Light Weight Prefabricated Roof Element For Long Spans

HAMK
UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Construction Engineering

Sheet Metal Centre, March,2013

Yu Xinyao

BACHELOR'S THESIS

HAMK
UNIVERSITY OF APPLIED SCIENCES

Degree programme
Location Hämeenlinna, Finland

Title Light Weight Prefabricated Roof Element For Long Span

Author Yu Xinyao

Supervised by Lassi Martikainen

Approved on _____._____________.20______

Approved by

ABSTRACT

HAMK
UNIVERSITY OF APPLIED SCIENCES

VISAMAKI
Degree Programme in Construction Engineering

Author Yu Xinyao **Year** 2013

Subject of Bachelor's thesis Light Weight Prefabricated Roof Element for Long Spans

ABSTRACT

The goal of this thesis was to study the properties of a new type of roof element for long span building such as a factory and warehouse. Longer beams provide a larger space for the building. The main objective was to study the feasibility of a new type of load-bearing element. Main issues were to design a beam that is strong enough to carry the load over such long span and to resist the bending moment due to the length of the span. Furthermore, the structure had to be strong enough to resist failure at support and deflections. In addition, the whole structure has to be economical, light and able to be made with the existing work process.

The thesis consists of the theoretical part and practical part. The practical activities took place in the Sheet Metal Centre(SMC), and all material and equipment for the manufacture and test were provided by SMC. Firstly, surveying and studying of existing roof elements was done. Then, several possible solutions were designed according to the surveying. The loading bearing capacity of the specimens was calculated by checking its deflection, shear resistance and bending resistance. Then, small-scaled specimens had to be made to demonstrate the behavior of the beams. Specimens were completed by using a combination of various of equipment. The whole manufacturing process contains cutting, bending and fixing. Great attention was paid during the process preventing a negative effect on the final result as much as possible. Then the specimens were taken to the test. Many trials were done before the final goal was reached. Test whole test results clearly indicate the behavior of beams under the load and the effect of beams and insulations.

Keywords Lightweight, Long span, Small-scale. Comparison test

Pages 42 p.

1 INTRODUCTION

This thesis report was commissioned by Sheet Metal Centre (SMC) which is a research and development center examining various steel structures and other productions. It was established in 1998 and it holds a business and educational relationship with HAMK University of Applied Sciences. It employs graduating students from HAMK every year and students may participate in different practical structural tests.

The research program carried out in Sheet Metal Centre (SMC) aims to design a roof beam that goes from the main girder to the main girder, which will be needed in buildings with a large open area such as stadiums, warehouses and factories.

The main objective is to design, manufacture and test a new type of load-bearing element. The beams have to be designed strong enough to carry the load over such a long span and to resist the bending moment and support reaction due to the length of the span. In addition, the whole structure has to be light-weighted and possible to be made with existing work process.

Because the whole process was completed by one person, and many trials and modification had to be done before the final decision, the beams were designed, manufactured and tested on a small scale. The tests mainly focused on the effect of stiffeners and insulations, and buckling mode of the beams. The results could be used in the design of a full-scale beam.

The content and the most important aims of the thesis project are: survey of the prefabricated roof elements used in buildings, study of the structural behavior of the element and analysis of results.

In the second chapter of the thesis, some examples of similar prefabricated roof element are found and compared with each other. The features of such kind of roof elements were studied. This would help with the design.

The aim of the third chapter is to study the feasibility of box-section structures for load-bearing elements. In this chapter, the focus is the study of the structural behavior of the element. Firstly, the structural behavior is estimated by simple calculations. There are four choices of the beam cross section: only steel frame, steel sandwich panel with PU-core and steel frame partly insulated with PU (in two different cases).The one which meet the requirement best will be manufactured on a small scale and tested.

The fourth chapter is focused on the experimental research. The test arrangements and results are presented in this chapter. At the end, the result is analyzed and in the following chapter the conclusions are drawn.

2 SOLUTIONS FOR A LONG SPAN

The expression “long span” means that the distance between two intermediate supports is more than 8m. Buildings such as factories and warehouses are long span buildings.

In this chapter, some examples of similar prefabricated roof elements are found and compared with each other. Those examples are divided according to materials, which are made of steel and timber.

2.1 Steel Intensive Solutions

2.1.1 Smartruss System

The Smartruss system is an advanced framing technology for roof support system for roofs and buildings. Smartruss system builds building on the experience and product knowledge of Tata BlueScope Building Products in the steel building industry, to enhance construction practice for the building segment. Figure 1 shows the Smartruss system.

Figure1. smartruss system

Smartruss System offers a range benefits over other building materials and is made from light weight high strength steel which provides inner strength to protect and maintain the roof`s structural integrity and quality of construction. It is light weight and therefore easier to handle, store and transport. It`s durable, strong, none-combustible, thermallu resistant and offers better corrosion protection and it is maintenance-free. The truss members are made from fully-recyclable steel and are environmentally friendly. Moreover, Smartruss system is designed to support any type of roofing product and provides a sustainable base to roof aesthetics. Figure 2 shows the structural details of Smartruss system.

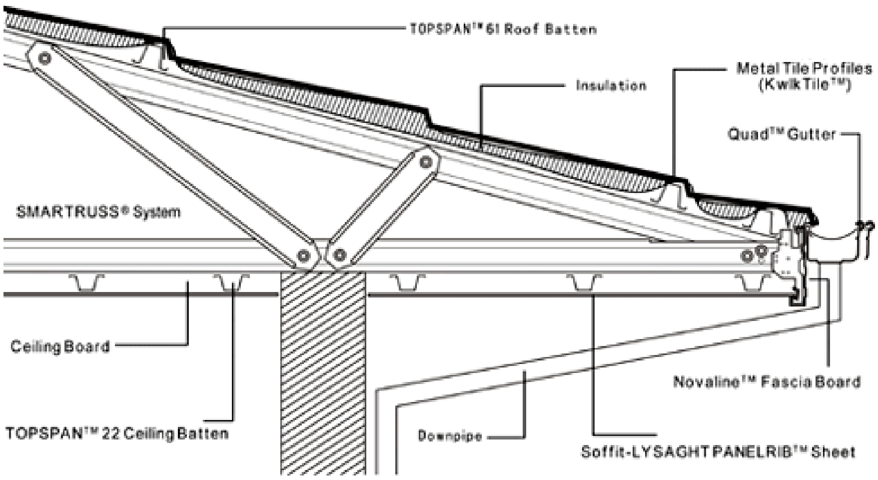


Figure2. smartruss system cross section

2.1.2 Legato Arch System

The Legato arch roof system is a self-supporting system with the maximum span of 22.5m, depending on the choice of profile, material thickness and roof structure. It corresponds statically to a two-hinge arch with fixed supports. For the calculation of the single sheet arch the system is shown as a two-dimensional rod draft of traverse with a meter of width of influence. The double-sheet arch is shown as a system of two concentric drafts of traverse, distanced by a radial rod. Figure 3 shows the Legato Arch system.

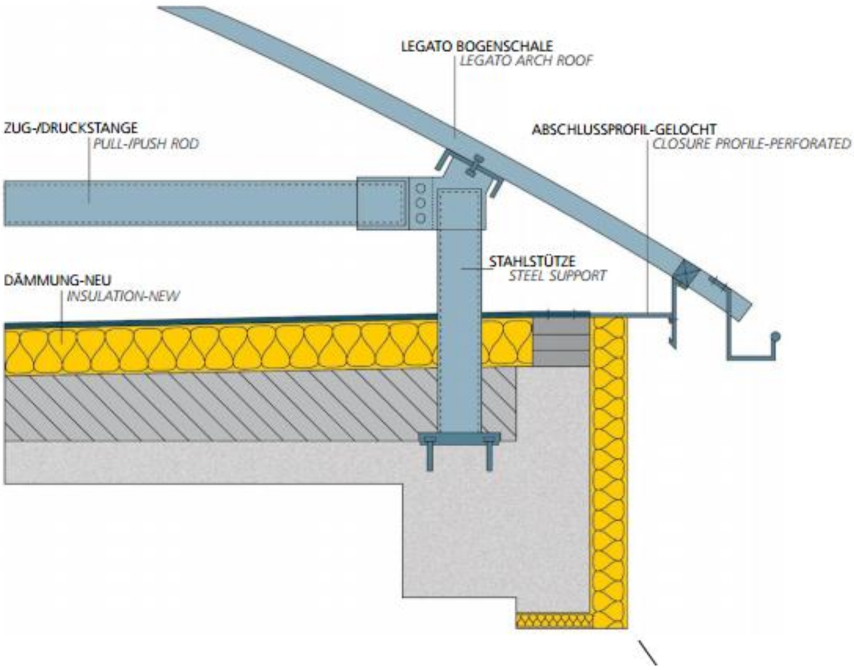


Figure 3. legato arch system

The horizontal loads from vertical loads must be taken up by tied arches. These are usually arranged in the supporting longitudinal section at a distance of 2m-3m. The curve together with the supporting longitudinal section and the tied arches form a closed system the delivers no outward horizontal force with vertical applied loads. The horizontal loads from wind force can be carried either by pressure profiles or by the substructure.

Besides, this system has a double-sheet thermal insulation which can be produced as the fire class R 90 components with structural safety up to 90 minutes. Figure 4 shows the sheet profile for Legato Arch system.

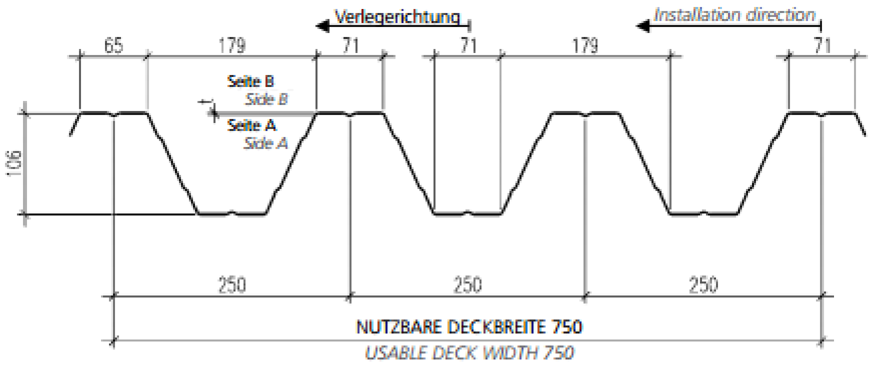


Figure 4. cross section of the roof sheet

2.1.3 Lattice Beam System

Metsec lattice roof beams or roof trusses can offer the ideal solution for supporting a wide variety of roofing systems due to their strength to weight ratio. Typically a Metsec lattice beam can weigh up to 50% less than its hot rolled steel counterpart and yet still achieve spans of up to 40 meters without intermediate supporting columns, this allows designers greater flexibility when working to optimise internal space.

The internal space can also be optimised by passing services through the web of the lattice steel beam. By doing this, there would not be a significant loss of headroom and aesthetic properties.

In addition, this system can help to reduce the environmental footprint of the project by using off-site fabrication to speed up the construction process. The lighter steel beam or steel truss sections can generally be transported and handled more efficiently on site. Figure 5 shows the Lattice Beam system.

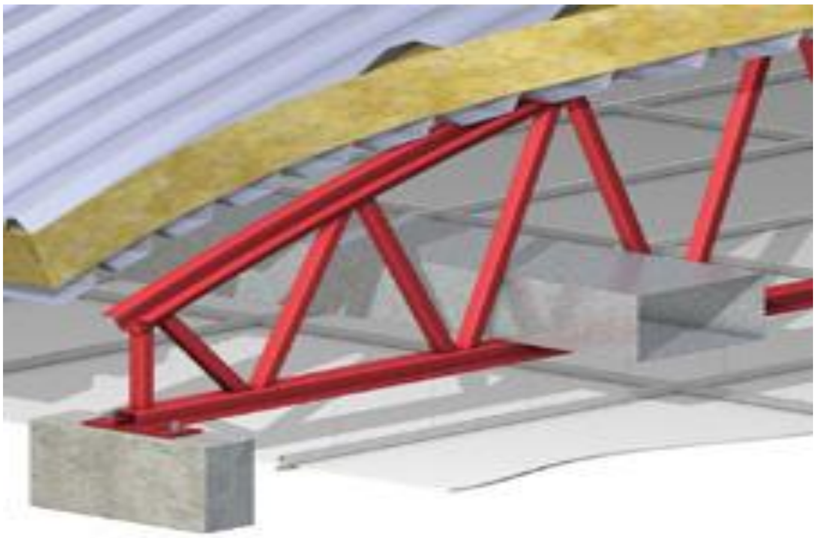


Figure 5. lattice roof beam

2.1.4 Kingspan X-DEK Longspan Roofpanel

X-dek panels are insulated membrane covered roof panels suitable for flat roofs for all building applications except where there are low temperature internal conditions. The panel secures the base for final waterproof covering of the roof installed by others. Figure 5 shows the X-dek system.

Figure 5. X-dek longspan roofpanel

X-dek panels are insulated roof panels suitable for flat roofs with a slope that is more than 1%. They are long-span composite roofing panels, which provide the necessary structural strength and stiffness and the required level of thermal insulation. They are suitable for green roof solutions and can be used as a standard panel or part of the steel structure.

A X-dek panel has the standard length of 2.5m to 13.5m. All the panels are manufactured with on-bottom trapezoidal steel. Internal skin is hot-dipped zinc coated steel S350GD+Z275, and external skin is hot-dipped zinc coated steel

S220GD+Z275. The insulation is isophenic rigid foam, known as IPN, with the nominal density of 40 kg/m^3 .Available nominal thickness of the core is from 80mm to 100mm. Figure 6 shows the cross section of X-dek roofpanel.

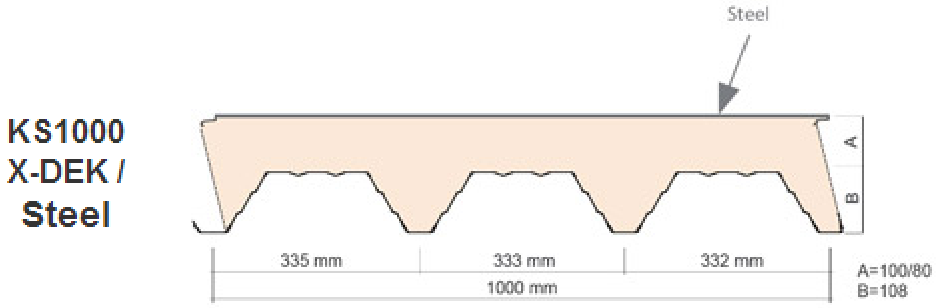


Figure 6. cross section of X-dek longspan roofpanel

2.1.5 Fixcel Metal Core Panel

Fixcel metal core panel provides a functional structure for constructions that require both horizontal and vertical rigidity. It is manufactured using triple seam rolling technology to join metal profiles together, thus forming a load bearing structure in the required width and length. Figure 7 shows the Fixcel metal core panel.

Figure 7. Fixcel Metal Core Panel

The Fixcel metal core panels can be made of hot-galvanised steel, stainless steel, carbon steel, copper, aluminium or marine aluminium. Applications include modular multi-storey houses, floating buildings, elevator shafts, shipbuilding, pontoons and so on. It has possibility to use several insulation material such as EPS, mineral wool and PU.

The structure is extremely lightweight with 17 to 40 kilogram per square meter. At the same time, it has a very high vertical load bearing capacity of 19 tons per meter. Besides, the panel is energy efficient and hermetically sealed, which provides good energy efficiency and low air leakage. The fire-proof grade is REI 60. Furthermore, the structure is environmentally friendly because it is 100% recyclable. Figure 8 shows the technical data of the system.

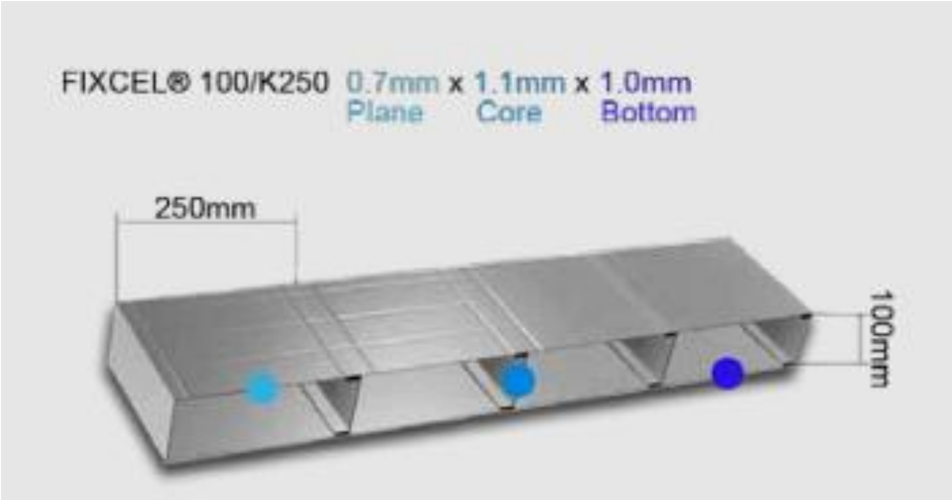


Figure 8. technical data of Fixcel metal core panel

2.2 Timber Intensive Solutions

2.2.1 Kerto-Ripa Long Span Beam

Kerto-Ripa roofing solutions are ideal for a long span, up to 18m, roof structures, enabling the designer to remove columns and increase design flexibility. They can be of both open and closed construction.Besides, they can be insulated to meet exact requirements. Figure 1 shows the Kerto-Ripa system.

Figure 9. Krato-Ripa beam

This roofing solution offers the developer and architect designer a variety of benefits including design flexibility, efficient off-site construction and rapid installation. What`s more, it has a low embodied energy and a carbon footprint that contributes to a healthy environment.

Mechanically, the cross section of the structure is simple, which makes it easy for structural designers to calculate internal actions and choose the profile.

The Kerto-Ripa panel is a structural engineered timber building element made from glued prefabricated members. It is used to create the ground, intermediate floors and roofs of residential, commercial and public buildings. Kerto-Ripa can be used in both thermally-insulated structures and non-insulated structures. Figure 9 shows the structural details of the system.

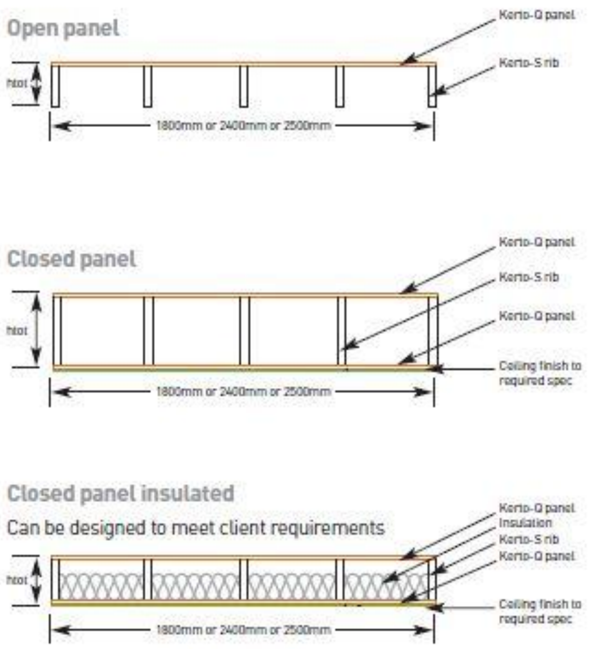


Figure 9. detail of Krato-Ripa beam

2.2.2 Glöckel-Roof-Element

The Glöckel roof element has numerous variants and superstructures. It is used in industrial and commercial construction and for some special requirements.

The basic construction consists of solid structural timber, which clad top and bottom, and which sandwiches the thermal insulation and vapour barrier in-between in accordance with the structural requirements. This produces a versatile roof element which can be optimally adapted to the respective requirements in terms of statics and building physics and assembled in a time-efficient manner. Figure 10 shows the Glöckel roof element.

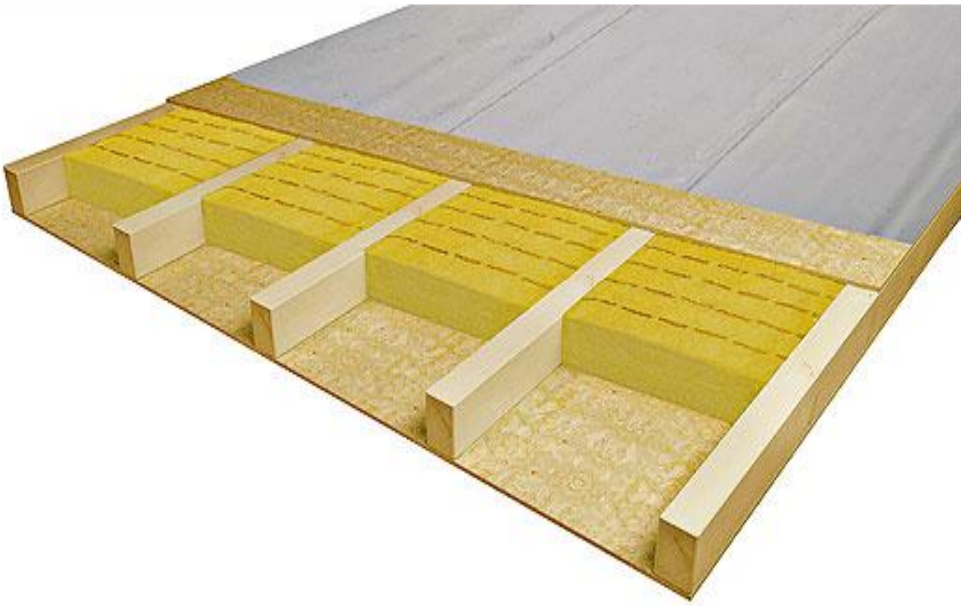


Figure 10. Glockel roof element

The Glöckel roof element can be used in its standard version for a maximum span of 7.5 meters and is 16 to 28 centimeters high, depending on the load situation. Special versions are also possible for a free span of 10 meters and more. In this case, the element has a height of 40 to 60 centimeters and an integrated supporting structure of laminated beam.

The Glöckel roof elements are rated for fire resistance classes REI 30, REI 60 and REI 90 under standard EN 13501-2 and conform to all applicable European regulations. All elements have a heat insulation layer of at least 18 cm, as prescribed under class REI 30. Moreover, the U-value of the structure is 0.20 W/m^2 k and sound proof capacity is 46 dB. Figure 11 shows the structural details of the system.

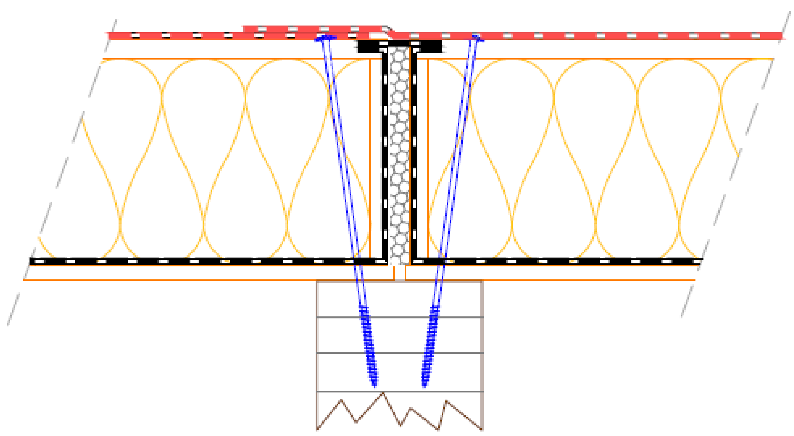


Figure 11. Joint between elements above the supports

2.3 Comparison of Different System

After the information collection and research of every roof system, the table below shows the most important properties of each system and their advantages as well as disadvantages.

Table 1. Comparison of Different Solutions

	Maximum Span(m)	Weight(kg /m2)	Advantage
Smartruss	18	6.9-9.1	lightweight, made from high strength steel which provides inner strength to protect and maintain the roof`s structural integrity and quality of construction.
Legato	22.5	varies	longspan, Cost-conscious, rational and efficient, good fire resistance, water proof and good ventilation
Lattice	40	18-37	longspan, lightweight, greater flexibility
X-deck	15	15.8-22.2	longspan, lightweight, greater flexibility
Fixcel	7.6	17-40	lightweight, high vertical load bearing capacity, good energy efficiency, low air leakage
Kerto-Ripa	18	not mentioned	longspan, greater flexibility, faster installation, efficient off-site construction
Glokel	7.5	not mentioned	greater flexibility

As it can be seen from this table, the Fixcel roof panel has the best properties for long span, lightweight, low cost, great flexibility. It can be a good example for the research and development of this thesis.

3 DESIGN OF SHEET METAL ELEMENTS

The aim of this chapter is to study the feasibility of box-section structures for load-bearing elements. The section was designed with feasibility, and after that, the section was checked by shear resistance , deflection and bending resistance.

3.1 The Design of Cross Section and Roof

The sections are composed of 5 box sections in a row. In the first and second sections, connections are made of rivets. In the third section, both rivets and self-drill screws are used. The picture below shows the detail of the sections. The width of each cell is 400mm and the total width of the cross section is 2000mm. Other dimensions would be determined after the calculation. Figure 12 shows the designed cross sections.

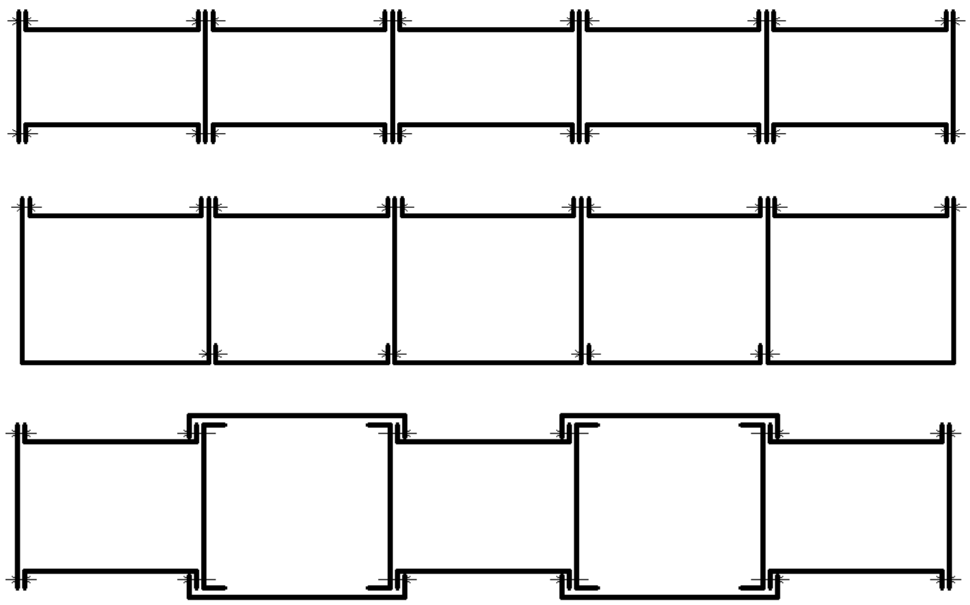


Figure 12. designed cross sections

The roof was composed of a PVC water proof layer of 3mm and a mineral wool insulation of 150mm. The layer had U-value of 0.21 which was less than the maximum U-value allowed for the roof as 0.24, which means the design of insulation was acceptable. Figure 12 shows the designed roof.

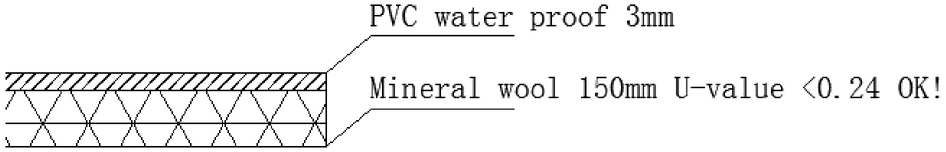


Figure 13. designed roof

3.2 Examining and Calculation of Cross Section

The aim of the calculation is to estimate the dimensions of the section, according to the mechanic behavior when they are bearing the load.

As there are only the snow load and self weight, they are considered as nominal distributed load in the calculation. The snow load on the ground is taken as 2.5 kN/m^2. Some detailed parameter such as span, material thickness, height of the section are estimated and taken into calculation to check if they meet the requirement of resistance. Besides, all the calculations are done with an ultimate limit state.

In the calculation, the span was firstly estimated as 8000mm and the thickness as 2mm. At the same time, the height was estimated as 300mm.

The calculation contains load calculation, deflection check, shear resistance check and bending moment check. Firstly, the snow load on the roof was calculated according to the the snow load on the ground and the dead load was calculated according to the density of the materials and the dimensions of every part. Then the second moment of inertia was calculated to get to the deflection. What follows, the shear force at support and the shear resistance were both calculated and compared with each other. Finally, the maximum bending moment at mid span were compared with the bending resistance of the beam.

Calculations are below:

Calculations of Load

ULS

$L := 8000mm \quad t := 2mm \quad H := 300mm$

Use snow load on the ground and the span to get the snow load on the roof

$$q_{snow} := 2.0\frac{kN}{m^2}\cdot L = 16\frac{kN}{m}$$

The density of wool, PVC and steels are:

$$\rho_{wool} := 160\frac{kg}{m^3} \qquad \rho_{pvc} := 1410\frac{kg}{m^3} \qquad \rho_{steel} := 7850\frac{kg}{m^3}\cdot\frac{2000mm\cdot H\cdot t}{2000mm\cdot h} \qquad G := 9.8\frac{N}{kg}$$

The thickness of roof layers are:

$h_1 := 150mm \qquad h_2 := 3mm$

The dead load of the whole structure

$$q_{sw} := \rho_{wool}\cdot G\cdot h_1 + \rho_{pvc}\cdot G\cdot h_2 + \rho_{steel}\cdot G\cdot L = 5.783\frac{kN}{m}$$

The load on the roof under ULS

$$q_{du} := 1.5\cdot q_{snow} + 1.15\cdot q_{sw} = 30.65\frac{kN}{m}$$ load per unit width $$q_{duw} := \frac{q_{du}}{2000mm} = 15.325\frac{kN}{mm}$$

The load on the roof under SLS

$$q_{ds} := 1\cdot q_{snow} + 1\cdot q_{sw} = 21.783\frac{kN}{m}$$ load per unit width $$q_{dsw} := \frac{q_{ds}}{2000mm} = 10.891\frac{kN}{mm}$$

The calculation of second moment of Inertia

Thickness of upper flange

$t_1 := 2mm$

$$I_1 := \frac{400mm \cdot t_1^3}{12} + 400mm \cdot t_1 \cdot \left(\frac{H}{2}\right)^2$$

$$I_2 := \frac{t_1 \cdot (50mm)^3}{12} + t_1 \cdot 50mm \cdot \left(\frac{H}{2}\right)^2$$

Thickness of lower flange

$t_2 := 1mm$

$$I_3 := \frac{400mm \cdot t_2^3}{12} + 400mm \cdot t_2 \cdot \left(\frac{H}{2}\right)^2$$

$$I_4 := \frac{t_2 \cdot (50mm)^3}{12} + t_2 \cdot 50mm \cdot \left(\frac{H}{2}\right)^2$$

Second moment of inertia of upper flange

$$I_{f1} := 5 \cdot I_1 + 10 \cdot I_2 = 1.126 \cdot 10^{8}\, mm^4$$

Second moment of inertia of lower flange

$$I_{f2} := 5 \cdot I_3 + 10 \cdot I_4 = 5.636 \cdot 10^{7}\, mm^4$$

Thickness of webs

$t_3 := 2mm$

Second moment of inertia of webs

$$I_5 := \frac{t_3 \cdot (H)^3}{12}$$

$$I_w := 6 \cdot I_5 = 2.7 \cdot 10^{7}\, mm^4$$

Second moment of inertia of the whole section

$$I := I_{f1} + I_{f2} + I_w = 1.96 \cdot 10^{8}\, mm^4$$

I per unit width

$$I_{pw} := \frac{I}{2000mm} = 9.80 \cdot 10^{7}\, mm^4 \frac{1}{m}$$

Deflection

Elastic modulus of steel is:

$$E := 210000 \frac{N}{mm^2}$$

The deflection is:

$$\omega := \frac{5}{384} \cdot \frac{q_{du} L^4}{EI} = 39.702\, mm$$

The allowed deflection is 1/200 of the span length

$$\omega_{allowed} := \frac{L}{200} = 40\, mm$$

The deflection of the beam is less than the allowed deflection, so the design is acceptable

.

Acceptable

The shear resistance of one web is:

$$V_{bRd\_i} := \frac{\frac{h_w}{\sin(\phi)} \cdot t_3 \cdot f_{bv}}{\gamma_{M0}} = 53.215\,kN$$

There are 6 webs in the section

$$V_{bRd} := 6 \cdot V_{bRd\_i} = 319.289\,kN$$ Acceptable

The shear force at support is less than the shear resistance, so the section is acceptable
.

Maximum bending moment at mid span

$$M_{max} := \frac{q_{du} \cdot L^2}{8} = 245.302\,kN \cdot m$$

Bending moment per unit width

$$M_w := \frac{M_{max}}{2000\,mm} = 122.651\,kN \cdot m \cdot \frac{1}{m}$$

Bending resistance calculations are below

The section modulus is:

$$e := \frac{H}{2} \qquad W := \frac{I}{e}$$

$$M_{cRd} := W \cdot \frac{f_y}{\gamma_{M0}} = 457.483\,kN \cdot m$$

The bending moment at mid span is less than the bending resistance, so the section is acceptable

3.3 Calculation result analysis

The result showed that all the checks were acceptable. Some parameters were changed for a further calculation to get a better solution, but the they did not pass the resistance check. So the final decision would be: span as 8000mm, height as 300mm, thickness of top flange and web as 2mm ,thickness of bottom flange 1mm. Figure 14 shows the firstly designed section.

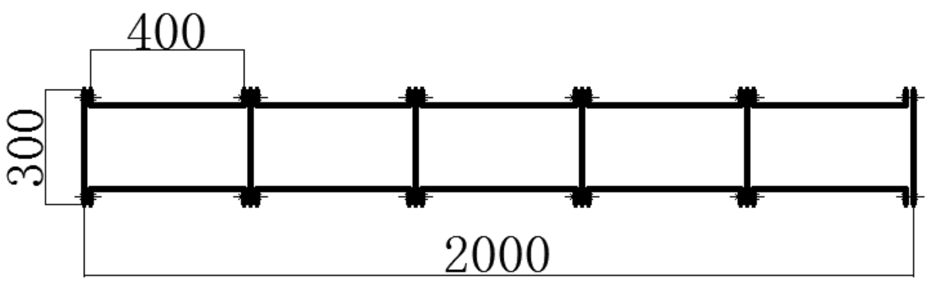


Figure 14. designed cross section

This graph below in Figure 15 shows the how much load the beam takes under different conditions of span length and height. The X-axis stands for the spans of the beam and it varies from 5500mm to 9500mm. The Y-axis stands for the load it can take when it reaches that maximum deflection before it breaks. The height of the beam varies from 230mm to 310mm.

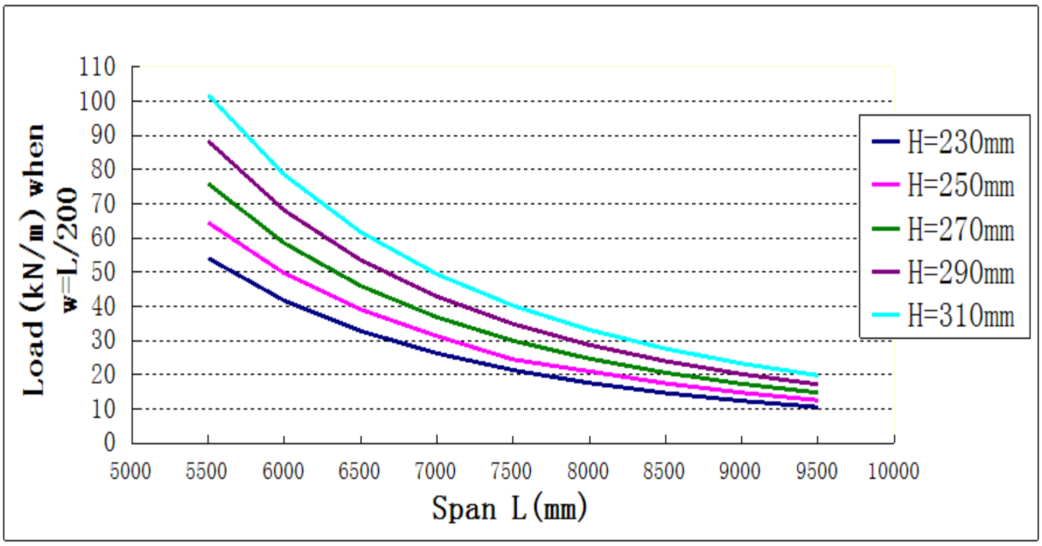


Figure 15. designed cross section

4 EXPERIMENTAL RESEARCH

This chapter mainly focuses on the tests of small-scale beams. The aim of the test is to demonstrate the failure mode and to test the function of stiffeners and insulations. These small scale elements were designed as one single cell out of the long span element which is composed of five cells. Many different sections were made with different conditions of insulation and stiffening method. The equipment and place for the manufacturing and test were provided by Sheet Metal Centre. The whole manufacturing process was completed by one person.

4.1 Basic Information of Different Cross Section

The first cross section (named as cross section A) was made of steel only. It had no stiffeners or insulations. Figure 16 below shows the structure of the cross section.

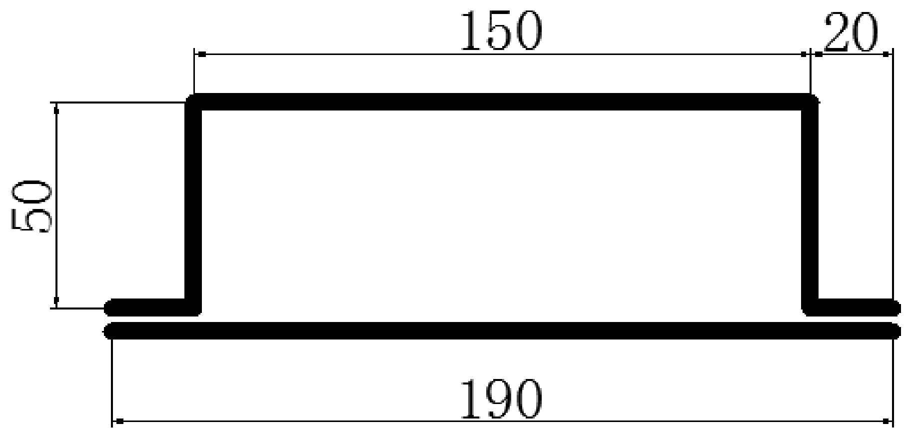


Figure 16. Cross Section A

The second cross section (named as cross section B) was also steel-only beam without insulations. But it had stiffeners on the top flange. Figure 17 below shows the structure of the cross section.

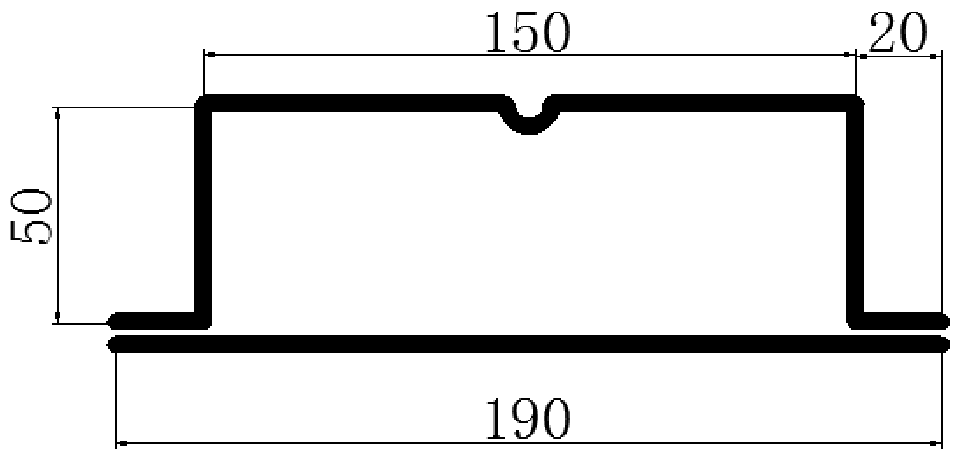


Figure 17. Cross Section B

The third cross section (named as cross section C) was steel box-section with no stiffeners. But the webs were glued with polyurethane. Figure 18 below shows the structure of the cross section.

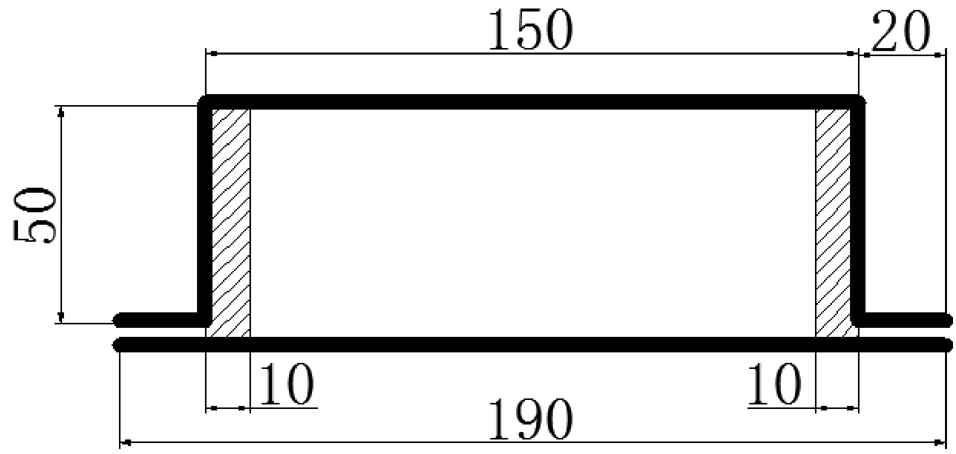


Figure 18. Cross Section C

The fourth cross section (named as cross section D) was a steel box-section with no stiffeners. But the top flange was glued with polyurethane. Figure 19 below shows the structure of the cross section.

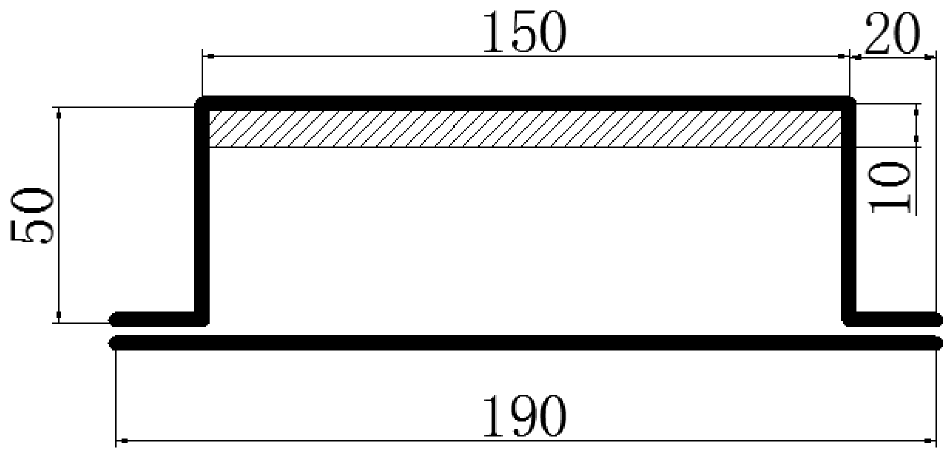


Figure 19. Cross Section D

The fifth cross section (named as cross section E) was a steel box-section with no stiffeners. But the whole hollow area was glued with polyurethane. Figure 20 below shows the structure of the cross section.

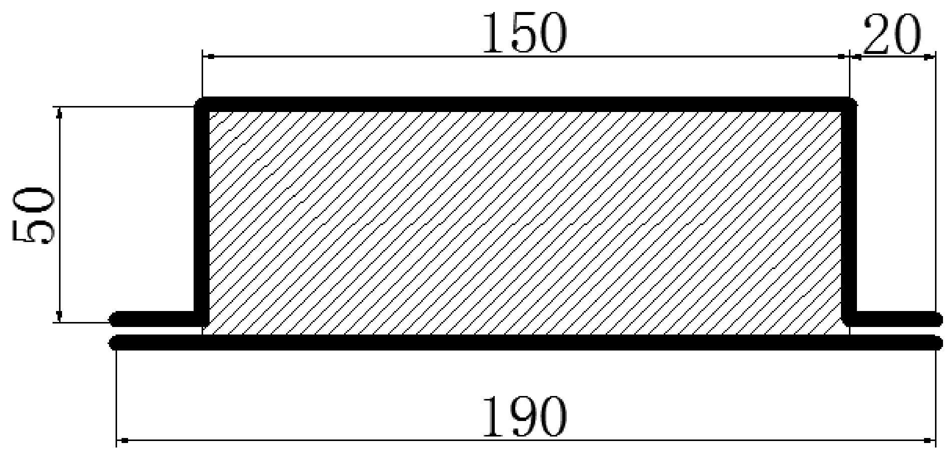


Figure 20. Cross Section E

The sixth cross section (named as cross section F) was steel box-section with stiffeners on the top flange, and the whole hollow area was insulated with polyurethane. But glue was not used in this section. Figure 21 below shows the structure of the cross section.

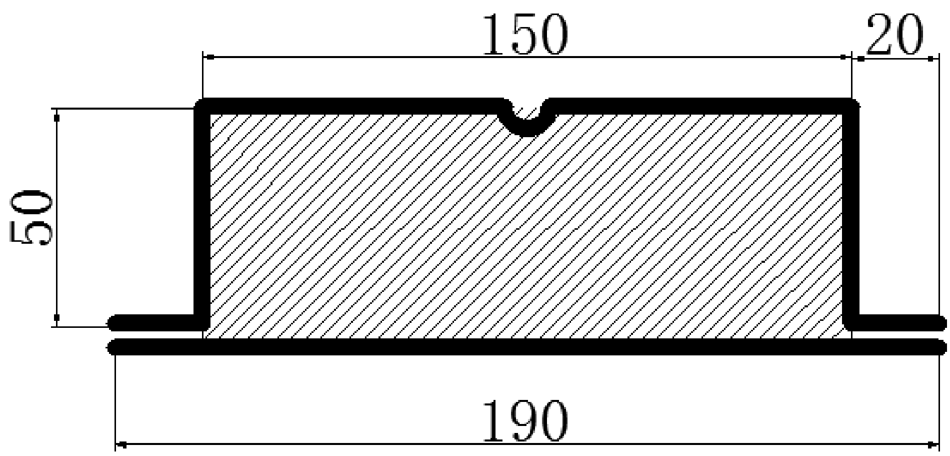


Figure 21. Cross Section E

The seventh cross section (named as cross section G) was a steel box-section with no stiffeners or linear insulations. But the parts under the concentrated load during the test were reinforced with plywood blocks. The location of the plywood was every one third along the span. Figure 22 below shows the timber reinforcement.

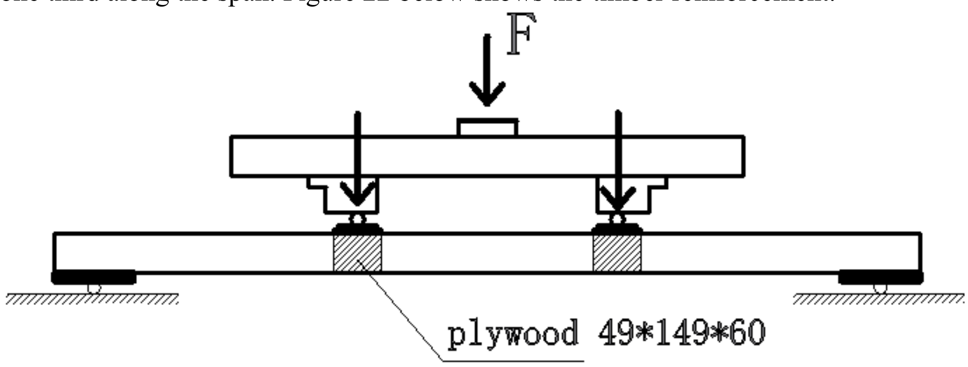


Figure 22. timber reinforcement under concentrated load

The seventh cross section (named as cross section H) had the same cross section and timber reinforcement as section G. But both supports were insulated with an L-shape stiffener and they are located at 50mm from both ends of the beam. Figures 23 below shows the location of stiffeners and its dimensions.

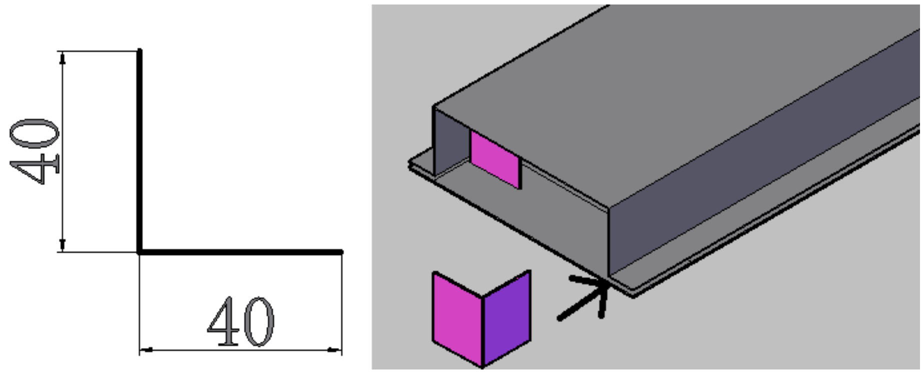


Figure 23. L-shape Stiffeners

The last cross section (named as cross section I) had the same cross section and timber reinforcement with section H. But those timber reinforcements were replaced by longer plywood blocks with the length of 150mm.

4.2 The Manufacturing of the small-scale specimen

4.2.1 Material

The material for the box-section was steel which has the yield strength of 400 N/mm and zinc layer on the surface to protect it from corrosion. The thickness of it was 0.7mm.

The material for the insulations was polyurethane. Polyurethane (PUR and PU) is a polymer composed of a chain of organic units joined by carbamate links. While most polyurethanes are thermosetting polymers that do not melt when heated, thermoplastic polyurethanes are also available. Polyurethane polymers are formed by reacting an isocyanate with a polyol. Both the isocyanates and polyols used to make polyurethanes contain on average two or more functional groups per molecule.

The fixing methods of each solution were glue and rivet. Glue was used to attach steel and polyurethane, and rivets were used to attach the upper U section to the bottom flange. Figure 25 below tshow the rivet machine.

Figure 24. The Rivet Machine

The glue was Macroplast UK 8572 B5. It is a solvent-free and two-component adhesive based on polyurethane. Its main application is the production of sandwich elements. Furthermore, this product is used as a potting, filling and coating compound. The resin part (component A) contains organic compounds with hydroxyl element, the hardener (component B) is based on isocyanates. In this test, the glue is mixed by component A and component B with a ratio of 4:1. A technical data is showed in Table 2. (MACROPLAST UK 8572 B5 technical data, PDF file. SMC)

The rivets were automatically put into the beam with the rivet machine. The space between two rivets was 100mm.

4.2.2 Manufacturing Process

One specimen had length of 1100 mm, width of 190 mm and height of 50mm. A metal sheet with the dimension of 1250 mm by 1250 mm was chosen to be cut. It was required to manufacture six similar but different specimens

The first step was to cut pieces from the metal sheet. One piece had length of 1100 mm and width of 290 mm, this piece was used for the top flange and webs of the beam. Another piece had the length of 1000 mm and width of 190 mm, this piece was used for the bottom flange of the beam. The equipment for the cutting process was the cutting machine in Sheet Metal Center. It was a very accurate machine that provides the exact dimension that was required for the metal sheet.

The second step was to bend the 1100mm by 290mm metal sheet into U section to form the top flange and webs for a beam. The picture below shows the dimension of the U section(Figure 25).

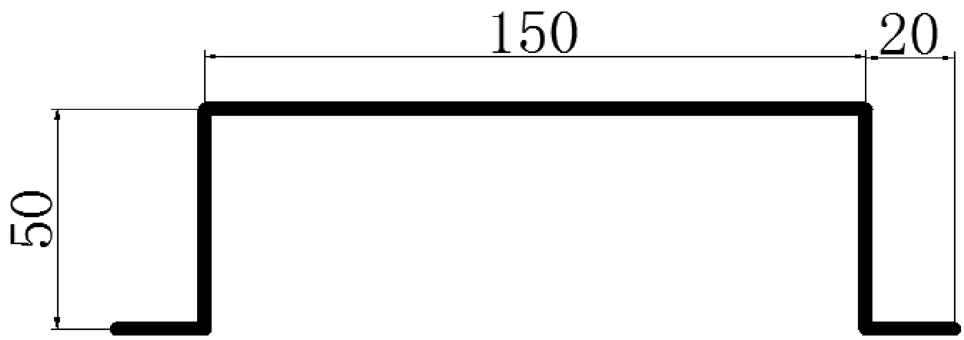


Figure 25. the dimension of the U section

The equipment for the bending process was the bending machine in the workshop of Ruukki company, it may causes some inaccuracy with the angle but it provides absolutely symmetric section.

The third step was to make a stiffener on the top flange. The stiffener was a groove in the middle of surface of the top flange which makes the beam stronger against bending. This process was simply done with the grooving machine. The picture below in Figure 26 shows the U section with the stiffener which was made after by steps mentioned before.

Figure 26. the U-section with stiffener

The fourth step was to cut polyurethane (Figure 27) for different type of insulations. For the cross section C, it required two pieces of polyurethane with length of 1100 mm, width of 50 mm and height of 10 mm. For the cross section D, it required one piece of polyurethane with the length of 1100 mm, width of 150 mm and height of 10 mm. For cross section E and F, they both required one piece of polyurethane with the length of 1100 mm, width of 150mm and height of 50 mm. But for cross section F, there had to be a groove on the polyurethane to fit the top flange, or it would cause some bending upwards when gluing them together.

Figure 27. polyurethane for insulation

The fifth step was to glue the polyurethane in the U-section. To keep the polyurethane and metal contacting each other well before the glue solidified, the U-section was clamped with two timber sticks (Figure 28). This also helped to fix the inaccuracy caused by the bending machine.

Figure 28. gluing process

The last step was to attach the U-section onto the bottom flange (Figure 29). The attaching method was using rivets. Rivets are a firm connection and they don`t take too much time and effort to complete the process.

Figure 29 beam completed

After all these six steps of manufacturing process, the beam was completed and ready for the test.

4.3 Arrangement of the test

The total length of the beam was 1100 mm and the width of support was 100 mm.As the result of this, the effective length, which was measured between the center of both supports, was 1000 mm. In the test, the load was arranged as two point load by using a load distributing beam. The one point load from the test machine was distributed into two point loads which were located every 333mm along the span. A balancer was put under the one point load to avoid deviation in case the whole system was not absolutely horizontal. Steel and rubber slides were put under each load point as the buffer to the effect of impact. At the same time, it makes the point load further distributed into linear load in order to avoid the beam from buckling by concentrated force. Figure 30 below shows the test arrangement.

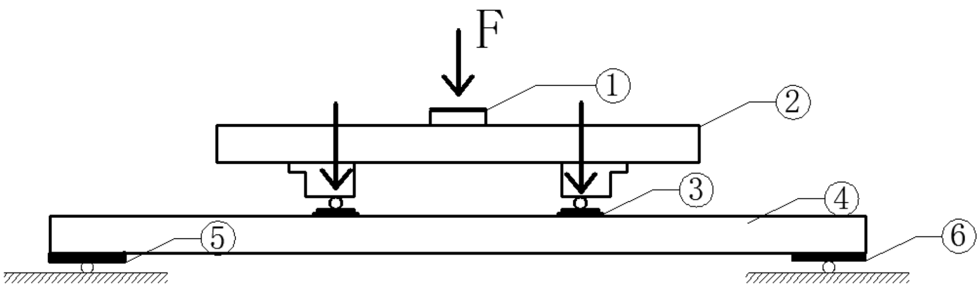


Figure 30. Technical Drawing of Test arrangement
In which: 1.Balancer 2.Load distributing beam 3.Steel and rubber slides 4. Testing beam 5.Fixed support 6.Free support

The support was arranged as fixed on one side and free on the other. This means that on one side the support plate was free for horizontal motion, but the other side was totally prevented from any motion. By doing this, there would be no force in the X axis (horizontal direction) which could be caused by the support. What`s more, two stages were arranged on both supports to lift the whole system to the required level. The whole system were arranged and checked to be absolutely horizontal. Figure 31 shows the picture taken in the test.

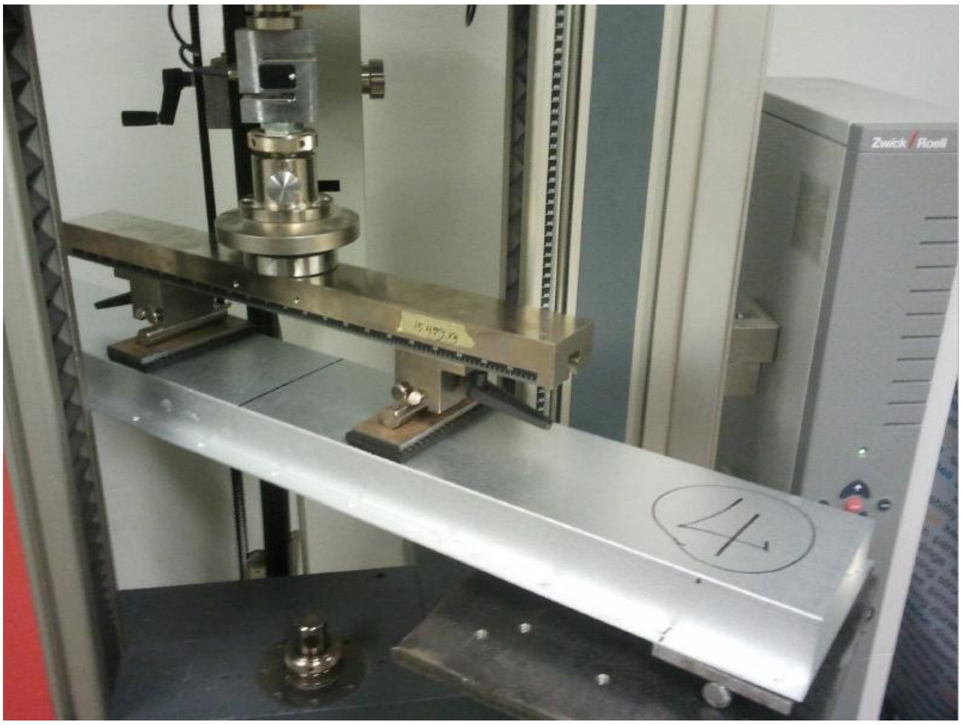


Figure 31. test arrangement

The testing equipment was the tensile test machine in Sheet Metal Center. It provides pressure force as much as 15kN, which is suitable for the beam test.

4.4 Test result

The beams were tested with a continuously increasing load until it reached the maximum load they could bear. When the load reached the load bearing capacity of the beam, the beams failed as the result of buckling on the top flange and also on the webs. Figure 32 is a picture of the beam failure.

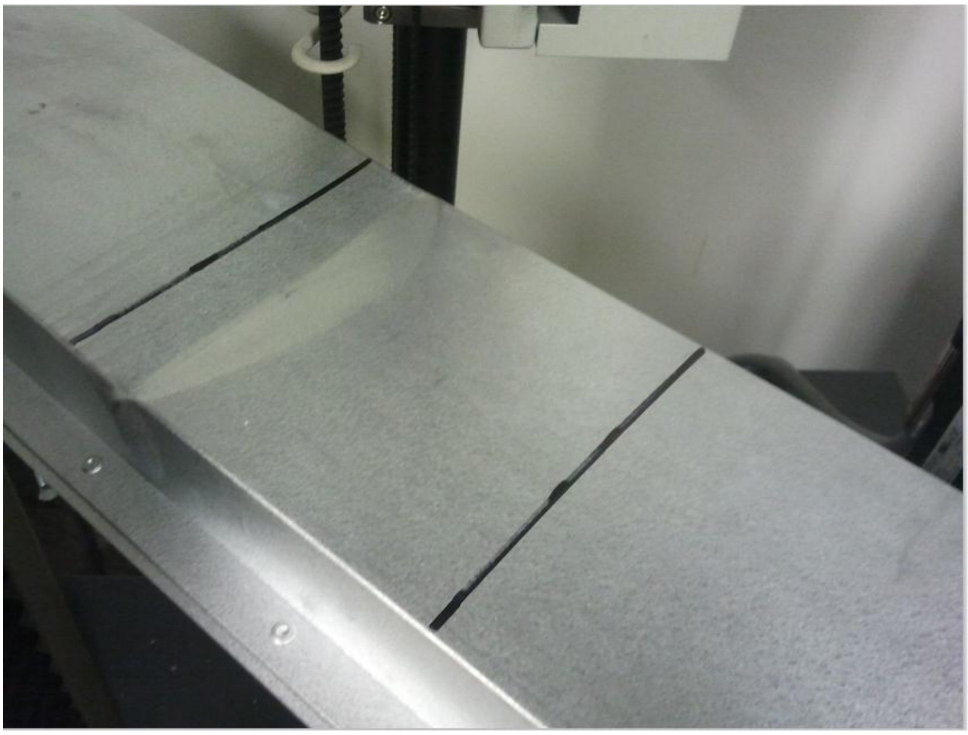


Figure 32. beam failure

Here are the deflection/load chart for each beam, the X-axis stands for the deflection of the beam (mm) while the Y-axis stands for the load it took (N). The highest point of the curve shows the maximum load it took.

Beam A
This beam had no stiffeners nor insulations. It took 3670.07N force before it buckled. Figure 33 shows the buckling curve of beam A.

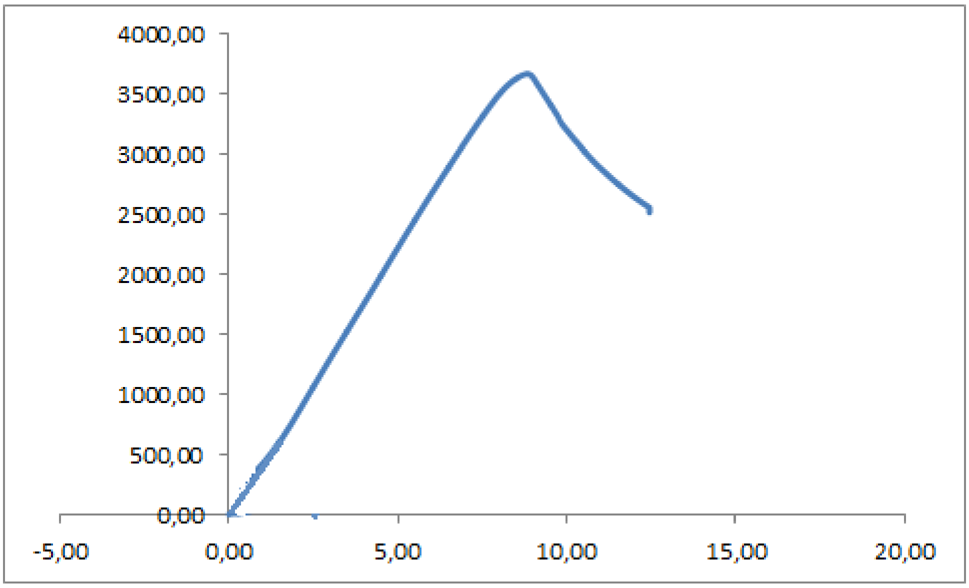


Figure 33. Buckling Curve of Beam A

Beam B
This beam had no insulations, but it had stiffener on the top flange, It took 3982.67N force before it buckled. Figure 34 shows the buckling curve of beam B.

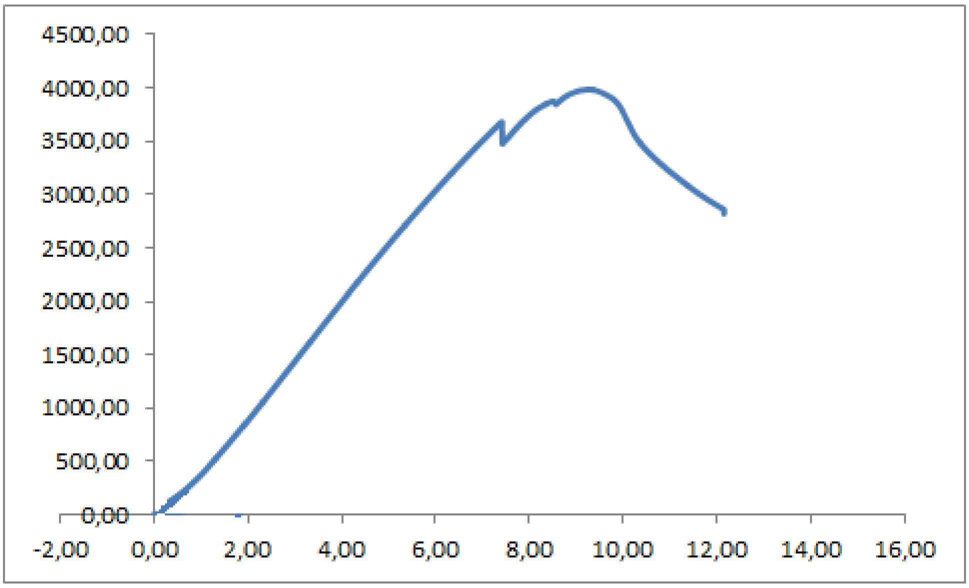


Figure 34. Buckling Curve of Beam B

Beam C
This beam had no stiffeners, but it had insulation on the top flange, It took 3871.87N force before it buckled. Figure 35 shows the buckling curve of beam C.

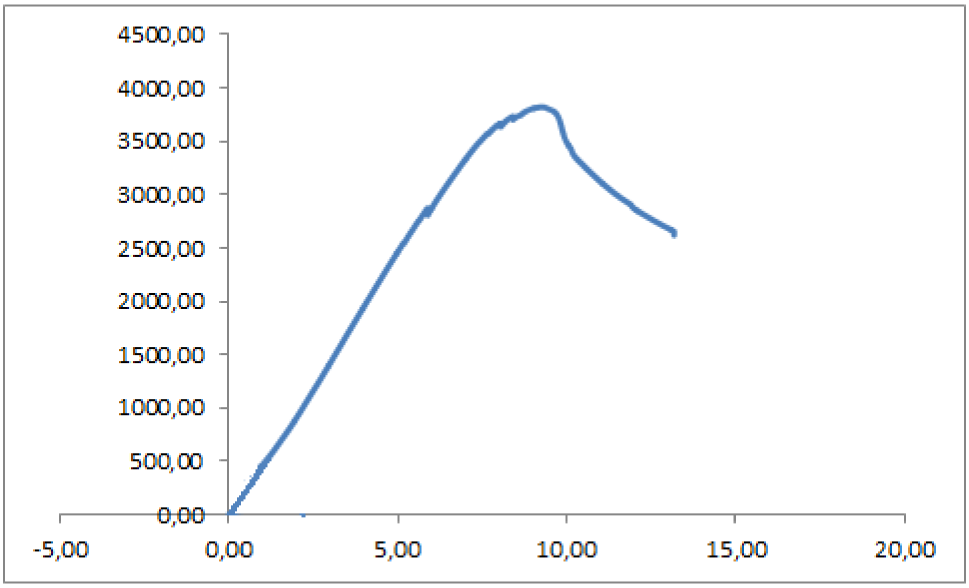


Figure 35. Buckling Curve of Beam C

Beam D
This beam had no stiffeners, but it had insulation on both webs. It took 4231.67N force before it buckled. Figure 36 shows the buckling curve of beam D.

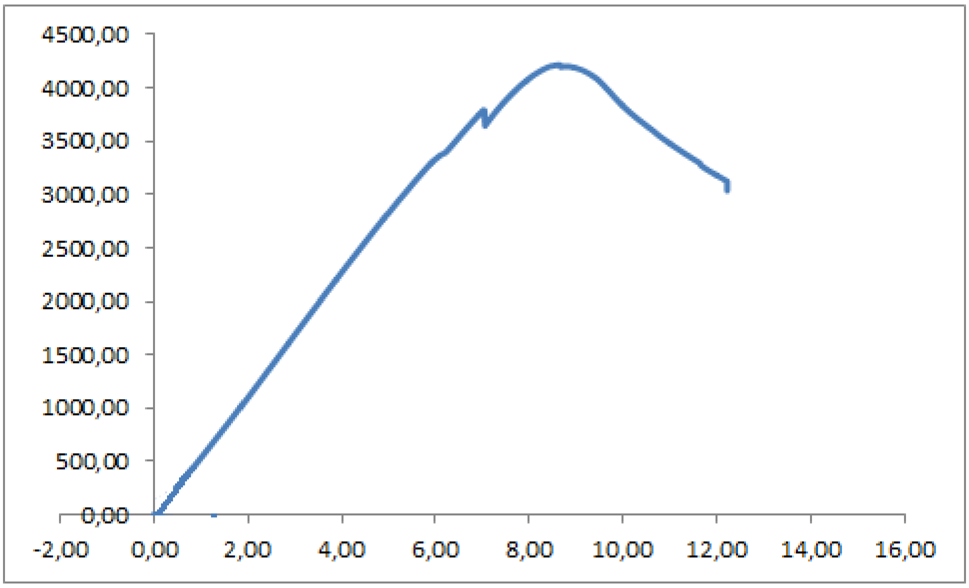


Figure 36. Buckling Curve of Beam D

Beam E
This beam had full insulations, but it had no stiffeners. It took 4965.37N force before it buckled. Figure 37 shows the buckling curve of beam E.

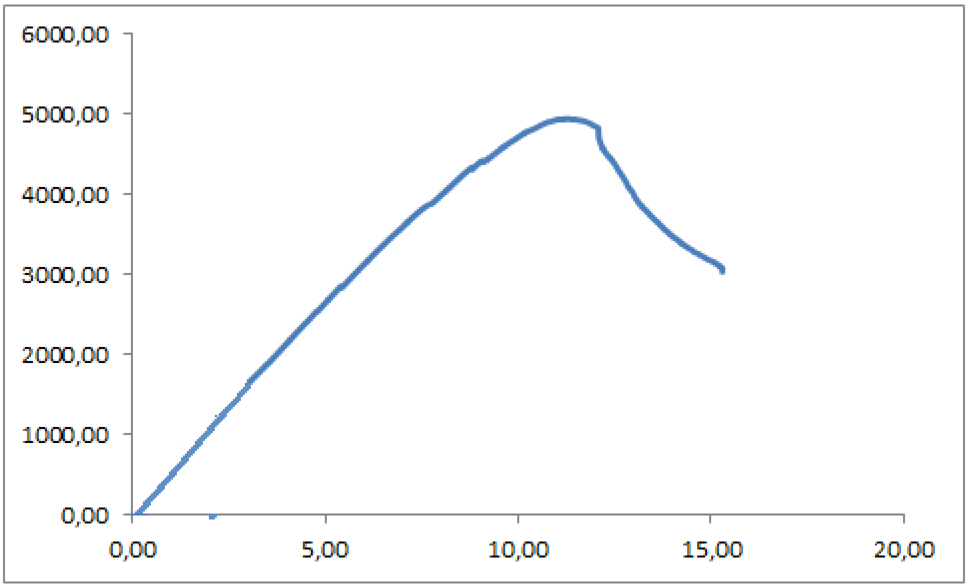


Figure 37. Buckling Curve of Beam E

Beam F
This beam had full insulations and stiffener on the top flange, but there was no glue within this solution. It took 4177.24N force before it buckled. Figure 38 shows the buckling curve of beam F.

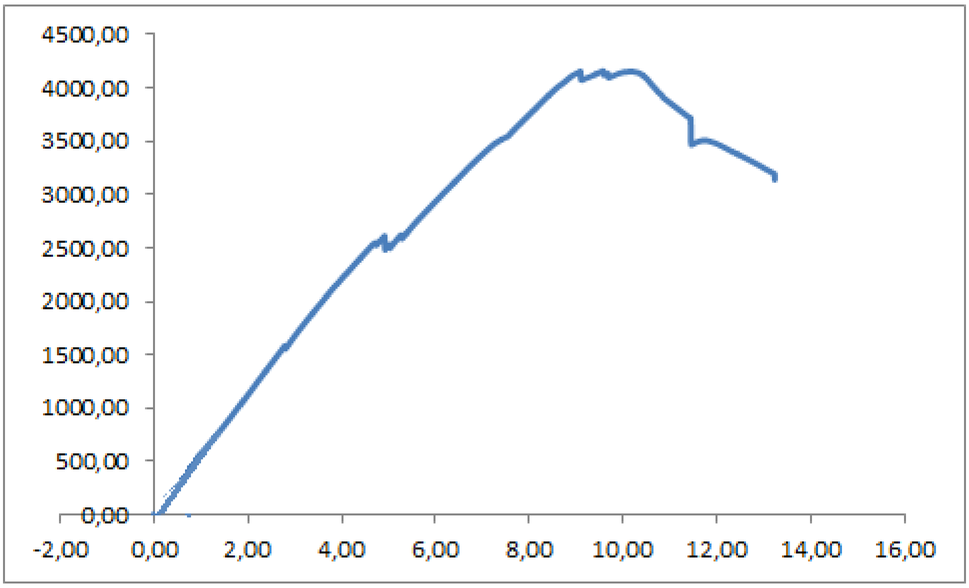
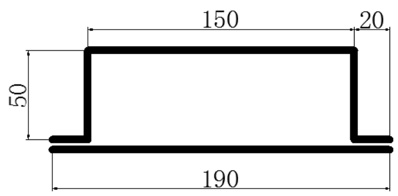
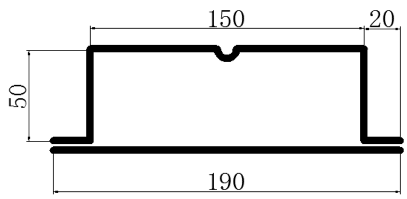
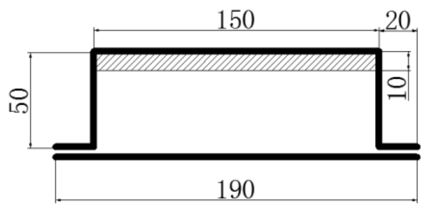
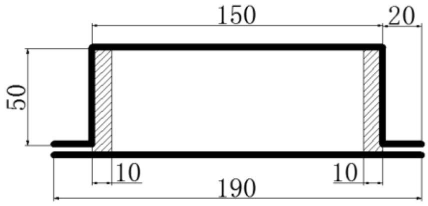
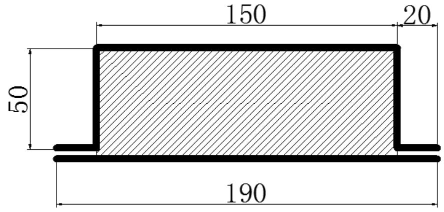
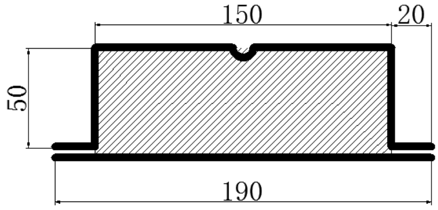
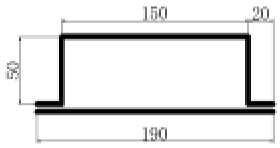
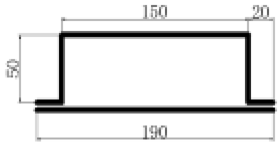
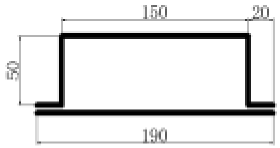


Figure 38. Buckling Curve of Beam F

The table below shows the results for each beam section type , maximum load, deflection when it was maximum load and failure load.

Table 2. Test Results

Beam Section Type	Maximum load (N)	Maximum Deflection(mm)	Failure mode
	3679	11.5	Failure at loading point
	3982	11	Failure at loading point
	3817	11.4	Failure at loading point

	4213	7.8	Failure at loading point
	4965	13.3	Failure at loading point
	4177	10.6	Failure at loading point
 (timber reinforced)	4327	10	Failure at loading point
 (timber reinforced and stiffened at support)	4523	9.5	Failure at loading point
 (longer timber reinforcement)	4896	9.9	Failure near mid span

4.5 Analysis of Test results

Most beams were buckled on the top flange and on the webs near the loading point, that means that the concentrated force was playing an important role in the failure of beams. In addition, it could be seen that the insulation and stiffeners had an effect on reducing the buckling.

Beam A took the least load because it had no insulation or stiffeners. Beam B took more load with the stiffener. Beam C also took more load than A with the insulation on the top flange, but it was less than B. This means that stiffeners are more effective than the 10 mm insulation on the top flange. Beam D took more load than C. This means, under this condition, that the insulation on the webs more effective than those on the top flange. Beam E had the best result even without stiffeners because it was full insulated and glued, which reduced the buckling on the top flange and webs a lot. Beam F was also fully insulated and, what`s more, it had stiffener. However, it took less load than D. As the result of that, it is obvious that the glue was very important to attach the insulation and the outer section. Beam G had the same cross section with beam A, but the part under loading point with plywood. The result shows that beam G took much more load than A, which means that the reinforcement helped a lot to reduce the effect of concentrated force. But beam G still failed near the loading point. Beam H had L-profile at both supports. The L-profile was made to reduce the failure at support. However, the failure did not happen there. But still it increased the load bearing capacity. Beam I had the plywood reinforcement as long as 150mm, it increased the load bearing capacity well, and at the same time, it displaced the failure location near the mid span.

The failure mostly happened near the loaded points, the beams were mostly failed by a concentrated force.

To get a failure mode at support and mid span, another group of tests was taken for the failure mode demonstration. In the test shorter beams were used to avoid the failure at load point.

In this test, three different specimens span of 200mm were tested under one-point load.

The first specimen (named as beam J) was only hat section without any stiffeners. The result was that the failure happened at the support. Figure 41 show how it buckled.

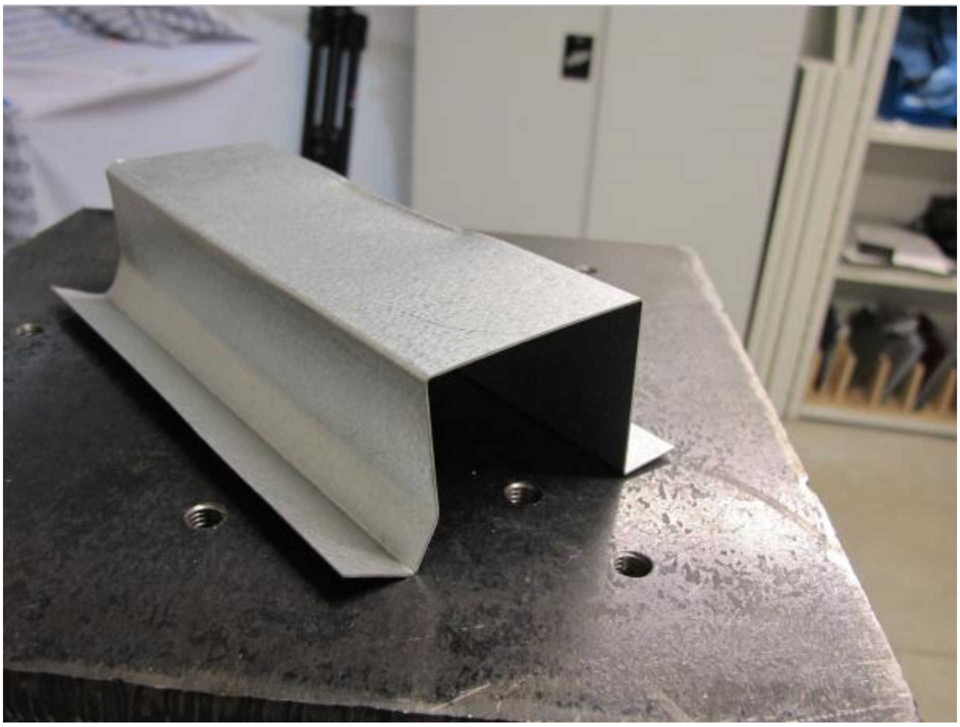


Figure 41. failure of beam G

The second specimen (named as beam K) was box section without any stiffeners. The result was that the failure happened at the mid-span. Figure 42 show how it buckled.

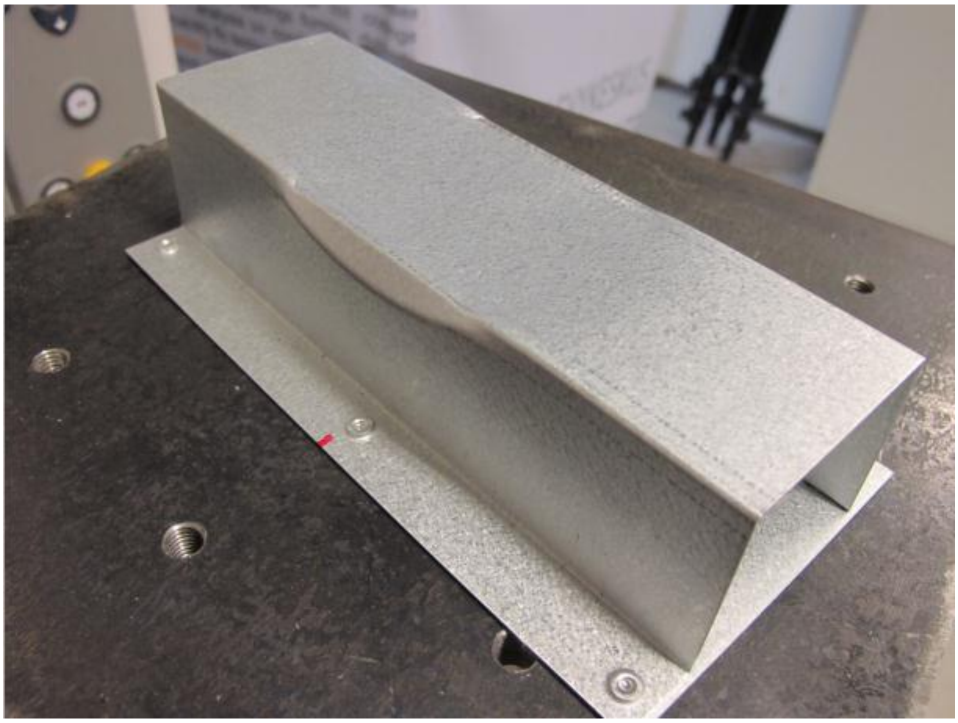


Figure 42. Failure of Beam H

The third specimen (named as beam L) was box section with L-shape stiffeners at the support. The result was that the failure happened at the mid-span. Figure 43 show how it buckled.

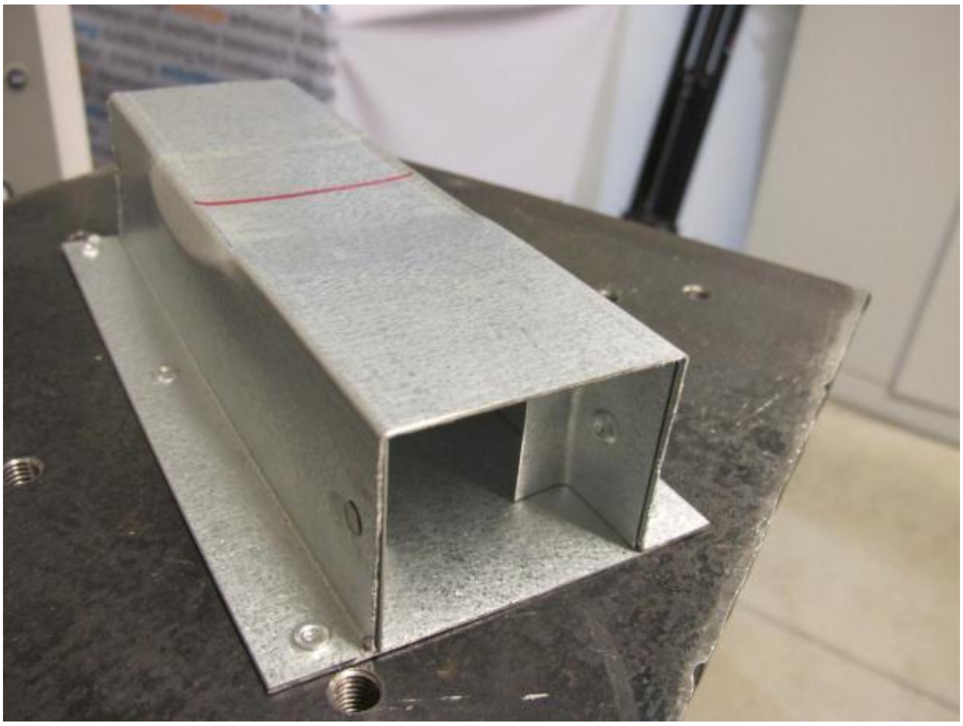


Figure 43. Failure of Beam I

The result shows that the failures happen in the mid span even though the support was not stiffened. The stiffeners at support turned out to be less important than the flange itself in the full-scale section of long-span beam.

Table 3. Failure Demonstration Test Results

Beam type	Failure mode
Beam J (hat section)	Failure at support
Beam K (box section)	Failure at mid-span
Beam L (box section with L-shape stiffeners)	Failure at mid-span

After studying the results of the tests, some changes were made in the earlier designed beam. The long-span roof should be insulated with Polyurethane inside the section on the top flange and outer webs. They are also assigned as the reinforcement between the top flange and the floor layers. They are attached together with self-drilling screws. However, the design of the fixing method was not included in this thesis. It has to be reconsidered in practice.

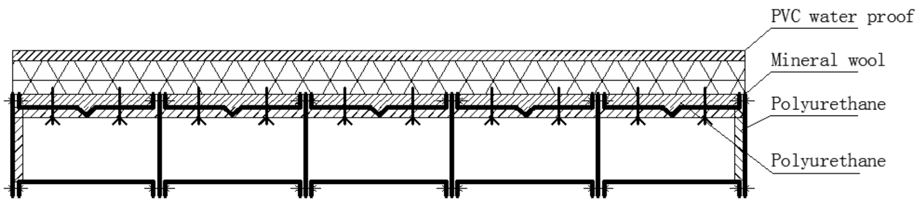


Figure 44. Final Design of Beam

5 CONCLUSION

This project aimed to study and create an innovative design a long span roof element with light weight. Through searching information of currently existing solutions and consulting the experts and the supervisor, the Fixcel panel was found as a good example for the solution of a long-span beam. Then, the section composed of five cells, which was described in Chapter 3, was designed as the solution of a long-span roof element. Single cells were made on small-scale with different detail solutions to determine the load bearing capacity and to demonstrate the failure mode.

The specimens were made of metal sheet with a thickness of 0.7mm and yield strength of 400N/mm. They were firstly bended into U-section and insulated with different insulations. Then the insulated U-sections were attached to the bottom flange with rivets to form box section specimens. Many trials were done before the final decision was made, it failed with plenty of times and many changes had been done to make the beam more suitable for the test.

According to the results, the failure happens at the loading point or near the middle point of the span. That means, in the design of a full-scale case, that the beam should be strongly reinforced against the concentrated force, and failures at support seems not to happen easily.

In addition, after comparing the load bearing capacity of different beams with each other, it could be seen that to enhance the top flange and webs turned out to be the most important part in the box-section design. This should be paid a lot of attention to. The long-span roof should be insulated with Polyurethane inside the section, but only on the top flange and outer webs. Plywood should be assigned as the reinforcement between the top flange and the floor layers.

Despite the unavoidable errors and inaccuracy, the test result is still enough to illustrate the advantages and disadvantages of these specimens. The results would be helpful when designing the beam in full scale which could be applied in human daily life with their superiority in span and weight.

This test could be effectively refined and improved provided the manufacturing error and natural deviations were deducted. All those beams for testing were not manufactured professionally and the whole process was done by only one person. Besides that there still exist some other options which were not tested yet. At the time, there would better results if there was more enhancement in the loading point for the concentrated force. It aimed to find out the best method for a light weight roof element for long span, and it would be probably applied in real life if produced in a professional production line.

SOURCES

Kerto-Ripa long span beam.
http://www.metsawood.com/building-and-construction/Pages/Roofingsolutions.aspx?TMI=topMenuContainer3. Accessed on 1th July 2012.

Fixcel metal core panel
http://www.neapo.fi/en/www/page.php?id=128
Accessed on 1th July 2012.

Kingspan X-dek.
http://www.kingspan.info/KS1000-X-DEK-18446.html
Accessed on 10th July 2012.

Polyurethane
http://en.wikipedia.org/wiki/Polyurethane
Accessed on 10th July 2012.

Lattice beam.
http://www.metsec.com/products/steel-lattice-beams/lightweight-roof-beam-systems.asp
Accessed on 11th July 2012.

Glockel roo-element
http://www.gloeckel.at
Accessed on 12th July 2012.

Dimensional Analysis of Structural Steel Beam Design, Elizondo Michael , 1991
Accessed on 12nd July 2012.

Design of Long Spans, Jay Ruby, 2007
Accessed on 12nd July 2012

Smartruss beam.
http://www.bluescopesteel.com.cn/residential/solution/roofing.asp. Accessed on 12th July 2012.

Legato-arch system,
http://www.zeman-stahl.com/cms/index.php?option=com_content&view=article&id=58&Itemid=65&lang=en
Accessed on 22th July 2012.

SFS-EN 1993-1-3
Accessed on 5th September 2012.

MACROPLAST UK 8572 B5 technical data, PDF file. SMC. Accessed on 5th September 2012.