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Masterthesis

Comparative life-cycle cost analysis between carbon steel and stainless steel structure for transmission towers

PROMOTOR :
Prof. dr. ir. Jose GOUVEIA HENRIQUES

COPROMOTOR :
Prof. dr. ir. Herve DEGEE

Orin Ubachs
Scriptie ingediend tot het behalen van de graad van master in de industriële wetenschappen: bouwkunde

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Preface

The final step before graduating as master civil engineering, is writing a master's thesis. This allowed me to converge the theoretical knowledge, which I gathered during my 4 year study, into a practical final work. This was a great opportunity to see what it is like to be a researcher and make my first initial steps into the scientific world.

This research would not be possible without the support and help of other people. Therefore I would like to thank my promoters, my family and everyone that helped me during this research.

In particular, I want to thanks my promoters, Prof. dr. ir. José A. Gouveia Henriques and Prof. dr. ir. Hervée Degée for the excellent guidance during this research. They always gave me proper feedback and helped me whenever I ran into trouble.

Furthermore, I would like to give a special thanks to Senior Project Manager Koen Palings from Engie Electrabel, for the excellent cooperation. This study would not have been possible without his help. He gave me the plans, the calculation notes and prices of the original transmission tower to get the study started.

Finally, I would like to thank Revenue Manager Joeri Vandewinkel from Aperam, for the help with the prices around stainless steel and their maintenance.

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Abstract

Energy plays a vital role in daily life of the western civilization and transmission towers form the backbone of the energy supply network, since any system failures would lead to a breakup in the energy supply. Therefore it is very important to properly maintain the towers to ensure its structural integrity. This study proposes to assess the technical and economic advantages of the use of structural stainless steel over carbon steel, when the complete life cycle is considered. Since stainless steel has high initial costs but will have lower maintenance costs due to its high corrosion resistance. To investigate the possible advantages of stainless steel, an existing tower was used as case study. The case study was redesigned according to EN 1993-1-4, for austenitic-, ferritic and duplex stainless steel grades. Followed by an economic analysis of the existing carbon structure and the newly designed stainless steel structures for comparison. The economic analysis considered the initial costs for the construction of the tower, the costs due to maintenance and the residual costs. The results of the study have proven the potential economic benefits of the use of structural stainless steel over carbon steel, a cost reduction up to 19% could be obtained with a change of material. These results are promising, nevertheless, further investigation is needed to determine more precise costs and to extend the study to other tower configurations.

Abstract in het Nederlands

Energie speelt een vitale rol in het dagelijkse leven van de westerse beschaving en elektriciteitsmasten vormen de ruggengraat van het energievoorzieningsnetwerk. Daarom is het erg belangrijk om de torens fatsoenlijk te onderhouden en de structurele integriteit te waarborgen. Deze studie stelt voor om de technische en economische voordelen van roestvrij staal in plaats van koolstofstaal te onderzoeken, wanneer de volledige levenscyclus in acht wordt genomen. Omdat roestvrij staal hogere initiële kosten heeft, maar goedkoper zal zijn in onderhoud vanwege zijn hoge corrosieweerstand. Om de mogelijke voordelen van roestvrij staal te onderzoeken, werd een bestaande toren gebruikt als casestudy. De casestudy werd opnieuw ontworpen volgens EN 1993-1-4, voor austenitisch-, ferritisch en duplex roestvrij staal. Vervolgens werd ter vergelijking een economische analyse van de bestaande koolstofstaal en de nieuw ontwerpen roestvrij staal structuren gemaakt. De economische analyse hield rekening met de initiële kosten voor de bouw van de toren, de onderhoudskosten, de afbraakkosten en de rest waarde van de materialen. De resultaten van de studie bewijzen de potentiële economische voordelen voor het gebruik van roestvrij staal in plaats van koolstofstal, er kon een kostvermindering tot 19% behaald worden. Deze resultaten zijn veelbelovend, maar verder onderzoek is nodig om de exacte kosten te bepalen en uit te breiden naar andere configuraties van elektriciteitsmasten.

1 INTRODUCTION

Belgium is an industrialized country where energy plays a vital role in daily life. The energy is produced in different types of power plants such as nuclear power plants, gas and coal power plants and hydroelectric power plants throughout the country, but the capacity of the Belgian plants is not sufficient enough to keep up with Belgium's consumption and therefore the electricity is partly introduced from neighbouring countries. To ensure Belgium's energy demand a good working transportation system is of crucial importance .This is fulfilled by its transmission towers and lines to create a supply network, connecting national and international power plants and connecting the power plants with the consumers.

Transmission towers, part of the energy network, are currently being constructed out of carbon steel. A material which is known for its sensitivity to corrosion. Consequently, it is necessary to conduct several maintenances on the transmission towers during the service life. The choice of carbon steel for the construction of these towers relies on the low initial cost in comparison with other alternatives. However, if the choice is based on a long term perspective, as the whole service life of the infrastructure is taken into account, a more cost efficient solution can be obtained using stainless steel. Stainless steel is known to present adequate strength and significant corrosion resistance.

The potential of the stainless steel may be obtained in a long term perspective and consequently, the economic benefit may be used to further develop the Belgium energy network, rather than spent in unnecessary maintenance.

This study is aimed to investigate if stainless steel transmission towers could provide a more economic beneficial solution over carbon steel, when taking account of the entire life cycle. The study will consist out of a literature review to highlight the materials properties and investigate if stainless steel could provide a more cost-efficient solution while keeping the structural performance. A real transmission tower will be used as case study to analyse and design the new transmission towers in stainless steel. Followed by an economic analysis of all the case studies to determine if the stainless steel solutions could provide a more cost efficient solution. Furthermore the results of the study can also be compared to a similar study conducted in Brazil, where the potential of stainless steel for this type of infrastructures was demonstrated, and in this way compare these two different markets, South America and Europe.

2 CARBON AND STAINLESS STEEL

2.1 Steel

Steel is known to be one of the most innovative and essential materials in the world. It is everywhere in modern society and enabled our current way of life. It was able to obtain this position because of its ability to become more efficient as a product and application. To further prove its relative importance, figure 1 shows the world's crude steel production from 1950 to 2017. In 2017 the world's crude steel production was 1.689 billion tons and according to predictions it will increase with another 1.8% in 2018 and 0.9% in 2019 [1].

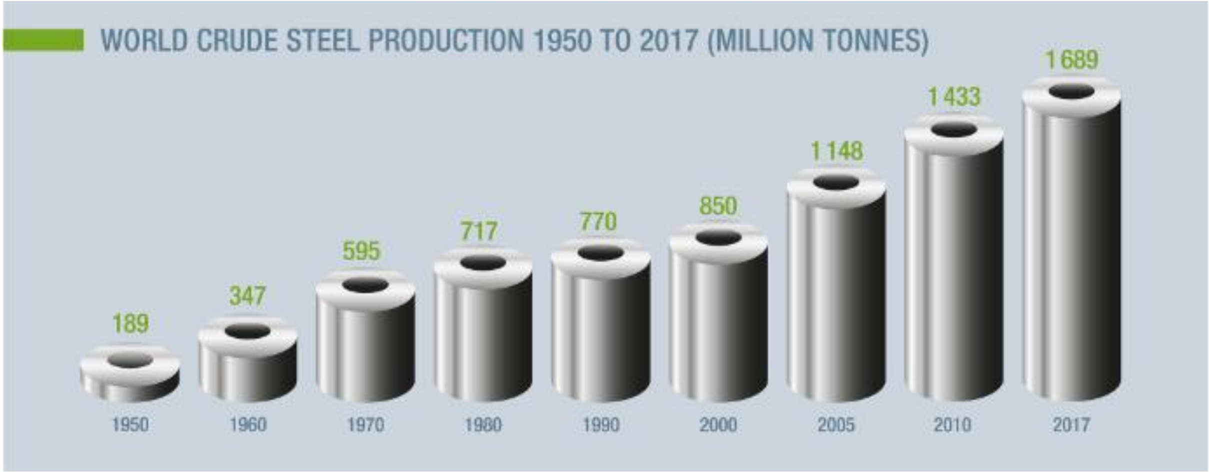


Figure 1: World's crude steel production from 1950 till 2017 [1]

Steel is not a single product, it total there are over 3500 different steel grades each with different properties and purposes. Steel is made of iron and carbon containing less than 2% carbon, different materials such as nickel, chromium, manganese, niobium, vanadium and molybdenum are added to produce the different alloys. Till this day the alloys keep changing with new a different materials to optimize its properties and its applications. Steel can be split up into 3 different groups: carbon steels, high-alloyed steels and low-alloyed steels. Steel is considered high-alloyed when the weight of the other elements besides iron and carbon are larger than 8% of the total weight of the steel, and carbon steels when that weight is less than 1% [2].

2.1.1 Iron

The major component of steel is iron, depending on the temperature iron exists in 3 states. Each state is a well-ordered crystal structure. The crystal structure of iron comes in 2 different forms, a body-centred cubic (bcc) arrangement and a face-centred cubic (fcc) arrangement. The big difference between the 2 arrangements is the fact that the distances between neighbouring planes in the fcc arrangement are about 25% larger than in the bcc arrangements. Therefore making the fcc arrangement better for keeping foreign atoms in its solid solution.

Up to 910°C iron is in the bcc arrangement which is also called alpha ferrite (αFe). Between 910°C and 1390°C it changes to it fcc arrangement and this is called austenite or gamma iron (γFe). When the temperature increases to over 1390°C iron will revert back to a bcc arrangement up until its melting point of 1538°C which is called delta ferrite (δFe). Furthermore there is also the beta iron term, in this form iron has strong magnetic characteristics. Iron will be in this form when the temperature is below 770°C [2] [3].

2.1.2 Effects of carbon

Iron in itself is a soft material and is not very useful from an engineering standpoint. Carbon is added in small amounts to increase hardness and create steel. In typical steel alloys carbon content is between 0.002% and 2.1%. The carbon content is in linear correlation with the hardness and brittleness of the steel. It is limited at 2.1% because it would break when being loaded due to brittleness. The carbon within the steel is found in two forms. Firstly it is found as solid solution in ferrite and austenite and secondly it is found as a carbide. The carbide either comes in the form of an iron carbide (Fe_3C), better known as cementite, or is derived from an alloying element [3].

2.2 Steel production process

Steel production can be done through various ways but they are all based on the same principles: melting, purifying, alloying, casting and forming. In modern steelmaking the process is split up in 2 groups: primary and secondary steelmaking, these 2 groups cover the first 3 basic principles of the steel production process. Primary steelmaking involves melting and purifying while secondary steelmaking involves a refining process of the crude steel. Today the 2 main commercial methods for primary steelmaking are basic oxygen furnace (BOF) and electrical arc furnace (EAF). The difference in these methods lies in the raw materials that are used and the choice between either of them relies on the availability of those raw materials. For BOF iron ore, such as hematite (Fe_2O_3) and magnetite (Fe_2O_4), and steel scrap are used. While EAF uses only scrap or a mixture of steel scrap and direct reduced iron (DRI). In secondary steelmaking is performed in ladles and turns the crude steel into a high-quality steel by adding alloying agents, de-oxidation, removing dissolved gasses, and refining or removing of inclusions. Figure 2 shows the steelmaking process step by step [3] [4] [5] [6].

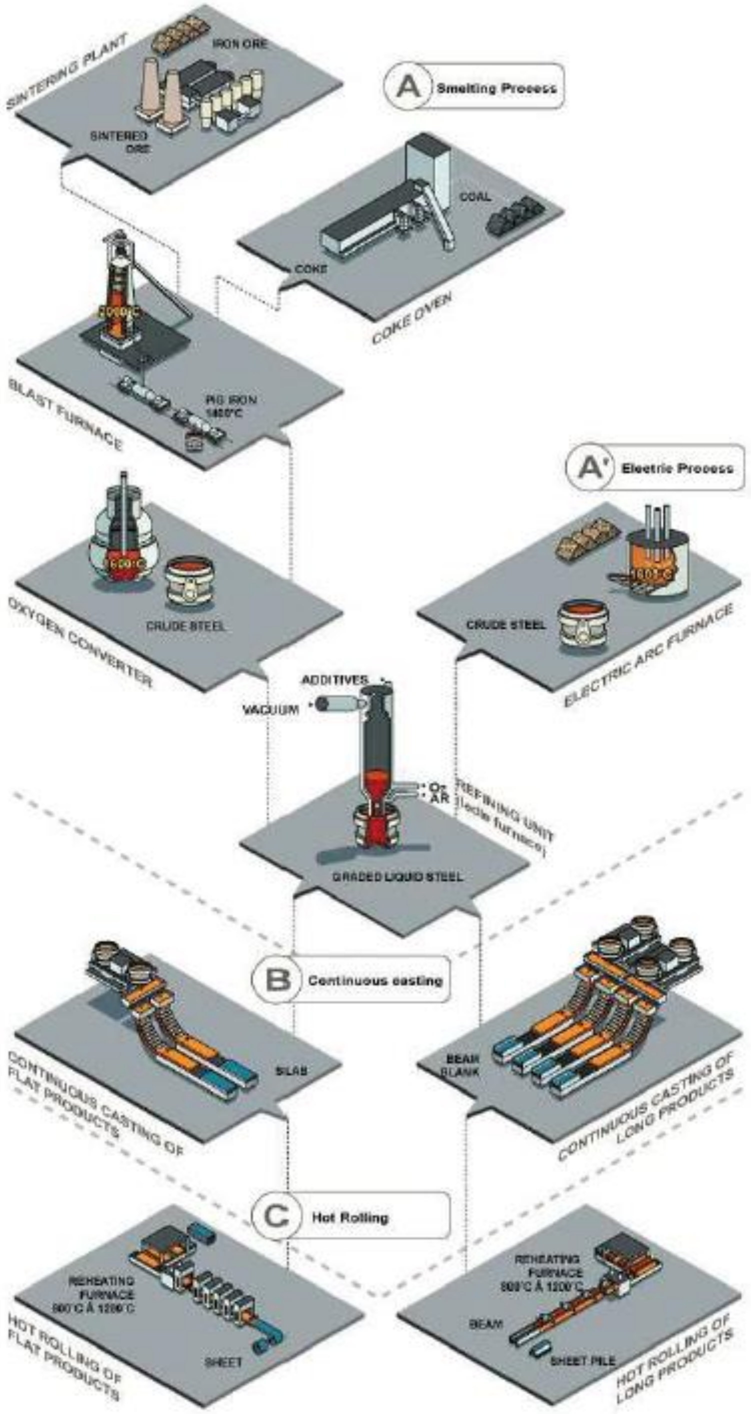


Figure 2: Step by step overview of modern steel production [6]

2.2.1 Primary steelmaking

As seen before primary steelmaking can be split up into 2 main groups, here each process will be further explained to get a better understanding of the differences.

2.2.1.1 BOF

The iron ores are not always of high enough quality to go straight into the liquid blast furnace, therefore most of the ore go through a ‘beneficiation’ process also known as sintering. During the sintering the finely-sized ore is mixed with cokes and fluxes and gets heated to around 1480°C while moving on a bed. The iron atoms within the ore will group together under influence of the heat to form sinter, while the contaminants will bind itself to the fluxes, this sinter contains more Fe and has better properties for the high temperatures inside the blast furnace [5].

The cokes used for sintering are produced with dry distillation process. During this process coal is heated up to 1000-1200°C in a furnace without oxygen present. The process has 2 products as a result, firstly there are the cokes which are used in the sintering process and later will also be added to the blast furnace. Secondly coal powder is formed, the powder can be blown straight into blast furnace and will reduce the amount of cokes needed to create pig iron. This technique is referred to as ‘pulverized-coal injection’ (PCI) and is used to reduce the cost because of the fact that the making of cokes is very cost intensive [5] [6].

Cokes, high grade iron ore, sinter and fluxes (limestone) are charged into the top of the blast furnace. The blast furnace itself is a tall water cooled shaft, where the materials are heated by the burning of the coke. The air required for burning the coke is blown in at high temperature at the base of the furnace, to save energy the air gets heated up by the exhaust gasses of the furnace. However the coke is not entirely intended as fuel, but also as a reductant. During the chemical reduction process the carbon in the cokes react with the injected oxygen and forms CO and CO_2, because of the high temperature the CO will react the iron ore to remove its oxygen. As the materials move down the shaft the oxygen in the iron ore will progressively be removed and will produce liquid iron (pig iron) by the time it reaches the hearth of the furnace. Furthermore there will form a by-product named slag at the hearth of the furnace because of the fact that the iron ore contains impurities. These impurities react with the fluxes and form the slag, which floats on top of the pig iron. The pig iron and the slag are tapped of separately through tap holes in the furnace. The slag is sold of separately to the cement industry or to road constructors where they serve a great use [5] [6].

To turn the pig iron into steel and further remove its impurities such as excess carbon, nitrogen, phosphorus, silicon and sulphur, the pig iron is taken to the BOF, also known as an oxygen converter. First of all steel scrap will be added to the BOF, about 20-25% of the total charge will be scrap. This results in a great recycling of the material and its further use will later be explained. Thereafter the BOF will be filled with liquid iron from the blast furnace. Secondly a desulfurization of the iron is done, which is carried out by lowering a water cooled lance into the mixture that injects magnesium or calcium, these materials are added because of their high affinity with sulphur. After reacting with the sulphur a slag will form at the top of the pig iron which can be skimmed off. Thirdly the carbon will be lowered to refine the iron, because up until now it still has a 4.5% carbon content. The oxidation of carbon is done by lowering a different lance which remains above the surface of the molten iron. The lance will blow pure oxygen at supersonic speed onto the surface of the mixture and start the chemical reaction. The silicon impurities will react with the oxygen and will form silica, to neutralise the silica lime is added simultaneously with the oxygen blow. These additions are automatically controlled which allows for changes in the oxygen flow rates, lime additions and lance height when needed. The slag formed by the reaction of the silica and the lime will act as a reservoir and will react with the other impurities of the iron. Furthermore the oxygen will react with the excess carbon and will form CO and CO_2, this exothermic reaction will generate a large amount of heat and start a carbon monoxide boil. The boil is very important for the mixing of the liquid iron, which enhances the chemical reactions and purges the iron from hydrogen and nitrogen impurities. The scrap steel added in the beginning will melt completely and is used as cooling for the reaction. In 20 minutes the charge will be finished and will contain around 0.06% carbon. Fourthly aluminium (Al) or silicon (Si) are added to deoxidize the steel, these will react to form alumina or silica and will be absorbed by the slag. Lastly the slag will be tapped and the liquid steel will be reading for secondary steelmaking [3] [5] [6].

To speed up the process argon or nitrogen can be injected through special bricks at the bottom of the BOF. This will increase the speed of the chemical reactions and will result in a faster charge.

2.2.1.2 EAF

The other to make steel is known as AEF, which is much older than the BOF method, the reason being that mankind is only possible to produce huge amounts of tonnage oxygen since the 1950s. The major raw material used in AEF is scrap steel, but because of the huge demand and the fact that there is insufficient steel scrap available to meet this the demand, other raw materials such as hot steel or DRI are used as well. The use of other materials is also enhanced because of the impurities present in the steel scrap due to previous alloying of the scrap steel and the fact that the producer wants to keep these residuals as low as possible to create a high quality steel [3] [4] [5].

The DRI is produced through a direct reduction process. During the reduction process a natural gas is reformed to release hydrogen (H_2) and carbon monoxide (CO). These gasses will react with the iron ore and will convert them to solid iron pellets which contain over 94% Fe, resulting in an almost residual free product [4] [5].

Depending on the purity of the steel scrap the charge will be filled with only steel scrap or a mixture of steel scrap and DRI or hot steel which are in solid state. Once the furnace is filled 3 carbon electrodes are lower into the furnace between which an high-current electric arc is struck. The arc generates huge amounts of heat and will melt the steel present. To accelerate the process oxygen or other fuels can be injected via several lances to evenly distribute the heating. Slag such a carbon-lime are injected in the mixture to remove the little impurities which are present in the liquid iron. The slag gets removed by pouring it through the rear door of the furnace into a slag pot underneath. Once all the slag is removed then the liquid iron will be ready for secondary steelmaking [3] [4] [5].

2.2.2 Secondary steelmaking

The steel produced by BOF or AEF are basically the same apart from some minor chemical compositions. These differences are only important for the production of some special steel grades. The refined liquid steel is tapped from the furnaces into a ladle where its chemical composition can be changed further to create different steel grades. Secondary steelmaking is carried out in a ladle so that the primary furnace can operate at higher speeds, which allows for higher steel production. Therefore secondary steelmaking is also known as ladle metallurgy [4].

The properties of each steel grade determine which secondary steelmaking processes are needed. For some basic steel grades secondary steelmaking is not needed as they can be casted straight after they come out of the BOF or AEF. But for operational reasons secondary steelmaking equipment is almost always installed, since the steel will cool off once its tapped into the ladle. The most common secondary steelmaking furnace is the ladle-arc furnace (LAF), this furnace will not melt steel but will maintain its temperature so it will not turn too cold for casting. Furthermore the final elements are added to finish the chemical composition of the alloy at the LAF, or elements are added to create special slag to remove certain impurities. Together with the LAF some plants have lance injection facilities, which use a argon gas to blow materials deep into the steel and remove impurities. The most common one is the creation of very low sulphur steel by blowing in calcium [7].

An alternative to the LAF can be found in the Composition Adjustment System with Oxygen Blowing (CAS-OB). The CAS-OB can only be used in plants where the steel grades are allowed to contain a certain amount of aluminium (Al). Simply because of the fact that within the CAS-OB system a snorkel is lowered into the ladle which injects powdered aluminium and oxygen to create a exothermic reaction coming from the oxidation of the aluminium. The heat is evenly distributed by the stirring of argon which is injected deeply into the liquid steel to create and opening in the slag where the snorkel can inject its aluminium powder and oxygen into the steel [7].

Next to keeping the steel at the right temperature for casting, there are a lot of gasses other than oxygen dissolved in the liquid steel that need to be removed. Not removing them will have harmful effects on the quality of the steel and lead to cracking problems. The main 2 being hydrogen and nitrogen and will be removed through a degasser. The type of degassers is chosen on basis of the produced steel grades as well as the available capital and operating cost. The basic principle of the degasser is to create a vacuum to withdraw the hydrogen and nitrogen. Once the liquid steel has all its alloying agents and is degassed then it is ready for casting [7].

2.2.3 Casting

Once the steel is prepared the ladle with the liquid steel will be transported to the casting section of the factory. The temperature of the mixture sits around 1650°C and differs for different alloys and production methods. The steel will rest until the temperature drops to 1560°C at this point it will be 30°C above the solidification temperature of an 0.2% carbon steel. Once this temperature is reached casting can start. This temperatures differ for different alloys and is important to counter the undesirable effect of segregation during casting. Segregation is known as the splitting of the different elements in the liquid steel, resulting in a not uniform and product and therefore lowering its mechanical properties. The casting process can be done through 2 ways: by casting in a mould or by continuous casting. In the following paragraphs the 2 casting methods will be explained [3] [4].

2.2.3.1 Casting in moulds

The steel is poured in moulds through valves at the bottom of the ladle into moulds mounted on carts and rails. Once the mould is filled the valve closes and the cart will move to a resting place where the solidification process can occur. When the steel is solid and cooled of the moulds get remove and the process can repeat. Casting in moulds is a slower process and more cost intensive process and is therefore only done for special forms which cannot be obtained through continuous casting [3] [4].

2.2.3.2 Continuous casting

Since the 1960's steelmakers shifted to a new production process known as continuous casting and most of the world's steel nowadays is produced via this method. Continuous casting has a lot of advantages over casting in moulds: Firstly there is the fact that it is a continuous process and can keep running as long as required, increasing the yield considerably. Secondly there is the fact that the expensive moulds are no longer required resulting in lowering of the initial production costs. Thirdly the common surface defects of the moulds can be avoided leading to a higher quality end product. Fourthly there is the fact that there is less waste because there is only one contraction cavity at the end of the cast to remove as waste. Finally there is less forming of the steel because the section shape produced is closer of that of the end product [7].

The principle of continuous casting is the same for each different cross section. The liquid steel from the ladle is tapped into a tundish, which acts as a reservoir and controls the flow rate of the steel to different open-ended copper moulds. This makes it possible to cast several ladles of steel after another without stopping and therefore the process got its name continuous casting. Depending on the different type of cross-section the tundish feeds up to 8 moulds through valves at the bottom of the tundish. Water runs through passages in the walls of the open-ended moulds to cool them down and make it possible to continuously cast. Most commonly the strands emerging out of the moulds are curved and converted to horizontal by a series of heavily cooled rollers underneath the mould, once straightened the strands are then cut of at appropriate length by an flame torch. Some high alloyed steel grades are being casted in a vertical pit because of the fact that they are susceptible to cracking when casted in a curve, however this increases the capital costs because of the fact that the casting pit has to be a lot deeper. Once cut off at specific length the strand move on to be formed into their end products [3] [7].

2.2.4 Forming of steel

The majority of the steel forming process are done at 1100-1200°C because of steel's low resistance to plastic deformation at this temperature and is referred to as hot rolling. But before the steel can be rolled into their end products they need to be reheated. This is done through a re-heating furnace which uses the waste gases of the plant to lower its impact on the environment and simultaneously save costs. Depending on the different types cross-section the strands pass through a different mill, each mill has a different configuration of rolls which transform the brittle strands into a though and ductile steel [3] [8].

Cold rolling can further be applied on strips as a secondary steelmaking process to create some special applications, improve the mechanical properties even further or to further smoothen the surface. Firstly before it can be cold rolled the oxide coating formed during hot rolling needs to be removed by passing through an acid bad. Once cleaned the strips will move into the cold rolling mill and be transformed into their end product [3] [8].

2.2.5 Treating of steel

There are 2 types of treating of steel:

Firstly there is the types of treating whom are used during the production of the steel such as tempering and quenching. These techniques consist of rapidly cooling of the steel once its formed and lead to a further increase of mechanical properties then when they are cooled by air. Most common used products are oil, salt brine and water. Oil having the mildest and salt brine the largest effect [3].

Secondly there are the treating techniques used once the steel is completely formed, consisting of cold rolling and coating. Cold rolling has already been covered in the section above. Coating consists of adding an extra layer to the steel to give it protection or certain surface properties such as corrosion resistance [3] [8].

2.3 Comparison carbon and stainless steel

2.3.1 Carbon steel

Carbon steel is the most commonly used steel in the world, accounting for around 90% of the world's steel applications. It is a steel where the main alloying element is carbon and no minimum percentage of other alloying elements are required. Furthermore it contains up to 1.65% manganese, 0.6% silicon, 0.6% Copper, some small amounts of phosphorus and sulphur and residual elements from the steelmaking process. Carbon steels can be further grouped according to carbon content into: high-carbon steels; medium-carbon steels; low-carbon steels; extra-low-carbon steels; and ultralow-carbon steels. These contain, respectively, above 0.5% carbon, between 0.2 and 0.49% carbon, between 0.05 and 0.19% carbon, between 0.015 and 0.05% carbon, and less than 0.015% carbon. The hardness and brittleness of the steel increases with the carbon content, making a low-carbon steel soft and ductile whilst making a high-carbon steel very hard and brittle [3] [9].

In the present study, a S355J2 carbon steel was used for the transmission towers The chemical composition of this steel grade is shown in table 1.

Table 1: Steel grade S355J2 chemicals composition [10]

Steel grade	C %	Mn %	Si %	P %	S %	Cu %
S355J2	0.20	1.60	0.55	0.030	0.030	0.55

Where:

- C % = Carbon content in percent
- Mn % = Manganese content in percent
- Si % = Silicon content in percent
- P % = Phosphorus content in percent
- S % = Sulphur content in percent
- Cu % = Copper content in percent

According to the chemical composition, S355J2 steel grade can be classified under the medium-carbon steels, this could be expected because most structural applications use low- or medium-carbon steel.

2.3.2 Stainless steel

Stainless steels is a group of steel that forms when a minimum of 10.5% chromium is added as an alloy. This group is characterized by an chromium-rich oxide film at its surface, this film forms spontaneously and reforms immediately with the presence of oxygen when being damaged. The passive layer gives stainless steel the special property of corrosion resistance and its stability depends on the corrosiveness of the surrounding environment. Its stability can be increased by increasing the chromium content or adding other alloying elements such as nitrogen and molybdenum to the steel. Stainless steels can be classified into 5 groups: austenitic stainless steel, ferritic stainless steel, duplex stainless steel, martensitic stainless steel and precipitation stainless steel. Each of these groups is specified by different mechanical and corrosion properties. Giving the high cost of the different type of stainless steels, associated to the amount of alloying element, it is important to select the most cost-effective type of stainless steel adequate for the application. For the sake of this study we will only consider the stainless steel suitable for structural applications, which are austenitic-, ferritic- and duplex stainless steels [3] [11].

2.3.2.1 Austenitic stainless steel

Austenitic stainless steel is characterised by 16.5 to 19.5% chromium and 8 to 11% nickel as alloying elements in its chemical composition. Furthermore it has a fcc arrangement compared to the bcc arrangement of classic structural carbon steels. As well as an considerably better toughness over a wide range of temperatures. Their combination of good corrosion resistance, strength, weldability, formability and high plastic deformation before fracturing makes them by far the most frequently used material when it comes to construction and structural applications. For this study the grade 1.4318 austenitic stainless steel will be used and its chemical composition is given in table 2 [11].

Table 2: Austenitic stainless steel grade 1.4318 chemical composition [12]

Steel grade	C %	Si %	Mn %	Cr %	Ni %	P %	S %	N %
1.4318	0.03	1.0	2.0	16.5 - 18.5	6.0 - 8.0	0.045	0.015	0.1 - 0.2

Where:

- C % = Carbon content in percent
- Si % = Silicon content in percent
- Mn % = Manganese content in percent
- Cr % = Chromium content in percent
- Ni % = Nickel content in percent
- P % = Phosphorus content in percent
- S % = Sulphur content in percent
- N % = Nitrogen content in percent

The chemical composition shows that grade 1.4318 is a high nitrogen and low carbon stainless steel and presents high mechanical properties which will be discussed further on in the thesis.

2.3.2.2 Ferritic stainless steel

The alloying elements that make a ferritic stainless steel are between 10.5 and 18% chromium and either no or very small amounts of nickel. Their crystalline structure is bcc and is the same as a structural carbon steel. Furthermore it has similar mechanical properties to a S355 structural carbon steel. When compared to equal austenitic grades they show less weldability and ductility, but on the other hand, it is less costly than austenitic stainless steel grades of equivalent corrosion resistance, due to the lower content of nickel, and knows less price fluctuations because of it. For this study, the grade 1.4003 ferritic stainless steel will be used which the chemical composition is given in table 3 [11].

Table 3: Ferritic stainless steel grade 1.4003 chemical composition [13]

Steel grade	C %	Si %	Mn %	Cr %	Ni %	P %	S %	N %
1.4003	0.03	1	1.5	10.5 - 12.5	0.3 - 1.0	0.04	0.015	0.03

Where:

- C % = Carbon content in percent
- Si % = Silicon content in percent
- Mn % = Manganese content in percent
- Cr % = Chromium content in percent
- Ni % = Nickel content in percent
- P % = Phosphorus content in percent
- S % = Sulphur content in percent
- N % = Nitrogen content in percent

The 1.4003 grade is a low carbon, low nickel stainless steel and is chosen because of its similar mechanical properties to an S355 steel which is also used in this study for the carbon steel.

2.3.2.3 Duplex stainless steel

Duplex stainless steels are characterised by the following alloying elements content: 20 to 26% chromium, 1 to 8% nickel, 0.05 to 5% molybdenum, and 0.05 to 0.3% nitrogen. Its internal structure is a mixture of ferrite and austenite, therefore it sometimes is also known as austenitic-ferritic steel. Their mechanical properties are twice as strong compared to a austenitic steel, which translates in a reduction of cross-section when used for the same application. It also makes duplex stainless steel a great option for weight-sensitive structures. But because of the high strength it has less formability then austenitic stainless steels. For this study the grade 1.4462 duplex stainless steel will be used and table 4 below will show its chemical composition [11]:

Table 4: Duplex stainless steel grade 1.4462 chemical composition [14]

Steel grade	C %	Si %	Mn %	Cr %	Ni %	P %	S %	N %	Mo %
1.4462	0.03	1	2	21 – 23	4.5 – 6.5	0.03	0.02	0.1 – 0.22	2.5 – 3.5

Where:

- C % = Carbon content in percent
- Si % = Silicon content in percent
- Mn % = Manganese content in percent
- Cr % = Chromium content in percent
- Ni % = Nickel content in percent

- P % = Phosphorus content in percent
- S % = Sulphur content in percent
- N % = Nitrogen content in percent
- Mo % = Molybdenum content in percent

The 1.4462 grade has very highs strength properties and is chosen to use in the study to study how small the cross-sections can be made.

2.3.3 Mechanical behaviour

Steel is an isotropic material, which means that it has equal mechanical properties independently of the orientation plane. The material strength properties are given by its characteristic yield strength (f_y) and characteristic ultimate strength (f_u) which can be derived from coupon tests (tension tests) and expressed by means of stress-strain curves. Figure 3 and Figure 4 compare the different stress-strain behaviours for the different materials on a single graph. They respectively represent the stress-strain curves of a S355 carbon steel and the various stainless steels used in this study up to 0.75% strains and to failure [9] [11].

When comparing the stress-strain curves it is easily noticeable that the shape of the curve for the different materials differ. Where the stainless steel shows a more rounded curve with no well-defined yield strength, the carbon steel shows a linear behaviour up to yield strength followed by a plateau before further increasing to reach ultimate strength and failure. The yield strengths of the stainless steels is defined as a proof strength, found through the offsetting of the elastic proportional limit to a 0.2% strain. Figure 5 below shows the definition of the 0.2% proof strength. Note that these values are specified as a minimum and that for smaller thicknesses and diameters their yield strength can exceed these values by 20 to 40% for austenitic stainless steel and by 5 to 20% for duplex stainless steels. For thicknesses and diameters > 25 mm the yield strength lies around the minimum values. The ultimate strength is given by the tensile strength right before failure [11].

These stress-strain curves show that stainless steel has adequate strength properties to replace carbon steel when constructing transmission towers. Table 5 below will show the exact characteristic yield and ultimate strengths of the different grades used in this study.

Table 5: Characteristic yield strength (fy) and characteristic ultimate strength (fu) values for the different steel grades

Steel grade	f_y (N/mm^2)	f_u (N/mm^2)
S355J2	355	490
1.4318	330	650
1.4003	280	450
1.4462	550	750

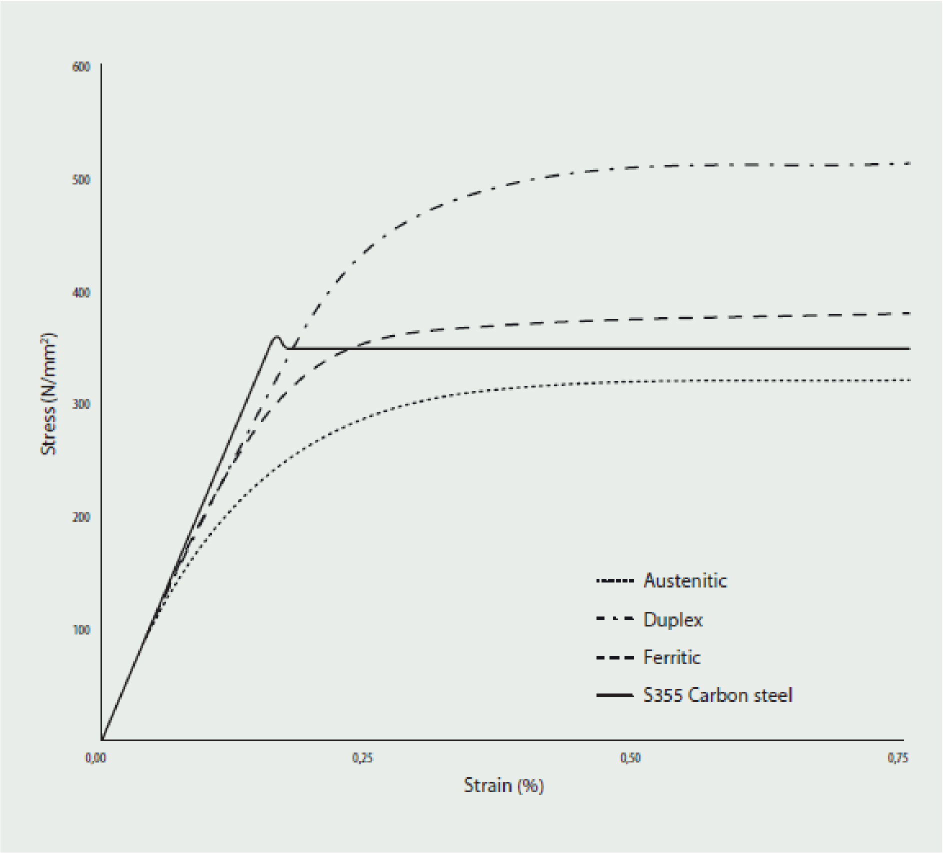


Figure 3: Stress-strain curves for carbon steel and the various stainless steels from 0 to 0.75% strain [11]

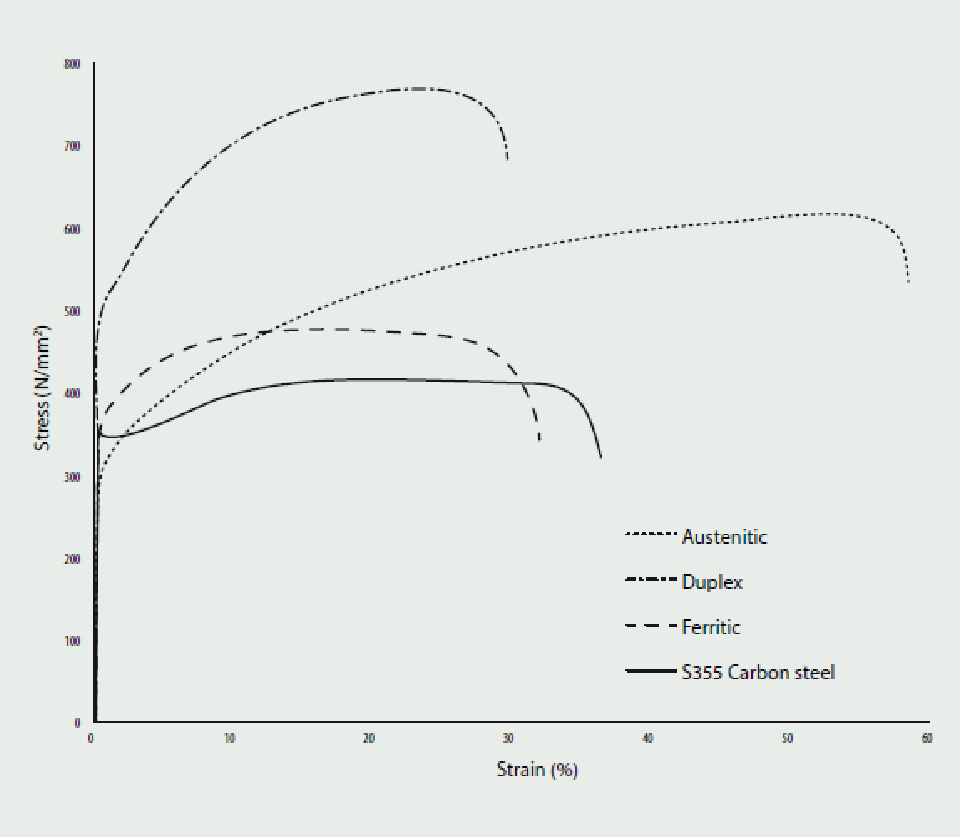


Figure 4: Stress-strain curves for carbon steel and the various stainless steels to failure [11]

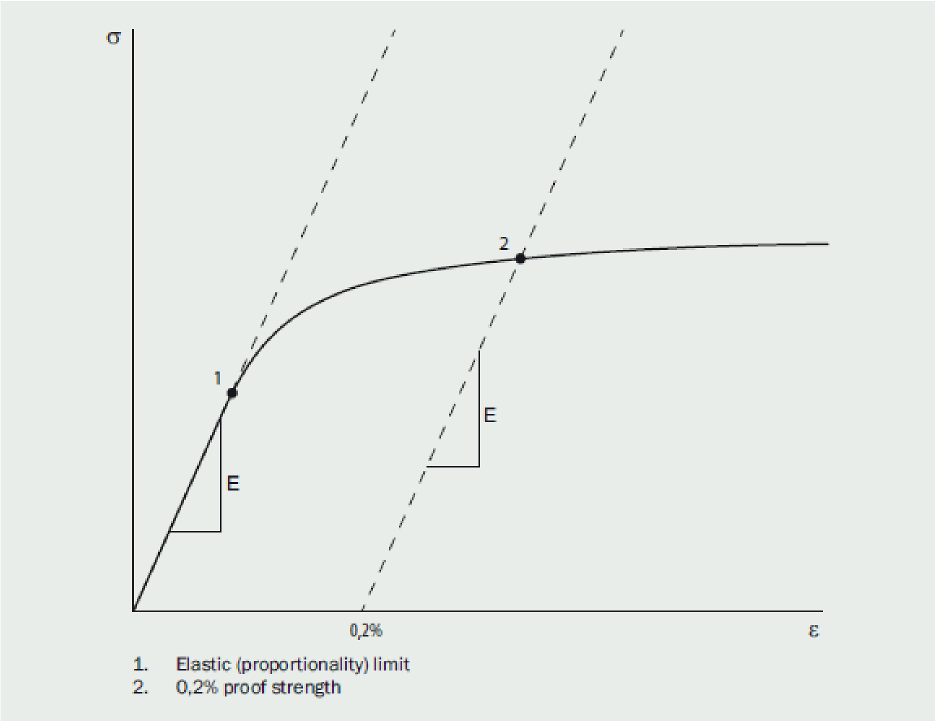


Figure 5: Definition of the 0.2% proof strength [11]

2.3.4 Corrosion behaviour

Carbon steel is known to be affected by corrosion when being exposed to water and oxygen. The corrosion process is the result of the chemical reaction between the iron atoms with water and oxygen, and may be expressed as follows:

$$\mathrm{Fe} + 3\mathrm{O}_2 + 2\mathrm{H}_2\mathrm{O} = 2\mathrm{Fe}_2\mathrm{O}_3\mathrm{H}_2\mathrm{O} \tag{1}$$

During this chemical reaction the iron in the steel oxidizes and forms hydrated ferric oxide better known as rust. The rust has approximately 6 times the volume of the original material and has insignificant resistance, therefore leading to a degradation of the material. The cross-section of the steel elements is then significantly reduced resulting in a loss of resistance and compromising the structural integrity. The corrosion rate, and therefore the rate depends on the exposure to corrosive environments [9].

Application of protective coatings such as painting and galvanization can provide a certain degree of protection to corrosion for carbon steel but they need maintenance to protect the structure for its complete life time.

Stainless steel on the other hand have a very good corrosion resistance because of their chromium oxide surface. The corrosion resistance differs per stainless steel grade and is predominately dependent on content of the alloying elements. Higher content of alloying elements will lead to an increase of corrosion resistance but also lead to an increase in material costs. Furthermore the limit of corrosion resistance depends on the exposure to corrosive environments. Table 6 shows the corrosion resistance for each different stainless steel grade used in this study.

Table 6: : Corrosion resistance for each steel grade [11]

Steel grade	Corrosion resistance	Lifespan of the corrosion resistance
S355J2	No corrosion resistance without coating	The coating protects the steel for 15 years
1.4318	Good corrosion resistance	The complete service life*
1.4003	Good for interior or mild exterior conditions	The complete service life*
1.4462	Very high corrosion resistance	The complete service life*

***The complete service life considered in this study is 60 years.**

The transmission towers, subject of investigation in this thesis, are particularly sensitive structures to corrosion given their permanent exposure to weather conditions. In order to search the potential of the different stainless steels available in the market, different grades are used in the performed analysis. In some areas there will be less exposure to corrosive environments and therefore it might be more cost efficient to use grades which have less corrosion resistance.

2.3.5 Cost

The cost difference between carbon steel and stainless steel lies in the addition of alloying elements to get a corrosive resistance material. Figure 6 shows the average material cost for carbon and austenitic stainless steel. It shows that the initial cost for austenitic stainless steel can be more than 5 times that of carbon steel. It also shows that stainless steel is way more susceptive to price volatility because of the additional alloying elements. Note that the price difference here only include raw material costs, and costs due to protective coatings were not taken into account in figure 6. Furthermore the prices shown below are average prices and these differ per grade of stainless steel, but later, in the economic analysis, this issue will be further discussed.

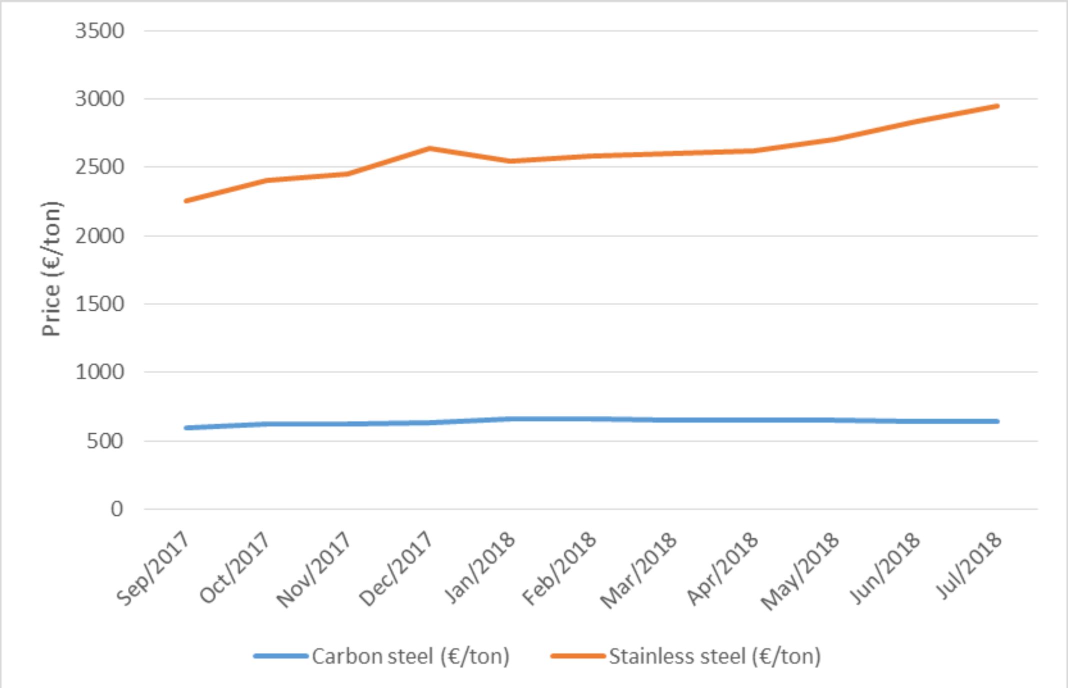


Figure 6: Price comparison carbon and stainless steel [15]

3 TRANSMISSION TOWERS IN BELGIUM

The power grid is the backbone of the electricity transmission system that connects the producers with its consumers. The grid is constructed out of transformation stations and transmission lines. The Belgian power grid also lies in the heart of an interconnected system stretching from Portugal to Poland. The system was built to enable the commercial exchange of energy and increase the reliability of electricity supply within the countries that are part of the system. This is something that Belgium desperately needs since it got confronted with several problems within some of their nuclear production plants being deactivated. Note that the reliability of electricity supply can only be guaranteed when the supply network is adequate and secure. The transmission lines are either overhead power lines connected onto transmission towers or power lines installed underground. Transmission towers are vulnerable to environmental conditions, where the supply relies on the structural integrity of the transmission tower. Whereas the underground power lines are not affected by environmental conditions since they are buried underground. However, the initial costs of underground power lines is considerably higher than those for transmission towers [16].

The Belgian power grid can be divided into 2 groups: the transmission lines on federal level and on regional level, the difference lies in the voltage running through the lines. In Belgium the voltages are grouped into 380kV to 110kV on federal level and 70kV and below on regional level and generally consist out of overhead transmission lines and transmission towers. The purpose of the transmission towers is to keep the conductors at necessary distance from another, from the earth and the people living close by. Furthermore they form the supports and the foundations of the supply network. These transmission towers are designed with a life time of 60 years. But the actual lifetime can differ on base of the structural integrity of the transmission tower, since a collapse has to be avoided at all cost [16].

Transmission towers in Belgium are currently being constructed out of carbon steel, which is not ideal for the environmental conditions in Belgium. In order to protect it from corrosion, the carbon steel is galvanized and painted with 3 layers of 2 component epoxy paint, and requires several maintenance interventions during their lifetime.

3.1 Type of transmission towers used in Belgium

The transmission towers used in Belgium are all truss structures with a different layout depending on their location, the transporting voltage and other static aspects. Figures 7 and 8 show a few examples of transmission towers used in Belgium. Note that some transmission towers are painted red and white, this will make them visible at night for planes in order to prevent them crashing into them.

Figure 7: 380kV transmission tower build at Brume [17]

Figure 8: 150kV transmission tower build at Keerbergen [17]

3.2 Maintenance of transmission towers

The main reason to perform maintenance on transmission towers is because of security reasons. Malfunctions could cause harm to people who get close to the transmissions towers as well as interruptions in the electricity distribution. In order to prevent this Elia, the Belgian network administrator, conducts manual revisions every 6 months. Most problems are found on the earth leakage of the transmissions towers, which are the main safety valves when it comes to electrocution. A good earth leakage is achieved through several conductors which are buried in the ground and which will deflect the electricity into the ground during a malfunction. These conductors are electrodes which are known to be susceptive to corrosion and need proper maintenance to ensure there working. Furthermore the workers will also carry out a visual check on the transmissions tower to validate the structural integrity and reparation are planned if needed. Additionally they conduct minor maintenance (lubrication and timing adjustments) on the high-voltage air-blast breakers. The costs of these semi-annual revisions are fairly high due to the required specialised equipment for the maintenance of the earth leakage. [18] [19]

Secondly every 10 years, the replacement of some minor parts is performed. Followed by a major maintenance every 15 years, during which an overhaul of the high-voltage air-blast breakers is performed alongside a complete repainting of the tower to renew its resistance against corrosion. The major maintenance is performed to ensure the longevity of the structures lifetime and to reduce failure costs as much as possible, because studies have shown that regular maintenance will be more cost efficient than replacements costs due to failure [19].

The costs due to transportation to and from the transmission towers for maintenance are not high in Belgium, because Belgium is a small country and has high population density results in easy accessibility for most transmission towers. However there still are some transmission towers build in rural areas but because they are a minority these costs will not be taken into account during this study.

3.3 Potential of the stainless steel

Stainless steel has proven to have adequate strength to replace carbon steel in transmission towers. Studies [20] have also proven that stainless steel has good electrical conductivity resulting in the conductors for the earth leakage can also be changed with stainless steel. Since all corrosive elements can now be replaced by a non-corrosive material the amount of required revisions will decrease drastically. Less maintenance will decrease the costs and make up for the higher initial cost of the stainless steel. Resulting in an overall cheaper and more durable application for transmission towers. Exact cost calculations and comparisons will be conducted in the economic analysis further on.

Furthermore, painting normally requires the use of pollutant products which will have a negative impact in the environment. Here, also the benefits of the stainless steel can be evident has the required maintenance interventions should be significantly smaller. Though this is an important issue in the present days, the environmental impact is not subject of the present thesis.

4 CASE STUDY

4.1 Description of case study

A case-study of a transmission tower was used to evaluate the effectiveness of stainless steel. This located in Godsheide (Diepenbeek) Belgium, and is used in a 70kV line. This tower, is constructed out of S355J2 galvanized steel, connected by 4.6, 5.8 and 8.8 DIN7990 galvanized bolts, and has a total height of 46.35 m divided in 4 parts: the foot, the bottom part, the upper part and the peak. When different heights are required within the same transmission line, the foot layout changes while the rest of the structures remains the same. Figure 9 below shows the structural layout of the case studied. The tower structure consist in a 3D truss structure typically used in this type of infrastructure.

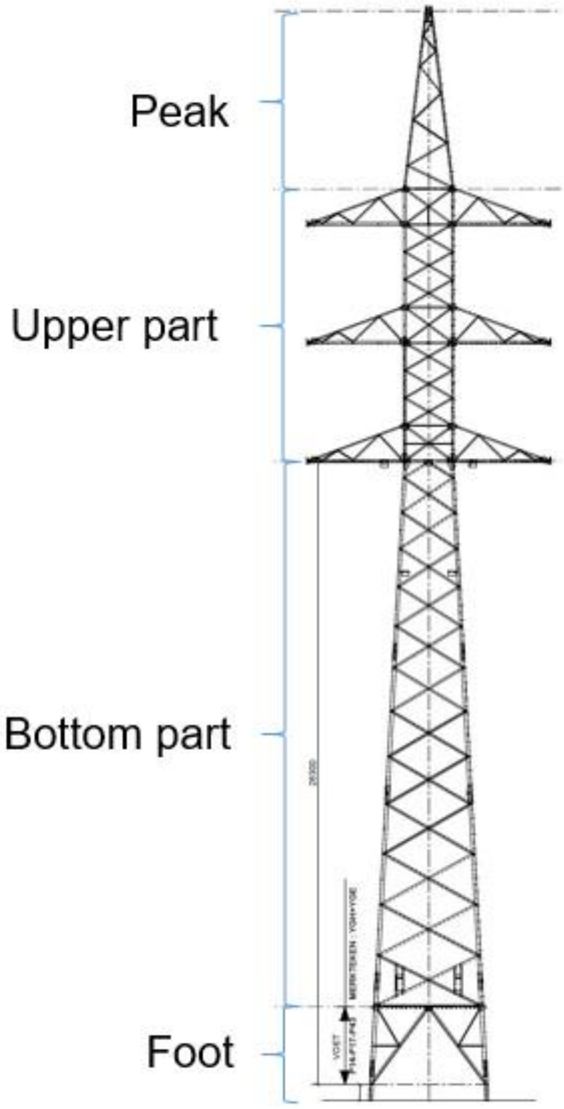


Figure 9: Structural scheme of the transmission tower used as case study

The realized study considered the design of the tower using different type of steel. In total four cases were designed using the following steel grades: S355 carbon steel, 1.4318 austenitic stainless steel, 1.4003 ferritic stainless steel, 1.4462 duplex stainless steel. The performed design only considered the tower structural member, the design of the connections was not part of the present investigation. The structural design followed the guidelines within Eurocode 3, more specifically EN1993-1-1 [21] and EN1993-1-4 [22], to meet European standards. Furthermore for the sake of simplicity, a single cross-section catalogue was used for all materials, to obtain the cross-section properties needed for the design process.

4.2 Structural model

The linear analysis of the tower is carried out with Autodesk Robot Structural Analysis Professional (RSAP). To perform a linear analysis, a structural model was built according to the original as built plans of the case study. The structure was modelled with as space truss frame, using beam elements, to perform a 3D analysis. The considered loads were the following: self-weight, cables, voltage breakers and wind. Figure 10 below shows the structural model built in RSAP.

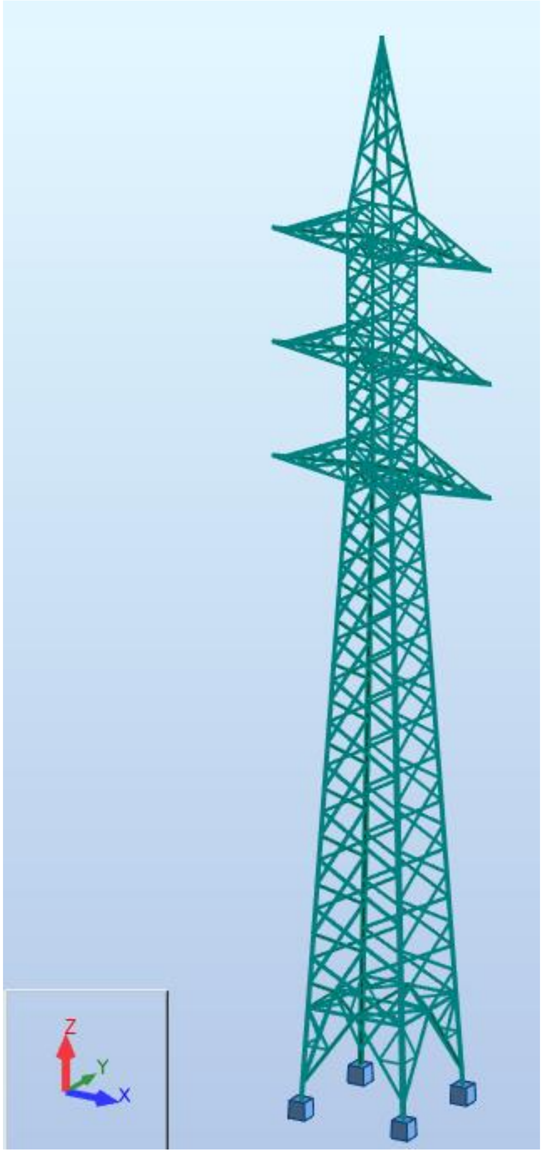


Figure 10: Structural model in RSAP of the transmission tower

4.3 Loading and combination of loads

The original loads, which were used by the engineering company that designed the real transmission tower, were applied in the structural model to recreate the current situation as accurately as possible. This allows for the design of adequate stainless steel solutions, which could directly be applied in practice. The different load cases are grouped by numbers as followed 1001.000, each number refers to a different case, were the first 4 numbers refer to a cable configuration and the conditions, while the last 3 refer to the direction of the wind. Within these cases only the wind on the cables is taken into account, the wind on the tower itself is generated with RSAP, and combined with the load cases and the wind afterwards. Figure 11 below shows an example of a load case.

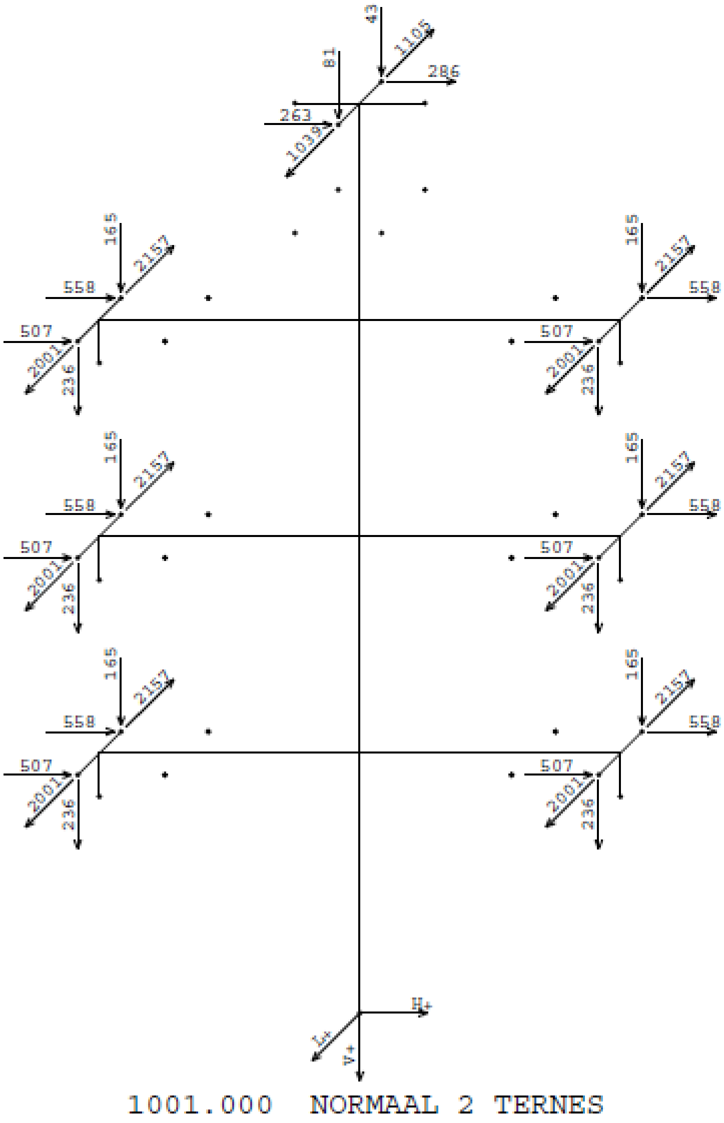


Figure 11: Example load case

The load cases range from 1001.000 to 5003.89 and a complete overview can be found in Annex A. Cases 1001.000 till 1003.315 take wind into account from all the possible angles, whereas all the other cases only consider wind at a 89-90° angle because this leads to the most critical loads. Figure 12 below shows the definition of the wind angle and table 7 shows the description of the load cases.

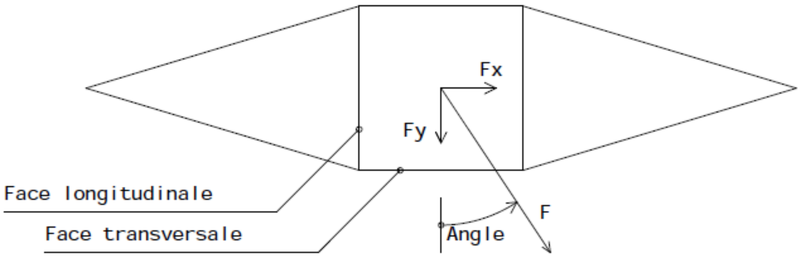
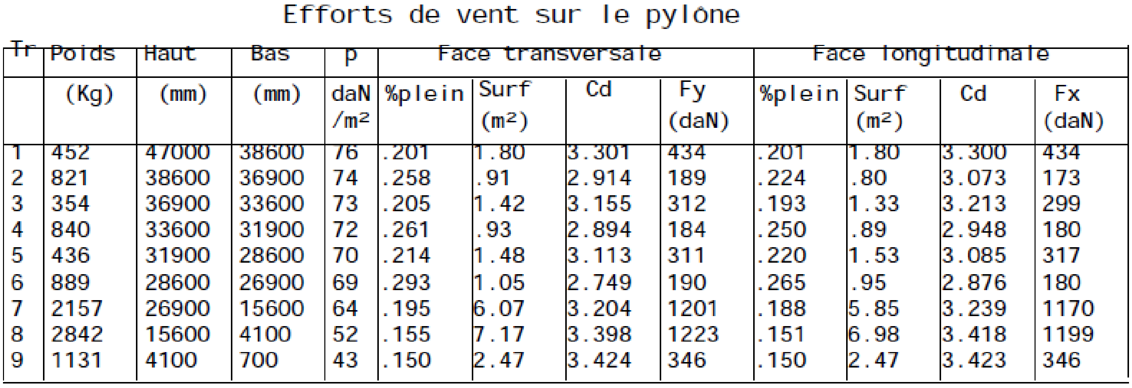


Figure 12: Definition of the wind angle

Table 7: Description of the load cases

Load cases	Conditions
1001 to 1003	Normal conditions
2001	Exceptional wind
3001 to 3030	Accidental where 1 cable breaks off
4001 to 4003	Maintenance
5001 to 5003	Winter conditions with ice formed on the cables

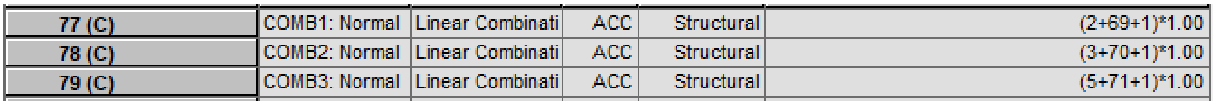
As mentioned above, the wind loads on the transmission tower are generated with a built-in function in RSAP. The wind generation function allows for wind generation in 8 different directions, starting at 0° and summing 45° at a time resulting in following possibilities: 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°. This meant that it was only possible to generate load combinations for these specific wind angles, and that some of the angles in normal conditions were left out, but that did not affect the results of the study because the most critical angles were among the generated wind directions. Figure 13 shows a table with the wind loads acting on the transmission tower, it is noticeable that the wind loads increase linearly with the height of the structure. Haut and bas give the corresponding height for which wind pressure p is valid. To recreate this in RSAP a wind profile was used, which allowed us to enter the wind pressure at the bottom of the tower and generated the correct wind pressure with the corresponding height. Once the wind was generated, the load combinations were created. Each load combination consisted of the self-weight of the structure, the wind load matching the wind direction of the specific load case and the load case itself. Figure 14 below shows an example of the load combinations and a complete overview can be found in annex A. Note that all loads, obtained from the original design notes, were already affected by the partial safety factors, resulting in the fact that all new load combinations are accidental, so that their partial safety factors are equal to 1. Otherwise the partial safety factors would be applied twice, leading to an overly conservative design.



Efforts de vent sur le pylône

Tr	Poids	Haut	Bas	p	Face transversale				Face longitudinale			
	(Kg)	(mm)	(mm)	daN /m²	%plein	Surf (m²)	Cd	Fy (daN)	%plein	Surf (m²)	Cd	Fx (daN)
1	452	47000	38600	76	.201	1.80	3.301	434	.201	1.80	3.300	434
2	821	38600	36900	74	.258	.91	2.914	189	.224	.80	3.073	173
3	354	36900	33600	73	.205	1.42	3.155	312	.193	1.33	3.213	299
4	840	33600	31900	72	.261	.93	2.894	184	.250	.89	2.948	180
5	436	31900	28600	70	.214	1.48	3.113	311	.220	1.53	3.085	317
6	889	28600	26900	69	.293	1.05	2.749	190	.265	.95	2.876	180
7	2157	26900	15600	64	.195	6.07	3.204	1201	.188	5.85	3.239	1170
8	2842	15600	4100	52	.155	7.17	3.398	1223	.151	6.98	3.418	1199
9	1131	4100	700	43	.150	2.47	3.424	346	.150	2.47	3.423	346

Figure 13: Wind loads in function of the corresponsive height on the transmission tower



77 (C)	COMB1: Normal	Linear Combinati	ACC	Structural	(2+69+1)*1.00
78 (C)	COMB2: Normal	Linear Combinati	ACC	Structural	(3+70+1)*1.00
79 (C)	COMB3: Normal	Linear Combinati	ACC	Structural	(5+71+1)*1.00

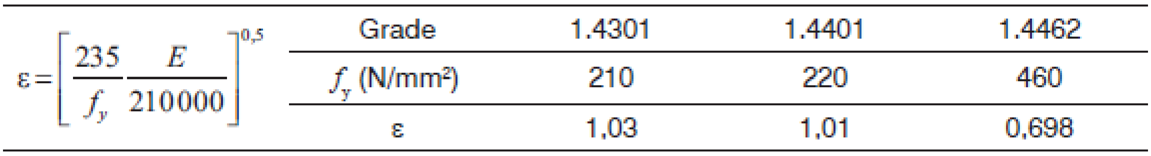
Figure 14: Example of the load combinations made

4.4 Structural Design

The structural design is split in 2 parts, the design within RSAP and the design in excel. RSAP did not allow a change in design codes to EN1993-1-4, the design stainless steel solutions was then performed manually in a Excel file implementing the design prescriptions for this type of steel. Table 8 shows the yield strength, ultimate strength, elasticity modulus and density per steel grade used for the design. Note that the elasticity modulus (E) is equal for all stainless steel grades, but the elasticity modulus for ferritic stainless steel grades is 220x10^3 N/mm^2 given by EN1993-1-4. The change is made because tests consistently indicate that a value of 200x10^3 N/mm^2 is more appropriate, and therefore the next revision of EN1993-1-4 will adapt and recommend this value for structural design for all stainless steels [11]. Furthermore the yield strength of the 1.4462 duplex stainless steel is lowered to 460 from 550 as shown in figure 15. Lastly table 9 shows the partial factors used during the design for carbon and stainless steel.

Table 8: Mechanical properties used during the design [11]

Steel grade	f_y (N/mm^2)	f_u (N/mm^2)	E (N/mm^2)	ρ (kg/m^3)
S355J2	355	490	210000	7850
1.4318	330	650	200000	7900
1.4003	280	450	200000	7700
1.4462	460	750	200000	7800



$$\varepsilon = \left[\frac{235}{f_y}\frac{E}{210000}\right]^{0,5}$$

Grade	1.4301	1.4401	1.4462
f_y (N/mm²)	210	220	460
ε	1,03	1,01	0,698

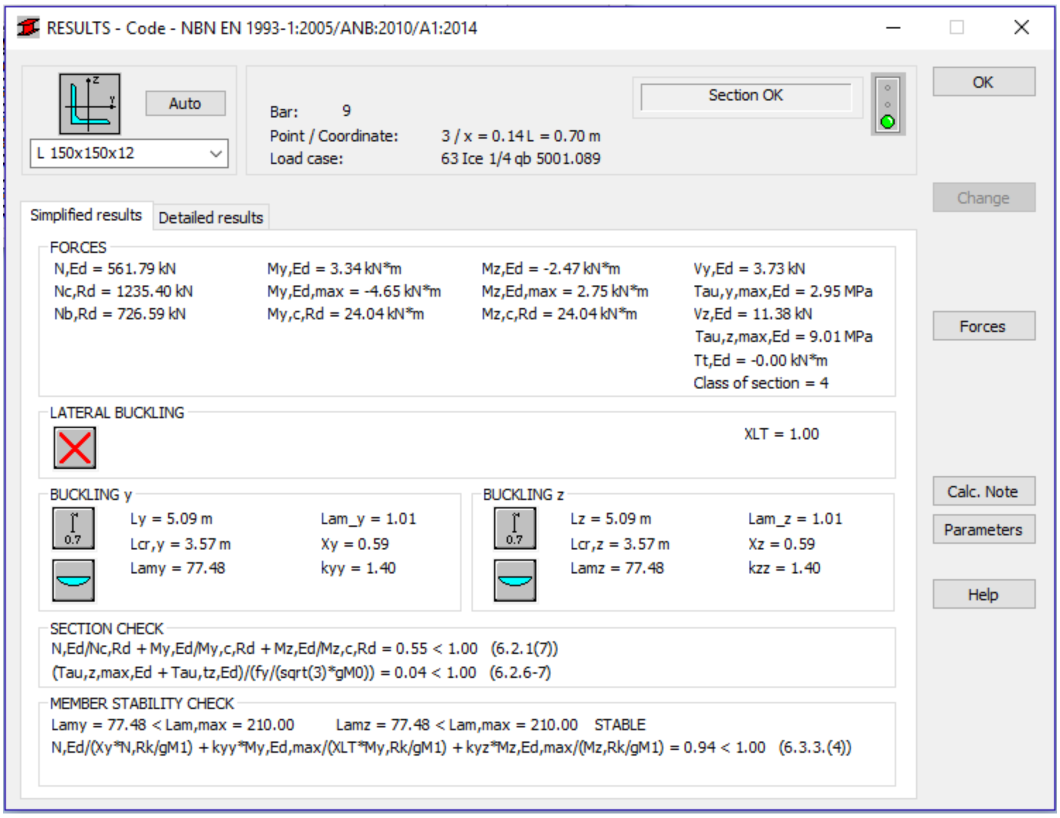
Figure 15: Characteristic yield strength value for 1.4462 [11]

Table 9: Partial factors used during design [21] [22]

Partial factor	Carbon steel	Stainless steel
γ_{Mo}	1	1.1
γ_{M1}	1	1.1
γ_{M2}	1.25	1.25

4.4.1 Carbon steel

Since the carbon steel tower is already designed by an engineering company the choice was made to only verify the original design within RSAP. The verification followed the design rules in EN1993-1-1 and figure 16 shows an example of a design check of a structural element. A complete list of the verification can be found in annex B.



```
Bar:              9
Point / Coordinate:   3 / x = 0.14 L = 0.70 m
Load case:            63 Ice 1/4 qb 5001.089

FORCES
N,Ed = 561.79 kN        My,Ed = 3.34 kN*m          Mz,Ed = -2.47 kN*m         Vy,Ed = 3.73 kN
Nc,Rd = 1235.40 kN      My,Ed,max = -4.65 kN*m     Mz,Ed,max = 2.75 kN*m      Tau,y,max,Ed = 2.95 MPa
Nb,Rd = 726.59 kN       My,c,Rd = 24.04 kN*m       Mz,c,Rd = 24.04 kN*m       Vz,Ed = 11.38 kN
                                                                              Tau,z,max,Ed = 9.01 MPa
                                                                              Tt,Ed = -0.00 kN*m
                                                                              Class of section = 4

LATERAL BUCKLING
                                                                   XLT = 1.00

BUCKLING y                                     BUCKLING z
     Ly = 5.09 m         Lam_y = 1.01               Lz = 5.09 m          Lam_z = 1.01
     Lcr,y = 3.57 m      Xy = 0.59                  Lcr,z = 3.57 m       Xz = 0.59
     Lamy = 77.48        kyy = 1.40                 Lamz = 77.48         kzz = 1.40

SECTION CHECK
N,Ed/Nc,Rd + My,Ed/My,c,Rd + Mz,Ed/Mz,c,Rd = 0.55 < 1.00   (6.2.1(7))
(Tau,z,max,Ed + Tau,tz,Ed)/(fy/(sqrt(3)*gM0)) = 0.04 < 1.00   (6.2.6-7)

MEMBER STABILITY CHECK
Lamy = 77.48 < Lam,max = 210.00       Lamz = 77.48 < Lam,max = 210.00    STABLE
N,Ed/(Xy*N,Rk/gM1) + kyy*My,Ed,max/(XLT*My,Rk/gM1) + kyz*Mz,Ed,max/(Mz,Rk/gM1) = 0.94 < 1.00   (6.3.3.(4))
```

Figure 16: Verification of 1 of the carbon steel elements

4.4.2 Stainless steel

The material properties were changed and a linear analysis was run in RSAP to determine the design loads. The design of the of the stainless steel elements was done according to EN1993-1-4, and in order to not make the calculations over complex the study limited itself to a class 3 cross-section. During the design following steps were followed, note that following equations only are used for class 3 cross-sections and are therefore not valid for other classes:

1. Classification of the cross-section.

In order to not exceed class 3, the profiles cross-section's maxim width-to-thickness ratio had to comply with:

$$\frac{h}{t} \leq 15 * \varepsilon \ ; \frac{b+h}{2*t} \leq 11.5 * \varepsilon \qquad (2)$$

$$\varepsilon = \left[\frac{235}{f_y} * \frac{E}{200000}\right]^{0.5} \qquad (3)$$

Where:

h	is the height of the cross-section;
b	is the width of the cross-section;
t	is the thickness of the cross-section;
ε	is the strain;
f_y	is the yield strength;
E	is the elasticity modulus;

2. Determination of the compression and tension resistance.

For some load cases an element would be in compression while in other cases it was in tension, and therefore the study checked both the compression and tension resistance of the element for each critical case.

Compression:

$$N_{c,Rd} = \frac{A*f_y}{\gamma_{M0}} \qquad (4)$$

Where :

$N_{c,Rd}$	is the bending resistance;
A	is the area of the cross-section;
f_y	is the characteristic yield strength;

Tension:

$$N_{pl,Rd} = \frac{A*f_y}{\gamma_{M0}} \qquad (5)$$

Where:

$N_{pl,Rd}$	is the tension resistance;
A	is the area of the cross-section;
f_y	is the characteristic yield strength;

3. Verification the maximum stress.

In the cases of combined axial force and bending moment, the stresses within the stainless steel elements should satisfy the following criterion, in case it is bigger than the resistance stability problems will occur:

$$\sigma x \leq \frac{f_y}{\gamma_{M0}} \qquad (6)$$

$$\sigma x = \frac{N_{Ed}}{A} + \frac{M_{Ed}}{W_{el}} \qquad (7)$$

Where:

σ_x	is the maximum stress in the element;

- f_y is the characteristic yield strength;
- A is the gross area;
- N_{Ed} is the maximum axial force in the element;
- M_{Ed} is the maximum bending moment in the element
- W_{el} is the elastic section modulus corresponding to the fibre with the maximum elastic stress;

4. Determination of the bending resistance.

$$M_{c,Rd} = \frac{W_{el} * f_y}{\gamma_{M0}} \tag{8}$$

Where:

- $M_{c,rd}$ is the bending resistance;
- W_{el} is the elastic section modulus corresponding to the fibre with the maximum elastic stress;
- f_y is the characteristic yield strength;

5. Verification of the shear resistance.

$$V_{pl,Rd} = \frac{Av * (f_y/\sqrt{3})}{\gamma_{M0}} \tag{9}$$

$$\frac{V_{Ed}}{V_{pl,Rd}} \leq 1.0 \tag{10}$$

Where:

- $V_{pl,Rd}$ is the shear resistance;
- Av is the shear area;
- f_y is the characteristic yield strength;
- V_{Ed} is the maximum design shear force;

6. Determination of the buckling resistance.

$$N_{b,Rd} = \frac{\chi * A * f_y}{\gamma_{M1}} \tag{11}$$

Where:

- $N_{b,Rd}$ is the buckling resistance;
- f_y is the characteristic yield strength;
- A is the gross area;
- χ is the reduction factor accounting for buckling, given by:

$$\chi = \frac{1}{\phi + [\phi^2 - \lambda^2]^{0.5}} \leq 1 \tag{12}$$

In which:

$$\phi = 0.5\,(1 + \alpha(\lambda - \lambda_0) + \lambda^2) \tag{13}$$

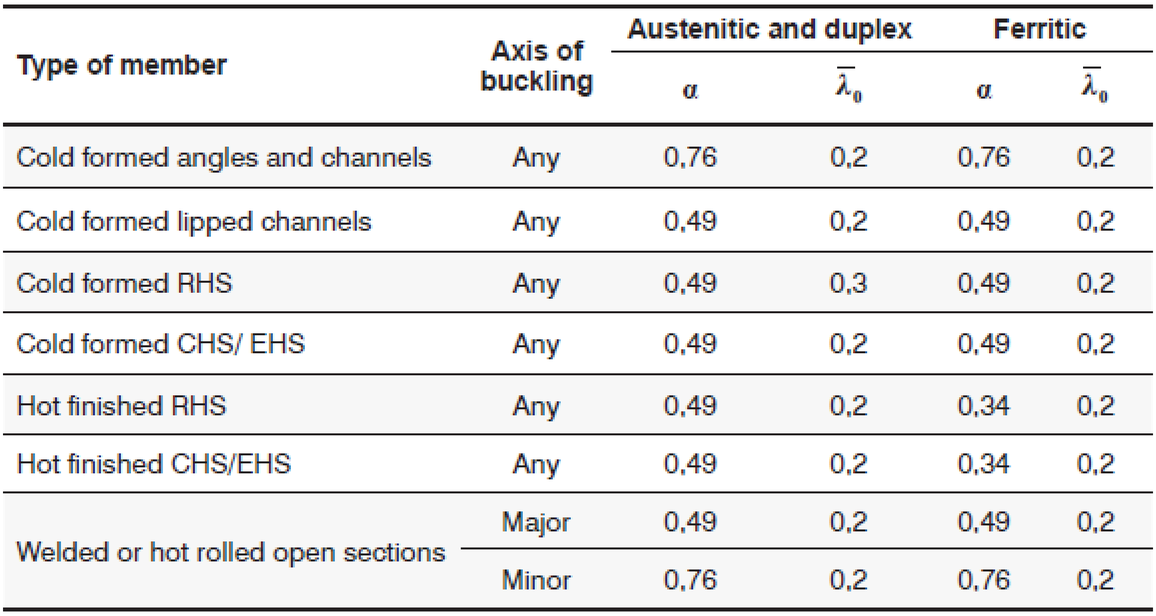
$$\lambda = \sqrt{\frac{A * f_y}{N_{cr}}} \tag{14}$$

$$N_{cr} = \frac{\pi^2 * E * I}{{L_{cr}}^2} \qquad (15)$$

Where:

- α is the imperfection factor defined in figure 17;
- λ is the limiting slenderness;
- λ_0 is the non-dimensional limiting slenderness;
- N_{cr} is the critical buckling force relevant to the buckling mode;
- L_{cr} is the buckling length in the considered buckling plane;
- E is the elasticity modulus;
- I is the moment of inertia;

Note that the values in figure 17 are more conservative than those in EN1993-1-4. This is because experimental research over the last 10 years has demonstrated that the values in EN1993-1-4 are too optimistic, and that there is a difference in the behaviour of austenitic and duplex stainless steels compared to ferritic stainless steels. It is therefore expected that EN1993-1-4 will adopt the values defined in figure 17.



Type of member	Axis of buckling	Austenitic and duplex		Ferritic	
		α	$\bar{\lambda}_0$	α	$\bar{\lambda}_0$
Cold formed angles and channels	Any	0,76	0,2	0,76	0,2
Cold formed lipped channels	Any	0,49	0,2	0,49	0,2
Cold formed RHS	Any	0,49	0,3	0,49	0,2
Cold formed CHS/ EHS	Any	0,49	0,2	0,49	0,2
Hot finished RHS	Any	0,49	0,2	0,34	0,2
Hot finished CHS/EHS	Any	0,49	0,2	0,34	0,2
Welded or hot rolled open sections	Major	0,49	0,2	0,49	0,2
	Minor	0,76	0,2	0,76	0,2

Figure 17: Values for α and λ_0 for buckling [11]

7. Determination of the lateral-torsional buckling (LTB) resistance.

Note that for angled cross-sections the calculations for LTB are carried out around the principal axes instead of the geometric axes. So the y and z axis should be taken as the u and v axis respectively.

$$M_{b,Rd} = \frac{\chi_{lt} * W_{el} * f_y}{\gamma_{M1}} \qquad (16)$$

Where:

- $M_{b,Rd}$ is the buckling resistance;
- W_{el} is the elastic section modulus corresponding to the fibre with the maximum elastic stress;
- f_y is the characteristic yield strength;

- χ_{lt} is the reduction factor accounting for LTB, given by:

$$\chi_{lt} = \frac{1}{\phi_{lt}+[{\phi_{lt}}^2-{\lambda_{lt}}^2]^{0.5}} \leq 1 \tag{17}$$

In which:

$$\phi_{lt} = 0.5\,(1+\alpha_{lt}(\lambda_{lt}-0.4)+{\lambda_{lt}}^2) \tag{18}$$

$$\lambda_{lt} = \sqrt{\frac{W_{el}*f_y}{M_{cr}}} \tag{19}$$

Where:

- α_{lt} is the imperfection factor for LTB defined in table 10;
- λ_{lt} is the limiting slenderness for LTB;
- W_{el} is the elastic section modulus corresponding to the fibre with the maximum elastic stress;
- f_y is the characteristic yield strength;
- M_{cr} is the critical bending moment for LTB defined in equation (20);

Table 10: Imperfection factors for LTB

Sections	A
Cold formed sections and hollow sections	0.34
Welded open sections and sections for which no data is available	0.76

Following equation is taken out of the American design guide for steel buildings [23] and gives the calculation method for M_{cr}:

$$Mcr = \frac{9*E*A*r_z*t*C_b}{8*L_b}\left[\sqrt{1+\left(4.4\frac{\beta_w*r_z}{L_b*t}\right)^2}+4.4\frac{\beta_w*r_z}{L_b*t}\right] \tag{20}$$

Where:

- E is the elasticity modulus;
- A is the area of the angle;
- r_z is the radius of gyration about the minor principal axis;
- t is the thickness of the cross-section;
- L_b is the maximum laterally unbraced length of the element;
- B_w is 0 for equal leg members;
- C_b is given by:

$$Cb = \frac{12.5M_{max}}{2.5M_{max}+3M_A+4M_B+M_B} \leq 1.5 \tag{21}$$

In which:

- M_{max} is the absolute value of the maximum moment in the unbraced segment;
- M_A is the absolute value of the moment at ¼ point in the unbraced segment;
- M_B is the absolute value of the moment at ½ point in the unbraced segment;
- M_C is the absolute value of the moment at ¾ point in the unbraced segment;

Because the bending moment were not very high, the following check was made to see if LTB calculations were needed:

$$\frac{M_{ed}}{M_{cr}} \leq 0.16 \tag{22}$$

For all 3 stainless steels the most critical element was checked, and it was concluded that none of them needed LTB calculations.

8. Stability verification.

Members subjected to a combination of axial loads and bending the moments are split up in to 2 groups: axial tension and bending, and axial compression and bending. Since some elements can be in both states depending on the load case, they should respectively satisfy equations (23) and (24) to pass the design verification:

$$\frac{N_{ed}}{N_{pl,Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1 \tag{23}$$

Where:

N_{ed}	is the design tensile load;
$N_{pl,Rd}$	is the tension resistance;
$M_{y,Ed}$	is the design moment around the y-axis;
$M_{y,Rd}$	is the moment resistance around the y-axis;
$M_{z,Ed}$	is the design moment around the z-axis;
$M_{y,Rd}$	is the moment resistance around the z-axis;

$$\frac{N_{ed}}{N_{b,Rd,min}} + k_y \frac{M_{y,Ed}+N_{ed}*e_{Ny}}{\beta_{w,y}*W_{pl,y}*\frac{f_y}{\gamma_{M1}}} + k_z \frac{M_{z,Ed}+N_{ed}*e_{Nz}}{\beta_{w,z}*W_{pl,z}*\frac{f_y}{\gamma_{M1}}} \leq 1 \tag{24}$$

Where:

- N_{ed}, $M_{y,Ed}$, $M_{z,Ed}$ are the design values of the compression force and the maximum bending moments;

e_{Ny}, e_{Nz}	are the shifts in the neutral axes and are 0 for class 3;
$N_{b,Rd,min}$	is the smallest resistance value for the buckling around y-axis and buckling around z-axis;
$W_{pl,y}$, $W_{pl,z}$	= $W_{el,y}$ and $W_{el,z}$ for angled cross-sections.
$B_{w,y}$, $\beta_{w,z}$	= W_{el}/W_{pl} for class 3, and is 1 in this case because $W_{el} = W_{pl}$.
f_y	is the characteristic yield strength;
k_y, k_z	are given by equations (25) and (26):

$$k_y = 1 + 2(\lambda_y - 0.5)\frac{N_{ed}}{N_{b,Rd,y}} \;\; but\; 1.2 \leq k_y \leq 1.2 + 2\frac{N_{ed}}{N_{b,Rd,y}} \tag{25}$$

$$k_z = 1 + 2(\lambda_z - 0.5)\frac{N_{ed}}{N_{b,Rd,z}} \;\; but\; 1.2 \leq k_z \leq 1.2 + 2\frac{N_{ed}}{N_{b,Rd,z}} \tag{26}$$

A complete overview of the stainless steel design calculation notes can be found in annex C.

4.4.3 Results

The results of the redesigned carbon steel elements into stainless steel are shown in table 11. While table 12 shows an overview of the global weight and surface area per transmission tower. The results show a slight increase in global weight for the stainless steel transmission towers, this can be attributed to two factors: the safety levels present within the stainless steel design codes, and the fact that this study only considered class 3 cross-sections. It is therefore worth mentioning that a more optimal solution could be obtained when considering all classes of cross-sections. The stainless steel solutions have resulted in an increase of global weight by 6.35%, 5.74% and 2.64% for austenitic-, ferritic- and duplex stainless steel respectively. Furthermore a decrease in surface area can be noticed, this can be attributed to the fact that the general dimensions of the stainless steel cross-section got smaller, but increased in thickness. The stainless steel transmission towers decreased in surface area by 15.94%, 14.12% and 23.06% for austenitic-, ferritic- and duplex stainless steel respectively.

Table 11: Overview of the redesigned transmission towers

Original cross-section (mm)	Number of bars	New cross-section (mm)		
		Austenitic	Ferritic	Duplex
L150x150x12	4	L150x150x16	L150x150x16	L140x140x18
L140x140x12	4	L120x120x13	L130x130x13	L110x110x14
L140x140x10	4	L110x110x14	L120x120x12	L100x100x14
L120x120x10	4	L110x110x12	L110x110x12	L100x100x14
L100x100x8	12	L80x80x9	L80x80x8	L70x70x9
L100x100x7	4	L80x80x9	L80x80x9	L60x60x8
L100x100x6	2	L60x60x7	L60x60x7	L60x60x8
L90x90x6	12	L70x70x8	L70x70x8	L60x60x8
L80x80x6	12	L70x70x8	L70x70x7	L60x60x8
L75x75x6	36	L60x60x7	L70x70x7	L60x60x8
L75x75x5	28	L60x60x7	L60x60x7	L60x60x8
L70x70x5	54	L60x60x7	L60x60x7	L50x50x9
L65x65x4	30	L50x50x6	L50x50x6	L45x45x6
L60x60x5	24	L60x60x7	L60x60x7	L50x50x9
L60x60x4	63	L50x50x6	L50x50x6	L50x50x7
L56x56x4	27	L50x50x6	L50x50x6	L45x45x6
L50x50x4	78	L35x35x4	L35x35x4	L35x35x5
L45x45x4	36	L35x35x4	L35x35x4	L35x35x5
L40x40x4	68	L35x35x4	L35x35x4	L35x35x5

Table 12: Global weight and surface for each designed transmission tower

Material	Global weight (kg)	Surface area(m^2)
Carbon steel	8399	350.06
Austenitic stainless steel	8932	294.27
Ferritic stainless steel	8881	300.63
Duplex stainless steel	8621	269.32

5 ECONOMIC ANALYSIS

The economic evaluation is based on a methodology known as Life-Cycle Cost (LCC) analysis. Experience shows that taking the complete life-cycle cost into account instead of just initial costs, when comparing different design solutions for different materials, can lead to a more cost-effective solution. In this study, it is the purpose to assess the potential of the stainless steel, a corrosion resistant material, when replacing carbon steel for the construction of transmission towers. It is expected that maintenance costs are significantly reduce, reducing the required interventions during the life time of the structure, and consequently, becoming a competitive solution. Thus, the performed LCC takes account the following:

- Production costs
- Erection costs
- Maintenance costs
- Disassembly and recycling costs

The following expression was used for the life-cycle cost analysis:

$$LCC = PC + EC + \sum_{i=1}^{n} MC + DC - RC$$

Considering PC as the production cost, EC as the erection cost, MC as the maintenance cost for a given year i, n as the considered lifetime, DC as the disassembly cost and RC as the sale of the scrap. Note that during the LCC analysis, the influence of the nominal inflation rates and interest rates were not taken into account. All the values used, are the values present at the time of the performed study.

5.1 Life-cycle estimation of the transmission tower

In general terms, it is not easy to determine the life-cycle of a transmission tower because several factors can affect its structural integrity such as a natural phenomenal, damaged electricity lines, the environment its placed in and subsidence's. Since Belgium is not known for severe weather conditions a life time of 60 years was taken, the same for which the tower was designed. To ensure the longevity of the structure the maintenance recommendations are followed, resulting in following schedule: semi-annual checks, a minor maintenance every 10 years and a major maintenance every 15 years. Over a lifespan of 60 years this leads to 112 semi-annual checks, 4 minor and 4 major maintenances. The difference between carbon steel and stainless steel transmissions towers, lies in the fact that during the major maintenance the carbon steel towers need to be completely repainted to ensure corrosion resistance and stainless steel towers do not. After its 60 year service life the transmission tower gets disassembled and the scrap is sold for recycling. Both carbon steel and stainless steel have high residual scrap value, due to the fact that they are 100% recyclable, which leads to diversions of landfills and a recycling into new metals.

5.2 Cost estimations

In the following sections, a summary of the cost per stage of the life cycle will be given, the detailed calculations can be found in annex D. Note that the given values are average values and that they differ from case to case, as well as from company to company and contractor to contractor.

5.2.1 Production

Its known that the initial costs for structural stainless steel are considerably higher than those for structural carbon steel, depending on the grade of stainless steel. However, the initial costs difference decreases when taking the costs of corrosion resistance coatings into account, and can be lowered even further upon utilising high strength stainless steel grades, resulting in a decrease in section size and overall weight of the structure. Table 13 shows an overview of the production costs for each case study. The production costs consists out of the design costs for the transmission tower, the material costs, costs of corrosive coatings and the transportation of the pre-built sections to the building site. Furthermore a linear correlation can be seen between the increase in production costs and higher grades of stainless steels.

Table 13: Production costs per case study [24] [25]

Case study	Production cost
Carbon steel	€ 33 499
Austenitic stainless steel	€ 51 143
Ferritic stainless steel	€ 39 337
Duplex stainless steel	€ 60 761

5.2.2 Erection

Erection costs considers all the costs that are made on site to build a operational transmission tower. Thus, consisting of the costs made to construct the foundations, the assembly of the transmission tower, and in case of the carbon steel the application of the last layer of paint to ensure its corrosion resistance. For the assembly of the tower a unit price in kilograms to construct is used, which includes the price of the crane needed for the construction. The price for the finishing layer of painting is given according to the surface to be painted, for which the costs of all the needed equipment, personnel are included. Furthermore costs such as plates for the crane to move on, lighting, land prices and signalisation objects are not included since they defer for each different location and are not material depend, and therefore add no value to the study. Table 14 shows an overview of the erection costs per case study. Note that the prices for the stainless steel cases are lower than for carbon steel, a fact that can bit attributed to the fact that the stainless steel towers do not need a finishing layer of paint for corrosion resistance. Furthermore the small differences in price between the stainless steel cases can be attributed to the small differences in weight of the different structures.

Table 14: Erection costs per case study [24]

Case study	Erection cost
Carbon steel	€ 114 710
Austenitic stainless steel	€ 106 971
Ferritic stainless steel	€ 106 874
Duplex stainless steel	€ 113 113

5.2.3 Maintenance

The recommended maintenance schedule is followed to ensure the structural integrity of the structure for as long as possible, because studies [19] have shown that failure costs are more cost intensive then maintenance costs. For each intervention, following non material depended costs were considered: transportation, administrative costs, equipment and safety measurements. Additionally, there is the costs of repainting to ensure the corrosion resistance of the carbon steel structures. Table 15 shows an overview of the total maintenance costs per case study for a tower with a lifetime of 60 years. As it can be observed, the stainless steel costs are considerably lower than the carbon steel. This can be attributed to the fact that stainless steel does not need extra protective coatings or maintenance of these coatings to ensure its corrosion resistance. The cost savings due to component replacement because of corrosion were not taken into account, but would increase the potential of the stainless steel transmission towers even further.

Table 15: Maintenance costs per case study [19] [24]

Case study	Maintenance cost
Carbon steel	€ 463 018
Austenitic stainless steel	€ 358 000
Ferritic stainless steel	€ 358 000
Duplex stainless steel	€ 358 000

5.2.4 Recycling

The recycling costs is split up into 2 parts: the disassembly costs and the recycling costs. The disassembly costs is given in costs per transmission tower to be disassembled, in which following costs are included: administration, crane, safety measurements, personnel, removing the foundations and land improvements . Costs accounted for transportation are not taken into account because they differ per location. Recycling costs are being subtracted from the total cost because the scrap is sold off to a steel producer for recycling. Table 16 below gives an overview of the recycling costs for each case study. Due to the high residual scrap value of stainless steel money can be recovered in this stage of the life cycle. The recovered money increase with the grade of stainless steel, because higher stainless steel grades have higher scrap value. For the carbon steel structure the scrap value reduces are not covering the disassembly costs consequently, there is still a small cost to account for in this stage.

Table 16: Recycling cost per case study [24] [25]

Case study	Recycling cost
Carbon steel	€ 9 074
Austenitic stainless steel	€ -468
Ferritic stainless steel	€ -407
Duplex stainless steel	€ -6 992

5.3 Comparative analysis

The impact of the cost at each stage of the life-cycle, within the total cost, is given as followed. Firstly the maintenance costs, which represent 75%, 69%, 71% and 68% of the total cost for carbon-, austenitic-, ferritic- and duplex stainless steel, respectively. Secondly there are the erection costs, which were 18%, 21%, 21% and 22% of the total cost for carbon-, austenitic-, ferritic- and duplex stainless steel, respectively. Thirdly the production costs, which were 5%, 10%, 8% and 12% for carbon-, austenitic-, ferritic- and duplex stainless steel respectively and lastly the recycling costs which slightly reduced the total cost for the stainless steel and had a small impact for the carbon steel. Figure 18 and 19 show a visual overview of the impact of the costs of each stage of the life-cycle within the total costs.

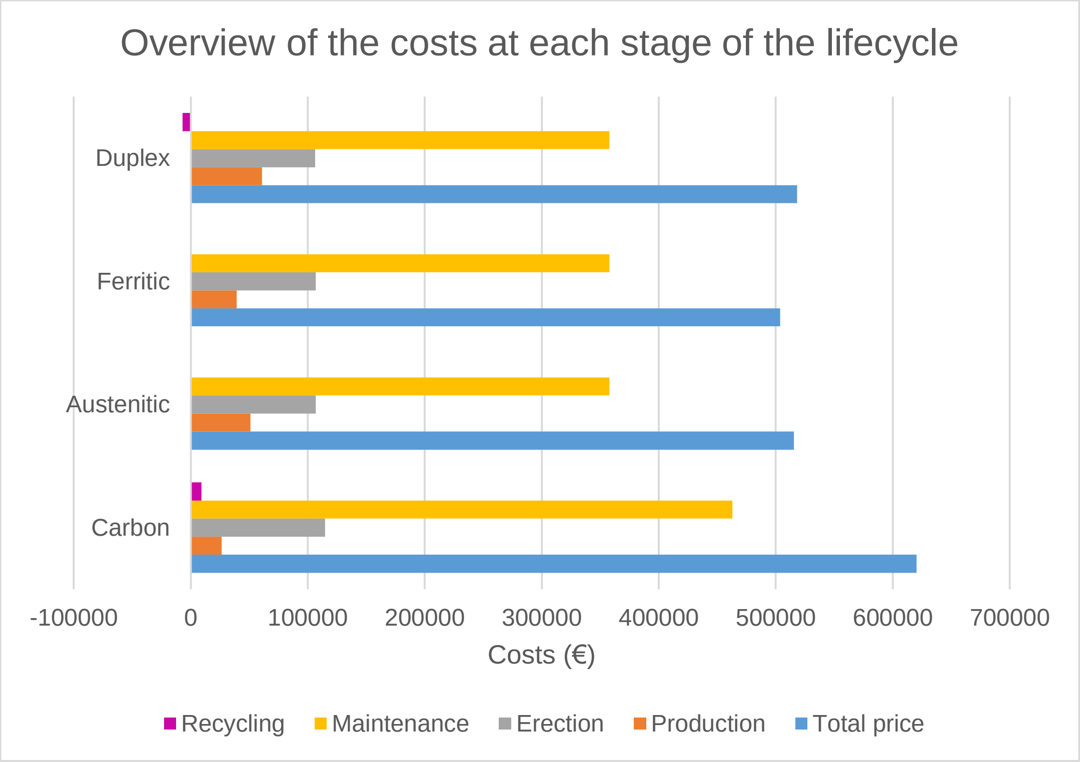


Figure 18: Overview of the costs at each stage of the lifecycle

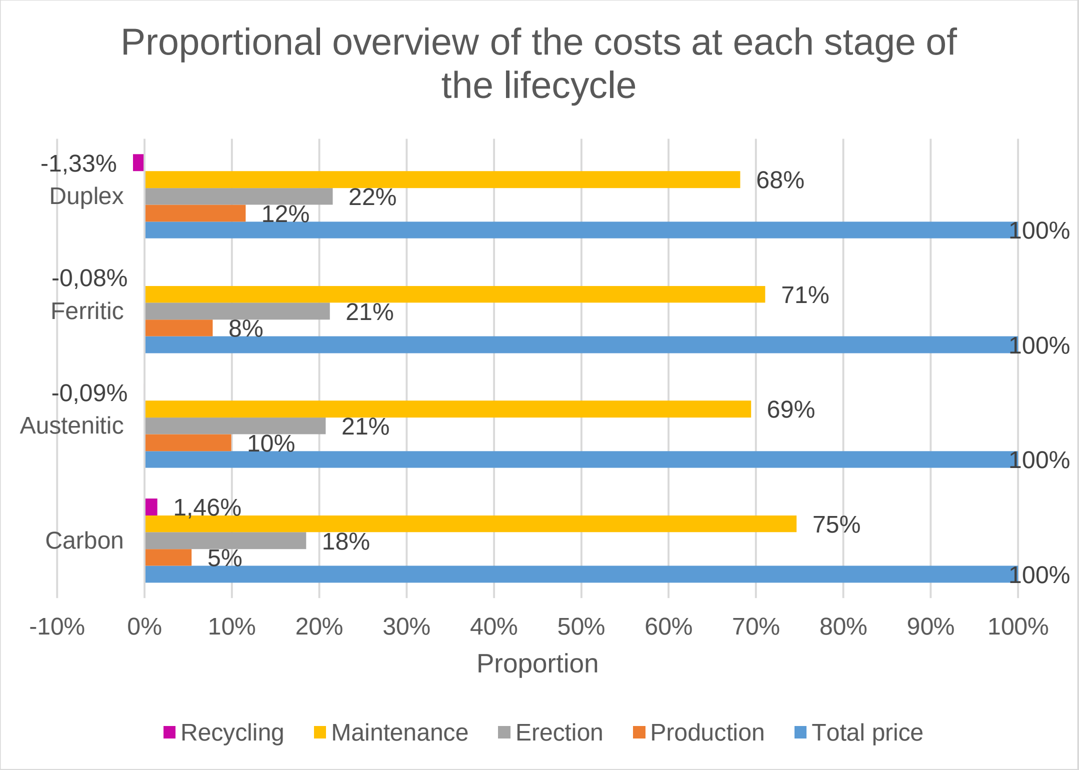


Figure 19: Proportional overview of the costs at each stage of the lifecycle

Figure 20 shows that stainless steel transmission towers are more cost efficient then carbon steel transmission towers, when the complete life cycle of the tower is taken into account. The economic benefit of the stainless steel solutions are 17%, 19% and 16% for austenitic-, ferritic- and duplex stainless steel respectively. This can be attributed to the fact that stainless steel transmission towers are significantly less cost intensive when it comes to maintenance then carbon steel, even though that the amount of maintenances is kept the same. Since maintenance costs have a high impact on the total cost, a decrease will lead to significant economic benefits.

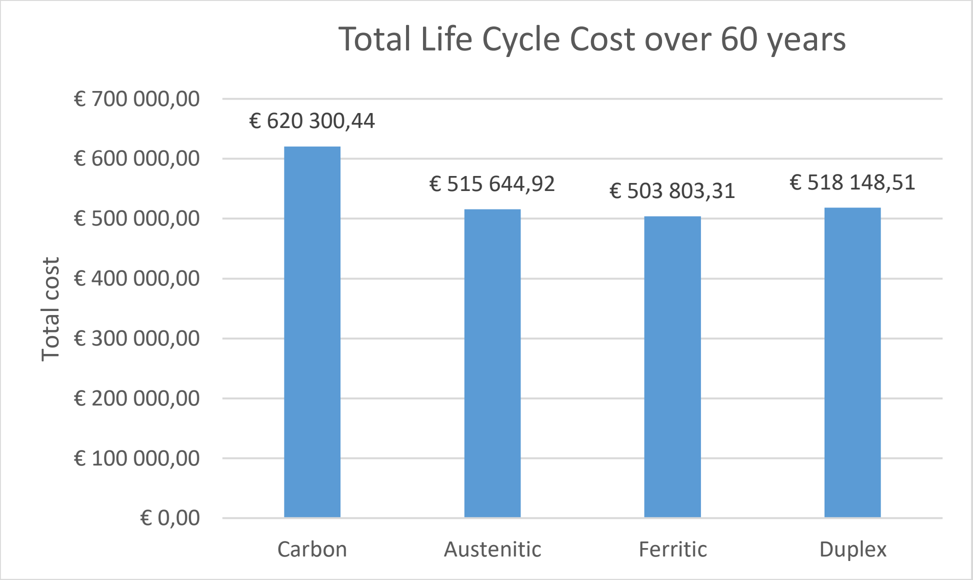


Figure 20: Total life cycle cost over 60 years per case study

In general terms, it can be stated that the higher initial costs for stainless steel are exceeded after 15 years, from the beginning and 15 years for austenitic-, ferritic- and duplex stainless steel respectively. Figure 21 shows an overview of the total costs per case study in function of the years past, and figure 22 gives a more detailed visual reference to the exceeding of the initial costs of the stainless steel. Furthermore its noticeable that the differences between the different stainless steel grades is small and that ferritic stainless steel would result in the least cost intensive solution. However the corrosion resistance of the ferritic grade is the lowest of the 3 stainless steel grades, and is therefore not applicable in every location. But proper research of the corrosive environment will allow for the proper material choice.

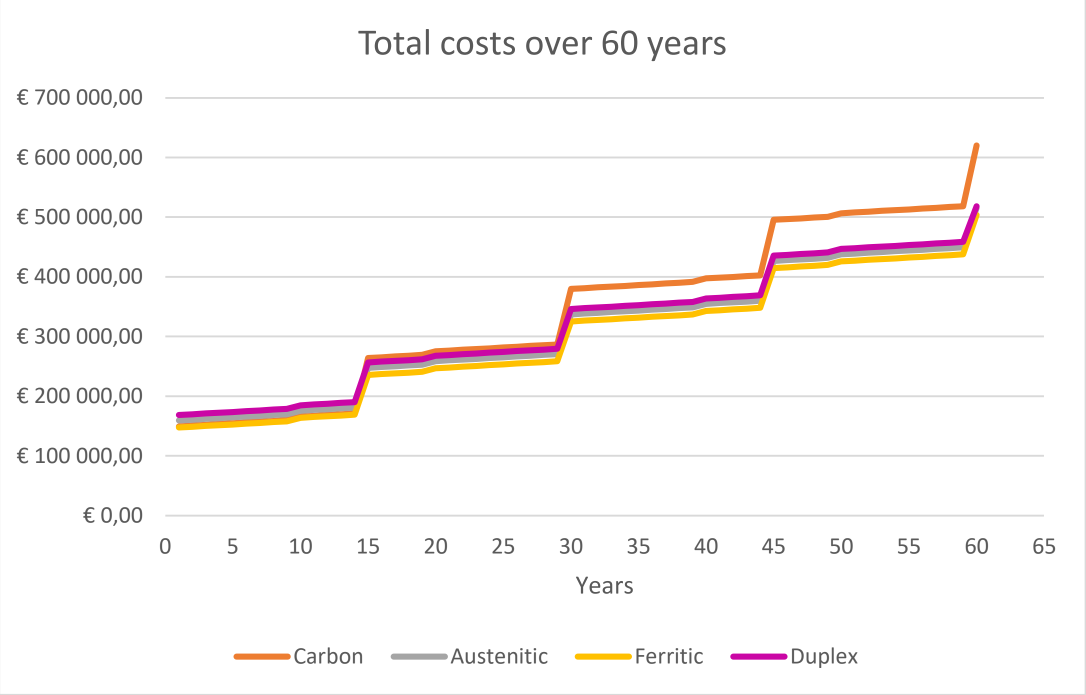


Figure 21:Timeline of the total costs per case study

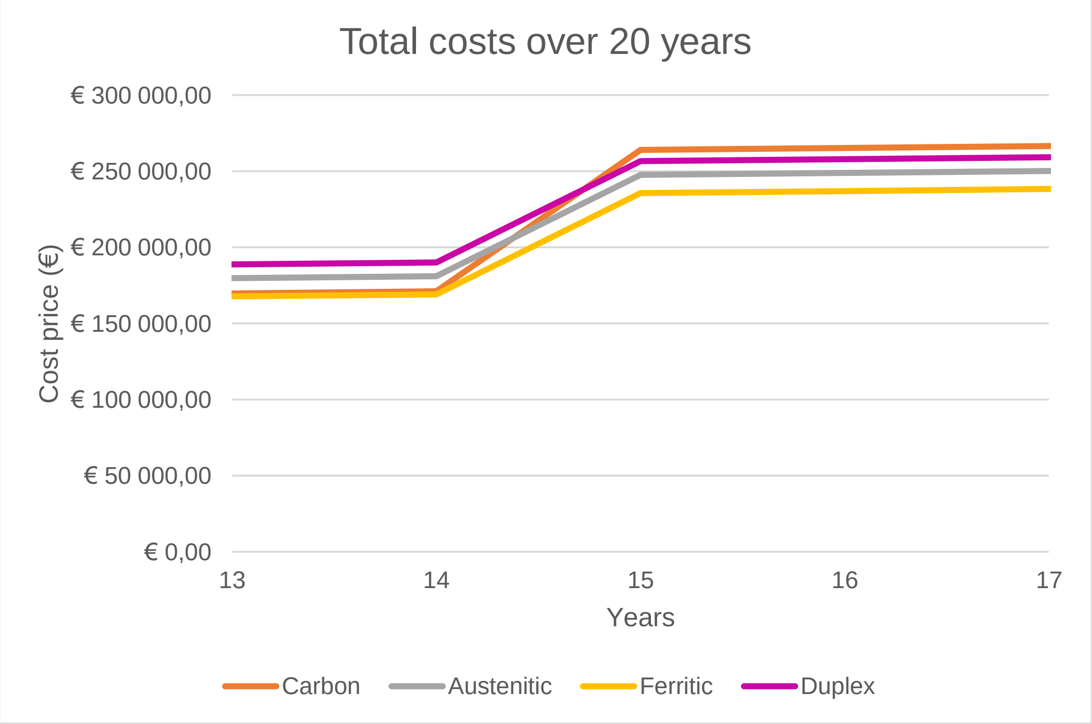


Figure 22: Detailed view of the timeline of the total costs

A similar study [26] was conducted in Brazil, the study showed similar results as the present study conducted in Belgium. The difference lies in the fact that, in the Brazilian study, they researched the use of 1 type of stainless steel for 3 different transmission towers, and the present study researched one tower with 3 different grades of stainless steel. Since austenitic stainless steel grades were used in both studies the comparison will be made for the results for this specific material. Table 17 gives an overview of the results of the 2 studies. The results within the Brazilian study were given in USD ($) and were converted to EUROS (€) for comparison. The Brazilian study showed an economic benefit of 20%, 22% and 42% for case studies 1, 2, 3 respectively [26], while the present study shows an economic benefit of 17% for austenitic stainless steel. The Brazilian study shows that the economic benefit is inversely proportional with the height of the tower, a fact that further research might prove for Belgium as well, but was not part of the present work. The 2 studies show results of the same proportions, 22% and 17%, when comparing transmission towers of equal heights. Leading to the fact that stainless steel could provide a more beneficial solution for the Brazilian as well as the Belgian market. When comparing the total costs between the 2 studies, a big difference is noticeable, this can be attributed to the fact that in the present study the maintenance of the high-voltage air-blast breakers is included and it was not included in the Brazilian study. The maintenance cost, for the high-voltage air-blast breakers, is € 264.000 over the complete life-time. When this is subtracted, the difference is around € 80.000 for carbon steel and € 25.000 for stainless steel. This difference is significantly smaller and can be attributed to the differences in personnel costs between Belgium and Brazil.

Table 17: Results overview of both the Belgian and Brazilian study [26]

Case study	Tower height (m)	Carbon steel	Austenitic stainless steel
Brazilian 1	57.2	€ 311 646.15	€ 284 182.13
Brazilian 2	45.2	€ 274 670.44	€ 225 331.77
Brazilian 3	13.2	€ 227 440.53	€ 159 383.97
Belgian	46.35	€ 620 300.44	€ 515 644.92

6 CONCLUSION

This study aimed to investigate if the use of stainless steel in transmission towers. A life cycle analysis was conducted to determine if stainless steel could provide an economic solution over carbon steel when the complete life cycle was accounted for. The results revealed that stainless steel would provide an adequate solution in structural and economic terms. The overall weight of the transmission towers increases but the surface area would decrease. These two facts can be attributed to an overall decrease in cross-section but an increase in thickness due to the fact that only class 3 cross-sections were used.

In economic terms, the stainless steel solutions would lead to a decrease in overall price of 16 to 19%. The initial costs of the stainless steel are slightly higher however, this higher initial cost is compensated when the cost of the protective coatings, needed in a carbon steel, are taken into account. The further need of maintenance of the protective coatings to ensure structural integrity result in high maintenance costs for carbon steel. A fact that stainless steel do not need, which results in a more cost efficient solution with the application of stainless steel.

Although these results are promising and satisfactory, the reminder has to be made that the costs given in these study are only cost estimations and that further research is required to determine exact results for specific case studies. Furthermore there still are some costs that need to be considered, that were not part of the present study, such as the failure costs due to collapse and costs for the replacement of carbon steel towers. Additionally, as different types of transmission towers can be found in the Belgium territory, to fulfil the different market needs, it is important to extend the present study to other tower structure configurations and geometry.

However, since environment is a hot topic right now, it is worth mentioning that the emission of polluting gases derived from the production of stainless steel is lower than with the production of carbon steel, resulting in a lower environmental impact.

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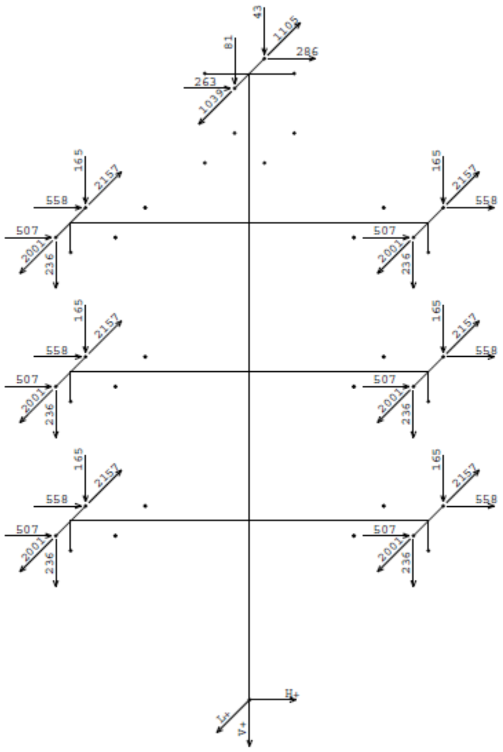
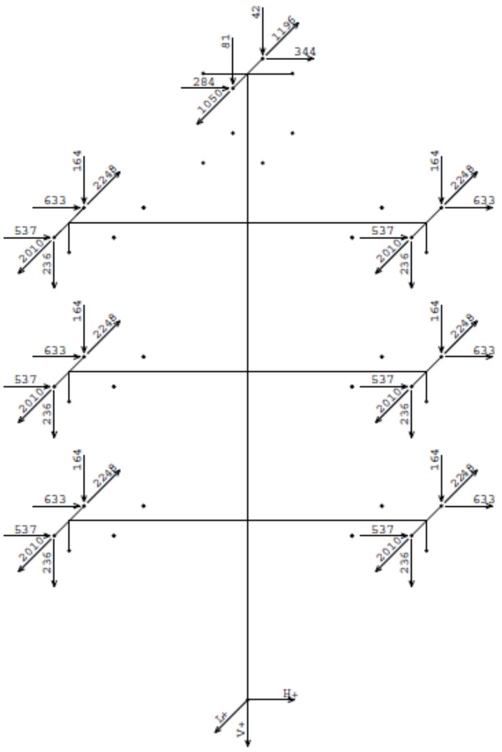
Annex list

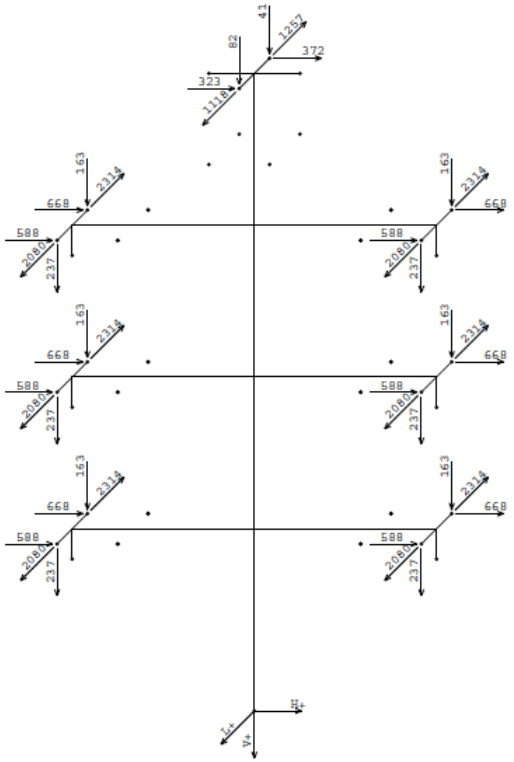
Annex A LOADS AND LOAD COMBINATIONS



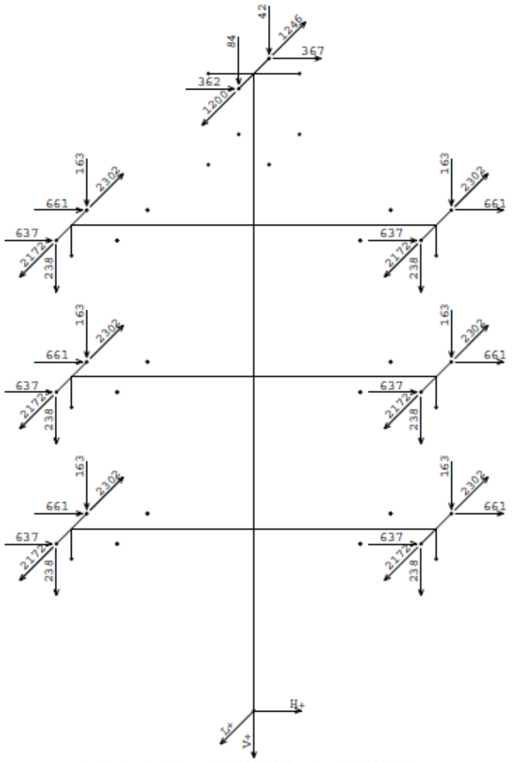
1001.000 NORMAAL 2 TERNES



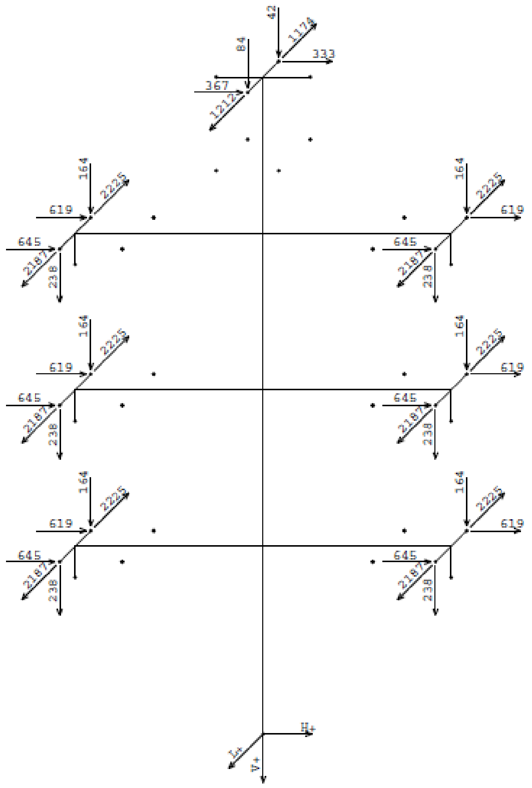
1001.045 NORMAAL 2 TERNES



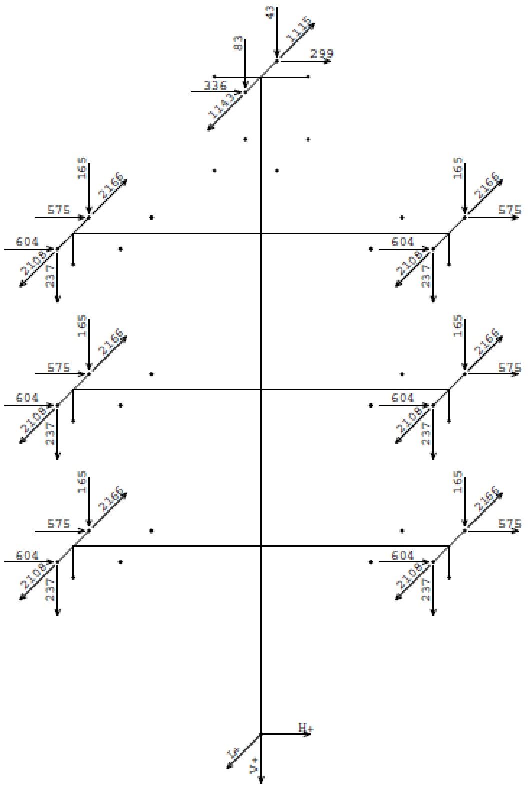
1001.067 NORMAAL 2 TERNES



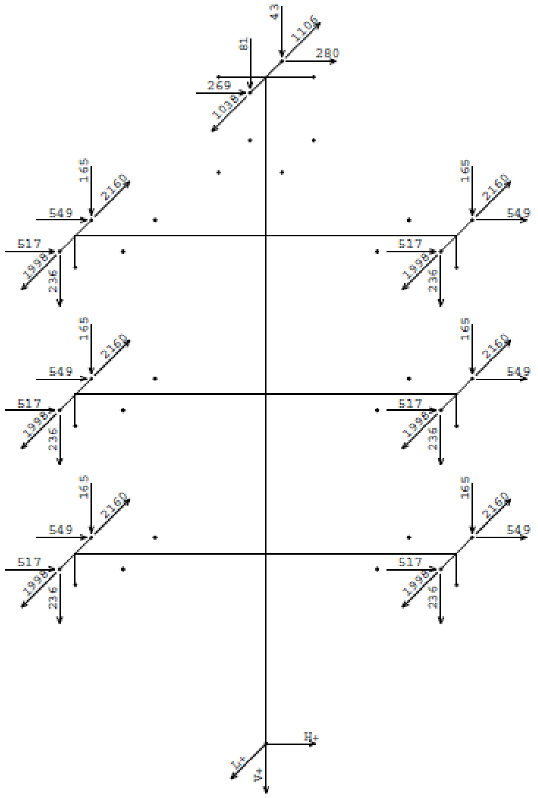
1001.090 NORMAAL 2 TERNES



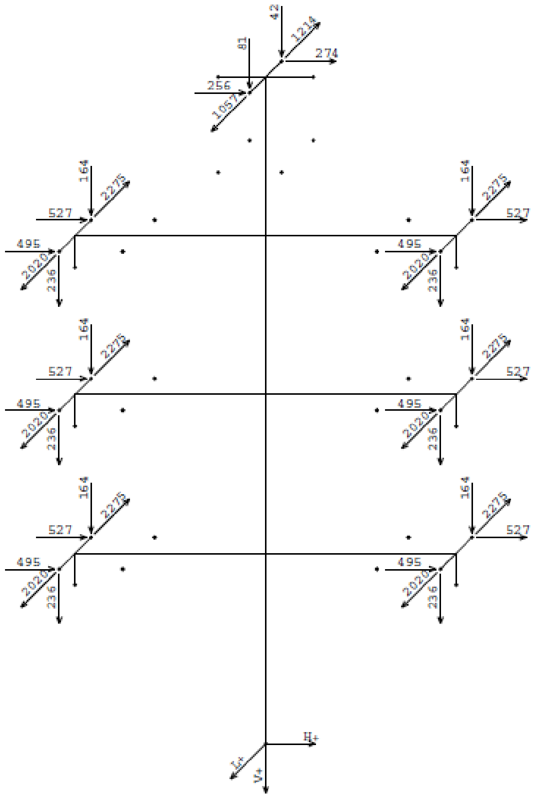
1001.112 NORMAAL 2 TERNES



1001.135 NORMAAL 2 TERNES



1001.180 NORMAAL 2 TERNES



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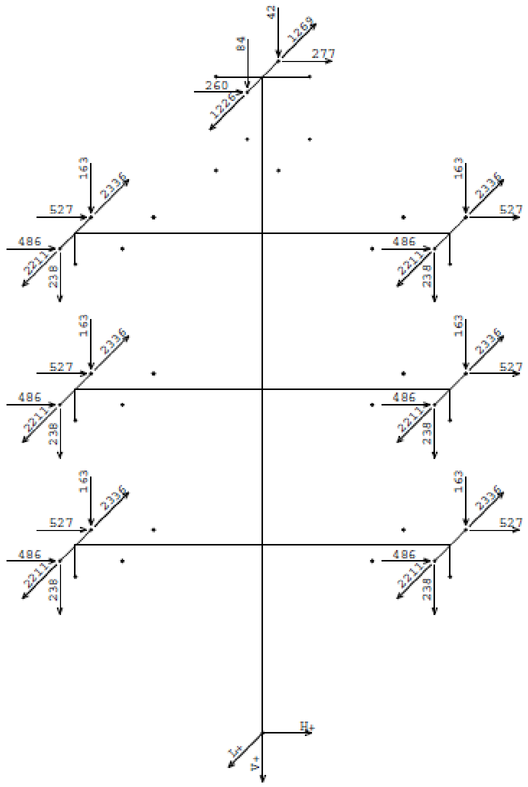
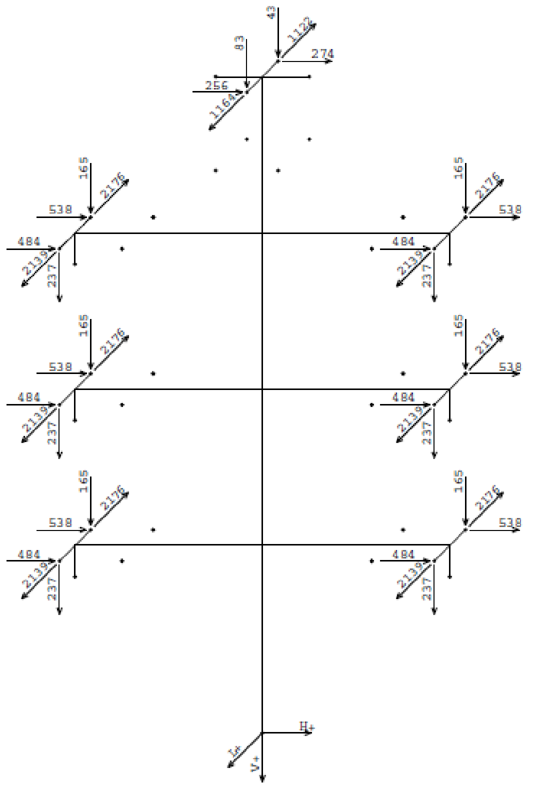
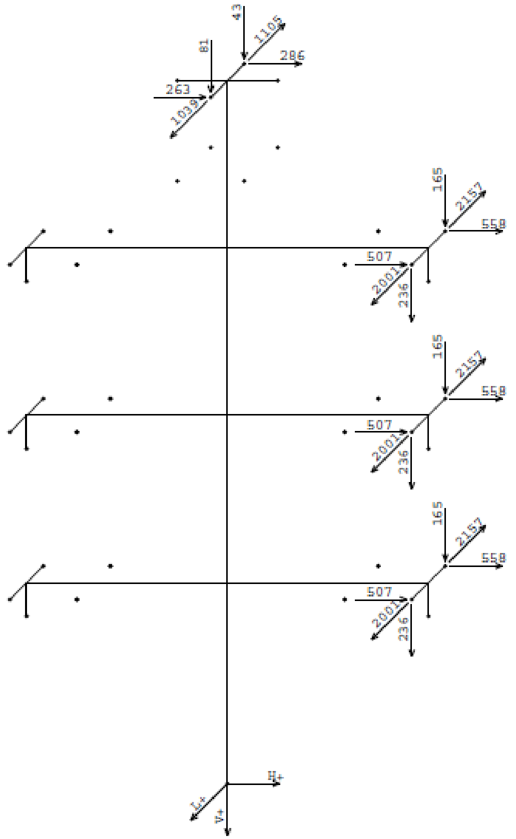


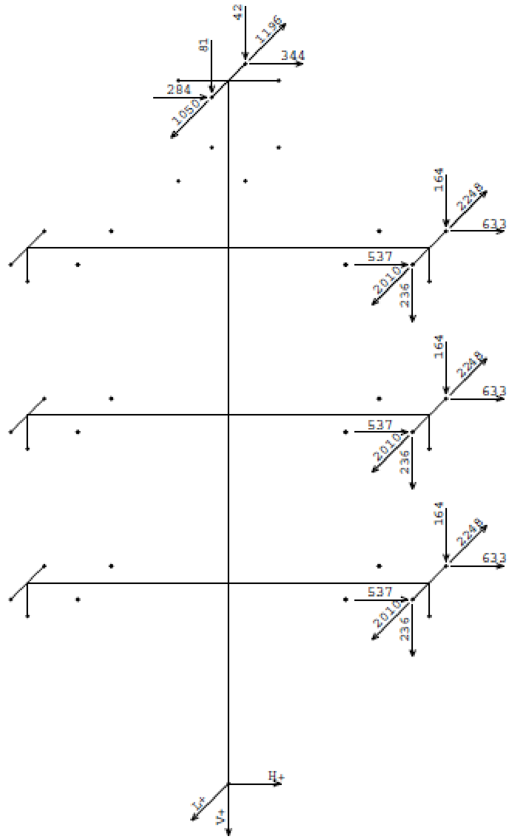
1001.270 NORMAAL 2 TERNES



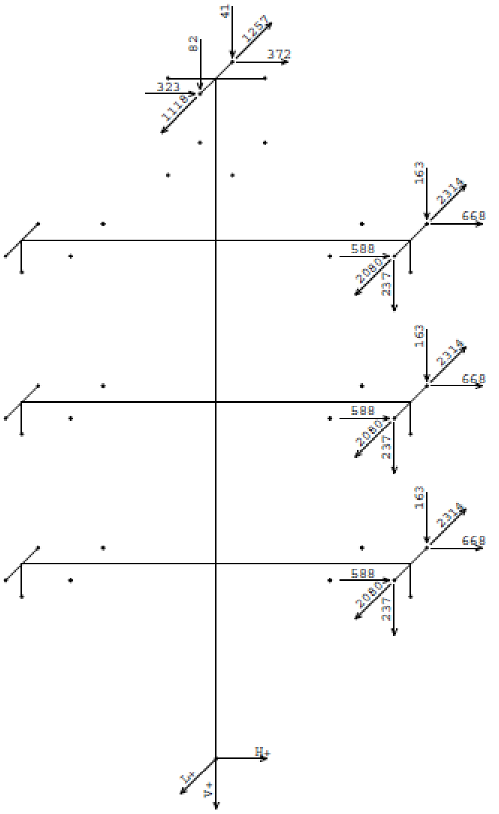
1001.315 NORMAAL 2 TERNES



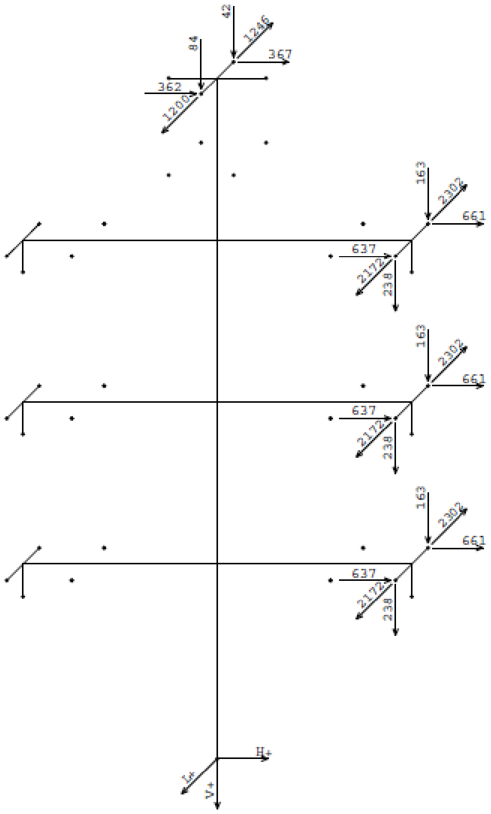
1002.000 NORMAAL 1 TERNE, droite



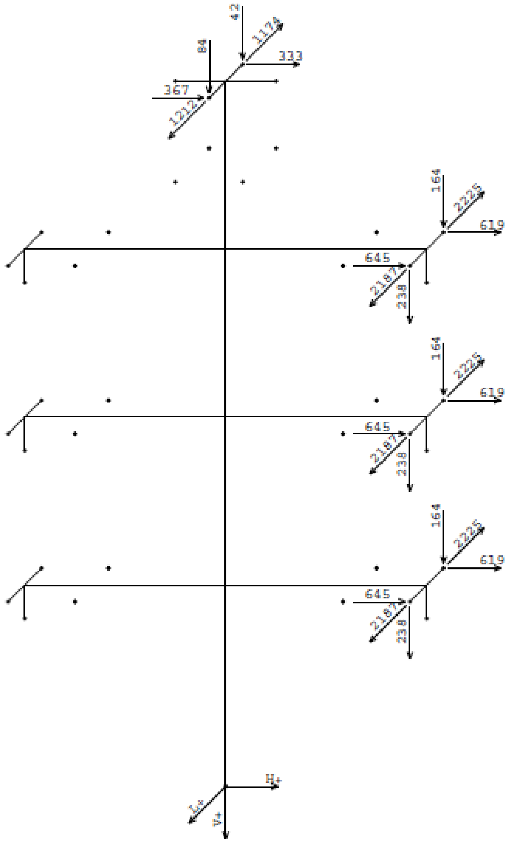
1002.045 NORMAAL 1 TERNE, droite



1002.067 NORMAAL 1 TERNE, droite



1002.090 NORMAAL 1 TERNE, droite



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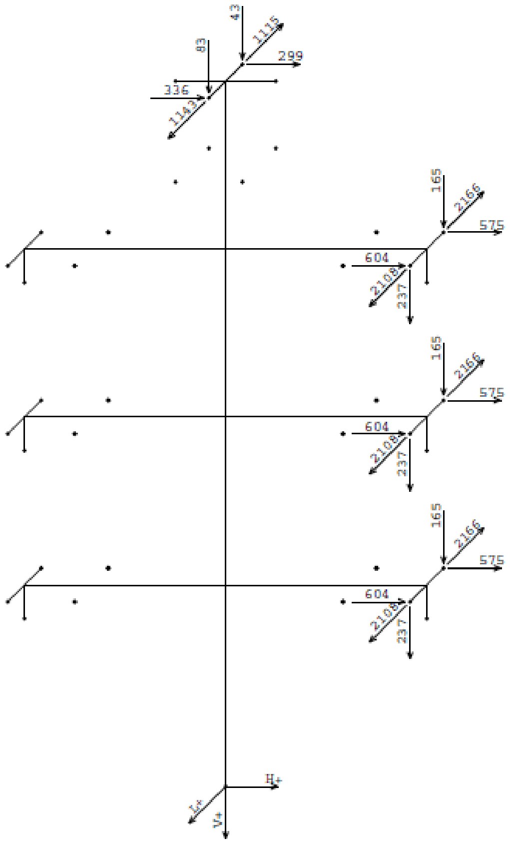

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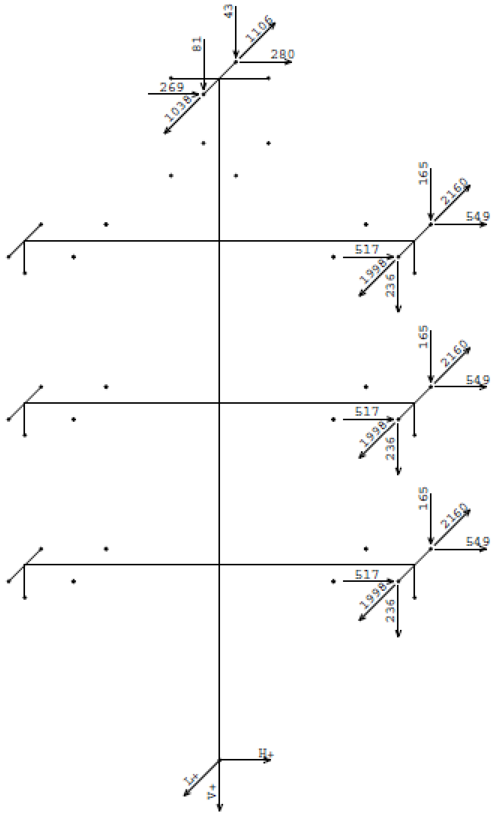

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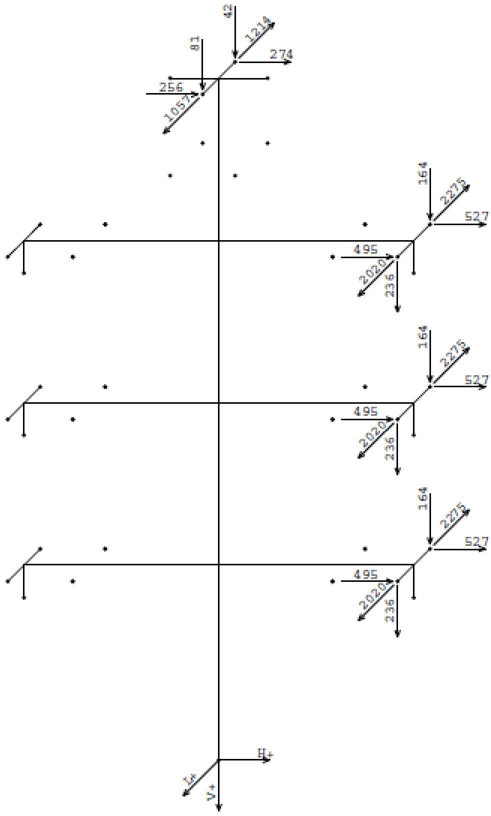

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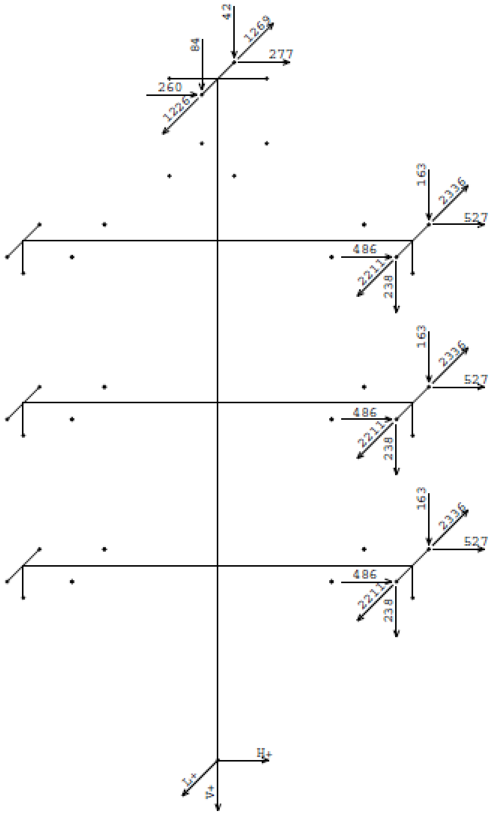
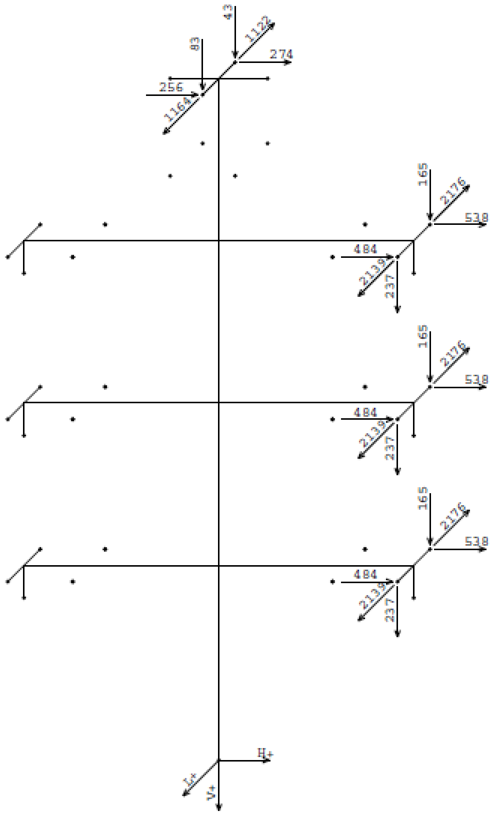
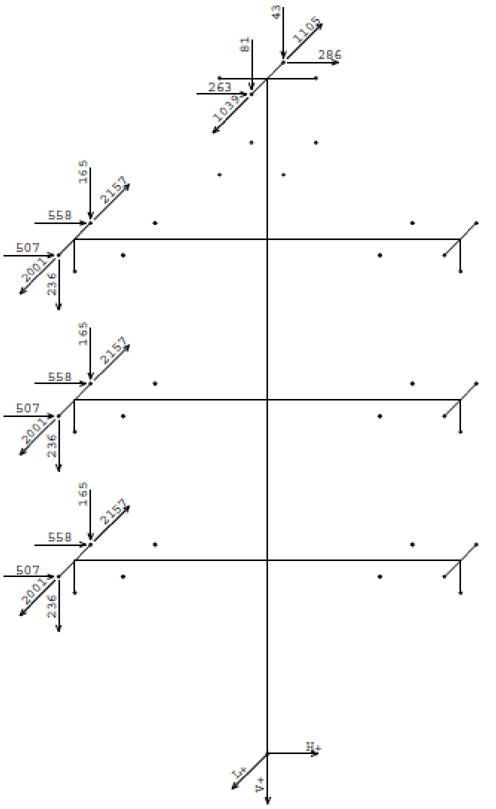


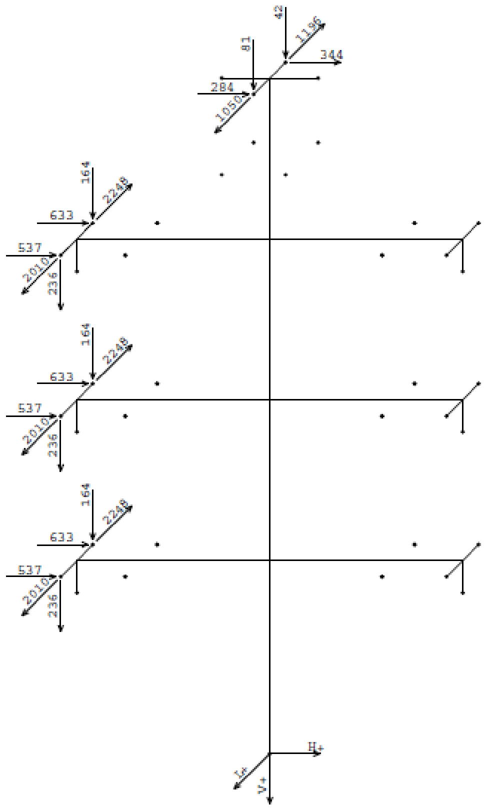
1002.270 NORMAAL 1 TERNE, droite



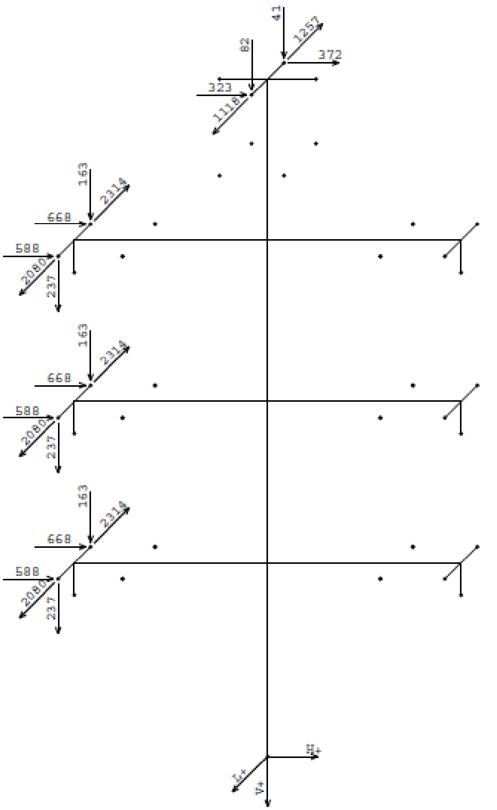
1002.315 NORMAAL 1 TERNE, droite



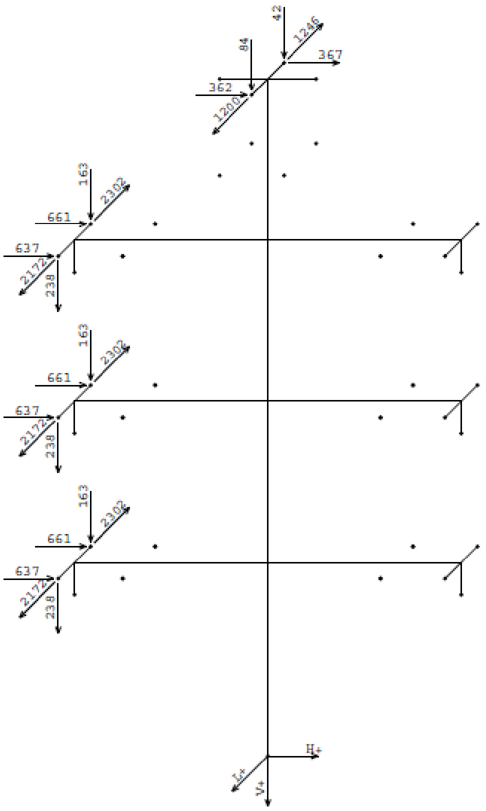
1003.000 NORMAAL 1 TERNE, gauche



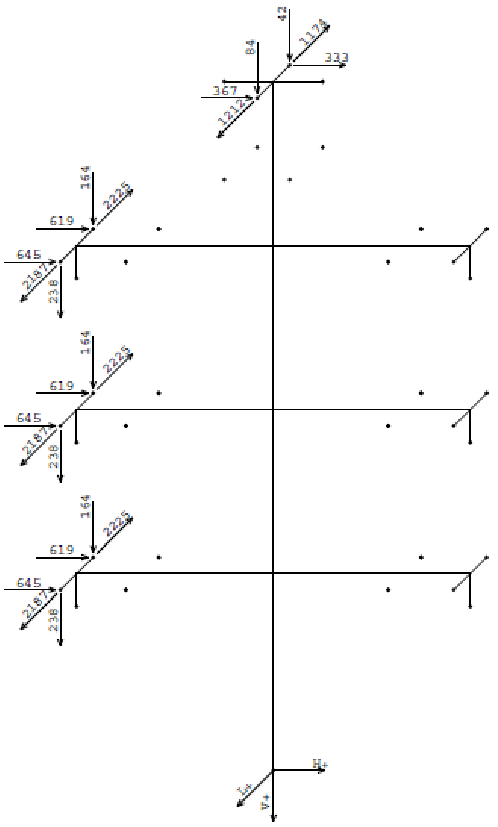
1003.045 NORMAAL 1 TERNE, gauche



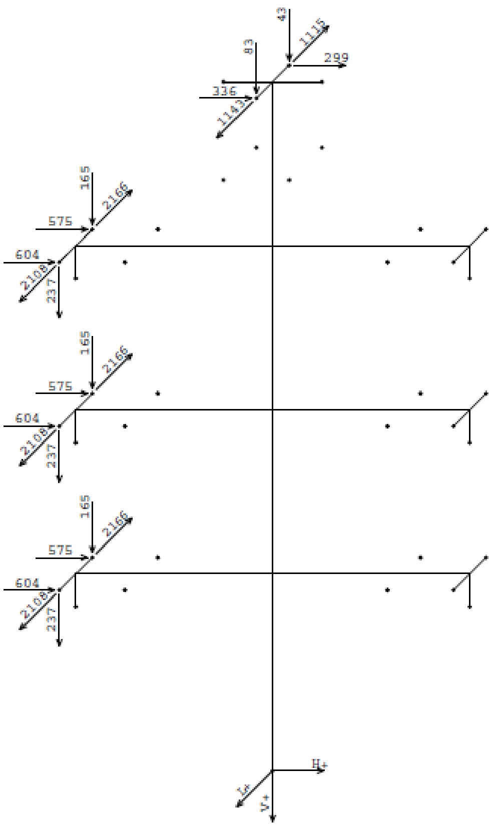
1003.067 NORMAAL 1 TERNE, gauche



1003.090 NORMAAL 1 TERNE, gauche



1003.112 NORMAAL 1 TERNE, gauche



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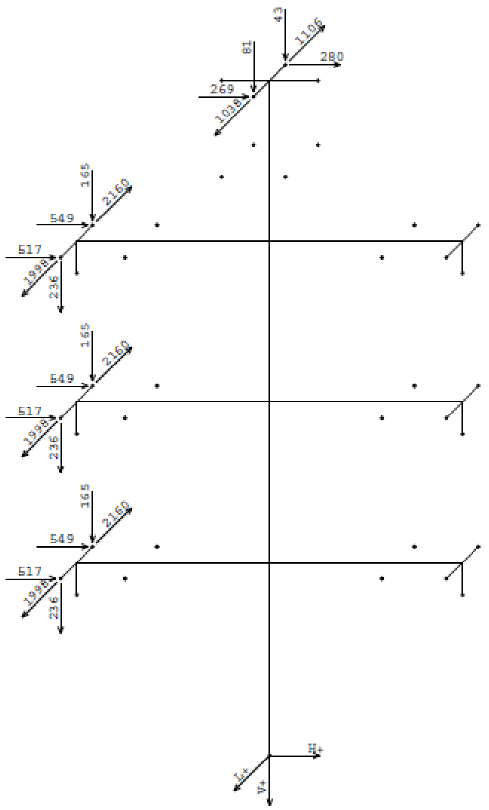

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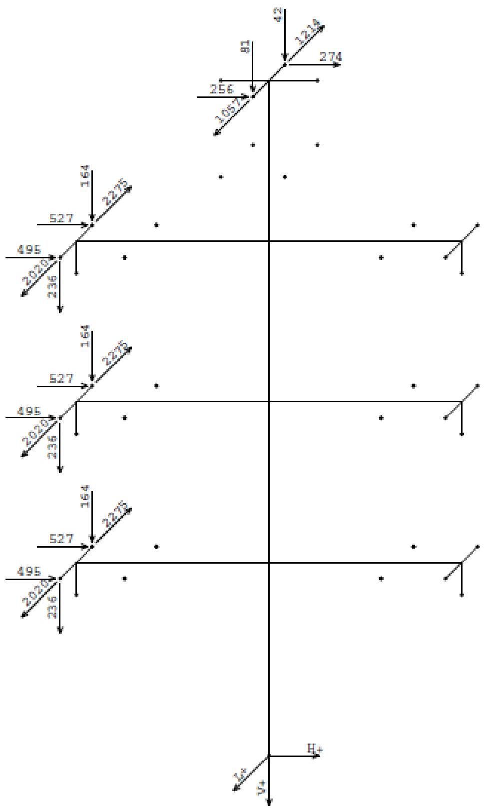

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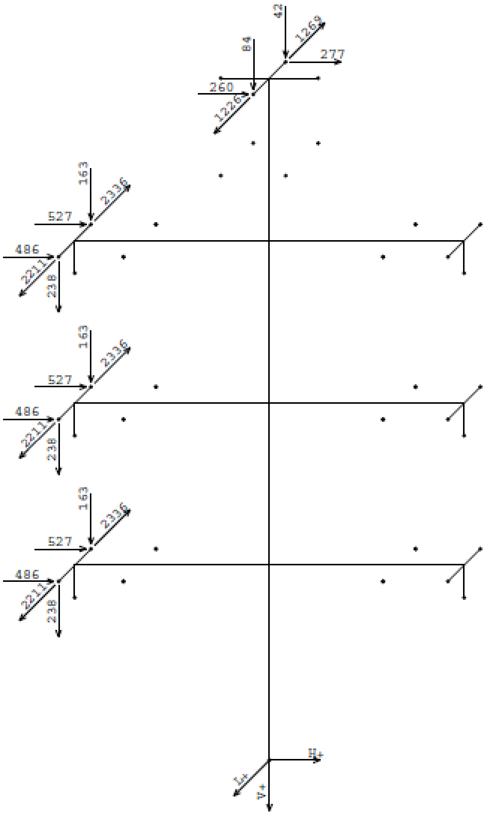

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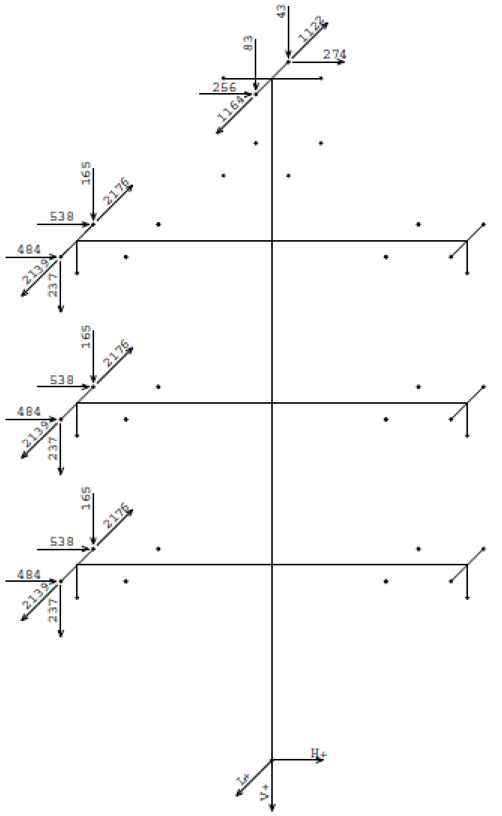
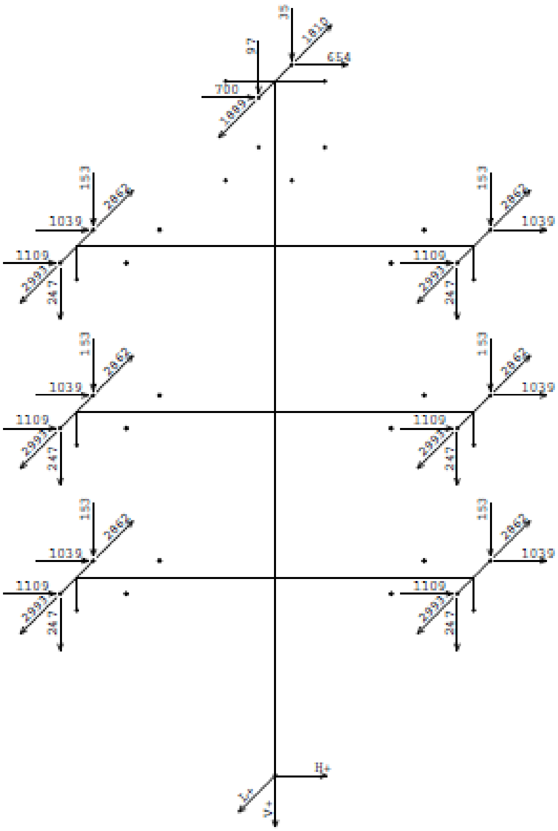
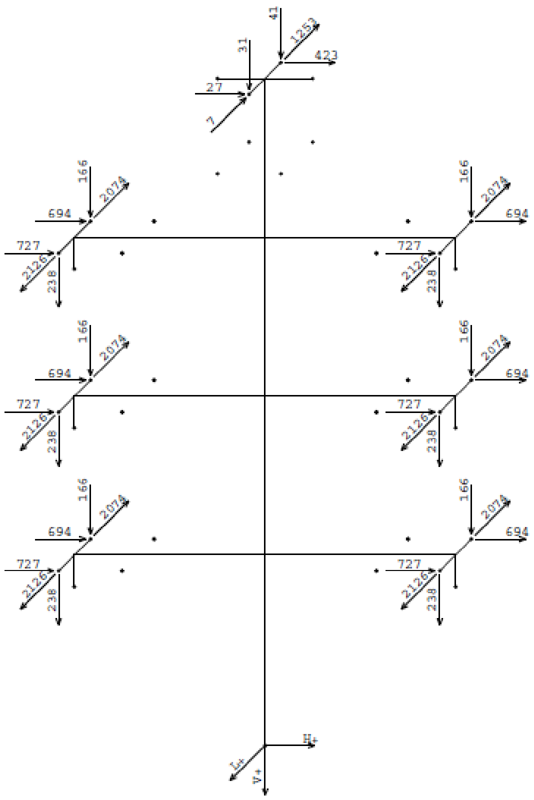


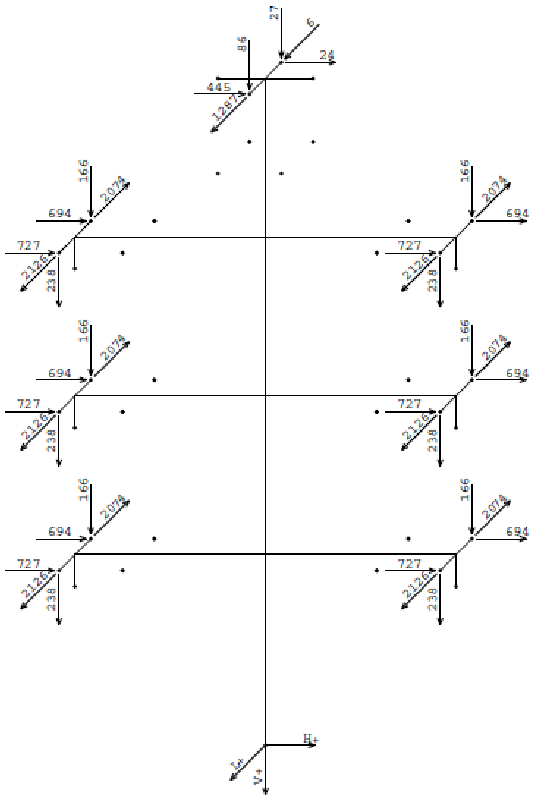
1003.315 NORMAAL 1 TERNE, gauche



2001.090 UITZOND 2 TERNES



3001.089 gebroke cdg 2T



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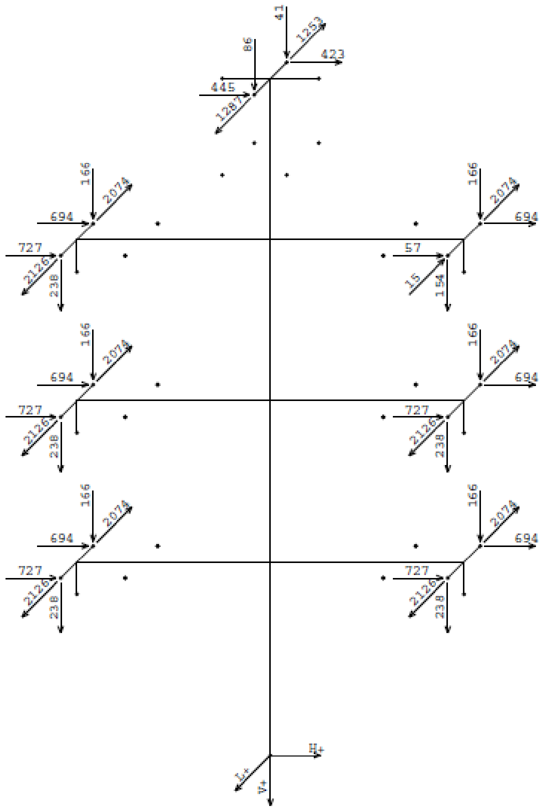

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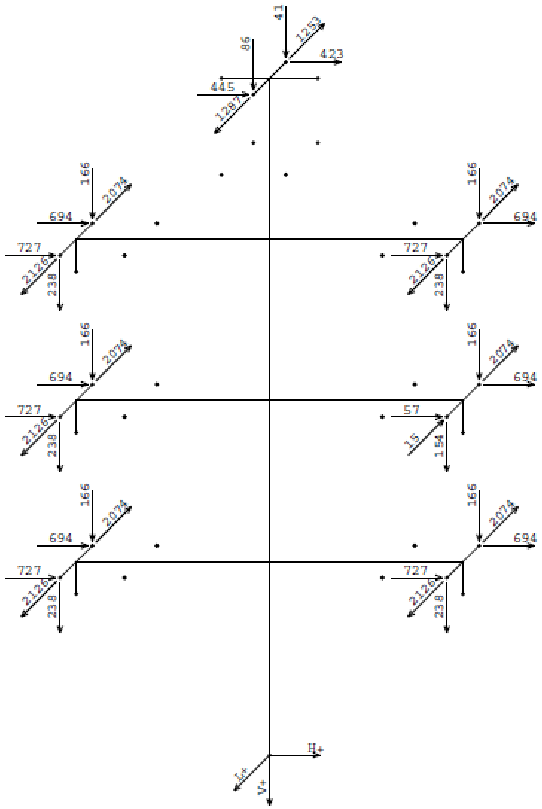

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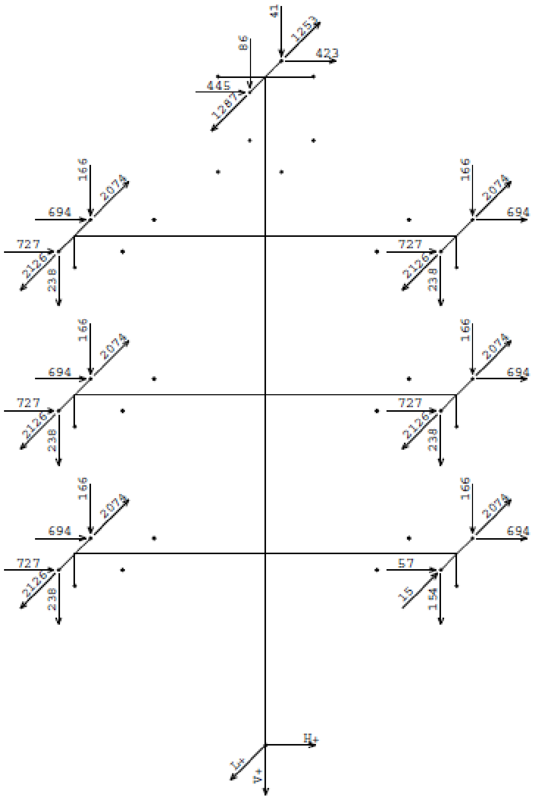

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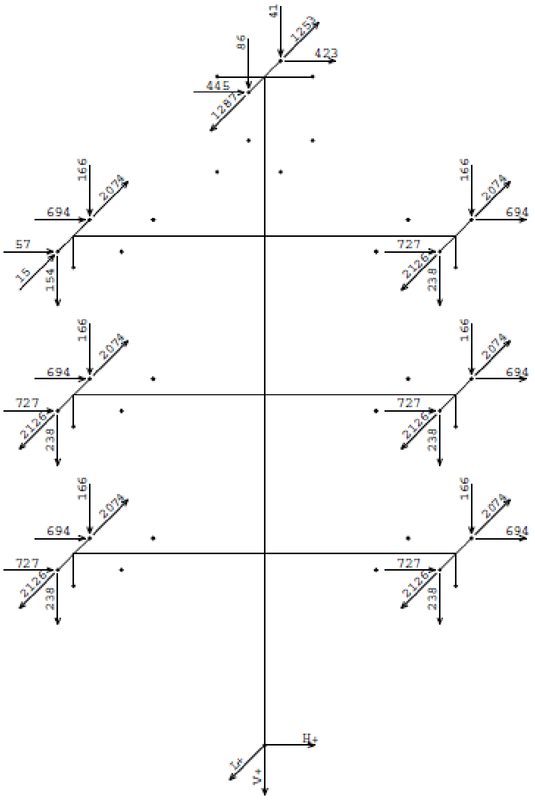

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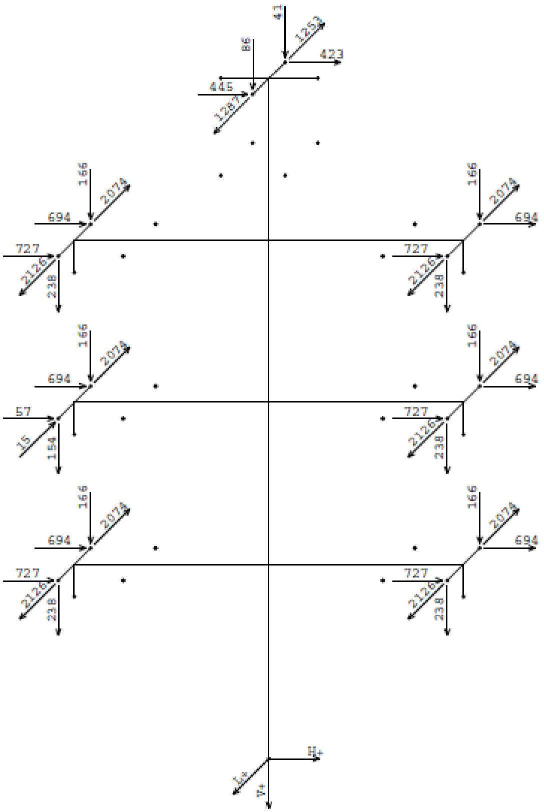

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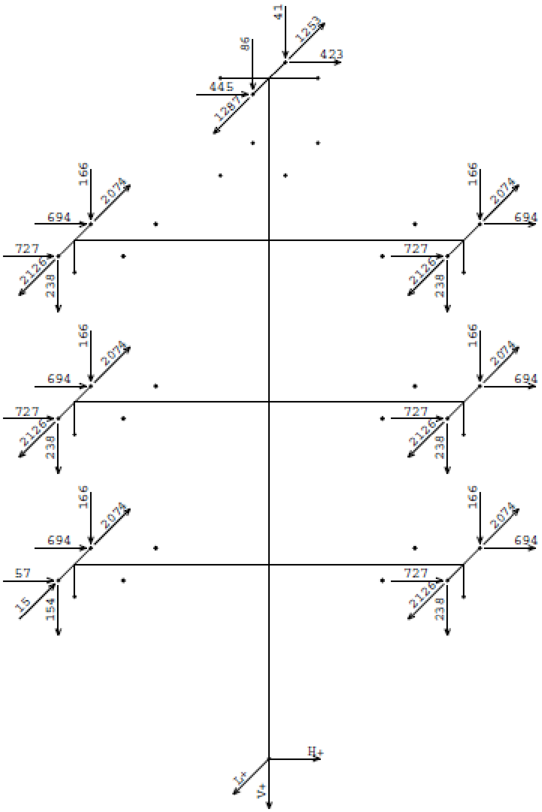
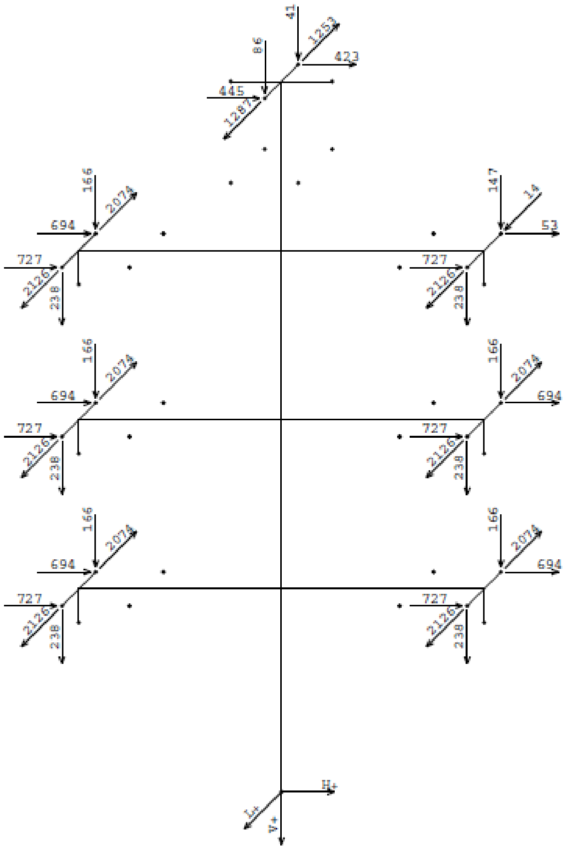
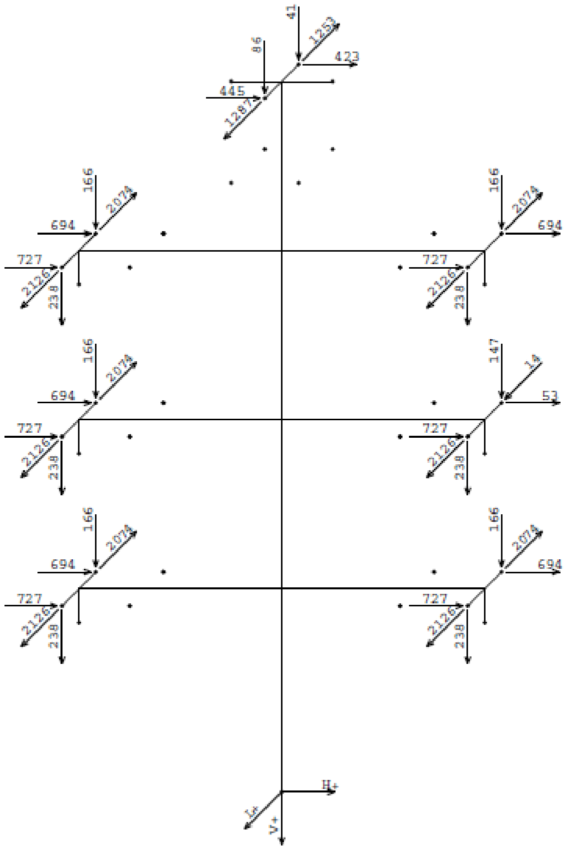


3008.089 gebroke cdg 2T



3009.089 gebroke cdg 2T



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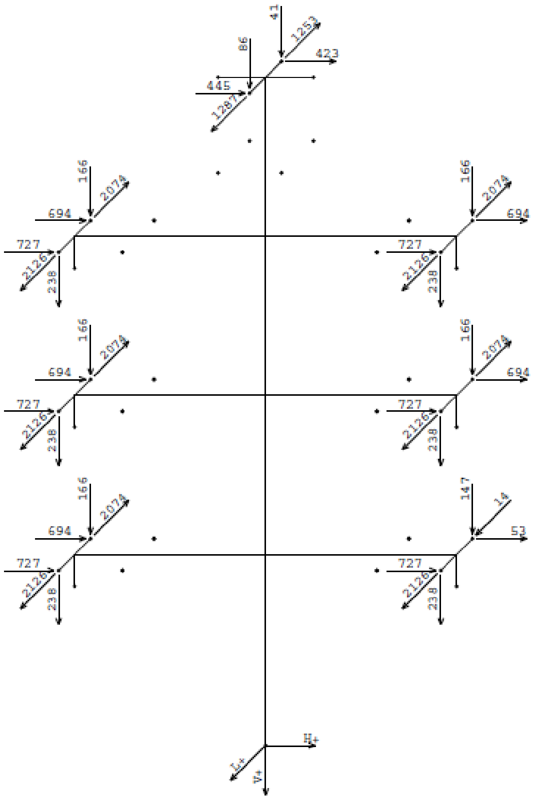

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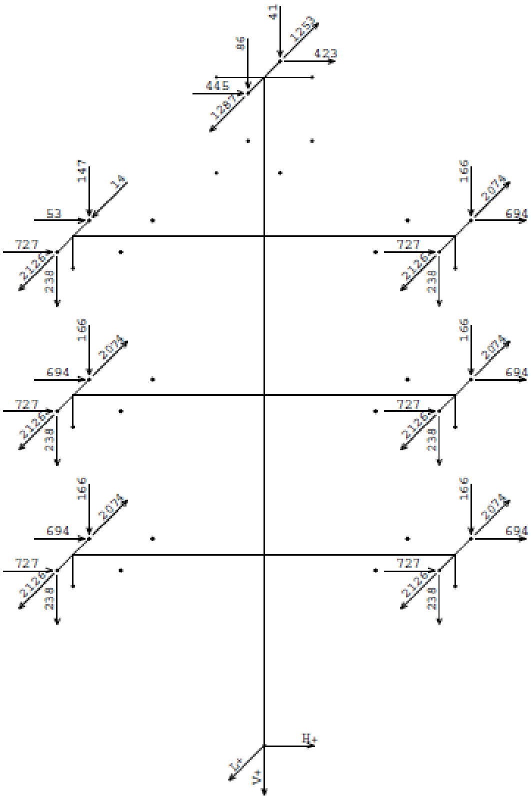

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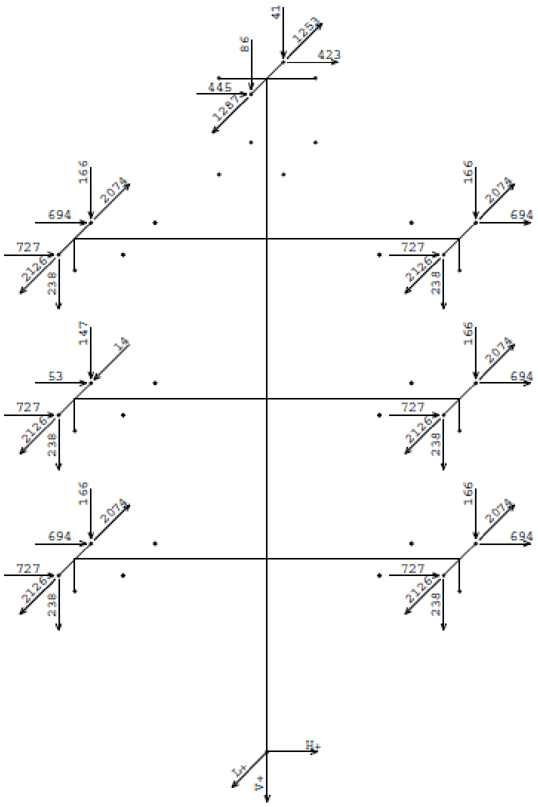

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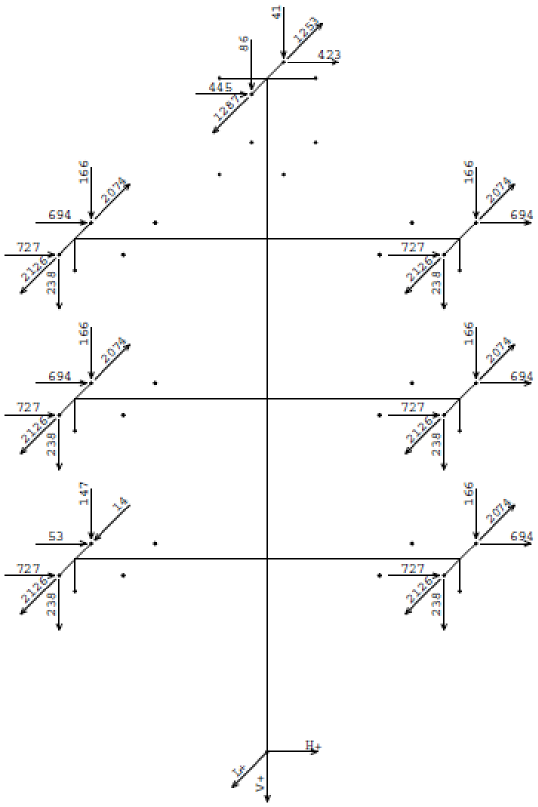

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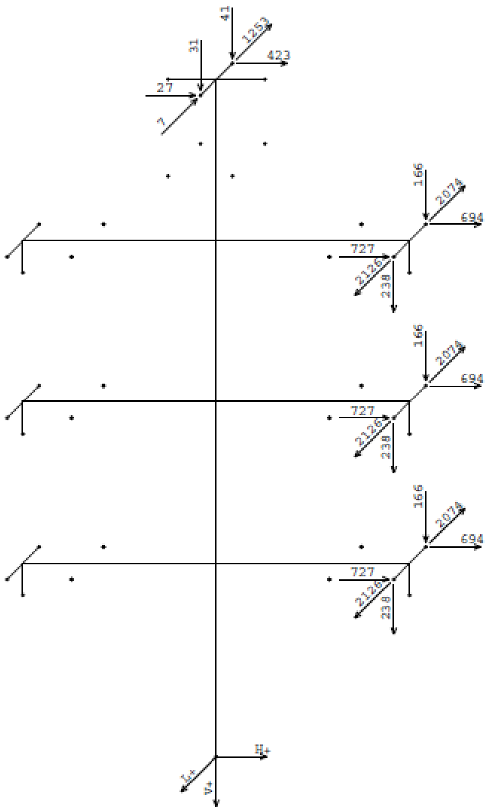
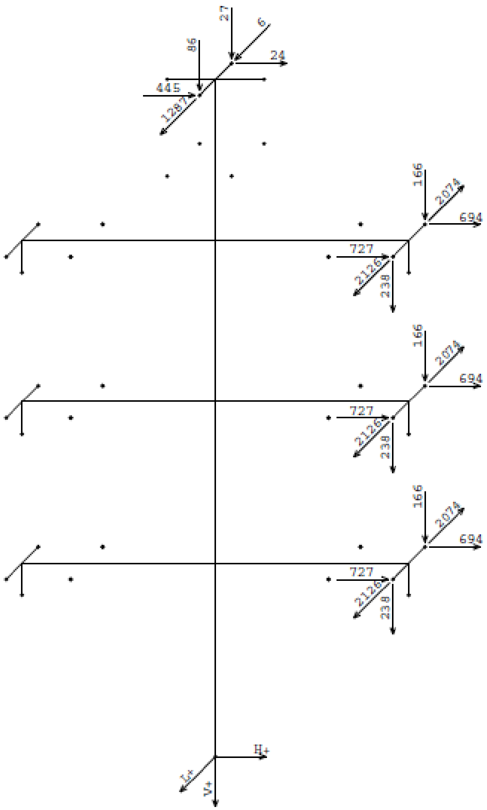


3015.089 gebroke cdg 1T droite



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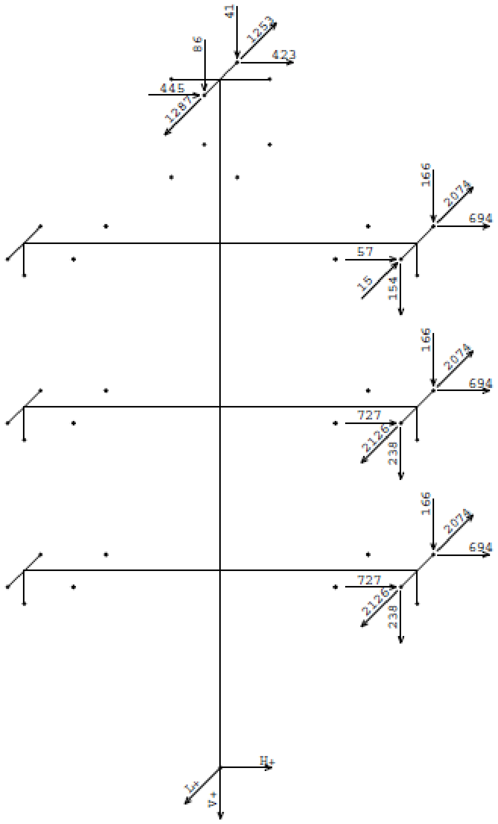

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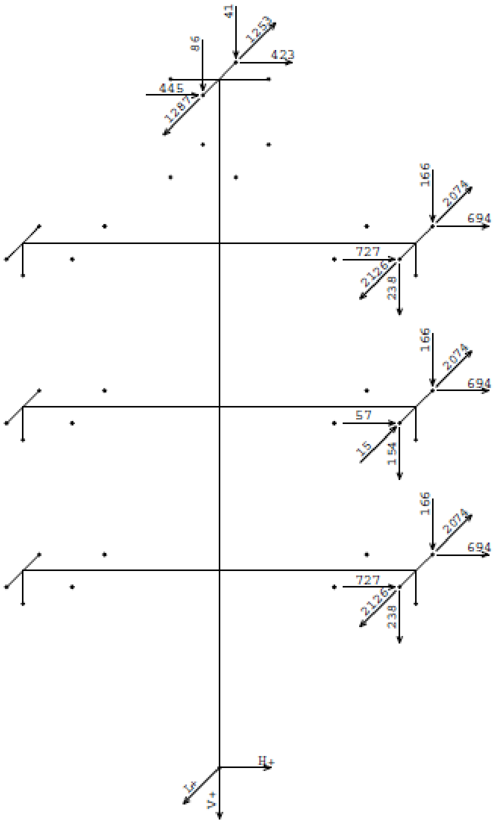

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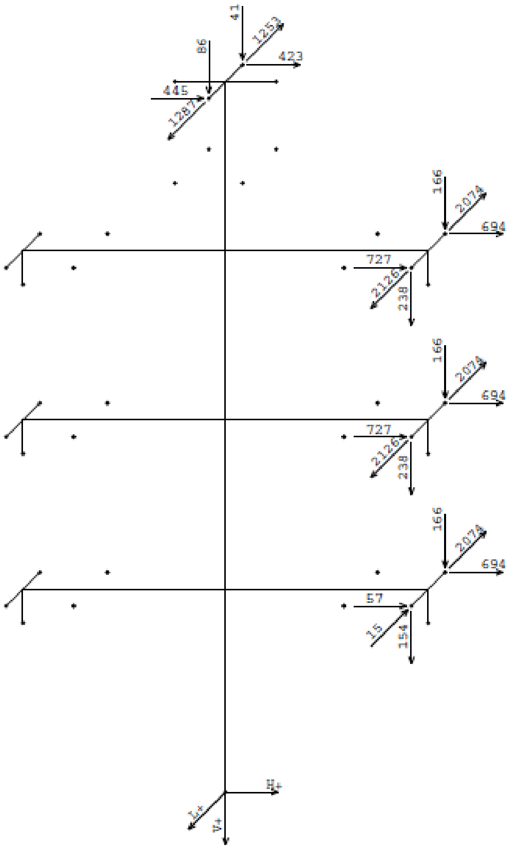

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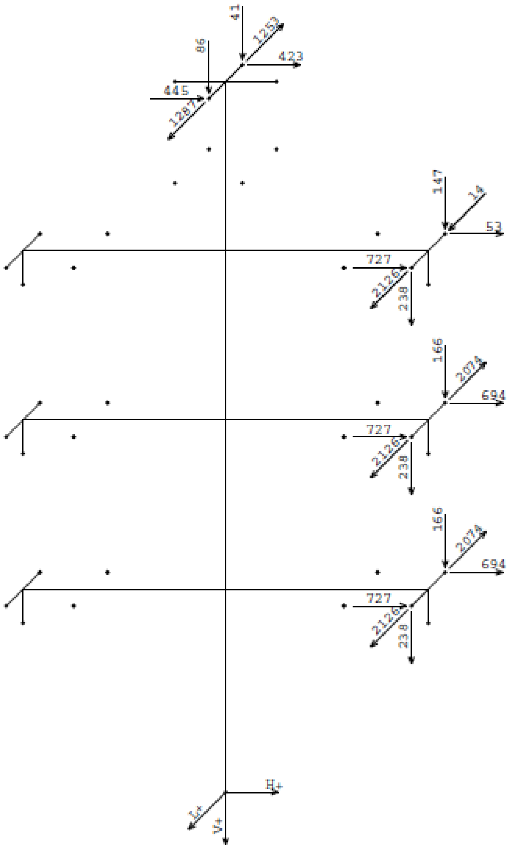

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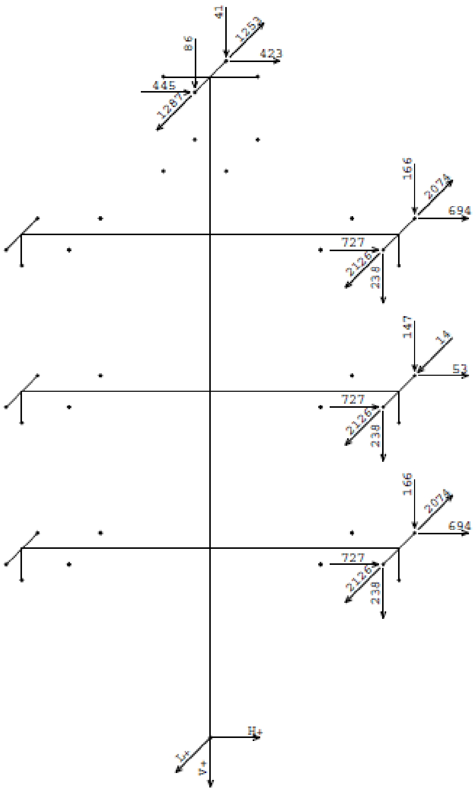

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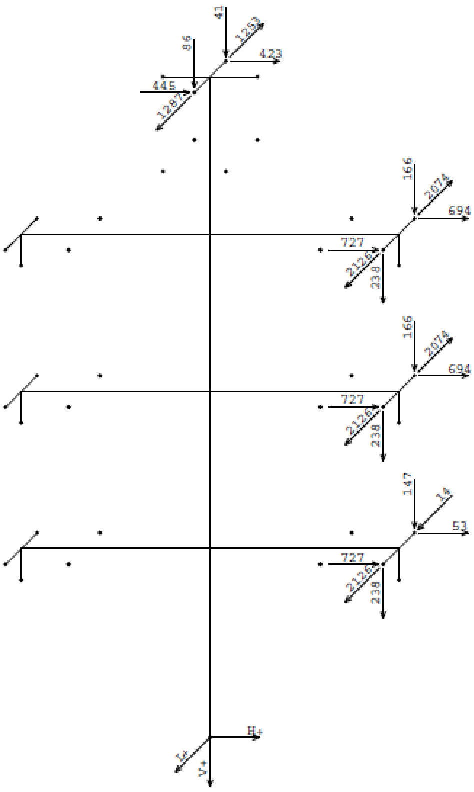

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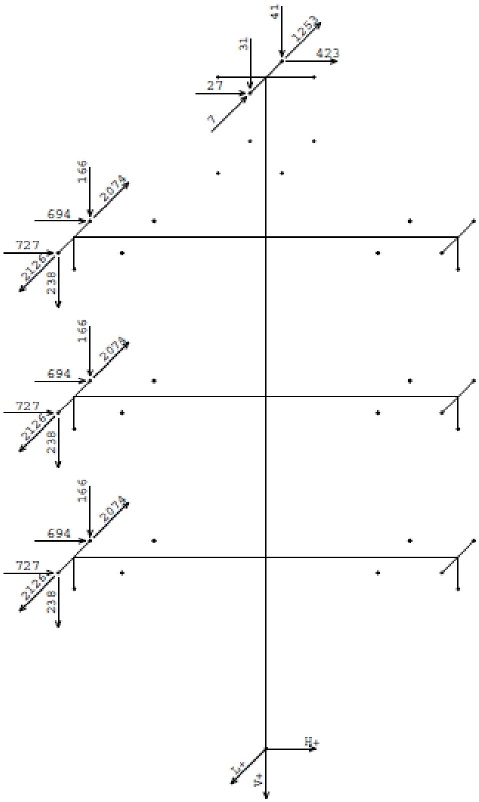
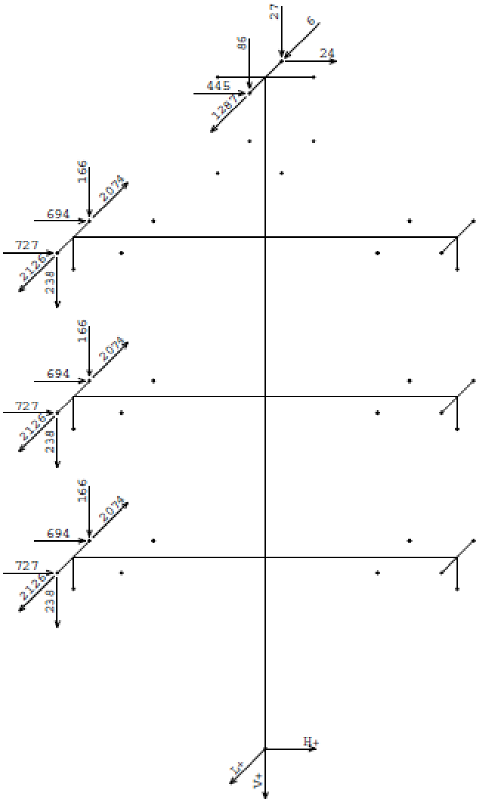


3023.089 gebroke cdg 1T gauche



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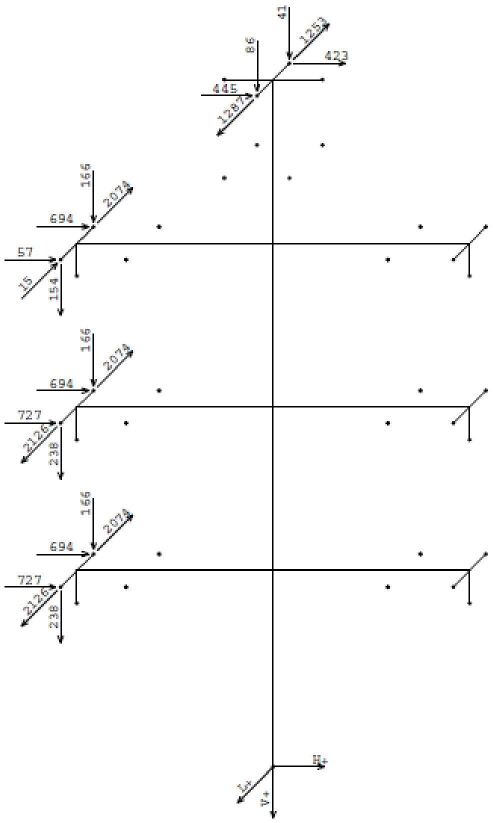

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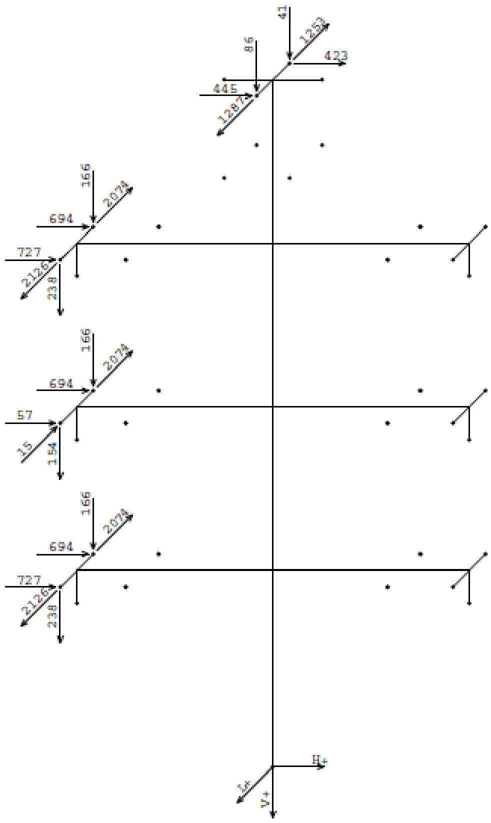

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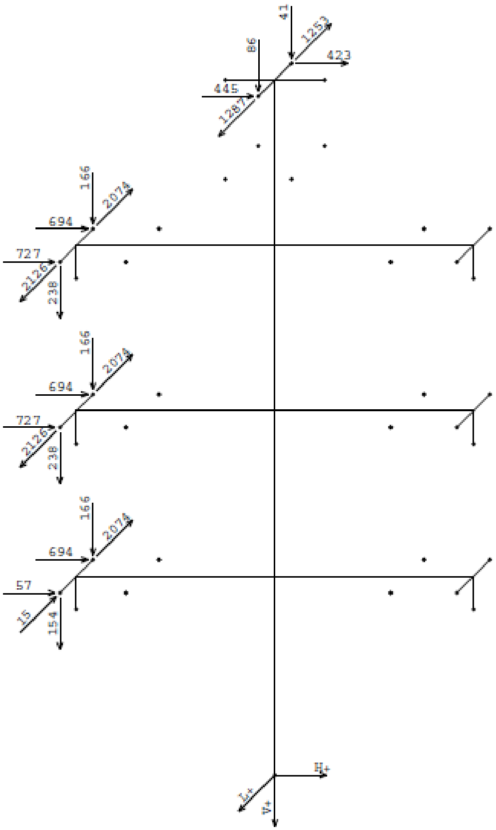
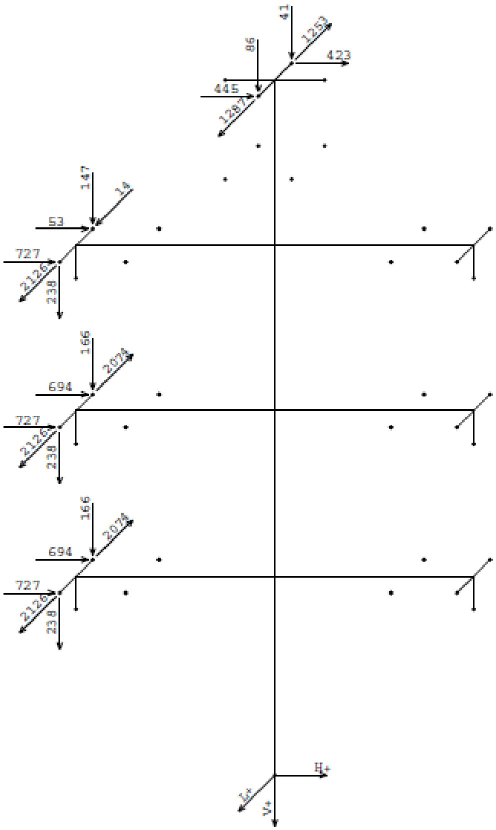
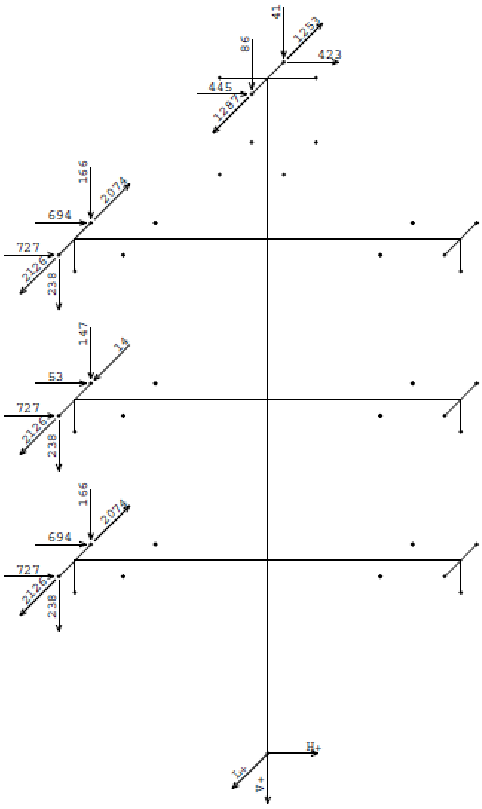


3027.089 gebroke cdg 1T gauche



3028.089 gebroke cdg 1T gauche



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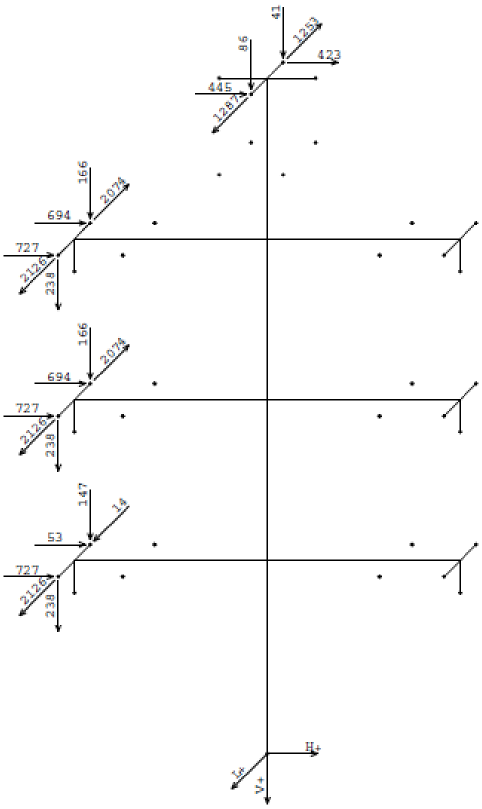
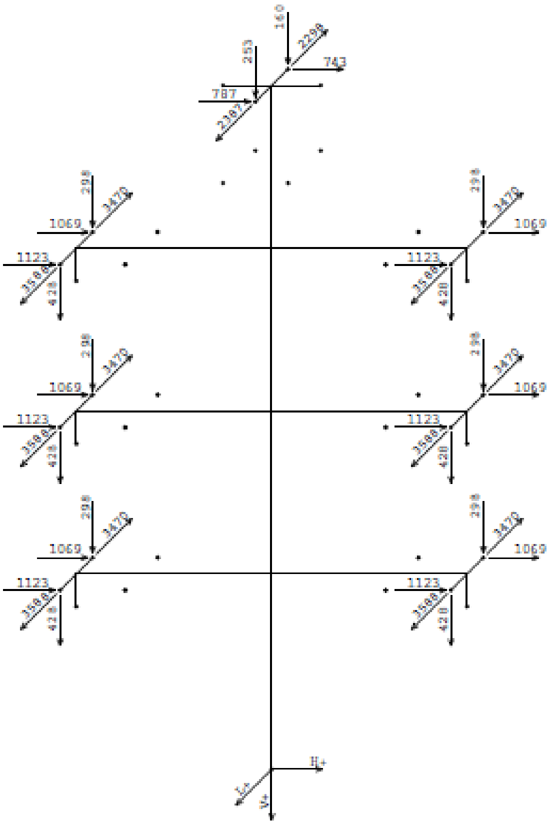
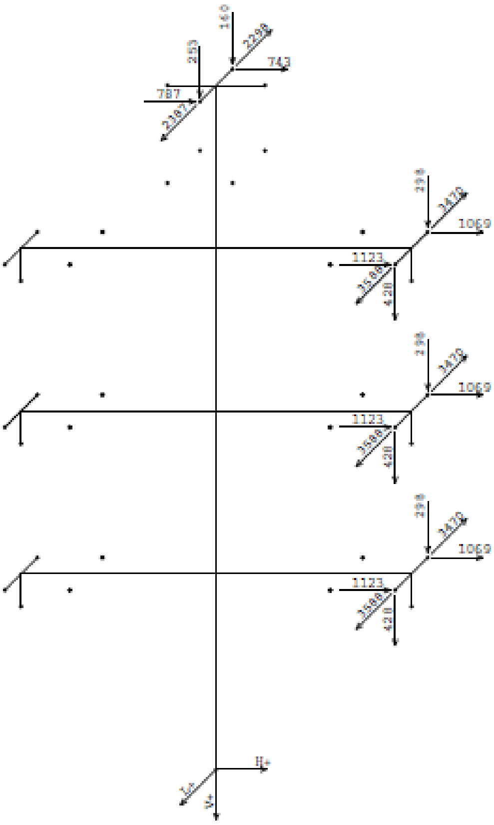


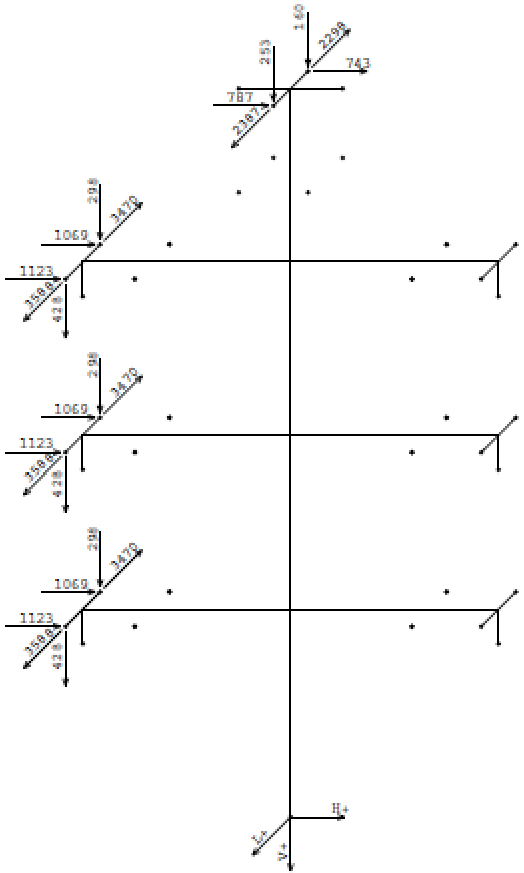
3030.089 gebroke cdg 1T gauche



5001.089 ijsgeval 2TERNES



5002.089 ijsgeval 1TERNE, droite



5003.089 ijsgeval 1TERNE, gauche

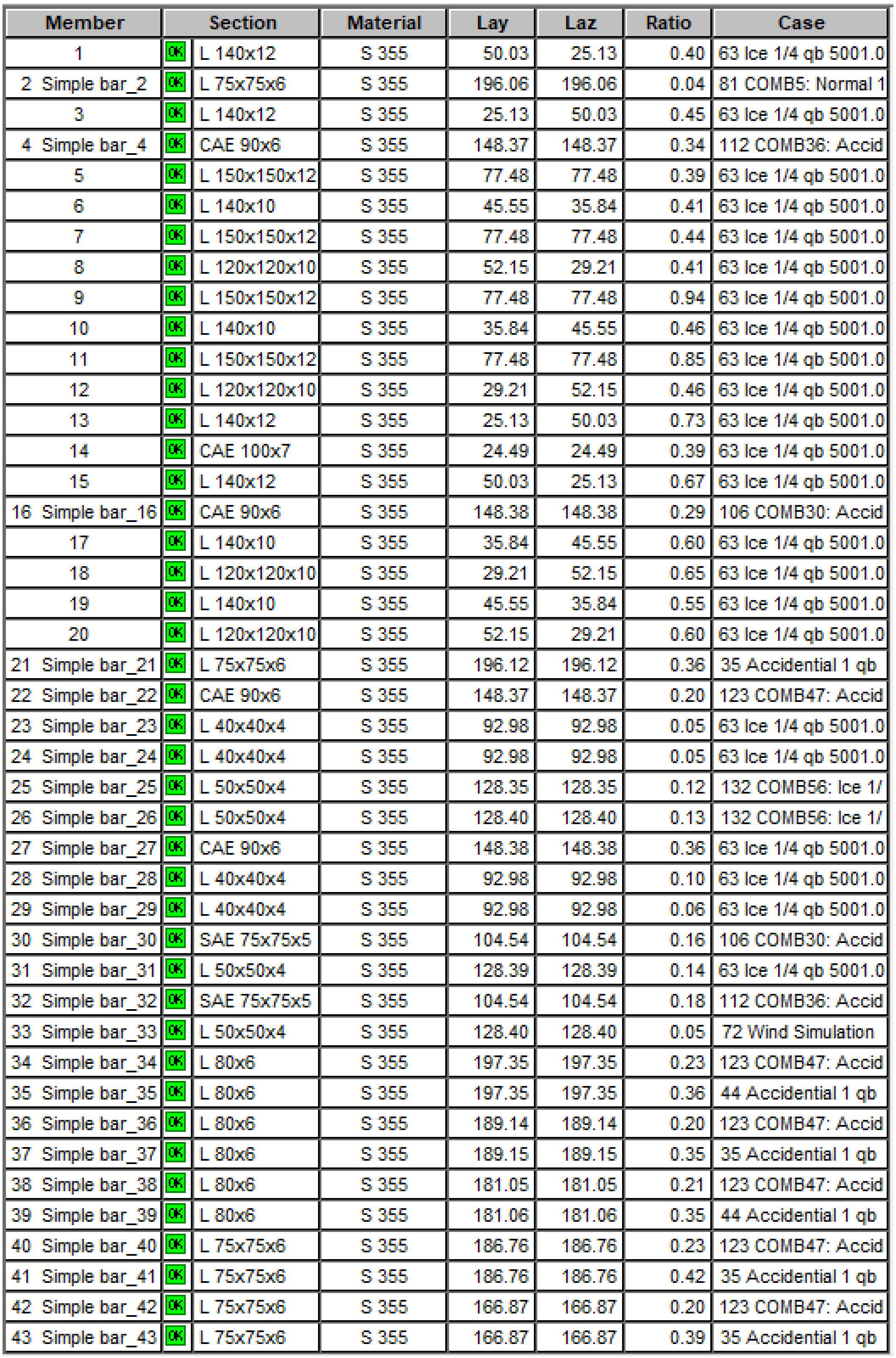
Combinations	Name	Analysis type	Combination type	Case nature	Definition
77 (C)	COMB1: Normal 1001.000	Linear Combination	ACC	Structural	(2+69+1)*1.00
78 (C)	COMB2: Normal 1001.045	Linear Combination	ACC	Structural	(3+70+1)*1.00
79 (C)	COMB3: Normal 1001.090	Linear Combination	ACC	Structural	(5+71+1)*1.00
80 (C)	COMB4: Normal 1001.135	Linear Combination	ACC	Structural	(7+72+1)*1.00
81 (C)	COMB5: Normal 1001.180	Linear Combination	ACC	Structural	(8+73+1)*1.00
82 (C)	COMB6: Normal 1001.225	Linear Combination	ACC	Structural	(9+74+1)*1.00
83 (C)	COMB7: Normal 1001.270	Linear Combination	ACC	Structural	(10+75+1)*1.00
84 (C)	COMB8: Normal 1001.315	Linear Combination	ACC	wind	(1+2+76)*1.00
85 (C)	COMB9: 1 Cable right 1002.000	Linear Combination	ACC	wind	(12+69+1)*1.00
86 (C)	COMB10: 1 Cable right 1002.045	Linear Combination	ACC	wind	(13+70+1)*1.00
87 (C)	COMB11: 1 Cable right 1002.090	Linear Combination	ACC	wind	(1+15+71)*1.00
88 (C)	COMB13: 1 Cable right 1002.180	Linear Combination	ACC	wind	(18+73+1)*1.00
89 (C)	COMB14: 1 Cable right 1002.225	Linear Combination	ACC	wind	(19+74+1)*1.00
90 (C)	COMB15: 1 Cable right 1002.270	Linear Combination	ACC	wind	(20+75+1)*1.00
91 (C)	COMB16: 1 Cable right 1002.315	Linear Combination	ACC	wind	(21+76+1)*1.00

93 (C)	COMB17: 1 Cable left 1003.000	Linear Combination	ACC	wind	(22+69+1)*1.00
94 (C)	COMB18: 1 Cable left 1003.045	Linear Combination	ACC	wind	(13+70+1)*1.00
95 (C)	COMB19: 1 Cable left 1003.090	Linear Combination	ACC	wind	(25+71+1)*1.00
96 (C)	COMB20: 1 Cable left 1003.135	Linear Combination	ACC	wind	(27+72+1)*1.00
97 (C)	COMB21: 1 Cable left 1003.180	Linear Combination	ACC	wind	(28+73+1)*1.00
98 (C)	COMB22: 1 Cable left 1003.225	Linear Combination	ACC	wind	(29+74+1)*1.00
99 (C)	COMB23: 1 Cable left 1003.270	Linear Combination	ACC	wind	(30+75+1)*1.00
100 (C)	COMB24: 1 Cable left 1003.315	Linear Combination	ACC	wind	(31+76+1)*1.00
101 (C)	COMB25: Special wind 2qb 2001.090	Linear Combination	ACC	wind	(32+71+1)*1.00
102 (C)	COMB26: Accidental 1 qb 3001.089	Linear Combination	ACC	wind	(33+71+1)*1.00
103 (C)	COMB27: Accidental 1 qb 3002.089	Linear Combination	ACC	wind	(34+71+1)*1.00
104 (C)	COMB28: Accidental 1 qb 3003.089	Linear Combination	ACC	wind	(35+71+1)*1.00
105 (C)	COMB29: Accidental 1 qb 3004.089	Linear Combination	ACC	wind	(36+71+1)*1.00
106 (C)	COMB30: Accidental 1 qb 3005.089	Linear Combination	ACC	wind	(37+71+1)*1.00
107 (C)	COMB31: Accidental 1 qb 3006.089	Linear Combination	ACC	wind	(38+71+1)*1.00
108 (C)	COMB32: Accidental 1 qb 3007.089	Linear Combination	ACC	wind	(39+71+1)*1.00

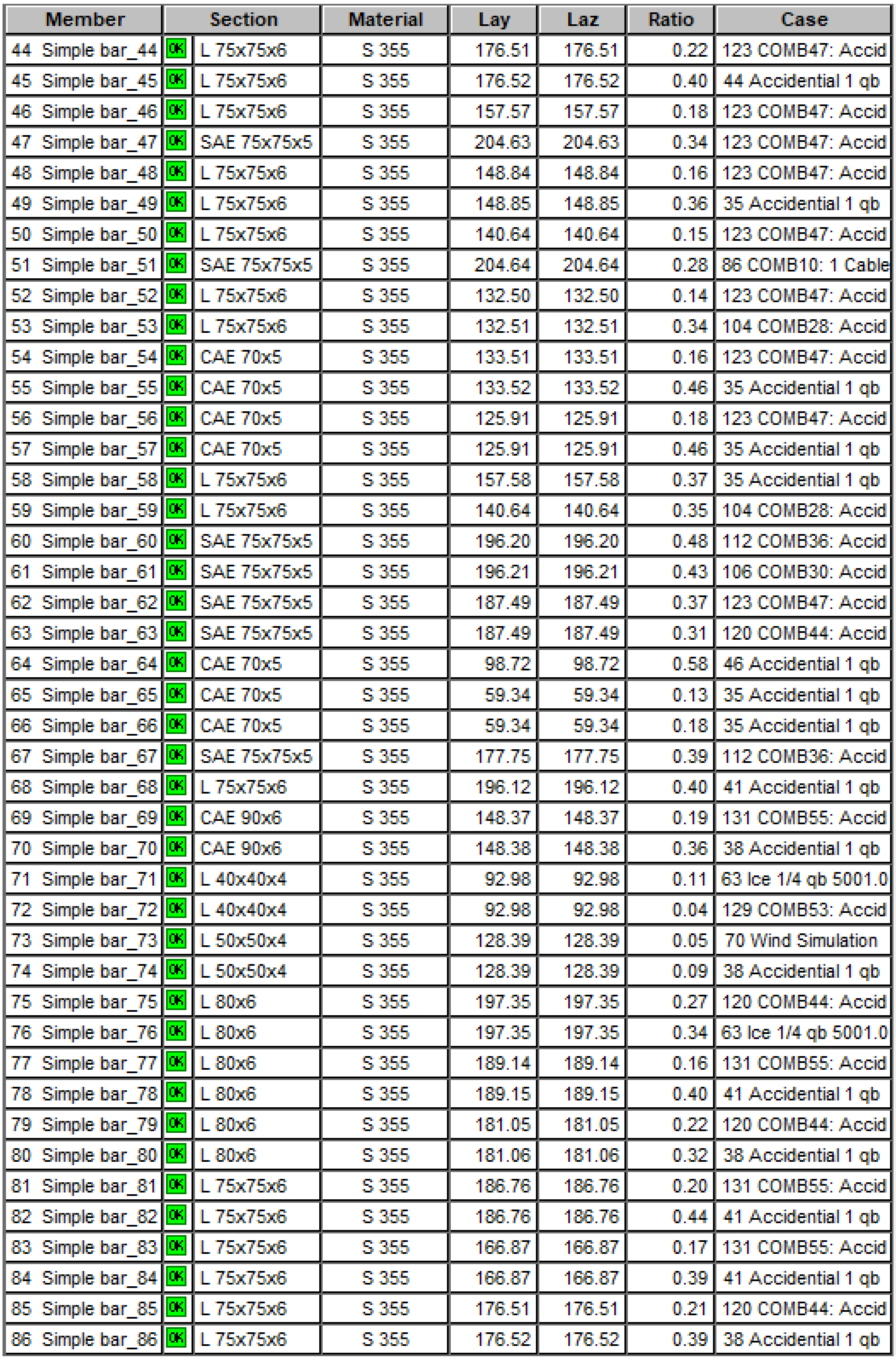
109 (C)	COMB33: Accidental 1 qb 3008.089	Linear Combination	ACC	wind	(40+71+1)*1.00
110 (C)	COMB34: Accidental 1 qb 3009.089	Linear Combination	ACC	wind	(41+71+1)*1.00
111 (C)	COMB35: Accidental 1 qb 3010.089	Linear Combination	ACC	wind	(42+71+1)*1.00
112 (C)	COMB36: Accidental 1 qb 3011.089	Linear Combination	ACC	wind	(43+71+1)*1.00
113 (C)	COMB37: Accidental 1 qb 3012.089	Linear Combination	ACC	wind	(44+71+1)*1.00
114 (C)	COMB38: Accidental 1 qb 3013.089	Linear Combination	ACC	wind	(45+71+1)*1.00
115 (C)	COMB39: Accidental 1 qb 3014.089	Linear Combination	ACC	wind	(46+71+1)*1.00
116 (C)	COMB40: Accidental 1 cable right 3015.089	Linear Combination	ACC	wind	(47+71+1)*1.00
117 (C)	COMB42: Accidental 1 cable right 3016.089	Linear Combination	ACC	wind	(48+71+1)*1.00
118 (C)	COMB42: Accidental 1 cable right 3017.089	Linear Combination	ACC	wind	(49+71+1)*1.00
119 (C)	COMB43: Accidental 1 cable right 3018.089	Linear Combination	ACC	wind	(50+71+1)*1.00
120 (C)	COMB44: Accidental 1 cable right 3019.089	Linear Combination	ACC	wind	(51+71+1)*1.00
121 (C)	COMB45: Accidental 1 cable right 3020.089	Linear Combination	ACC	wind	(52+71+1)*1.00
122 (C)	COMB46: Accidental 1 cable right 3021.089	Linear Combination	ACC	wind	(53+71+1)*1.00
123 (C)	COMB47: Accidental 1 cable right 3022.089	Linear Combination	ACC	wind	(54+71+1)*1.00
124 (C)	COMB48: Accidental 1 cable left 3023.089	Linear Combination	ACC	wind	(55+71+1)*1.00

125 (C)	COMB49: Accidental 1 cable left 3024.089	Linear Combination	ACC	wind	(56+71+1)*1.00
126 (C)	COMB50: Accidental 1 cable left 3025.089	Linear Combination	ACC	wind	(57+71+1)*1.00
127 (C)	COMB51: Accidental 1 cable left 3026.089	Linear Combination	ACC	wind	(58+71+1)*1.00
128 (C)	COMB52: Accidental 1 cable left 3027.089	Linear Combination	ACC	wind	(59+71+1)*1.00
129 (C)	COMB53: Accidental 1 cable left 3028.089	Linear Combination	ACC	wind	(60+71+1)*1.00
130 (C)	COMB54: Accidental 1 cable left 3029.089	Linear Combination	ACC	wind	(61+71+1)*1.00
131 (C)	COMB55: Accidental 1 cable left 3030.089	Linear Combination	ACC	wind	(62+71+1)*1.00
132 (C)	COMB56: Ice 1/4 qb 5001.089	Linear Combination	ACC	wind	(63+71+1)*1.00
133 (C)	COMB57: Ice 1 cable right 1/4 qb 5002.089	Linear Combination	ACC	wind	(64+71+1)*1.00
134 (C)	COMB58: Ice 1 cable left 1/4 qb 5003.089	Linear Combination	ACC	wind	(65+71+1)*1.00
135 (C)	COMB59: Maintenance 1/4 qb 4001.089	Linear Combination	ACC	wind	(66+71+1)*1.00
136 (C)	COMB60: Maintenance 1 cable right 4002.089	Linear Combination	ACC	wind	(67+71+1)*1.00
137 (C)	COMB61: Maintenance 1 cable left 4003.089	Linear Combination	ACC	wind	(68+71+1)*1.00

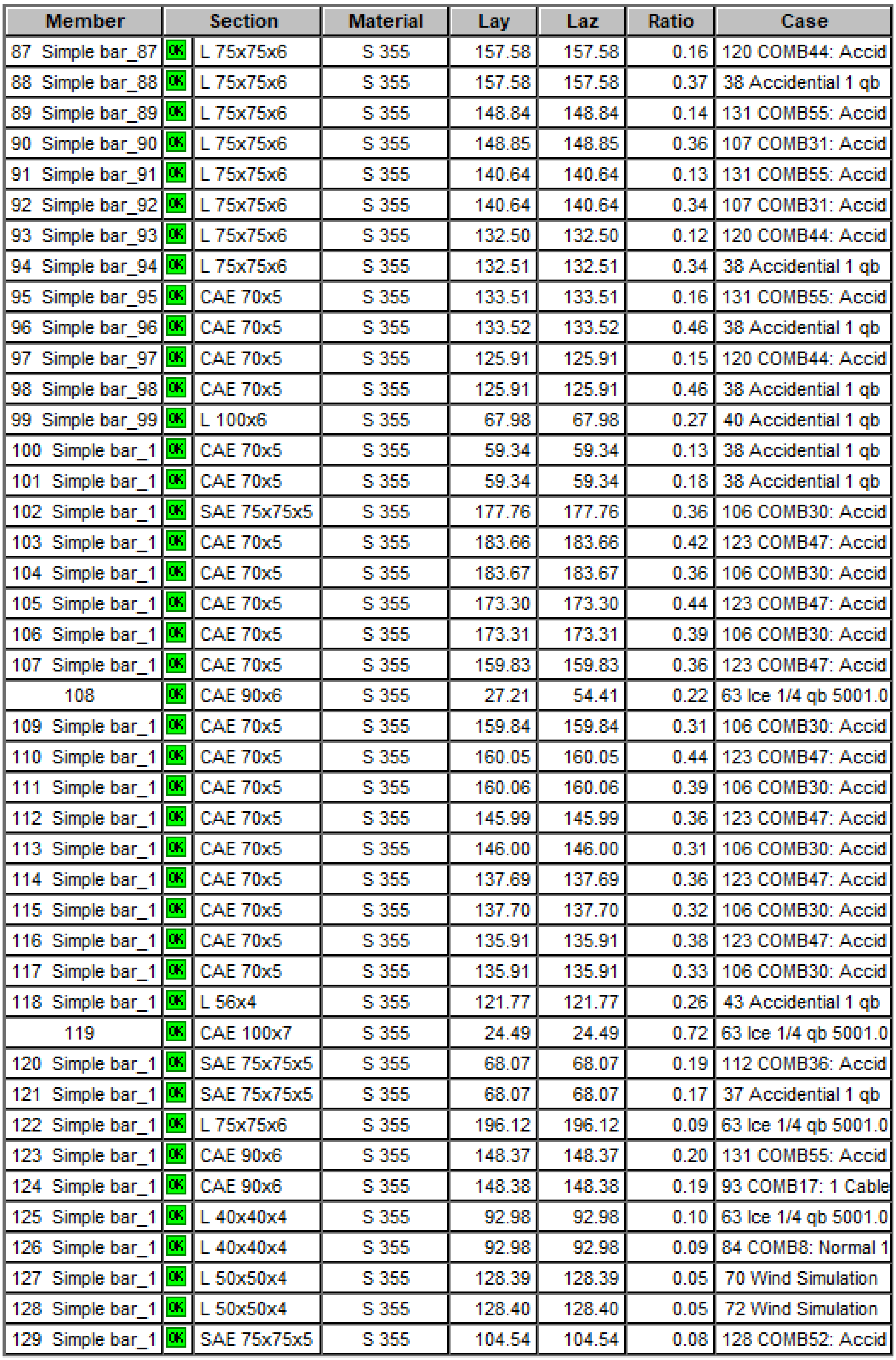
Annex B VERIFICATION OF THE CARBON STEEL ELEMENTS



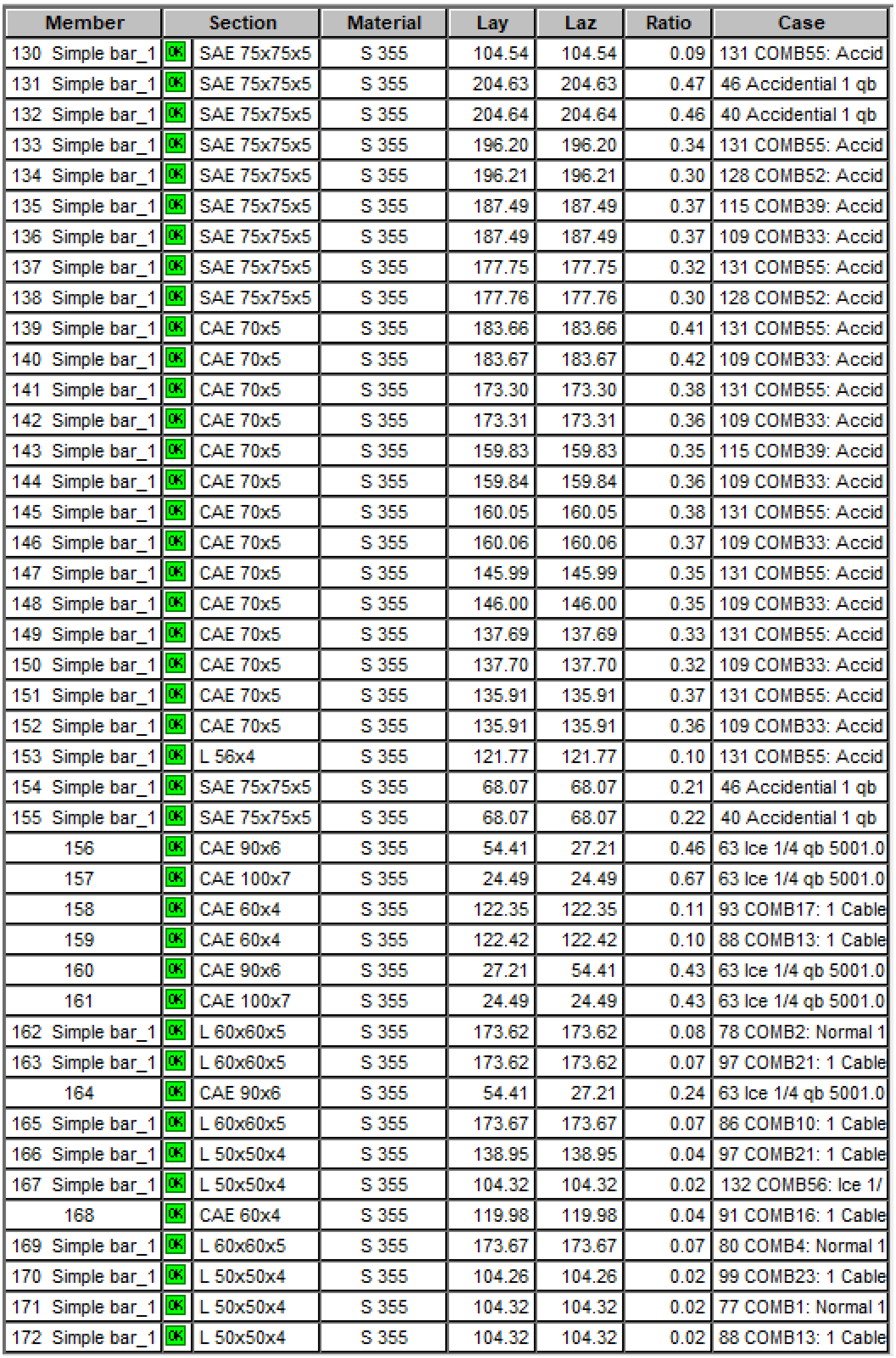
Member		Section	Material	Lay	Laz	Ratio	Case
1	OK	L 140x12	S 355	50.03	25.13	0.40	63 Ice 1/4 qb 5001.0
2 Simple bar_2	OK	L 75x75x6	S 355	196.06	196.06	0.04	81 COMB5: Normal 1
3	OK	L 140x12	S 355	25.13	50.03	0.45	63 Ice 1/4 qb 5001.0
4 Simple bar_4	OK	CAE 90x6	S 355	148.37	148.37	0.34	112 COMB36: Accid
5	OK	L 150x150x12	S 355	77.48	77.48	0.39	63 Ice 1/4 qb 5001.0
6	OK	L 140x10	S 355	45.55	35.84	0.41	63 Ice 1/4 qb 5001.0
7	OK	L 150x150x12	S 355	77.48	77.48	0.44	63 Ice 1/4 qb 5001.0
8	OK	L 120x120x10	S 355	52.15	29.21	0.41	63 Ice 1/4 qb 5001.0
9	OK	L 150x150x12	S 355	77.48	77.48	0.94	63 Ice 1/4 qb 5001.0
10	OK	L 140x10	S 355	35.84	45.55	0.46	63 Ice 1/4 qb 5001.0
11	OK	L 150x150x12	S 355	77.48	77.48	0.85	63 Ice 1/4 qb 5001.0
12	OK	L 120x120x10	S 355	29.21	52.15	0.46	63 Ice 1/4 qb 5001.0
13	OK	L 140x12	S 355	25.13	50.03	0.73	63 Ice 1/4 qb 5001.0
14	OK	CAE 100x7	S 355	24.49	24.49	0.39	63 Ice 1/4 qb 5001.0
15	OK	L 140x12	S 355	50.03	25.13	0.67	63 Ice 1/4 qb 5001.0
16 Simple bar_16	OK	CAE 90x6	S 355	148.38	148.38	0.29	106 COMB30: Accid
17	OK	L 140x10	S 355	35.84	45.55	0.60	63 Ice 1/4 qb 5001.0
18	OK	L 120x120x10	S 355	29.21	52.15	0.65	63 Ice 1/4 qb 5001.0
19	OK	L 140x10	S 355	45.55	35.84	0.55	63 Ice 1/4 qb 5001.0
20	OK	L 120x120x10	S 355	52.15	29.21	0.60	63 Ice 1/4 qb 5001.0
21 Simple bar_21	OK	L 75x75x6	S 355	196.12	196.12	0.36	35 Accidential 1 qb
22 Simple bar_22	OK	CAE 90x6	S 355	148.37	148.37	0.20	123 COMB47: Accid
23 Simple bar_23	OK	L 40x40x4	S 355	92.98	92.98	0.05	63 Ice 1/4 qb 5001.0
24 Simple bar_24	OK	L 40x40x4	S 355	92.98	92.98	0.05	63 Ice 1/4 qb 5001.0
25 Simple bar_25	OK	L 50x50x4	S 355	128.35	128.35	0.12	132 COMB56: Ice 1/
26 Simple bar_26	OK	L 50x50x4	S 355	128.40	128.40	0.13	132 COMB56: Ice 1/
27 Simple bar_27	OK	CAE 90x6	S 355	148.38	148.38	0.36	63 Ice 1/4 qb 5001.0
28 Simple bar_28	OK	L 40x40x4	S 355	92.98	92.98	0.10	63 Ice 1/4 qb 5001.0
29 Simple bar_29	OK	L 40x40x4	S 355	92.98	92.98	0.06	63 Ice 1/4 qb 5001.0
30 Simple bar_30	OK	SAE 75x75x5	S 355	104.54	104.54	0.16	106 COMB30: Accid
31 Simple bar_31	OK	L 50x50x4	S 355	128.39	128.39	0.14	63 Ice 1/4 qb 5001.0
32 Simple bar_32	OK	SAE 75x75x5	S 355	104.54	104.54	0.18	112 COMB36: Accid
33 Simple bar_33	OK	L 50x50x4	S 355	128.40	128.40	0.05	72 Wind Simulation
34 Simple bar_34	OK	L 80x6	S 355	197.35	197.35	0.23	123 COMB47: Accid
35 Simple bar_35	OK	L 80x6	S 355	197.35	197.35	0.36	44 Accidential 1 qb
36 Simple bar_36	OK	L 80x6	S 355	189.14	189.14	0.20	123 COMB47: Accid
37 Simple bar_37	OK	L 80x6	S 355	189.15	189.15	0.35	35 Accidential 1 qb
38 Simple bar_38	OK	L 80x6	S 355	181.05	181.05	0.21	123 COMB47: Accid
39 Simple bar_39	OK	L 80x6	S 355	181.06	181.06	0.35	44 Accidential 1 qb
40 Simple bar_40	OK	L 75x75x6	S 355	186.76	186.76	0.23	123 COMB47: Accid
41 Simple bar_41	OK	L 75x75x6	S 355	186.76	186.76	0.42	35 Accidential 1 qb
42 Simple bar_42	OK	L 75x75x6	S 355	166.87	166.87	0.20	123 COMB47: Accid
43 Simple bar_43	OK	L 75x75x6	S 355	166.87	166.87	0.39	35 Accidential 1 qb



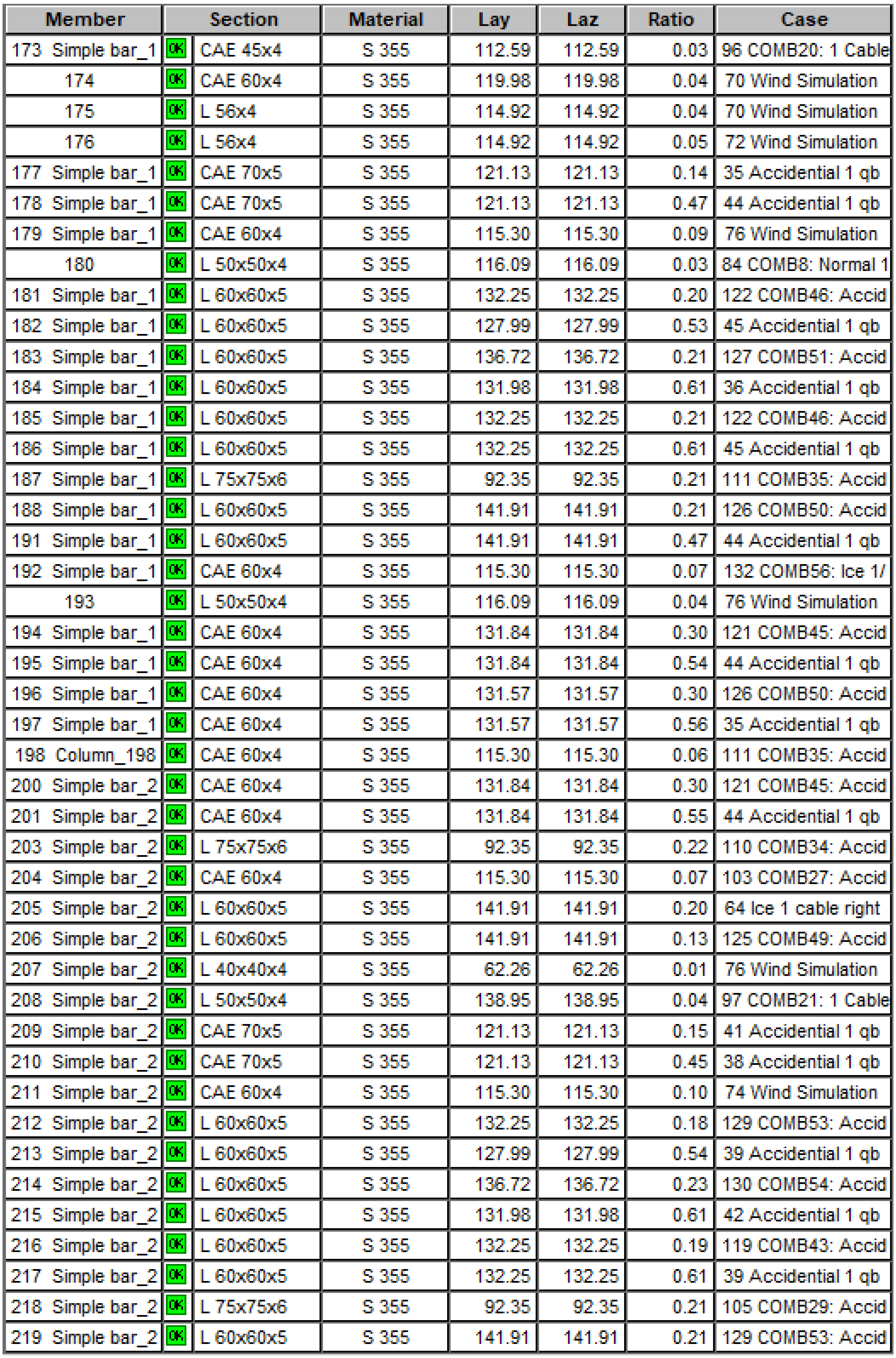
Member		Section	Material	Lay	Laz	Ratio	Case
44 Simple bar_44	OK	L 75x75x6	S 355	176.51	176.51	0.22	123 COMB47: Accid
45 Simple bar_45	OK	L 75x75x6	S 355	176.52	176.52	0.40	44 Accidential 1 qb
46 Simple bar_46	OK	L 75x75x6	S 355	157.57	157.57	0.18	123 COMB47: Accid
47 Simple bar_47	OK	SAE 75x75x5	S 355	204.63	204.63	0.34	123 COMB47: Accid
48 Simple bar_48	OK	L 75x75x6	S 355	148.84	148.84	0.16	123 COMB47: Accid
49 Simple bar_49	OK	L 75x75x6	S 355	148.85	148.85	0.36	35 Accidential 1 qb
50 Simple bar_50	OK	L 75x75x6	S 355	140.64	140.64	0.15	123 COMB47: Accid
51 Simple bar_51	OK	SAE 75x75x5	S 355	204.64	204.64	0.28	86 COMB10: 1 Cable
52 Simple bar_52	OK	L 75x75x6	S 355	132.50	132.50	0.14	123 COMB47: Accid
53 Simple bar_53	OK	L 75x75x6	S 355	132.51	132.51	0.34	104 COMB28: Accid
54 Simple bar_54	OK	CAE 70x5	S 355	133.51	133.51	0.16	123 COMB47: Accid
55 Simple bar_55	OK	CAE 70x5	S 355	133.52	133.52	0.46	35 Accidential 1 qb
56 Simple bar_56	OK	CAE 70x5	S 355	125.91	125.91	0.18	123 COMB47: Accid
57 Simple bar_57	OK	CAE 70x5	S 355	125.91	125.91	0.46	35 Accidential 1 qb
58 Simple bar_58	OK	L 75x75x6	S 355	157.58	157.58	0.37	35 Accidential 1 qb
59 Simple bar_59	OK	L 75x75x6	S 355	140.64	140.64	0.35	104 COMB28: Accid
60 Simple bar_60	OK	SAE 75x75x5	S 355	196.20	196.20	0.48	112 COMB36: Accid
61 Simple bar_61	OK	SAE 75x75x5	S 355	196.21	196.21	0.43	106 COMB30: Accid
62 Simple bar_62	OK	SAE 75x75x5	S 355	187.49	187.49	0.37	123 COMB47: Accid
63 Simple bar_63	OK	SAE 75x75x5	S 355	187.49	187.49	0.31	120 COMB44: Accid
64 Simple bar_64	OK	CAE 70x5	S 355	98.72	98.72	0.58	46 Accidential 1 qb
65 Simple bar_65	OK	CAE 70x5	S 355	59.34	59.34	0.13	35 Accidential 1 qb
66 Simple bar_66	OK	CAE 70x5	S 355	59.34	59.34	0.18	35 Accidential 1 qb
67 Simple bar_67	OK	SAE 75x75x5	S 355	177.75	177.75	0.39	112 COMB36: Accid
68 Simple bar_68	OK	L 75x75x6	S 355	196.12	196.12	0.40	41 Accidential 1 qb
69 Simple bar_69	OK	CAE 90x6	S 355	148.37	148.37	0.19	131 COMB55: Accid
70 Simple bar_70	OK	CAE 90x6	S 355	148.38	148.38	0.36	38 Accidential 1 qb
71 Simple bar_71	OK	L 40x40x4	S 355	92.98	92.98	0.11	63 Ice 1/4 qb 5001.0
72 Simple bar_72	OK	L 40x40x4	S 355	92.98	92.98	0.04	129 COMB53: Accid
73 Simple bar_73	OK	L 50x50x4	S 355	128.39	128.39	0.05	70 Wind Simulation
74 Simple bar_74	OK	L 50x50x4	S 355	128.39	128.39	0.09	38 Accidential 1 qb
75 Simple bar_75	OK	L 80x6	S 355	197.35	197.35	0.27	120 COMB44: Accid
76 Simple bar_76	OK	L 80x6	S 355	197.35	197.35	0.34	63 Ice 1/4 qb 5001.0
77 Simple bar_77	OK	L 80x6	S 355	189.14	189.14	0.16	131 COMB55: Accid
78 Simple bar_78	OK	L 80x6	S 355	189.15	189.15	0.40	41 Accidential 1 qb
79 Simple bar_79	OK	L 80x6	S 355	181.05	181.05	0.22	120 COMB44: Accid
80 Simple bar_80	OK	L 80x6	S 355	181.06	181.06	0.32	38 Accidential 1 qb
81 Simple bar_81	OK	L 75x75x6	S 355	186.76	186.76	0.20	131 COMB55: Accid
82 Simple bar_82	OK	L 75x75x6	S 355	186.76	186.76	0.44	41 Accidential 1 qb
83 Simple bar_83	OK	L 75x75x6	S 355	166.87	166.87	0.17	131 COMB55: Accid
84 Simple bar_84	OK	L 75x75x6	S 355	166.87	166.87	0.39	41 Accidential 1 qb
85 Simple bar_85	OK	L 75x75x6	S 355	176.51	176.51	0.21	120 COMB44: Accid
86 Simple bar_86	OK	L 75x75x6	S 355	176.52	176.52	0.39	38 Accidential 1 qb



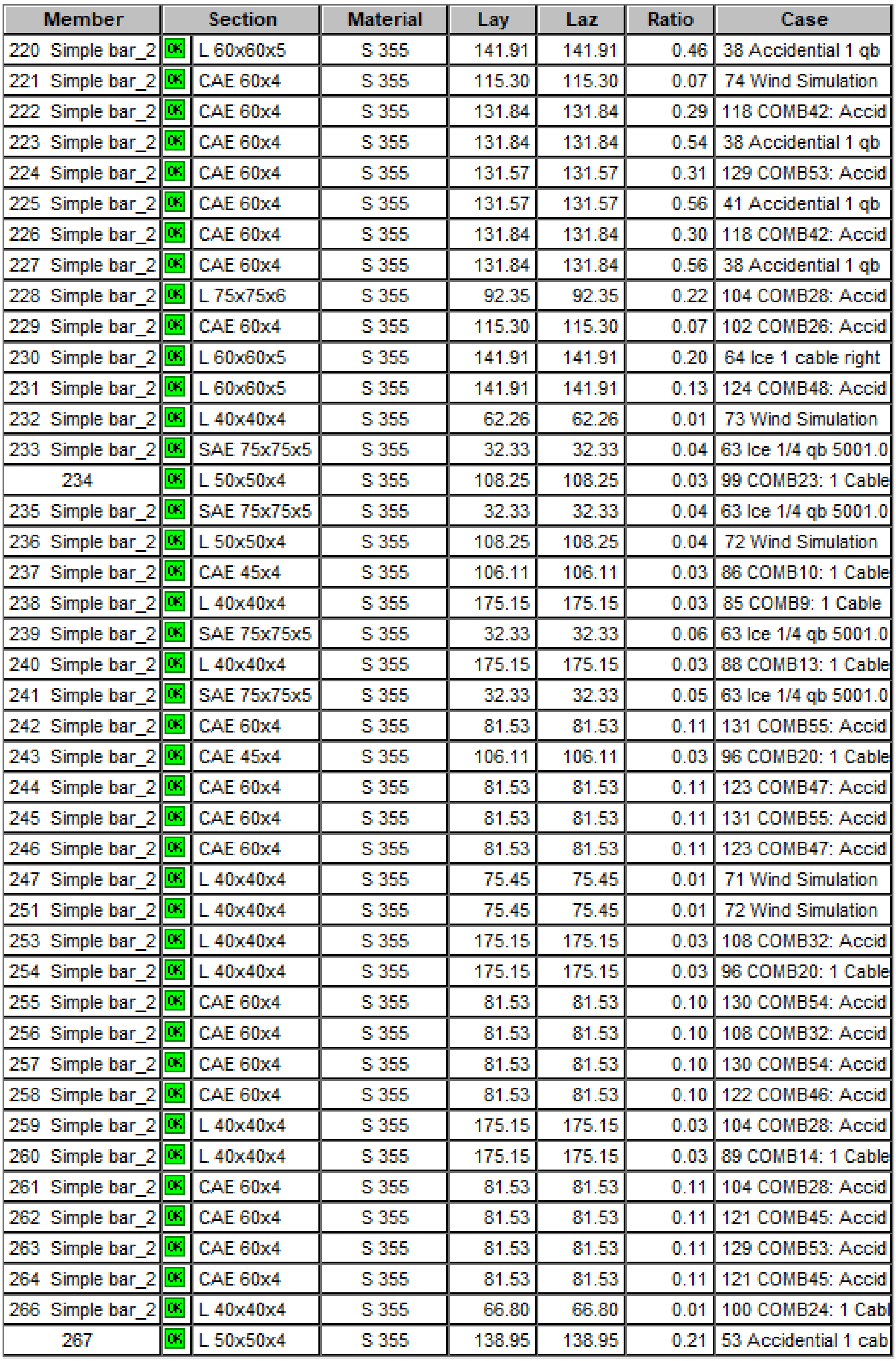
Member	Section		Material	Lay	Laz	Ratio	Case
87 Simple bar_87	OK	L 75x75x6	S 355	157.58	157.58	0.16	120 COMB44: Accid
88 Simple bar_88	OK	L 75x75x6	S 355	157.58	157.58	0.37	38 Accidential 1 qb
89 Simple bar_89	OK	L 75x75x6	S 355	148.84	148.84	0.14	131 COMB55: Accid
90 Simple bar_90	OK	L 75x75x6	S 355	148.85	148.85	0.36	107 COMB31: Accid
91 Simple bar_91	OK	L 75x75x6	S 355	140.64	140.64	0.13	131 COMB55: Accid
92 Simple bar_92	OK	L 75x75x6	S 355	140.64	140.64	0.34	107 COMB31: Accid
93 Simple bar_93	OK	L 75x75x6	S 355	132.50	132.50	0.12	120 COMB44: Accid
94 Simple bar_94	OK	L 75x75x6	S 355	132.51	132.51	0.34	38 Accidential 1 qb
95 Simple bar_95	OK	CAE 70x5	S 355	133.51	133.51	0.16	131 COMB55: Accid
96 Simple bar_96	OK	CAE 70x5	S 355	133.52	133.52	0.46	38 Accidential 1 qb
97 Simple bar_97	OK	CAE 70x5	S 355	125.91	125.91	0.15	120 COMB44: Accid
98 Simple bar_98	OK	CAE 70x5	S 355	125.91	125.91	0.46	38 Accidential 1 qb
99 Simple bar_99	OK	L 100x6	S 355	67.98	67.98	0.27	40 Accidential 1 qb
100 Simple bar_1	OK	CAE 70x5	S 355	59.34	59.34	0.13	38 Accidential 1 qb
101 Simple bar_1	OK	CAE 70x5	S 355	59.34	59.34	0.18	38 Accidential 1 qb
102 Simple bar_1	OK	SAE 75x75x5	S 355	177.76	177.76	0.36	106 COMB30: Accid
103 Simple bar_1	OK	CAE 70x5	S 355	183.66	183.66	0.42	123 COMB47: Accid
104 Simple bar_1	OK	CAE 70x5	S 355	183.67	183.67	0.36	106 COMB30: Accid
105 Simple bar_1	OK	CAE 70x5	S 355	173.30	173.30	0.44	123 COMB47: Accid
106 Simple bar_1	OK	CAE 70x5	S 355	173.31	173.31	0.39	106 COMB30: Accid
107 Simple bar_1	OK	CAE 70x5	S 355	159.83	159.83	0.36	123 COMB47: Accid
108	OK	CAE 90x6	S 355	27.21	54.41	0.22	63 Ice 1/4 qb 5001.0
109 Simple bar_1	OK	CAE 70x5	S 355	159.84	159.84	0.31	106 COMB30: Accid
110 Simple bar_1	OK	CAE 70x5	S 355	160.05	160.05	0.44	123 COMB47: Accid
111 Simple bar_1	OK	CAE 70x5	S 355	160.06	160.06	0.39	106 COMB30: Accid
112 Simple bar_1	OK	CAE 70x5	S 355	145.99	145.99	0.36	123 COMB47: Accid
113 Simple bar_1	OK	CAE 70x5	S 355	146.00	146.00	0.31	106 COMB30: Accid
114 Simple bar_1	OK	CAE 70x5	S 355	137.69	137.69	0.36	123 COMB47: Accid
115 Simple bar_1	OK	CAE 70x5	S 355	137.70	137.70	0.32	106 COMB30: Accid
116 Simple bar_1	OK	CAE 70x5	S 355	135.91	135.91	0.38	123 COMB47: Accid
117 Simple bar_1	OK	CAE 70x5	S 355	135.91	135.91	0.33	106 COMB30: Accid
118 Simple bar_1	OK	L 56x4	S 355	121.77	121.77	0.26	43 Accidential 1 qb
119	OK	CAE 100x7	S 355	24.49	24.49	0.72	63 Ice 1/4 qb 5001.0
120 Simple bar_1	OK	SAE 75x75x5	S 355	68.07	68.07	0.19	112 COMB36: Accid
121 Simple bar_1	OK	SAE 75x75x5	S 355	68.07	68.07	0.17	37 Accidential 1 qb
122 Simple bar_1	OK	L 75x75x6	S 355	196.12	196.12	0.09	63 Ice 1/4 qb 5001.0
123 Simple bar_1	OK	CAE 90x6	S 355	148.37	148.37	0.20	131 COMB55: Accid
124 Simple bar_1	OK	CAE 90x6	S 355	148.38	148.38	0.19	93 COMB17: 1 Cable
125 Simple bar_1	OK	L 40x40x4	S 355	92.98	92.98	0.10	63 Ice 1/4 qb 5001.0
126 Simple bar_1	OK	L 40x40x4	S 355	92.98	92.98	0.09	84 COMB8: Normal 1
127 Simple bar_1	OK	L 50x50x4	S 355	128.39	128.39	0.05	70 Wind Simulation
128 Simple bar_1	OK	L 50x50x4	S 355	128.40	128.40	0.05	72 Wind Simulation
129 Simple bar_1	OK	SAE 75x75x5	S 355	104.54	104.54	0.08	128 COMB52: Accid



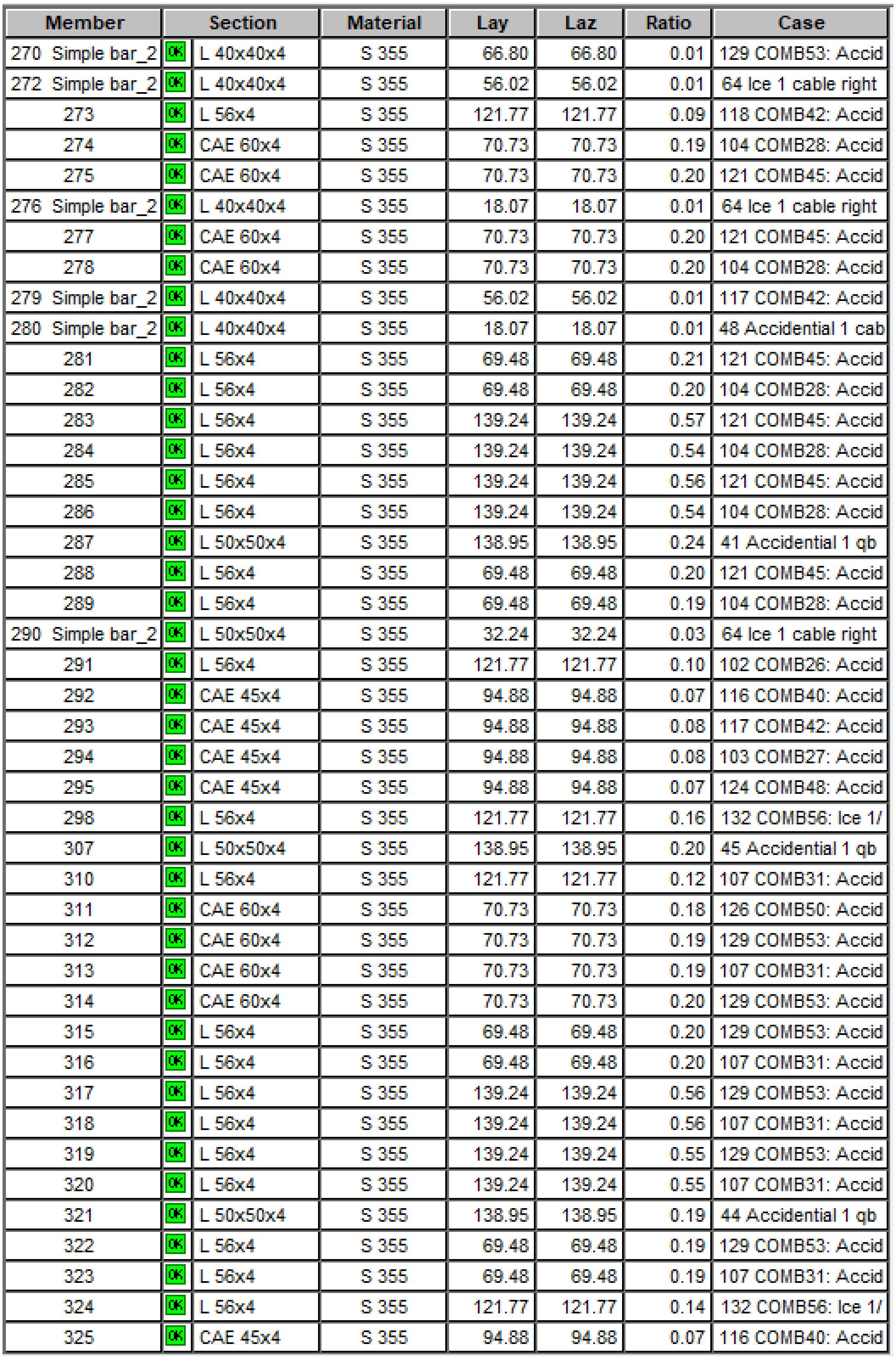
Member		Section	Material	Lay	Laz	Ratio	Case
130 Simple bar_1	OK	SAE 75x75x5	S 355	104.54	104.54	0.09	131 COMB55: Accid
131 Simple bar_1	OK	SAE 75x75x5	S 355	204.63	204.63	0.47	46 Accidential 1 qb
132 Simple bar_1	OK	SAE 75x75x5	S 355	204.64	204.64	0.46	40 Accidential 1 qb
133 Simple bar_1	OK	SAE 75x75x5	S 355	196.20	196.20	0.34	131 COMB55: Accid
134 Simple bar_1	OK	SAE 75x75x5	S 355	196.21	196.21	0.30	128 COMB52: Accid
135 Simple bar_1	OK	SAE 75x75x5	S 355	187.49	187.49	0.37	115 COMB39: Accid
136 Simple bar_1	OK	SAE 75x75x5	S 355	187.49	187.49	0.37	109 COMB33: Accid
137 Simple bar_1	OK	SAE 75x75x5	S 355	177.75	177.75	0.32	131 COMB55: Accid
138 Simple bar_1	OK	SAE 75x75x5	S 355	177.76	177.76	0.30	128 COMB52: Accid
139 Simple bar_1	OK	CAE 70x5	S 355	183.66	183.66	0.41	131 COMB55: Accid
140 Simple bar_1	OK	CAE 70x5	S 355	183.67	183.67	0.42	109 COMB33: Accid
141 Simple bar_1	OK	CAE 70x5	S 355	173.30	173.30	0.38	131 COMB55: Accid
142 Simple bar_1	OK	CAE 70x5	S 355	173.31	173.31	0.36	109 COMB33: Accid
143 Simple bar_1	OK	CAE 70x5	S 355	159.83	159.83	0.35	115 COMB39: Accid
144 Simple bar_1	OK	CAE 70x5	S 355	159.84	159.84	0.36	109 COMB33: Accid
145 Simple bar_1	OK	CAE 70x5	S 355	160.05	160.05	0.38	131 COMB55: Accid
146 Simple bar_1	OK	CAE 70x5	S 355	160.06	160.06	0.37	109 COMB33: Accid
147 Simple bar_1	OK	CAE 70x5	S 355	145.99	145.99	0.35	131 COMB55: Accid
148 Simple bar_1	OK	CAE 70x5	S 355	146.00	146.00	0.35	109 COMB33: Accid
149 Simple bar_1	OK	CAE 70x5	S 355	137.69	137.69	0.33	131 COMB55: Accid
150 Simple bar_1	OK	CAE 70x5	S 355	137.70	137.70	0.32	109 COMB33: Accid
151 Simple bar_1	OK	CAE 70x5	S 355	135.91	135.91	0.37	131 COMB55: Accid
152 Simple bar_1	OK	CAE 70x5	S 355	135.91	135.91	0.36	109 COMB33: Accid
153 Simple bar_1	OK	L 56x4	S 355	121.77	121.77	0.10	131 COMB55: Accid
154 Simple bar_1	OK	SAE 75x75x5	S 355	68.07	68.07	0.21	46 Accidential 1 qb
155 Simple bar_1	OK	SAE 75x75x5	S 355	68.07	68.07	0.22	40 Accidential 1 qb
156	OK	CAE 90x6	S 355	54.41	27.21	0.46	63 Ice 1/4 qb 5001.0
157	OK	CAE 100x7	S 355	24.49	24.49	0.67	63 Ice 1/4 qb 5001.0
158	OK	CAE 60x4	S 355	122.35	122.35	0.11	93 COMB17: 1 Cable
159	OK	CAE 60x4	S 355	122.42	122.42	0.10	88 COMB13: 1 Cable
160	OK	CAE 90x6	S 355	27.21	54.41	0.43	63 Ice 1/4 qb 5001.0
161	OK	CAE 100x7	S 355	24.49	24.49	0.43	63 Ice 1/4 qb 5001.0
162 Simple bar_1	OK	L 60x60x5	S 355	173.62	173.62	0.08	78 COMB2: Normal 1
163 Simple bar_1	OK	L 60x60x5	S 355	173.62	173.62	0.07	97 COMB21: 1 Cable
164	OK	CAE 90x6	S 355	54.41	27.21	0.24	63 Ice 1/4 qb 5001.0
165 Simple bar_1	OK	L 60x60x5	S 355	173.67	173.67	0.07	86 COMB10: 1 Cable
166 Simple bar_1	OK	L 50x50x4	S 355	138.95	138.95	0.04	97 COMB21: 1 Cable
167 Simple bar_1	OK	L 50x50x4	S 355	104.32	104.32	0.02	132 COMB56: Ice 1/
168	OK	CAE 60x4	S 355	119.98	119.98	0.04	91 COMB16: 1 Cable
169 Simple bar_1	OK	L 60x60x5	S 355	173.67	173.67	0.07	80 COMB4: Normal 1
170 Simple bar_1	OK	L 50x50x4	S 355	104.26	104.26	0.02	99 COMB23: 1 Cable
171 Simple bar_1	OK	L 50x50x4	S 355	104.32	104.32	0.02	77 COMB1: Normal 1
172 Simple bar_1	OK	L 50x50x4	S 355	104.32	104.32	0.02	88 COMB13: 1 Cable



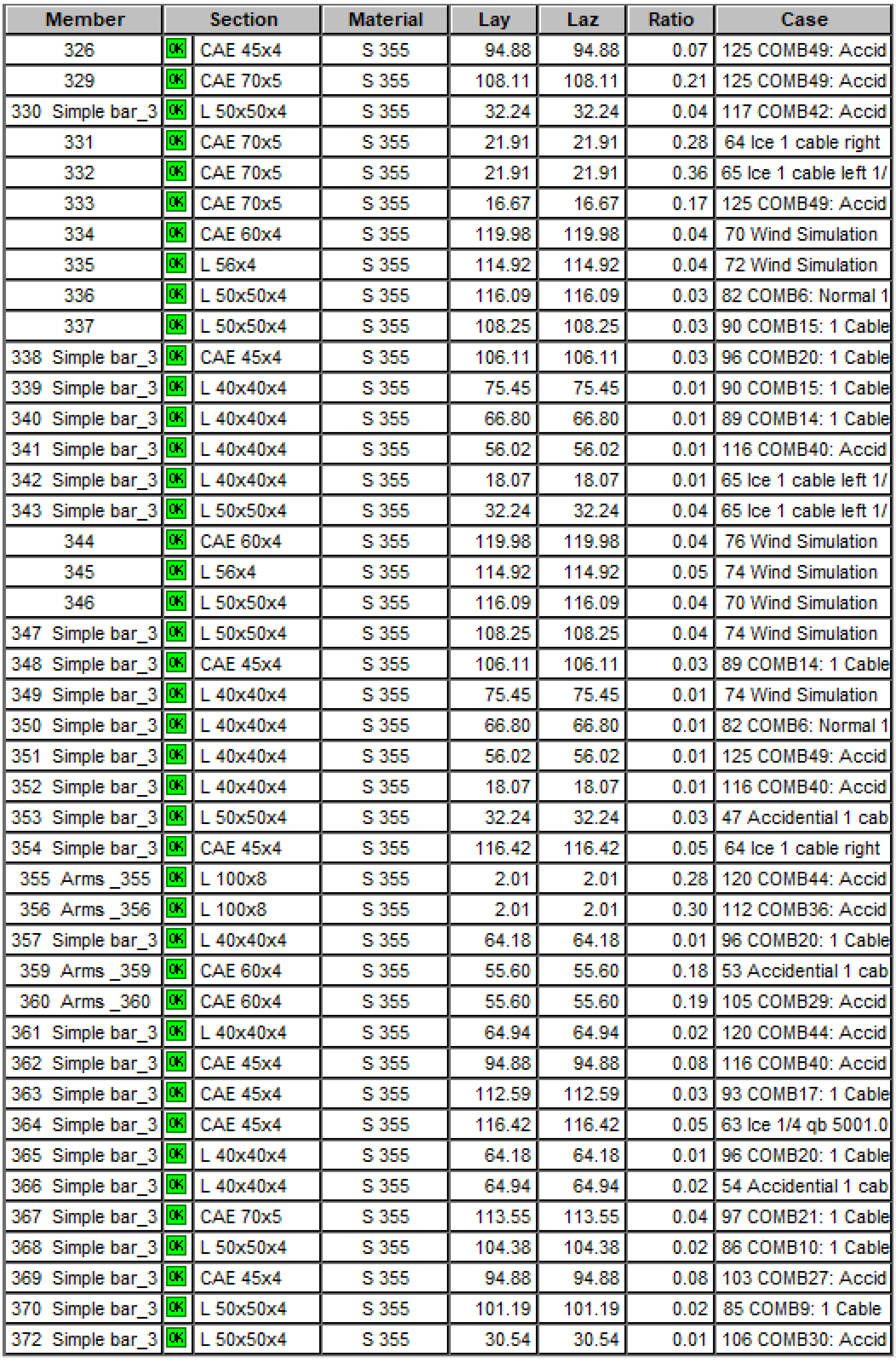
Member	Section		Material	Lay	Laz	Ratio	Case
173 Simple bar_1	OK	CAE 45x4	S 355	112.59	112.59	0.03	96 COMB20: 1 Cable
174	OK	CAE 60x4	S 355	119.98	119.98	0.04	70 Wind Simulation
175	OK	L 56x4	S 355	114.92	114.92	0.04	70 Wind Simulation
176	OK	L 56x4	S 355	114.92	114.92	0.05	72 Wind Simulation
177 Simple bar_1	OK	CAE 70x5	S 355	121.13	121.13	0.14	35 Accidential 1 qb
178 Simple bar_1	OK	CAE 70x5	S 355	121.13	121.13	0.47	44 Accidential 1 qb
179 Simple bar_1	OK	CAE 60x4	S 355	115.30	115.30	0.09	76 Wind Simulation
180	OK	L 50x50x4	S 355	116.09	116.09	0.03	84 COMB8: Normal 1
181 Simple bar_1	OK	L 60x60x5	S 355	132.25	132.25	0.20	122 COMB46: Accid
182 Simple bar_1	OK	L 60x60x5	S 355	127.99	127.99	0.53	45 Accidential 1 qb
183 Simple bar_1	OK	L 60x60x5	S 355	136.72	136.72	0.21	127 COMB51: Accid
184 Simple bar_1	OK	L 60x60x5	S 355	131.98	131.98	0.61	36 Accidential 1 qb
185 Simple bar_1	OK	L 60x60x5	S 355	132.25	132.25	0.21	122 COMB46: Accid
186 Simple bar_1	OK	L 60x60x5	S 355	132.25	132.25	0.61	45 Accidential 1 qb
187 Simple bar_1	OK	L 75x75x6	S 355	92.35	92.35	0.21	111 COMB35: Accid
188 Simple bar_1	OK	L 60x60x5	S 355	141.91	141.91	0.21	126 COMB50: Accid
191 Simple bar_1	OK	L 60x60x5	S 355	141.91	141.91	0.47	44 Accidential 1 qb
192 Simple bar_1	OK	CAE 60x4	S 355	115.30	115.30	0.07	132 COMB56: Ice 1/
193	OK	L 50x50x4	S 355	116.09	116.09	0.04	76 Wind Simulation
194 Simple bar_1	OK	CAE 60x4	S 355	131.84	131.84	0.30	121 COMB45: Accid
195 Simple bar_1	OK	CAE 60x4	S 355	131.84	131.84	0.54	44 Accidential 1 qb
196 Simple bar_1	OK	CAE 60x4	S 355	131.57	131.57	0.30	126 COMB50: Accid
197 Simple bar_1	OK	CAE 60x4	S 355	131.57	131.57	0.56	35 Accidential 1 qb
198 Column_198	OK	CAE 60x4	S 355	115.30	115.30	0.06	111 COMB35: Accid
200 Simple bar_2	OK	CAE 60x4	S 355	131.84	131.84	0.30	121 COMB45: Accid
201 Simple bar_2	OK	CAE 60x4	S 355	131.84	131.84	0.55	44 Accidential 1 qb
203 Simple bar_2	OK	L 75x75x6	S 355	92.35	92.35	0.22	110 COMB34: Accid
204 Simple bar_2	OK	CAE 60x4	S 355	115.30	115.30	0.07	103 COMB27: Accid
205 Simple bar_2	OK	L 60x60x5	S 355	141.91	141.91	0.20	64 Ice 1 cable right
206 Simple bar_2	OK	L 60x60x5	S 355	141.91	141.91	0.13	125 COMB49: Accid
207 Simple bar_2	OK	L 40x40x4	S 355	62.26	62.26	0.01	76 Wind Simulation
208 Simple bar_2	OK	L 50x50x4	S 355	138.95	138.95	0.04	97 COMB21: 1 Cable
209 Simple bar_2	OK	CAE 70x5	S 355	121.13	121.13	0.15	41 Accidential 1 qb
210 Simple bar_2	OK	CAE 70x5	S 355	121.13	121.13	0.45	38 Accidential 1 qb
211 Simple bar_2	OK	CAE 60x4	S 355	115.30	115.30	0.10	74 Wind Simulation
212 Simple bar_2	OK	L 60x60x5	S 355	132.25	132.25	0.18	129 COMB53: Accid
213 Simple bar_2	OK	L 60x60x5	S 355	127.99	127.99	0.54	39 Accidential 1 qb
214 Simple bar_2	OK	L 60x60x5	S 355	136.72	136.72	0.23	130 COMB54: Accid
215 Simple bar_2	OK	L 60x60x5	S 355	131.98	131.98	0.61	42 Accidential 1 qb
216 Simple bar_2	OK	L 60x60x5	S 355	132.25	132.25	0.19	119 COMB43: Accid
217 Simple bar_2	OK	L 60x60x5	S 355	132.25	132.25	0.61	39 Accidential 1 qb
218 Simple bar_2	OK	L 75x75x6	S 355	92.35	92.35	0.21	105 COMB29: Accid
219 Simple bar_2	OK	L 60x60x5	S 355	141.91	141.91	0.21	129 COMB53: Accid



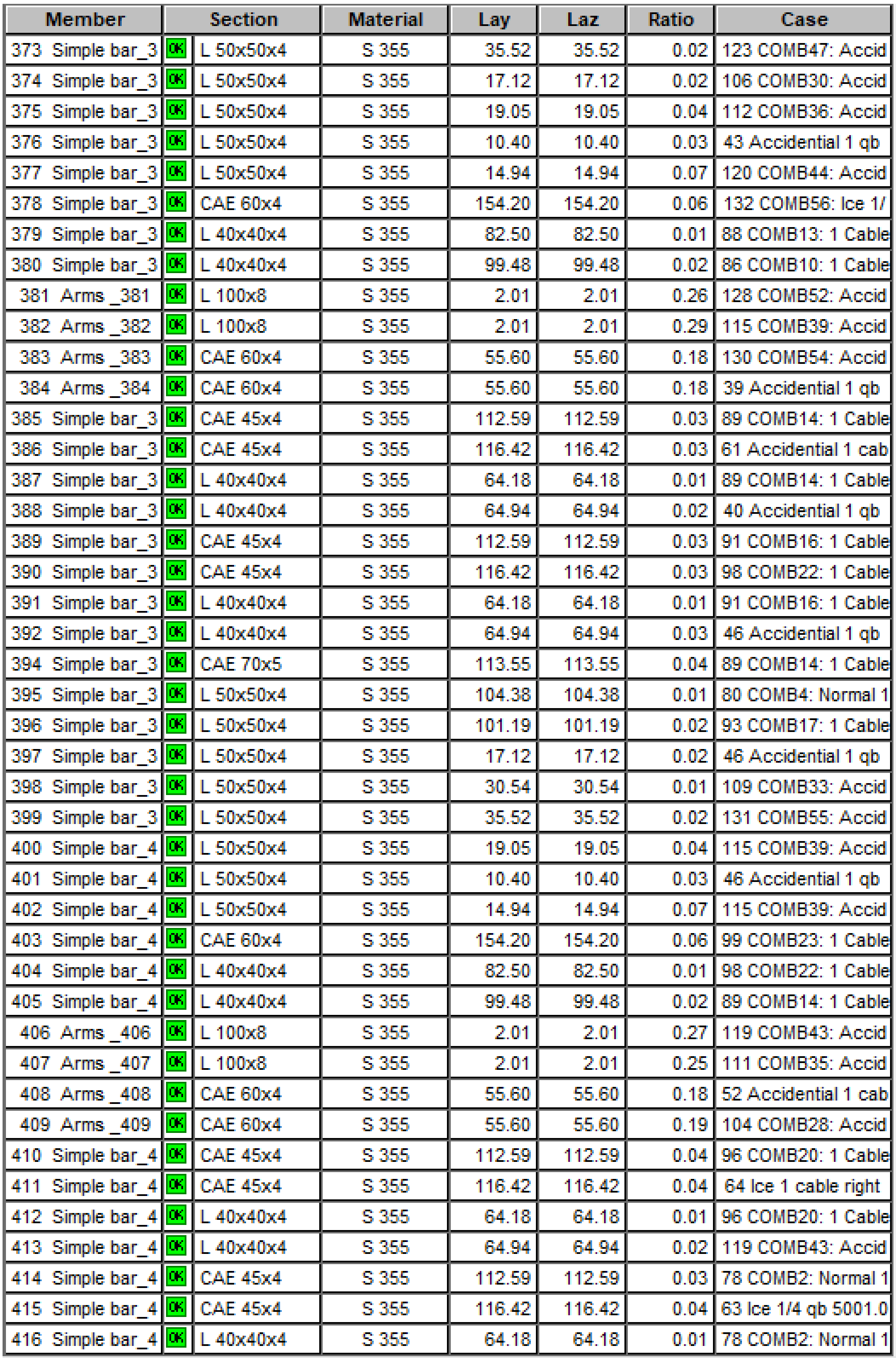
Member	Section		Material	Lay	Laz	Ratio	Case
220 Simple bar_2	OK	L 60x60x5	S 355	141.91	141.91	0.46	38 Accidential 1 qb
221 Simple bar_2	OK	CAE 60x4	S 355	115.30	115.30	0.07	74 Wind Simulation
222 Simple bar_2	OK	CAE 60x4	S 355	131.84	131.84	0.29	118 COMB42: Accid
223 Simple bar_2	OK	CAE 60x4	S 355	131.84	131.84	0.54	38 Accidential 1 qb
224 Simple bar_2	OK	CAE 60x4	S 355	131.57	131.57	0.31	129 COMB53: Accid
225 Simple bar_2	OK	CAE 60x4	S 355	131.57	131.57	0.56	41 Accidential 1 qb
226 Simple bar_2	OK	CAE 60x4	S 355	131.84	131.84	0.30	118 COMB42: Accid
227 Simple bar_2	OK	CAE 60x4	S 355	131.84	131.84	0.56	38 Accidential 1 qb
228 Simple bar_2	OK	L 75x75x6	S 355	92.35	92.35	0.22	104 COMB28: Accid
229 Simple bar_2	OK	CAE 60x4	S 355	115.30	115.30	0.07	102 COMB26: Accid
230 Simple bar_2	OK	L 60x60x5	S 355	141.91	141.91	0.20	64 Ice 1 cable right
231 Simple bar_2	OK	L 60x60x5	S 355	141.91	141.91	0.13	124 COMB48: Accid
232 Simple bar_2	OK	L 40x40x4	S 355	62.26	62.26	0.01	73 Wind Simulation
233 Simple bar_2	OK	SAE 75x75x5	S 355	32.33	32.33	0.04	63 Ice 1/4 qb 5001.0
234	OK	L 50x50x4	S 355	108.25	108.25	0.03	99 COMB23: 1 Cable
235 Simple bar_2	OK	SAE 75x75x5	S 355	32.33	32.33	0.04	63 Ice 1/4 qb 5001.0
236 Simple bar_2	OK	L 50x50x4	S 355	108.25	108.25	0.04	72 Wind Simulation
237 Simple bar_2	OK	CAE 45x4	S 355	106.11	106.11	0.03	86 COMB10: 1 Cable
238 Simple bar_2	OK	L 40x40x4	S 355	175.15	175.15	0.03	85 COMB9: 1 Cable
239 Simple bar_2	OK	SAE 75x75x5	S 355	32.33	32.33	0.06	63 Ice 1/4 qb 5001.0
240 Simple bar_2	OK	L 40x40x4	S 355	175.15	175.15	0.03	88 COMB13: 1 Cable
241 Simple bar_2	OK	SAE 75x75x5	S 355	32.33	32.33	0.05	63 Ice 1/4 qb 5001.0
242 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	131 COMB55: Accid
243 Simple bar_2	OK	CAE 45x4	S 355	106.11	106.11	0.03	96 COMB20: 1 Cable
244 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	123 COMB47: Accid
245 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	131 COMB55: Accid
246 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	123 COMB47: Accid
247 Simple bar_2	OK	L 40x40x4	S 355	75.45	75.45	0.01	71 Wind Simulation
251 Simple bar_2	OK	L 40x40x4	S 355	75.45	75.45	0.01	72 Wind Simulation
253 Simple bar_2	OK	L 40x40x4	S 355	175.15	175.15	0.03	108 COMB32: Accid
254 Simple bar_2	OK	L 40x40x4	S 355	175.15	175.15	0.03	96 COMB20: 1 Cable
255 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.10	130 COMB54: Accid
256 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.10	108 COMB32: Accid
257 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.10	130 COMB54: Accid
258 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.10	122 COMB46: Accid
259 Simple bar_2	OK	L 40x40x4	S 355	175.15	175.15	0.03	104 COMB28: Accid
260 Simple bar_2	OK	L 40x40x4	S 355	175.15	175.15	0.03	89 COMB14: 1 Cable
261 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	104 COMB28: Accid
262 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	121 COMB45: Accid
263 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	129 COMB53: Accid
264 Simple bar_2	OK	CAE 60x4	S 355	81.53	81.53	0.11	121 COMB45: Accid
266 Simple bar_2	OK	L 40x40x4	S 355	66.80	66.80	0.01	100 COMB24: 1 Cabl
267	OK	L 50x50x4	S 355	138.95	138.95	0.21	53 Accidential 1 cab



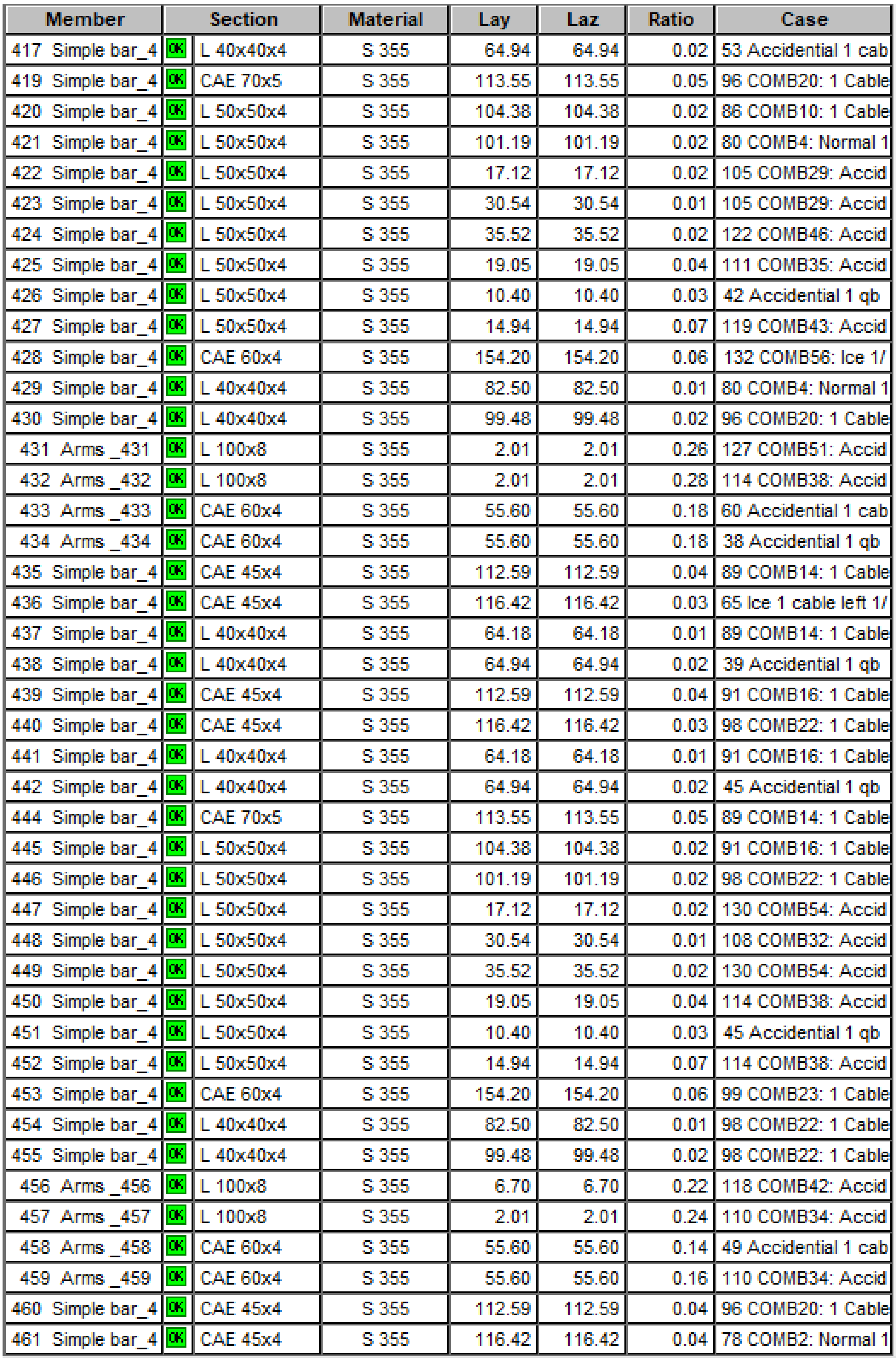
Member		Section	Material	Lay	Laz	Ratio	Case
270 Simple bar_2	OK	L 40x40x4	S 355	66.80	66.80	0.01	129 COMB53: Accid
272 Simple bar_2	OK	L 40x40x4	S 355	56.02	56.02	0.01	64 Ice 1 cable right
273	OK	L 56x4	S 355	121.77	121.77	0.09	118 COMB42: Accid
274	OK	CAE 60x4	S 355	70.73	70.73	0.19	104 COMB28: Accid
275	OK	CAE 60x4	S 355	70.73	70.73	0.20	121 COMB45: Accid
276 Simple bar_2	OK	L 40x40x4	S 355	18.07	18.07	0.01	64 Ice 1 cable right
277	OK	CAE 60x4	S 355	70.73	70.73	0.20	121 COMB45: Accid
278	OK	CAE 60x4	S 355	70.73	70.73	0.20	104 COMB28: Accid
279 Simple bar_2	OK	L 40x40x4	S 355	56.02	56.02	0.01	117 COMB42: Accid
280 Simple bar_2	OK	L 40x40x4	S 355	18.07	18.07	0.01	48 Accidential 1 cab
281	OK	L 56x4	S 355	69.48	69.48	0.21	121 COMB45: Accid
282	OK	L 56x4	S 355	69.48	69.48	0.20	104 COMB28: Accid
283	OK	L 56x4	S 355	139.24	139.24	0.57	121 COMB45: Accid
284	OK	L 56x4	S 355	139.24	139.24	0.54	104 COMB28: Accid
285	OK	L 56x4	S 355	139.24	139.24	0.56	121 COMB45: Accid
286	OK	L 56x4	S 355	139.24	139.24	0.54	104 COMB28: Accid
287	OK	L 50x50x4	S 355	138.95	138.95	0.24	41 Accidential 1 qb
288	OK	L 56x4	S 355	69.48	69.48	0.20	121 COMB45: Accid
289	OK	L 56x4	S 355	69.48	69.48	0.19	104 COMB28: Accid
290 Simple bar_2	OK	L 50x50x4	S 355	32.24	32.24	0.03	64 Ice 1 cable right
291	OK	L 56x4	S 355	121.77	121.77	0.10	102 COMB26: Accid
292	OK	CAE 45x4	S 355	94.88	94.88	0.07	116 COMB40: Accid
293	OK	CAE 45x4	S 355	94.88	94.88	0.08	117 COMB42: Accid
294	OK	CAE 45x4	S 355	94.88	94.88	0.08	103 COMB27: Accid
295	OK	CAE 45x4	S 355	94.88	94.88	0.07	124 COMB48: Accid
298	OK	L 56x4	S 355	121.77	121.77	0.16	132 COMB56: Ice 1/
307	OK	L 50x50x4	S 355	138.95	138.95	0.20	45 Accidential 1 qb
310	OK	L 56x4	S 355	121.77	121.77	0.12	107 COMB31: Accid
311	OK	CAE 60x4	S 355	70.73	70.73	0.18	126 COMB50: Accid
312	OK	CAE 60x4	S 355	70.73	70.73	0.19	129 COMB53: Accid
313	OK	CAE 60x4	S 355	70.73	70.73	0.19	107 COMB31: Accid
314	OK	CAE 60x4	S 355	70.73	70.73	0.20	129 COMB53: Accid
315	OK	L 56x4	S 355	69.48	69.48	0.20	129 COMB53: Accid
316	OK	L 56x4	S 355	69.48	69.48	0.20	107 COMB31: Accid
317	OK	L 56x4	S 355	139.24	139.24	0.56	129 COMB53: Accid
318	OK	L 56x4	S 355	139.24	139.24	0.56	107 COMB31: Accid
319	OK	L 56x4	S 355	139.24	139.24	0.55	129 COMB53: Accid
320	OK	L 56x4	S 355	139.24	139.24	0.55	107 COMB31: Accid
321	OK	L 50x50x4	S 355	138.95	138.95	0.19	44 Accidential 1 qb
322	OK	L 56x4	S 355	69.48	69.48	0.19	129 COMB53: Accid
323	OK	L 56x4	S 355	69.48	69.48	0.19	107 COMB31: Accid
324	OK	L 56x4	S 355	121.77	121.77	0.14	132 COMB56: Ice 1/
325	OK	CAE 45x4	S 355	94.88	94.88	0.07	116 COMB40: Accid



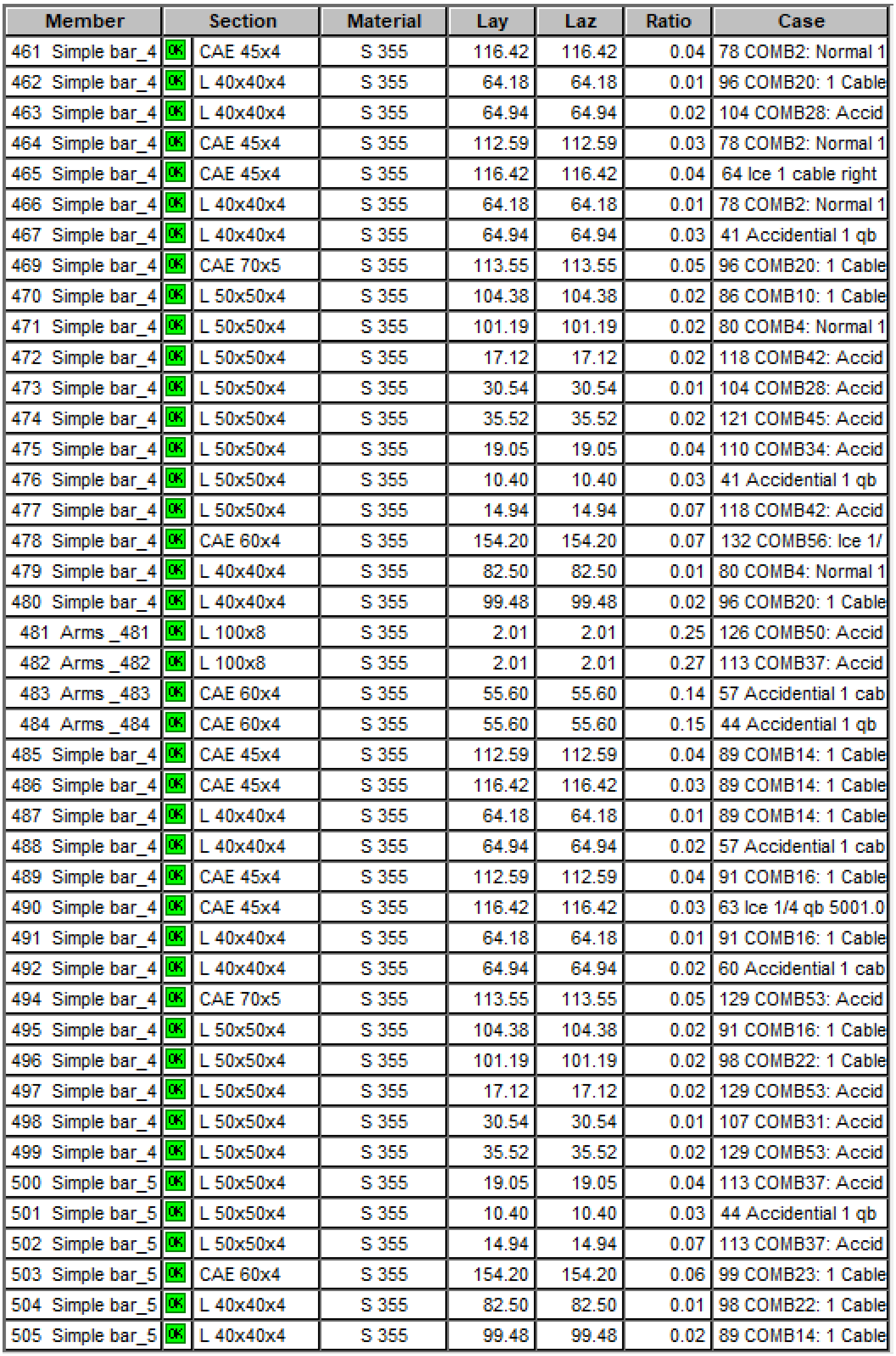
Member	Section		Material	Lay	Laz	Ratio	Case
326	OK	CAE 45x4	S 355	94.88	94.88	0.07	125 COMB49: Accid
329	OK	CAE 70x5	S 355	108.11	108.11	0.21	125 COMB49: Accid
330 Simple bar_3	OK	L 50x50x4	S 355	32.24	32.24	0.04	117 COMB42: Accid
331	OK	CAE 70x5	S 355	21.91	21.91	0.28	64 Ice 1 cable right
332	OK	CAE 70x5	S 355	21.91	21.91	0.36	65 Ice 1 cable left 1/
333	OK	CAE 70x5	S 355	16.67	16.67	0.17	125 COMB49: Accid
334	OK	CAE 60x4	S 355	119.98	119.98	0.04	70 Wind Simulation
335	OK	L 56x4	S 355	114.92	114.92	0.04	72 Wind Simulation
336	OK	L 50x50x4	S 355	116.09	116.09	0.03	82 COMB6: Normal 1
337	OK	L 50x50x4	S 355	108.25	108.25	0.03	90 COMB15: 1 Cable
338 Simple bar_3	OK	CAE 45x4	S 355	106.11	106.11	0.03	96 COMB20: 1 Cable
339 Simple bar_3	OK	L 40x40x4	S 355	75.45	75.45	0.01	90 COMB15: 1 Cable
340 Simple bar_3	OK	L 40x40x4	S 355	66.80	66.80	0.01	89 COMB14: 1 Cable
341 Simple bar_3	OK	L 40x40x4	S 355	56.02	56.02	0.01	116 COMB40: Accid
342 Simple bar_3	OK	L 40x40x4	S 355	18.07	18.07	0.01	65 Ice 1 cable left 1/
343 Simple bar_3	OK	L 50x50x4	S 355	32.24	32.24	0.04	65 Ice 1 cable left 1/
344	OK	CAE 60x4	S 355	119.98	119.98	0.04	76 Wind Simulation
345	OK	L 56x4	S 355	114.92	114.92	0.05	74 Wind Simulation
346	OK	L 50x50x4	S 355	116.09	116.09	0.04	70 Wind Simulation
347 Simple bar_3	OK	L 50x50x4	S 355	108.25	108.25	0.04	74 Wind Simulation
348 Simple bar_3	OK	CAE 45x4	S 355	106.11	106.11	0.03	89 COMB14: 1 Cable
349 Simple bar_3	OK	L 40x40x4	S 355	75.45	75.45	0.01	74 Wind Simulation
350 Simple bar_3	OK	L 40x40x4	S 355	66.80	66.80	0.01	82 COMB6: Normal 1
351 Simple bar_3	OK	L 40x40x4	S 355	56.02	56.02	0.01	125 COMB49: Accid
352 Simple bar_3	OK	L 40x40x4	S 355	18.07	18.07	0.01	116 COMB40: Accid
353 Simple bar_3	OK	L 50x50x4	S 355	32.24	32.24	0.03	47 Accidential 1 cab
354 Simple bar_3	OK	CAE 45x4	S 355	116.42	116.42	0.05	64 Ice 1 cable right
355 Arms _355	OK	L 100x8	S 355	2.01	2.01	0.28	120 COMB44: Accid
356 Arms _356	OK	L 100x8	S 355	2.01	2.01	0.30	112 COMB36: Accid
357 Simple bar_3	OK	L 40x40x4	S 355	64.18	64.18	0.01	96 COMB20: 1 Cable
359 Arms _359	OK	CAE 60x4	S 355	55.60	55.60	0.18	53 Accidential 1 cab
360 Arms _360	OK	CAE 60x4	S 355	55.60	55.60	0.19	105 COMB29: Accid
361 Simple bar_3	OK	L 40x40x4	S 355	64.94	64.94	0.02	120 COMB44: Accid
362 Simple bar_3	OK	CAE 45x4	S 355	94.88	94.88	0.08	116 COMB40: Accid
363 Simple bar_3	OK	CAE 45x4	S 355	112.59	112.59	0.03	93 COMB17: 1 Cable
364 Simple bar_3	OK	CAE 45x4	S 355	116.42	116.42	0.05	63 Ice 1/4 qb 5001.0
365 Simple bar_3	OK	L 40x40x4	S 355	64.18	64.18	0.01	96 COMB20: 1 Cable
366 Simple bar_3	OK	L 40x40x4	S 355	64.94	64.94	0.02	54 Accidential 1 cab
367 Simple bar_3	OK	CAE 70x5	S 355	113.55	113.55	0.04	97 COMB21: 1 Cable
368 Simple bar_3	OK	L 50x50x4	S 355	104.38	104.38	0.02	86 COMB10: 1 Cable
369 Simple bar_3	OK	CAE 45x4	S 355	94.88	94.88	0.08	103 COMB27: Accid
370 Simple bar_3	OK	L 50x50x4	S 355	101.19	101.19	0.02	85 COMB9: 1 Cable
372 Simple bar_3	OK	L 50x50x4	S 355	30.54	30.54	0.01	106 COMB30: Accid



Member	Section		Material	Lay	Laz	Ratio	Case
373 Simple bar_3	OK	L 50x50x4	S 355	35.52	35.52	0.02	123 COMB47: Accid
374 Simple bar_3	OK	L 50x50x4	S 355	17.12	17.12	0.02	106 COMB30: Accid
375 Simple bar_3	OK	L 50x50x4	S 355	19.05	19.05	0.04	112 COMB36: Accid
376 Simple bar_3	OK	L 50x50x4	S 355	10.40	10.40	0.03	43 Accidential 1 qb
377 Simple bar_3	OK	L 50x50x4	S 355	14.94	14.94	0.07	120 COMB44: Accid
378 Simple bar_3	OK	CAE 60x4	S 355	154.20	154.20	0.06	132 COMB56: Ice 1/
379 Simple bar_3	OK	L 40x40x4	S 355	82.50	82.50	0.01	88 COMB13: 1 Cable
380 Simple bar_3	OK	L 40x40x4	S 355	99.48	99.48	0.02	86 COMB10: 1 Cable
381 Arms _381	OK	L 100x8	S 355	2.01	2.01	0.26	128 COMB52: Accid
382 Arms _382	OK	L 100x8	S 355	2.01	2.01	0.29	115 COMB39: Accid
383 Arms _383	OK	CAE 60x4	S 355	55.60	55.60	0.18	130 COMB54: Accid
384 Arms _384	OK	CAE 60x4	S 355	55.60	55.60	0.18	39 Accidential 1 qb
385 Simple bar_3	OK	CAE 45x4	S 355	112.59	112.59	0.03	89 COMB14: 1 Cable
386 Simple bar_3	OK	CAE 45x4	S 355	116.42	116.42	0.03	61 Accidential 1 cab
387 Simple bar_3	OK	L 40x40x4	S 355	64.18	64.18	0.01	89 COMB14: 1 Cable
388 Simple bar_3	OK	L 40x40x4	S 355	64.94	64.94	0.02	40 Accidential 1 qb
389 Simple bar_3	OK	CAE 45x4	S 355	112.59	112.59	0.03	91 COMB16: 1 Cable
390 Simple bar_3	OK	CAE 45x4	S 355	116.42	116.42	0.03	98 COMB22: 1 Cable
391 Simple bar_3	OK	L 40x40x4	S 355	64.18	64.18	0.01	91 COMB16: 1 Cable
392 Simple bar_3	OK	L 40x40x4	S 355	64.94	64.94	0.03	46 Accidential 1 qb
394 Simple bar_3	OK	CAE 70x5	S 355	113.55	113.55	0.04	89 COMB14: 1 Cable
395 Simple bar_3	OK	L 50x50x4	S 355	104.38	104.38	0.01	80 COMB4: Normal 1
396 Simple bar_3	OK	L 50x50x4	S 355	101.19	101.19	0.02	93 COMB17: 1 Cable
397 Simple bar_3	OK	L 50x50x4	S 355	17.12	17.12	0.02	46 Accidential 1 qb
398 Simple bar_3	OK	L 50x50x4	S 355	30.54	30.54	0.01	109 COMB33: Accid
399 Simple bar_3	OK	L 50x50x4	S 355	35.52	35.52	0.02	131 COMB55: Accid
400 Simple bar_4	OK	L 50x50x4	S 355	19.05	19.05	0.04	115 COMB39: Accid
401 Simple bar_4	OK	L 50x50x4	S 355	10.40	10.40	0.03	46 Accidential 1 qb
402 Simple bar_4	OK	L 50x50x4	S 355	14.94	14.94	0.07	115 COMB39: Accid
403 Simple bar_4	OK	CAE 60x4	S 355	154.20	154.20	0.06	99 COMB23: 1 Cable
404 Simple bar_4	OK	L 40x40x4	S 355	82.50	82.50	0.01	98 COMB22: 1 Cable
405 Simple bar_4	OK	L 40x40x4	S 355	99.48	99.48	0.02	89 COMB14: 1 Cable
406 Arms _406	OK	L 100x8	S 355	2.01	2.01	0.27	119 COMB43: Accid
407 Arms _407	OK	L 100x8	S 355	2.01	2.01	0.25	111 COMB35: Accid
408 Arms _408	OK	CAE 60x4	S 355	55.60	55.60	0.18	52 Accidential 1 cab
409 Arms _409	OK	CAE 60x4	S 355	55.60	55.60	0.19	104 COMB28: Accid
410 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.04	96 COMB20: 1 Cable
411 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.04	64 Ice 1 cable right
412 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	96 COMB20: 1 Cable
413 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.02	119 COMB43: Accid
414 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.03	78 COMB2: Normal 1
415 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.04	63 Ice 1/4 qb 5001.0
416 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	78 COMB2: Normal 1

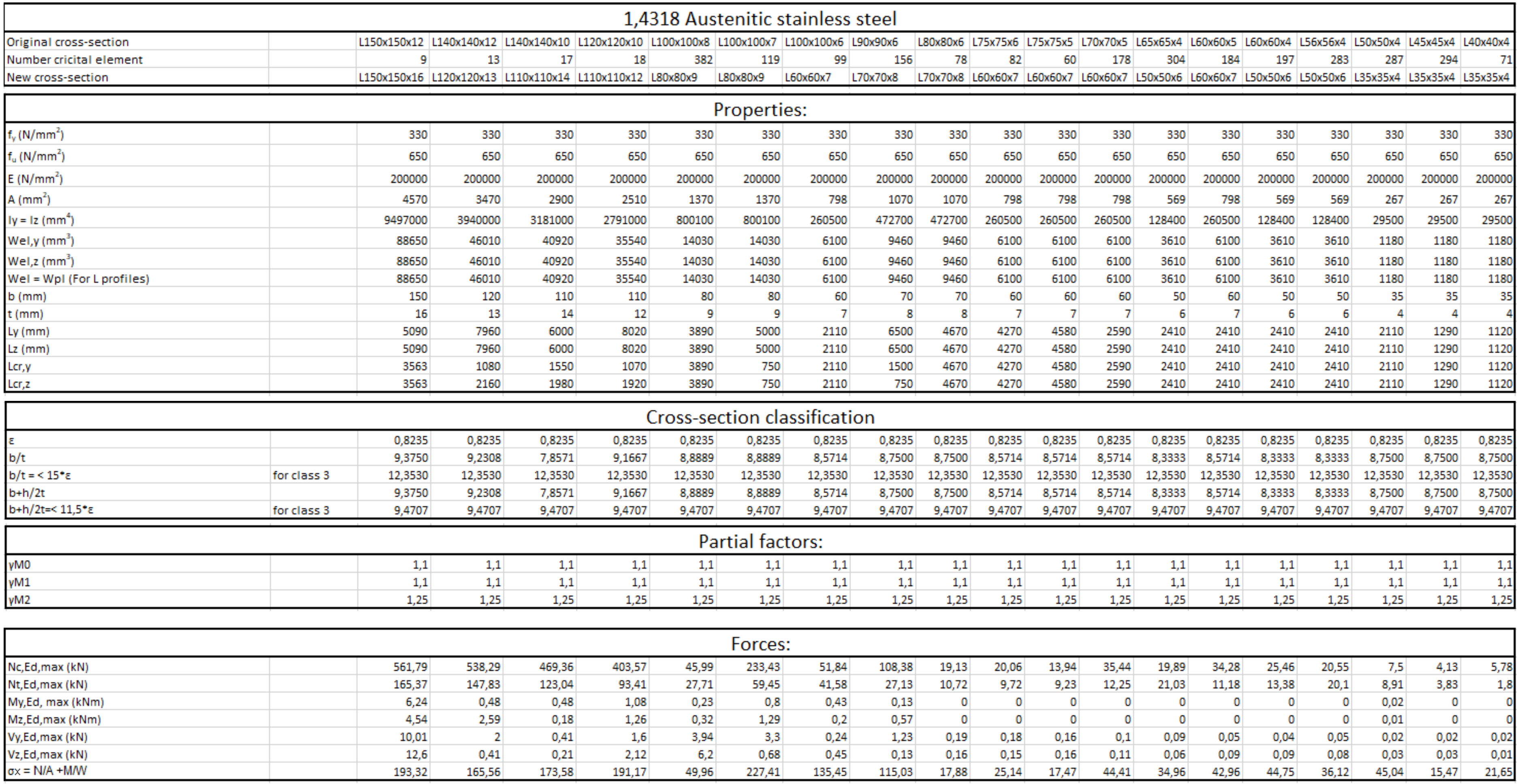


Member		Section	Material	Lay	Laz	Ratio	Case
417 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.02	53 Accidential 1 cab
419 Simple bar_4	OK	CAE 70x5	S 355	113.55	113.55	0.05	96 COMB20: 1 Cable
420 Simple bar_4	OK	L 50x50x4	S 355	104.38	104.38	0.02	86 COMB10: 1 Cable
421 Simple bar_4	OK	L 50x50x4	S 355	101.19	101.19	0.02	80 COMB4: Normal 1
422 Simple bar_4	OK	L 50x50x4	S 355	17.12	17.12	0.02	105 COMB29: Accid
423 Simple bar_4	OK	L 50x50x4	S 355	30.54	30.54	0.01	105 COMB29: Accid
424 Simple bar_4	OK	L 50x50x4	S 355	35.52	35.52	0.02	122 COMB46: Accid
425 Simple bar_4	OK	L 50x50x4	S 355	19.05	19.05	0.04	111 COMB35: Accid
426 Simple bar_4	OK	L 50x50x4	S 355	10.40	10.40	0.03	42 Accidential 1 qb
427 Simple bar_4	OK	L 50x50x4	S 355	14.94	14.94	0.07	119 COMB43: Accid
428 Simple bar_4	OK	CAE 60x4	S 355	154.20	154.20	0.06	132 COMB56: Ice 1/
429 Simple bar_4	OK	L 40x40x4	S 355	82.50	82.50	0.01	80 COMB4: Normal 1
430 Simple bar_4	OK	L 40x40x4	S 355	99.48	99.48	0.02	96 COMB20: 1 Cable
431 Arms _431	OK	L 100x8	S 355	2.01	2.01	0.26	127 COMB51: Accid
432 Arms _432	OK	L 100x8	S 355	2.01	2.01	0.28	114 COMB38: Accid
433 Arms _433	OK	CAE 60x4	S 355	55.60	55.60	0.18	60 Accidential 1 cab
434 Arms _434	OK	CAE 60x4	S 355	55.60	55.60	0.18	38 Accidential 1 qb
435 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.04	89 COMB14: 1 Cable
436 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.03	65 Ice 1 cable left 1/
437 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	89 COMB14: 1 Cable
438 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.02	39 Accidential 1 qb
439 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.04	91 COMB16: 1 Cable
440 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.03	98 COMB22: 1 Cable
441 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	91 COMB16: 1 Cable
442 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.02	45 Accidential 1 qb
444 Simple bar_4	OK	CAE 70x5	S 355	113.55	113.55	0.05	89 COMB14: 1 Cable
445 Simple bar_4	OK	L 50x50x4	S 355	104.38	104.38	0.02	91 COMB16: 1 Cable
446 Simple bar_4	OK	L 50x50x4	S 355	101.19	101.19	0.02	98 COMB22: 1 Cable
447 Simple bar_4	OK	L 50x50x4	S 355	17.12	17.12	0.02	130 COMB54: Accid
448 Simple bar_4	OK	L 50x50x4	S 355	30.54	30.54	0.01	108 COMB32: Accid
449 Simple bar_4	OK	L 50x50x4	S 355	35.52	35.52	0.02	130 COMB54: Accid
450 Simple bar_4	OK	L 50x50x4	S 355	19.05	19.05	0.04	114 COMB38: Accid
451 Simple bar_4	OK	L 50x50x4	S 355	10.40	10.40	0.03	45 Accidential 1 qb
452 Simple bar_4	OK	L 50x50x4	S 355	14.94	14.94	0.07	114 COMB38: Accid
453 Simple bar_4	OK	CAE 60x4	S 355	154.20	154.20	0.06	99 COMB23: 1 Cable
454 Simple bar_4	OK	L 40x40x4	S 355	82.50	82.50	0.01	98 COMB22: 1 Cable
455 Simple bar_4	OK	L 40x40x4	S 355	99.48	99.48	0.02	98 COMB22: 1 Cable
456 Arms _456	OK	L 100x8	S 355	6.70	6.70	0.22	118 COMB42: Accid
457 Arms _457	OK	L 100x8	S 355	2.01	2.01	0.24	110 COMB34: Accid
458 Arms _458	OK	CAE 60x4	S 355	55.60	55.60	0.14	49 Accidential 1 cab
459 Arms _459	OK	CAE 60x4	S 355	55.60	55.60	0.16	110 COMB34: Accid
460 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.04	96 COMB20: 1 Cable
461 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.04	78 COMB2: Normal 1



Member	Section		Material	Lay	Laz	Ratio	Case
461 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.04	78 COMB2: Normal 1
462 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	96 COMB20: 1 Cable
463 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.02	104 COMB28: Accid
464 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.03	78 COMB2: Normal 1
465 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.04	64 Ice 1 cable right
466 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	78 COMB2: Normal 1
467 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.03	41 Accidential 1 qb
469 Simple bar_4	OK	CAE 70x5	S 355	113.55	113.55	0.05	96 COMB20: 1 Cable
470 Simple bar_4	OK	L 50x50x4	S 355	104.38	104.38	0.02	86 COMB10: 1 Cable
471 Simple bar_4	OK	L 50x50x4	S 355	101.19	101.19	0.02	80 COMB4: Normal 1
472 Simple bar_4	OK	L 50x50x4	S 355	17.12	17.12	0.02	118 COMB42: Accid
473 Simple bar_4	OK	L 50x50x4	S 355	30.54	30.54	0.01	104 COMB28: Accid
474 Simple bar_4	OK	L 50x50x4	S 355	35.52	35.52	0.02	121 COMB45: Accid
475 Simple bar_4	OK	L 50x50x4	S 355	19.05	19.05	0.04	110 COMB34: Accid
476 Simple bar_4	OK	L 50x50x4	S 355	10.40	10.40	0.03	41 Accidential 1 qb
477 Simple bar_4	OK	L 50x50x4	S 355	14.94	14.94	0.07	118 COMB42: Accid
478 Simple bar_4	OK	CAE 60x4	S 355	154.20	154.20	0.07	132 COMB56: Ice 1/
479 Simple bar_4	OK	L 40x40x4	S 355	82.50	82.50	0.01	80 COMB4: Normal 1
480 Simple bar_4	OK	L 40x40x4	S 355	99.48	99.48	0.02	96 COMB20: 1 Cable
481 Arms _481	OK	L 100x8	S 355	2.01	2.01	0.25	126 COMB50: Accid
482 Arms _482	OK	L 100x8	S 355	2.01	2.01	0.27	113 COMB37: Accid
483 Arms _483	OK	CAE 60x4	S 355	55.60	55.60	0.14	57 Accidential 1 cab
484 Arms _484	OK	CAE 60x4	S 355	55.60	55.60	0.15	44 Accidential 1 qb
485 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.04	89 COMB14: 1 Cable
486 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.03	89 COMB14: 1 Cable
487 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	89 COMB14: 1 Cable
488 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.02	57 Accidential 1 cab
489 Simple bar_4	OK	CAE 45x4	S 355	112.59	112.59	0.04	91 COMB16: 1 Cable
490 Simple bar_4	OK	CAE 45x4	S 355	116.42	116.42	0.03	63 Ice 1/4 qb 5001.0
491 Simple bar_4	OK	L 40x40x4	S 355	64.18	64.18	0.01	91 COMB16: 1 Cable
492 Simple bar_4	OK	L 40x40x4	S 355	64.94	64.94	0.02	60 Accidential 1 cab
494 Simple bar_4	OK	CAE 70x5	S 355	113.55	113.55	0.05	129 COMB53: Accid
495 Simple bar_4	OK	L 50x50x4	S 355	104.38	104.38	0.02	91 COMB16: 1 Cable
496 Simple bar_4	OK	L 50x50x4	S 355	101.19	101.19	0.02	98 COMB22: 1 Cable
497 Simple bar_4	OK	L 50x50x4	S 355	17.12	17.12	0.02	129 COMB53: Accid
498 Simple bar_4	OK	L 50x50x4	S 355	30.54	30.54	0.01	107 COMB31: Accid
499 Simple bar_4	OK	L 50x50x4	S 355	35.52	35.52	0.02	129 COMB53: Accid
500 Simple bar_5	OK	L 50x50x4	S 355	19.05	19.05	0.04	113 COMB37: Accid
501 Simple bar_5	OK	L 50x50x4	S 355	10.40	10.40	0.03	44 Accidential 1 qb
502 Simple bar_5	OK	L 50x50x4	S 355	14.94	14.94	0.07	113 COMB37: Accid
503 Simple bar_5	OK	CAE 60x4	S 355	154.20	154.20	0.06	99 COMB23: 1 Cable
504 Simple bar_5	OK	L 40x40x4	S 355	82.50	82.50	0.01	98 COMB22: 1 Cable
505 Simple bar_5	OK	L 40x40x4	S 355	99.48	99.48	0.02	89 COMB14: 1 Cable

Annex C CALCULATION NOTES OF THE STAINLESS STEEL ELEMENTS



1,4318 Austenitic stainless steel

Original cross-section		L150x150x12	L140x140x12	L140x140x10	L120x120x10	L100x100x8	L100x100x7	L100x100x6	L90x90x6	L80x80x6	L75x75x6	L75x75x5	L70x70x5	L65x65x4	L60x60x5	L60x60x4	L56x56x4	L50x50x4	L45x45x4	L40x40x4
Number cricital element		9	13	17	18	382	119	99	156	78	82	60	178	304	184	197	283	287	294	71
New cross-section		L150x150x16	L120x120x13	L110x110x14	L110x110x12	L80x80x9	L80x80x9	L60x60x7	L70x70x8	L70x70x8	L60x60x7	L60x60x7	L60x60x7	L50x50x6	L60x60x7	L50x50x6	L50x50x6	L35x35x4	L35x35x4	L35x35x4

Properties:

f_y (N/mm^2)		330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
f_u (N/mm^2)		650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
E (N/mm^2)		200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000
A (mm^2)		4570	3470	2900	2510	1370	1370	798	1070	1070	798	798	798	569	798	569	569	267	267	267
Iy = Iz (mm^4)		9497000	3940000	3181000	2791000	800100	800100	260500	472700	472700	260500	260500	260500	128400	260500	128400	128400	29500	29500	29500
Wel,y (mm^3)		88650	46010	40920	35540	14030	14030	6100	9460	9460	6100	6100	6100	3610	6100	3610	3610	1180	1180	1180
Wel,z (mm^3)		88650	46010	40920	35540	14030	14030	6100	9460	9460	6100	6100	6100	3610	6100	3610	3610	1180	1180	1180
Wel = Wpl (For L profiles)		88650	46010	40920	35540	14030	14030	6100	9460	9460	6100	6100	6100	3610	6100	3610	3610	1180	1180	1180
b (mm)		150	120	110	110	80	80	60	70	70	60	60	60	50	60	50	50	35	35	35
t (mm)		16	13	14	12	9	9	7	8	8	7	7	7	6	7	6	6	4	4	4
Ly (mm)		5090	7960	6000	8020	3890	5000	2110	6500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lz (mm)		5090	7960	6000	8020	3890	5000	2110	6500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lcr,y		3563	1080	1550	1070	3890	750	2110	1500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lcr,z		3563	2160	1980	1920	3890	750	2110	750	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120

Cross-section classification

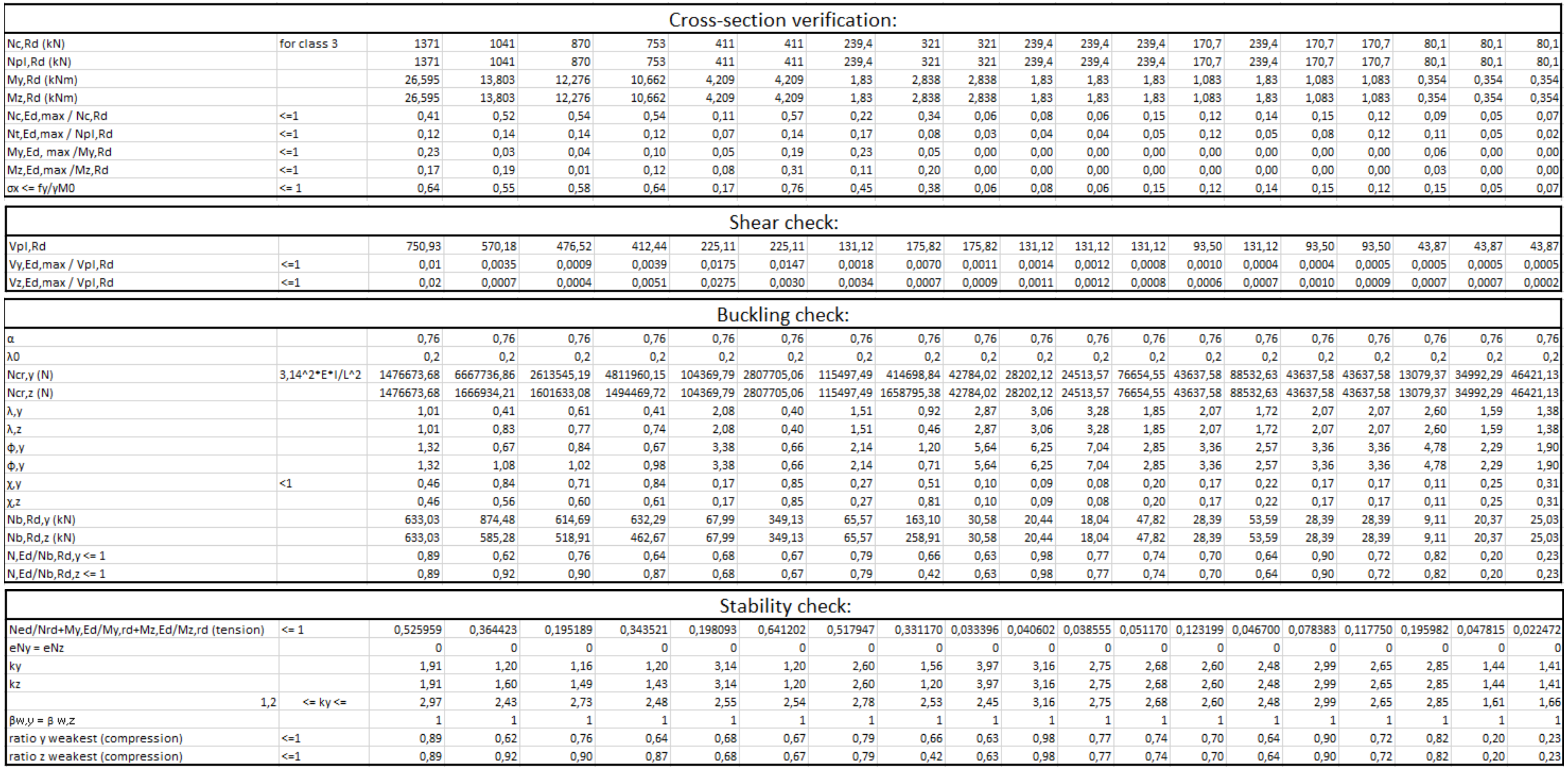
ε		0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235	0,8235
b/t		9,3750	9,2308	7,8571	9,1667	8,8889	8,8889	8,5714	8,7500	8,7500	8,5714	8,5714	8,5714	8,3333	8,5714	8,3333	8,3333	8,7500	8,7500	8,7500
b/t = < 15*ε	for class 3	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530	12,3530
b+h/2t		9,3750	9,2308	7,8571	9,1667	8,8889	8,8889	8,5714	8,7500	8,7500	8,5714	8,5714	8,5714	8,3333	8,5714	8,3333	8,3333	8,7500	8,7500	8,7500
b+h/2t=< 11,5*ε	for class 3	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707	9,4707

Partial factors:

γM0		1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
γM1		1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
γM2		1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25

Forces:

Nc,Ed,max (kN)		561,79	538,29	469,36	403,57	45,99	233,43	51,84	108,38	19,13	20,06	13,94	35,44	19,89	34,28	25,46	20,55	7,5	4,13	5,78
Nt,Ed,max (kN)		165,37	147,83	123,04	93,41	27,71	59,45	41,58	27,13	10,72	9,72	9,23	12,25	21,03	11,18	13,38	20,1	8,91	3,83	1,8
My,Ed, max (kNm)		6,24	0,48	0,48	1,08	0,23	0,8	0,43	0,13	0	0	0	0	0	0	0	0	0,02	0	0
Mz,Ed,max (kNm)		4,54	2,59	0,18	1,26	0,32	1,29	0,2	0,57	0	0	0	0	0	0	0	0	0,01	0	0
Vy,Ed,max (kN)		10,01	2	0,41	1,6	3,94	3,3	0,24	1,23	0,19	0,18	0,16	0,1	0,09	0,05	0,04	0,05	0,02	0,02	0,02
Vz,Ed,max (kN)		12,6	0,41	0,21	2,12	6,2	0,68	0,45	0,13	0,16	0,15	0,16	0,11	0,06	0,09	0,09	0,08	0,03	0,03	0,01
σx = N/A +M/W		193,32	165,56	173,58	191,17	49,96	227,41	135,45	115,03	17,88	25,14	17,47	44,41	34,96	42,96	44,75	36,12	45,04	15,47	21,65



Cross-section verification:

Nc,Rd (kN)	for class 3	1371	1041	870	753	411	411	239,4	321	321	239,4	239,4	239,4	170,7	239,4	170,7	170,7	80,1	80,1	80,1
Npl,Rd (kN)		1371	1041	870	753	411	411	239,4	321	321	239,4	239,4	239,4	170,7	239,4	170,7	170,7	80,1	80,1	80,1
My,Rd (kNm)		26,595	13,803	12,276	10,662	4,209	4,209	1,83	2,838	2,838	1,83	1,83	1,83	1,083	1,83	1,083	1,083	0,354	0,354	0,354
Mz,Rd (kNm)		26,595	13,803	12,276	10,662	4,209	4,209	1,83	2,838	2,838	1,83	1,83	1,83	1,083	1,83	1,083	1,083	0,354	0,354	0,354
Nc,Ed,max / Nc,Rd	<=1	0,41	0,52	0,54	0,54	0,11	0,57	0,22	0,34	0,06	0,08	0,06	0,15	0,12	0,14	0,15	0,12	0,09	0,05	0,07
Nt,Ed,max / Npl,Rd	<=1	0,12	0,14	0,14	0,12	0,07	0,14	0,17	0,08	0,03	0,04	0,04	0,05	0,12	0,05	0,08	0,12	0,11	0,05	0,02
My,Ed, max /My,Rd	<=1	0,23	0,03	0,04	0,10	0,05	0,19	0,23	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,06	0,00	0,00
Mz,Ed,max /Mz,Rd	<=1	0,17	0,19	0,01	0,12	0,08	0,31	0,11	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00	0,00
σx <= fy/γM0	<= 1	0,64	0,55	0,58	0,64	0,17	0,76	0,45	0,38	0,06	0,08	0,06	0,15	0,12	0,14	0,15	0,12	0,15	0,05	0,07

Shear check:

Vpl,Rd		750,93	570,18	476,52	412,44	225,11	225,11	131,12	175,82	175,82	131,12	131,12	131,12	93,50	131,12	93,50	93,50	43,87	43,87	43,87
Vy,Ed,max / Vpl,Rd	<=1	0,01	0,0035	0,0009	0,0039	0,0175	0,0147	0,0018	0,0070	0,0011	0,0014	0,0012	0,0008	0,0010	0,0004	0,0004	0,0005	0,0005	0,0005	0,0005
Vz,Ed,max / Vpl,Rd	<=1	0,02	0,0007	0,0004	0,0051	0,0275	0,0030	0,0034	0,0007	0,0009	0,0011	0,0012	0,0008	0,0006	0,0007	0,0010	0,0009	0,0007	0,0007	0,0002

Buckling check:

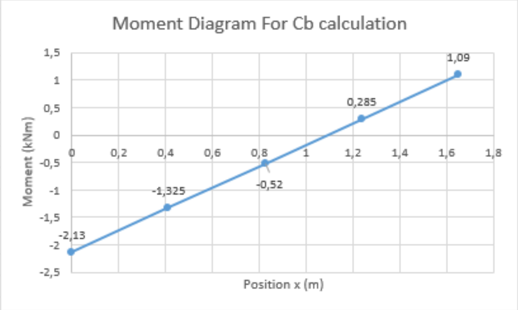
α		0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76
λ0		0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Ncr,y (N)	3,14^2*E*I/L^2	1476673,68	6667736,86	2613545,19	4811960,15	104369,79	2807705,06	115497,49	414698,84	42784,02	28202,12	24513,57	76654,55	43637,58	88532,63	43637,58	43637,58	13079,37	34992,29	46421,13
Ncr,z (N)		1476673,68	1666934,21	1601633,08	1494469,72	104369,79	2807705,06	115497,49	1658795,38	42784,02	28202,12	24513,57	76654,55	43637,58	88532,63	43637,58	43637,58	13079,37	34992,29	46421,13
λ,y		1,01	0,41	0,61	0,41	2,08	0,40	1,51	0,92	2,87	3,06	3,28	1,85	2,07	1,72	2,07	2,07	2,60	1,59	1,38
λ,z		1,01	0,83	0,77	0,74	2,08	0,40	1,51	0,46	2,87	3,06	3,28	1,85	2,07	1,72	2,07	2,07	2,60	1,59	1,38
Φ,y		1,32	0,67	0,84	0,67	3,38	0,66	2,14	1,20	5,64	6,25	7,04	2,85	3,36	2,57	3,36	3,36	4,78	2,29	1,90
Φ,y		1,32	1,08	1,02	0,98	3,38	0,66	2,14	0,71	5,64	6,25	7,04	2,85	3,36	2,57	3,36	3,36	4,78	2,29	1,90
χ,y	<1	0,46	0,84	0,71	0,84	0,17	0,85	0,27	0,51	0,10	0,09	0,08	0,20	0,17	0,22	0,17	0,17	0,11	0,25	0,31
χ,z		0,46	0,56	0,60	0,61	0,17	0,85	0,27	0,81	0,10	0,09	0,08	0,20	0,17	0,22	0,17	0,17	0,11	0,25	0,31
Nb,Rd,y (kN)		633,03	874,48	614,69	632,29	67,99	349,13	65,57	163,10	30,58	20,44	18,04	47,82	28,39	53,59	28,39	28,39	9,11	20,37	25,03
Nb,Rd,z (kN)		633,03	585,28	518,91	462,67	67,99	349,13	65,57	258,91	30,58	20,44	18,04	47,82	28,39	53,59	28,39	28,39	9,11	20,37	25,03
N,Ed/Nb,Rd,y <= 1		0,89	0,62	0,76	0,64	0,68	0,67	0,79	0,66	0,63	0,98	0,77	0,74	0,70	0,64	0,90	0,72	0,82	0,20	0,23
N,Ed/Nb,Rd,z <= 1		0,89	0,92	0,90	0,87	0,68	0,67	0,79	0,42	0,63	0,98	0,77	0,74	0,70	0,64	0,90	0,72	0,82	0,20	0,23

Stability check:

Ned/Nrd+My,Ed/My,rd+Mz,Ed/Mz,rd (tension)	<= 1	0,525959	0,364423	0,195189	0,343521	0,198093	0,641202	0,517947	0,331170	0,033396	0,040602	0,038555	0,051170	0,123199	0,046700	0,078383	0,117750	0,195982	0,047815	0,022472
eNy = eNz		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ky		1,91	1,20	1,16	1,20	3,14	1,20	2,60	1,56	3,97	3,16	2,75	2,68	2,60	2,48	2,99	2,65	2,85	1,44	1,41
kz		1,91	1,60	1,49	1,43	3,14	1,20	2,60	1,20	3,97	3,16	2,75	2,68	2,60	2,48	2,99	2,65	2,85	1,44	1,41
1,2	<= ky <=	2,97	2,43	2,73	2,48	2,55	2,54	2,78	2,53	2,45	3,16	2,75	2,68	2,60	2,48	2,99	2,65	2,85	1,61	1,66
βw,y = β w,z		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ratio y weakest (compression)	<=1	0,89	0,62	0,76	0,64	0,68	0,67	0,79	0,66	0,63	0,98	0,77	0,74	0,70	0,64	0,90	0,72	0,82	0,20	0,23
ratio z weakest (compression)	<=1	0,89	0,92	0,90	0,87	0,68	0,67	0,79	0,42	0,63	0,98	0,77	0,74	0,70	0,64	0,90	0,72	0,82	0,20	0,23

LTB:

v (mm)		106				
u1 (mm)		60,6				
Iv (mm^4)		3908000				
Iu (mm^4)		15090000				
iv (mm)		29,2		x	M	
Mv = My *sin45°+Mz*cos45°		7,62	Mmax	0	-2,13	
Mu = My*cos 45°+Mz*sin45°		7,62	Ma	0,4125	-1,325	
Wv		4836,65	Mb	0,825	-0,52	
Wu		32667,27	Mc	1,2375	0,285	
Lb(mm)		1650	Mend	1,65	1,09	
βw		0				
Cb		1,5				
Mcr (kNm)		436,73	Cb	2,530	> 1,5	so Cb = 1,5
Med / Mcr	if <0,16 no LTB	0,0175				
		No LTB calculation required				



1,4003 Ferritic stainless steel

Original cross-section		L150x150x12	L140x140x12	L140x140x10	L120x120x10	L100x100x8	L100x100x7	L100x100x6	L90x90x6	L80x80x6	L75x75x6	L75x75x5	L70x70x5	L65x65x4	L60x60x5	L60x60x4	L56x56x4	L50x50x4	L45x45x4	L40x40x4
Number cricital element		9	13	17	18	382	119	99	156	78	82	60	178	304	184	197	283	287	294	71
New cross-section		L150x150x16	L130x130x13	L120x120x12	L110x110x12	L80x80x8	L80x80x8	L60x60x7	L70x70x8	L70x70x7	L70x70x7	L60x60x7	L60x60x7	L50x50x6	L60x60x7	L50x50x6	L50x50x6	L35x35x4	L35x35x4	L35x35x4

Properties:

f_y (N/mm^2)		280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280	280
f_u (N/mm^2)		450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
E (N/mm^2)		200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000
A (mm^2)		4570	3230	2750	2510	1370	1370	798	1070	1070	1070	798	798	569	798	569	569	267	267	267
Iy = Iz (mm^4)		9497000	5065000	3677000	2791000	722500	722500	260500	472700	423000	423000	260500	260500	128400	260500	128400	128400	29500	29500	29500
Wel,y (mm^3)		88650	54350	42730	35540	12580	12580	6100	9460	8410	8410	6100	6100	3610	6100	3610	3610	1180	1180	1180
Wel,z (mm^3)		88650	54350	42730	35540	12580	12580	6100	9460	8410	8410	6100	6100	3610	6100	3610	3610	1180	1180	1180
Wel = Wpl (For L profiles)		88650	54350	42730	35540	12580	12580	6100	9460	8410	8410	6100	6100	3610	6100	3610	3610	1180	1180	1180
b (mm)		150	130	120	110	80	80	60	70	70	70	60	60	50	60	50	50	35	35	35
t (mm)		16	13	12	12	8	8	7	8	7	7	7	7	6	7	6	6	4	4	4
Ly (mm)		5090	7960	6000	8020	3890	5000	2110	6500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lz (mm)		5090	7960	6000	8020	3890	5000	2110	6500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lcr,y		3563	1080	1550	1070	3890	750	2110	1500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lcr,z		3563	2160	1980	1920	3890	750	2110	750	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120

Cross-section classification

ε		0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940	0,8940
b/t		9,3750	10,0000	10,0000	9,1667	10,0000	10,0000	8,5714	8,7500	10,0000	10,0000	8,5714	8,5714	8,3333	8,5714	8,3333	8,3333	8,7500	8,7500	8,7500
b/t = < 15*ε	for class 3	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107	13,4107
b+h/2t		9,3750	10,0000	10,0000	9,1667	10,0000	10,0000	8,5714	8,7500	10,0000	10,0000	8,5714	8,5714	8,3333	8,5714	8,3333	8,3333	8,7500	8,7500	8,7500
b+h/2t=< 11,5*ε	for class 3	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815	10,2815

Partial factors:

γM0		1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
γM1		1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
γM2		1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25

Forces:

Nc,Ed,max (kN)		561,79	538,29	469,36	403,57	45,99	233,43	51,84	108,38	19,13	20,06	13,94	35,44	19,89	34,28	25,46	20,55	7,5	4,13	5,78
Nt,Ed,max (kN)		165,37	147,83	123,04	93,41	27,71	59,45	41,58	27,13	10,72	9,72	9,23	12,25	21,03	11,18	13,38	20,1	8,91	3,83	1,8
My,Ed, max (kNm)		6,24	0,48	0,48	1,08	0,23	0,8	0,43	0,13	0	0	0	0	0	0	0	0	0,02	0	0
Mz,Ed,max (kNm)		4,54	2,59	0,18	1,26	0,32	1,29	0,2	0,57	0	0	0	0	0	0	0	0	0,01	0	0
Vy,Ed,max (kN)		10,01	2	0,41	1,6	3,94	3,3	0,24	1,23	0,19	0,18	0,16	0,1	0,09	0,05	0,04	0,05	0,02	0,02	0,02
Vz,Ed,max (kN)		12,6	0,41	0,21	2,12	6,2	0,68	0,45	0,13	0,16	0,15	0,16	0,11	0,06	0,09	0,09	0,08	0,03	0,03	0,01
σx = N/A +M/W		193,32	175,48	181,91	191,17	51,85	233,98	135,45	115,03	17,88	18,75	17,47	44,41	34,96	42,96	44,75	36,12	45,04	15,47	21,65

Cross-section verification:

Nc,Rd (kN)	for class 3	1163,27273	822,181818	700	638,909091	348,727273	348,727273	203,12727	272,363636	272,3636	272,3636	203,1273	203,1273	144,8364	203,1273	144,8364	144,8364	67,96364	67,96364	67,96364
Npl,Rd (kN)		1163,27273	822,181818	700	638,909091	348,727273	348,727273	203,12727	272,363636	272,3636	272,3636	203,1273	203,1273	144,8364	203,1273	144,8364	144,8364	67,96364	67,96364	67,96364
My,Rd (kNm)		22,5654545	13,8345455	10,8767273	9,04654545	3,20218182	3,20218182	1,5527273	2,408	2,140727	2,140727	1,552727	1,552727	0,918909	1,552727	0,918909	0,918909	0,300364	0,300364	0,300364
Mz,Rd (kNm)		22,5654545	13,8345455	10,8767273	9,04654545	3,20218182	3,20218182	1,5527273	2,408	2,140727	2,140727	1,552727	1,552727	0,918909	1,552727	0,918909	0,918909	0,300364	0,300364	0,300364
Nc,Ed,max / Nc,Rd	<=1	0,48	0,65	0,67	0,63	0,13	0,67	0,26	0,40	0,07	0,07	0,07	0,17	0,14	0,17	0,18	0,14	0,11	0,06	0,09
Nt,Ed,max / Npl,Rd	<=1	0,14	0,18	0,18	0,15	0,08	0,17	0,20	0,10	0,04	0,04	0,05	0,06	0,15	0,06	0,09	0,14	0,13	0,06	0,03
My,Ed, max /My,Rd	<=1	0,28	0,03	0,04	0,12	0,07	0,25	0,28	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,07	0,00	0,00
Mz,Ed,max /Mz,Rd	<=1	0,20	0,19	0,02	0,14	0,10	0,40	0,13	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00	0,00
σx <= fy/γM0	<= 1	0,76	0,69	0,71	0,75	0,20	0,92	0,53	0,45	0,07	0,07	0,07	0,17	0,14	0,17	0,18	0,14	0,18	0,06	0,09

Shear check:

Vpl,Rd		637,15	450,33	383,41	349,94	191,01	191,01	111,26	149,18	149,18	149,18	111,26	111,26	79,33	111,26	79,33	79,33	37,23	37,23	37,23
Vy,Ed,max / Vpl,Rd	<=1	0,02	0,0044	0,0011	0,0046	0,0206	0,0173	0,0022	0,0082	0,0013	0,0012	0,0014	0,0009	0,0011	0,0004	0,0005	0,0006	0,0005	0,0005	0,0005
Vz,Ed,max / Vpl,Rd	<=1	0,02	0,0009	0,0005	0,0061	0,0325	0,0036	0,0040	0,0009	0,0011	0,0010	0,0014	0,0010	0,0008	0,0008	0,0011	0,0010	0,0008	0,0008	0,0003

Buckling check:

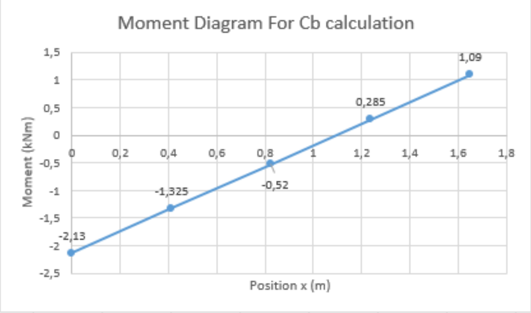
α		0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76
λ0		0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Ncr,y (N)	3,14^2*E*I/L^2	1476673,68	8571595,73	3021064,34	4811960,15	94247,19	2535391,71	115497,49	414698,84	38285,68	45794,61	24513,57	76654,55	43637,58	88532,63	43637,58	43637,58	13079,37	34992,29	46421,13
Ncr,z (N)		1476673,68	2142898,93	1851369,01	1494469,72	94247,19	2535391,71	115497,49	1658795,38	38285,68	45794,61	24513,57	76654,55	43637,58	88532,63	43637,58	43637,58	13079,37	34992,29	46421,13
λ,y		0,93	0,32	0,50	0,38	2,02	0,39	1,39	0,85	2,80	2,56	3,02	1,71	1,91	1,59	1,91	1,91	2,39	1,46	1,27
λ,z		0,93	0,65	0,64	0,69	2,02	0,39	1,39	0,42	2,80	2,56	3,02	1,71	1,91	1,59	1,91	1,91	2,39	1,46	1,27
Φ,y		1,21	0,60	0,74	0,64	3,23	0,65	1,92	1,11	5,40	4,67	6,13	2,53	2,98	2,29	2,98	2,98	4,19	2,05	1,71
Φ,y		1,21	0,88	0,88	0,92	3,23	0,65	1,92	0,68	5,40	4,67	6,13	2,53	2,98	2,29	2,98	2,98	4,19	2,05	1,71
χ,y	<1	0,50	0,91	0,78	0,86	0,17	0,86	0,31	0,55	0,10	0,12	0,09	0,23	0,19	0,25	0,19	0,19	0,13	0,29	0,35
χ,z		0,50	0,68	0,68	0,65	0,17	0,86	0,31	0,83	0,10	0,12	0,09	0,23	0,19	0,25	0,19	0,19	0,13	0,29	0,35
Nb,Rd,y (kN)		585,85	744,13	543,14	551,53	60,73	299,32	62,63	149,71	27,19	31,78	17,72	46,19	27,55	51,58	27,55	27,55	8,91	19,52	23,77
Nb,Rd,z (kN)		585,85	556,17	475,75	416,88	60,73	299,32	62,63	226,73	27,19	31,78	17,72	46,19	27,55	51,58	27,55	27,55	8,91	19,52	23,77
N,Ed/Nb,Rd,y <= 1		0,96	0,72	0,86	0,73	0,76	0,78	0,83	0,72	0,70	0,63	0,79	0,77	0,72	0,66	0,92	0,75	0,84	0,21	0,24
N,Ed/Nb,Rd,z <= 1		0,96	0,97	0,99	0,97	0,76	0,78	0,83	0,48	0,70	0,63	0,79	0,77	0,72	0,66	0,92	0,75	0,84	0,21	0,24

Stability check:

Ned/Nrd+My,Ed/My,rd+Mz,Ed/Mz,rd (tension)	<= 1	0,619881	0,401710	0,236451	0,404865	0,251218	0,823157	0,610437	0,390307	0,039359	0,035688	0,045439	0,060307	0,145198	0,055039	0,092380	0,138777	0,230978	0,056354	0,026485
eNy = eNz		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ky		1,83	1,20	1,20	1,20	2,71	1,20	2,47	1,51	2,61	2,46	4,96	2,73	2,64	2,45	3,05	2,69	2,88	1,41	1,37
kz		1,83	1,29	1,29	1,36	2,71	1,20	2,47	1,20	2,61	2,46	4,96	2,73	2,64	2,45	3,05	2,69	2,88	1,41	1,37
1,2	<= ky <=	3,12	2,65	2,93	2,66	2,71	2,76	2,86	2,65	2,61	2,46	2,77	2,73	2,64	2,53	3,05	2,69	2,88	1,62	1,69
βw,y = β w,z		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ratio y weakest (compression)	<=1	0,96	0,72	0,86	0,73	0,76	0,78	0,83	0,72	0,70	0,63	0,79	0,77	0,72	0,66	0,92	0,75	0,84	0,21	0,24
ratio z weakest (compression)	<=1	0,96	0,97	0,99	0,97	0,76	0,78	0,83	0,48	0,70	0,63	0,79	0,77	0,72	0,66	0,92	0,75	0,84	0,21	0,24

LTB:

v (mm)		106					
u1 (mm)		60,6					
Iv (mm^4)		3908000					
Iu (mm^4)		15090000					
iv (mm)		29,2			x	M	
Mv = My *sin45°+Mz*cos45°		7,62		Mmax	0	-2,13	
Mu = My*cos 45°+Mz*sin45°		7,62		Ma	0,4125	-1,325	
Wv		4836,65		Mb	0,825	-0,52	
Wu		32667,27		Mc	1,2375	0,285	
Lb(mm)		1650		Mend	1,65	1,09	
βw		0					
Cb		1,5					
Mcr (kNm)		436,73		Cb	2,530	> 1,5	so Cb = 1,5
Med / Mcr	if <0,16 no LTB	0,0175					
		No LTB calculation required					

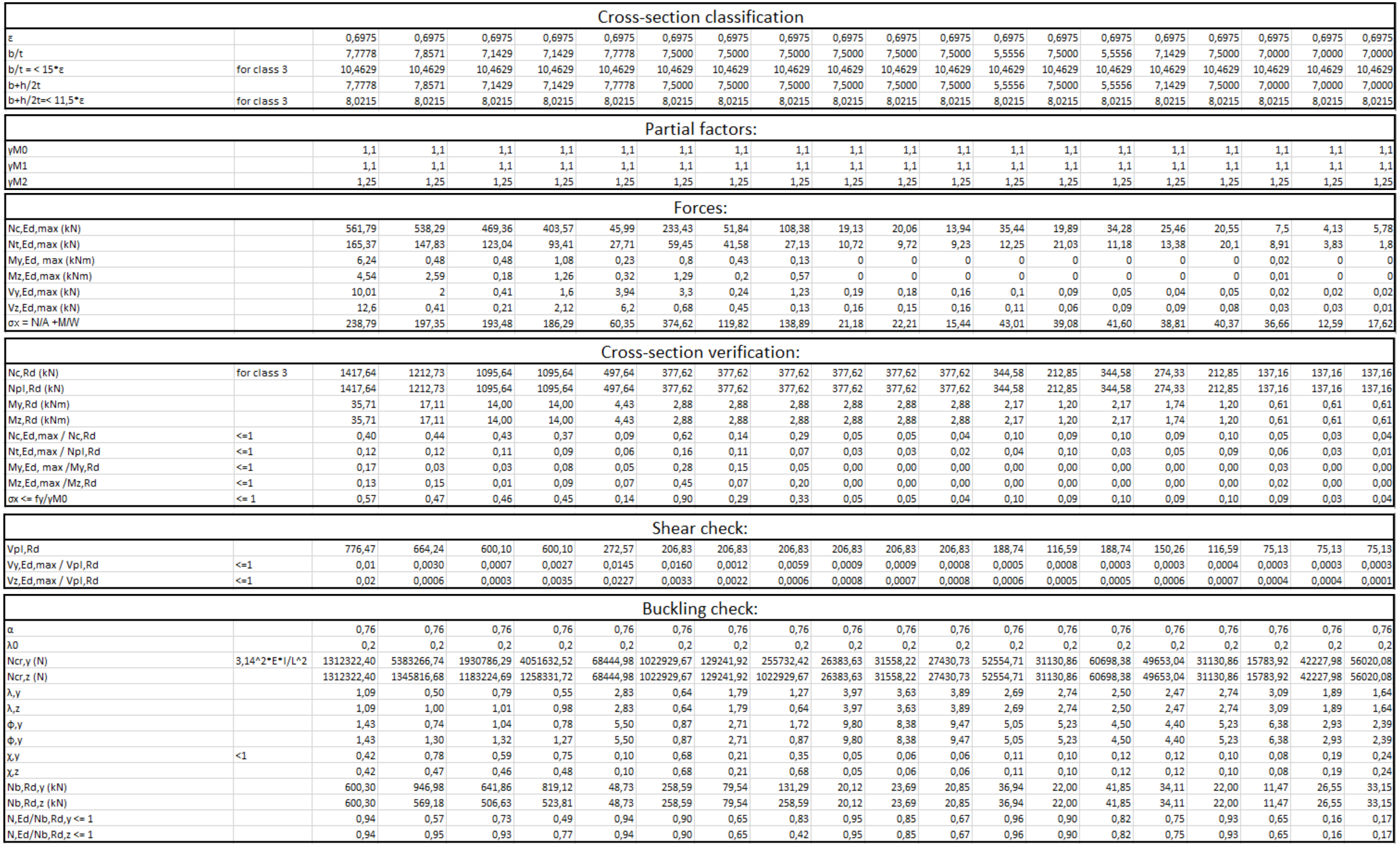


1,4462 Duplex stainless steel

Original cross-section		L150x150x12	L140x140x12	L140x140x10	L120x120x10	L100x100x8	L100x100x7	L100x100x6	L90x90x6	L80x80x6	L75x75x6	L75x75x5	L70x70x5	L65x65x4	L60x60x5	L60x60x4	L56x56x4	L50x50x4	L45x45x4	L40x40x4
Number cricital element		9	13	17	18	382	119	99	156	78	82	60	178	304	184	197	283	287	294	71
New cross-section		L140x140x18	L110x110x14	L100x100x14	L100x100x14	L70x70x9	L60x60x8	L60x60x8	L60x60x8	L60x60x8	L60x60x8	L60x60x8	L50x50x9	L45x45x6	L50x50x9	L50x50x7	L45x45x6	L35x35x5	L35x35x5	L35x35x5

Properties:

f_y (N/mm^2)		460	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460	460
f_u (N/mm^2)		750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
E (N/mm^2)		200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000	200000
A (mm^2)		3390	2900	2620	2620	1190	903	903	903	903	903	903	824	509	824	656	509	328	328	328
Iy = Iz (mm^4)		8440000	3181000	2350000	2350000	524700	291500	291500	291500	291500	291500	291500	178600	91600	178600	146100	91600	35600	35600	35600
Wel,y (mm^3)		85400	40920	33480	33480	10600	6890	6890	6890	6890	6890	6890	5200	2880	5200	4160	2880	1450	1450	1450
Wel,z (mm^3)		85400	40920	33480	33480	10600	6890	6890	6890	6890	6890	6890	5200	2880	5200	4160	2880	1450	1450	1450
Wel = Wpl (For L profiles)		85400	40920	33480	33480	10600	6890	6890	6890	6890	6890	6890	5200	2880	5200	4160	2880	1450	1450	1450
b (mm)		140	110	100	100	70	60	60	60	60	60	60	50	45	50	50	45	35	35	35
t (mm)		18	14	14	14	9	8	8	8	8	8	8	9	6	9	7	6	5	5	5
Ly (mm)		5090	7960	3	8020	3890	5000	2110	6500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lz (mm)		5090	7960	3	8020	3890	5000	2110	6500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lcr,y		3563	1080	1550	1070	3890	750	2110	1500	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120
Lcr,z		3563	2160	1980	1920	3890	750	2110	750	4670	4270	4580	2590	2410	2410	2410	2410	2110	1290	1120



Cross-section classification																				
ε		0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975	0,6975
b/t		7,7778	7,8571	7,1429	7,1429	7,7778	7,5000	7,5000	7,5000	7,5000	7,5000	7,5000	5,5556	7,5000	5,5556	7,1429	7,5000	7,0000	7,0000	7,0000
b/t = < 15*ε	for class 3	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629	10,4629
b+h/2t		7,7778	7,8571	7,1429	7,1429	7,7778	7,5000	7,5000	7,5000	7,5000	7,5000	7,5000	5,5556	7,5000	5,5556	7,1429	7,5000	7,0000	7,0000	7,0000
b+h/2t=< 11,5*ε	for class 3	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215	8,0215

Partial factors:																				
γM0		1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
γM1		1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
γM2		1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25	1,25

Forces:																				
Nc,Ed,max (kN)		561,79	538,29	469,36	403,57	45,99	233,43	51,84	108,38	19,13	20,06	13,94	35,44	19,89	34,28	25,46	20,55	7,5	4,13	5,78
Nt,Ed,max (kN)		165,37	147,83	123,04	93,41	27,71	59,45	41,58	27,13	10,72	9,72	9,23	12,25	21,03	11,18	13,38	20,1	8,91	3,83	1,8
My,Ed, max (kNm)		6,24	0,48	0,48	1,08	0,23	0,8	0,43	0,13	0	0	0	0	0	0	0	0	0,02	0	0
Mz,Ed,max (kNm)		4,54	2,59	0,18	1,26	0,32	1,29	0,2	0,57	0	0	0	0	0	0	0	0	0,01	0	0
Vy,Ed,max (kN)		10,01	2	0,41	1,6	3,94	3,3	0,24	1,23	0,19	0,18	0,16	0,1	0,09	0,05	0,04	0,05	0,02	0,02	0,02
Vz,Ed,max (kN)		12,6	0,41	0,21	2,12	6,2	0,68	0,45	0,13	0,16	0,15	0,16	0,11	0,06	0,09	0,09	0,08	0,03	0,03	0,01
σx = N/A +M/W		238,79	197,35	193,48	186,29	60,35	374,62	119,82	138,89	21,18	22,21	15,44	43,01	39,08	41,60	38,81	40,37	36,66	12,59	17,62

Cross-section verification:																				
Nc,Rd (kN)	for class 3	1417,64	1212,73	1095,64	1095,64	497,64	377,62	377,62	377,62	377,62	377,62	377,62	344,58	212,85	344,58	274,33	212,85	137,16	137,16	137,16
Npl,Rd (kN)		1417,64	1212,73	1095,64	1095,64	497,64	377,62	377,62	377,62	377,62	377,62	377,62	344,58	212,85	344,58	274,33	212,85	137,16	137,16	137,16
My,Rd (kNm)		35,71	17,11	14,00	14,00	4,43	2,88	2,88	2,88	2,88	2,88	2,88	2,17	1,20	2,17	1,74	1,20	0,61	0,61	0,61
Mz,Rd (kNm)		35,71	17,11	14,00	14,00	4,43	2,88	2,88	2,88	2,88	2,88	2,88	2,17	1,20	2,17	1,74	1,20	0,61	0,61	0,61
Nc,Ed,max / Nc,Rd	<=1	0,40	0,44	0,43	0,37	0,09	0,62	0,14	0,29	0,05	0,05	0,04	0,10	0,09	0,10	0,09	0,10	0,05	0,03	0,04
Nt,Ed,max / Npl,Rd	<=1	0,12	0,12	0,11	0,09	0,06	0,16	0,11	0,07	0,03	0,03	0,02	0,04	0,10	0,03	0,05	0,09	0,06	0,03	0,01
My,Ed, max /My,Rd	<=1	0,17	0,03	0,03	0,08	0,05	0,28	0,15	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00	0,00
Mz,Ed,max /Mz,Rd	<=1	0,13	0,15	0,01	0,09	0,07	0,45	0,07	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,00
σx <= fy/γM0	<= 1	0,57	0,47	0,46	0,45	0,14	0,90	0,29	0,33	0,05	0,05	0,04	0,10	0,09	0,10	0,09	0,10	0,09	0,03	0,04

Shear check:																				
Vpl,Rd		776,47	664,24	600,10	600,10	272,57	206,83	206,83	206,83	206,83	206,83	206,83	188,74	116,59	188,74	150,26	116,59	75,13	75,13	75,13
Vy,Ed,max / Vpl,Rd	<=1	0,01	0,0030	0,0007	0,0027	0,0145	0,0160	0,0012	0,0059	0,0009	0,0009	0,0008	0,0005	0,0008	0,0003	0,0003	0,0004	0,0003	0,0003	0,0003
Vz,Ed,max / Vpl,Rd	<=1	0,02	0,0006	0,0003	0,0035	0,0227	0,0033	0,0022	0,0006	0,0008	0,0007	0,0008	0,0006	0,0005	0,0005	0,0006	0,0007	0,0004	0,0004	0,0001

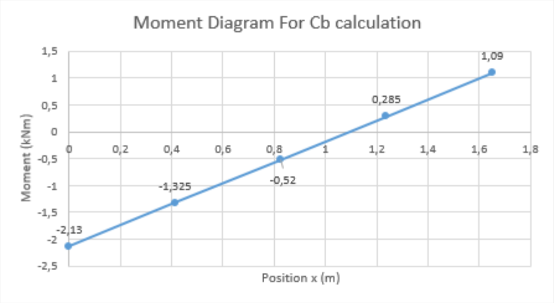
Buckling check:																				
α		0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76	0,76
λ0		0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Ncr,y (N)	3,14^2*E*I/L^2	1312322,40	5383266,74	1930786,29	4051632,52	68444,98	1022929,67	129241,92	255732,42	26383,63	31558,22	27430,73	52554,71	31130,86	60698,38	49653,04	31130,86	15783,92	42227,98	56020,08
Ncr,z (N)		1312322,40	1345816,68	1183224,69	1258331,72	68444,98	1022929,67	129241,92	1022929,67	26383,63	31558,22	27430,73	52554,71	31130,86	60698,38	49653,04	31130,86	15783,92	42227,98	56020,08
λ,y		1,09	0,50	0,79	0,55	2,83	0,64	1,79	1,27	3,97	3,63	3,89	2,69	2,74	2,50	2,47	2,74	3,09	1,89	1,64
λ,z		1,09	1,00	1,01	0,98	2,83	0,64	1,79	0,64	3,97	3,63	3,89	2,69	2,74	2,50	2,47	2,74	3,09	1,89	1,64
Φ,y		1,43	0,74	1,04	0,78	5,50	0,87	2,71	1,72	9,80	8,38	9,47	5,05	5,23	4,50	4,40	5,23	6,38	2,93	2,39
Φ,y		1,43	1,30	1,32	1,27	5,50	0,87	2,71	0,87	9,80	8,38	9,47	5,05	5,23	4,50	4,40	5,23	6,38	2,93	2,39
χ,y	<1	0,42	0,78	0,59	0,75	0,10	0,68	0,21	0,35	0,05	0,06	0,06	0,11	0,10	0,12	0,12	0,10	0,08	0,19	0,24
χ,z		0,42	0,47	0,46	0,48	0,10	0,68	0,21	0,68	0,05	0,06	0,06	0,11	0,10	0,12	0,12	0,10	0,08	0,19	0,24
Nb,Rd,y (kN)		600,30	946,98	641,86	819,12	48,73	258,59	79,54	131,29	20,12	23,69	20,85	36,94	22,00	41,85	34,11	22,00	11,47	26,55	33,15
Nb,Rd,z (kN)		600,30	569,18	506,63	523,81	48,73	258,59	79,54	258,59	20,12	23,69	20,85	36,94	22,00	41,85	34,11	22,00	11,47	26,55	33,15
N,Ed/Nb,Rd,y <= 1		0,94	0,57	0,73	0,49	0,94	0,90	0,65	0,83	0,95	0,85	0,67	0,96	0,90	0,82	0,75	0,93	0,65	0,16	0,17
N,Ed/Nb,Rd,z <= 1		0,94	0,95	0,93	0,77	0,94	0,90	0,65	0,42	0,95	0,85	0,67	0,96	0,90	0,82	0,75	0,93	0,65	0,16	0,17

Stability check:

Ned/Nrd+My,Ed/My,rd+Mz,Ed/Mz,rd (tension)	<= 1	0,418505	0,301305	0,159440	0,252391	0,179760	0,882808	0,328765	0,314793	0,028388	0,025740	0,024443	0,035550	0,098800	0,032445	0,048774	0,094431	0,114434	0,027923	0,013123
eNy = eNz		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ky		2,10	1,20	1,42	1,20	3,09	1,25	2,50	2,28	3,10	2,89	2,54	3,12	3,01	2,84	2,69	3,07	2,51	1,43	1,40
kz		2,10	1,94	1,94	1,74	3,09	1,25	2,50	1,20	3,10	2,89	2,54	3,12	3,01	2,84	2,69	3,07	2,51	1,43	1,40
1,2	<= ky <=	3,07	2,34	2,66	2,19	3,09	3,01	2,50	2,85	3,10	2,89	2,54	3,12	3,01	2,84	2,69	3,07	2,51	1,51	1,55
βw,y = β w,z		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ratio y weakest (compression)	<=1	0,94	0,57	0,73	0,49	0,94	0,90	0,65	0,83	0,95	0,85	0,67	0,96	0,90	0,82	0,75	0,93	0,65	0,16	0,17
ratio z weakest (compression)	<=1	0,94	0,95	0,93	0,77	0,94	0,90	0,65	0,42	0,95	0,85	0,67	0,96	0,90	0,82	0,75	0,93	0,65	0,16	0,17

LTB:

v (mm)		99				
u1 (mm)		58,3				
Iv (mm^4)		3500000				
Iu (mm^4)		13380000				
iv (mm)		27,2		x	M	
Mv = My *sin45°+Mz*cos45°		7,62	Mmax	0	-2,13	
Mu = My*cos 45°+Mz*sin45°		7,62	Ma	0,4125	-1,325	
Wv		4637,98	Mb	0,825	-0,52	
Wu		30108,13	Mc	1,2375	0,285	
Lb(mm)		1650	Mend	1,65	1,09	
βw		0				
Cb		1,5				
Mcr (kNm)		339,49	Cb	2,530	> 1,5	so Cb = 1,5
Med / Mcr	if <0,16 no LTB	0,0225				
		No LTB calculation required				



Annex D ECONOMIC ANALYSIS NOTES

Economic analysis 70kV transmission tower								
			Carbon steel				Austinitic stainless steel	
				Price			Price	
Item	Description	Unit	Quantity	Unit price	Total price	Quantity	Unit price	Total price
1	Production							
1.1	Designing the transmission tower	pcs	1	€ 5 500	€ 5 500	1	€ 5 500	€ 5 500
1.2	Material cost, includes galvanized coating and transportation to the building site	kg	8399	€ 2,50	€ 20 998	8932	5,11	€ 45 643
1.3	First layer of protective paint	m^2	350,06	€ 20	€ 7 001	294,27	€ 0	€ 0
				Subtotal	€ 33 499		Subtotal	€ 51 143
2	Erection							
2.1	Construction of the foundations	pcs	1	€ 90 000	€ 90 000	1	€ 90 000	€ 90 000
2.2	Assembly on site	kg	8399	€ 1,20	€ 10 079	8932	€ 1,20	€ 10 718
2.3	Erection with crane	kg	8399	€ 0,70	€ 5 879	8932	€ 0,70	€ 6 252
2.4	2nd and 3rd layer (alterations) of paint to protect against corrosion	m^2	350,06	€ 25	€ 8 752	294,27	€ 0	€ 0
				Subtotal	€ 114 710		Subtotal	€ 106 971
3	Maintenance							
3.1	semi-annual maintenance	pcs	112	€ 650	€ 72 800	112	€ 650	€ 72 800
3.2	10 year minor maintenance	pcs	4	€ 5 300	€ 21 200	4	€ 5 300	€ 21 200
3.3	15 years major maintenance	pcs	4	€ 66 000	€ 264 000	4	€ 66 000	€ 264 000
3.4	Repainting every 15 years to protect the structure from corrosion (3 layers)	pcs	4	€ 26 255	€ 105 018	294,27	€ 0	€ 0
				Subtotal	€ 463 018		Subtotal	€ 358 000
4	Recycling							

4.1	Disassembly	pcs	1	€ 3 500	€ 3 500	1	€ 3 500	€ 3 500
4.2	Crane for disassembly	pcs	1	€ 1 500	€ 1 500	1	€ 1 500	€ 1 500
4.3	Removing the concrete foundations till a depth of 0,8m	pcs	1	€ 5 000	€ 5 000	1	€ 5 000	€ 5 000
4.4	Land improvements	pcs	1	€ 250	€ 250	1	€ 250	€ 250
4.2	Recycling value	kg	8399	€ -0,14	€ -1 176	8932	€ -1,20	€ -10 718
				Subtotal	€ 9 074		Subtotal	€ -468
				Total	€ 620 300		Total	€ 515 645

Economic analysis 70kV transmission tower								
			Carbon steel				Ferritic stainless steel	
				Price			Price	
Item	Description	Unit	Quantity	Unit price	Total price	Quantity	Unit price	Total price
1	Production							
1.1	Designing the transmission tower	pcs	1	€ 5 500	€ 5 500	1	€ 5 500	€ 5 500
1.2	Material cost, includes galvanized coating and transportation to the building site	kg	8399	€ 2,50	€ 20 998	8881	€ 3,81	€ 33 837
1.3	First layer of protective paint	m^2	350,06	€ 20	€ 7 001	300,63	€ 0	€ 0
				Subtotal	€ 33 499		Subtotal	€ 39 337
2	Erection							
2.1	Construction of the foundations	pcs	1	€ 90 000	€ 90 000	1	€ 90 000	€ 90 000
2.2	Assembly on site	kg	8399	€ 1,20	€ 10 079	8881	€ 1,20	€ 10 657
2.3	Erection with crane	kg	8399	€ 0,70	€ 5 879	8881	€ 0,70	€ 6 217
2.4	2nd layer of paint to protect against corrosion	m^2	350,06	€ 25	€ 8 752	0	€ 25	€ 0
				Subtotal	€ 114 710		Subtotal	€ 106 874
3	Maintenance							
3.1	semi-annual maintenance	pcs	112	€ 650	€ 72 800	112	€ 650	€ 72 800
3.2	10 year minor maintenance	pcs	4	€ 5 300	€ 21 200	4	€ 5 300	€ 21 200
3.3	15 years major maintenance	pcs	4	€ 66 000	€ 264 000	4	€ 66 000	€ 264 000
3.4	Repainting every 15 years to protect the structure from corrosion (3 layers)	pcs	4	€ 26 255	€ 105 018	300,63	€ 0	€ 0
				Subtotal	€ 463 018		Subtotal	€ 358 000
4	Recycling							
4.1	Disassembly	pcs	1	€ 3 500	€ 3 500	1	€ 3 500	€ 3 500
4.2	Crane for disassembly	pcs	1	€ 1 500	€ 1 500	1	€ 1 500	€ 1 500

4.3	Removing the concrete foundations till a depth of 0,8m	pcs	1	€ 5 000	€ 5 000	1	€ 5 000	€ 5 000
4.4	Land improvements	pcs	1	€ 250	€ 250	1	€ 250	€ 250
4.2	Recycling value	kg	8399	€ -0,14	€ -1 176	8881	€ -1,20	€ -10 657
				Subtotal	€ 9 074		Subtotal	€ -407
				Total	€ 620 300		Total	€ 503 803

Economic analysis 70kV transmission tower								
			Carbon steel				Duplex stainless steel	
				Price			Price	
Item	Description	Unit	Quantity	Unit price	Total price	Quantity	Unit price	Total price
1	Production							
1.1	Designing the transmission tower	pcs	1	€ 5 500	€ 5 500	1	€ 5 500	€ 5 500
1.2	Material cost, includes galvanized coating and transportation to the building site	kg	8399	€ 2,50	€ 20 998	8621	€ 6,41	€ 55 261
1.3	First layer of protective paint	m^2	350,06	€ 20	€ 7 001	269,32	€ 0	€ 0
				Subtotal	€ 26 498		Subtotal	€ 60 761
2	Erection							
2.1	Construction of the foundations	pcs	1	€ 90 000	€ 90 000	1	€ 90 000	€ 90 000
2.2	Assembly on site	kg	8399	€ 1,20	€ 10 079	8621	€ 1,20	€ 10 345
2.3	Erection with crane	kg	8399	€ 0,70	€ 5 879	8621	€ 0,70	€ 6 035
2.4	Finishing layer of paint to protect against corrosion	m^2	350,06	€ 25	€ 8 752	269,32	€ 0	€ 0
				Subtotal	€ 114 710		Subtotal	€ 106 380
3	Maintenance							
3.1	semi-annual maintenance	pcs	112	€ 650	€ 72 800	112	€ 650	€ 72 800
3.2	10 year minor maintenance	pcs	4	€ 5 300	€ 21 200	4	€ 5 300	€ 21 200
3.3	15 years major maintenance	pcs	4	€ 66 000	€ 264 000	4	€ 66 000	€ 264 000
3.4	Repainting every 15 years to protect the structure from corrosion (3 layers)	pcs	4	€ 26 255	€ 105 018	269,32	€ 0	€ 0
				Subtotal	€ 463 018		Subtotal	€ 358 000
4	Recycling							
4.1	Disassembly	pcs	1	€ 3 500	€ 3 500	1	€ 3 500	€ 3 500
4.2	Crane for disassembly	pcs	1	€ 1 500	€ 1 500	1	€ 1 500	€ 1 500

4.3	Removing the concrete foundations till a depth of 0,8m	pcs	1	€ 5 000	€ 5 000	1	€ 5 000	€ 5 000
4.4	Land improvements	pcs	1	€ 250	€ 250	1	€ 250	€ 250
4.2	Recycling value	kg	8399	€ -0,14	€ -1 176	8621	€ -2,00	€ -17 242
				Subtotal	€ 9 074		Subtotal	€ -6 992
				Total	€ 613 299		Total	€ 524 882