DESIGN AND CONSTRUCTION OF RAILWAY SHELTER

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ABSTRACT

This thesis is about the design and construction of a railway shelter for Iittala Asema with indigenes specialized in painting of art works. This design was to be driven by the relationship between the bus shelter, the users and a local profession artist. Specifically the purpose of the shelter was to provide psychological and physical comfort, display relevant information about the transportation system and adverts of local businesses and activities.

The project consisted modelling of railway shelter parts and frames and modifying the design with consideration to the dimensions, materials, display information, quality, exceptionality of style, and thus creating a modernized alternative shelter with sophistication of the structure. This shelter was to have a full roof supported on three sides by constructions with seats, adverts and illumination to reflect the businesses of the area.

Keywords Stress analysis, finite element method, bending, beam and structure.

Pages 38 pages including appendices 9 pages

LIST OF USED TERMS

LCD: Liquid crystal display

AC: Air condition

DL: Dead load

WL: Wind load

QFD: Quality function distribution

N/m^2: Newton per meter square

N/m: Newton per meter

Kg: Kilogram

m/s^2: Meter per second square

Kg/mm^3: Kilogram per millimeter cube

mm^3: Millimeter cube

Ce: Exposure co-efficient

Ct: Thermal co-efficient

Sk: Snow load in ground

EQ: Earthquake

MD: Maximum deflection

DL: Distributed load

FEM: Finite element method

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1 INTRODUCTION

The objective of this thesis was for the design and construction of a railway shelter to be modernized to a 21th century shelter that was to showcase an exceptional outlook and style to the passers-by, onlookers and users. It will also in a show an attractive concept defining the artistic trade of the people in the area.

The weather adaptation, reliability and safety is another focus of the design and construction of the shelter. Therefore structural analysis is of great importance since the identification of the critical parts which will require special attention is needed to be identify. This will assist to show the details of the structure and gives a more comprehensive knowledge of the designed structure.

Each segment of the shelter, beams and frames has its purpose in the structure. The importance of this should be identified before the shelter is finally constructed.

2 COMPANY REQUIREMENT FOR RAILWAY SHELTER DESIGN

Linnan Kehitys Oy, the commissioning company responsible for coordinating the design process of railway shelter had its desired goals for the shelter design.

The company's requirements were as follows:

Basic 1 requirements

1. Sufficient protective cover against extreme weather conditions – rain, snow, wind and variable temperatures; solid (glass, sheet metal, plywood etc.) walls on three (3) sides.
2. Rigid, welded steel-beam framework capable of carrying 250 kg additional weight on roof.
3. Blind, deaf, wheelchair – users must be taken in consideration (loops, strips, braille, sounds etc).
4. Simple seats for 8-12 passengers.
5. Travelling information available (spoken and written).
6. Internet and AC electricity connections available (chargers etc).
7. Surveillance cameras as an option.
8. Open, fully covered space: 5m x (8 – 10m) and 2.6 m high.
9. Walls made of security glass – allows use of laminated LCD panels on wall surfaces.
10. In basic version the shelter is not heated, air-conditioned or mechanically ventilated.

Basic II requirements (extension of BASIC I)

1. Basement heat isolated with easy-to-clean surface materials.
   2. Single walls without isolation on four (4) sides, doors (double) on two sides.
   3. Walls made of security glass – allows use of laminated LCD panels on wall surfaces.
   4. Mechanical ventilation.

Basic III requirements (extension to BASIC II)

1. Basement heat isolated with easy-to-clean surface materials.
2. Corten steel a weathering steel material which is easy to maintain.
3. Ultra-strength materials for exceptional strength and effective weight management.
4. Single walls without isolation on four (4) sides, doors (double) on two sides.

5. Walls made of security glass – allows use of laminated LCD panels on wall surfaces.
6. Mechanical ventilation.

Cost Requirement

The estimated cost requirement for this thesis construction is about €20000 (twenty thousand euro) which includes architectural design, structural, design, shelter construction and external development.

2.1 Structural design regulation in Finland

According to Finnish building requirement Act, from the A2 National Building code of Finland as quoted from the Land Use and Building Act, section 120, paragraphs 1 and 2 (2003, Land use and building act):
A design shall be prepared for construction that meets the requirements of this Act and provisions and regulations issued under it, and the requirements of good building practice.

A qualified person shall be in charge of the design in its entirety and of its quality, ensuring that the building design and any special designs form a complete entity which meets the requirements set for it (principal designer). (Land Use and Building Act, section 131, paragraph 1, 2003).
Building permits shall be applied for in writing. Applications shall include proof the master drawings signed by the designer Land Use and Building Act, section 120, paragraph 3, 2003.

The person in charge of each special design shall ensure that the design meets the requirements set for it. When a special design is prepared by more than one designer, one of them must be appointed as the designer responsible for the special field concerned in its entirety.
Table 1 illustrates the design requirements in Finland.

Table 1 Design requirements for load-bearing structures

<table>
<tr><td colspan="6">Design of load-bearing structures</td></tr>
<tr><td>Minor design task</td><td colspan="2">Conventional design task</td><td colspan="2">Difficult design task</td><td>Exceptionally difficult design task</td></tr>
<tr><td>Sufficient expertise for the design task in question.</td><td colspan="2">Has successfully completed at least the qualification of technician in the field of building technology, building production or mechanical engineering, or has completed the degree of bachelor of science in technology (180 credits), and the degree or supplementary studies have included at least 30 credit points of studies related to structural engineering and the design and function of the structures in question, including courses in the following fields (or other equivalent fields):structural mechanics and structural design materials and manufacturing engineering studies listed under the structural material in question.</td><td colspan="2">Has successfully completed the degree of master of science in technology, master of engineering (at a university of applied sciences), or bachelor of engineering (at a university of applied sciences) in the field of building technology or another appropriate field, or an engineering degree in the field of building technology or mechanical engineering, and the degree or supplementary studies have included at least 40 credit points of studies related to structural engineering and the design and function of the structures in question, including courses in the following fields (or other equivalent fields): Structural mechanics and structural design materials and manufacturing engineering studies listed under the structural material in question.</td><td>Has successfully completed the degree of master of science in technology or master of engineering (at a university of applied sciences) in the field of building technology or another appropriate field, and the degree or supplementary studies have included at least 45 credit points of studies related to structural engineering and the design and function of the structures in question, including courses in the following fields (or other equivalent fields): structural mechanics and structural design material and manufacturing engineering and material models studies listed under the structural material in question.</td></tr>
<tr><td colspan="6">Concrete structures</td></tr>
<tr><td colspan="2">Design of concrete structures and concrete building.</td><td colspan="2">Design of concrete structures and concrete building.</td><td colspan="2">Design of concrete structures and concrete building
design of prestressed structures</td></tr>
<tr><td colspan="6">Steel structures</td></tr>
<tr><td colspan="2">Design of steel structures and steel building</td><td colspan="2">Design of steel structures and steel building</td><td colspan="2">Design of steel structures and steel building</td></tr>
<tr><td colspan="6">Aluminium structures</td></tr>
<tr><td colspan="3">Studies such as those listed under steel structures</td><td colspan="3">Studies such as those listed under steel structures</td></tr>
<tr><td colspan="6">Timber structures</td></tr>
<tr><td colspan="2">Design of timber structures and timber building</td><td colspan="2">Design of timber structures and timber building timber product technology</td><td colspan="2">Design of timber structures and timber building timber product technology</td></tr>
<tr><td colspan="6">Masonry structures</td></tr>
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<tr><td colspan="4">Composite structures</td></tr>
<tr><td colspan="2">Studies required for difficult design tasks for the materials in question, and experience of composite structures.</td><td colspan="2">Studies required for difficult design tasks for the materials in question and for an exceptionally difficult design task for one of the materials, and experience of composite structures.</td></tr>
<tr><td>AND</td><td colspan="2">AND</td><td>AND</td></tr>
<tr><td>Has at least three years of experience of assisting in design</td><td colspan="2">Has at least four years of experience of working on</td><td>Has at least six years of experience</td></tr>
</table>

2.2 International standard

Euro code 3 is the standard that applies to the design of buildings and civil engineering works in steel and it is a valid standard in Europe. This code complies with the principles and requirements for the safety and serviceability of structures, the basis of design and verification that are given in EN 1990 Basis of structural design.

Euro code 3 only concerns requirements for resistance, serviceability, durability and fire resistance of steel structures. Other requirements, e.g. concerning thermal or sound insulation, are not covered in this standard code.

An example of a modernist shelter in the 1930s is shown in Figure 1.

Figure: 1 Modernist bus shelter (Transport for London, 1934)

In the 1930s of London Transport the poster campaigns, stations and even bus shelters reflected the modernist style that is often identified as Art

Deco. London Transport contributed greatly to bringing the modernist style into everyday in life. This unusual bus stop was designed by architect Charles Holden. On top is what is referred to as a flagpole roundel. This was designed and constructed on 12 May 1934 (London Transport Museum, 2016)

2.3 Modern shelter

Modern day shelters are designed to be environmentally friendly and beautiful. Most often through a lot of financial commitment is attached to achieving this taste of modern design because of the qualities of the materials to be used, internal fittings such as high quality seats, display screens, internet Wi-Fi, and stereo for 24hours music, charger spots, magazines, kiosk, lawn, trees and flowers as well as special audio system for the dissipation of information. Effective usability and economy of utilized materials and space is a target of modern day shelter design and construction. There is also strategic conversation and of recreation plan to reflect the culture and priorities of the people of the area and for economic and social benefit of the residing community.

Examples of modern design shelters show a distinction from the old design.Figure 2 illustrates a shelter with innovative design with wireless charging point for an electric bus. It is also designed with charging points for mobile phones and laptops. It is a simple prototype for the working logistics of the next public transport infrastructure.

Figure: 2   Bus shelter (2017, Tuvie-Futuristic Technology)

Also in figure 4 below the shelter has an interior design for good visibility of transit bus or train. The roof style allows for better draining for rain or snow away from passengers. Attached with it are solar panels for as renewable power source for a constant availability of electricity for display screens, power points, lightings, chargers, stereos etc.

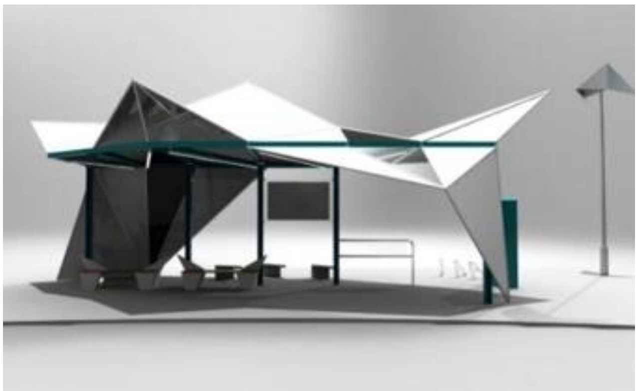


Figure: 3 Bus Shelter (Core77, 2017)

2.4 Design in this project

The design in this project was chosen to reflect the culture and priority of Iittala Village.

The exceptional features of this design include:

1. Uniqueness of colour of steel material. The steel material to be used in this design was CORTEN steel for both the beams and the sheet metals. Corten steel is a weathering steel with a stable rust appearance which serves as an alternative to painting. Corten has an increasing resistance to corrosive effects from snow, rain, and ice by forming a darkish brown oxidation coating over the steel metal. The oxidation coating helps to prevent deeper penetration of rust and of need for preventive painting which in turn reduce the cost of maintenance over the years.(2004, Corus: weathering steel)
2. The rectangular shape of 5m by (8-10m) and 2.6m high. Though there are a lot of rectangular shaped shelters but this is unique for the passenger comfort, outlook, the internal fittings of seats, foot rest, digital display, lighting, wireless internet connection, Iittala inscription, transparent glass covering on the side for visibility etc.

3. Exceptional truss and roof design with an intension to reduce dead load on the vertical beams by the use of lighter trusses designed with beams and sheet metal. The roof is slanted in an angle to allow easy dropping of live loads of rain, wind and snow.
4. Design and material selection according to Eurocode 3 which is applicable in Europe and use in Finland.
5. Material quality is carefully attended to for the durability, reliability, strength and life span.

Figure: 5 Iittala shelter (Arkkitehtitoimisto Planko, 2017)

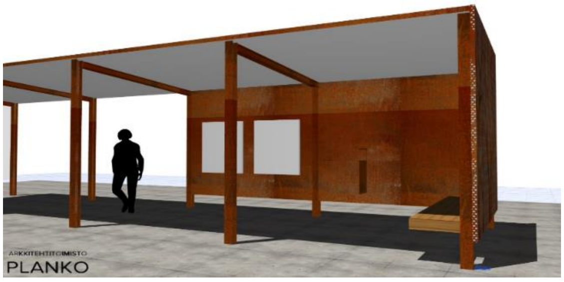


Figure: 6 Iittala Asama railway shelter (Arkkitehtitoimisto Planko,2017)

Figure: 7 Iittala Asama railway shelter (Arkkitehtitoimisto Planko, 2017)

3 DESIGN AND ANALYSIS

3.1 Introduction

The analysis and procedure for the design of this railway shelter were prescribed according to the regulations and Eurocode 3. The individual components of this structure were analysed for shear forces, axial, moment, buckling and deflection. This allowed defining the limit which the structural components should not exceed i.e. the minimum analysis.

3.2 Design of slab

Slab is a structural element subjected to distributed loads on the plan. Slabs are designed in various ways with regards to the length and breadth of openings like One-way slab, Two-way slab, Continuous slab etc. The type of slab for a particular floor structure depends on many factors. Economy of construction is obviously an important consideration, and it is geographical variable. The design loads, required spans, serviceability requirements, and strength requirements are all important.

Euro code 2, 2008 the international standard rule which deals with the design of reinforced concrete structures – buildings, bridges and other civil engineering works. This allows to calculate the action effects and of resistances of concrete structures and contains all the prescriptions and good practices for properly detailing the reinforcement.

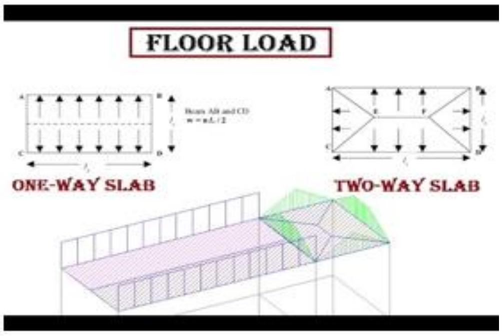


Figure: 8 Slab load (Pro tutorial, 2016)

3.2.1 Column design

Column is the part of a building which transfer the loads over it and its weight to the foundation. They are primarily compressed members which has to resist bending forces. Two types of columns according to line of action of the loads. They are "Axially loaded columns" and "Eccentrically loaded columns". The latter column is subdivided into "Uni-axial column" and "Bi-axial column". Beams connected to the column face usually inducing a small bending moment in the column because of the eccentric application of transferred force. The columns are usually continuous over the height of the building.

EN 1993-1-1 the only option for members in combined axial compression and bending is the general guidance.

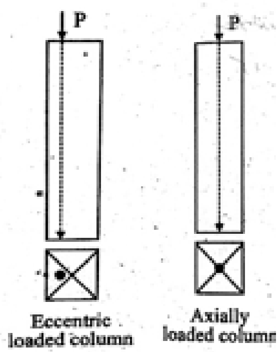


Figure: 9 Types of column (Engineering intro, 2014)

3.2.2 Beam design

Beams are the parts of the structure in the horizontal plan which transfer the dead and live loads to the vertical members of the structures. These loads act at right angle to the beam and are in cross section with the length. The ratio of the width and depth of a beam to the length is very small. There are various types of beam i.e. "Simply supported beam", "Fixed beam", "Cantilever beam", "Continuous beam". In this thesis we have both "Singly reinforced beam" and "Doubly reinforced beam" with shear reinforcement.

Beams are subjected to two kind forces which are external and internal forces in two opposition directions. The loads acting externally are the loads applied to the beam and reactions to the loads from the supports. The two kinds of internal force are bending moments and shear forces. The shear force and bending moment can be represented as pairs of forces.

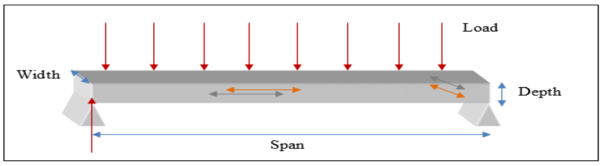


Figure: 10 Beam with action forces (Basic civil engineering, 2015)

3.3 Procedure for analysis and design of roof truss system

There is a need for a basic understanding of the behavior of a structure and structural members subjected to various types of forces form the basics of structural analysis. The structural components that constitute the whole structure should be built to standard, in this case the standard was Euro code 3, 2005.

Sometimes, the structural system is portal framed with rigid connections and without bracings, to provide clearance for the requirements of the layout of machines and equipment, and to create more working space. In general, portal-framed structural systems reduce the size of structural components, hence reducing the space required and minimizing cost.

The methods of analysis are as listed:

1. Selection of truss system
2. Estimation of loads
3. Analysis and design of purlins
4. Analysis and design of sag rods
5. Dead load (DL) and wind load (WL) analysis
6. Design of columns
7. Design of column base plate and concrete footing
8. Earthquake load analysis
9. Combination of DL and WL to determine the design bar forces
10. Design of members according to the design bar forces

11. Design of bracing system
12. Design of bolt connections
13. Beam-column joint design
14. Truss-column joint design

3.4 Eurocode basis for design

The Eurocode is a series of 10 European Standards, EN 1990 - EN 1999, providing a common requirements and approach for the design of structural buildings and other civil engineering works and construction products. These are the recommended means of giving a presumption of conformity with the basic requirements for structural regulation. (European standard, 2017).

EN 1991: Action on structure.
1-1 Self-weight.
1-2 Fire action
1-3 Snow
1-4 Wind
1-5 Thermal actions
1-6 Construction loads
1-7 Accidental actions
2. Traffic on bridges
3. Loads from cranes
4. Silo loads
EN 1992 TO 1999
Eurocode 2: Concrete structure
Eurocode 3: Steel structure
Eurocode 3:-
EN 1993-1-1: General rules and rules for buildings.
EN 1993-1-2: General rules - Structural fire design.
EN 1993-1-3: General rules - Supplementary rules for cold-formed members and sheeting.
EN 1993-1-4: General rules - Supplementary rules for stainless steels.
EN 1993-1-5: General rules - Plated structural elements.

EN 1993-1-6: General rules - Strength and stability of shell structures.

EN 1993-1-7: General rules - Strength and stability of planar plated structures subject to out of plane loading.

EN 1993-1-8: Design of joints.

EN 1993-1-9: Fatigue.

EN 1993-1-10: Material toughness and through-thickness properties.

EN 1993-1-11: Design of structures with tension components.

EN 1993-1-12: General - High strength steels.

EN 1993-2: Steel bridges.

EN 1993-3-1: Towers, masts and chimneys – Towers and masts.

EN 1993-3-2: Towers, masts and chimneys – Chimneys

EN 1993-4-1: Silos

EN 1993-4-2: Tanks

EN 1993-4-3: Pipelines

EN 1993-5: Piling

EN 1993-6: Crane supporting structures

Eurocode 4: Composite structure

Eurocode 5: Timber structure

Eurocode 6: Masonry structure

Eurocode 7: Geotechnical design

Eurocode 8: Design in seismic areas

Eurocode 9: Aluminium structure (The European Union Edict of Government, 2005)

4 THEORY BEHIND THE PROJECT

4.1 Introduction

It is common knowledge that any structural building should be designed to resist forces that might cause damage. Structures should be strong and stiff to withstand the stresses caused by the loads. It is therefore very important to know the anticipated loading conditions. Calculating the loads acting on a structure determines the allowable stress values for design. These values determine the design of the joints, columns and beams used in constructing the building. (2015, Jianqiao Ye: Structural and stress analysis)

4.2 House of quality

Below is the House of Quality for quality function deployment (QFD) to scale customer requirement and satisfaction in the designing the railway shelter structure and coordination of the processes to achieving the final structure.

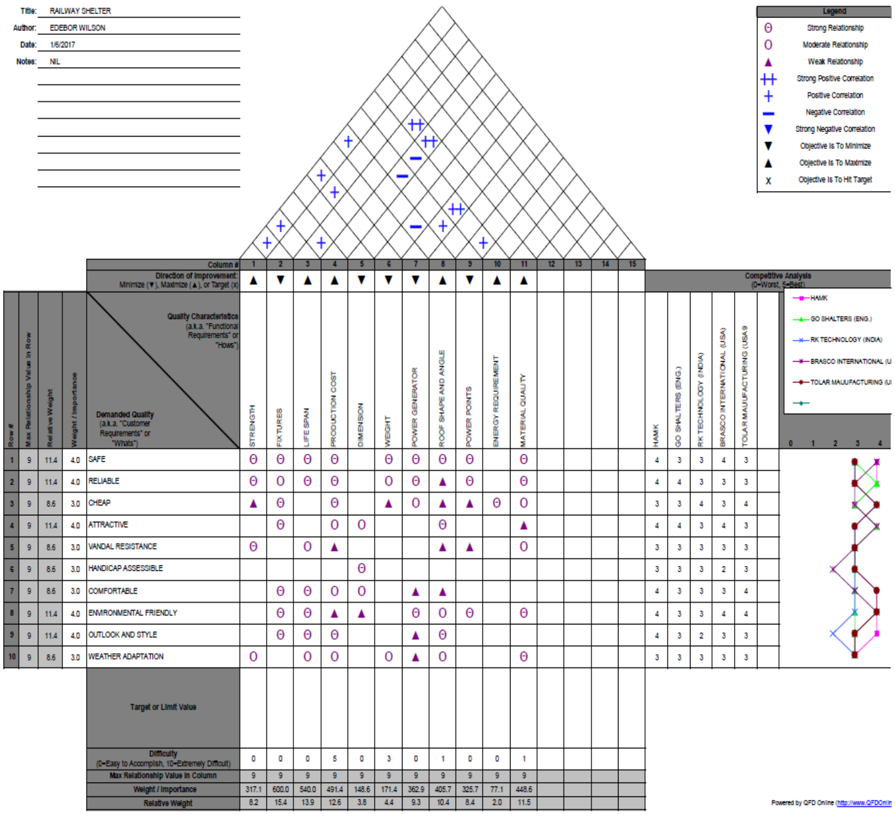


Figure: 11 House of Quality

4.2.1 HOQ details

Figure 11 above illustrates the quality function deployment in accordance to customer needs and requirements. Details are as follows:

- Following the house of quality, priority focus on the fixture i.e. the style of design to suite the present era.
- The life span in the next in priority. This design has a goal for a structure with good and long age of life span.
- We desire to achieve this life span goal by focusing next on the required cost for the structure.
- Followed by the quality of the material to be used in the construction of this railway shelter.
- Roofing material quality, shape, truss designed to suit the roof style is the next focus. The roof design and material needs to be sustainable able to withstand the weather elements and uniform load caused by the snow bile.

4.3 Eurocode EN-1991 and EN- 1993

Euro-code standard states that there are different quantities of loads for different types of buildings. "Areas in residential, social, commercial and administrative buildings shall be divided into categories according to their specific uses." (EN 1991-1-1:2002:20-21).

Also, EN1993-1-9 code states that "Structural members shall be designed for fatigue such that there is an acceptable level of probability that their performance will be satisfactory throughout their design life". This code provides the requirement for structure to have resistance to fatigue and quality life span of structural members.

4.4 Determination of load

Loads on buildings are classified into two major categories. Gravity loads and lateral loads. Gravity loads pull vertically downwards due to gravity while lateral loads act in the horizontal direction.

4.5 Category of load

Table: 2 Load categories

Lateral load type	Gravity load type
Wind load	Dead load
Earthquake load	Live load

These are the major loading types which act on any structure. They can act alone or as in many cases occur together. Tracing the loads from one part of the structural building is very important since not all structural elements experience direct forces. Loads on a surface area are expressed in Newton´s per square meter (N/m^2) while those on linear elements such as a beam are in Newton´s per meter (N/m).

4.5.1 Dead load

As the name suggests a dead load does not change over time and acts permanently on the structure. In the euro code standards, dead loads are referred to as permanent actions. The definition states that "the self-weight of construction works should be classified as a permanent fixed action." (EN 1991-1-1:2002, 12). A permanently fixed structure such as finishing that remains fixed is also classified as dead load.
The total weight of a structure might not be directly available in most cases. Also, redesigning the structure leads to change in total weight. Material properties such as density and volume of the individual members of the structure are used to calculate the weight.

$$\text{Mass} = \text{Density } (Kg/mm^3) * \text{Volume } (mm^3) \quad (1)$$

$$\text{Weight} = \text{Mass } (Kg) * \text{Gravity } (m/s^2) \quad (2)$$

4.5.2 Live load

Live loads change over time and are temporarily attached to a structural building. They result from using and occupying the building. Environmental or human interactions are examples that cause live loads.

4.5.3 Snow load

Snow loads are sub category of gravity loads and hence act vertically on the roof. Snow load varies and changes with the location of a building. Therefore, different designs due to the snow loads are required. Unaffected snow measured from the ground is a good estimate of how much snow is on the roof. The figure below shows an example of accumulated snow load on a building.

Figure: 12 Snow load accumulation (North roof load zone, n.d.)

(EN 1991-1-3: 2002, 17) Accumulation of snow on the roof is influenced by the following factors;

- The shape of the roof.
- Heat generated below the roof.
- Distance of close by buildings.
- Surface roughness of the roof.
- The surrounding terrain.

Standards are used to calculate the snow load due to the many factors listed above. The snow load on roofs is determined by formula three (3).

$$S = \mu_i * C_e * C_t * S_k \quad (3)$$

Where μ_i is snow load shape co-efficient, C_e is the exposure co-efficient, C_t is the thermal co-efficient and S_k is value of snow load on the ground depending on the geographical position. (EN 1991-1-3: 2002, 18).

4.5.4 Wind load

Wind acts horizontally on a structure and changes in magnitude and direction with time. Wind pressure might lead to dynamic responses from the building. Hence in some cases it might lead to fatigue stresses especially on the foundation. Wind load effects on a structure are affected by the following factors:

- ➢ The height above the ground; obstacles on the ground level reduce wind speed.
- ➢ Exposure of the building to its surroundings; trees and other tall buildings block the wind speed.

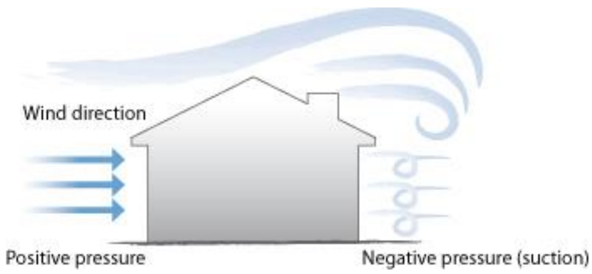


Figure: 13 Wind blowing against building (Build right, 2007)

The wind load is mainly resisted by proper anchoring of the foundation and adding stiffening elements. Lateral forces tend to force structures to move horizontally and this makes the foundation to experience high stresses. Stiffening elements such as braces help to maintain columns into their original position.

4.5.5 Earthquake load

An earthquake is a vibration that travels on the ground. Several modes of vibration are expected to occur depending on the height of the building. Earthquakes vary in magnitude depending on the geographical location of a building. The earthquake load induces dynamic loading on the foundation of a building leading to shear and fatigue stresses and also causes deformation of a structure. Design of the building requires that the structure can withstand some levels of displacement at the base (Murty, n.d, 1-5)

The inertia force experienced leads to the damaging of the structure. It happens so that the base of the building moves while the upper part moves in the opposite direction leading to inertia force on the roof. This causes buckling on the columns of the building. That is the basic way how the damage occurs due to the earthquake. It is important that the columns are designed to withstand high buckling forces.

4.5.6 Earthquake spell

Earthquake Spell does percentage damage. Normal spell does damage to everything, but also four times the damage on walls.

Normal:

One Level 4 EQ spell = 1 - 0.12 = 88% remaining

Two Level 4 EQ spells = 0.88 - (0.88*.0.12) = 77.44% remaining

Three Level 4 EQ spells = 0.7744 - (0.7744*0.12) = 68.15% remaining

Four Level 4 EQ spells = 0.6815 - (0.6815*0.12) = 60.0% remaining

Walls:

One Level 4 EQ spell = 0.88 - (0.88*0.48) = 45.76% remaining

Two Level 4 EQ spells = 0.4576 - (0.4576*0.48) = 23.8% remaining

Three Level 4 EQ spells = 0.238 - (0.238*0.48) = 12.38%

Four Level 4 EQ spells = Knock Out!

Regardless of the level, 4 Earthquake Spells will take out any level wall. And no less than that will break any walls. Must use exactly 4 of any level Earthquake Spells to remove walls. Four level 1 Earthquake Spells are able remove level 11 walls, same as level 4 walls. (2015, Eternal625)

The Earthquake Spell has a 3.5 tile radius, and can knock out 8 tiles of walls. Why 8? Because half a tile is rounded to one, thus 3.5 radius would be rounded to 4 and so the diameter length would be 8. However, this requires very good placement of the Earthquake Spell.

4.5.7 Ground frost action

In polar and temperate climate, winter is the coldest season in the year caused by axis of the earth in the hemisphere being faced off from the path of sun. During the winter season in the North hemisphere, it will be summer in be Southern hemisphere interchangeable.

The low temperature of the winter season causes the ground to freeze or thaw. This gives rise to potholes in the roads and can also create landforms caused by subjection of the liquid water underground to pressure. This feeds the ice layers pushing upwards the from beneath the ground.

4.5.8 Processes of frost action

The frost action processes are;

1. Frost heave: This process occurs when underground water turns into ice and expands. There is upward movement in the ground due to the expansion. This movement causes damages on bridges, buildings and roads.
2. Thaw weakening: This occurs when ice and frozen ground thaws. Due to unequal rates of thawing, uneven surfaces are created and formed.

4.6 Basic calculation of load

In standard manuals, most of the loads are given in pressure units, for example (kN/m^2). In some cases the pressure load needs to be converted to a uniformly distributed line load (kN/m). The line load as well is in some cases need to be in form of a point load (N). It is important that the techniques of converting the loads are well defined.

4.6.1 Pressure load to line load

To find a uniformly distributed load on a pressure surface, equation 4 is used. Choosing the length depends on the axis that you wish the line load to be. If line load one is desired, the length perpendicular to the line load for example b is used and vice versa as it is shown in the figure below;

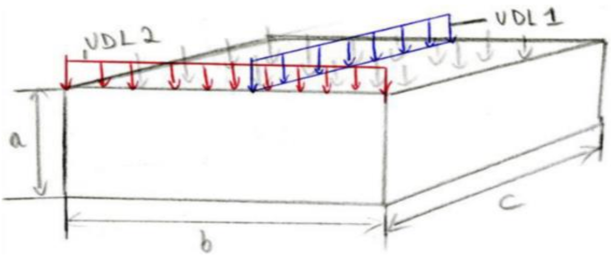


Figure: 14 Pressure load to uniformly distributed load

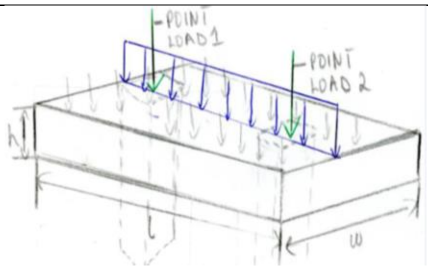
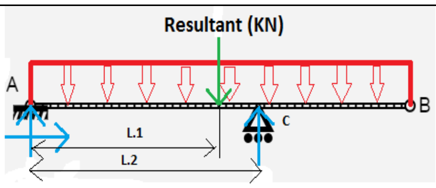
$$\text{Pressure load } (kN/m^2) * \text{length (m)} = \text{Line load } (kN/m) \qquad (4)$$

4.6.2 Line load to point load

Since the structure is static, equations of equilibrium are used to determine the point loads. Equation 5 is used to determine one of the forces involved in the statics calculation.

$$\text{Line load } (kN/m) * length\ (m) = Resultantload\ (kN) \qquad (5)$$

Table: 3 Load analysis

	Schematic and free body diagram
Stage 1: Physical problem	
Stage2: Free body diagram	
Stage 3: Equation Of equilibrium	$\Sigma f(x) = 0$ $\Sigma f(y) = 0$ $\Sigma M = 0$ $\Sigma f(y) := A_y + C_y - \text{Resultant}$ $M_A := C_Y \cdot l_2 - \text{Resultant} \cdot I_1$ $C_Y = (\text{Resultant} \cdot I_1)/I_2$ $A_Y = \text{Resultant} - C_Y$

The force calculated in equation 4 is used to find the resultant forces at A and B which represents the point loads of the two columns. The force calculated in equation 5, is used to find the resultant forces at A and B which represents the point loads of the two columns.

NOTE

It is important to identify all the loads that act on a building for the purpose of stress calculations. Loads can be combined to find the stress if necessary. The most common loads that are combined are for example the snow load and wind load. Earthquake loads do not occur frequently in Finland because Finland is not in the seismic zone. Therefore design against this type of loads is not highly emphasized in this analysis.

4.7 Material selection

Material selection is important for all forms of engineering design as it determines the reliability, efficiency and customer satisfaction with relation to both economics and industrial aspect. This is influenced by many factors associated to the material and to prevent failure in the long run. Some of the selection focus are; mechanical properties, availability , cost, maintainability, compatibility with other component structure, reliability, life span, attractiveness and the importance to the design.
The table below shows the selection of materials suitable for the railway shelter.
Table: 4 Material Selection (Eva M.H, Martin K, Jörg S, Susanne W, 2015)

	Steel S355	Corten steel	HSS Steel	Aluminium 6061-T6	Toughened Glass
Tensile Strength(MPa)	515	515	850	310	120-200
Young’s Modulus (GPa)	193	193	200	68.9	70
Weldability	Excellent	Excellent	Excellent	Averagely good	-
Ductility	High	High	High	High	Low
Corrosive Resistance	High	Excellent	High	High	-
Thermal Conductivity(W/mk)	16.3	42.7100	21.7	167	0.04
Density(kgm^{-3})	7850	7850	8138	2700	2500

4.8 Recommendation on material

From the above material selection in table 4, all evaluated material are suitable for usage, using aluminium 6061-T6 for areas for parts that require aluminium, toughened glass for glass materials and corten steel for steel material because of its weathering corrosion resistance, the excellent properties (thermal conductivity, corrosion resistance, tensile strength, and weldability), visual point of view and requires no painting.

5 DESIGN OF RAILWAY SHELTER

5.1 Introduction to design of railway shelter

The simplest design is often considered to be the best, therefore we first established the simplest design that would meet the criteria that were set beforehand.

A plate was to be used as the roof panel, steel is the most common material for that purpose as is it strong enough to withstand the load from rain and snow pile up, and it is also relatively cheap and easy to work with, in the sense that it is easy to drill weld or bend.

A set of four beams was needed in the edges to provide the structure a support to the load on top of the top plate and the plate own mass, also to be able to attach the roof to the mainframe.

A layer of paint was to be applied to the entire structure to provide protection from the weather elements and corrosion, also to make it easy to modify the aesthetics of the structure.

5.2 Changes during design process

5.2.1 First design

This first design had a bevelled front roof and a very steep-sloped roof behind for easy flow of snow to reduce the live weight on the structure. The shape from the side view looks like a sea horse.

A set of steel beams are attached to the roof panel as there is need for support to the structure to combat bending moment, which is caused by uniform load from the mass of the snow as well as the panel's own mass.

The beams use for this design are hollow rectangular beams as it is the most effective profile to combat static uniformly distributed load.

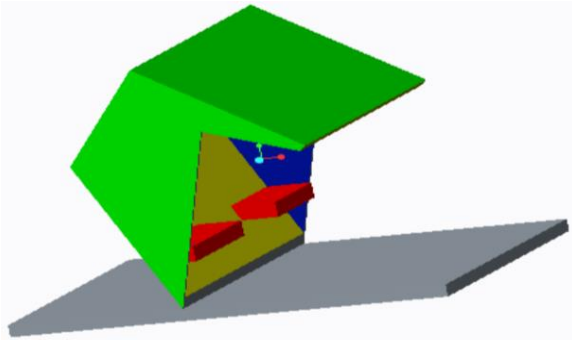


Figure: 15a Model of first design, side view left.

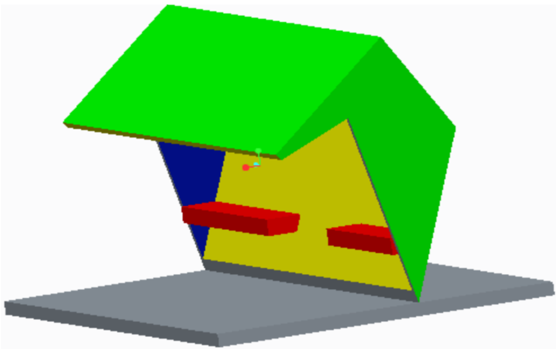


Figure: 15b Model of first design, side view right.

5.2.2 New design

This design has a rectangular outlook with a gentle slope of the roof structure. It has a visible vertical beam (10 pieces) as the structural support as the column structure. The railway shelter has a dimension of 8m x 1.9m x 2.5m with a large inner space for user's comfort.

There are seats as part of the inner fixture for those who would like to rest while waiting for the next train. Also consideration is given to those with disability for their easy entry and exit.

Crested on the front panel is the name IITTALA which is the name of the indigenous place where the shelter will be installed.

The unique dusty brown colour which is the main material colour. The material to be used is CORTEN steel (S355) a weathering steel material which has exceptional weathering corrosion resistance, excellent properties and can be used without painting. This will be used as beam, truss, roof and cover panel material.

Quality, reliability, durability, strength and long term use are the focus for this new design.

Figure: 16a The new design (2017, Arkkitehtitoimisto Planko)

Figure: 16b The new design (2017, Arkkitehtitoimisto Planko)

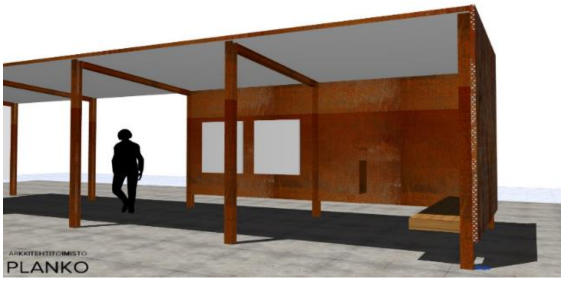


Figure: 16c The new design (2017, Arkkitehtitoimisto Planko)

5.3 Structural calculation and analysis

5.3.1 Roof beam structure

Figure: 17 Shelter view showing modular beam structures (2017, Arkkitehtitoimisto Planko)

The analysis and calculations was focused on the modular structure beams with length 2m for the modular trusses design to resist applied lateral loads. One important phase in this thesis is selecting a beam profile and material. A cantilever beam structural steel (S355 and HSS) with densities of $8000kNm^{-3}$ and $8138kNm^{-3}$ have been selected according standards. Structural steel 355WH, 355J2H and 355J2H an SSAB product is a choice steel with rectangular hollow section which have anti-corrosive properties, which minimize the need for maintenance and corrosion-prevention treatment. This steel meets the standard requirements of EN 10219.

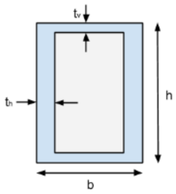


Figure 17: Beam sectional Definition

Shape	Material	E (MPa)	v	ρ (kg/m^3)
Hollow Rectangular	Structural Steel	193000	0.27	7850

Figure: 18 Beam property (Eva M.H, Martin K, Jörg S, Susanne W, 2015)

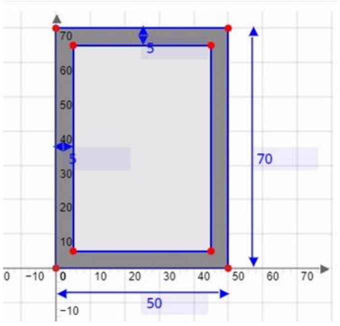


Figure: 19 Beam Section

b=0.05m

h=0.07m

d=0.005m

Mass=8.13kg/m (source: SSAB catalogue)

Length= 8m

5.3.2 Centroid

Area of beam, $A_A = A_1 - A_2 = (0.07 \times 0.05) - (0.06 \times 0.04) = 0.0011m^2$

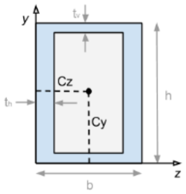


Figure: 20 Centroid definition

Centroid about Y-axis = 0.07 / 2= 0.035m

Centroid about Z-axis = 0.05/2 = 0.025m

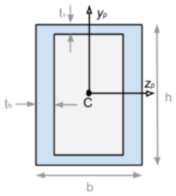


Figure: 21 Moment of Inertia definition

Area moment of inertia about Y-axis (I_y) = $(bh^3 - (b\text{-}2d)(h\text{-}2d)^3) / 12$

$= (0.05 \times 0.07^3) - (0.04 \times 0.06^3) / 12 = 7.0917 \times 10^{-7} m^4$

Area moment of inertia about Z-axis (I_Z) = (b^3h–$(b\text{-}2d)^3$ (h-2d)) / 12

= (0.05^3 x 0.07) – (0.04^3 x 0.06)/ 12 = 4.0917 x 10^{-7} m^4

Sectional modulus, Z = I_y /y = 7.0917 x 10^{-7} / 0.035 = 2.0262 x 10^{-5} m^3

Radius of gyration, R = $(Iy/A_A)^{1/2}$

= $(7.0917 \times 10^{-7} / 0.0011)^{1/2}$

= 2.5391 x10^{-2}m

5.4 Load calculation

According to EN1991-1-3 on snow loads, railway shelter belongs to Category C for snow loads calculation.

For 1m^2 area of snow with 0.3m deed for this category weighs 96kg.

Roof dimension is 8m x 1.9m.

Each section of the shelter is 2m x 1.9. These will be used as a base for this calculation.

Roof area = 2x 1.9 = 3.8m^2

If 1m^2= 96kg then, 3.8m^2= 3.8 x 96 = 364.8kg snow mass.

Pressure load (kN/m^2) = (364.8 x 9.81) /3.8 = 940.73Nm^{-2}

5.5 Load calculation for a beam 2m in length

Line load

Pressure load (kN/m^2) $*$ length (m) = Line load (kN/m) (4)

940.73Nm^{-2}x 2m = 1881.46Nm^{-1}

Point load

Point load = line load x (length / 2) = 1881.46N

Weight of beam = 8.13 x 9.81 = 79.7553N

Total load = 1881.46 + 79.7553 = 1961.21N

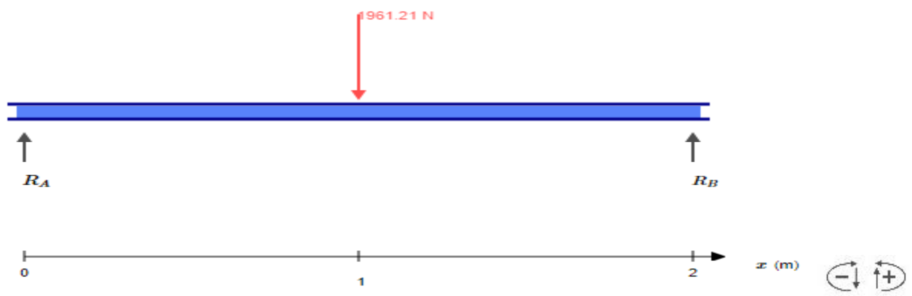


Figure: 22 Beam with loads

Distributed load with magnitude equal to its area acting through the area's centroid.

Equivalent load of DL x =0 to x =2:

Let the left support have a vertical reaction R_A and the right have a vertical reaction R_B.

Sum of forces acting along *y-axis* equal zero for static equilibrium:

$+\uparrow \Sigma f(y) = 0$

$R_A + R_B - 1961.21 = 0$

$R_A + R_B = 1916.21N$ (1)

Sum of moment about the left support equals zero for static equilibrium:

$\Sigma M = 0$

$R_B (2-0) + (-1961.21)(1) = 0$

$R_B = +980.605N$ (2)

From (1) $R_A + R_B = 1916.21N$

$R_A = 1916.21 - R_B$

$A_y = 1916.21 - 980.605 = 980.605N$

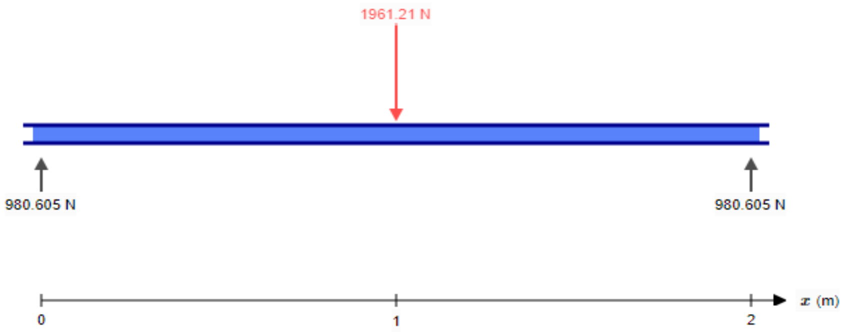


Figure: 23 Beam with loaded forces and reactions

5.6 Bending moment and shear force

5.6.1 Bending moment

Finding moment due to the DL for x = 0 to x = 2:

The rectangular DL acts at distance x/2 from the cut.

Taking a cut for $0 \le x \le 1$:

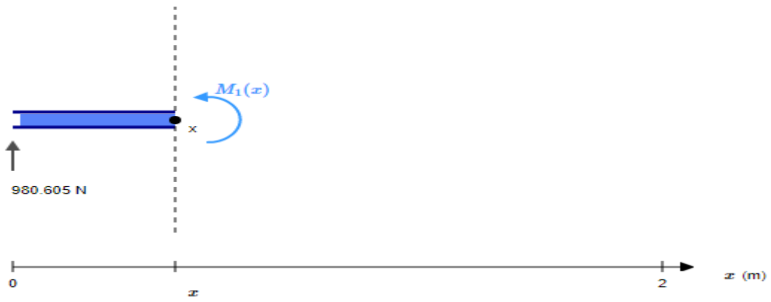


Figure: 24a Cut section of beam

$\Sigma M_x = 0$

$+908.605(x\text{-}0) - M_1(x) = 0$

$M_1(x) = +908.605x$ equation for $0 \leq x \leq 1$

Taking a cut for $01 \leq x \leq 2$:

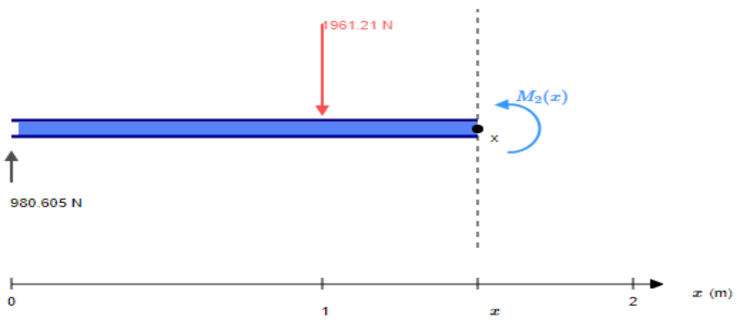


Figure: 24b Cut section of beam

Finding moment due to the DL for $x = 0$ to $x = 2$:

$\Sigma M_x = 0$

$+908.605(x\text{-}0) + (-1961.21)\ (x\text{-}1) - M_2(x) = 0$

$M_2(x) = +1962.21\text{-}908.605x$ equation for $1 \leq x \leq 2$

5.6.2 Maximum bending moment

The bending moment is maximum at the middle of the beam where $x = 1$.

Using the generated equation for the beam; $M_{max}(x) = +1962.21\text{-}908.605x$

Therefore, $M_{max}(1) = +1962.21\text{-}908.605(1) = 908.605\text{KNm}$

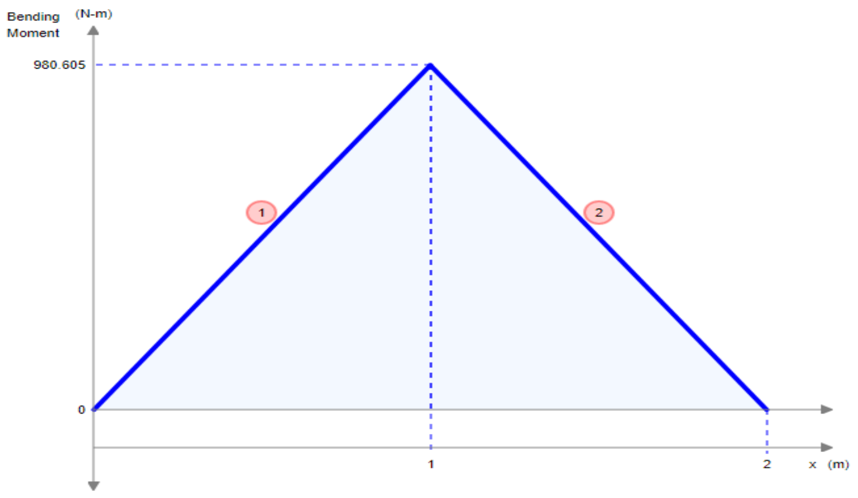


Figure: 25 Bending moment diagram for 2m beam

5.6.3 Beam deflection

The maximum deflection of the beam occurs at $x = 1$

Maximum deflection $\delta_C = \frac{FL^3}{48EI}$

F = Force acting at the centre of the beam

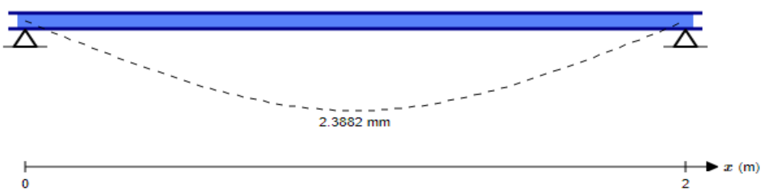
L = Length of the beam between the supports

E = Modulus of elasticity

I = Area moment of inertia of cross section

Therefore,

δ_C = (1961.21x 2^3) / (48 x 193000 x 7.0917 x 10^{-7}) = 2.3882 x 10^{-3}m



Deflection Value (mm)	Locations along Beam (m)
-2.3882	1
0	0, 2

Figure: 26 Deflection of beam

Maximum allowable deflection = L/240 for this structure from Eurocode 3 standard.

Therefore MD = (2 x 1000) /240 = 8.333.

This implies that the material deflection is good.

5.6.4 Bending stress

The bending stress along the length of a beam is calculated using

$\sigma b = (-MZ)/ I c$

M= bending moment

Z= distance from neutral axis

$I c$ = moment of inertia

σ_b= (908.605 x 2.0262 x 10^{-5}) / 7.0917 x 10^{-7} = 25.64MPa (Maximum bending stress)

5.6.5 Shear force

Finding force due to the DL for $x = 0$ to $x = 2$:

The rectangular DL acts at distance $x/2$ from the cut.

Taking a cut for $0 \leq x \leq 1$

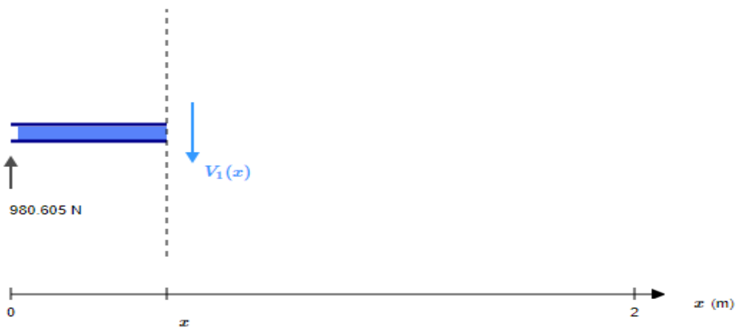


Figure: 27 Cut section of beam

$+\uparrow \Sigma f(y) = 0$

$+980.605 - V_1x = 0$

$V_1x = +908.605$ equation for $0 \leq x \leq 41$

Taking a cut for $1 \leq x \leq 2$

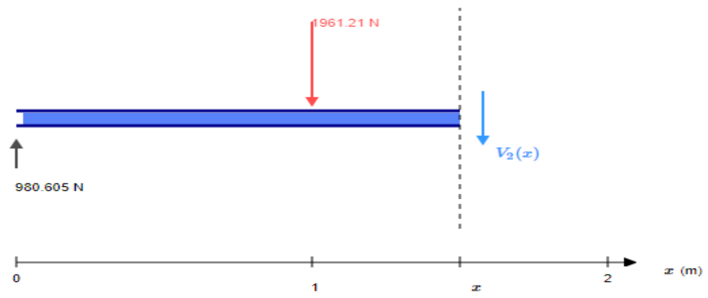


Figure: 28 Cut section of beam

Finding force due to the DL for $x = 0$ to $x = 2$:

$+\uparrow \Sigma f(y) = 0$

$+908.605 - 1961.21 - V_2x = 0$

$V_2x = -908.605$ equation for $1 \leq x \leq 2$

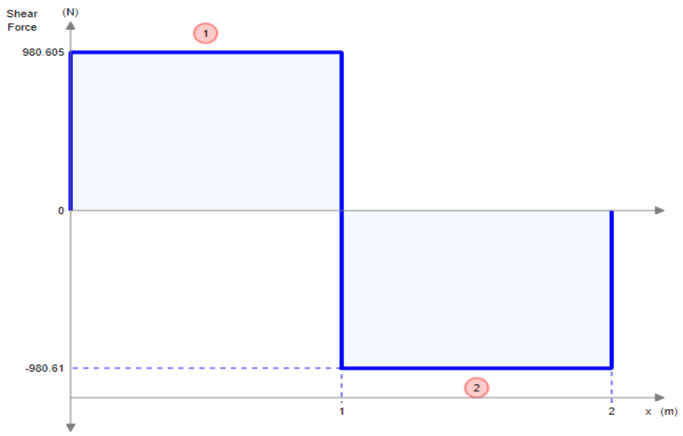


Figure: 29 Shear force diagram for 2m beam

5.6.6 Maximum shear force

Maximum shear force $\sigma_{max} = (y_{max}\,FL)/4I$

Where σ_{max}= Maximum shear force

F = Total load

L = Beam length

I = Moment of inertia

y_{max} = Maximum distance from centroid

$\sigma_{max} = (0.0035 \times 1961.21 \times 2) / (4 \times 7.0917 \times 10^{-7}) = 4839625.901 Nm^{-2}$

Therefore σ_{max} = 4.8396MPa

Since the Yield strength of S355 is 355MPa, the shear force (4.8396MPa) is small compared to the material yield strength. The material is good for the structure without any unexpected failure

5.7 Buckling

Figure: 17 Shelter view showing modular column structures (2017, Arkkitehtitoimisto Planko)

This section of calculation is focused on modular column structures to transmit loads from the the roof slab, beams and ist weigth to the foudation.

Buckling is a failure due to compressive loading of a structural column. Column in a structure is a vertical member supporting the load of the structure which in general terms the effective length that exceeds twelve times the least radius of gyration. For rectangular column, the effective length exceeds three times the least lateral dimension. The longer and more slender the column is, the lower the compressive stress it can stand.

5.7.1 Long column

A long column has a ratio of effective length to its radius of gyration greater than 50. For rectangular sectional column, the ratio of effective length to its lateral dimension is greater than 15.

5.7.2 Short column

A short column has a ratio of effective length to its radius of gyration less than 50. For rectangular sectional column, the ratio of effective length to its lateral dimension is less than 15.

For this thesis, the column used is a hollow rectangular sectional column with a length of 2.5m.

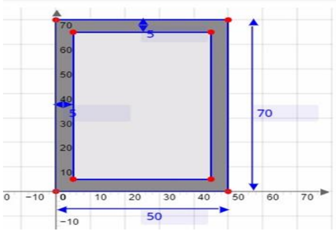


Figure: 30 Column section

The lateral section of this column is 50mm.

Ratio = 2.5/0.05 = 50 > 15. Therefore this column is a long column.

Since this column is long, Euler's Formula is applicable for buckling calculation.

Euler's Formula for Critical force $P_{cr} = \pi^2 EI / L_e^2$

P_{cr} = Critical load

E = Modulus of elasticity of the material

I = Moment of inertia of the material

L_e= Effective length of the column

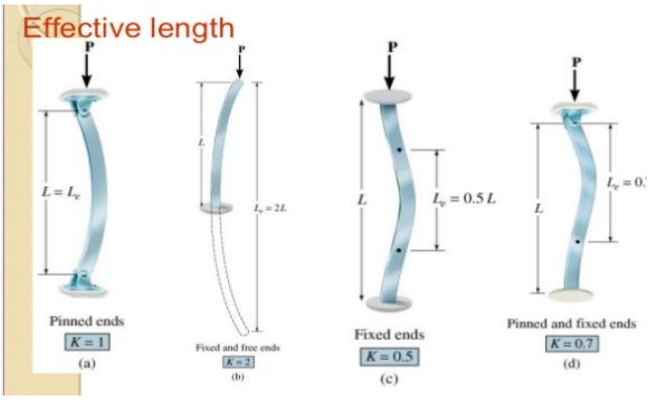


Figure: 31 Effective length of Column support (2014, Column-truss-Euler-theory)

Table: 5 Constant of column joints

End Fixing	Practical K Value
Pinned Frictionless End	K = 1
Fixed Ends	K = 0.65
Fixed-pinned and guided	K = 0.8
Fixed-free	K = 2.1

The column support for this thesis is pinned ends which indicates that the constant K = 1.

Therefore, the effective length L_e= L x K = 2.5 x 1 = 2.5m

Buckling of beam will occur about the axis with least moment of inertia.

To calculate this, calculated moment of inertia are;

Area moment of inertia about Y-axis (I_y) = 7.0917 x 10^{-7} m^4

Area moment of inertia about Z-axis (I_Z) = 4.0917 x 10^{-7} m^4

So, buckling will occur about the Z- axis.

Radius of gyration about the Z-axis, R = $(I_Z/A_A)^{1/2}$

= $(4.0917 \times 10^{-7} / 0.0011)^{1/2}$

= 1.9287 x10^{-2}m

Slenderness ratio (S) = L_e / R

Therefore, S = L_e / R = 2.5 / 1.9287 x10^{-2} = 129.6237

5.7.3 Critical force

Critical force $P_{cr} = \pi^2 EI / L_e^2$

For column 2.5m, P_{cr}= (π^2 x 193000x 4.0917 x 10^{-7}x 10^{12}) / 2.5^2

= 124704.1255N = 125KN (Buckling force for 2.5m column)

5.7.4 Critical stress

Critical Stress ($\sigma_{critical}$) = $\pi^2 E / (L_e/ R)^2$

$\sigma_{critical} = \pi^2$ x 193000/ (2.5 / 1.9287 x10^{-2})^2= 113.3722MPa

Result show that the critical stress is less than the material yield stress.

5.7.5 Yield force

Yield Stress σ_{yield} = Yield force (P_{yield}) / Area (A)

$P_{yield} = \sigma_{yield}$ x A. The yield stress for S355 is 355MPa

P_{yield} = 355 x 0.0011 x 10^6 = 390500N = 391KN (355 yield force)

Since the material yield force (391KN) is greater than the buckling force (125KN), the material is good for this railway shelter structure.

5.8 Material properties

Properties	Value (units)
Mass (m)	8.13 kg/m
Young's Modulus (E)	193 GPa
Length (L)	8m and 1.9m
Second Moment of Area (I)	7.0917×10^{-7} m^4
Area (A)	$0.0011m^2$
Max Bending Moment (Mmax)	908.605KNm
Distance from centroidal axis (y)	0.035m
Yield Force	391KN
Critical Force (Buckling Force)	125KN
Yield Stress	355MPa
Critical Stress	113.3722MPa
Bending stress	25.64MPa

Table: 6 Properties of 355WH beam.

5.9 FEM analysis

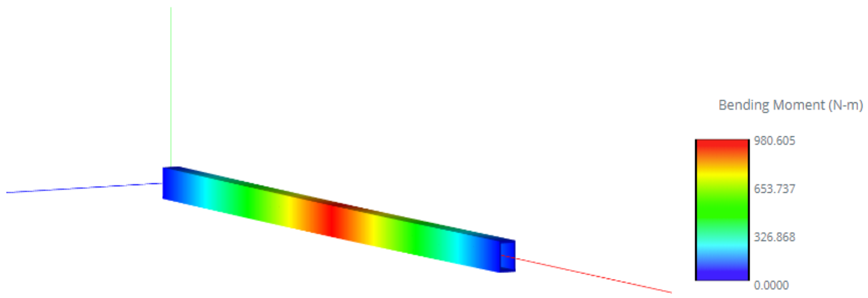


Figure: 32 FEM result for bending moment.

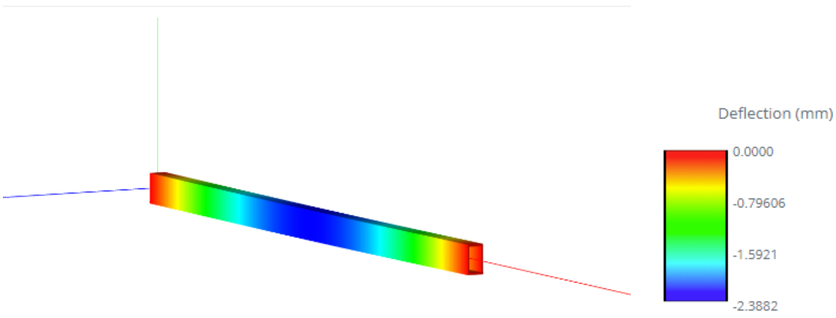


Figure: 33 FEM result for deflection.

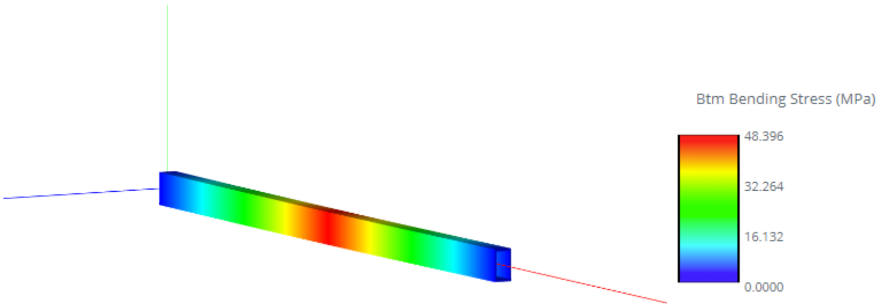


Figure: 34 FEM result for shear stress

6 CONCLUSION AND RECOMMENDATION

The aim project is to design and construct a railway shelter for Iittal Asema as a traditional design with a modern twist. The main users of this shelter will be daily commuters of various works of life who use public transportation to travel. The optimal aim of this shelter was the safety and comfort of the user at any time of use. These users require an environmental friendly, spacious and a reliable shelter that guarantees safety from harsh weather and a place for rest while waiting for a train. The group of users include:

1. The elderly.
2. Passengers with young children.
3. Passengers with pushchairs.
4. Passengers with traveling luggage.
5. Passengers with shopping baggage.

This design is incorporated with solar panels for electrical power supply to power an LCD screen, lightings and other electrical appliances.
The method of design, the calculations and analysis were carefully conducted for optimal customer satisfaction, sustainability, reliability and a good life span at the end of the construction.

The shelter was structurally analysed and proved reliable. During the design process various changes were made as required and corrective measures were taken during the application of the made changes. These changes were made and applied with consideration to the forces generated by the loads created, strength of the materials, mechanics of design knowledge and calculative analysis results. The new changes improved the strength of the shelter and further support the design.

Development ideas
There is room for design improvement for this shelter however. For instance, the effect of temperature changes on the structure and the

materials used can be analysed and the mechanics of the dynamics of the structure can also be calculated and analysed.

This can be used for future design with confidence and can be presented to interested parties.

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Appendix 1

MATERIAL SELECTION TABLE

Table: 7 Material selection table (SSAB material data sheet, 2017)

Height x Width	2.0mm (kg/m)	2.5mm (kg/m)	3.0mm (kg/m)	4.0mm (kg/m)	5.0mm (kg/m)	6.0mm (kg/m)	7.1mm (kg/m)	8.0mm (kg/m)	8.8mm (kg/m)	10.0mm (kg/m)	12.5mm (kg/m)
40 x 20 mm	1.68	2.03	2.36								
40 x 30 mm	1.99	2.42	2.83								
50 x 30 mm	2.31	2.82	3.30	4.20							
60 x 40 mm	2.93	3.60	4.25	5.45	6.56						
70 x 50 mm	3.56	4.39	5.19	6.71	8.13						
80 x 40 mm	3.56	4.39	5.19	6.71	8.13						
80 x 60 mm		5.17	6.13	7.97	9.70						
90 x 50 mm		5.17	6.13	7.97	9.70						
100 x 40 mm		5.17	6.13	7.97	9.70						
100 x 50 mm		5.6	6.60	8.59	10.5	12.3					
100 x 60 mm		5.95	7.07	9.22	11.3	13.2					
100 x 80 mm		6.74	8.01	10.5	12.8	15.1					
120 x 40 mm		5.96	7.07	9.22	11.3	13.2					
120 x 50 mm		6.35	7.54	9.85	12.1	14.2					
120 x 60 mm		6.74	8.01	10.5	12.8	15.1					
120 x 80 mm		7.53	8.96	11.7	14.4	17.0	19.4	21.4	23.1	25.6	
120 x 100 mm		8.31	9.90	13.0	16.0	18.9					
140 x 60 mm			8.96	11.7	14.4	17.0					
140 x 70 mm		7.92	9.43	12.4	15.2	17.9					
140 x 80 mm			9.90	13.0	16.0	18.9					
150 x 50 mm		7.53	8.96	11.7	14.4	17.0					
150 x 100 mm			11.3	14.9	18.3	21.7	24.9	27.7	30.0	33.4	
160 x 70 mm				13.6	16.8	19.8		25.2			
160 x 80 mm			10.8	14.3	17.6	20.8	23.8	26.4	28.6	31.8	
160 x 90 mm			11.3	14.9	18.3	21.7	24.9	27.7	30.0		
180 x 100 mm				16.8	20.7	24.5	28.3	31.4	34.2	38.1	
180 x 120 mm				18.0	22.3	26.4	30.5	34.0	36.9	41.3	48.7

Chemical Composition

C (max %)	Si (max %)	Mn (%)	P (max %)	S (max %)	Al_{tot} (min %)	Cr (%)	Cu (%)
0.12	0.50	0.50- 1.50	**0.020**	**0.010**	0.020	0.40- 0.80	0.25- 0.55

Appendix 2

TECHNICAL DRAWING OF ASSEMBLY

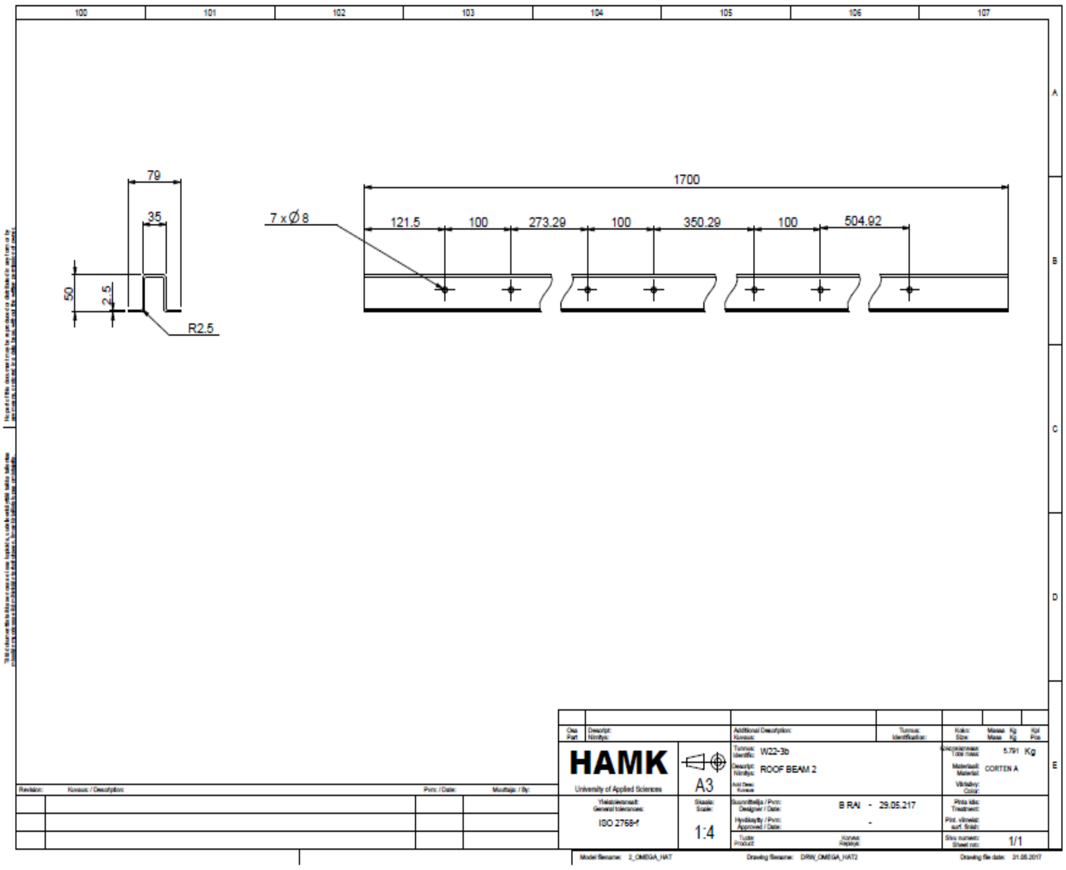

Figure: 35 Truss 1

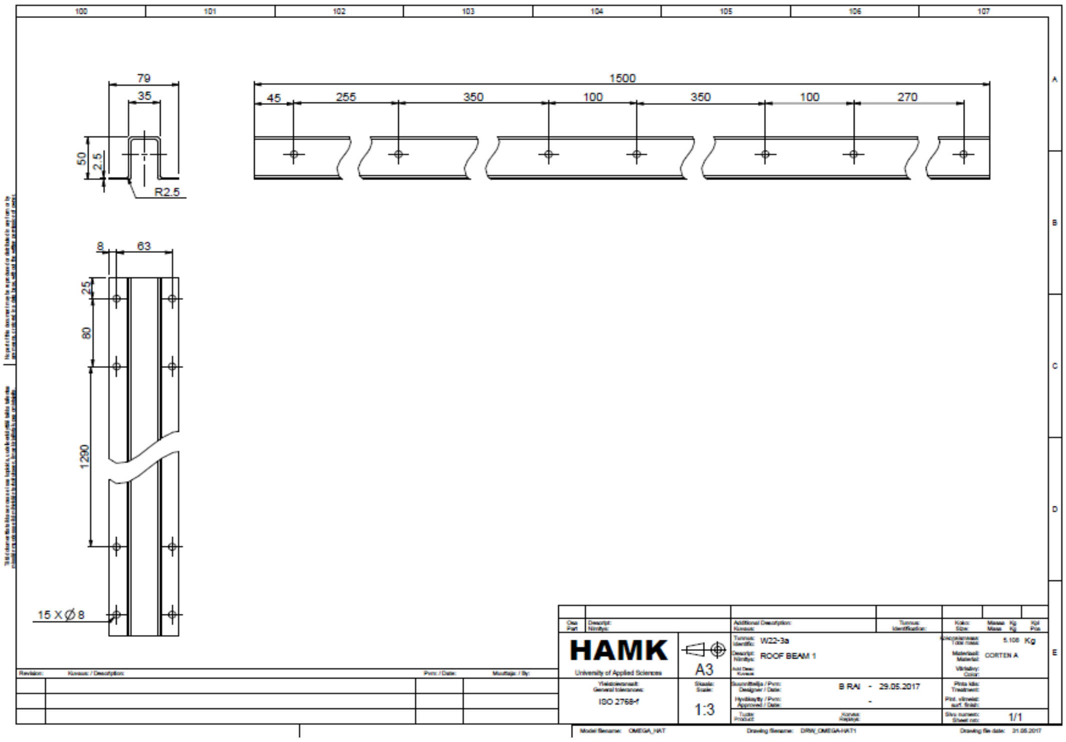

Figure: 36 Truss 2

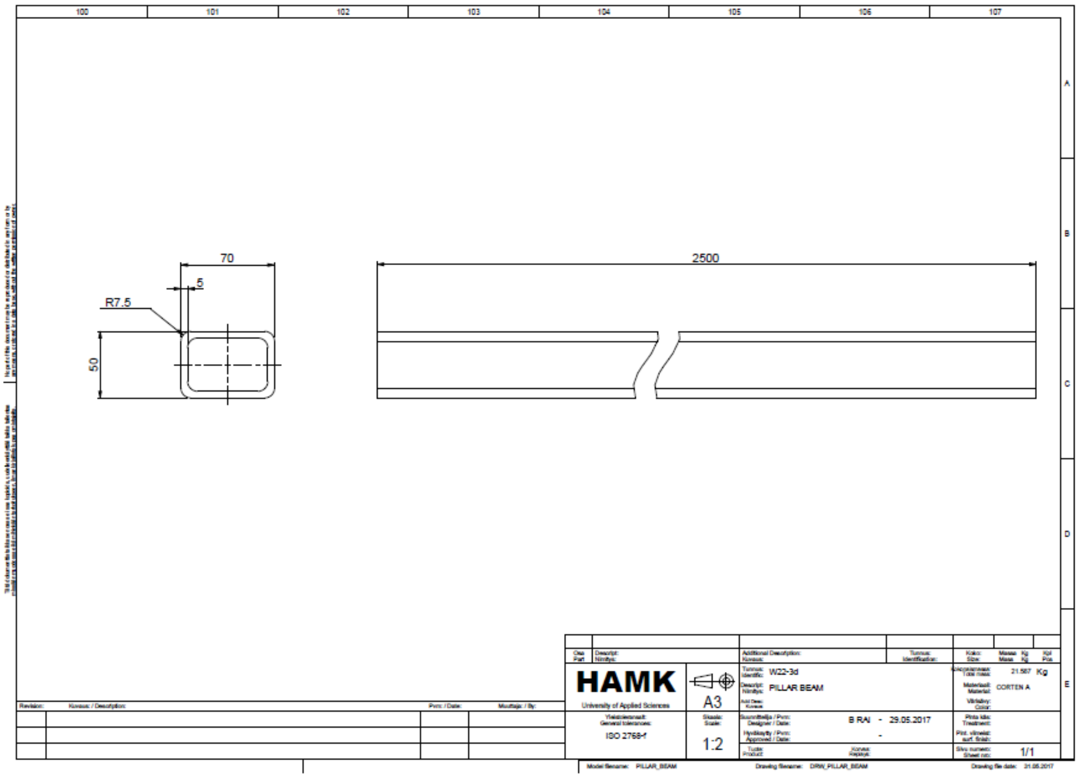

Figure: 37 Pillar beam

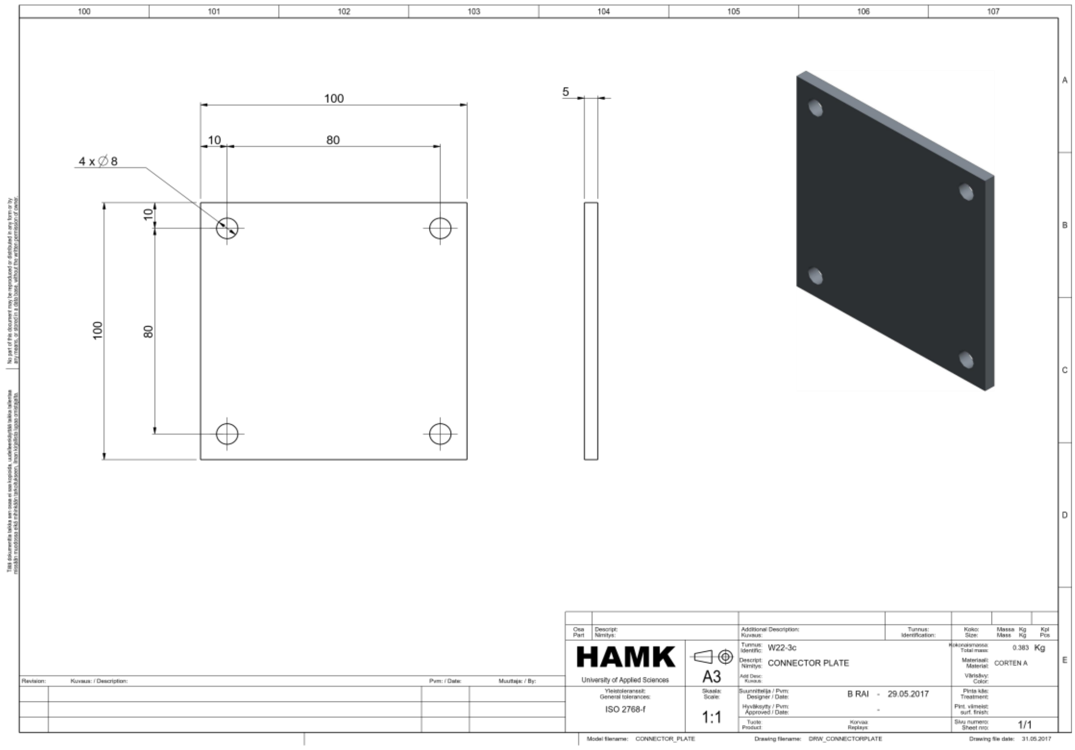

Figure: 38 Connector plate

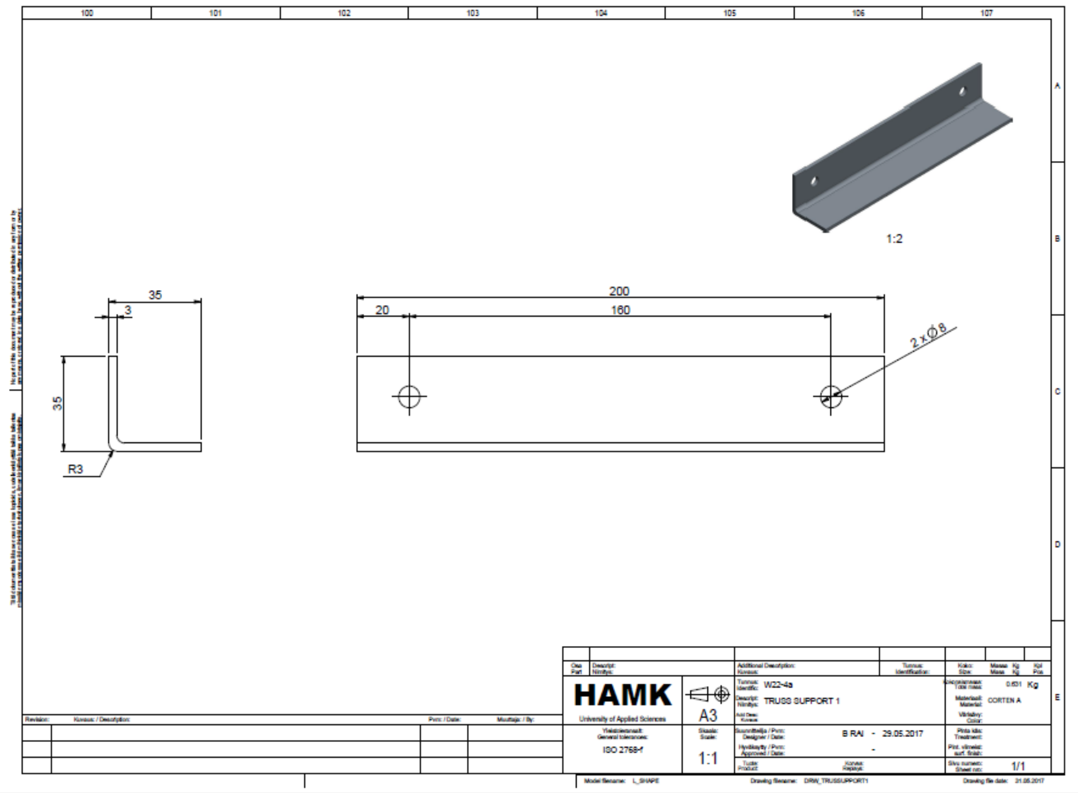

Figure: 39 Truss support 1

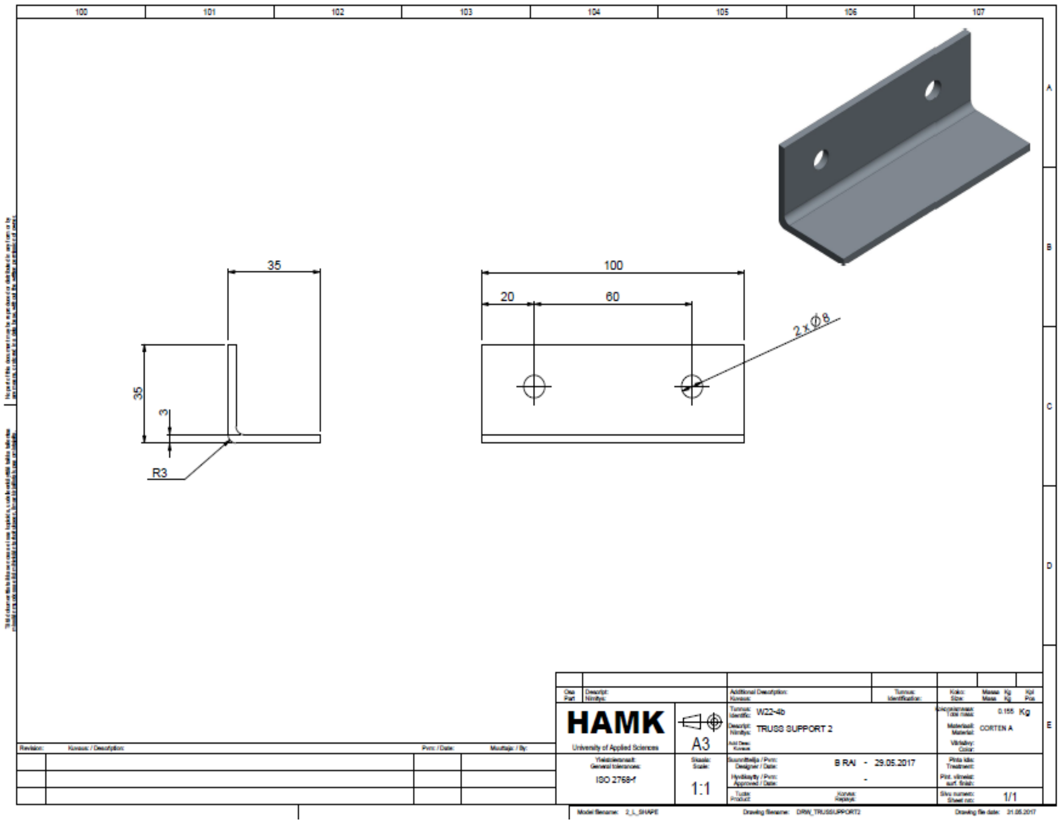

Figure: 40 Truss support 2

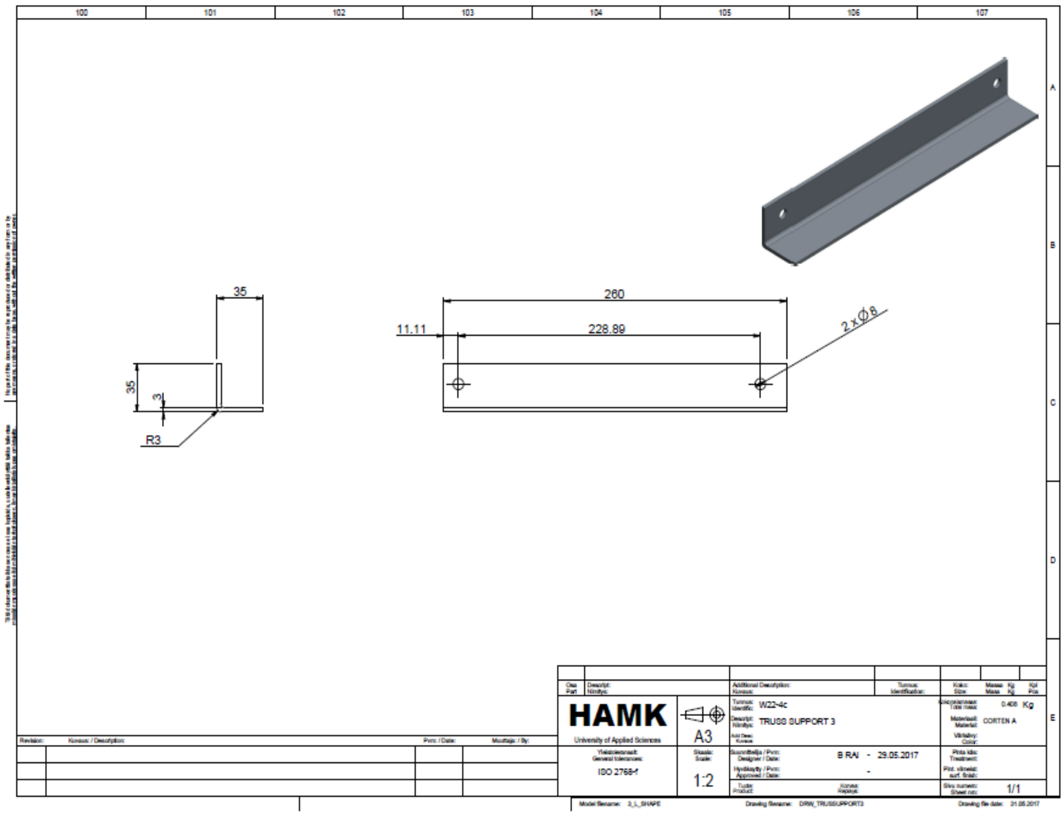

Figure: 41 Truss support 3

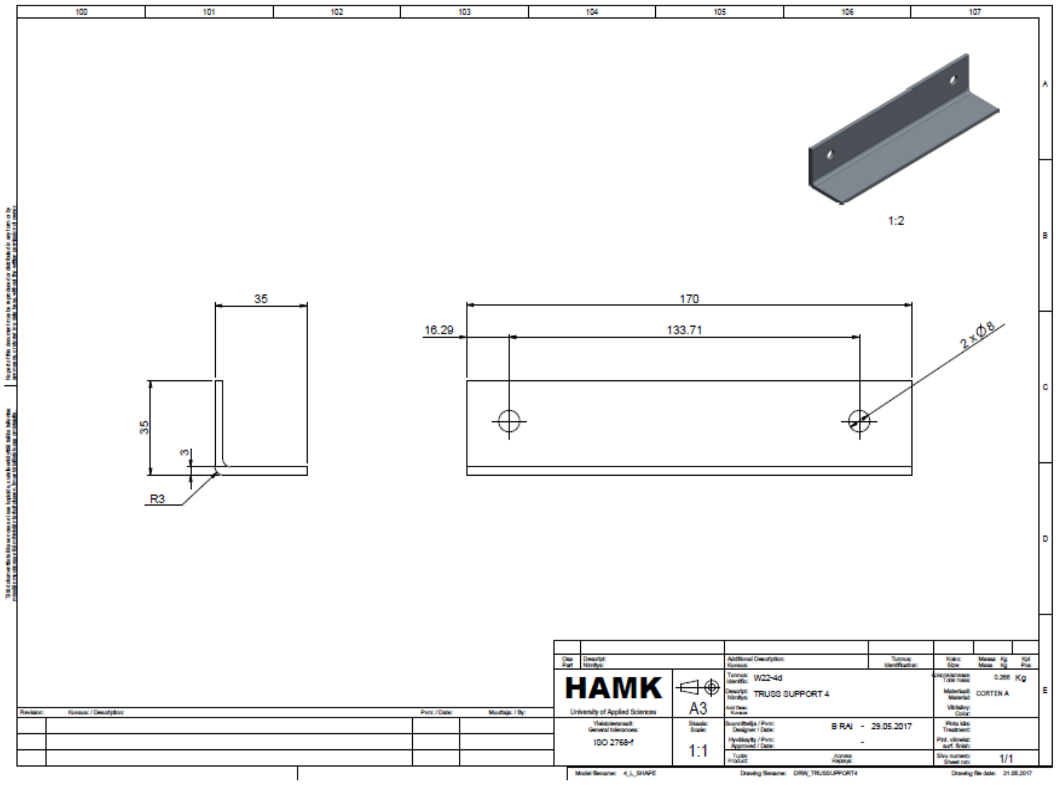

Figure: 42 Truss support 4

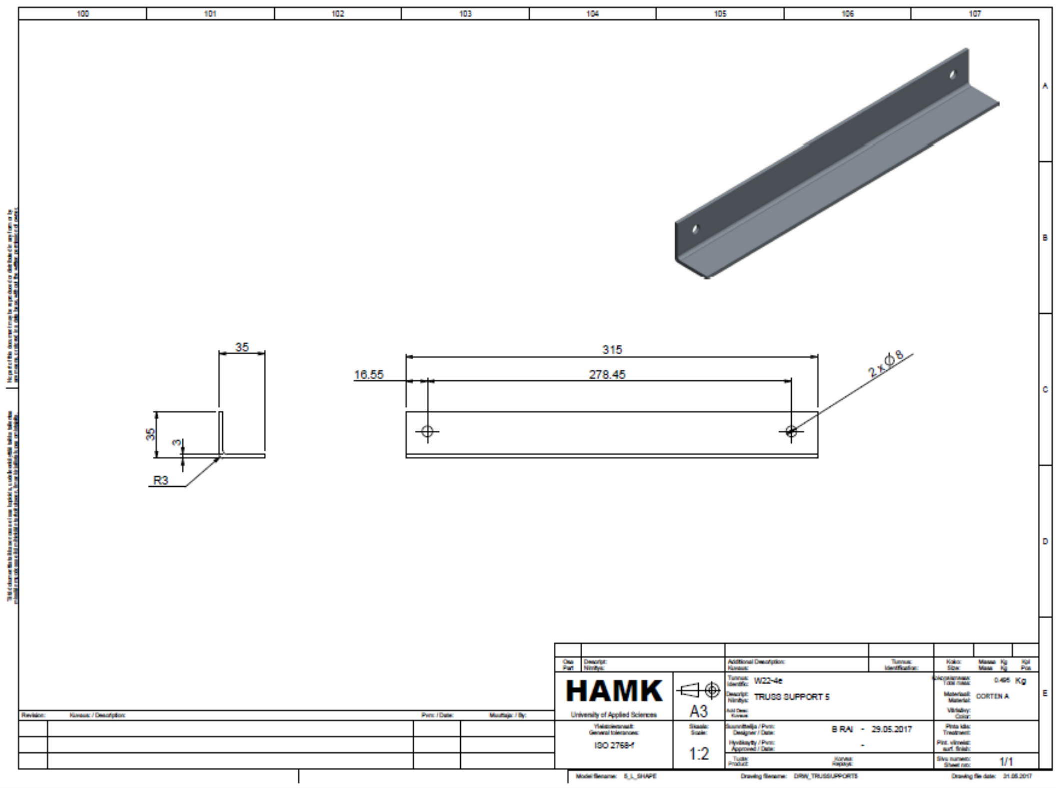

Figure: 43 Truss support 5

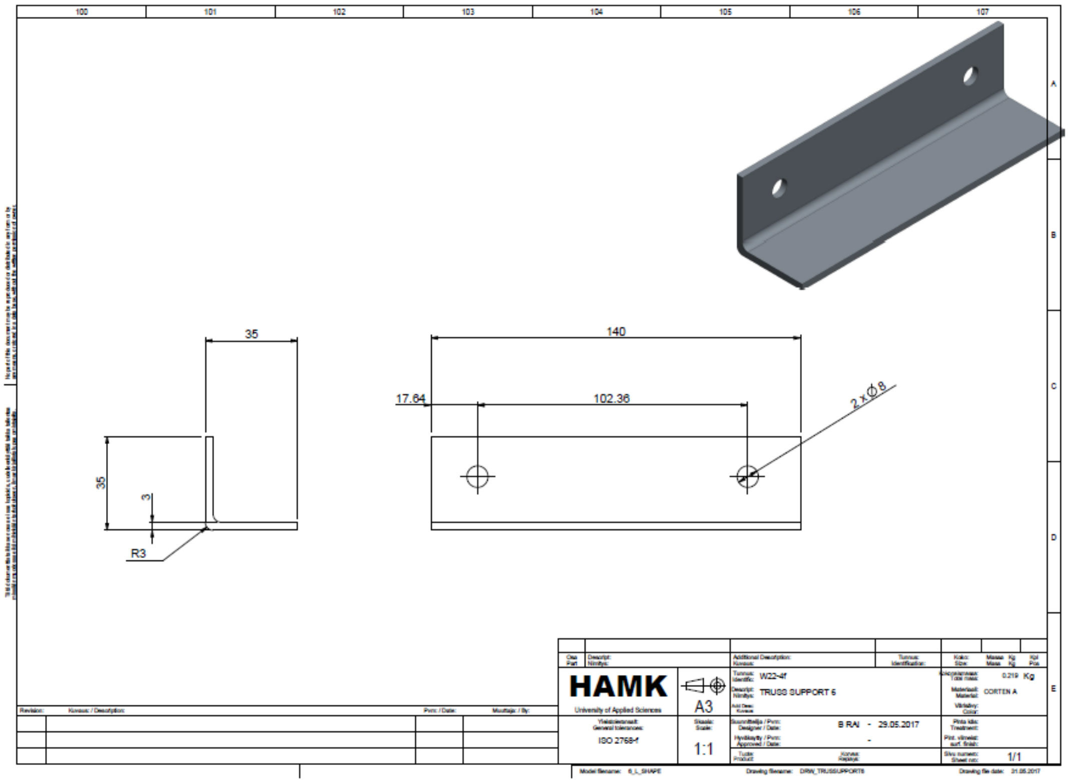

Figure: 44 Truss support 6

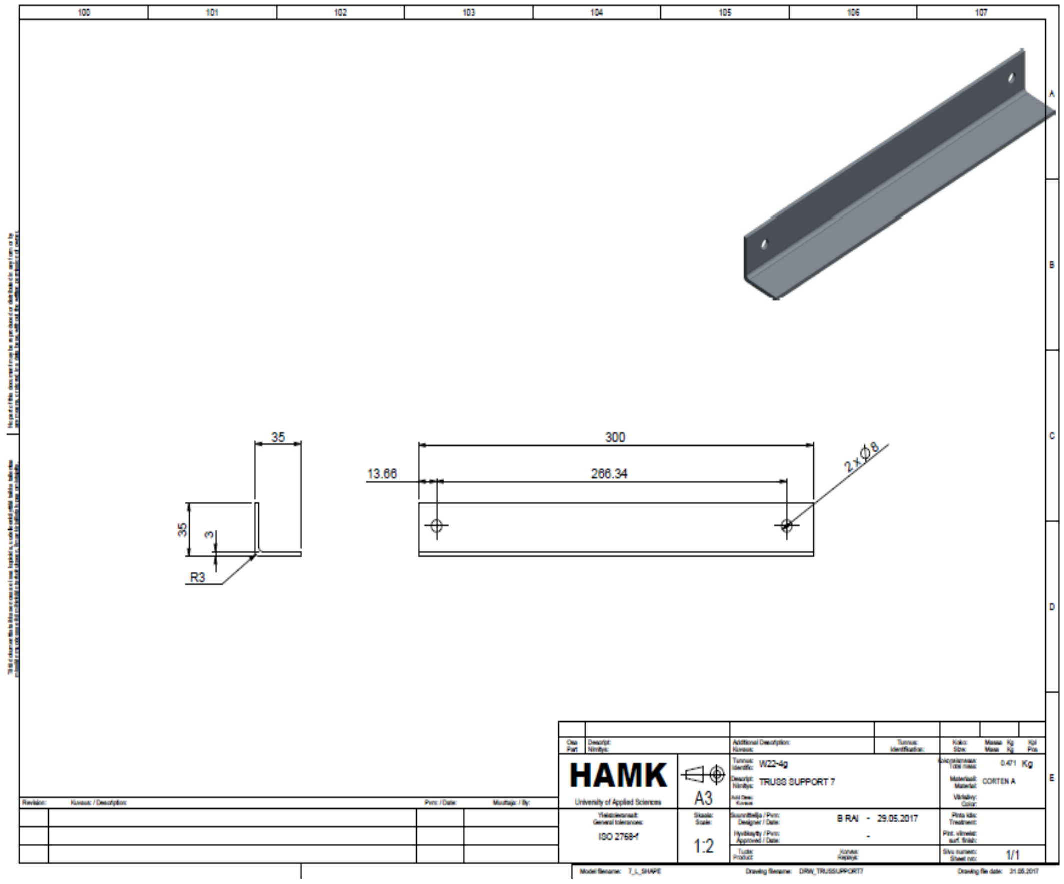

Figure: 45 Truss support 7

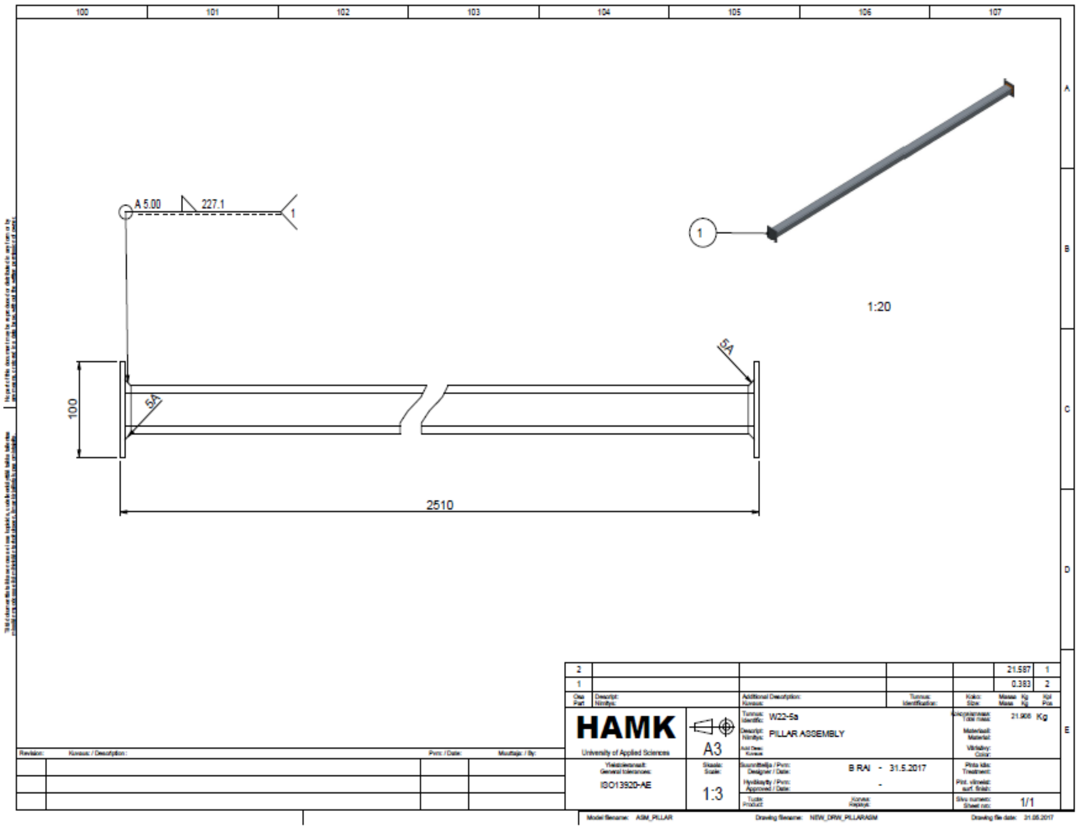

Figure: 46 Pillar beam with fittings

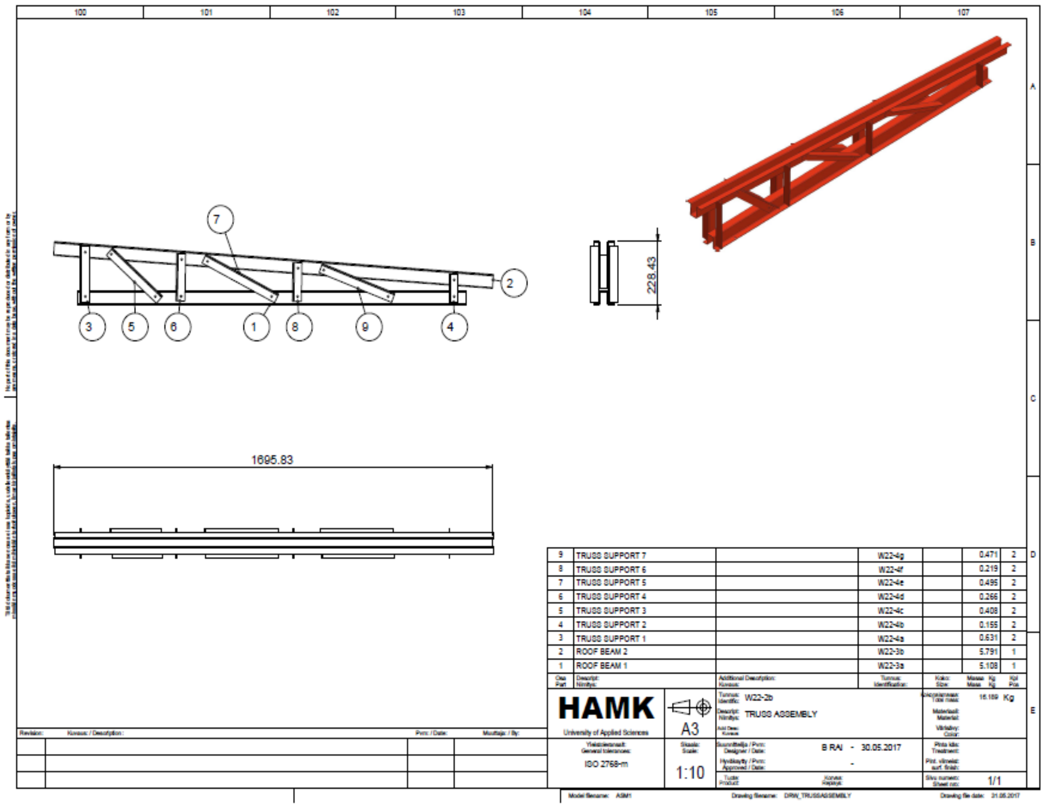

Figure: 47 Truss assembly

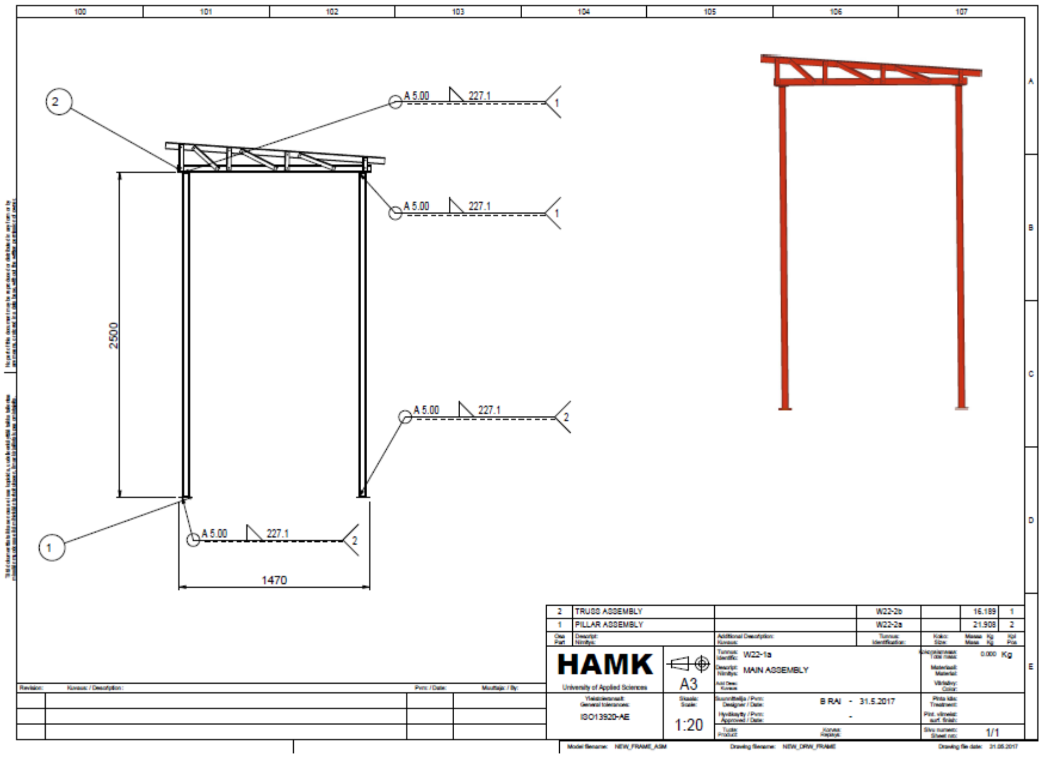

Figure: 48 Frame

Appendix 3

PHOTOS OF BUILDING WORKS

Figure: 49 Frost/Cold protection (2017, Legalett)

Figure: 50 Installed anchur bolt (2017, FK Bud llc)

Figure: 51 Grounded beam. (2014, Felix group)