are therefore not included. However, as the cross-sections are secondary structural members of the bridge, it has no impact on the fatigue life estimation.		

Table 8.1 – 8.10 of EN 1993-1-9 presents detail categories that are associated with a S-N curve given in the same code. Each detail category represents a constructional detail including plain material, welded connections, bolted connections and connections in tubular construction. The different detail categories are numbered, representing the constant amplitude stress range [N/mm^2] with design value of endurance being 2 x 10^6 cycles [25]. For plain members and mechanically fastened joints, as presented in table 10, the critical members considered in this case study are identified as detail category 90 and 160.

Table 10 Detail category of constructional detail [20, s. 20-29]

Detail category	Constructional detail	Description
90		Structural element with holes subject to bending and axial forces.
160		Rolled I- or H-sections.

6.7 Fatigue life estimation of uncorroded elements

EN 1993-1-9 gives methods for the assessment of fatigue resistance of members, connections and joints subjected to fatigue loading [20, s. 6]. The fatigue life assessment for the case study is performed using the safe life method according to the Eurocode. This method is to be applied for critical elements where local formation of cracks could rapidly lead to failure of either the structural component or the whole structure. As follows, the method provides an acceptable level of reliability that the structure will perform satisfactorily for its design life without requirement of regular in-service inspection for fatigue damage [20, s. 10].

6.7.1 Selection of fatigue curve

Truss members are considered category 90, where stresses are calculated at the endpoints:

$$\Delta\sigma_C = 90\ MPa$$

Cross girders are subjected to stress at midspan, and are considered detail category 160:

$$\Delta\sigma_C = 160\ MPa$$

Each detail category are provided with a corresponding S-N curve in EN 1993-1-9, presented in figure 12. The S-N curves are plotted on a logarithmic scale with direct nominal stresses $\Delta\sigma_R$ vs. the number of cycles until fatigue damage.

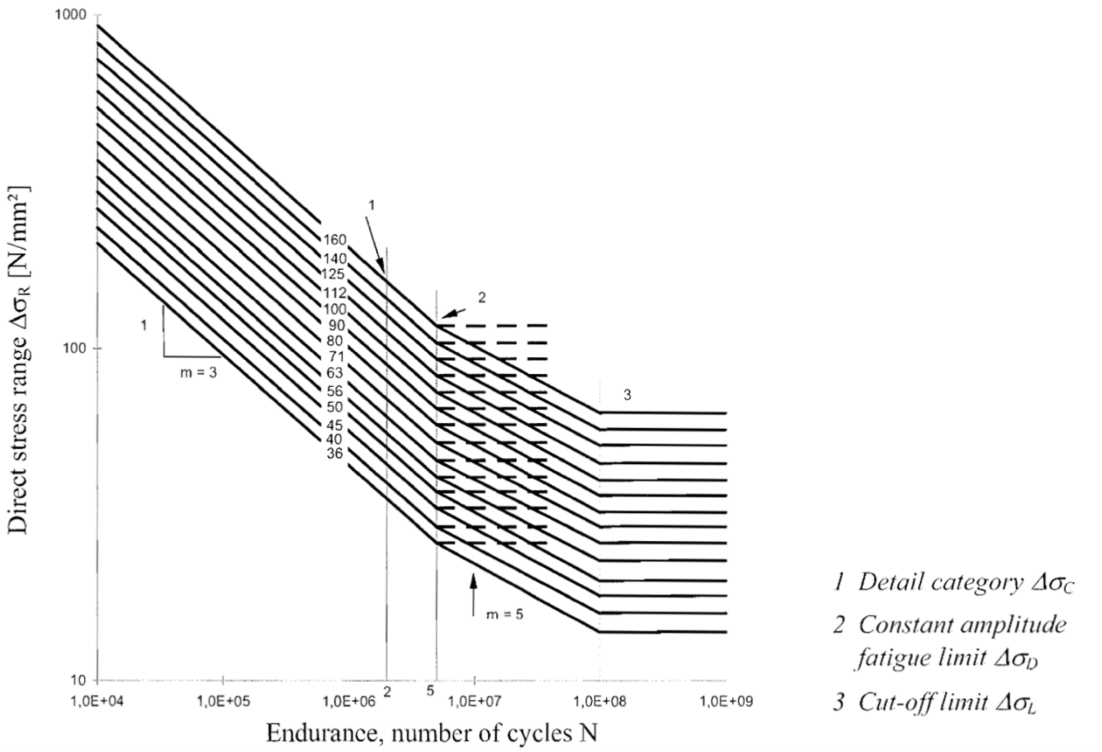


Figure 12 Fatigue strength curves for nominal stress ranges [20, s. 15]

Stress ranges $\Delta\sigma$ are multiplied by partial factors to obtain the direct nominal stresses $\Delta\sigma_R$.

$$\Delta\sigma_R = \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma \tag{6.2}$$

Recommended partial factor for fatigue strength γ_{Mf} is specified in Tab. NA.3.1 from EN 1993-1-9. However, as the bridge is located in Sri Lanka, this factor is recommended to be defined as:

$$\gamma_{Mf} = 1{,}0$$

The fatigue factor for fatigue loads are recommended in EN 1993-2 as:

$$\gamma_{Ff} = 1{,}0$$

The stress ranges are then used to obtain the number of cycles without fatigue damage N_R. For constant amplitude nominal stress ranges the fatigue strength can be found from:

If $\Delta\sigma_R \geq \Delta\sigma_D$:

$$N_R = \left(\frac{\Delta\sigma_C}{\Delta\sigma_R}\right)^3 2 \cdot 10^6 \tag{6.3}$$

If $\Delta\sigma_D \geq \Delta\sigma_R \geq \Delta\sigma_L$:

$$N_R = \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^5 5 \cdot 10^6 \tag{6.4}$$

If $\Delta\sigma_R \leq \Delta\sigma_L$:

$$N_R \to \infty \tag{6.5}$$

Where $\Delta\sigma_D$ is the constant amplitude limit defined as:

$$\Delta\sigma_D = 0.737\Delta\sigma_C \tag{6.6}$$

And the cut of limit is as follows:

$$\Delta\sigma_L = 0.549\Delta\sigma_C \tag{6.7}$$

6.7.2 Fatigue verification and damage accumulation

Fatigue verification and application of damage theory are performed using "Miners Rule" described by formula 6.8. Total trains per day are provided from the traffic mix (table 4) and multiplied with 365 to obtain total trains per year n_i for each train type $n_{VEH1} - n_{VEH8}$.

$$D_i = \sum_{i=1}^{n} \frac{n_i}{N_i} \leq 1.0 \tag{6.8}$$

The approach are applied to all critical elements, and the results are presented in table 11. The calculations can be found in Appendix D.

***Table 11** Fatigue verification*

Detail	Fatigue verification	
HEA220	0.02 < 1.0	Satisfied
HEA240	0.022 < 1.0	Satisfied
HEA260	0.027 < 1.0	Satisfied
HEA550	0.01 < 1.0	Satisfied
HEB260	0.01 < 1.0	Satisfied
IPE550	0.019 < 1.0	Satisfied
Plate 80x8	0.001 < 1.0	Satisfied
Plate 220x8	0.002 < 1.0	Satisfied
UB686/284/125	0.032 < 1.0	Satisfied

Total damage accumulated in the detail are used to estimate the remaining fatigue life are performed using formula 6.9, and the calculations can be found in Appendix D.

$$Fatigue\ life = \frac{1}{D_i} \tag{6.9}$$

6.8 Fatigue life estimation of corroded elements

How railway bridges are exposed to fatigue damage due to cyclic loading of traffic loads has now been covered. As the majority of railway bridges are exceeding their design lives, precise life extension methods are important, especially regarding replacement of structural details and other retrofits. This may be more challenging due to an increase of axle loading and corrosion damage on bridges [26, s. 1].

As the calculations of the fatigue life in the previous subchapter does not consider the effect of corrosion, the newly proposed formula for stress-life curve to predict the fatigue life of riveted steel bridges in corrosive environments, covered in chapter 4, will be applied for the same critical elements. The difference will be discussed further in chapter 7.

6.8.1 Fatigue strength of corroded structural details

Proposed formulas, 4.2 and 4.3, for the fatigue strength of riveted details in a corrosive environment were covered in chapter 4. These formulas can be solved with respect to N_R to find number of cycles to fatigue failure of corroding structural details.

If $\Delta\sigma_{cor} \geq \Delta\sigma_{D.cor}$:

$$N_R = \left[\frac{\Delta\sigma_{cor}}{\Delta\sigma_D \cdot N_{f.LCF}^{c} \cdot N_{f.CAFL}^{\frac{1}{m}}}\right]^{\frac{1}{c-\frac{1}{m}}} \tag{6.10}$$

If $\Delta\sigma_{cor} \leq \Delta\sigma_{D.cor}$:

$$N_R = N_{f.CAFL}\left[\frac{\Delta\sigma_{cor}}{\Delta\sigma_{D.cor}}\right]^{\frac{1}{c}} \tag{6.11}$$

The nominal stress ranges $\Delta\sigma$ from Appendix C are used as $\Delta\sigma_{cor}$. Other parameters are given for constructional details in Eurocode (table 7).

Number of cycles to fatigue failure of uncorroded materials at the yield strength:

$$N_{f.LCF} = 10^4$$

Number of cycles at variable amplitude fatigue limit:

$$N_{f.CAFL} = 5 \cdot 10^6$$

Stress range at intersecting points of two slopes of corroded fatigue at number of cycles at constant amplitude fatigue limit:

$$\Delta\sigma_{D.cor} = 0.497 \cdot \Delta\sigma_D$$

Stress range at number of cycles at variable amplitude fatigue limit:

$$\Delta\sigma_{L.cor} = 0.356 \cdot \Delta\sigma_L$$

6.8.2 Calculation of fatigue life by proposed method

The obtained N_R are inserted in formula 6.8 to find total damage $D_{i.cor}$ accumulated in the corroded element. Assuming that corrosion occurs after $t = 10\ years$, the predicted fatigue life can be found from following formula:

$$Fatigue\ life = \left[\frac{(1 - 10 \cdot D_i)}{D_{i.cor}} + 10\right] \tag{6.12}$$

Where D_i is the damage per year for uncorroded elements. The calculations of the corroded elements are given in Appendix E.

7. Results and discussion

The applicability and significance of the proposed framework will be discussed in this chapter by comparing fatigue lives of uncorroded and corroded critical elements.

7.1 Comparison of fatigue lives

The fatigue life estimation of an existing steel bridge in a marine environment has now been performed by using both conventional (method 1) and proposed method (method 2). The results are presented in table 12.

Table 12 *Comparison of the calculated fatigue lives of cross sectional groups with conventional and proposed methods*

Cross sectional group	Method 1: Uncorroded members	Method 2: Corroded members
HEA220	50.2 years	22.2 years
HEA240	45.2 years	21.4 years
HEA260	37 years	19 years
HEA550	103.2 years	33.2 years
HEB260	96.9 years	32.3 years
IPE550	52.8 years	23.2 years
Plate 80x8	684.1 years	75.6 years
Plate 220x8	660.6 years	74.8 years
UB686/284/125	31.5 years	18.8 years

Method 2 considering corrosion shows a significant reduction in predicted fatigue lives compared to method 1. Average reduction of the critical members when corrosion is taken into account is 62.8 %. This reduction of fatigue lives emphasizes the importance of using accurate S-N curves of corroding structural details and members.

All critical elements were satisfactory by fatigue verification using both methods. However, estimated fatigue lives obtained from the assessment should only be an indication of the state of the bridge, e.g. conservative maintenance execution. More precise measurements is required to corrosion wastage and remaining cross-sectional area due to corrosion. Nevertheless, the reduction of estimated fatigue life illustrates the importance of methods to predict fatigue strength of corroding structural elements to avoid critical damage, and at worst collapse of the structure.

7.2 Applicability and significance of the proposed method

The reduction in estimated fatigue life emphasizes the importance and significance of the proposed method. By following the framework and determining the stresses from the structural analysis, the procedure of fatigue assessment is rather uncomplicated as the Eurocode provides necessary formulas and associated parameters in form of S-N curves for the different detail categories. This also applies to the proposed method as the formulas do not require any material properties other than those provided by S-N curves in codes. The newly proposed method is therefore an applicable method for assessing structural integrity due to EAC.

8. Conclusions

8.1 Conclusive remarks

A thorough literature review was performed prior to the fatigue assessment to better understand how EAC affects structural elements of ageing steel bridges. As EAC is one of the main deterioration processes that affect the integrity of bridges, the importance of establishing methods to predict EAC has been verified through fatigue assessment of a steel bridge in corrosive environment.

A framework was proposed to determine the fatigue life of structural details in corrosive environments. The framework illustrates the applicability of the fatigue assessment of corroded elements as the structural analysis and determination of stresses are the same as conventional approaches. Furthermore, the newly proposed formulas do not require any material properties other than those provided by S-N curves in the Eurocode.

Fatigue strength formula for structural details in corrosive environments resulted in a significant reduction of the fatigue life of critical members evaluated in the case study compared to conventional fatigue calculations. This emphasizes the importance of considering EAC for maintenance of corroded steel bridges to avoid critical damage. The fatigue verification shows satisfactory results, however, due to the noticeable fatigue life reduction, a sufficient corrosion protection of the steel should be determined.

8.2 Recommendations for future work

An extensive evaluation of the present state of the bridge could be taken into consideration to suggest life extension strategy and maintenance of the bridge. Furthermore, measurements of the actual traffic loading can be performed to give more precise bridge response in form of stress ranges. The framework could also be applied for a case study where the corrosion wastage is measured to compare with estimated fatigue life.

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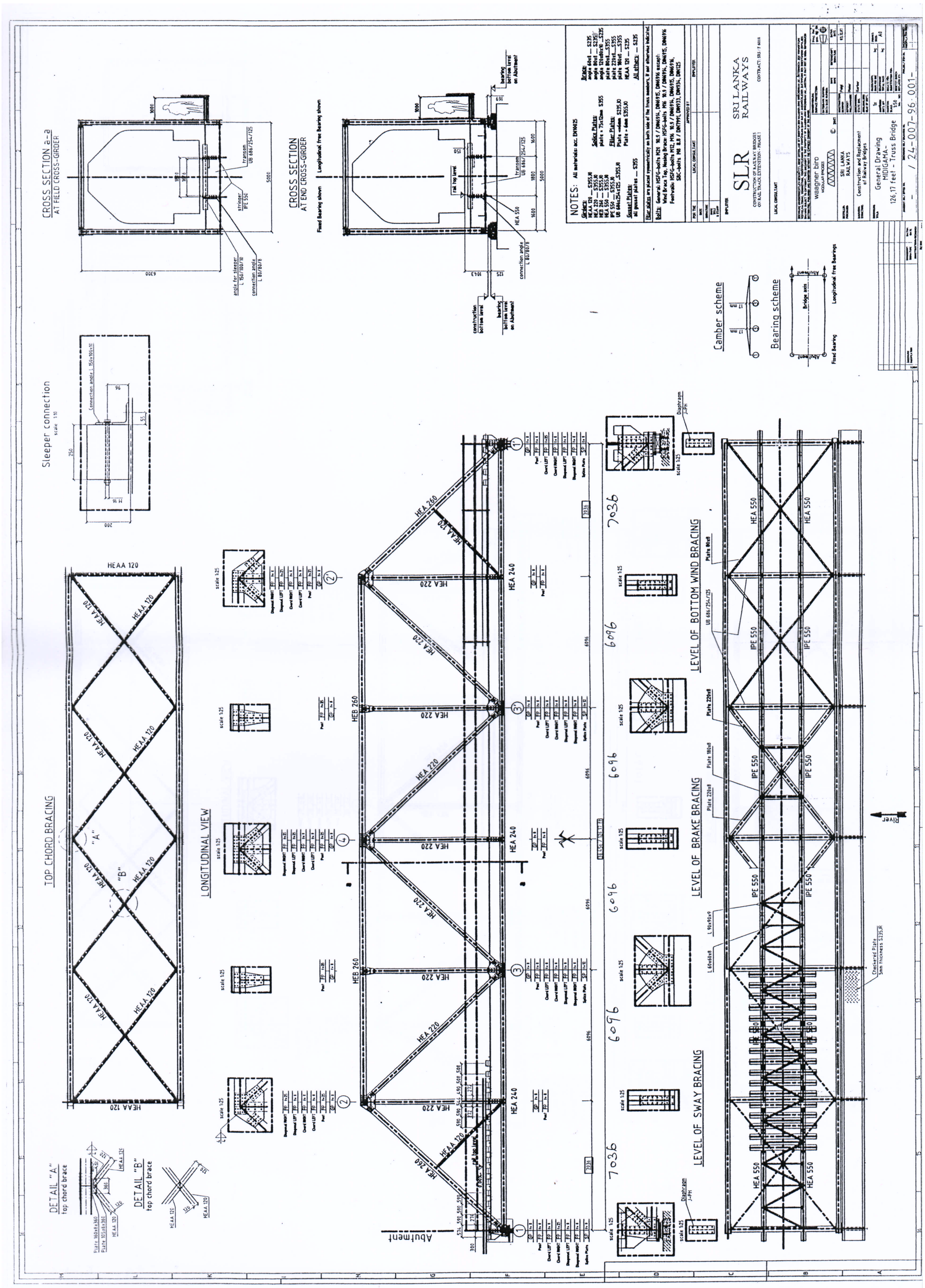
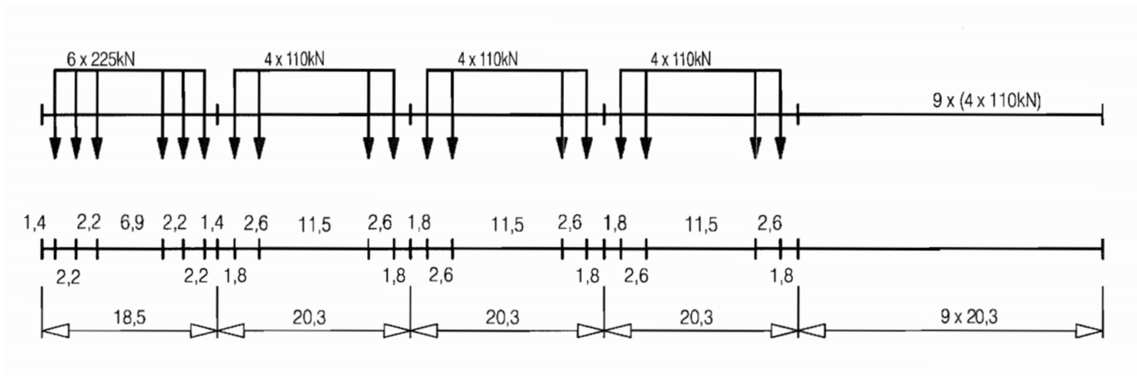
Appendix A - Detail drawing

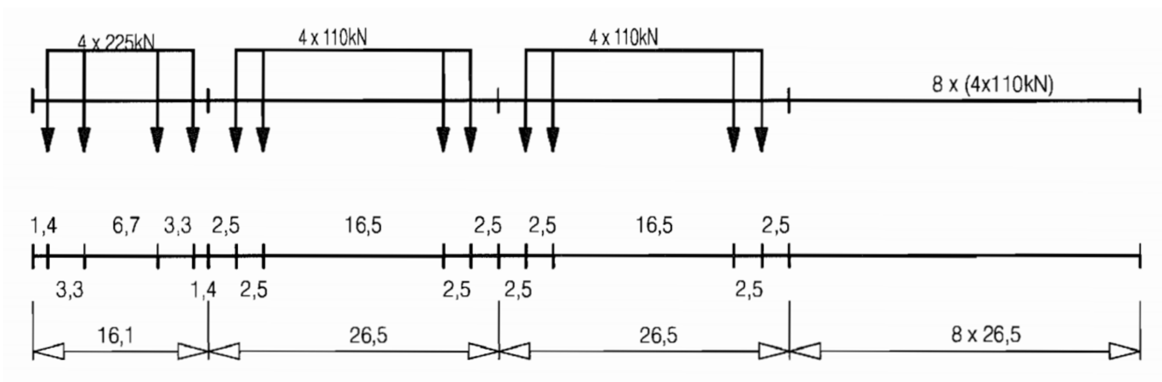


Appendix B - Train models of «Standard traffic mix»

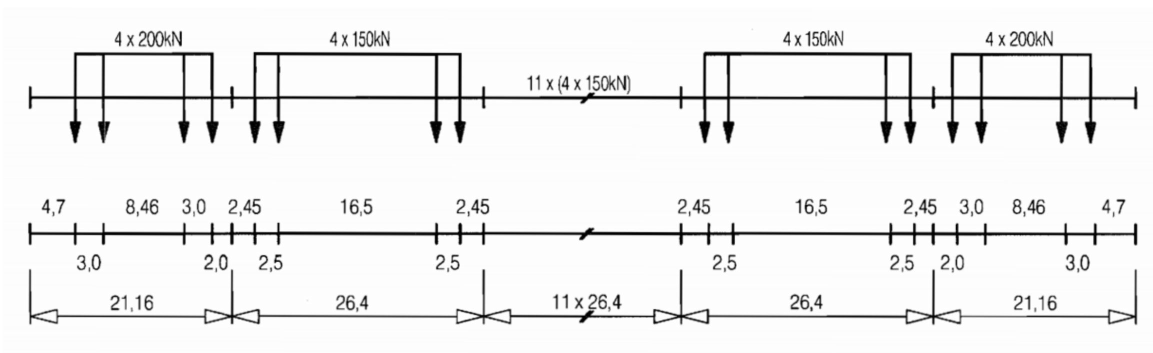
Type 1	Locomotive-hauled passenger train



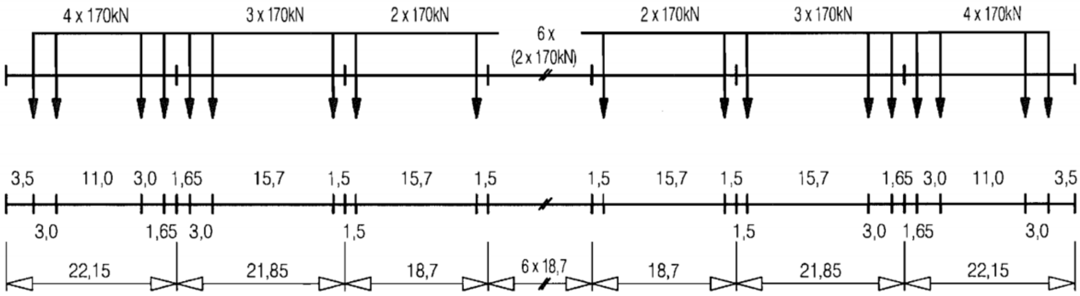
Type 2	Locomotive-hauled passenger train



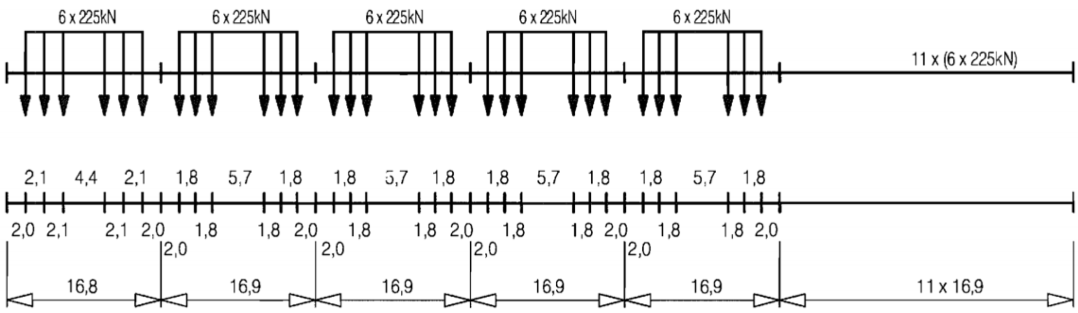
Type 3	High speed passenger train



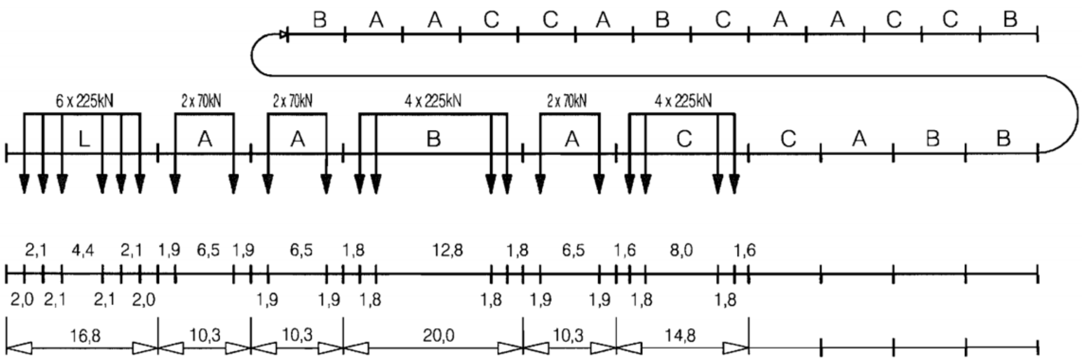
Type 4	**High speed passenger train**



Type 5	Locomotive-hauled freight train



Type 6	Locomotive-hauled freight train



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<tr><td>Type 7</td><td>Locomotive-hauled freight train</td></tr>
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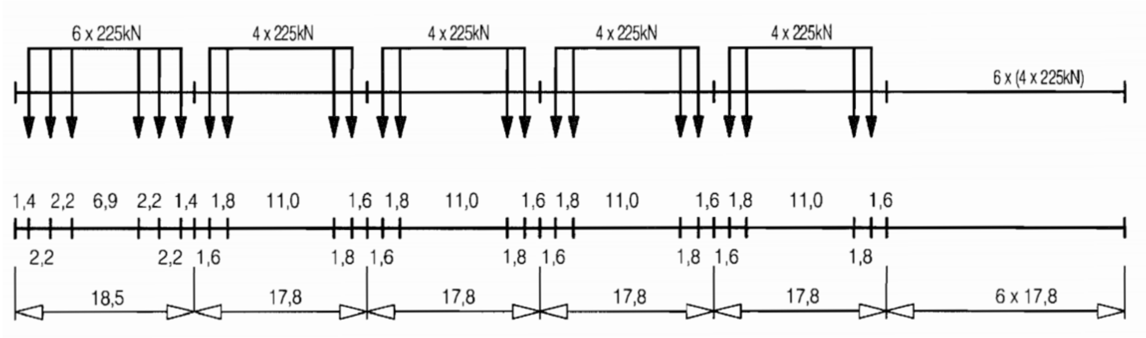

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<tr><td>Type 8</td><td>Locomotive-hauled freight train</td></tr>
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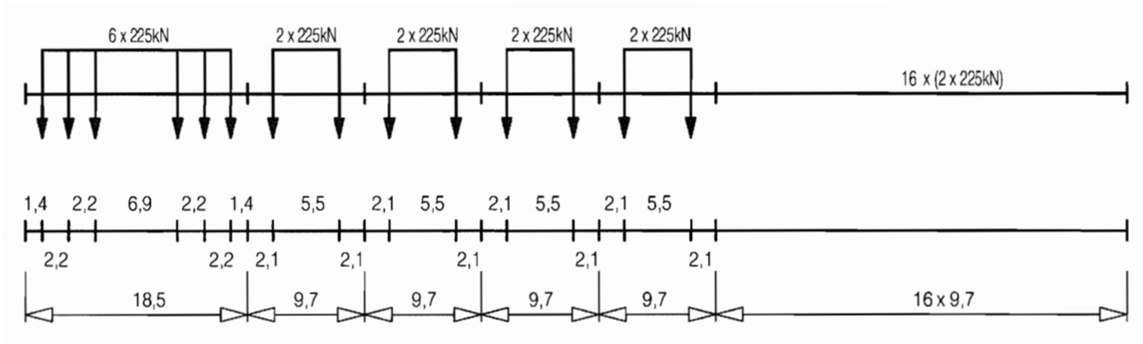

</td></tr>
</table>

Appendix C - Stress ranges

Stress range - HEA220

Critical detail: Element 59

$A := 6.43 \cdot 10^3\ mm^2$

$W_{el.33} := 515 \cdot 10^3\ mm^3$

$W_{el.22} := 178 \cdot 10^3 \cdot mm^3$

VEH1

At 0 mm

$P_{max} := 444401.35\ N$ $\quad M_{33.max} := 1239953.66 \cdot N \cdot mm$ $\quad M_{22.max} := 577959.39\ N \cdot mm$

$P_{min} := -58845\ N$ $\quad M_{33.min} := -164740.67\ N \cdot mm$ $\quad M_{22.min} := -3737940.32\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.032 \cdot 10^5\right)\ N$ $\quad \Delta M_{33} = \left(1.405 \cdot 10^6\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(4.316 \cdot 10^6\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 105.24\ MPa$

At 8766.48 mm

$P_{max} := 444401.35\ N$ $\quad M_{33.max} := 101316.41 \cdot N \cdot mm$ $\quad M_{22.max} := 1930624.11\ N \cdot mm$

$P_{min} := -58845\ N$ $\quad M_{33.min} := -668390.01\ N \cdot mm$ $\quad M_{22.min} := -1074964.4\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.032 \cdot 10^5\right)\ N$ $\quad \Delta M_{33} = \left(7.697 \cdot 10^5\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.006 \cdot 10^6\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 96.645\ MPa$

Max stress range:

$\Delta\sigma_{VEH1} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 105.24\ MPa$

<u>VEH2</u>

At 0 mm

$P_{max} := 326758.89\ N$ $\quad M_{33.max} := 917200.75 \cdot N \cdot mm$ $\quad M_{22.max} := 388579.75\ N \cdot mm$

$P_{min} := -38505.8\ N$ $\quad M_{33.min} := -126384.82\ N \cdot mm$ $\quad M_{22.min} := -2661392.22\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.653 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(1.044 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.05 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 75.967\ MPa$

At 8766.48 mm

$P_{max} := 326758.89\ N$ $\quad M_{33.max} := 68939.01 \cdot N \cdot mm$ $\quad M_{22.max} := 1429431.71\ N \cdot mm$

$P_{min} := -38505.8\ N$ $\quad M_{33.min} := -481068.23\ N \cdot mm$ $\quad M_{22.min} := -737270\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.653 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(5.5 \cdot 10^{5}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.167 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 70.047\ MPa$

Max stress range

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 75.967\ MPa$

VEH3

At 0 mm

$P_{max} := 295388.42\ N$ $M_{33.max} := 887593.71 \cdot N \cdot mm$ $M_{22.max} := 359843.11\ N \cdot mm$

$P_{min} := -35247.79\ N$ $M_{33.min} := -117873.67\ N \cdot mm$ $M_{22.min} := -2442706.15\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.306 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.005 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.803 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 69.118\ MPa$

At 8766.48 mm

$P_{max} := 295388.42\ N$ $M_{33.max} := 64231.6 \cdot N \cdot mm$ $M_{22.max} := 1288750.11\ N \cdot mm$

$P_{min} := -35247.79\ N$ $M_{33.min} := -452995.5\ N \cdot mm$ $M_{22.min} := -710703.3\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.306 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.172 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.999 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 63.658\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 69.118\ MPa$

VEH4

At 0 mm

$P_{max} := 275648.82\ N$ $M_{33.max} := 916061.21 \cdot N \cdot mm$ $M_{22.max} := 349657.82\ N \cdot mm$

$P_{min} := -34507.37\ N$ $M_{33.min} := -102230.65\ N \cdot mm$ $M_{22.min} := -2564522.39\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.102 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.018 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.914 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 66.585\ MPa$

At 8766.48 mm

$P_{max} := 275648.82\ N$ $M_{33.max} := 65448.59 \cdot N \cdot mm$ $M_{22.max} := 1220738.71\ N \cdot mm$

$P_{min} := -34507.37\ N$ $M_{33.min} := -462236.33\ N \cdot mm$ $M_{22.min} := -698777.15\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.102 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.277 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.92 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 60.044\ MPa$

Max stress range:

$\Delta\sigma_{VEH4} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 66.585\ MPa$

VEH5

At 0 mm

$P_{max} := 583682.83\ N$ $\quad M_{33.max} := 1726778.01 \cdot N \cdot mm$ $\quad M_{22.max} := 621815.59\ N \cdot mm$

$P_{min} := -61621.21\ N$ $\quad M_{33.min} := -184870.37\ N \cdot mm$ $\quad M_{22.min} := -4673443.11\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.453 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(1.912 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(5.295 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 133.819\ MPa$

At 8766.48 mm

$P_{max} := 583682.83\ N$ $\quad M_{33.max} := 107128.67 \cdot N \cdot mm$ $\quad M_{22.max} := 2430274.4\ N \cdot mm$

$P_{min} := -61621.21\ N$ $\quad M_{33.min} := -838624.8\ N \cdot mm$ $\quad M_{22.min} := -1338462.52\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.453 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(9.458 \cdot 10^{5}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.769 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 123.367\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 133.819\ MPa$

VEH6

At 0 mm

$P_{max} := 478533.42\ N$ $M_{33.max} := 1499290.71 \cdot N \cdot mm$ $M_{22.max} := 588145.12\ N \cdot mm$

$P_{min} := -59539.05\ N$ $M_{33.min} := -169773.09\ N \cdot mm$ $M_{22.min} := -4167887.75\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.381 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.669 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.756 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 113.642\ MPa$

At 8766.48 mm

$P_{max} := 478533.42\ N$ $M_{33.max} := 106731.81 \cdot N \cdot mm$ $M_{22.max} := 2092338.14\ N \cdot mm$

$P_{min} := -59539.05\ N$ $M_{33.min} := -722417.86\ N \cdot mm$ $M_{22.min} := -1229222.22\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.381 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(8.291 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.322 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 103.952\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 113.642\ MPa$

VEH7

At 0 mm

$P_{max} := 517526.67\ N$ $\quad M_{33.max} := 1566238.74 \cdot N \cdot mm$ $\quad M_{22.max} := 577959.39\ N \cdot mm$

$P_{min} := -58845\ N$ $\quad M_{33.min} := -164740.67\ N \cdot mm$ $\quad M_{22.min} := -4425590.52\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.764 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(1.731 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(5.004 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 121.109\ MPa$

At 8766.48 mm

$P_{max} := 517526.67\ N$ $\quad M_{33.max} := 107710.71 \cdot N \cdot mm$ $\quad M_{22.max} := 2190598.35\ N \cdot mm$

$P_{min} := -58845\ N$ $\quad M_{33.min} := -814829.51\ N \cdot mm$ $\quad M_{22.min} := -1314123.23\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.764 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(9.225 \cdot 10^{5}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.505 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 111.119\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 121.109\ MPa$

VEH8

At 0 mm

$P_{max} := 456988.23\ N$ $M_{33.max} := 1332173.14 \cdot N \cdot mm$ $M_{22.max} := 577959.39 \cdot N \cdot mm$

$P_{min} := -58845\ N$ $M_{33.min} := -164740.67\ N \cdot mm$ $M_{22.min} := -3966590.19\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.158 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.497 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.545 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 108.661\ MPa$

At 8766.48 mm

$P_{max} := 456988.23\ N$ $M_{33.max} := 102560.08 \cdot N \cdot mm$ $M_{22.max} := 1972305.89\ N \cdot mm$

$P_{min} := -58845\ N$ $M_{33.min} := -706050.66\ N \cdot mm$ $M_{22.min} := -1138246.42\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.158 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(8.086 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.111 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 99.268\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 108.661\ MPa$

Stress range - HEA240

Critical detail: Element 30

$A := 7.68 \cdot 10^3\ mm^2$

$W_{el.33} := 675 \cdot 10^3\ mm^3$

$W_{el.22} := 231 \cdot 10^3 \cdot mm^3$

VEH1

At 0 mm

$P_{max} := 649876.36\ N$ $M_{33.max} := 3779559.86 \cdot N \cdot mm$ $M_{22.max} := 33560.31\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -3655391.1\ N \cdot mm$ $M_{22.min} := -3613095.54\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = (6.499 \cdot 10^5)\ N$ $\Delta M_{33} = (7.435 \cdot 10^6)\ N \cdot mm$ $\Delta M_{22} = (3.647 \cdot 10^6)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 111.42\ MPa$

At 6096 mm

$P_{max} := 649876.36\ N$ $M_{33.max} := 7579194.18 \cdot N \cdot mm$ $M_{22.max} := 2150235.54\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -801974.63\ N \cdot mm$ $M_{22.min} := -182961.58\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = (6.499 \cdot 10^5)\ N$ $\Delta M_{33} = (8.381 \cdot 10^6)\ N \cdot mm$ $\Delta M_{22} = (2.333 \cdot 10^6)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 107.136\ MPa$

Max stress range:

$\Delta\sigma_{VEH1} := \max(\Delta\sigma_1, \Delta\sigma_2) = 111.42\ MPa$

VEH2

At 0 mm

$P_{max} := 478005.07\ N$ $M_{33.max} := 2799449.61 \cdot N \cdot mm$ $M_{22.max} := 32890.34\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -2704238.39\ N \cdot mm$ $M_{22.min} := -2595826.09\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.78 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.504 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.629 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 81.774\ MPa$

At 6096 mm

$P_{max} := 478005.07\ N$ $M_{33.max} := 5462709.42 \cdot N \cdot mm$ $M_{22.max} := 1499951.81\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -583763.35\ N \cdot mm$ $M_{22.min} := -131039.31\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.78 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(6.046 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.631 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 78.259\ MPa$

Max stress range:

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 81.774\ MPa$

VEH3

At 0 mm

$P_{max} := 440746.64\ N$ $\quad M_{33.max} := 2631708.26 \cdot N \cdot mm$ $\quad M_{22.max} := 35591.26\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -2511446.84\ N \cdot mm$ $\quad M_{22.min} := -2481362.16\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.407 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(5.143 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.517 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 75.904\ MPa$

At 6096 mm

$P_{max} := 440746.64\ N$ $\quad M_{33.max} := 5182996.1 \cdot N \cdot mm$ $\quad M_{22.max} := 1488349.76\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -552565.77\ N \cdot mm$ $\quad M_{22.min} := -135628.94\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.407 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(5.736 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.624 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 72.916\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 75.904\ MPa$

VEH4

At 0 mm

$P_{max} := 391027.5\ N$ $M_{33.max} := 2502597.37 \cdot N \cdot mm$ $M_{22.max} := 37173.97\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -2311223.42\ N \cdot mm$ $M_{22.min} := -2202003.26\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.91 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(4.814 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.239 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 67.74\ MPa$

At 6096 mm

$P_{max} := 391027.5\ N$ $M_{33.max} := 5347009.24 \cdot N \cdot mm$ $M_{22.max} := 1353197.09\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -556095.61\ N \cdot mm$ $M_{22.min} := -138882.64\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.91 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.903 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.492 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 66.12\ MPa$

Max stress range:

$\Delta\sigma_{VEH4} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 67.74\ MPa$

VEH5

At 0 mm

$P_{max} := 944965.8\ N$ $M_{33.max} := 4399670.49 \cdot N \cdot mm$ $M_{22.max} := 51339.21\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -4121108.75\ N \cdot mm$ $M_{22.min} := -5080866.54\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(9.45 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(8.521 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(5.132 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 157.883\ MPa$

At 6096 mm

$P_{max} := 944965.8\ N$ $M_{33.max} := 9385124.03 \cdot N \cdot mm$ $M_{22.max} := 2819579.04\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -930409.99\ N \cdot mm$ $M_{22.min} := -232562.62\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(9.45 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.032 \cdot 10^{7}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.052 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 151.537\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 157.883\ MPa$

VEH6

At 0 mm

$P_{max} := 723126.93\ N$ $\quad M_{33.max} := 4071250.17 \cdot N \cdot mm$ $\quad M_{22.max} := 50429.03\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -3915058.97\ N \cdot mm$ $\quad M_{22.min} := -4035580.02\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.231 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(7.986 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(4.086 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 123.677\ MPa$

At 6096 mm

$P_{max} := 723126.93\ N$ $\quad M_{33.max} := 8441760.31 \cdot N \cdot mm$ $\quad M_{22.max} := 2437950.41\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -827181.47\ N \cdot mm$ $\quad M_{22.min} := -198952.23\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.231 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(9.269 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.637 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 119.304\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 123.677\ MPa$

VEH7

At 0 mm

$P_{max} := 75144.88\ N$ $M_{33.max} := 4277611.71 \cdot N \cdot mm$ $M_{22.max} := 51719.79\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -4165563.94\ N \cdot mm$ $M_{22.min} := -4137525.63\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.514 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(8.443 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.189 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 40.428\ MPa$

At 6096 mm

$P_{max} := 75144.88\ N$ $M_{33.max} := 9078947.24 \cdot N \cdot mm$ $M_{22.max} := 2474572.65\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -834447.7\ N \cdot mm$ $M_{22.min} := -206610.29\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.514 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(9.913 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.681 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 36.078\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 40.428\ MPa$

VEH8

At 0 mm

$P_{max} := 725734.12\ N$ $M_{33.max} := 3862474.62 \cdot N \cdot mm$ $M_{22.max} := 45542.59 \cdot N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := 3744229.75\ N \cdot mm$ $M_{22.min} := -3855193.03\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.257 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.182 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.901 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 111.558\ MPa$

At 6096 mm

$P_{max} := 725734.12\ N$ $M_{33.max} := 8111800.38 \cdot N \cdot mm$ $M_{22.max} := 2252169.28\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -815185.87\ N \cdot mm$ $M_{22.min} := -11519.15\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.257 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(8.927 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.264 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 117.521\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 117.521\ MPa$

Stress range - HEA260

Critical detail: Element 51

$A := 8.68 \cdot 10^3\ mm^2$

$W_{el.33} := 836 \cdot 10^3\ mm^3$

$W_{el.22} := 282 \cdot 10^3 \cdot mm^3$

VEH1

At 0 mm

$P_{max} := 39.59\ N$ $\quad M_{33.max} := 0 \cdot N \cdot mm$ $\quad M_{22.max} := 553624.9\ N \cdot mm$

$P_{min} := -681987.07\ N$ $\quad M_{33.min} := -7652430.09\ N \cdot mm$ $\quad M_{22.min} := -4346689.27\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.82 \cdot 10^5\right)\ N$ $\quad \Delta M_{33} = \left(7.652 \cdot 10^6\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(4.9 \cdot 10^6\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 105.105\ MPa$

At 9444.33 mm

$P_{max} := 39.67\ N$ $\quad M_{33.max} := 485772.21 \cdot N \cdot mm$ $\quad M_{22.max} := 7107676.66\ N \cdot mm$

$P_{min} := -681215.61\ N$ $\quad M_{33.min} := -726929\ N \cdot mm$ $\quad M_{22.min} := -1982292.6\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.813 \cdot 10^5\right)\ N$ $\quad \Delta M_{33} = \left(1.213 \cdot 10^6\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(9.09 \cdot 10^6\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 112.17\ MPa$

Max stress range:

$\Delta\sigma_{VEH1} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 112.17\ MPa$

VEH2

At 0 mm

$P_{max} := 39.59\ N$ $M_{33.max} := 0 \cdot N \cdot mm$ $M_{22.max} := 466093.12\ N \cdot mm$

$P_{min} := -489856.42\ N$ $M_{33.min} := -5538873.5\ N \cdot mm$ $M_{22.min} := -3098099.69\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.899 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.539 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.564 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 75.704\ MPa$

At 9444.33 mm

$P_{max} := 39.67\ N$ $M_{33.max} := 351266.28 \cdot N \cdot mm$ $M_{22.max} := 5121564.81\ N \cdot mm$

$P_{min} := -489304.45\ N$ $M_{33.min} := -524575.64\ N \cdot mm$ $M_{22.min} := 1649065.16\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.893 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(8.758 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.472 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 69.738\ MPa$

Max stress range:

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 75.704\ MPa$

VEH3

At 0 mm

$P_{max} := 35.19\ N$ $M_{33.max} := 0 \cdot N \cdot mm$ $M_{22.max} := 430314.39\ N \cdot mm$

$P_{min} := -462948.85\ N$ $M_{33.min} := -5267870.27\ N \cdot mm$ $M_{22.min} := -2873085.58\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.63 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.268 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.303 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 71.355\ MPa$

At 9444.33 mm

$P_{max} := 35.27\ N$ $M_{33.max} := 317082.76 \cdot N \cdot mm$ $M_{22.max} := 4849366.28\ N \cdot mm$

$P_{min} := -462417.55\ N$ $M_{33.min} := -465160.33\ N \cdot mm$ $M_{22.min} := -1534073.69\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.625 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(7.822 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(6.383 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 76.85\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 76.85\ MPa$

VEH4

At 0 mm

$P_{max} := 29.91\ N$ $M_{33.max} := 0 \cdot N \cdot mm$ $M_{22.max} := 464776.33\ N \cdot mm$

$P_{min} := -429886.79\ N$ $M_{33.min} := -4902130.5\ N \cdot mm$ $M_{22.min} := -2670998.36\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.299 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(4.902 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.136 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta \sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta \sigma_1 = 66.513\ MPa$

At 9444.33 mm

$P_{max} := 29.98\ N$ $M_{33.max} := 266327.08 \cdot N \cdot mm$ $M_{22.max} := 4280105.5\ N \cdot mm$

$P_{min} := -429386.05\ N$ $M_{33.min} := -377087.78\ N \cdot mm$ $M_{22.min} := -1561041.64\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.294 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(6.434 \cdot 10^{5}\right)\ N \cdot mm$ $\Delta M_{22} = \left(5.841 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta \sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta \sigma_2 = 70.955\ MPa$

Max stress range:

$\Delta \sigma_{VEH4} := \max\left(\Delta \sigma_1, \Delta \sigma_2\right) = 70.955\ MPa$

VEH5

At 0 mm

$P_{max} := 39.59\ N$ $M_{33.max} := 0 \cdot N \cdot mm$ $M_{22.max} := 643194.64\ N \cdot mm$

$P_{min} := -992619.23\ N$ $M_{33.min} := -10748661.2\ N \cdot mm$ $M_{22.min} := -5986765.41\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(9.927 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.075 \cdot 10^{7}\right)\ N \cdot mm$ $\Delta M_{22} = \left(6.63 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 150.729\ MPa$

At 9444.33 mm

$P_{max} := 39.67\ N$ $M_{33.max} := 611023.65 \cdot N \cdot mm$ $M_{22.max} := 10174777.13\ N \cdot mm$

$P_{min} := -991498.7\ N$ $M_{33.min} := -833599.57\ N \cdot mm$ $M_{22.min} := -2355448.33\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(9.915 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.445 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.253 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 160.394\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 160.394\ MPa$

VEH6

At 0 mm

$P_{max} := 39.59\ N$ $M_{33.max} := 0 \cdot N \cdot mm$ $M_{22.max} := 630128.33\ N \cdot mm$

$P_{min} := -770621.85\ N$ $M_{33.min} := -8279959.43\ N \cdot mm$ $M_{22.min} := -4931973.35\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.707 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(8.28 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(5.562 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 118.414\ MPa$

At 9444.33 mm

$P_{max} := 39.67\ N$ $M_{33.max} := 505142.91 \cdot N \cdot mm$ $M_{22.max} := 7961330.7\ N \cdot mm$

$P_{min} := -769755.85\ N$ $M_{33.min} := -714883.2\ N \cdot mm$ $M_{22.min} := -2145740.15\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.698 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.22 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.011 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 125.986\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 125.986\ MPa$

VEH7

At 0 mm

$P_{max} := 39.59\ N$ $\quad M_{33.max} := 0 \cdot N \cdot mm$ $\quad M_{22.max} := 610991.72\ N \cdot mm$

$P_{min} := -788765.68\ N$ $\quad M_{33.min} := -8871175.12\ N \cdot mm$ $\quad M_{22.min} := -4878442.94\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = (7.888 \cdot 10^5)\ N$ $\quad \Delta M_{33} = (8.871 \cdot 10^6)\ N \cdot mm$ $\quad \Delta M_{22} = (5.489 \cdot 10^6)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 120.954\ MPa$

At 9444.33 mm

$P_{max} := 39.67\ N$ $\quad M_{33.max} := 539287.85 \cdot N \cdot mm$ $\quad M_{22.max} := 7968184.07\ N \cdot mm$

$P_{min} := -787860.06\ N$ $\quad M_{33.min} := -780535.39\ N \cdot mm$ $\quad M_{22.min} := -2105778.02\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = (7.879 \cdot 10^5)\ N$ $\quad \Delta M_{33} = (1.32 \cdot 10^6)\ N \cdot mm$ $\quad \Delta M_{22} = (1.007 \cdot 10^7)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 128.074\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max(\Delta\sigma_1, \Delta\sigma_2) = 128.074\ MPa$

VEH8

At 0 mm

$P_{max} := 39.59\ N$ $\quad M_{33.max} := 0 \cdot N \cdot mm$ $\quad M_{22.max} := 569919.26 \cdot N \cdot mm$

$P_{min} := -746182.33\ N$ $\quad M_{33.min} := -8161895.81\ N \cdot mm$ $\quad M_{22.min} := -4758020.47\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.462 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(8.162 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(5.328 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 114.627\ MPa$

At 9444.33 mm

$P_{max} := 39.67\ N$ $\quad M_{33.max} := 495840.08 \cdot N \cdot mm$ $\quad M_{22.max} := 7904597.33\ N \cdot mm$

$P_{min} := -745349.5\ N$ $\quad M_{33.min} := -736980.59\ N \cdot mm$ $\quad M_{22.min} := -2018860.58\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.454 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(1.233 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(9.923 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 122.539\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 122.539\ MPa$

Stress range - HEA550

Critical detail: Element 89

$$A := 21.2 \cdot 10^3\ mm^2$$

$$W_{el.33} := 4150 \cdot 10^3\ mm^3$$

$$W_{el.22} := 721 \cdot 10^3 \cdot mm^3$$

VEH1

At 0 mm

$P_{max} := 32390.65\ N$ $\quad M_{33.max} := 77628585.98 \cdot N \cdot mm$ $\quad M_{22.max} := 40002.16\ N \cdot mm$

$P_{min} := -1195.36\ N$ $\quad M_{33.min} := -150509879\ N \cdot mm$ $\quad M_{22.min} := -16889377.8\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.359 \cdot 10^4\right)\ N$ $\quad \Delta M_{33} = \left(2.281 \cdot 10^8\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.693 \cdot 10^7\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$$\Delta\sigma_1 = 80.038\ MPa$$

At 7036 mm

$P_{max} := 32390.65\ N$ $\quad M_{33.max} := 2248601.31 \cdot N \cdot mm$ $\quad M_{22.max} := 20581742.13\ N \cdot mm$

$P_{min} := -1195.36\ N$ $\quad M_{33.min} := -247494.74\ N \cdot mm$ $\quad M_{22.min} := -88844.8\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.359 \cdot 10^4\right)\ N$ $\quad \Delta M_{33} = \left(2.496 \cdot 10^6\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.067 \cdot 10^7\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$$\Delta\sigma_2 = 30.855\ MPa$$

Max stress range:

$$\Delta\sigma_{VEH1} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 80.038\ MPa$$

VEH2

At 0 mm

$P_{max} := 23108.39\ N$ $M_{33.max} := 58453453.65 \cdot N \cdot mm$ $M_{22.max} := 40002.16\ N \cdot mm$

$P_{min} := -814.18\ N$ $M_{33.min} := -119132053\ N \cdot mm$ $M_{22.min} := -12211610.4\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.392 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(1.776 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.225 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 60.913\ MPa$

At 7036 mm

$P_{max} := 23108.39\ N$ $M_{33.max} := 1599544.61 \cdot N \cdot mm$ $M_{22.max} := 14845937.93\ N \cdot mm$

$P_{min} := -814.18\ N$ $M_{33.min} := -180485.44\ N \cdot mm$ $M_{22.min} := -88844.8\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.392 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(1.78 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.493 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 22.271\ MPa$

Max stress range:

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 60.913\ MPa$

VEH3

At 0 mm

$P_{max} := 22071.19\ N$ $\quad M_{33.max} := 54009465.44 \cdot N \cdot mm$ $\quad M_{22.max} := 35557.48\ N \cdot mm$

$P_{min} := -795.86\ N$ $\quad M_{33.min} := -115266988\ N \cdot mm$ $\quad M_{22.min} := -11614615.3\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.287 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.693 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.165 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 58.026\ MPa$

At 7036 mm

$P_{max} := 22071.19\ N$ $\quad M_{33.max} := 1528680.79 \cdot N \cdot mm$ $\quad M_{22.max} := 13981845.2\ N \cdot mm$

$P_{min} := -795.86\ N$ $\quad M_{33.min} := -160431.5\ N \cdot mm$ $\quad M_{22.min} := -78973.16\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.287 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.689 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.406 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 20.987\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 58.026\ MPa$

<u>VEH4</u>

At 0 mm

$P_{max} := 19726.35\ N$ $\quad M_{33.max} := 50776883.49 \cdot N \cdot mm$ $\quad M_{22.max} := 30223.85\ N \cdot mm$

$P_{min} := -927.21\ N$ $\quad M_{33.min} := -97048155\ N \cdot mm$ $\quad M_{22.min} := -10318224.5\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.065 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.478 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.035 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 50.948\ MPa$

At 7036 mm

$P_{max} := 19726.35\ N$ $\quad M_{33.max} := 1360883.89 \cdot N \cdot mm$ $\quad M_{22.max} := 12286041.6\ N \cdot mm$

$P_{min} := -927.21\ N$ $\quad M_{33.min} := -199081.19\ N \cdot mm$ $\quad M_{22.min} := -67127.19\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.065 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.56 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.235 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 18.484\ MPa$

Max stress range:

$\Delta\sigma_{VEH4} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 50.948\ MPa$

VEH5

At 0 mm

$P_{max} := 47440.77\ N$ $M_{33.max} := 84815628.42 \cdot N \cdot mm$ $M_{22.max} := 40002.16\ N \cdot mm$

$P_{min} := -1227.71\ N$ $M_{33.min} := -210739215\ N \cdot mm$ $M_{22.min} := -25778227.7\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.867 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.956 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.582 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 109.323\ MPa$

At 7036 mm

$P_{max} := 47440.77\ N$ $M_{33.max} := 3209902.99 \cdot N \cdot mm$ $M_{22.max} := 30562238.28\ N \cdot mm$

$P_{min} := -1227.71\ N$ $M_{33.min} := -295460.9\ N \cdot mm$ $M_{22.min} := -88844.8\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.867 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(3.505 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.065 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 45.652\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 109.323\ MPa$

VEH6

At 0 mm

$P_{max} := 36266.78\ N$ $\quad M_{33.max} := 81186529.2 \cdot N \cdot mm$ $\quad M_{22.max} := 43156.75\ N \cdot mm$

$P_{min} := -1218.55\ N$ $\quad M_{33.min} := -185712550\ N \cdot mm$ $\quad M_{22.min} := -19802278.9\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.749 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(2.669 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.985 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 93.606\ MPa$

At 7036 mm

$P_{max} := 36266.78\ N$ $\quad M_{33.max} := 2464784.65 \cdot N \cdot mm$ $\quad M_{22.max} := 23406867.03\ N \cdot mm$

$P_{min} := -1218.55\ N$ $\quad M_{33.min} := -259807.15\ N \cdot mm$ $\quad M_{22.min} := -91795.25\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.749 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(2.725 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.35 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 35.016\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 93.606\ MPa$

VEH7

At 0 mm

$P_{max} := 37025.34\ N$ $\quad M_{33.max} := 82514709.43 \cdot N \cdot mm$ $\quad M_{22.max} := 41495.14\ N \cdot mm$

$P_{min} := -1219.75\ N$ $\quad M_{33.min} := -177737132\ N \cdot mm$ $\quad M_{22.min} := -19753428.8\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.825 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(2.603 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.979 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 91.97\ MPa$

At 7036 mm

$P_{max} := 37025.34\ N$ $\quad M_{33.max} := 2541333.31 \cdot N \cdot mm$ $\quad M_{22.max} := 23414296.79\ N \cdot mm$

$P_{min} := -1219.75\ N$ $\quad M_{33.min} := -249054.26\ N \cdot mm$ $\quad M_{22.min} := -\square\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.825 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(2.79 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(4.317 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 62.348\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 91.97\ MPa$

VEH8

At 0 mm

$P_{max} := 36623.89\ N$ $\quad M_{33.max} := 79571990.12 \cdot N \cdot mm$ $\quad M_{22.max} := 40002.16 \cdot N \cdot mm$

$P_{min} := -1195.36\ N$ $\quad M_{33.min} := -152971707\ N \cdot mm$ $\quad M_{22.min} := -19578632.9\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.782 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(2.325 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.962 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 85.029\ MPa$

At 7036 mm

$P_{max} := 36623.89\ N$ $\quad M_{33.max} := 2507393.84 \cdot N \cdot mm$ $\quad M_{22.max} := 23298336.85\ N \cdot mm$

$P_{min} := -1195.36\ N$ $\quad M_{33.min} := -247494.74\ N \cdot mm$ $\quad M_{22.min} := -88844.8\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.782 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(2.755 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.339 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 34.885\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 85.029\ MPa$

Stress ranges - HEB260

Critical detail: Element 40

$A := 11.8 \cdot 10^3\ mm^2$

$W_{el.33} := 1150 \cdot 10^3\ mm^3$

$W_{el.22} := 395 \cdot 10^3 \cdot mm^3$

VEH1

At 0 mm

$P_{max} := 64.7\ N$ $\quad M_{33.max} := 12917.95 \cdot N \cdot mm$ $\quad M_{22.max} := 3798604.46\ N \cdot mm$

$P_{min} := -751039.82\ N$ $\quad M_{33.min} := -8858412.74\ N \cdot mm$ $\quad M_{22.min} := -627027.89\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.511 \cdot 10^5\right)\ N$ $\quad \Delta M_{33} = \left(8.871 \cdot 10^6\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(4.426 \cdot 10^6\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 82.571\ MPa$

At 6096 mm

$P_{max} := 64.7\ N$ $\quad M_{33.max} := 10172108.44 \cdot N \cdot mm$ $\quad M_{22.max} := 81756.37\ N \cdot mm$

$P_{min} := -751039.82\ N$ $\quad M_{33.min} := -33335.08\ N \cdot mm$ $\quad M_{22.min} := -3117401.59\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.511 \cdot 10^5\right)\ N$ $\quad \Delta M_{33} = \left(1.021 \cdot 10^7\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.199 \cdot 10^6\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 80.626\ MPa$

Max stress range:

$\Delta\sigma_{VEH1} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 82.571\ MPa$

VEH2

At 0 mm

$P_{max} := 64.7\ N$ $\quad M_{33.max} := 12917.95 \cdot N \cdot mm$ $\quad M_{22.max} := 2750412.65\ N \cdot mm$

$P_{min} := -547146.48\ N$ $\quad M_{33.min} := -6409464.31\ N \cdot mm$ $\quad M_{22.min} := -491434.66\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.472 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(6.422 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.242 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 60.166\ MPa$

At 6096 mm

$P_{max} := 64.7\ N$ $\quad M_{33.max} := 7338822.87 \cdot N \cdot mm$ $\quad M_{22.max} := 79505.67\ N \cdot mm$

$P_{min} := -547146.48\ N$ $\quad M_{33.min} := -30291.43\ N \cdot mm$ $\quad M_{22.min} := -2290531.61\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.472 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(7.369 \cdot 10^{6}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.37 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 58.782\ MPa$

Max stress range:

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 60.166\ MPa$

VEH3

At 0 mm

$P_{max} := 57.51\ N$ $M_{33.max} := 11482.63 \cdot N \cdot mm$ $M_{22.max} := 2587349.59\ N \cdot mm$

$P_{min} := -509537.3\ N$ $M_{33.min} := -5856032.03\ N \cdot mm$ $M_{22.min} := -474611.69\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.096 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.868 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.062 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 56.04\ MPa$

At 6096 mm

$P_{max} := 57.51\ N$ $M_{33.max} := 6973440.87 \cdot N \cdot mm$ $M_{22.max} := 70671.71\ N \cdot mm$

$P_{min} := -509537.3\ N$ $M_{33.min} := -26925.71\ N \cdot mm$ $M_{22.min} := -2127234.72\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.096 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(7 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.198 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 54.838\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 56.04\ MPa$

VEH4

At 0 mm

$P_{max} := 48.88\ N$ $M_{33.max} := 9760.23 \cdot N \cdot mm$ $M_{22.max} := 2407836.38\ N \cdot mm$

$P_{min} := -461985.27\ N$ $M_{33.min} := -5570615.5\ N \cdot mm$ $M_{22.min} := -470219.82\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.62 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.58 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.878 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 51.294\ MPa$

At 6096 mm

$P_{max} := 48.88\ N$ $M_{33.max} := 6693757.56 \cdot N \cdot mm$ $M_{22.max} := 72954.45\ N \cdot mm$

$P_{min} := -461985.27\ N$ $M_{33.min} := -28252.28\ N \cdot mm$ $M_{22.min} := -1992210.34\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.62 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(6.722 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(2.065 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 50.229\ MPa$

Max stress range:

$\Delta\sigma_{VEH4} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 51.294\ MPa$

VEH5

At 0 mm

$P_{max} := 64.7\ N$ $M_{33.max} := 12917.95 \cdot N \cdot mm$ $M_{22.max} := 5410328.97\ N \cdot mm$

$P_{min} := -1074498.01\ N$ $M_{33.min} := -11944703.9\ N \cdot mm$ $M_{22.min} := -809675.16\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.075 \cdot 10^{6}\right)\ N$ $\Delta M_{33} = \left(1.196 \cdot 10^{7}\right)\ N \cdot mm$ $\Delta M_{22} = \left(6.22 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 117.209\ MPa$

At 6096 mm

$P_{max} := 64.7\ N$ $M_{33.max} := 13147119.51 \cdot N \cdot mm$ $M_{22.max} := 90214.08\ N \cdot mm$

$P_{min} := -1074498.01\ N$ $M_{33.min} := -35653.73\ N \cdot mm$ $M_{22.min} := -4514732.16\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.075 \cdot 10^{6}\right)\ N$ $\Delta M_{33} = \left(1.318 \cdot 10^{7}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.605 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 114.186\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 117.209\ MPa$

VEH6

At 0 mm

$P_{max} := 64.7\ N$ $M_{33.max} := 13085.54 \cdot N \cdot mm$ $M_{22.max} := 4195305.36\ N \cdot mm$

$P_{min} := -818676.14\ N$ $M_{33.min} := -9545762.82\ N \cdot mm$ $M_{22.min} := -699056.58\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.187 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(9.559 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.894 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 90.088\ MPa$

At 6096 mm

$P_{max} := 64.7\ N$ $M_{33.max} := 11051480.34 \cdot N \cdot mm$ $M_{22.max} := 90214.08\ N \cdot mm$

$P_{min} := -818676.14\ N$ $M_{33.min} := -35653.73\ N \cdot mm$ $M_{22.min} := -3442406.27\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.187 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.109 \cdot 10^{7}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.533 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 87.969\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 90.088\ MPa$

VEH7

At 0 mm

$P_{max} := 64.7\ N$ $\quad M_{33.max} := 13085.54 \cdot N \cdot mm$ $\quad M_{22.max} := 4380633.33\ N \cdot mm$

$P_{min} := -861614.54\ N$ $\quad M_{33.min} := -10189278.2\ N \cdot mm$ $\quad M_{22.min} := -740008.04\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.617 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(1.02 \cdot 10^{7}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(5.121 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 94.859\ MPa$

At 6096 mm

$P_{max} := 64.7\ N$ $\quad M_{33.max} := 12073921.76 \cdot N \cdot mm$ $\quad M_{22.max} := 90214.08\ N \cdot mm$

$P_{min} := -861614.54\ N$ $\quad M_{33.min} := -35653.73\ N \cdot mm$ $\quad M_{22.min} := -3580816.98\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.617 \cdot 10^{5}\right)\ N$ $\quad \Delta M_{33} = \left(1.211 \cdot 10^{7}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.671 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 92.847\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 94.859\ MPa$

VEH8

At 0 mm

$P_{max} := 64.7\ N$ $M_{33.max} := 12917.95 \cdot N \cdot mm$ $M_{22.max} := 4134386.5 \cdot N \cdot mm$

$P_{min} := -807486.03\ N$ $M_{33.min} := -9324549.05\ N \cdot mm$ $M_{22.min} := -670034.04\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.076 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(9.337 \cdot 10^{6}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.804 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 88.719\ MPa$

At 6096 mm

$P_{max} := 64.7\ N$ $M_{33.max} := 10739802.33 \cdot N \cdot mm$ $M_{22.max} := 81756.37\ N \cdot mm$

$P_{min} := -807486.03\ N$ $M_{33.min} := -33335.08\ N \cdot mm$ $M_{22.min} := -3445427.87\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.076 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(1.077 \cdot 10^{7}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.527 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 86.734\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 88.719\ MPa$

Stress range - IPE550

Critical detail: Element 6

$A := 13.4 \cdot 10^3 \ mm^2$

$W_{el.33} := 2440 \cdot 10^3 \ mm^3$

$W_{el.22} := 254 \cdot 10^3 \cdot mm^3$

VEH1

At 0 mm

$P_{max} := 78142.91 \ N$ $\quad M_{33.max} := 61109345.36 \cdot N \cdot mm$ $\quad M_{22.max} := 23051.37 \ N \cdot mm$

$P_{min} := -236.39 \ N$ $\quad M_{33.min} := -138725247 \ N \cdot mm$ $\quad M_{22.min} := -2980851.38 \ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.838 \cdot 10^4\right) N$ $\quad \Delta M_{33} = \left(1.998 \cdot 10^8\right) N \cdot mm$ $\quad \Delta M_{22} = \left(3.004 \cdot 10^6\right) N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 99.575 \ MPa$

At 6096 mm

$P_{max} := 78142.91 \ N$ $\quad M_{33.max} := 75210671.29 \cdot N \cdot mm$ $\quad M_{22.max} := 1706537.57 \ N \cdot mm$

$P_{min} := -236.39 \ N$ $\quad M_{33.min} := -113448360 \ N \cdot mm$ $\quad M_{22.min} := -94312.21 \ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.838 \cdot 10^4\right) N$ $\quad \Delta M_{33} = \left(1.887 \cdot 10^8\right) N \cdot mm$ $\quad \Delta M_{22} = \left(1.801 \cdot 10^6\right) N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 90.258 \ MPa$

Max stress range:

$\Delta\sigma_{VEH1} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 99.575 \ MPa$

VEH2

At 0 mm

$P_{max} := 56543.92\ N$ $\quad M_{33.max} := 46604637.77 \cdot N \cdot mm$ $\quad M_{22.max} := 22621.72\ N \cdot mm$

$P_{min} := -236.39\ N$ $\quad M_{33.min} := -114106155\ N \cdot mm$ $\quad M_{22.min} := -2157898.11\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.678 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.607 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.181 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 78.687\ MPa$

At 6096 mm

$P_{max} := 56543.92\ N$ $\quad M_{33.max} := 58110000.17 \cdot N \cdot mm$ $\quad M_{22.max} := 1216590\ N \cdot mm$

$P_{min} := -236.39\ N$ $\quad M_{33.min} := -96663298\ N \cdot mm$ $\quad M_{22.min} := 62949.57\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.678 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.548 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.154 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 72.211\ MPa$

Max stress range:

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 78.687\ MPa$

VEH3

At 0 mm

$P_{max} := 53266.78\ N$ $\quad M_{33.max} := 46475615.97 \cdot N \cdot mm$ $\quad M_{22.max} := 22770.02\ N \cdot mm$

$P_{min} := -210.12\ N$ $\quad M_{33.min} := -98914166\ N \cdot mm$ $\quad M_{22.min} := -1976778.84\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.348 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.454 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(2 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 71.449\ MPa$

At 6096 mm

$P_{max} := 53266.78\ N$ $\quad M_{33.max} := 55700228.25 \cdot N \cdot mm$ $\quad M_{22.max} := 1095344.2\ N \cdot mm$

$P_{min} := -210.12\ N$ $\quad M_{33.min} := -82227534\ N \cdot mm$ $\quad M_{22.min} := -62770.28\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.348 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.379 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.158 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 65.078\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 71.449\ MPa$

VEH4

At 0 mm

$P_{max} := 46710.3\ N$ $\quad M_{33.max} := 41927522.86 \cdot N \cdot mm$ $\quad M_{22.max} := 21576.76\ N \cdot mm$

$P_{min} := -178.6\ N$ $\quad M_{33.min} := -93478155\ N \cdot mm$ $\quad M_{22.min} := -1687457.09\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.689 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.354 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.709 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 65.722\ MPa$

At 6096 mm

$P_{max} := 46710.13\ N$ $\quad M_{33.max} := 51431652.03 \cdot N \cdot mm$ $\quad M_{22.max} := 945537.35\ N \cdot mm$

$P_{min} := -178.6\ N$ $\quad M_{33.min} := -78350011\ N \cdot mm$ $\quad M_{22.min} := -58842.98\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(4.689 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = \left(1.298 \cdot 10^{8}\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.004 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 60.643\ MPa$

Max stress range:

$\Delta\sigma_{VEH4} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 65.722\ MPa$

VEH5

At 0 mm

$P_{max} := 116460.27\ N$ $\qquad M_{33.max} := 70494809.13 \cdot N \cdot mm$ $\qquad M_{22.max} := 31931.52\ N \cdot mm$

$P_{min} := -236.39\ N$ $\qquad M_{33.min} := -188375517\ N \cdot mm$ $\qquad M_{22.min} := -4147399.64\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\qquad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\qquad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.167 \cdot 10^{5}\right)\ N$ $\qquad \Delta M_{33} = \left(2.589 \cdot 10^{8}\right)\ N \cdot mm$ $\qquad \Delta M_{22} = \left(4.179 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 131.257\ MPa$

At 6096 mm

$P_{max} := 116460.27\ N$ $\qquad M_{33.max} := 89336637.2 \cdot N \cdot mm$ $\qquad M_{22.max} := 2208507.35\ N \cdot mm$

$P_{min} := -236.39\ N$ $\qquad M_{33.min} := -156706698\ N \cdot mm$ $\qquad M_{22.min} := -113557.31\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\qquad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\qquad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.167 \cdot 10^{5}\right)\ N$ $\qquad \Delta M_{33} = \left(2.46 \cdot 10^{8}\right)\ N \cdot mm$ $\qquad \Delta M_{22} = \left(2.322 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 118.688\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 131.257\ MPa$

VEH6

At 0 mm

$P_{max} := 89074.6\ N$ $M_{33.max} := 62312992.94 \cdot N \cdot mm$ $M_{22.max} := 31931.52\ N \cdot mm$

$P_{min} := -295.04\ N$ $M_{33.min} := -165488554\ N \cdot mm$ $M_{22.min} := -3202155.85\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.937 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.278 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.234 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 112.763\ MPa$

At 6096 mm

$P_{max} := 89074.6\ N$ $M_{33.max} := 78685423.98 \cdot N \cdot mm$ $M_{22.max} := 1832569\ N \cdot mm$

$P_{min} := -295.04\ N$ $M_{33.min} := -136250186\ N \cdot mm$ $M_{22.min} := -96926.81\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.937 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.149 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.929 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 102.354\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 112.763\ MPa$

VEH7

At 0 mm

$P_{max} := 88757.39\ N$ $M_{33.max} := 66994345.06 \cdot N \cdot mm$ $M_{22.max} := 31931.52\ N \cdot mm$

$P_{min} := -278.04\ N$ $M_{33.min} := -158780803\ N \cdot mm$ $M_{22.min} := -3362070.85\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.904 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.258 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.394 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 112.537\ MPa$

At 6096 mm

$P_{max} := 88757.39\ N$ $M_{33.max} := 85560674.11 \cdot N \cdot mm$ $M_{22.max} := 1888885.67\ N \cdot mm$

$P_{min} := -278.04\ N$ $M_{33.min} := -134089529\ N \cdot mm$ $M_{22.min} := -97506.39\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.904 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.197 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.986 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 104.485\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 112.537\ MPa$

VEH8

At 0 mm

$P_{max} := 88214.19\ N$ $M_{33.max} := 66009311.11 \cdot N \cdot mm$ $M_{22.max} := 27280.85 \cdot N \cdot mm$

$P_{min} := -236.39\ N$ $M_{33.min} := -140803867\ N \cdot mm$ $M_{22.min} := -3198979.02\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.845 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.068 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.226 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 104.062\ MPa$

At 6096 mm

$P_{max} := 88214.19\ N$ $M_{33.max} := 81132773.94 \cdot N \cdot mm$ $M_{22.max} := 1747474.17\ N \cdot mm$

$P_{min} := -236.39\ N$ $M_{33.min} := -115378295\ N \cdot mm$ $M_{22.min} := -94881.53\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.845 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(1.965 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.842 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 94.391\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 104.062\ MPa$

Stress range - Plate 80x8

Critical detail: Element 90

$A := 640\ mm^2$

$W_{el.33} := 853.33\ mm^3$

$W_{el.22} := 8533.33 \cdot mm^3$

VEH1

At 0 mm

$P_{max} := 24813.46\ N$ $\quad M_{33.max} := 475.19 \cdot N \cdot mm$ $\quad M_{22.max} := 65676.46\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -251.32\ N \cdot mm$ $\quad M_{22.min} := -7071.32\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.481 \cdot 10^4\right)\ N$ $\quad \Delta M_{33} = 726.51\ N \cdot mm$ $\quad \Delta M_{22} = \left(7.275 \cdot 10^4\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 48.148\ MPa$

At 8631.65 mm

$P_{max} := 24813.46\ N$ $\quad M_{33.max} := 651.69 \cdot N \cdot mm$ $\quad M_{22.max} := 28614.06\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -155.41\ N \cdot mm$ $\quad M_{22.min} := -7255.03\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.481 \cdot 10^4\right)\ N$ $\quad \Delta M_{33} = 807.1\ N \cdot mm$ $\quad \Delta M_{22} = \left(3.587 \cdot 10^4\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 43.92\ MPa$

Max stress range:

$\Delta\sigma_{VEH1} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 48.148\ MPa$

VEH2

At 0 mm

$P_{max} := 17790.09\ N$ $\quad M_{33.max} := 346.56 \cdot N \cdot mm$ $\quad M_{22.max} := 47519.27\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -179.14\ N \cdot mm$ $\quad M_{22.min} := -4901.53\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.779 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = 525.7\ N \cdot mm$ $\quad \Delta M_{22} = \left(5.242 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 34.556\ MPa$

At 8631.65 mm

$P_{max} := 17790.09\ N$ $\quad M_{33.max} := 455.63 \cdot N \cdot mm$ $\quad M_{22.max} := 18968.21\ N \cdot mm$

$P_{min} := 0\ N$ $\quad M_{33.min} := -129.72\ N \cdot mm$ $\quad M_{22.min} := -6423.68\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.779 \cdot 10^{4}\right)\ N$ $\quad \Delta M_{33} = 585.35\ N \cdot mm$ $\quad \Delta M_{22} = \left(2.539 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 31.459\ MPa$

Max stress range:

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 34.556\ MPa$

VEH3

At 0 mm

$P_{max} := 16852.11\ N$ $M_{33.max} := 337.02 \cdot N \cdot mm$ $M_{22.max} := 43781.81\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -168.33\ N \cdot mm$ $M_{22.min} := -4355.27\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.685 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = 505.35\ N \cdot mm$ $\Delta M_{22} = \left(4.814 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 32.565\ MPa$

At 8631.65 mm

$P_{max} := 16852.11\ N$ $M_{33.max} := 425.06 \cdot N \cdot mm$ $M_{22.max} := 20135.53\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -132.4\ N \cdot mm$ $M_{22.min} := -5450.86\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.685 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = 557.46\ N \cdot mm$ $\Delta M_{22} = \left(2.559 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 29.983\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 32.565\ MPa$

VEH4

At 0 mm

$P_{max} := 15729.26\ N$ $M_{33.max} := 340.8 \cdot N \cdot mm$ $M_{22.max} := 39465.11\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -161.8\ N \cdot mm$ $M_{22.min} := -5998.61\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.573 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = 502.6\ N \cdot mm$ $\Delta M_{22} = \left(4.546 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 30.494\ MPa$

At 8631.65 mm

$P_{max} := 15729.26\ N$ $M_{33.max} := 436.39 \cdot N \cdot mm$ $M_{22.max} := 19375.96\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -137.91\ N \cdot mm$ $M_{22.min} := -5507.3\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.573 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = 574.3\ N \cdot mm$ $\Delta M_{22} = \left(2.488 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 28.166\ MPa$

Max stress range:

$\Delta\sigma_{VEH4} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 30.494\ MPa$

VEH5

At 0 mm

$P_{max} := 36084.19\ N$

$M_{33.max} := 595.79 \cdot N \cdot mm$

$M_{22.max} := 95885.57\ N \cdot mm$

$P_{min} := 0\ N$

$M_{33.min} := -313.37\ N \cdot mm$

$M_{22.min} := -7573.21\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.608 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = 909.16\ N \cdot mm$

$\Delta M_{22} = \left(1.035 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 69.571\ MPa$

At 8631.65 mm

$P_{max} := 36084.19\ N$

$M_{33.max} := 772.77 \cdot N \cdot mm$

$M_{22.max} := 38103.44\ N \cdot mm$

$P_{min} := 0\ N$

$M_{33.min} := -211.16\ N \cdot mm$

$M_{22.min} := -8613.57\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.608 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = 983.93\ N \cdot mm$

$\Delta M_{22} = \left(4.672 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 63.009\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 69.571\ MPa$

VEH6

At 0 mm

$P_{max} := 28020.31\ N$

$M_{33.max} := 524.96 \cdot N \cdot mm$

$M_{22.max} := 74368.99\ N \cdot mm$

$P_{min} := 0\ N$

$M_{33.min} := -285.35\ N \cdot mm$

$M_{22.min} := -7573.21\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.802 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = 810.31\ N \cdot mm$

$\Delta M_{22} = \left(8.194 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 54.334\ MPa$

At 8631.65 mm

$P_{max} := 28028.31\ N$

$M_{33.max} := 721.63 \cdot N \cdot mm$

$M_{22.max} := 31256.3\ N \cdot mm$

$P_{min} := 0\ N$

$M_{33.min} := -193.86\ N \cdot mm$

$M_{22.min} := -8287.98\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.803 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = 915.49\ N \cdot mm$

$\Delta M_{22} = \left(3.954 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 49.501\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 54.334\ MPa$

VEH7

At 0 mm

$P_{max} := 28703.91\ N$ $M_{33.max} := 534.22 \cdot N \cdot mm$ $M_{22.max} := 74554.22\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -289.99\ N \cdot mm$ $M_{22.min} := -7576.89\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.87 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = 824.21\ N \cdot mm$ $\Delta M_{22} = \left(8.213 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 55.44\ MPa$

At 8631.65 mm

$P_{max} := 28703.91\ N$ $M_{33.max} := 771.63 \cdot N \cdot mm$ $M_{22.max} := 33078.53\ N \cdot mm$

$P_{min} := 0\ N$ $M_{33.min} := -199.17\ N \cdot mm$ $M_{22.min} := -7896.22\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.87 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = 970.8\ N \cdot mm$ $\Delta M_{22} = \left(4.097 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 50.789\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 55.44\ MPa$

VEH8

At 0 mm

$P_{max} := 27038.64\ N$

$M_{33.max} := 512.36 \cdot N \cdot mm$

$M_{22.max} := 71199.15 \cdot N \cdot mm$

$P_{min} := 0\ N$

$M_{33.min} := -267.54\ N \cdot mm$

$M_{22.min} := -7071.32\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.704 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = 779.9\ N \cdot mm$

$\Delta M_{22} = \left(7.827 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 52.334\ MPa$

At 8631.65 mm

$P_{max} := 27038.64\ N$

$M_{33.max} := 691.95 \cdot N \cdot mm$

$M_{22.max} := 32435.6\ N \cdot mm$

$P_{min} := 0\ N$

$M_{33.min} := -180.87\ N \cdot mm$

$M_{22.min} := -7493.35\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(2.704 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = 872.82\ N \cdot mm$

$\Delta M_{22} = \left(3.993 \cdot 10^{4}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 47.95\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 52.334\ MPa$

Stress range - Plate 220x8

Critical detail: Element 85

$A := 1760\ mm^2$

$W_{el.33} := 2346.67\ mm^3$

$W_{el.22} := 64533.33 \cdot mm^3$

VEH1

At 0 mm

$P_{max} := 53637.66\ N$ $\quad M_{33.max} := 1835.63 \cdot N \cdot mm$ $\quad M_{22.max} := 212283.84\ N \cdot mm$

$P_{min} := -1.62\ N$ $\quad M_{33.min} := -955.67\ N \cdot mm$ $\quad M_{22.min} := -444772.83\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.364 \cdot 10^4\right)\ N$ $\quad \Delta M_{33} = \left(2.791 \cdot 10^3\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(6.571 \cdot 10^5\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 41.848\ MPa$

At 7884.24 mm

$P_{max} := 53637.66\ N$ $\quad M_{33.max} := 1998.46 \cdot N \cdot mm$ $\quad M_{22.max} := 52229.65\ N \cdot mm$

$P_{min} := -1.62\ N$ $\quad M_{33.min} := -894.62\ N \cdot mm$ $\quad M_{22.min} := -995131.33\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\quad \Delta M_{33} := M_{33.max} - M_{33.min}$ $\quad \Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.364 \cdot 10^4\right)\ N$ $\quad \Delta M_{33} = \left(2.893 \cdot 10^3\right)\ N \cdot mm$ $\quad \Delta M_{22} = \left(1.047 \cdot 10^6\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 47.939\ MPa$

Max stress range:

$\Delta\sigma_{VEH1} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 47.939\ MPa$

VEH2

At 0 mm

$P_{max} := 38542.16\ N$ $M_{33.max} := 1312.37 \cdot N \cdot mm$ $M_{22.max} := 163930.86\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -647.02\ N \cdot mm$ $M_{22.min} := -306735.98\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.854 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(1.959 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.707 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 30.028\ MPa$

At 7884.24 mm

$P_{max} := 38542.16\ N$ $M_{33.max} := 1376.03 \cdot N \cdot mm$ $M_{22.max} := 51797.08\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -651.68\ N \cdot mm$ $M_{22.min} := -672090\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.854 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.028 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(7.239 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 33.981\ MPa$

Max stress range:

$\Delta\sigma_{VEH2} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 33.981\ MPa$

VEH3

At 0 mm

$P_{max} := 36544.92\ N$ $M_{33.max} := 1278.75 \cdot N \cdot mm$ $M_{22.max} := 46137.1\ N \cdot mm$

$P_{min} := -1.44\ N$ $M_{33.min} := -601.01\ N \cdot mm$ $M_{22.min} := -681543.68\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.655 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(1.88 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(7.277 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 32.842\ MPa$

At 7884.24 mm

$P_{max} := 36544.92\ N$ $M_{33.max} := 1192.78 \cdot N \cdot mm$ $M_{22.max} := 160802.4\ N \cdot mm$

$P_{min} := -1.44\ N$ $M_{33.min} := -611.35\ N \cdot mm$ $M_{22.min} := -307741.37\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(3.655 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(1.804 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.685 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 28.794\ MPa$

Max stress range:

$\Delta\sigma_{VEH3} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 32.842\ MPa$

VEH4

At 0 mm

$P_{max} := 34366.92\ N$ $M_{33.max} := 1179.11 \cdot N \cdot mm$ $M_{22.max} := 159053.14\ N \cdot mm$

$P_{min} := -1.92\ N$ $M_{33.min} := -597.43\ N \cdot mm$ $M_{22.min} := -283873.35\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = (3.437 \cdot 10^4)\ N$ $\Delta M_{33} = (1.777 \cdot 10^3)\ N \cdot mm$ $\Delta M_{22} = (4.429 \cdot 10^5)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 27.148\ MPa$

At 7884.24 mm

$P_{max} := 34366.92\ N$ $M_{33.max} := 1344.04 \cdot N \cdot mm$ $M_{22.max} := 39135.57\ N \cdot mm$

$P_{min} := -1.23\ N$ $M_{33.min} := -546.75\ N \cdot mm$ $M_{22.min} := -633675.48\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = (3.437 \cdot 10^4)\ N$ $\Delta M_{33} = (1.891 \cdot 10^3)\ N \cdot mm$ $\Delta M_{22} = (6.728 \cdot 10^5)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 30.759\ MPa$

Max stress range:

$\Delta\sigma_{VEH4} := \max(\Delta\sigma_1, \Delta\sigma_2) = 30.759\ MPa$

VEH5

At 0 mm

$P_{max} := 77405.35\ N$ $M_{33.max} := 2048.71 \cdot N \cdot mm$ $M_{22.max} := 251911.25\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -1059.45\ N \cdot mm$ $M_{22.min} := -563015.65\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.741 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(3.108 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(8.149 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 57.934\ MPa$

At 7884.24 mm

$P_{max} := 77405.35\ N$ $M_{33.max} := 2266.21 \cdot N \cdot mm$ $M_{22.max} := 52720.57\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -1022.58\ N \cdot mm$ $M_{22.min} := -1363070.9\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.741 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(3.289 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.416 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 67.322\ MPa$

Max stress range:

$\Delta\sigma_{VEH5} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 67.322\ MPa$

VEH6

At 0 mm

$P_{max} := 60256.31\ N$ $M_{33.max} := 1984.99 \cdot N \cdot mm$ $M_{22.max} := 224986.73\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -987.14\ N \cdot mm$ $M_{22.min} := -471715.33\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.026 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.972 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(6.967 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 46.3\ MPa$

At 7884.24 mm

$P_{max} := 60256.31\ N$ $M_{33.max} := 2192.56 \cdot N \cdot mm$ $M_{22.max} := 52321.28\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -915.5\ N \cdot mm$ $M_{22.min} := -1117205.6\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.026 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(3.108 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.17 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 53.685\ MPa$

Max stress range:

$\Delta\sigma_{VEH6} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 53.685\ MPa$

VEH7

At 0 mm

$P_{max} := 62439.21\ N$ $M_{33.max} := 2063.73 \cdot N \cdot mm$ $M_{22.max} := 231024.56\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -1009.25\ N \cdot mm$ $M_{22.min} := -510485.37\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.244 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(3.073 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(7.415 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 48.278\ MPa$

At 7884.24 mm

$P_{max} := 62439.21\ N$ $M_{33.max} := 2331.87 \cdot N \cdot mm$ $M_{22.max} := 51797.08\ N \cdot mm$

$P_{min} := -1.62\ N$ $M_{33.min} := -941.7\ N \cdot mm$ $M_{22.min} := -1153025.73\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(6.244 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(3.274 \cdot 10^{3}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.205 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 55.543\ MPa$

Max stress range:

$\Delta\sigma_{VEH7} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 55.543\ MPa$

VEH8

At 0 mm

$P_{max} := 57938.28\ N$

$M_{33.max} := 1873.39 \cdot N \cdot mm$

$M_{22.max} := 213496.93 \cdot N \cdot mm$

$P_{min} := -1.62\ N$

$M_{33.min} := -976.82\ N \cdot mm$

$M_{22.min} := -487928.1\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.794 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = \left(2.85 \cdot 10^{3}\right)\ N \cdot mm$

$\Delta M_{22} = \left(7.014 \cdot 10^{5}\right)\ N \cdot mm$

$$\Delta\sigma_1 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_1 = 45.004\ MPa$

At 7884.24 mm

$P_{max} := 57938.28\ N$

$M_{33.max} := 2119.72 \cdot N \cdot mm$

$M_{22.max} := 527020.57\ N \cdot mm$

$P_{min} := -1.62\ N$

$M_{33.min} := -900.3\ N \cdot mm$

$M_{22.min} := -1127119.93\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.794 \cdot 10^{4}\right)\ N$

$\Delta M_{33} = \left(3.02 \cdot 10^{3}\right)\ N \cdot mm$

$\Delta M_{22} = \left(1.654 \cdot 10^{6}\right)\ N \cdot mm$

$$\Delta\sigma_2 := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma_2 = 59.84\ MPa$

Max stress range:

$\Delta\sigma_{VEH8} := \max\left(\Delta\sigma_1, \Delta\sigma_2\right) = 59.84\ MPa$

Stress range - UB686/254/125

Critical detail: Element 121

$A := 15.9 \cdot 10^3\ mm^2$

$W_{el.33} := 3481 \cdot 10^3\ mm^3$

$W_{el.22} := 346 \cdot 10^3 \cdot mm^3$

VEH1

At 1600.3 mm

$P_{max} := 0\ N$

$M_{33.max} := 404316352 \cdot N \cdot mm$

$M_{22.max} := 28224335.21\ N \cdot mm$

$P_{min} := -73945.39\ N$

$M_{33.min} := -32399610\ N \cdot mm$

$M_{22.min} := -58030.24\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.395 \cdot 10^4\right)\ N$

$\Delta M_{33} = \left(4.367 \cdot 10^8\right)\ N \cdot mm$

$\Delta M_{22} = \left(2.828 \cdot 10^7\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 211.849\ MPa$

VEH2

At 1600.3 mm

$P_{max} := 0\ N$

$M_{33.max} := 286627376.7 \cdot N \cdot mm$

$M_{22.max} := 20198028.52\ N \cdot mm$

$P_{min} := -54154.93\ N$

$M_{33.min} := -24521043.5\ N \cdot mm$

$M_{22.min} := -58030.24\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$

$\Delta M_{33} := M_{33.max} - M_{33.min}$

$\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.415 \cdot 10^4\right)\ N$

$\Delta M_{33} = \left(3.111 \cdot 10^8\right)\ N \cdot mm$

$\Delta M_{22} = \left(2.026 \cdot 10^7\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 151.334\ MPa$

VEH3

At 1600.3 mm

$P_{max} := 0\ N$ $M_{33.max} := 268722769.7 \cdot N \cdot mm$ $M_{22.max} := 19697330.91\ N \cdot mm$

$P_{min} := -51612.07\ N$ $M_{33.min} := -22449439\ N \cdot mm$ $M_{22.min} := -51582.43\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.161 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(2.912 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.975 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 143.97\ MPa$

VEH4

At 1600.3 mm

$P_{max} := 0\ N$ $M_{33.max} := 283154678.1 \cdot N \cdot mm$ $M_{22.max} := 17607033.21\ N \cdot mm$

$P_{min} := -50084.41\ N$ $M_{33.min} := -21681304.9\ N \cdot mm$ $M_{22.min} := -43845.07\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(5.008 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(3.048 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(1.765 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 141.735\ MPa$

VEH5

At 1600.3 mm

$P_{max} := 0\ N$ $M_{33.max} := 475678257 \cdot N \cdot mm$ $M_{22.max} := 43254600.28\ N \cdot mm$

$P_{min} := -105512.24\ N$ $M_{33.min} := -36836158\ N \cdot mm$ $M_{22.min} := -58030.24\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(1.055 \cdot 10^{5}\right)\ N$ $\Delta M_{33} = \left(5.125 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(4.331 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 279.049\ MPa$

VEH6

At 1600.3 mm

$P_{max} := 0\ N$ $M_{33.max} := 439006353 \cdot N \cdot mm$ $M_{22.max} := 33272556.76\ N \cdot mm$

$P_{min} := -83008.15\ N$ $M_{33.min} := -33847895\ N \cdot mm$ $M_{22.min} := -58030.24\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ $\Delta M_{33} := M_{33.max} - M_{33.min}$ $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.301 \cdot 10^{4}\right)\ N$ $\Delta M_{33} = \left(4.729 \cdot 10^{8}\right)\ N \cdot mm$ $\Delta M_{22} = \left(3.333 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 237.39\ MPa$

VEH7

At 1600.3 mm

$P_{max} := 0\ N$ | $M_{33.max} := 489039410 \cdot N \cdot mm$ | $M_{22.max} := 33612186.33\ N \cdot mm$

$P_{min} := -87439.55\ N$ | $M_{33.min} := -33878569\ N \cdot mm$ | $M_{22.min} := -58030.24\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ | $\Delta M_{33} := M_{33.max} - M_{33.min}$ | $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(8.744 \cdot 10^{4}\right)\ N$ | $\Delta M_{33} = \left(5.229 \cdot 10^{8}\right)\ N \cdot mm$ | $\Delta M_{22} = \left(3.367 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 253.033\ MPa$

VEH8

At 1600.3 mm

$P_{max} := 0\ N$ | $M_{33.max} := 430608195 \cdot N \cdot mm$ | $M_{22.max} := 33245558.24 \cdot N \cdot mm$

$P_{min} := -78293.33\ N$ | $M_{33.min} := -32930173\ N \cdot mm$ | $M_{22.min} := -58030.24\ N \cdot mm$

$\Delta P := P_{max} - P_{min}$ | $\Delta M_{33} := M_{33.max} - M_{33.min}$ | $\Delta M_{22} := M_{22.max} - M_{22.min}$

$\Delta P = \left(7.829 \cdot 10^{4}\right)\ N$ | $\Delta M_{33} = \left(4.635 \cdot 10^{8}\right)\ N \cdot mm$ | $\Delta M_{22} = \left(3.33 \cdot 10^{7}\right)\ N \cdot mm$

$$\Delta\sigma := \frac{\Delta P}{A} + \frac{\Delta M_{33}}{W_{el.33}} + \frac{\Delta M_{22}}{W_{el.22}}$$

$\Delta\sigma = 234.34\ MPa$

Appendix D - Fatigue life estimation of uncorroded members

Fatigue life of uncorroded member - HEA220

Stress evaluation

Stress range	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 105.24\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 75.967\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 69.118\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 66.585\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 133.819\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 113.642\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 121.109\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 108.661\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$ $\Delta\sigma_{R.VEH1} = 105.24\ MPa$

$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$ $\Delta\sigma_{R.VEH2} = 75.967\ MPa$

$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$ $\Delta\sigma_{R.VEH3} = 69.118\ MPa$

$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$ $\Delta\sigma_{R.VEH4} = 66.585\ MPa$

$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$ $\Delta\sigma_{R.VEH5} = 133.819\ MPa$

$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$ $\Delta\sigma_{R.VEH6} = 113.642\ MPa$

$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$ $\Delta\sigma_{R.VEH7} = 121.109\ MPa$

$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$ $\Delta\sigma_{R.VEH8} = 108.661\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$

$\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$

$\Delta\sigma_L = 36.415\ MPa$

Number of cycles without fatigue damage

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_D$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH1}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH1} = 1.251 \cdot 10^6$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_D$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH2}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH2} = 3.326 \cdot 10^6$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_D$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH3}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH3} = 4.416 \cdot 10^6$

$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_D$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH4}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH4} = 4.939 \cdot 10^6$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH5} = 6.084 \cdot 10^5$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_D$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH6}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH6} = 9.934 \cdot 10^5$$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_D$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH7}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH7} = 8.208 \cdot 10^5$$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_D$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH8}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH8} = 1.136 \cdot 10^6$$

3) Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 0.004$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} = 0.001$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} = 4.133 \cdot 10^{-4}$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} = 5.912 \cdot 10^{-4}$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 0.004$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 0.004$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 0.004$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 0.002$$

Total damage of uncorroded members

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.02$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 50.211$ years

Fatigue life of uncorroded member - HEA240

Stress evaluation

Stress range	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 111.41\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 81.774\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 75.904\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 67.74\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 157.883\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 123.677\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 40.428\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 117.521\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$ $\Delta\sigma_{R.VEH1} = 111.41\ MPa$

$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$ $\Delta\sigma_{R.VEH2} = 81.774\ MPa$

$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$ $\Delta\sigma_{R.VEH3} = 75.904\ MPa$

$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$ $\Delta\sigma_{R.VEH4} = 67.74\ MPa$

$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$ $\Delta\sigma_{R.VEH5} = 157.883\ MPa$

$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$ $\Delta\sigma_{R.VEH6} = 123.677\ MPa$

$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$ $\Delta\sigma_{R.VEH7} = 40.428\ MPa$

$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$ $\Delta\sigma_{R.VEH8} = 117.521\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$

$\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$

$\Delta\sigma_L = 36.415\ MPa$

Number of cycles without fatigue damage

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_D$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH1}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH1} = 1.054 \cdot 10^6$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_D$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH2}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH2} = 2.666 \cdot 10^6$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_D$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH3}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH3} = 3.334 \cdot 10^6$

$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_D$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH4}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH4} = 4.691 \cdot 10^6$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH5} = 3.705 \cdot 10^5$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_D$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH6}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH6} = 7.707 \cdot 10^5$$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_D$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH7}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH7} = 2.207 \cdot 10^7$$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_D$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH8}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH8} = 8.983 \cdot 10^5$$

Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $\quad$ $D_{VEH1} = 0.004$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $\quad$ $D_{VEH2} = 0.002$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $\quad$ $D_{VEH3} = 5.474 \cdot 10^{-4}$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $\quad$ $D_{VEH4} = 6.225 \cdot 10^{-4}$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $\quad$ $D_{VEH5} = 0.007$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $\quad$ $D_{VEH6} = 0.006$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $\quad$ $D_{VEH7} = 1.323 \cdot 10^{-4}$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $\quad$ $D_{VEH8} = 0.002$

Total damage of uncorroded members

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.022$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 45.214$ years

Fatigue life of uncorroded member - HEA260

Stress evaluation

Stress range	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 112.17\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 75.704\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 76.85\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 70.955\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 160.394\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 125.986\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 128.074\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 122.539\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$	$\Delta\sigma_{R.VEH1} = 112.17\ MPa$
$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$	$\Delta\sigma_{R.VEH2} = 75.704\ MPa$
$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$	$\Delta\sigma_{R.VEH3} = 76.85\ MPa$
$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$	$\Delta\sigma_{R.VEH4} = 70.955\ MPa$
$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$	$\Delta\sigma_{R.VEH5} = 160.394\ MPa$
$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$	$\Delta\sigma_{R.VEH6} = 125.986\ MPa$
$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$	$\Delta\sigma_{R.VEH7} = 128.074\ MPa$
$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$	$\Delta\sigma_{R.VEH8} = 122.539\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \ \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\quad \Delta\sigma_D = 66.33 \ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\quad \Delta\sigma_L = 36.415 \ MPa$

Number of cycles without fatigue damage

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_D$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH1}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH1} = 1.033 \cdot 10^6$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_D$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH2}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH2} = 3.36 \cdot 10^6$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_D$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH3}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH3} = 3.212 \cdot 10^6$

$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_D$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH4}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH4} = 4.081 \cdot 10^6$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH5} = 3.533 \cdot 10^5$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_D$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH6}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH6} = 7.291 \cdot 10^5$$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_D$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH7}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH7} = 6.94 \cdot 10^5$$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_D$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH8}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH8} = 7.924 \cdot 10^5$$

Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $\quad D_{VEH1} = 0.004$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $\quad D_{VEH2} = 0.001$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $\quad D_{VEH3} = 5.681 \cdot 10^{-4}$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $\quad D_{VEH4} = 7.154 \cdot 10^{-4}$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $\quad D_{VEH5} = 0.007$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $\quad D_{VEH6} = 0.006$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $\quad D_{VEH7} = 0.004$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $\quad D_{VEH8} = 0.003$

Total damage of uncorroded members

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.027$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 36.987$ years

Fatigue life of uncorroded member - HEA550

Stress evaluation

Stress range	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 80.038\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 60.913\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 58.026\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 50.948\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 109.323\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 93.606\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 91.97\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 85.029\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$	$\Delta\sigma_{R.VEH1} = 80.038\ MPa$
$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$	$\Delta\sigma_{R.VEH2} = 60.913\ MPa$
$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$	$\Delta\sigma_{R.VEH3} = 58.026\ MPa$
$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$	$\Delta\sigma_{R.VEH4} = 50.948\ MPa$
$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$	$\Delta\sigma_{R.VEH5} = 109.323\ MPa$
$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$	$\Delta\sigma_{R.VEH6} = 93.606\ MPa$
$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$	$\Delta\sigma_{R.VEH7} = 91.97\ MPa$
$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$	$\Delta\sigma_{R.VEH8} = 85.029\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$

$\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$

$\Delta\sigma_L = 36.415\ MPa$

Number of cycles without fatigue damage

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_D$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH1}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH1} = 2.844 \cdot 10^6$$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH2} \geq \Delta\sigma_L$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH2}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH2} = 7.655 \cdot 10^6$$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH3} \geq \Delta\sigma_L$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH3}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH3} = 9.759 \cdot 10^6$$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH4} \geq \Delta\sigma_L$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH4}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH4} = 1.87 \cdot 10^7$$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH5} = 1.116 \cdot 10^6$$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_D$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH6}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH6} = 1.778 \cdot 10^6$$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_D$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH7}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH7} = 1.874 \cdot 10^6$$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_D$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH8}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH8} = 2.372 \cdot 10^6$$

Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 0.002$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} = 5.721 \cdot 10^{-4}$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} = 1.87 \cdot 10^{-4}$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} = 1.561 \cdot 10^{-4}$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 0.002$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 0.002$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 0.002$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 9.234 \cdot 10^{-4}$$

Total damage of uncorroded members

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.01$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 103.193$ years

Fatigue life of uncorroded member - HEB260

Stress evaluation

Stress range	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 82.571\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 60.166\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 56.04\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 51.294\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 117.209\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 90.088\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 94.859\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 88.719\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$ $\Delta\sigma_{R.VEH1} = 82.571\ MPa$

$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$ $\Delta\sigma_{R.VEH2} = 60.166\ MPa$

$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$ $\Delta\sigma_{R.VEH3} = 56.04\ MPa$

$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$ $\Delta\sigma_{R.VEH4} = 51.294\ MPa$

$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$ $\Delta\sigma_{R.VEH5} = 117.209\ MPa$

$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$ $\Delta\sigma_{R.VEH6} = 90.088\ MPa$

$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$ $\Delta\sigma_{R.VEH7} = 94.859\ MPa$

$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$ $\Delta\sigma_{R.VEH8} = 88.719\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$

$\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$

$\Delta\sigma_L = 36.415\ MPa$

Number of cycles without fatigue damage

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_D$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH1}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH1} = 2.59 \cdot 10^6$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH2} \geq \Delta\sigma_L$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH2}}\right)^5 \cdot 5 \cdot 10^6$$

$N_{R.VEH2} = 8.143 \cdot 10^6$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH3} \geq \Delta\sigma_L$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH3}}\right)^5 \cdot 5 \cdot 10^6$$

$N_{R.VEH3} = 1.162 \cdot 10^7$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH4} \geq \Delta\sigma_L$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH4}}\right)^5 \cdot 5 \cdot 10^6$$

$N_{R.VEH4} = 1.808 \cdot 10^7$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH5} = 9.055 \cdot 10^5$

$$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_D \qquad N_{R.VEH6} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH6}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH6} = 1.994 \cdot 10^6$$

$$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_D \qquad N_{R.VEH7} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH7}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH7} = 1.708 \cdot 10^6$$

$$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_D \qquad N_{R.VEH8} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH8}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH8} = 2.088 \cdot 10^6$$

Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 0.002$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} = 5.379 \cdot 10^{-4}$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} = 1.571 \cdot 10^{-4}$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} = 1.615 \cdot 10^{-4}$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 0.003$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 0.002$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 0.002$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 0.001$$

Total damage of uncorroded member

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.01$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 96.859$ years

Fatigue life of uncorroded member - IPE550

Stress evaluation

Stress range	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 99.575\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 78.687\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 71.449\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 65.722\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 131.257\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 112.763\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 112.537\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 104.062\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$ $\Delta\sigma_{R.VEH1} = 99.575\ MPa$

$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$ $\Delta\sigma_{R.VEH2} = 78.687\ MPa$

$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$ $\Delta\sigma_{R.VEH3} = 71.449\ MPa$

$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$ $\Delta\sigma_{R.VEH4} = 65.722\ MPa$

$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$ $\Delta\sigma_{R.VEH5} = 131.257\ MPa$

$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$ $\Delta\sigma_{R.VEH6} = 112.763\ MPa$

$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$ $\Delta\sigma_{R.VEH7} = 112.537\ MPa$

$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$ $\Delta\sigma_{R.VEH8} = 104.062\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\quad \Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\quad \Delta\sigma_L = 36.415\ MPa$

<u>Number of cycles without fatigue damage</u>

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_D$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH1}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH1} = 1.477 \cdot 10^6$$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_D$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH2}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH2} = 2.993 \cdot 10^6$$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_D$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH3}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH3} = 1.6 \cdot 10^6$$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH4} \geq \Delta\sigma_L$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH4}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH4} = 5.236 \cdot 10^6$$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH5} = 6.447 \cdot 10^5$$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_D$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH6}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH6} = 1.017 \cdot 10^6$$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_D$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH7}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH7} = 1.023 \cdot 10^6$$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_D$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH8}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH8} = 1.294 \cdot 10^6$$

Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $\qquad D_{VEH1} = 0.003$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $\qquad D_{VEH2} = 0.001$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $\qquad D_{VEH3} = 0.001$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $\qquad D_{VEH4} = 5.577 \cdot 10^{-4}$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $\qquad D_{VEH5} = 0.004$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $\qquad D_{VEH6} = 0.004$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $\qquad D_{VEH7} = 0.003$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $\qquad D_{VEH8} = 0.002$

Total damage of uncorroded member

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.019$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 52.784$ years

Fatigue life - Plate 80x8

Stress evaluation - Element 90

Stress range	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 48.148\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 34.556\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 32.565\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 30.494\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 69.571\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 54.334\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 55.44\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 52.334\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$ $\Delta\sigma_{R.VEH1} = 48.148\ MPa$

$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$ $\Delta\sigma_{R.VEH2} = 34.556\ MPa$

$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$ $\Delta\sigma_{R.VEH3} = 32.565\ MPa$

$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$ $\Delta\sigma_{R.VEH4} = 30.494\ MPa$

$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$ $\Delta\sigma_{R.VEH5} = 69.571\ MPa$

$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$ $\Delta\sigma_{R.VEH6} = 54.334\ MPa$

$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$ $\Delta\sigma_{R.VEH7} = 55.44\ MPa$

$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$ $\Delta\sigma_{R.VEH8} = 52.334\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$$\Delta\sigma_C := 90\ \frac{N}{mm^2}$$

$$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C \qquad \Delta\sigma_D = 66.33\ MPa$$

$$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D \qquad \Delta\sigma_L = 36.415\ MPa$$

Number of cycles without fatigue damage

$$\Delta\sigma_D \ge \Delta\sigma_{R.VEH1} \ge \Delta\sigma_L \qquad N_{R.VEH1} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH1}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH1} = 2.481 \cdot 10^7$$

$$\Delta\sigma_{R.VEH2} \le \Delta\sigma_L \qquad N_{R.VEH2} := \infty$$

$$\Delta\sigma_{R.VEH3} \le \Delta\sigma_L \qquad N_{R.VEH3} := \infty$$

$$\Delta\sigma_{R.VEH4} \le \Delta\sigma_L \qquad N_{R.VEH4} := \infty$$

$$\Delta\sigma_{R.VEH5} \ge \Delta\sigma_D \qquad N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH5} = 4.33 \cdot 10^6$$

$$\Delta\sigma_D \ge \Delta\sigma_{R.VEH6} \ge \Delta\sigma_L \qquad N_{R.VEH6} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH6}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH6} = 1.356 \cdot 10^7$$

$$\Delta\sigma_D \ge \Delta\sigma_{R.VEH7} \ge \Delta\sigma_L \qquad N_{R.VEH7} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH7}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH7} = 1.226 \cdot 10^7$$

$$\Delta\sigma_D \ge \Delta\sigma_{R.VEH8} \ge \Delta\sigma_L \qquad N_{R.VEH8} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH8}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH8} = 1.635 \cdot 10^7$$

Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 1.765 \cdot 10^{-4}$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} := \lim_{x \to \infty} \left(\frac{n_{VEH2}}{x}\right) \to 0$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} := \lim_{x \to \infty} \left(\frac{n_{VEH3}}{x}\right) \to 0$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} := \lim_{x \to \infty} \left(\frac{n_{VEH4}}{x}\right) \to 0$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 5.901 \cdot 10^{-4}$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 3.231 \cdot 10^{-4}$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 2.382 \cdot 10^{-4}$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 1.339 \cdot 10^{-4}$$

Total damage

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.001$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 684.064$ years

Fatigue life - Plate 220x8

Stress evaluation - Element 85

Stress range | Number of cycles of each stress range

$\Delta\sigma_{VEH1} := 47.939\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 33.981\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 32.842\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 30.759\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 67.322\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 53.685\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 55.543\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 59.84\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$ $\Delta\sigma_{R.VEH1} = 47.939\ MPa$

$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$ $\Delta\sigma_{R.VEH2} = 33.981\ MPa$

$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$ $\Delta\sigma_{R.VEH3} = 32.842\ MPa$

$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$ $\Delta\sigma_{R.VEH4} = 30.759\ MPa$

$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$ $\Delta\sigma_{R.VEH5} = 67.322\ MPa$

$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$ $\Delta\sigma_{R.VEH6} = 53.685\ MPa$

$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$ $\Delta\sigma_{R.VEH7} = 55.543\ MPa$

$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$ $\Delta\sigma_{R.VEH8} = 59.84\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\Delta\sigma_L = 36.415\ MPa$

<u>Number of cycles without fatigue damage</u>

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH1} \geq \Delta\sigma_L$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH1}}\right)^5 \cdot 5 \cdot 10^6$$

$N_{R.VEH1} = 2.536 \cdot 10^7$

$\Delta\sigma_{R.VEH2} \leq \Delta\sigma_L$ $N_{R.VEH2} := \infty$

$\Delta\sigma_{R.VEH3} \leq \Delta\sigma_L$ $N_{R.VEH3} := \infty$

$\Delta\sigma_{R.VEH4} \leq \Delta\sigma_L$ $N_{R.VEH4} := \infty$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$N_{R.VEH5} = 4.778 \cdot 10^6$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH6} \geq \Delta\sigma_L$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH6}}\right)^5 \cdot 5 \cdot 10^6$$

$N_{R.VEH6} = 1.44 \cdot 10^7$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH7} \geq \Delta\sigma_L$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH7}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH7} = 1.214 \cdot 10^7$$

$\Delta\sigma_D \geq \Delta\sigma_{R.VEH8} \geq \Delta\sigma_L$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_D}{\Delta\sigma_{R.VEH8}}\right)^5 \cdot 5 \cdot 10^6$$

$$N_{R.VEH8} = 8.367 \cdot 10^6$$

Fatigue life estimation/Damage calculation

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 1.727 \cdot 10^{-4}$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} := \lim_{x \to \infty} \left(\frac{n_{VEH2}}{x}\right) \to 0$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} := \lim_{x \to \infty} \left(\frac{n_{VEH3}}{x}\right) \to 0$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} := \lim_{x \to \infty} \left(\frac{n_{VEH4}}{x}\right) \to 0$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 5.347 \cdot 10^{-4}$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 3.042 \cdot 10^{-4}$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 2.404 \cdot 10^{-4}$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 2.617 \cdot 10^{-4}$$

Total damage

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.002$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 660.561$ years

Fatigue life - UB686/254/125

Stress evaluation - Element 121

Stress ranges	Number of cycles of each stress range	
$\Delta\sigma_{VEH1} := 211.849\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{VEH2} := 151.334\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{VEH3} := 143.97\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{VEH4} := 141.735\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{VEH5} := 279.049\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{VEH6} := 237.39\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{VEH7} := 253.033\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{VEH8} := 234.34\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

Selection of fatigue curve

Partial factor of fatigue strength $\gamma_{Mf} := 1.0$

Partial factor of fatigue load $\gamma_{Ff} := 1.0$

$\Delta\sigma_{R.VEH1} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH1}$ $\Delta\sigma_{R.VEH1} = 211.849\ MPa$

$\Delta\sigma_{R.VEH2} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH2}$ $\Delta\sigma_{R.VEH2} = 151.334\ MPa$

$\Delta\sigma_{R.VEH3} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH3}$ $\Delta\sigma_{R.VEH3} = 143.97\ MPa$

$\Delta\sigma_{R.VEH4} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH4}$ $\Delta\sigma_{R.VEH4} = 141.735\ MPa$

$\Delta\sigma_{R.VEH5} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH5}$ $\Delta\sigma_{R.VEH5} = 279.049\ MPa$

$\Delta\sigma_{R.VEH6} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH6}$ $\Delta\sigma_{R.VEH6} = 237.39\ MPa$

$\Delta\sigma_{R.VEH7} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH7}$ $\Delta\sigma_{R.VEH7} = 253.033\ MPa$

$\Delta\sigma_{R.VEH8} := \gamma_{Mf} \cdot \gamma_{Ff} \cdot \Delta\sigma_{VEH8}$ $\Delta\sigma_{R.VEH8} = 234.34\ MPa$

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 160 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\Delta\sigma_D = 117.92\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\Delta\sigma_L = 64.738\ MPa$

Number of cycles without fatigue damage

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_D$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH1}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH1} = 8.616 \cdot 10^5$$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_D$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH2}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH2} = 2.364 \cdot 10^6$$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_D$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH3}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH3} = 2.745 \cdot 10^6$$

$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_D$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH4}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH4} = 2.877 \cdot 10^6$$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_D$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH5}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH5} = 3.77 \cdot 10^5$$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_D$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH6}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH6} = 6.124 \cdot 10^5$$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_D$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH7}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH7} = 5.057 \cdot 10^5$$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_D$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_C}{\Delta\sigma_{R.VEH8}}\right)^3 \cdot 2 \cdot 10^6$$

$$N_{R.VEH8} = 6.366 \cdot 10^5$$

Fatigue life estimation/Damage calculation

<u>Damage accumulation using "Miner's Rule"</u>

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $\quad D_{VEH1} = 0.005$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $\quad D_{VEH2} = 0.002$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $\quad D_{VEH3} = 6.648 \cdot 10^{-4}$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $\quad D_{VEH4} = 0.001$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $\quad D_{VEH5} = 0.007$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $\quad D_{VEH6} = 0.007$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $\quad D_{VEH7} = 0.006$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $\quad D_{VEH8} = 0.003$

Total damage

$$D_{total} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{total} = 0.032$ < 1.0 OK

Fatigue life

$\frac{1}{D_{total}} = 31.485$ years

Appendix E - Fatigue life estimation of corroded members

Fatigue life of corroded member - HEA220

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9 $\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\Delta\sigma_L = 36.415\ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966\ MPa$ $\Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964\ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113 \qquad \hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure: Number of cycles of each stress range

$\Delta\sigma_{R.VEH1} := 105.24\ MPa$ $n_{VEH1} := 12 \cdot 365$ $n_{VEH1} = 4380$

$\Delta\sigma_{R.VEH2} := 75.967\ MPa$ $n_{VEH2} := 12 \cdot 365$ $n_{VEH2} = 4380$

$\Delta\sigma_{R.VEH3} := 69.118\ MPa$ $n_{VEH3} := 5 \cdot 365$ $n_{VEH3} = 1825$

$\Delta\sigma_{R.VEH4} := 66.585\ MPa$ $n_{VEH4} := 8 \cdot 365$ $n_{VEH4} = 2920$

$\Delta\sigma_{R.VEH5} := 133.819\ MPa$ $n_{VEH5} := 7 \cdot 365$ $n_{VEH5} = 2555$

$\Delta\sigma_{R.VEH6} := 113.642\ MPa$ $n_{VEH6} := 12 \cdot 365$ $n_{VEH6} = 4380$

$\Delta\sigma_{R.VEH7} := 121.109\ MPa$ $n_{VEH7} := 8 \cdot 365$ $n_{VEH7} = 2920$

$\Delta\sigma_{R.VEH8} := 108.661\ MPa$ $n_{VEH8} := 6 \cdot 365$ $n_{VEH8} = 2190$

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH1} = 3.7 \cdot 10^{5}$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH2} = 7.687 \cdot 10^{5}$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH3} = 9.502 \cdot 10^{5}$

$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH4} = 1.033 \cdot 10^{6}$

$$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH5} = 2.159 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH6} = 3.115 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH7} = 2.7 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH8} = 3.444 \cdot 10^{5}$$

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 0.012$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} = 0.006$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} = 0.002$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} = 0.003$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 0.012$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 0.014$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 0.011$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 0.006$$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.065$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.02$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{\left(1 - 10 \cdot D_i\right)}{D_{i.cor}} + 10 \right) = 22.242 \text{ years}$$

Fatigue life of corroded member - HEA240

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$

$\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$

$\Delta\sigma_L = 36.415\ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966\ MPa$

$\Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964\ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113$$

$$\hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:

Number of cycles of each stress range

$\Delta\sigma_{R.VEH1} := 111.41\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{R.VEH2} := 81.774\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{R.VEH3} := 75.904\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{R.VEH4} := 67.74\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{R.VEH5} := 157.883\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{R.VEH6} := 123.677\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{R.VEH7} := 40.428\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{R.VEH8} := 117.521\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

$$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH1} = 3.257 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH2} = 6.516 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH3} = 7.701 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH4} = 9.941 \cdot 10^{5}$$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH5} = 1.49 \cdot 10^{5}$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH6} = 2.576 \cdot 10^{5}$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH7} = 3.164 \cdot 10^{6}$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH8} = 2.889 \cdot 10^{5}$

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $D_{VEH1} = 0.013$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $D_{VEH2} = 0.007$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $D_{VEH3} = 0.002$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $D_{VEH4} = 0.003$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $D_{VEH5} = 0.017$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $D_{VEH6} = 0.017$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $D_{VEH7} = 9.229 \cdot 10^{-4}$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $D_{VEH8} = 0.008$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.068$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.022$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{(1 - 10 \cdot D_i)}{D_{i.cor}} + 10\right) = 21.448 \text{ years}$$

Fatigue life of corroded member - HEA260

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \ \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\quad \Delta\sigma_D = 66.33 \ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\quad \Delta\sigma_L = 36.415 \ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966 \ MPa$ $\quad \Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964 \ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113 \qquad \hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:	Number of cycles of each stress range	
$\Delta\sigma_{R.VEH1} := 112.7 \ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{R.VEH2} := 75.704 \ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{R.VEH3} := 76.85 \ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{R.VEH4} := 70.955 \ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{R.VEH5} := 160.394 \ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{R.VEH6} := 125.986 \ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{R.VEH7} := 128.074 \ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{R.VEH8} := 122.539 \ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH1} = 3.174 \cdot 10^5$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH2} = 7.747 \cdot 10^5$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH3} = 7.49 \cdot 10^5$

$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH4} = 8.959 \cdot 10^5$

$$\Delta\sigma_{R.VEH5} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH5} = 1.438 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH6} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH6} = 2.472 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH7} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH7} = 2.382 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH8} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH8} = 2.63 \cdot 10^{5}$$

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \dfrac{n_{VEH1}}{N_{R.VEH1}}$ $\qquad D_{VEH1} = 0.014$

$D_{VEH2} := \dfrac{n_{VEH2}}{N_{R.VEH2}}$ $\qquad D_{VEH2} = 0.006$

$D_{VEH3} := \dfrac{n_{VEH3}}{N_{R.VEH3}}$ $\qquad D_{VEH3} = 0.002$

$D_{VEH4} := \dfrac{n_{VEH4}}{N_{R.VEH4}}$ $\qquad D_{VEH4} = 0.003$

$D_{VEH5} := \dfrac{n_{VEH5}}{N_{R.VEH5}}$ $\qquad D_{VEH5} = 0.018$

$D_{VEH6} := \dfrac{n_{VEH6}}{N_{R.VEH6}}$ $\qquad D_{VEH6} = 0.018$

$D_{VEH7} := \dfrac{n_{VEH7}}{N_{R.VEH7}}$ $\qquad D_{VEH7} = 0.012$

$D_{VEH8} := \dfrac{n_{VEH8}}{N_{R.VEH8}}$ $\qquad D_{VEH8} = 0.008$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.081$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.027$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{(1 - 10 \cdot D_i)}{D_{i.cor}} + 10 \right) = 18.988 \text{ years}$$

Fatigue life of corroded member - HEA550

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \, \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\quad \Delta\sigma_D = 66.33 \, MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\quad \Delta\sigma_L = 36.415 \, MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966 \, MPa$ $\quad \Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964 \, MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113 \qquad \hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:	Number of cycles of each stress range	
$\Delta\sigma_{R.VEH1} := 80.038 \, MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{R.VEH2} := 60.913 \, MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{R.VEH3} := 58.026 \, MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{R.VEH4} := 50.948 \, MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{R.VEH5} := 109.323 \, MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{R.VEH6} := 93.606 \, MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{R.VEH7} := 91.97 \, MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{R.VEH8} := 85.029 \, MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

$$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH1} = 6.838 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH2} = 1.262 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH3} = 1.407 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH4} = 1.883 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH5} = 3.398 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH6} = 4.813 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH7} = 5.007 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH8} = 5.97 \cdot 10^{5}$$

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 0.006$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} = 0.003$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} = 0.001$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} = 0.002$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 0.008$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 0.009$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 0.006$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 0.004$$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.039$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.01$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{\left(1 - 10 \cdot D_i\right)}{D_{i.cor}} + 10\right) = 33.168 \text{ years}$$

Fatigue life of corroded member - HEB260

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\qquad \Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\qquad \Delta\sigma_L = 36.415\ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966\ MPa$

$\Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964\ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113$$

$$\hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:	Number of cycles of each stress range	
$\Delta\sigma_{R.VEH1} := 82.571\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{R.VEH2} := 60.166\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{R.VEH3} := 56.04\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{R.VEH4} := 51.294\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{R.VEH5} := 117.209\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{R.VEH6} := 90.088\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{R.VEH7} := 94.859\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{R.VEH8} := 88.719\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

$$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH1} = 6.376 \cdot 10^5$$

$$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH2} = 1.297 \cdot 10^6$$

$$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH3} = 1.521 \cdot 10^6$$

$$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH4} = 1.855 \cdot 10^6$$

$$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH5} = 2.906 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH6} = 5.244 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH7} = 4.671 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH8} = 5.428 \cdot 10^{5}$$

Damage accumulation using "Miner's Rule"

$$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}} \qquad D_{VEH1} = 0.007$$

$$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}} \qquad D_{VEH2} = 0.003$$

$$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}} \qquad D_{VEH3} = 0.001$$

$$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}} \qquad D_{VEH4} = 0.002$$

$$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}} \qquad D_{VEH5} = 0.009$$

$$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}} \qquad D_{VEH6} = 0.008$$

$$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}} \qquad D_{VEH7} = 0.006$$

$$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}} \qquad D_{VEH8} = 0.004$$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.04$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.01$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{(1 - 10 \cdot D_i)}{D_{i.cor}} + 10\right) = 32.25 \quad \text{years}$$

Fatigue life of corroded member - IPE550

Detail category 90, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\Delta\sigma_L = 36.415\ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966\ MPa$ $\Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964\ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113 \qquad \hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:

Number of cycles of each stress range

$\Delta\sigma_{R.VEH1} := 99.575\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{R.VEH2} := 78.687\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{R.VEH3} := 71.449\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{R.VEH4} := 65.722\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{R.VEH5} := 131.257\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{R.VEH6} := 112.763\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{R.VEH7} := 112.537\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{R.VEH8} := 104.062\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH1} = 4.189 \cdot 10^{5}$

$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH2} = 7.104 \cdot 10^{5}$

$\Delta\sigma_{R.VEH3} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH3} = 8.82 \cdot 10^{5}$

$\Delta\sigma_{R.VEH4} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH4} = 1.064 \cdot 10^{6}$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH5} = 2.255 \cdot 10^5$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH6} = 3.17 \cdot 10^5$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH7} = 3.184 \cdot 10^5$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}^{\ c} \cdot N_{f.CAFL}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$N_{R.VEH8} = 3.795 \cdot 10^5$

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $D_{VEH1} = 0.01$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $D_{VEH2} = 0.006$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $D_{VEH3} = 0.002$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $D_{VEH4} = 0.003$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $D_{VEH5} = 0.011$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $D_{VEH6} = 0.014$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $D_{VEH7} = 0.009$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $D_{VEH8} = 0.006$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.062$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.019$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{\left(1 - 10 \cdot D_i\right)}{D_{i.cor}} + 10\right) = 23.165 \text{ years}$$

Fatigue life of corroded member - Plate 80x8

Detail category 160, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\Delta\sigma_L = 36.415\ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966\ MPa$

$\Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964\ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113$$

$$\hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:

$\Delta\sigma_{R.VEH1} := 48.148\ MPa$

$\Delta\sigma_{R.VEH2} := 34.556\ MPa$

$\Delta\sigma_{R.VEH3} := 32.565\ MPa$

$\Delta\sigma_{R.VEH4} := 30.494\ MPa$

$\Delta\sigma_{R.VEH5} := 69.571\ MPa$

$\Delta\sigma_{R.VEH6} := 54.334\ MPa$

$\Delta\sigma_{R.VEH7} := 55.44\ MPa$

$\Delta\sigma_{R.VEH8} := 52.334\ MPa$

Number of cycles of each stress range

$n_{VEH1} := 12 \cdot 365$ $n_{VEH1} = 4380$

$n_{VEH2} := 12 \cdot 365$ $n_{VEH2} = 4380$

$n_{VEH3} := 5 \cdot 365$ $n_{VEH3} = 1825$

$n_{VEH4} := 8 \cdot 365$ $n_{VEH4} = 2920$

$n_{VEH5} := 7 \cdot 365$ $n_{VEH5} = 2555$

$n_{VEH6} := 12 \cdot 365$ $n_{VEH6} = 4380$

$n_{VEH7} := 8 \cdot 365$ $n_{VEH7} = 2920$

$n_{VEH8} := 6 \cdot 365$ $n_{VEH8} = 2190$

$$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH1} = 2.138 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH2} = 4.499 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH3} \leq \Delta\sigma_{D.cor}$$

$$N_{R.VEH3} := N_{f.CAFL} \cdot \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_{D.cor}} \right)^{\frac{1}{\hat{c}}}$$

$$N_{R.VEH3} = 5.2 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH4} \leq \Delta\sigma_{D.cor}$$

$$N_{R.VEH4} := N_{f.CAFL} \cdot \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_{D.cor}} \right)^{\frac{1}{\hat{c}}}$$

$$N_{R.VEH4} = 6.421 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH5} = 9.363 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH6} = 1.63 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH7} = 1.558 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}}\right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH8} = 1.773 \cdot 10^{6}$$

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \dfrac{n_{VEH1}}{N_{R.VEH1}}$ $D_{VEH1} = 0.002$

$D_{VEH2} := \dfrac{n_{VEH2}}{N_{R.VEH2}}$ $D_{VEH2} = 9.736 \cdot 10^{-4}$

$D_{VEH3} := \dfrac{n_{VEH3}}{N_{R.VEH3}}$ $D_{VEH3} = 3.509 \cdot 10^{-4}$

$D_{VEH4} := \dfrac{n_{VEH4}}{N_{R.VEH4}}$ $D_{VEH4} = 4.547 \cdot 10^{-4}$

$D_{VEH5} := \dfrac{n_{VEH5}}{N_{R.VEH5}}$ $D_{VEH5} = 0.003$

$D_{VEH6} := \dfrac{n_{VEH6}}{N_{R.VEH6}}$ $D_{VEH6} = 0.003$

$D_{VEH7} := \dfrac{n_{VEH7}}{N_{R.VEH7}}$ $D_{VEH7} = 0.002$

$D_{VEH8} := \dfrac{n_{VEH8}}{N_{R.VEH8}}$ $D_{VEH8} = 0.001$

Total damage for corroded member

$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$

$D_{i.cor} = 0.012$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.019$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$\left(\dfrac{(1 - 10 \cdot D_i)}{D_{i.cor}} + 10 \right) = 75.573$ years

Fatigue life of corroded member - Plate 220x8

Detail category 160, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 90 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\quad \Delta\sigma_D = 66.33\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\quad \Delta\sigma_L = 36.415\ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 32.966\ MPa$ $\quad \Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 12.964\ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113 \qquad \hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:	Number of cycles of each stress range	
$\Delta\sigma_{R.VEH1} := 47.939\ MPa$	$n_{VEH1} := 12 \cdot 365$	$n_{VEH1} = 4380$
$\Delta\sigma_{R.VEH2} := 33.981\ MPa$	$n_{VEH2} := 12 \cdot 365$	$n_{VEH2} = 4380$
$\Delta\sigma_{R.VEH3} := 32.842\ MPa$	$n_{VEH3} := 5 \cdot 365$	$n_{VEH3} = 1825$
$\Delta\sigma_{R.VEH4} := 30.759\ MPa$	$n_{VEH4} := 8 \cdot 365$	$n_{VEH4} = 2920$
$\Delta\sigma_{R.VEH5} := 67.322\ MPa$	$n_{VEH5} := 7 \cdot 365$	$n_{VEH5} = 2555$
$\Delta\sigma_{R.VEH6} := 53.685\ MPa$	$n_{VEH6} := 12 \cdot 365$	$n_{VEH6} = 4380$
$\Delta\sigma_{R.VEH7} := 55.543\ MPa$	$n_{VEH7} := 8 \cdot 365$	$n_{VEH7} = 2920$
$\Delta\sigma_{R.VEH8} := 59.84\ MPa$	$n_{VEH8} := 6 \cdot 365$	$n_{VEH8} = 2190$

$$\Delta\sigma_{R.VEH1} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH1} = 2.159 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH2} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH2} = 4.671 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH3} \leq \Delta\sigma_{D.cor}$$

$$N_{R.VEH3} := N_{f.CAFL} \cdot \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_{D.cor}} \right)^{\frac{1}{\hat{c}}}$$

$$N_{R.VEH3} = 5.061 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH4} \leq \Delta\sigma_{D.cor}$$

$$N_{R.VEH4} := N_{f.CAFL} \cdot \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_{D.cor}} \right)^{\frac{1}{\hat{c}}}$$

$$N_{R.VEH4} = 6.245 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH5} = 1.008 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH6} = 1.675 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH7} = 1.552 \cdot 10^{6}$$

$$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c-\frac{1}{m}\right)}}$$

$$N_{R.VEH8} = 1.313 \cdot 10^{6}$$

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $D_{VEH1} = 0.002$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $D_{VEH2} = 9.377 \cdot 10^{-4}$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $D_{VEH3} = 3.606 \cdot 10^{-4}$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $D_{VEH4} = 4.675 \cdot 10^{-4}$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $D_{VEH5} = 0.003$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $D_{VEH6} = 0.003$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $D_{VEH7} = 0.002$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $D_{VEH8} = 0.002$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.012$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.019$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{(1 - 10 \cdot D_i)}{D_{i.cor}} + 10 \right) = 74.826 \text{ years}$$

Fatigue life of corroded member - UB686/254/125

Detail category 160, Ref. Tab. 8.1, EN 1993-1-9

$\Delta\sigma_C := 160 \frac{N}{mm^2}$

$\Delta\sigma_D := 0.737 \cdot \Delta\sigma_C$ $\Delta\sigma_D = 117.92\ MPa$

$\Delta\sigma_L := 0.549 \cdot \Delta\sigma_D$ $\Delta\sigma_L = 64.738\ MPa$

Parametres for constructional details in Eurocode:

$N_{f.LCF} := 10^4$

$N_{f.CAFL} := 5 \cdot 10^6$

$N_{f.VAFL} := 10^8$

$m := 3$

$\Delta\sigma_{D.cor} := \Delta\sigma_D \cdot 0.497 = 58.606\ MPa$

$\Delta\sigma_{L.cor} := \Delta\sigma_L \cdot 0.356 = 23.047\ MPa$

$$c := \frac{\log\left(\frac{\Delta\sigma_D}{\Delta\sigma_{D.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.LCF}}\right)} = 0.113$$

$$\hat{c} := \frac{\log\left(\frac{\Delta\sigma_{D.cor}}{\Delta\sigma_{L.cor}}\right)}{\log\left(\frac{N_{f.CAFL}}{N_{f.VAFL}}\right)} = -0.312$$

Number of cycles to fatigue failure:

Number of cycles of each stress range

$\Delta\sigma_{R.VEH1} := 211.849\ MPa$ $n_{VEH1} := 12 \cdot 365$ $n_{VEH1} = 4380$

$\Delta\sigma_{R.VEH2} := 151.334\ MPa$ $n_{VEH2} := 12 \cdot 365$ $n_{VEH2} = 4380$

$\Delta\sigma_{R.VEH3} := 143.97\ MPa$ $n_{VEH3} := 5 \cdot 365$ $n_{VEH3} = 1825$

$\Delta\sigma_{R.VEH4} := 141.735\ MPa$ $n_{VEH4} := 8 \cdot 365$ $n_{VEH4} = 2920$

$\Delta\sigma_{R.VEH5} := 279.049\ MPa$ $n_{VEH5} := 7 \cdot 365$ $n_{VEH5} = 2555$

$\Delta\sigma_{R.VEH6} := 237.39\ MPa$ $n_{VEH6} := 12 \cdot 365$ $n_{VEH6} = 4380$

$\Delta\sigma_{R.VEH7} := 253.033\ MPa$ $n_{VEH7} := 8 \cdot 365$ $n_{VEH7} = 2920$

$\Delta\sigma_{R.VEH8} := 234.34\ MPa$ $n_{VEH8} := 6 \cdot 365$ $n_{VEH8} = 2190$

$$\Delta\sigma_{R.VEH1} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH1} := \left(\frac{\Delta\sigma_{R.VEH1}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH1} = 2.8 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH2} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH2} := \left(\frac{\Delta\sigma_{R.VEH2}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH2} = 5.955 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH3} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH3} := \left(\frac{\Delta\sigma_{R.VEH3}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH3} = 6.66 \cdot 10^{5}$$

$$\Delta\sigma_{R.VEH4} \ge \Delta\sigma_{D.cor}$$

$$N_{R.VEH4} := \left(\frac{\Delta\sigma_{R.VEH4}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$$N_{R.VEH4} = 6.898 \cdot 10^{5}$$

$\Delta\sigma_{R.VEH5} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH5} := \left(\frac{\Delta\sigma_{R.VEH5}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH5} = 1.509 \cdot 10^{5}$

$\Delta\sigma_{R.VEH6} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH6} := \left(\frac{\Delta\sigma_{R.VEH6}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH6} = 2.169 \cdot 10^{5}$

$\Delta\sigma_{R.VEH7} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH7} := \left(\frac{\Delta\sigma_{R.VEH7}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH7} = 1.88 \cdot 10^{5}$

$\Delta\sigma_{R.VEH8} \geq \Delta\sigma_{D.cor}$

$$N_{R.VEH8} := \left(\frac{\Delta\sigma_{R.VEH8}}{\Delta\sigma_D \cdot N_{f.LCF}{}^{c} \cdot N_{f.CAFL}{}^{\frac{1}{m}}} \right)^{\frac{1}{\left(-c - \frac{1}{m}\right)}}$$

$N_{R.VEH8} = 2.233 \cdot 10^{5}$

Damage accumulation using "Miner's Rule"

$D_{VEH1} := \frac{n_{VEH1}}{N_{R.VEH1}}$ $D_{VEH1} = 0.016$

$D_{VEH2} := \frac{n_{VEH2}}{N_{R.VEH2}}$ $D_{VEH2} = 0.007$

$D_{VEH3} := \frac{n_{VEH3}}{N_{R.VEH3}}$ $D_{VEH3} = 0.003$

$D_{VEH4} := \frac{n_{VEH4}}{N_{R.VEH4}}$ $D_{VEH4} = 0.004$

$D_{VEH5} := \frac{n_{VEH5}}{N_{R.VEH5}}$ $D_{VEH5} = 0.017$

$D_{VEH6} := \frac{n_{VEH6}}{N_{R.VEH6}}$ $D_{VEH6} = 0.02$

$D_{VEH7} := \frac{n_{VEH7}}{N_{R.VEH7}}$ $D_{VEH7} = 0.016$

$D_{VEH8} := \frac{n_{VEH8}}{N_{R.VEH8}}$ $D_{VEH8} = 0.01$

Total damage for corroded member

$$D_{i.cor} := D_{VEH1} + D_{VEH2} + D_{VEH3} + D_{VEH4} + D_{VEH5} + D_{VEH6} + D_{VEH7} + D_{VEH8}$$

$D_{i.cor} = 0.092$ < 1.0 OK

Total damage for ucorroded member

$D_i := 0.019$ < 1.0 OK

Fatigue life by assuming corrosion starts after 10 years

$$\left(\frac{\left(1 - 10 \cdot D_i\right)}{D_{i.cor}} + 10 \right) = 18.764 \text{ years}$$