UNSW

Specifications for a Fire Testing Weighing Platform

MECH4100 – Mechanical Design 2

Fire and Rescue NSW Group 1

Prepared for: Fire and Rescue NSW

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Session 2 - 2016

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Executive Summary

Fire and Rescue NSW (FRNSW) and Professor Guan Heng Yeoh of UNSW have engaged Fire NSW Group 1 of UNSW to design a weighing platform for fire experiments. The final design will assist FRNSW in their ongoing research into the many aspects of fire. The design team (Fire NSW Group 1) consists of 10 students at UNSW completing their final year design subject, MECH4100 – Mechanical Design 2.

This Report provides the design documentation to manufacture and operate a fire experiment rig which measures mass loss and heat flux. The data collected from the rig will enable the calculation of the heat release rate of a fire – an important parameter for FRNSW's ongoing research. Engineering drawings specifying the design are provided in Appendix K - Engineering Drawings. An operations manual is provided in Appendix B - Operations Manual of this Report to facilitate accurate data collection and safe working procedures.

The final design consists of four load cells on each corner of a steel structure. The steel structure is welded together in a ladder shape style made primarily of rectangular hollow sections and parallel flange channel according to relevant AS/NZ standards. On top of the steel structure is 'CSR Hebel' for thermal insulation of the load cells and steel mesh to provide a safe working platform for operators walking on the device. Jockey wheels are mounted on the side performing two functions. The first function is portability around the FRNSW testing site. The second function of the jockey wheels is to allow each corner of the device to independently move up and down allowing packing slips to be placed under each corner. This ensures a level platform which is important for the reliability of the load cells. Lifting points allow the device to be lifted by a crane if required. Eye bolts attached to the steel structure are provided for towing equipment moving the platform around the FRNSW site. The final design specified here includes a retort style mounting for the heat flux sensors. Load cells attach to the four (4) corners of the steel structure. Underneath the load cells are concrete Besser blocks to allow compression of the load cells. During operation, fire rated plasterboard ('CSR Gyprock Fyrchek') is to be placed around the sides of the device. The final design is shown in Figure 1.

Finite Element Analysis (FEA) and analytical calculations were conducted to verify the steel structure can withstand the required weight of an 8000 kilogram load. A transient thermal analysis shows the heat released from a fire experiment will not significantly heat the load cells above their operating service temperature.

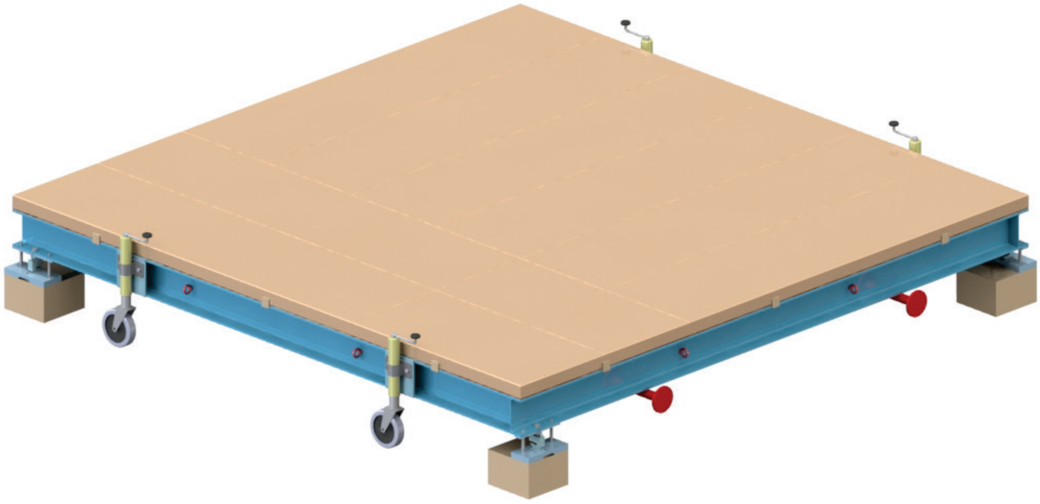

Figure 1: Fire testing weighing platform final design

The total upfront cost of the device is calculated to be $7178.98. The ongoing cost of replacing subsystems as they are damaged from the fire experiments is calculated to be $781.02, approximately every four (4) tests.

There were no prototypes created to test the performance of the device due to time and cost restraints. A project delivery plan is provided in this Report to ensure the device meets the requirements agreed upon by the client and the design team.

This Report recommends FRNSW purchase four new load cells. The model description of the recommended load cells from Kelba (Australia) Pty Ltd is 'SCAIME Model SK30X "S" Type Load Cell, IP68, Stainless Steel, 2000kg Capacity, 10 metre cable, IP68, Hermetically Sealed.'

This Report recommends an experiment be conducted to determine the incomplete combustion correction factor when converting mass loss rate to heat release rate as a function of the CO and CO_2 ratio.

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1. Introduction

Fire and Rescue NSW (FRNSW) in conjunction with Prof. Guan of UNSW have proposed a project for students studying at UNSW undertaking the final year engineering design subject; MECH4100 - Mechanical Design 2.

FRNSW is one of the world's largest urban fire and rescue services that work to improve community safety, quality of life and confidence by minimising the impacts of hazards and emergency incidents on the economy, environment and people of New South Wales. FRNSW's research department is internationally recognised with their research into fire behaviour helping protect the lives of firefighters and improving the safety of the general public [1].

FRNSW's research department employ computational fluid dynamic (CFD) engineers who conduct simulations to assist with FRNSW's ongoing research goals. The quality of the results of FRNSW's CFD fire simulations are only as good as the quality of the input data. The input data for the simulations can come from information gathered during real fire experiments.

FRNSW have engaged FRNSW Group 1 to design a device that will allow more information to be gathered from real fire experiments. The information gathered from the design will assist the CFD engineers in obtaining better results from their simulations furthering the research capability of FRNSW. These results can potentially lead to the improvement of relevant Australian Building Codes and Australian Standards and consumer products.

The device is to measure two parameters during a full scale fire experiment:

1. The mass loss rate (MLR) which can be used to calculate the heat release rate (HRR) and,
2. The heat flux

Section 2 of this Report summarises the design process that the design team undertook to achieve the design. Section 3 of this Report details and specifies the weighing platform design solution. Section 4 describes relevant validations as per customer requirements. Section 5 provides a project delivery plan to evaluate the performance of the device to ensure it meets requirements and specifications. Appendix B - Operations Manual provides an operations manual outlining correct and safe use of the device. Shown in Appendix K - Engineering Drawings are the engineering drawings for fabrication of the device.

1.1. Problem Definition

Through consultations with the client Morgan Cook from FRNSW and Professor Guan Yeoh on 16/08/2016 and 18/08/2016 (evidence provided in Appendix H –Minutes) a problem definition was formed by the design team.

To design a system that is capable of determining the heat generated from the mass change of the combustion of objects.

1.2. Background Information

1.2.1. Basics of Fire

The impetus for much of the research undertaken in the field of compartmental fire engineering falls under three broad categories. The first is either for the health and safety of the emergency response firefighters; the second is for fire forensic investigators to determine the source of a fire or the last is for the design of improved fire protection systems.

Compartment fires are significantly different to open fires due to the difference in their limiting factor. Compartment fires are limited by oxygen as there are usually only a handful of ventilation points in a room (e.g. door, window). Open fires, such as bush fires, are fuel controlled such that they are limited by the mass of combustible material. This has the main effect of changing the development of the fire and the temperatures reached at each development stage. In compartmental fires the development stages of a fire can be broken down into 5 main stages.

1. Ignition
2. Growth
3. Flashover
4. Fully Developed Fire
5. Decay

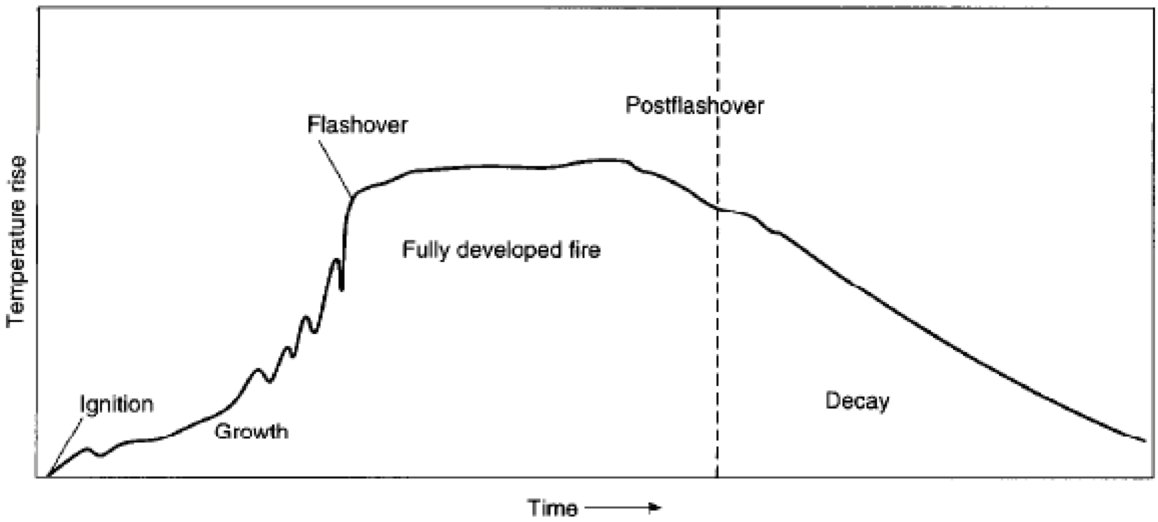


Figure 2: Fire Growth Curve [2]

Flashover is one of the most important stages as it causes the most rapid change in the fire development. Flashover occurs at approximately 600 degrees C. For a compartment fire, the restricted oxygen levels mean that a fully developed fire maintains a temperature around 1000 degrees C.

1.2.2. Fire Resistance Level

The fire resistance level (FRL) is an indicator of a material's resistance to fires. A FRL is useful in the design of fire rated building materials. The FRL composes of three (3) categories given in order as; structural adequacy, integrity and insulation. Structural adequacy relates to the material's ability to act as a load bearing. The integrity is the ability to prevent the transfer of flames and hot gases. The insulation is the ability to maintain the temperature of the surface furthest from the flames. Each of these categories is expressed in minutes as an indicator of how long they last in each category and is in accordance to AS1530.4 [3].

1.2.3. Heat Release Rate

Heat release rate (HRR) is defined as the heat transferred over time from a fire towards its surroundings. HRR is the most important parameter that characterises a fire as it defines various other parameters of the fire such as rate of temperature change and the concentrations of products of incomplete combustion. HRR also allows the estimation of fire growth and temperatures in structural fires [4]. HRR varies for different materials due to the nature of the combustion and is therefore necessary for experiments to calculate the HRR.

Biteau et al. outlines three (3) methods to determine the HRR in fire experiments [5]:

- Mass loss rate
- Calorimetry

- Heat flux

One of the simplest approaches to measure HRR is through mass loss rate ($\dot{m}$). Biteau et al. found a simple method for calculating the HRR can be obtained by knowing the heat of combustion (H) of the material burnt [5]. Babrauskas has also stated that the mass loss rate is proportional to the HRR as expressed in the following expression [6].

$$\dot{q} = H\dot{m}$$

This expression however assumes the complete combustion of the material. Since incomplete combustion is likely to take place, the HRR calculated is likely to be overestimated. Biteau et al. suggest incorporating the CO/CO_2 ratio to accommodate this error since the production of CO releases less energy than CO_2 however this would require gas analysis of the exhaust gases [5]. Such measurements are possible in future work. This mass loss method is simple due to the minimal required parameters however an understanding of the material that is to be burnt and its heat of combustion is needed.

A more complex and costly, but more accurate method to measure HRR is through calorimetry [5]. This method uses mass balance in stoichiometric equations of combustion to determine the heat release rate. The mass balance is determined from measurements of the gas concentrations and mass flow rate of the exhaust gases. Calorimetry is categorised into two categories; Oxygen Consumption (OC) if oxygen concentration is measured or Carbon Dioxide Generation (CDG) if carbon dioxide concentration is measured. The OC method uses the direct proportionality of oxygen consumed to combustion heat released within 5% of uncertainty for common combustible species where the proportionality constant is 13.1 MJ/kg of oxygen consumed [5] [7]. Similarly CDG relies on the proportionality of the CO_2 (13.3 MJ/kg of CO_2 produced within ±11%) and CO (11.1 MJ/kg of CO produced within ±18%) generated instead of consumed [5]. Biteau et al. have produced equations for the OC and CDG that use these values for the calculation of the HRR [5]. These methods prove to be very useful for materials that have unknown properties, however it makes several assumptions which lead to various uncertainties.

1.2.4. Heat Flux

Heat flux is the rate of heat energy that is transferred per unit surface area and is measured in kW/m^2 [2]. The heat flux can provide an indication of what can be ignited through radiant heat energy from fires [4]. Hence, a heat flux threshold that can cause ignition can be considered in the design of materials used in commercial products such as furniture or building materials in regards to safety. A high heat flux can potentially be lethal to occupants.

Generally, the heat flux is linearly proportional to the HRR [8]. The following equation calculates the incident heat flux from a fire to a target.

$$\dot{q}'' = \frac{x_r \dot{Q}}{4\pi R_0^2}$$

Where q'' is the heat flux, x_r is the radiant fraction, $\dot{Q}$ is the total heat release rate, R_0 is the distance from the target to the centre of a flame [9]. This equation applies to simple point source fires in which it is assumed there is a point within the fire that is the energy source. The radiant fraction relies on the fuel source's soot fraction, the amount of soot that is produced from the flame.

Several standards are available that outline the use of heat flux sensors within fire experimentation. The following standards have been provided by FRNSW. FRNSW wish to follow either one of these standards. The standard ISO 9705-1:2016 outlines the use of heat flux meters in fire experiments within a specifically designed room. At a height of 26 mm ±5 mm above the floor, a heat flux meter should be situated facing upwards at the centre of the room. ISO 9705 requires the use of water cooled Schmidt-Boelter (thermopile) type heat flux meters that are designed for 50 kW/m^2 heat fluxes and calibrated according to ISO 14934-3. Furthermore, the meter should be designed within the specifications outlined within the standard with a coat of a durable matte black finish on the meter's receiving face.

Similarly, the standard E603-13 has specified certain features that relate to how heat flux is measured. E603-13 identifies four ideal locations of heat flux meters:

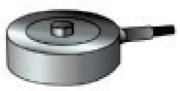
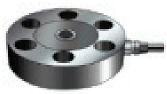
- One being as close as possible to the product or specimen that is initially ignited,
- Any fuel specimen that is likely to be involved in the fire spread,

- Remotely placed however within the confines of the compartment
- And outside the compartment viewing openings such as doors and windows.

1.2.5. Load Cell

A load cell is a transducer which can measure the force applied. There are a number of different types of load cells. The advantages and disadvantages are given in Table 1.

Table 1: Typical compression load cells [10]

Load Cell Type	Button Load Cell	Through Hole Load Cell	Pancake Load Cell	S-Type Load Cell
Diagram				
Description	Ideal for measuring compression force applied axially. They are compact and easy to use.	Rugged, industrial load cell for compression or tension forces. Hole with threads for attachment.	High capacity load cells up to 100 klbs for compression or tension load measurement.	Ideal for compression measurements, provide superior side load rejection, fit to restricted environment

Several factors can affect the load cell accuracy. The following specify standard operating techniques for optimal functionality of load cells.

- Ensure the load applied on the load cell is within the specification given by the manufacturers and ensure the floor or structure underneath the load cell withstands enough stress to bear the whole weight.
- During operation, the applied load must be solely borne by the load cells.
- The weight force on the load cell must purely be from the equipment weight itself and not from environment factors. Shock loading, vibrations, wind loading can cause result deviations.
- Interference with signal transmission such as radio frequency interference (RFI) and electromechanical interference (EMI).
- Moisture can reduce the capacitance between signal lines when present in the weighing junction box [11].

1.3. Requirements and Deliverables

Upon consultation with the Client, the requirements and deliverables for the project were established by the design team and are provided in this section.

The key deliverables to this project were:

1. A design report showing due diligence to the design process and specifying the final product design including engineering drawings for manufacture.
2. A project delivery plan proposing a recommended method to ensure the device is designed and manufactured according to all requirements.
3. An operations manual specifying safe and correct usage of the device

The requirements were categorised into two categories, functional requirements and technical requirements. Table 2 describes the functional requirements specifying tasks the system should do. Table 3 describes the technical requirements specifying the attributes and other non-functional constraints including quality.

Table 2: Functional Requirements

Item	Title	Description
FUNC_1	Portable	Able to be moved around FRNSW testing site using available resources and at minimum risk to manual handling.
FUNC_2	Fire Tolerant	All systems must withstand temperatures from a fully developed fire of at least 1000 °C for at least one hour in a single experiment.
FUNC_3	Electrical	Electrical systems are to be appropriately shielded from the high temperatures of the experiment
FUNC_4	Maximum load	The weighing platform is to be rated to a gross maximum of 8000 kg. This does not include overload loading.
FUNC_5	Level	Platform surface must be flat during use
FUNC_6	Water Resistant	Extinguishing of fire with water or other substances is not to damage any component of the system
FUNC_7	Corrosion Resistant	The system is to be suitably corrosion resistant
FUNC_8	Measuring Parameters	The system must measure the mass loss change with a maximum of 2 kg resolution. The system must be capable of measuring the heat flux.

Table 3: Technical Requirements

Item	Title	Description
TECH_1	Dimensions	3.6 m x 3.6 m (W x L)
TECH_2	Sensor Safety	During movement of the weighing platform, measurement sensors are to be appropriately protected and handled to avoid damage to the measurement sensors.
TECH_3	Hazard	System materials should be non-hazardous to operators or the environment during operation or at any time during its life cycle.
TECH_4	Height	Height of weighing platform to be minimised
TECH_5	Cost	Minimise cost by using off the shelf components
TECH_6	Time	The assembly process is not to exceed 10 minutes under normal conditions. The disassembly process is not to exceed 10 minutes under normal conditions.
TECH_7	Sensors	Measurement sensors are not significantly affected by heat generated from experiments
TECH_8	Factor of Safety	A reasonable factor of safety must be used.
TECH_9	Special Tools	Special tools are to be minimised for assembly and disassembly

1.4. Project Plan

A project plan was created by the team to effectively manage the various requirements and complex systems engineering needs of this project. The two main documents created early on in the projects timeline were the work break down structure (WBS) and a Gantt chart. These two documents provided a clear structure for the group ensuring deliverable or requirements were not forgotten and on schedule. The WBS is provided in Appendix F – Work Breakdown Structure. The Gantt chart is provided in Appendix G – Gantt Chart.

2. Conceptual Design

This section provides a brief summary of the concept design phase the design team went through.

2.1. Morphological Matrix

A morphological matrix was used to brainstorm and choose different ideas for each subsystem. Below in Table 4 are different options the design team conceived for each subsystem. Highlighted are the options which the design team determined would best suit this design.

Table 4: Morphological Matrix - A Summary of Competing Options for Each Subsystem

Subsystem	Option 1	Option 2	Option 3	Option 4
Dimensions	3.6 m x 3.6 m	3.6 m x 2.4 m		
Platform Style	Checker with I beams	Flat Plate	Ladder	Diagonal
Portability	Wheels Plus ramp to go onto trucks	Detachable Jockey Wheels	Forklift Holes with rotation system	Secondary pulley/lift system
Levelling	Levelling screws	Packing slips with forklift	Packing slips with places to put jack in	Jockey Wheels and packing slips
Temperature Shielding & Electrical System	Fire Resistant Cables (glass ceramic sheath)	Active Cooling system of load cells and cables	Heavy Insulation with Gyprock around cables and load cell	
Material Of Fire Rated Top Layer	Fibre Cement	Gyprock	Metal, 'Hebel' Composite	
Heat Flux Sensor	Not at all	Yes with fixed mount	Yes with movable mount like a camera tripod	Yes with retort stand mount.
Load Cell Resolution	1 kg	2 kg	16 kg	
Load Cell location	On the Corner	10-30 mm in from corner.		
Load Cell Attachment	Plate	L Shape	Shear pin design	

Appendix E - Conceptual Design outlines each subsystem, decides the successful option for each subsystem and provides an explanation of why the chosen option was successful.

3. Detailed Design

This section presents the final design solution specifications and reasoning's for design decisions. The weighing platform device which has been designed by FRNSW Group 1 satisfies the design problem by ensuring the mass loss rate can be accurately measured to ultimately calculate the goal state parameter, the heat release rate.

3.1. Systems Overview

Table 5 provides a summary of each system in the device detailing the description, function and material of each system. For materials denoted N/A, they are either commercial off the shelf products such as the jockey wheels or systems which FRNSW already own such as the heat flux mount and heat flux sensors.

Table 5: Systems overview

Name	Description	Function	Material
Steel Frame	Ladder frame design with holes and welds at various locations allowing connections to other systems.	Load bearing structure.	DuraGal C450 steel
Platform Top Layer	Bi-layered platform sitting on top of the steel structure.	Composite system to stop heat transfer from fire to load cell and flat platform allowing safe usage by operators.	Bottom layer - mesh steel. Top layer – 'CSR Hebel'
Lifting Points	Four, AS 4991.1 compliant lifting points welded on the underside of two c-channel sides of the steel structure.	Allows device to be moved onto a truck or onto high platforms through the use of a crane.	Steel
Load Cell	Four "S"-type load cells of 2 tonne capacity with combined error of 0.0017%. Located on each corner of the steel structure.	To measure the mass loss rate.	Hermetically sealed stainless steel

Table 4: Systems overview (continued)

Name	Description	Function	Material
Load Cell Attachment	Top and bottom parallel plates with M16 holes bolts and shear pins. Bottom plate has an extra hole for masonry anchoring.	Connects steel structure and load cell ensuring no lateral movement. Connects load cell to besser blocks underneath.	Steel
Jockey Wheels	Attaches to jockey wheel mount. Product code is JW8CHD.	Allows for portability around FRNSW testing site and for levelling process.	N/A
Jockey Wheel Attachment	Plate with unthreaded holes. Welded on two parallel sides of the steel structure.	Connects jockey wheel to steel structure.	Steel
Besser Blocks	Placed underneath the load cell attachment.	Ensures load cells have direct action to the ground.	Concrete
Heat Flux Mount	Placed anywhere on platform during experiments. Consists of a retort stand, boss head and clamp.	Secures the heat flux sensor.	N/A
Heat Flux Sensor	Clamped by the heat flux mount.	Measures the heat flux.	N/A
Thermal Shielding for Electrical System	Placed around the steel structure in a skirt arrangement.	Shields the load cells and load cell cables from fire radiation.	Fire rated plasterboard, - ‘CSR Gyprock Fyrcheck’

3.2. System Representation

Figure 3 shows the final design as an exploded view.

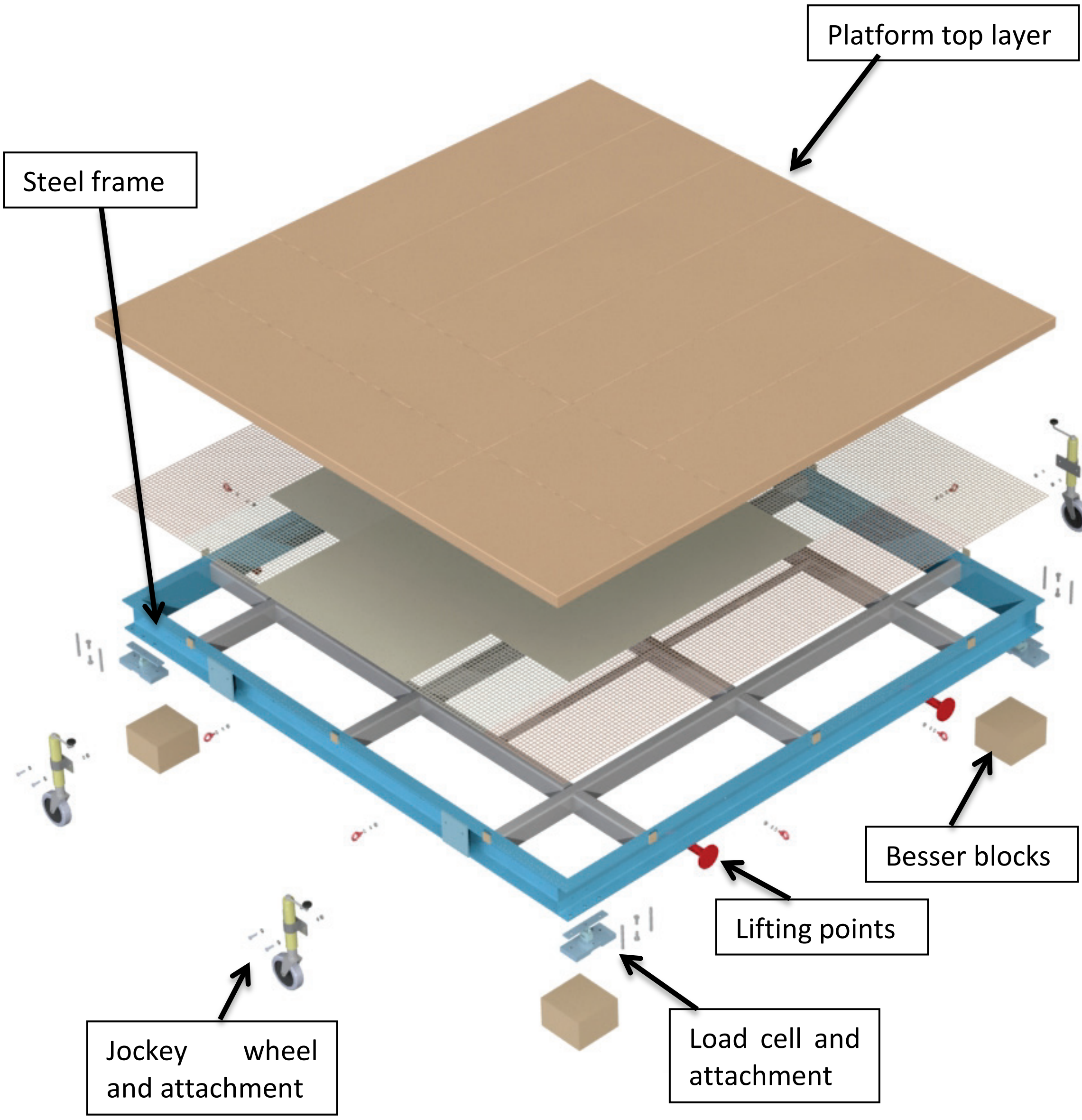


Figure 3: Exploded view of final design

3.3. Component Design

3.3.1. Steel Frame

The purpose of the steel frame is to support an applied load and distribute it evenly across the four load cells. The steel frame is the central system of the device to which other systems connect. Due to the centrality of the steel frame, other systems which attach to it will not be discussed in this subsection. The engineering drawing of the steel frame arrangement is given in Appendix K - Engineering Drawings. Figure 4 shows the steel frame.

The steel frame has the following properties:

- Overall ladder style shape for potential loads distributed on a centrally located area.
- Steel of grade C350 (OneSteel Duragal C450) satisfying the corrosion resistant requirement.
- Shape of steel members: RHS Beams and PFC beams.
- 3.6 m x 3.6 m.

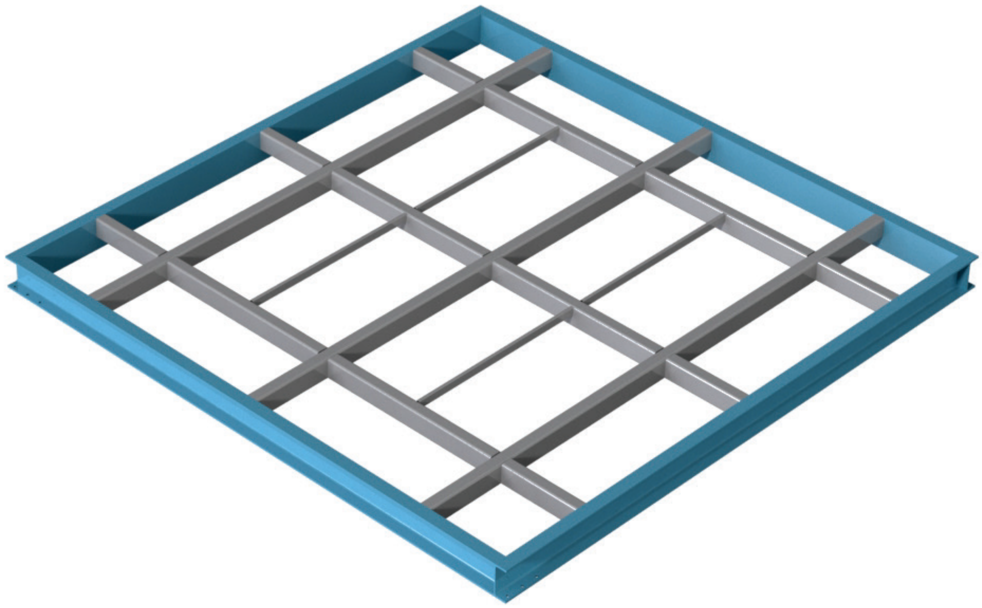


Figure 4: Steel frame

To minimise the costs associated with fabrication, all steel members comply with AS/NSZ 1163 and AS/NSZ 3679.1 standards – this ensures that parts for the assembly are readily available.

Tabs are welded on the sides protruding upwards. They are to secure the 'CSR Hebel PowerWall' panels to ensure they do not slip off during testing and during transportation. The side tabs have been chosen to be 50 mm high as this allows the user to easily access the 75 mm Hebel blocks to unload and reload when necessary. It also ensures that if the device is transported by towing with the jockey wheels on and with the Hebel blocks in place over bumpy terrain, the Hebel blocks will not jump out of their location and remain on the platform bed. This assumes a slow speed of towing dependent on the bumpiness of the terrain.

A number of other systems are attached onto the steel frame including jockey wheel mount plates, lifting points, eye bolts.

The structure must sustain 8000 kg (from requirements). The steel frame is the load carrying component in this system. To ensure the steel frame can withstand this load without failing, a finite element analysis of the structure is provided in section 4.

Weldments are divided into three main types. Appendix D –Weldment Analysis calculates the corresponding weldment height of these three types:

1. 125x75x5 RHS welded to 125x75x5 RHS or 200 PFC – 5 **mm high**
2. 50x20x2 RHS welded to 125x75x5 RHS – 3 **mm high**
3. 200 PFC welded to flat surface of 200 PFC – **8 mm high**

To simplify the weld analysis process, the most stressed joint was analysed for welding analysis as provided in section Appendix D –Weldment Analysis. The weld most likely to take the highest sustained load is the weld in the middle of the structure. The same weld dimension will be applied to other welds in the analysis. All unwelded sides of the connections are to be V-butt welds which are not suitable for calculation. Due to the uncertainty in the real welding strength (V-butt weld not included), common sense dictated high levels of safety factors to achieve reasonable weld heights. Welding is to be carried out to AS 1554.1 [12].

3.3.2. Platform Top Layer

The platform for this design is the flat section on top of the frame. The platform has two functions. The first is to thermally insulate the load cells from the fire on top of the platform. The second function is to evenly distribute the load over the whole structure.

Top layer is galvanised steel mesh. A solid sheet of steel added excess mass to the platform, decreasing its total payload. Furthermore, mesh allows for any water used in fire extinguishing to drain. The mesh is tacked to the steel frame. The mesh also doubles as a platform for FRNSW personnel to walk on when the Hebel is replaced.

On top of the sheet steel is AAC. CSR supply AAC in Australia under the brand name 'Hebel'. FRNSW already purchase this product and are familiar with its material properties and handling requirements at their test facility. The 'Hebel PowerPanel' product was chosen as it is CSR's only product that has flat edges allowing for easy assemblage and comes in the appropriate size. This product is manufactured in accordance with AS3700 [13]. 'Hebel PowerPanel' has a high FRL. Table 6 shows the FRL for various 'Hebel PowerPanel' thicknesses.

Table 6: Fire resistance level

Panel Thickness (mm)	Fire Resistance Level (minutes)
75	60
100	120

The thickness of the 'Hebel PowerPanel' recommended to be used is 75 mm because 100 mm thick panels results in a prohibitive mass increase. Section 4.3 provides a transient thermal analysis showing that a fire on top of the structure will not cause the load cells to increase to a temperature over their operating temperature after one hour has elapsed.

3.3.3. Lifting Points

Lifting points on the edges of the device have been added to assist with the portability of the device. Lifting points allow a crane or other machine to lift the device in and out of a truck. The lifting points satisfy AS 4991 – 2004 as described in section 4.2 [14]. The lifting points are shown in Figure 5.The lifting points engineering drawings can be found in Appendix K - Engineering Drawings.

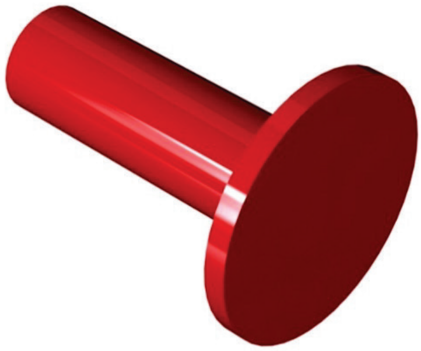


Figure 5: Lifting points

The lifting points are to be welded onto the steel frame. The weldments analysis is provided in section 4.

3.3.4. Load Cell

The purpose of load cells in this design is to measure the mass loss rate. The load cell weighs the mass of the device above it and the load. Since the mass of the platform does not change, load cells will measure the mass loss due to combustion. The load cell is shown in Figure 6.

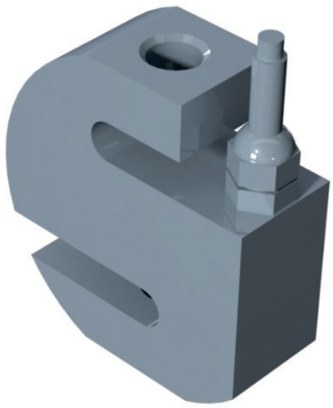


Figure 6: Load cell

The load cell type used in this device is to be S-type. S-type load cells use a strain gauge to measure the deflection of the load cell material which is then converted into an electrical signal and therefore, weight. The reason that an S-type load cell is recommended is due to low the combined error for large masses. Combined error is synonymous with resolution. The recommended product is the ZA30X 2 tonne capacity S-type load cell which can be procured from SCIAME Pty. Ltd.. An engineering drawing can be found in Appendix K - Engineering Drawings.

The maximum combined error for the ZA30X is 0.017%. This translates to a total resolution with the four load cells (on each corner) of 1.36 kg. A larger combined error is not recommended as this will cause a greater resolution which may not generate useful data.

The operating temperature for the ZA30X is - 10 ^{0}C to + 40 ^{0}C. This means it is important during testing that thermally insulating material is placed in front of the load cells to shield them from the radiant and convective heat emanating from a fire on top of the platform. Section 3.3.10 describes the system to rectify this problem.

In addition, it is recommended that thermocouples are placed in the near vicinity of the load cells to ensure that during experiments, the load cells temperature did not exceed the operating temperature range.

3.3.5. Load Cell Attachment

The purpose of the load cell attachment is to secure the load cell to the steel frame above and to the besser blocks below. The pins on the side also act to ensure that the M16 bolts that attach the load cell to the frame and the besser blocks do not fail in bending. Appendix K - Engineering Drawings provides engineering drawings of the load cell attachment. Figure 7 shows the load cell attachment.

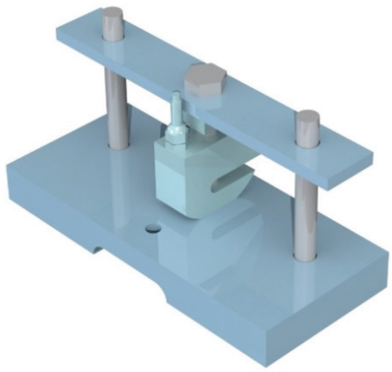


Figure 7: Load cell attachment

The load cell has a small contact area on the top and bottom surfaces and if there was any lateral motion on the platform it would cause the load cells to tip. The load cell attachment therefore has pins which transfer lateral motion, or relative motion of the platform to the besser blocks, into stress of the pins.

The load cells are arranged such that the cable points upwards and the cable is outboard and clear of the side flange channel of the steel structure. This to allow for an appropriate bend radius acting on the cable inverting the load cell would cause the cable and bottom load cell mount plate to interfere.

3.3.6. Jockey Wheel

Jockey wheels have two functions in this design. The first is for portability around the fire testing site for FRNSW. Jockey wheels serve an easy and efficient way to move the device around the fire testing site and allow quick assembly and disassembly. The second function is levelling. Levelling of the platform is necessary for the load cells to be accurate. Jockey wheels can move individual corners up and down allowing packing slips to be placed under each corner resulting in a flat platform for use in experiments. Figure 8 shows the jockey wheel and attachment plate.

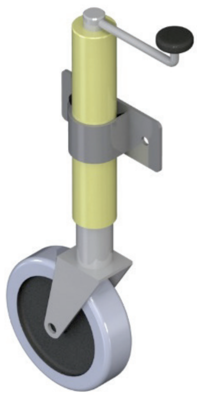


Figure 8: Jockey Wheel and attachment plate

Four (two on each side) JW8CHD heavy duty jockey wheels will be used in the design. Four jockey wheels were chosen as together they provide a loading capacity of 2 tonnes which is less than the unloaded platform. The unloaded platform weight was used for the capacity requirements as the jockey wheels are to be removed before each fire experiment. Properties of the jockey wheel are:

- 20 mm steel rims
- Solid rubber wheel
- Rust resistant
- Dacromet Finish
- 500 kg weight capacity
- 250 mm extension

Since the device does not have a dedicated braking system, it is recommended to the Client that the platform is moved around the facility using manual force (in accordance with the Clients' safety management policies) at a slow speed. Eye bolts are provided on four sides of platform for the attachment of towing ropes or chains. *Note that these eye bolts are not for lifting purposes.*

The jockey wheel specified includes a quick release mount. This quick release mount is to enable the jockey wheels to be removed whenever the platform is used for fire experiments as the plastics and rubbers on the wheel will degrade in high temperatures. The quick release mount included with the jockey wheel is to be bolted to the jockey wheel plate using the bolt sizes required by the jockey wheel.

3.3.7. Jockey Wheel Attachment Plate

The purpose of the jockey wheel attachment plate is to allow the jockey wheels to be attached and detached from the frame quickly and with minimum manual handling for each experiment.

The jockey wheel attachment engineering drawings are given in Appendix K - Engineering Drawings. The jockey wheel attachment plate is to be welded on to the side of the steel structure. The weldment type is a V type butt weld on both the top and bottom sides.

3.3.8. Besser Blocks

Jockey wheels attached to the steel frame have a minimum length greater than the height of the load cells. This leads to a situation where the load cells do not touch the ground. Besser blocks function as a support for the load cells allowing the load cells to interact with the ground whilst still letting the jockey wheels move up and down during the levelling process.

3.3.9. Heat Flux Mount

The purpose of the heat flux sensor is to measure the heat flux. The client already owns the SBG01 'Huskeflux' sensor. The heat flux sensor mount has been designed to allow easy operation, cheap fabrication costs and multi degrees of freedom. The mount system is a retort stand made up of a base, support stand, a boss head and a clamp as shown in Figure 9. The retort stand can be placed on a platform. The clamp holds in place the heat flux sensor. The heat flux sensor and mounting system are to be used in accordance with ISO 14934 [15] and AS/ISO 9705 – 2003 [16].

Figure 9: Heat flux and mount

3.3.10. Thermal Electrical Shielding System

This system ensures the load cells and the cables running off the load cells do not heat up to an extent where it causes invalid results or failure respectively. Fire rated plasterboard such as 'CSR Gyprock Fyrchek' is recommended to be placed around the side of the frame similar to a skirting board. A thickness is not specified as experiments are required to determine an adequate thickness. This is due to high complexity in running a computer simulation to determine the thickness.

3.4. Mass Budget

Table 7 provides a summary of the mass of each system and a total mass of the entire, unloaded device in normal use case operation.

Table 7: Mass budget

Part	Quantity	Mass (kg)
Steel Frame	1	633
Loading Points	4	3.7
Load Cell Attachment	4	13.04
Load Cell	4	9.72
Jockey Wheel	8	31.2
Jockey Wheel Attachment	8	7.2
Besser Blocks	4	66
Top steel sheet	1	66
	Total	1476

3.5. Cost Analysis

The cost of the weighing platform device consists of,

- Cost of fabrication of the steel platform
- Cost of various commercial off the shelf components and equipment.
- Shipping of the steel structure from the fabricators to the FRNSW testing site

Cost of fabrication for the steel structure should be billed as one job including cost of materials, cost of machining and cutting all steel parts and welding together all the parts. Estimating the cost of fabrication, Australian Steel Institute estimates steel fabrication costs of $4000 per tonne in NSW [17]. This figure includes the material cost and processing. From the mass budget in section 3.4, the mass of the steel structure is 625.29kg. Therefore the steel fabrication rate is $4000/tonne. The mass of the platform is 633 kg. Cost of fabrication is therefore $2532.00.

All other components and equipment are available commercial off the shelf with approximate cost estimates and suppliers summarised in Table 8.

Shipping to the test site is also added into the costs with Mainfreight quoting approximately $462.00 [18].

The cost of the test plan to ensure the final product satisfies all requirements given in section 5.3, will incur costs totalling $720.00. Table 8 provides a summary of the upfront cost estimates.

Table 8: Summary of upfront costs

Item	Supplier	Catalogue	Qty	Unit Price	Cost
Fabrication	OneSteel [17]	-	-	-	$2501.16
Testing	-	-	-	-	$720
Shipping	Mainfreight [18]	-	-	-	$462
Load Cells	Scaime [19]	ZA30X	4	$611.60	$2446.40
Jockey Wheels	Boat Trailer Spares [20]	JW8CHD	4	$75.50	$302
Besser Blocks	Bunnings [21]	3450457	4	$3.60	$14.40
Hebel Panels	BC Sands [22]	-	9	$86.78	$781.02
Welded Mesh	Blackwoods [23]	0158 3956	2	$147.27	$294.54
Jockey Wheel Bolt	Konnect Fasteners [24]	12X30MGBN	8	$0.93	$7.44
Jockey Wheel Nut	Konnect Fasteners [24]	12M8GN	8	$1.20	$9.60
Jockey Wheel Washer	Konnect Fasteners [24]	12MGW	8	$0.19	$1.52
Jockey Wheel Spring Washer	Konnect Fasteners [24]	12MGSW	8	$0.102	$0.82
Eye Bolt	Blackwoods [25]	0099 2637	4	$12.64	$50.56
Eye Bolt Nut	Konnect Fasteners [24]	12M8GN	4	$1.20	$4.80
Eye Bolt Washer	Konnect Fasteners [24]	12MGW	4	$0.19	$0.76
Eye Bolt Spring Washer	Konnect Fasteners [24]	12MGSW	4	$0.102	$0.41
Load Cell Mount Bolt	Konnect Fasteners [24]	16X40MGBN	8	$0.93	$7.44
				Total	**$7604.86**

The only destructive component in the device which requires maintenance costs is the 75 mm thick ‘CSR Hebel PowerWall’ thermal top layer which has a fire rating level of 60 minutes. If we are to assume each burn takes 60 minutes and the panels will degrade to

75% of their original performance after each fire test, approximately after every four fire tests, nine (9) new ‘CSR Hebel Powerwall’ panels will need to be bought. The ongoing cost therefore is **$781.02 per four (4) fire experiments**. This assumes that each burn has flame impinging directly on the Hebel. Often this will be not the case and therefore may be less than this.

3.6. Animation link

An animation of the device and its components is provided at:

https://www.youtube.com/watch?v=BiQDYzV6a74&feature=youtu.be

4. Validation

4.1. Steel Frame

A static structural analysis of the platform design was conducted in ANSYS Workbench 16.2. The platform was simplified by removing the accessories. A worst case loading scenario where the 8 tonne load was concentrated to the middle of the platform was examined. Several assumptions were made including,

- Material is isotropic and homogeneous,
- Singular rigid body rather than multi-member system with welded connections,
- All the loads applied to the platform will be assumed to be of uniform distribution,
- The load is assumed to be directly transferred to the load cells,
- Operation at standard atmospheric temperature
- Heat from fire assumed to have no changes to the material properties as thermal insulation sheets have been used at relevant points to protect the steel frame

An 8000 kg was applied as shown in Figure 10. The four corners where the load cells were placed were taken as fixed supports. An unstructured but fine mesh was used. The mesh was concentrated at points of high stress. The middle beam is a stronger grade steel. All material properties were taken from manufacturer's website [26].

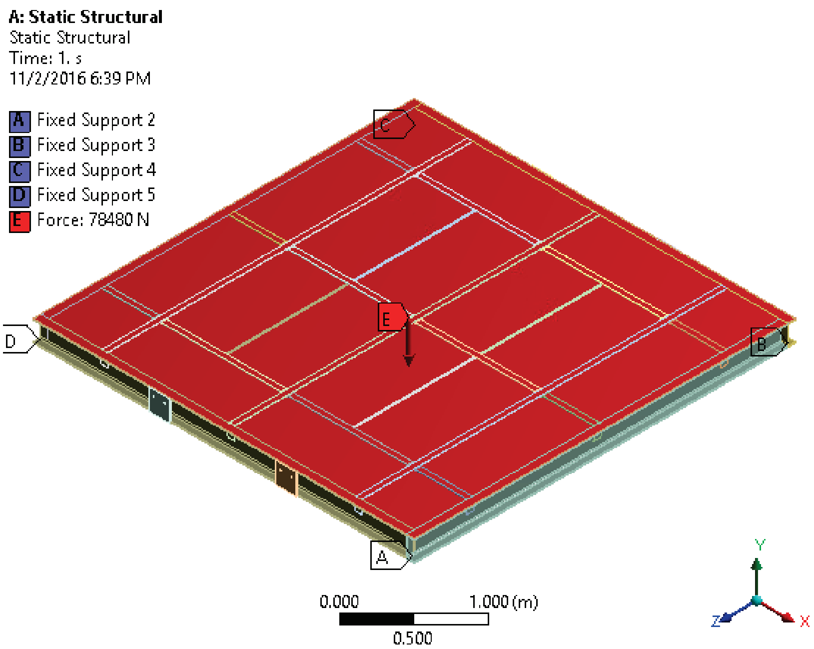


Figure 10: Boundary conditions of the platform (isometric view)

The maximum obtained stresses occurred at the middle member and the four small RHS' beams. Considering the yield strength of the middle member (350 MPa) and the small RHS beams (250 MPa) a factor of safety of 4.18 and 3.16 was found respectively. This complies with the AS 4100 [27]. Analytical calculations provided in Appendix I – Steel Structure Analytical Validation aim to validate the FEA results. Table 9 below shows the error between the obtained stresses for the hand calculation and the FE simulation.

Table 9: Error calculation

Beam	Stress (Analytical) (MPa)	Stress (FE Simulation) (MPa)	Error (%)
C-Section	22.62	39.96	75%
Middle RHS beam	47.38	83.70	77%
Small RHS	24.34	79.06	225%

As seen from the table, there is some discrepancy between the results. This is largely due to the assumption that the beams were assumed to be simply supported in the analytical calculations whereas in the FE simulation, there is bending in the adjacent beams. An average error of 125% was considered to be appropriate. Hence, the analytical calculations validate the FE results and provide a good estimate for the stresses on the platform.

4.2. Lifting Points

A static structural analysis of the lifting point was conducted in ANSYS Workbench 16.2. The lifting point was simplified by removing the end plate. The model used was 24 mm (R) and 100 mm (L). Another simplification was the removal of the 75 mm section that had to be welded to the platform. Boundary conditions consisted of a load of 500 kg that was subjected onto the lifting point and a fixed support that was on the end that had to be welded onto the platform as shown in Figure 11. Structural steel of yield strength 250 MPa was used as the material.

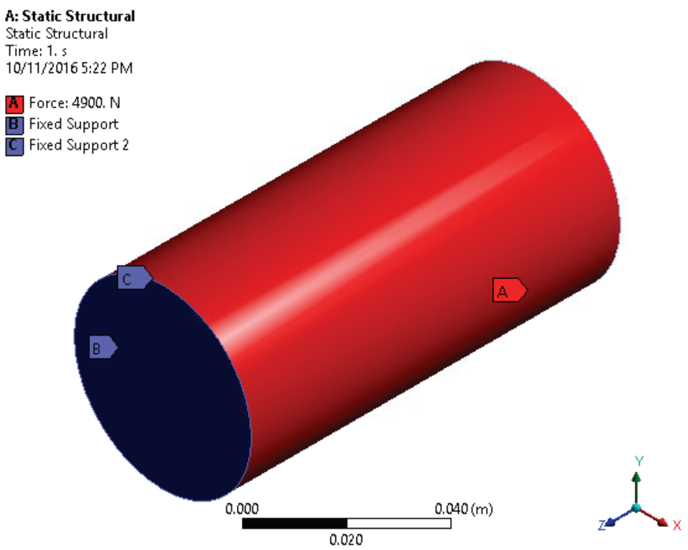


Figure 11: Boundary conditions of the lifting point

A maximum stress of 38.36 MPa was obtained. This stress results in a safety factor of 6.52 which is well within the limit specified in section 2.2.2 of the AS 4991 [14].

Fatigue life analysis was also done for the lifting point. The results obtained allowed for 1 million lifting cycles at the specified working load. This is also well below the specified limit of 20 000 cycles in section 2.2.2 of the AS 4991 [14]. The safety factor obtained was 2.25 as shown in Appendix J –FEA Results. This is again, greater than the specified limit. Hence, it can be concluded that the lifting that is to be used on the platform is ideal and should be able hold the required load of 500 kg.

4.3. ‘Hebel PowerPanel’

A time dependent thermal analysis was conducted in Ansys Workbench 16.1. The model used was 100 mm (L) x 100 mm (W) x *variable (75 mm and 100 mm)* (H). The material properties were taken from the technical data sheet on the ‘Hebel PowerPanel’ website [28]. The initial conditions were set to be 20 ^{0}C. The boundary conditions were set as no heat loss from the sides and a constant heat source on the top set at 1000 ^{0}C as shown in Figure 12. A fine, structured mesh was used. The analysis was set up for 3600 seconds with 3 steps, with each step comprising of 1000 sub steps.

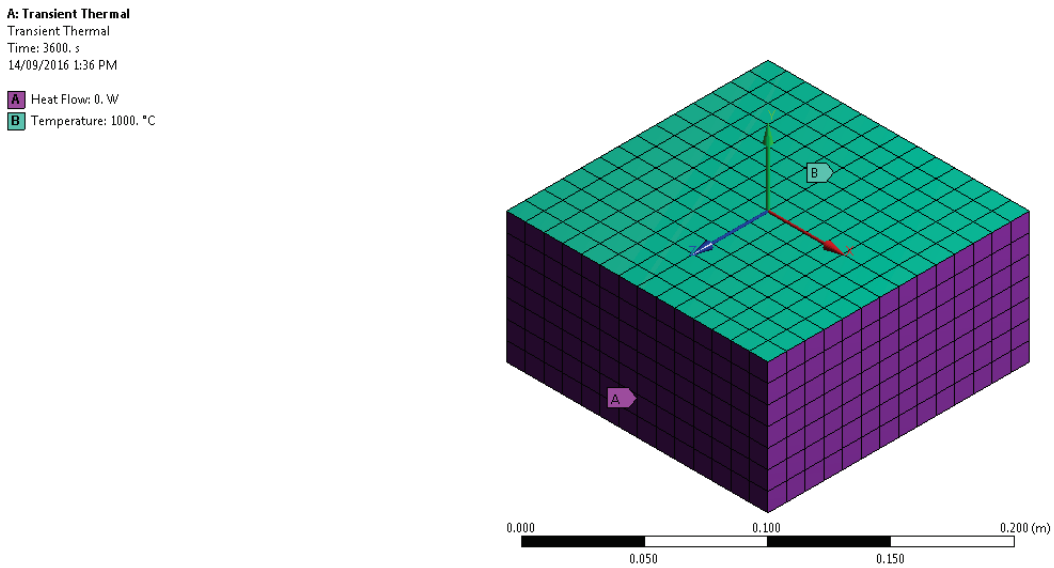


Figure 12: Boundary conditions for transient thermal analysis

Results from this experiment showed that over 3600 seconds, the 75 mm ‘Hebel PowerPanel’ would reach 134.34 ^{0}C whilst the 1000 mm would reach 47.06 ^{0}C.

The major assumptions made in this analysis were; no heat loss to surroundings of the ‘Hebel PowerPanel’, no steel structure between the ‘Hebel PowerPanel’ and the load cell and there would be 1000 ^{0}C constantly impinging on the corner of the structure. These three assumptions will drastically affect the results. It is therefore the opinion of the author that 75 mm thick is still a viable option as thermal insulating layer.

5. Project Delivery Plan

A project delivery plan is the recommended plan the client should undertake when deciding to fabricating, manufacturing and finally test the final product.

5.1. Prototyping

No prototypes were made of this design and have therefore not been tested. It is strongly recommended a small scale 3D printed prototype be first created of the design to ensure the design satisfies the requirements outlined in section 1.3. This is also so that the client can easily see if the final design is satisfactory.

It may also be in the interest of the client to create a scaled model and test the device similar to the test plan in section 5.3.

5.2. Manufacturing Plan

Since this device is to be custom built and only one final device is to be built; only a simple manufacturing plan need be stated as the company manufacturing the device shall conduct their own manufacturing plan. Therefore this plan will provide a general framework for the manufacturing of the device.

It is recommended the client engage with a steel fabricator to build the steel frame and all other steel components. The job for the steel fabricator should include procuring the raw materials, cutting them to size (including any holes that need to be tapped or drilled) and weld the cut steel sections to form the steel frame. Fabrication and weldment onto the steel structure of the jockey wheel attachment, load cell attachment, steel tabs and sheet steel top layer all should be included in the steel fabricator job.

5.3. Test Plan

The proposed design in this document requires testing to justify the design solution outlined in section 3 adequately meets the requirements for the customer. Below are two recommended tests that ensure most of the requirements are met.

- General Inspection Test - All materials, components and joins are of sound condition and meet the requirements.
- Fire Test - Ensure all system components withstand the high temperatures for a typical burn. In particular, ensure the load cells do not exceed their operating temperature range during normal use.

These two tests constitute the test plan. The tests are intended to be conducted after manufacturing of the product and before standard use.

Table 10 maps each requirement outlined in section 1.3 to either the general inspection or fire tests. The general inspection and fire tests are given in Appendix C. Note that these tests include the acceptance criteria to which all are recommended to pass before use.

Table 10: Requirements Traceability Matrix

Requirements			Test Cases	
			General	**Fire**
Functional	**FUNC_1**	Portable	*	
	FUNC_2	Fire Tolerant		*
	FUNC_3	Electrical		*
	FUNC_4	Maximum load	*	
	FUNC_5	Flat	*	
	FUNC_6	Water Resistant	-	
	FUNC_7	Corrosion Resistant	-	
	FUNC_8	Measuring Parameters		*
Technical	**TECH_1**	Dimensions	*	
	TECH_2	Sensor Safety	*	
	TECH_3	Hazard	*	
	TECH_4	Height	*	
	TECH_5	Cost	-	
	TECH_6	Time	*	
	TECH_7	Sensors	*	
	TECH_8	Safety Factor	*	
	TECH_9	Special Tools	*	

5.4. Future Work

The current design incorporates the measurement of mass loss and heat flux. However these two parameters only characterise a subset of the dynamics and properties of a fire. Other parameters exist and if these parameters were to be collected, a more complete representation of a fire can be achieved. Other parameters are discussed below which could be incorporated into the fire testing weighing platform device specified in this report.

Currently FRNSW perform Fourier Transform Infrared Spectroscopy (FTIR) gas analysis in their fire experiments which can measure gas concentrations. This instrument can also be included in the current design to provide an alternative to calculating HRR as outlined in section Heat Release Rate1.2.3. Furthermore, by obtaining gas concentrations of the carbon dioxide and carbon monoxide, a correctional factor for the heat release rate calculated from the mass loss can be calculated. This correctional factor (currently none given in the literature to the authors best knowledge) is of critical importance for accurate readings and is recommended for FRNSW to determine through future experiments.

Temperature is a parameter that can be easily measured through the use of thermocouples. FRNSW currently use this in their experiments. Incorporating thermocouples into the design, temperatures can also be measured. The temperatures can provide an adequate impression of fire growth and distribution.

Air velocity at ventilation openings both ingress and egress surrounding a fire can be measured to provide a greater understanding of the air flow. The effect of ventilation openings such as doors or windows can be measured relative to how the gases around the fire navigate.

The room atmospheric conditions of relative humidity and pressure can also provide a better understanding of the initial conditions and how it changes as the fire progresses.

Smoke obscuration is the lack of visibility due to the production of smoke. Measuring the smoke obscuration can improve the understanding of how the fire develops. Thick plumes of smoke are a hazard to occupants and fire fighters as it limits their visibility and can hamper their ability to react accordingly to the situation.

Video surveillance is another useful parameter which records fire growth in real time. Currently FRNSW use sacrificial CCTV cameras which provide video documentation of their experiments. These cameras can be installed at various positions to adequately monitor the fire progression from different angles.

6. Conclusion

The Client engaged FRNSW Group 1 to design a weighing platform for fire testing. The goal of the final product was to measure the mass loss rate and heat flux so the heat release rate could be measured.

A thorough review of the background information regarding fire, heat release rate and heat flux found that there are a number of ways to determine the heat release rate, with the mass loss rate method being the simplest, but potentially most prone to error.

Evidence for the various concepts drafted by the design team and the general design process the design team went through is provided in section 2.

The final design was designed to relevant AS/NZS standards with specifications provided in section 3. The final design is rated to 8 tonnes and consists of a ladder frame steel structure with adequate thermal shielding from fire during experiments. Portability is a key feature with jockey wheels allowing ease of transportation around the FRNSW testing site.

A project delivery plan in section 5 proposes a method to validate the final design complies with all the requirements agreed upon by the Client and design team.

Overall, the design team are of the opinion the final design is of a standard to be used by FRNSW. Significant care has been exercised in the design process to realistically manufacture the final design at minimum cost and time to FRNSW. It is also the opinion of the design team that the device is easy to use and can generate useful data for FRNSW to further their important research.

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Appendix A – Load Cell Calculation

Maximum capacity of the required load is 8000 kg. Since there are four (4) load cells, each load cell should be rated to a fourth of the total load which is 2000 kg. The maximum combined error of the load cell, which is analogous to the resolution of the load cell, is 0.017% for the Sciame SK30X load cell. This then gives a resolution per load cell of,

$$Resolution\ per\ load\ cell = Load\ cell\ capacity \times resolution$$

$$Resolution\ per\ load = 2000\ kg \times 0.00017$$

$$Resolution\ per\ load\ cell = 0.34\ kg$$

$$Total\ Resolution\ per\ four\ (4)\ load\ cells = Resolution\ per\ load\ cell \times four\ (4)\ load\ cells$$

$$Total\ Resolution\ per\ four\ (4)\ load\ cells = 0.34\ kg \times 4 = 1.36\ kg$$

Appendix B - Operations Manual

1. Overview

This section covers the steps required to operate and maintain the weighbridge in a suitable condition. This section also includes the data processing method to convert the gathered data into the heat release rate.

A summary of the equipment and tools required for assembly, operations, disassembly and maintenance are listed below in Table 11.

Table 11: Summary of tools and equipment

Section	Tool/Equipment	Quantity
Transportation and Setup	Besser Blocks	4
	Packing Skips	-
	JW8CHD	4
	Spirit Level	1
Installation	Load Cell Assembly	4
	'Huskeflux' Flux Sensor	4
	Retort Stand	1
	M12x55 Full Thread Hexagon Bolt /w washers	8
	M16x55 Full Thread Hexagon Bolt	8
	12 mm Spanner	1
	16 mm Spanner	1
	4.2 mm Diameter Tubes	2
Disassembly	16 mm Spanner	1
	18 mm Spanner	1
Maintenance	2.4 x 1.2 m 75 mm 'CSR Hebel' Sheets	9

2. Transportation

Transportation of the weighbridge system can be done by either of the following:

- Pushing or towing the weighbridge, rolling on the jockey wheels,
- Lifting points with a suitable crane system.

To transport with jockey wheels, jockey wheels must first be attached to the flanges located on the two lengths of the weighbridge. Two M12x55 bolts are required to securely attach each jockey wheel. To transport the weighbridge using the four lifting points located on adjacent sides of the jockey wheel mounts, a suitable, rated apparatus is to be used to lift the platform the end of the crane system must be attached to all four lifting points.

Important notes for transporting the weighbridge:

- Load cells should not be attached to the assembly when the weighbridge is not in use.
  - Load cells should be kept safe in a separate storage.
- When lifting points are used, it is advised that jockey wheels should also be removed to reduce possibility of unwanted rolling when weighbridge is moved. Jockey wheels do not provide any braking or holding support.
- Hebel sheets are kept on the weighbridge at all times unless maintenance is required.
  - Note that Hebel sheets are only attached using metal tabs limiting lateral movement. Hebel sheets can move out of place in a vertical manner at any time [29]especially if transported on bumpy terrain too quickly.

CAUTION

Platform can be a CRUSH hazard when transporting by jockey wheels or lifting points. Keep clear under the platform.

CAUTION

Be mindful of sharp corners and edges when transporting.

2.1. Risk Assessment

From AS 4991 - 2.8 [14], a risk assessment is required when using the lifting points. The section states:

A risk assessment shall be undertaken by a competent person before carrying out the operation required to be undertaken by the lifting device. The assessment shall be in writing and shall take into account the following:

- The task to be carried out

- The range of methods by which the task can be done
- The type of lifting device that will be required or that can be used
- The hazards involved and the associated risks
- The actual method and the other requisite plant and material
- Emergency and rescue procedures.

As a result of the risk assessment, the competent person shall formulate a safe working method procedure, which shall be monitored for ongoing effectiveness and modified whenever it is found to be deficient, when the task changes or when the associated risks change.

3. Assembly

3.1. Placement/Set-up

The steps for placing the weighbridge is dependent on the transportation method used. For the case of using jockey wheels to transport the weighbridge:

1. Roll the weighbridge to the desired location.
2. Align the corners of the weighbridge with the besser blocks below.
3. Install load cell assembly to the weighbridge using a 16mm Spanner.
4. Retract the jockey wheel to lower the weighbridge onto the besser blocks. Using a spirit level, ensure that the platform sits level to the ground. Use packing slips underneath the besser blocks to compensate for any corners which require elevation.
5. Remove the jockey wheels.
6. Install the heat flux sensor and mount.
7. Install safe guards (Refer to 3.6).

For transportation via the lifting points of the weighbridge:

1. Lower the weighbridge ensuring that the corners of the weighbridge align with the besser blocks below.
2. Install load cell assembly
3. Continue lowering the weighbridge onto the besser blocks whilst using a spirit level to ensure the platform is level. Use packing slips to level the platform where required.

CAUTION

Jockey wheels have a combined capacity of 2 tonnes. DO NOT load the platform until it is resting on besser blocks.

CAUTION

Lifting points are designed to safely lift an UNLOADED platform. DO NOT load the platform until it is resting on besser blocks

CAUTION

Do not lift the device by the eye bolts.

3.2. Installation of Equipment

3.2.1. Load Cells

NOTE

Readings from load cells are only accurate within its operating temperatures of -10 to +40 degrees Celsius.

The load cell will be mounted to the bottom of the platform during the assembly period. Figure 13 below shows the mounting plan of the load cell. Two spacers sit on the top and bottom of the load cell. The two 16mm bolts which connect the steel structure to the load cell, passing through the spacers require an assembly torque of 180 Nm [29]. The two 16mm unthreaded bolts acting as shear pins are to be positioned last (after the load cell mount is positioned with the steel structure) and should drop in through the steel structure through to the bottom of the lower spacer.

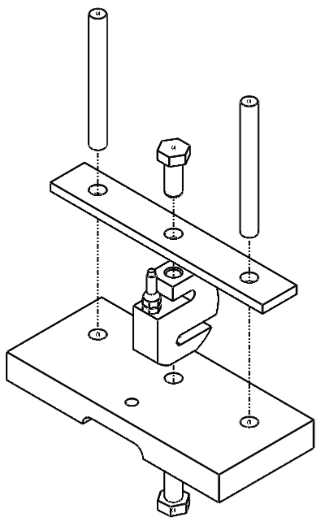


Figure 13: Exploded view of load cell mount

The completed assembly is shown in Figure 14 below. The cable coming off the load cell is to go directly down towards the ground with the safe guards adequately protecting the cables.

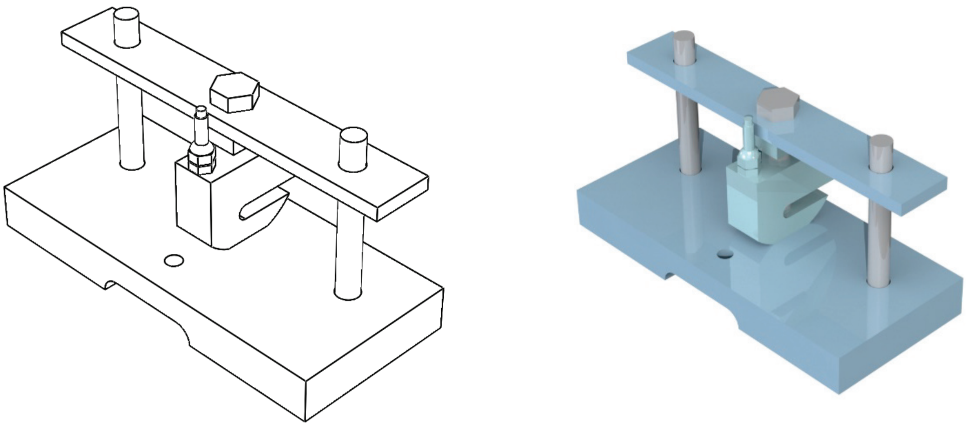
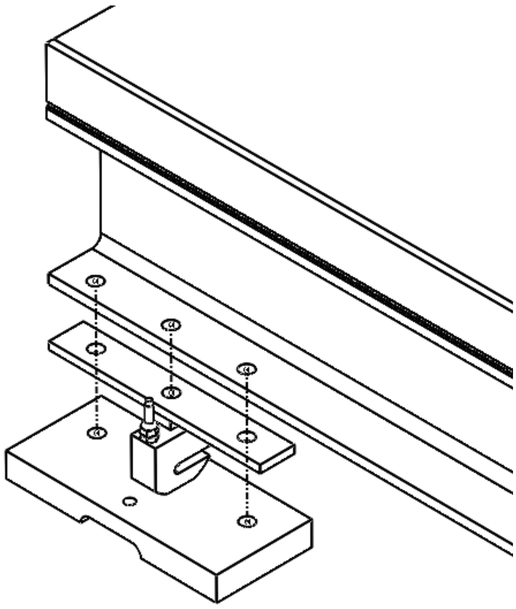


Figure 14: Complete assembly of load Cell mount

Figure 15 below demonstrates how the load cell is mounted with the platform. Once the platform is in place, four Besser blocks need to be ready on the ground and put under the load cells. After setting down the weighbridge, the whole weight of the platform will be supported only by the besser blocks under the load cells. A total of 4 load cells are installed at each corner of the weighbridge.



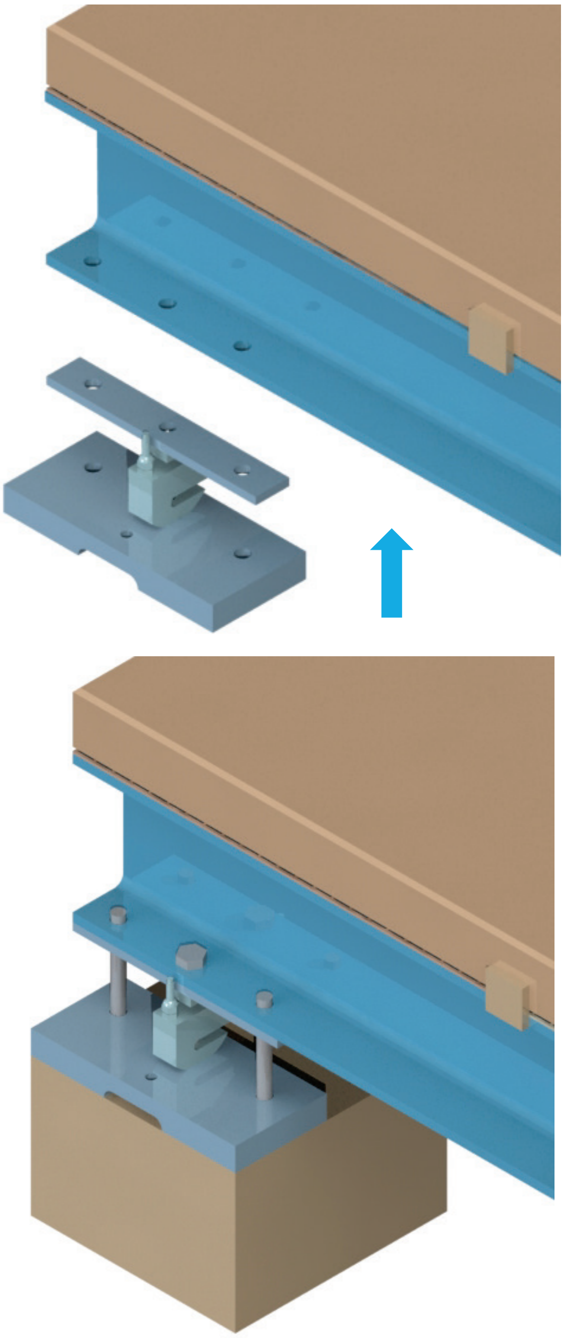


Figure 15: Complete assembly of load cells onto structure. Above: Exploded View. Below: Isometric view.

3.2.2. Jockey Wheels

The mounting plan of the jockey wheels is shown in Figure 16 below. Two bolts holes are supplied on the jockey wheel mount plate. The bolt used for assembly is M12x55 full thread hexagon (DIN933) with the material as specified in the engineering drawings in Appendix K - Engineering Drawings of this Report. The tightening torque is suggested to be 76 Nm along with the use of a washer and washer spring [29].

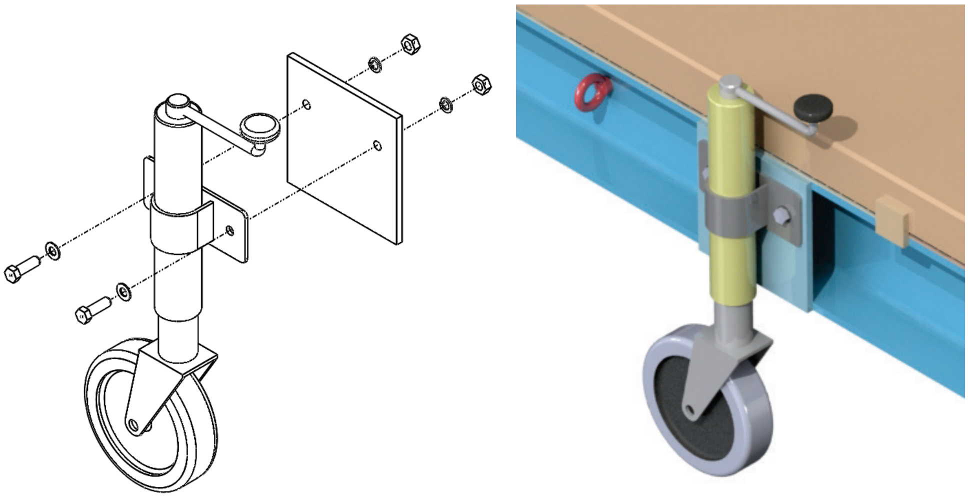


Figure 16: Jockey wheel mounting arrangement

NOTE

Jockey wheels must be REMOVED during burn tests to prevent damage from high temperatures.

3.2.3. Flux Sensors

The heat flux sensors can operate in any orientation and must be fitted with the protective cap for transportation or storage. The heat flux sensor generates a small voltage output signal without the need for a power supply. To connect the flux sensors to the data loggers, connect the white wire located at the back of the heat flux sensors to the amplifier. When operating the heat flux sensor, ensure the water cooling tubes at the rear of the sensor are working. The water cooling tubes will be compatible with 4.2mm diameter tubes. In order to hold the flux sensor in place, use a standard retort stand ensuring that all rubber pieces are removed.

To install the heat flux sensors;

1. Set up retort stand approximately 2-5m away from the flame
2. Clamp the flux sensor to the retort stand seen in Figure 17 below
3. Connect both the water cooling tubes and signal cable
4. Remove the protective cap

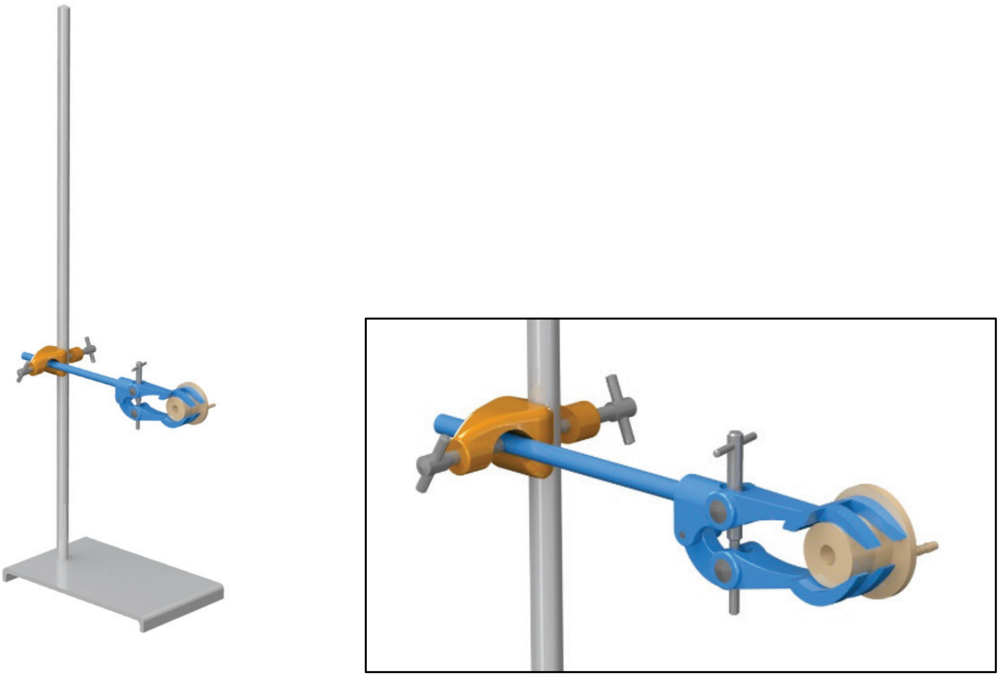


Figure 17: Heat flux sensor setup

3.2.4. Safe Guards

> **CAUTION**
>
> **Fyrchek must be replaced if exposed to water or fire. Any damage to the Fyrchek boards will be rendered unusable.**

To protect the exposed wiring, cables and electronic devices, a fire rated Gyprock Fyrchek wall is installed. It is a part of Gyprock's commercial select range of plasterboards.

- 'Gyprock Fyrchek' of 13mm thickness, 1200mm wide and standard length of 3600mm.
- Cut the panel into four pieces so that each piece will have the width of 300mm.
- Once the platform is lifted on the sitting blocks, put four pieces of Fyrchek panel around the base of the platform to protect the load cells from radiative heat from the fire.

Figure 18 below shows one of the four Fyrchek panels sitting vertically right next to the base. A 25mm gap is left to prevent the contact of the panels affecting the accuracy of results obtained by the load cells. Additional Fyrchek panels would be needed if there are wirings and cables required to be protected.

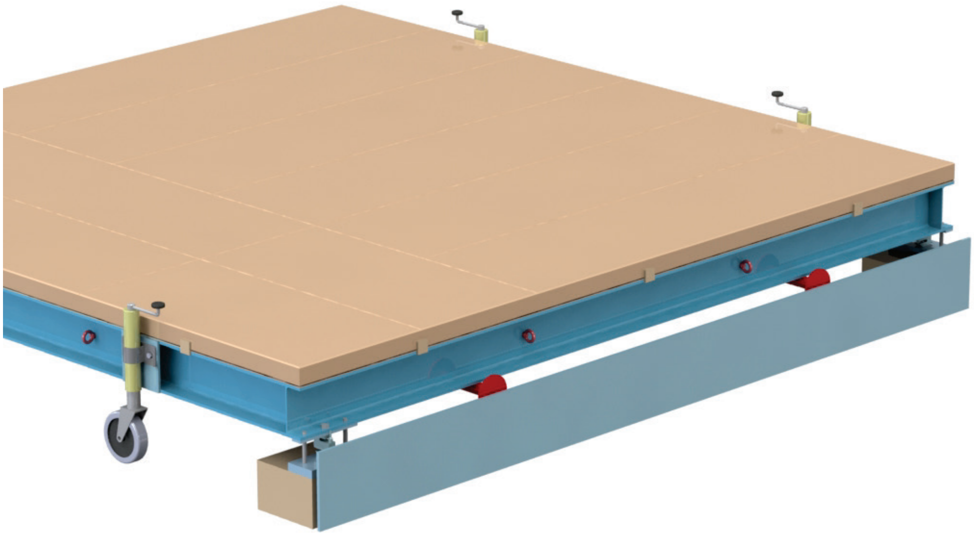


Figure 18: 'Gyprock Fyrchek' placement (typical)

3.2.5. Hebel Sheets

CAUTION

Hebel Sheets are heavy. Use Safe Working Procedures when handling.

CAUTION

Lowering Hebel sheets onto the platform can be a PINCH POINT hazard.

To secure the Hebel panels to the weighbridge, ensure that the panels sit within the metal ta bs located at the sides. To remove the Hebel panels, vertically lift the panels off the weighbridge seen in Figure 19 below.

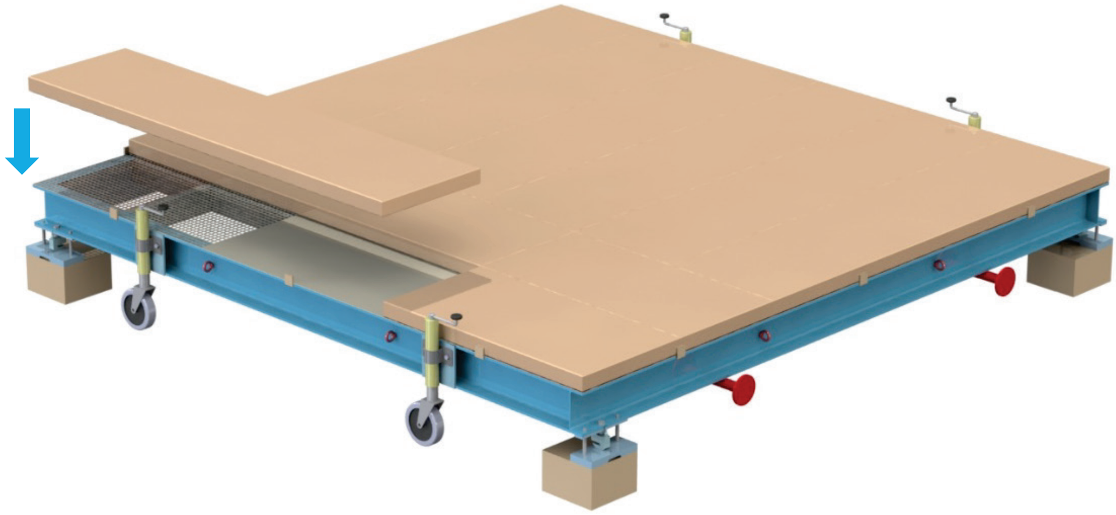


Figure 19: Hebel placement

As each panel weighs 72 kg, use approved Safe Working Procedures.

4. Disassembly

CAUTION

The platform and equipment will be HOT after burn tests.

4.1. Jockey Wheels

After completing the operation, the jockey wheels will be fixed back on the platform if the weighbridge is required to be rolled to another location. By extending the height of the jockey wheels, load cells will be lifted off the ground. Fix the heights of four jockey wheels at maximum position, and then move the platform outside the experiment area.

4.2. Load Cells

CAUTION

Load cells are fragile. Use care when handling.

Disassemble the load cell mount by performing the reverse steps in section 3.3. First remove the 16 mm unthreaded pins. Then remove the upper 16mm bolt in case the load cell drops on the ground and gets damaged. Once four load cells are dismounted from the platform, the data will be collected for investigation.

4.3. Flux Sensors

CAUTION

Heat flux sensors are fragile. Use care when handling.

To disassemble the heat flux sensor, disconnect the signal wire and two water cooling tubes. Proceed to remove the heat flux sensor from the clamp and put back on the protective cover.

5. Maintenance

5.1. Hebel Sheets

All Hebel sheets should be stored in a dry area. If Hebel Panels are stored outside, they should be stored off the ground and protected from the weather.

If 'Hebel' appears fire damaged, replace with new 'Hebel' sheets.

5.2. Jockey Wheels

Table 12 shows the jockey wheels' life expectancy.

Table 12: Average life expectancy of jockey wheel assembly

Components	**Life Time**
Wheels Bearing	+5 Years
Tire	+3 Years (Depend on the mass and moving ti me)

5.3. Heat Flux Sensors

To ensure the heat flux sensors are operating properly, Table 13 below highlights the procedures required at different operation intervals.

Table 13: Maintenance of heat flux sensor

Recommended Heat Flux Sensor Maintenance		
Interval	**Subject**	**Action**
Before and After every Test	Recalibration	Recalibrate against a local calibration reference
Before and After every Test	Inspection	Inspect sensor coating, sensor mounting, cable quality, supply tubing
After every Test	Data review	Judge the feasibility of the measurement data Flux and temperature measurements
After every Test	Lifetime assessment	Judge if the instrument will be reliable for another test

Appendix C – Test Plan

1. General

1.1. Aim

To confirm that the device meets specifications of design and meets basic requirements

Risk Assessment

Description of Risk	Device breaks and/or falls causing damage to body
Possible Consequences	Injury to persons
Probability of Risk	L
Severity of Risk	H
Overall Risk	M
Risk Mitigation	Personal Protective Equipment including Hard hat and steel cap boots.
Contingency Plan	First Aid Officer on site

1.2. Apparatus

- Completed device
- Measuring Tape
- Spirit Level
- Stopwatch
- 8 tonne load

1.3. Method

1. Check the dimensions of the device that it is 3.6 m x 3.6 m and other systems meet specifications as provided in the engineering drawings.
2. Set up the device and time how long it takes.
3. Move the completed device from its storage location to its use location with all sensors attached. Place device on a known level ground with a tolerance of ± 0.5° of 0°. Check the device is accurate to ± 1° of 0°
4. Visually inspect the sensors are working after having moved the device.

5. Place a measuring rod at the centre of the structure of length, 5 mm from the ground to underside of the steel structure. Place an 8 tonne load on the weighing platform. Observe whether the platform touches the measuring rod and how close.
6. Disassemble device and time how long it takes.
7. Note if any special tools were required in assemble or disassembly.

1.4. Pass/Fail Criteria

Result Item	**Pass Criteria**
Dimensions are within tolerance	Dimensions are within tolerance as stated in the engineering drawings
Angular tolerance	Weighing platform is within tolerance
Sensors	Sensors are still intact and working
Deflection	Platform does not touch measuring rod
Time	Set up time and disassembly time are both less than 10 minutes.
Portable	The device was portable with no system failing
Special tools	No special tools were used

1.5. Cost and Time

Roles	**Rate ($/hr)**	**Time (hr)**	**Cost ($)**
Test Coordinator	**50**	**4**	**200**
Test Assistant	**40**	**4**	**160**
		Total	**360**

2. Fire

2.1. Aim

To confirm that device operates successfully during a fire experiment,

2.2. Risk Assessment

Description of Risk	Extreme temperatures and high levels of smoke.
Possible Consequences	Burns to the skin of personnel. Smoke inhalation.
Probability of Risk	H
Severity of Risk	M
Overall Risk	H
Risk Mitigation	All standard precautions outlined by Fire NSW associated with fire. This includes but not limited to wearing proper PPE including face masks and fire suits.
Contingency Plan	Ensure first aid officer is close by. Call emergency services if medical emergency.

2.3. Apparatus

- Completed device
- Combustible material
- Thermocouples
- Extra Hebel panels (of any thickness)

2.4. Method

1. Assemble the device as stated in the operations manual.
2. Place a combustible material on the weighing platform. Note that the combustible material must be able to burn for an hour at a significant temperature. Also, the combustible material is to be flush with at least one corner or edge.
3. Place thermocouples as close as possible to the load cell/(s).
4. Ignite the sample with a butane burner or other ignition source.
5. After an hour, extinguish flame using standard methods (water/foam mixture from fire truck).
6. Let the device cool.
7. Observe the state of the Hebel to see the level of water and fire damage.
8. Inspect all cables.

2.5. Pass/Fail Criteria

Result Item	**Pass Criteria**
Sensors	All sensors stayed with their operating temperatures and did not suffer any other issues.
Thermal insulation material	'CSR Hebel' panels show minor fire damage signs and no visual water damage
Electrical	The experiment was not impeded by problems with electrical system. On inspection of electrical cables, no visual thermal damage is noted.

2.6. Cost and Time

Roles	**Rate ($/hr)**	**Time (hr)**	**Cost ($)**
Test Coordinator	**50**	**4**	**200**
Test Assistant	**40**	**4**	**160**
		Total	**360**

Appendix D –Weldment Analysis

Equations for hand calculation

The moment applied on the weld will be obtained by FEA.

The shear force on the weld is,

$$f_s = \frac{V}{L}$$

Where V is the shear force, and L is the length of the weld. The bending force on the weld is,

$$f_b = \frac{My}{I_u}$$

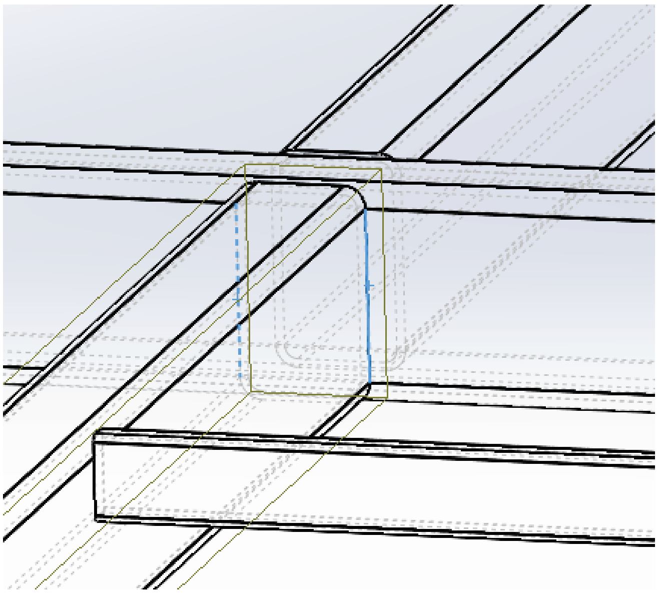
Where M is the moment, y is the distance and I is the section modulus. The total force is:

$$f_a = sqrt\left({f_s}^2 + {f_b}^2\right)$$

The height of the weld is therefore,

$$h_{WELD} = f_a * 3 * \frac{sqrt(2)n}{Su}$$

Case 1



The schematic diagram of the above weld is shown in below in Figure 20.

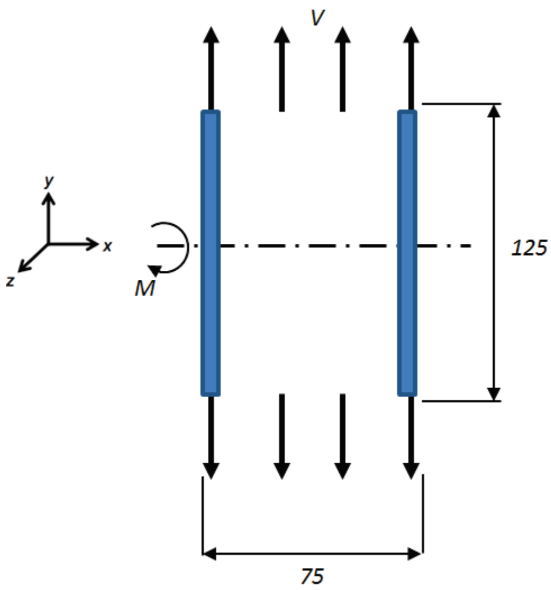


Figure 20: weld schematic

The shear force of the beam:

$$V = 15733$$

The shear force on the weld:

$$f_s = \frac{V}{L} = \frac{15733}{250mm} = 63N/mm$$

The unit second of inertia given by Shigley Table 9-2:

$$I_u = \frac{d^3}{6} = \frac{(125mm)^3}{6} = 325520.83mm^3$$

The bending moment is given by the results from FEA:

$$M = 132.09Nm = 132090Nmm$$

The bending force on the weld:

$$f_b = \frac{My}{I_u} = \frac{132090Nmm \times 62.5mm}{325520.833mm^3} = 25.36N/mm$$

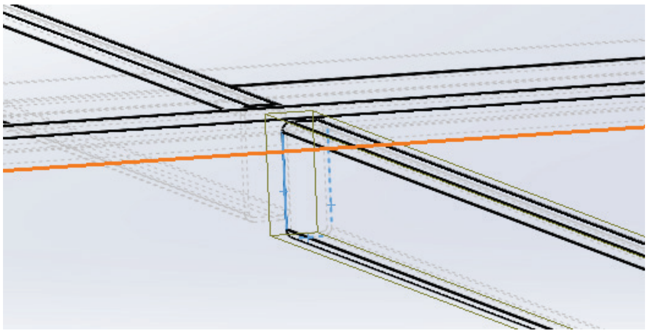
Then the total force:

$$f_a = sqrt\left({f_s}^2 + {f_b}^2\right) = sqrt(63^2 + 25.36^2) = 68N/mm$$

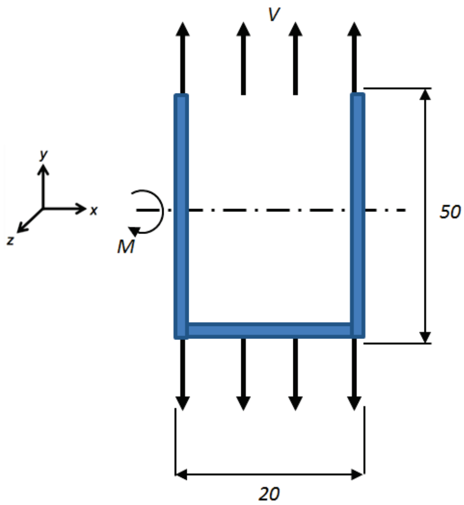
Regarding to the ultimate tensile strength of 410 MPa and a factor of safety of 5, the size of weld is then calculated as:

$$h_{WELD} = f_a * 3 * \frac{sqrt(2)n}{Su} = \frac{68N}{mm} \times 3 \times \frac{sqrt(2) \times 5}{410MPa} = 5mm$$

Case 2



The schematic diagram of the above weld is shown below:



The shear force of the beam:

$$V = 3758N$$

The shear force on the weld:

$$f_s = \frac{V}{L} = \frac{3758}{120mm} = 31N/mm$$

The unit second of inertia given by Shigley Table 9-2:

$$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b + 2d)\bar{y}^2 = \frac{2 \times 50^3}{3} - 2 \times 50^2 \times 20.83 + (20 + 50 \times 2)20.83^2$$
$$= 31250mm^3$$

The bending moment is given by the results from FEA:

$$M = 7.61Nm = 7610Nmm$$

The bending force on the weld:

$$f_b = \frac{My}{I_u} = \frac{7610Nmm \times 25mm}{31250mm^3} = 6.088N/mm$$

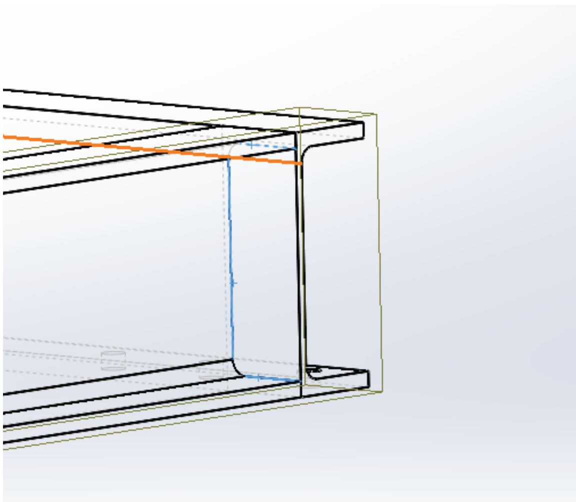
Then the total force:

$$f_a = sqrt\left({f_s}^2 + {f_b}^2\right) = sqrt(31^2 + 6.088^2) = 32N/mm$$

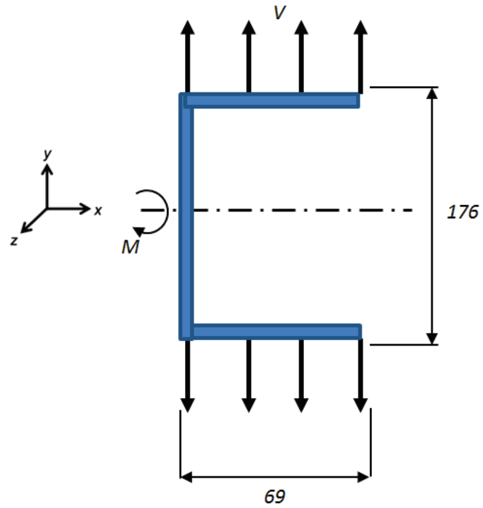
Regarding to the ultimate tensile strength of 410 MPa and a factor of safety of 9, the size of weld is then calculated as:

$$h_{WELD} = f_a * 3 * \frac{sqrt(2)n}{Su} = \frac{32N}{mm} \times 3 \times \frac{sqrt(2) \times 3}{410MPa} = 3mm$$

Case 3



The schematic diagram of the above weld is shown below:



The shear force of the beam:

$$V = 9912N$$

The shear force on the weld:

$$f_s = \frac{V}{L} = \frac{9912N}{314mm} = 32N/mm$$

The unit second of inertia given by Shigley Table 9-2:

$$I_u = \frac{d^2}{12}(6b + d) = \frac{176^2}{12}(6 \times 69 + 176) = 1522986.67mm^3$$

The bending moment is given by the results from FEA:

$$M = 9142.3Nm = 9142300Nmm$$

The bending force on the weld:

$$f_b = \frac{My}{I_u} = \frac{9142300Nmm \times 88mm}{1522986.67mm^3} = 528.25N/mm$$

Then the total force:

$$f_a = sqrt\left({f_s}^2 + {f_b}^2\right) = sqrt(32^2 + 528.25^2) = 529N/mm$$

Regarding to the ultimate tensile strength of 410 MPa and a factor of safety of 2, the size of weld is then calculated as:

$$h_{WELD} = f_a * 3 * \frac{sqrt(2)n}{Su} = \frac{529N}{mm} \times 3 \times \frac{sqrt(2) \times 2}{410MPa} = 8mm$$

Appendix E - Conceptual Design

Dimensions

Functional requirements state the platform is to be 3.6 m x 3.6 m. This requirement has been chosen because this will match a standard room. Another concept of 3.6 m x 2.4 m would allow the platform to be transported by a standard truck. The benefit of easily transporting the finished device would reduce transport costs without the need for an oversize truck.

The 3.6 m x 3.6 m was chosen by the design team after consulting with the FRNSW representative who stated that a bigger size is more important than the cost and ease of transport.

Platform Style

Four different platform styles were conceived each with a different maximum loading capacity, weight, amount of welding and cost of manufacturing. The successful platform style was chosen to be the ladder style because it was seen to be the best style capable of holding heavy loads that were distributed not on the edges. For example, a 2.4 m x 2.4 m structure could potentially be built on the weighing platform requiring the steel structure to take the load on the inner members.

Portability

There were two forms of portability identified by the team. The first is transporting around NSW in a truck or some other form. The second is transporting around the FRNSW Londonderry site. After consultation, it was determined that only the transportation around the FRNSW Londonderry site was required. Transportation around NSW would be dealt with by FRNSW.

Option 1 – “Wheels Plus ramp to go onto trucks” is immediately abandoned due to the above client’s request. Option 2 – “Detachable Jockey Wheels" is a cheap and simple solution using off the shelf parts. Option 3 and option 4 both require a complex custom designed system which would add significant time to the design phase. Option 3 and option 4 also would be of a higher cost. It was also the design team’s opinion that option 3 and option 4 would provide a non-significant time savings during set up and end processes (including disassembly and place back in storage) of each experiment. Detachable jockey wheels were chosen.

Levelling

Levelling is necessary for accurate functioning of load cells. This is because if a load is applied at an angle, the combined error of the load cell will increase. Two main ideas were conceived; either packing slips or levelling screws. Levelling screws are more accurate than packing slips. They also require careful design to ensure that the levelling screws have the correct tightening torque and can withstand the high compression loads. Packing slips are less accurate, slower but of simpler design. They also have a greater inherent risk as it requires manual handling of objects that are placed underneath the heavy platform structure.

Jockey wheels are capable of lifting up each corner of the platform independently allowing packing slips to be placed underneath. The results from the portability subsystem discussion states that jockey wheels are to be incorporated in the design. Since jockey wheels are already included in the design, it was the opinion of the team that jockey wheels with packing slips would be the best levelling subsystem to use due to simplicity of design.

Temperature Shielding & Electrical System

Radiation and high temperatures from fire during experiments is capable of melting cables leading from the load cell to the data acquisition unit.

Option 1 – ” Fire Resistant Cables (glass ceramic sheath)” are expensive and have an approximate maximum operating temperature range of 300 °C. Temperatures of fire exceed 600 °C and therefore may not be suitable. Option 2 – “Active Cooling system of load cells and cables” requires a complex system with a secondary system required just for this subsystem. This would increase set up time and complexity of the design. Option 3 – “Heavy Insulation with Gyprock around cables and load cell” will have some convective heat and radiation heat travel through the gaps around the thermally resistant material, however this is a cheap and simple solution. It was the opinion of the design team that option 3 – “Heavy Insulation with Gyprock around cables and load cell” is the best solution as the heat travelling through the gaps of this rudimentary solution is insignificant.

Material of Fire Rated Coating

All preliminary concept drawings included a fire resistant layer on top of the platform. This is because the heat from the fire moving downwards towards the load cell would very likely increase the temperature of the load cell above its maximum operating temperature. Materials that were considered were fire rated plasterboard, fibre cement, ‘CSR Hebel’ and a composite.

Heat flux sensor

Heat flux sensor was part of the scope of the project. However research into its use to find heat release rate was limited. This does not mean that heat flux is not an important parameter to be measured, that is, heat flux is still a useful parameter that FRNSW would like to be measured.

Option 1 – "Not at all" was conceived because heat flux was outlined by the projects customer that it exists as part of an optional scope. Option 2 "Fixed mount" is simple, however provides little use to FRNSW. Option 3 -"Movable mount like a camera tripod" is a simple and cheap solution. Option 4 - "Retort stand mount" is also a cheap and simple solution.

Option 4 was chosen over option 3 because it was deemed easier to design a retort stand mount that would withstand the high temperatures of a fire whilst minimising the amount of material used.

Load Cell Resolution

Calculations found in Appendix A show that using the load cells that FRNSW currently own give a resolution of 16 kg. Option 1 and 2 are based on common-sense estimates of the desired resolution that were supported by FRNSW. Option 2 was chosen as it represents the best possible resolution if FRNSW are to purchase new load cells from the same company that supplied them with their current load cells.

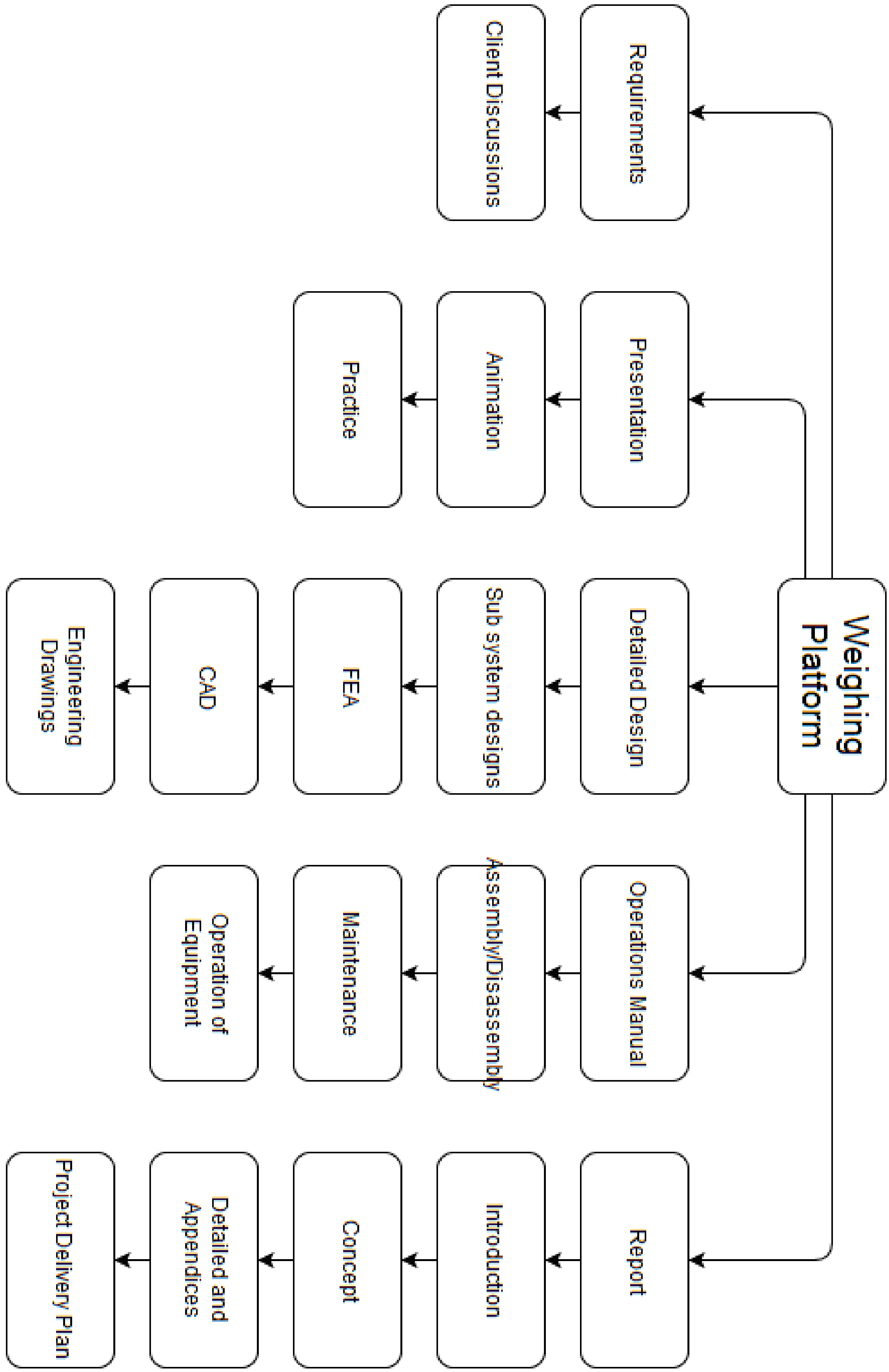
Load Cell Location

Option 2 represents that the load cell location is important for heat shielding to ensure the load cells remain within their operating temperatures during a fire experiment. Whilst option 1 is a simpler design enabling the load cell to attach directly onto the main frame it does not provide adequate heat shielding.

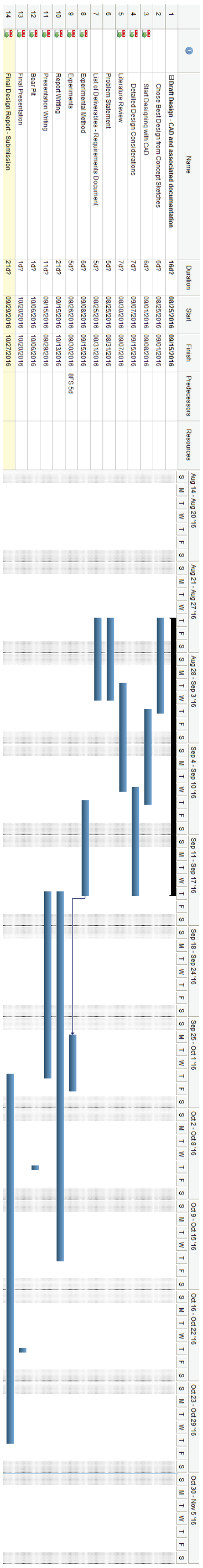
Load Cell Attachment

The load cell attachment is important to ensure that the load passes through the mid-plane of the load cell. Shear pin concept was chosen over the plate and L shape design because the plate and L shape design was considered unsatisfactory to hold the weight of the loaded device. Also, it was considered the L shape and plate design would make assembly and disassembly of the load cell awkward leading to increased assembly and disassembly times.

Appendix F – Work Breakdown Structure


Weighing Platform
Requirements
Client Discussions
Presentation
Animation
Practice
Detailed Design
Sub system designs
FEA
CAD
Engineering Drawings
Operations Manual
Assembly/Disassembly
Maintenance
Operation of Equipment
Report
Introduction
Concept
Detailed and Appendices
Project Delivery Plan

Appendix G – Gantt Chart



Appendix H –Minutes

Date Time:
18/08/2016
1200 at Ainsworth Lvl 4

Attendance:
Darson
Guan
All group

Notes
Fire NSW Owns:
Gas Analysis machine (FTIR)
Thermocouples
Heat Flux Sensor
Load Cell
Data Loggers

Group Project 1 - Mass Loss
Make a relation between the mass loss and the heat generation. The mass loss should be only dependent on material

To get mass loss of multiple masses, you can use a sand propane buner. Do not need each mass, can do it all together. You can then corroborate with other data and research.

Can download the heat release rates of each material from NIS.

Heat flux can be incorporated into project. Heat flux has to be pointed.

Gypsum board is good material for building the design.

Group Project 2 - Air Velocity
Measure air velocity in and out of a opening.

Pitot tubes clog up.

Project motivation: When the situation becomes untenable for humans and firefighters, approx 5 m/s gas, smoke, heat released, temperature are important for a jedgement whether it is safe to enter the building.

Can measure with bidirectional probe.

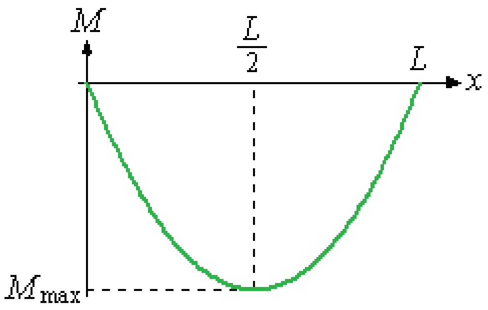
Take into consideration density.

Other Notes

They have a workshop to help build prototypes.

Appendix I – Steel Structure Analytical Validation

The equivalent (Von Mises) stress was found on the beams. The bending of the adjacent beams was ignored and the beam in question was taken to be simply supported. The following formula was used to find the stress:



$$M(x) = -\frac{1}{2}\, p\,(L - x)\, x$$

Figure 21: Stress on a simply supported beam [25]

$$M_{\max} = M\left(\frac{L}{2}\right) = -\frac{pL^2}{8} \qquad (1)$$

$$\sigma_{\max} = [M_{\max}]\frac{y}{I} = \left[\frac{pL^2}{8Z}\right] \qquad (2)$$

Where: M = moment

y = distance from neutral axes

I = moment of inertia

Z = section modulus

L = length

p = force/load on each member

To find the load acting on each of the beams the area of the top surface of the beam was used. The ratio between the area where the 8 tonne load was acting and the top surface area of the beams was examined. The results for the distributed load acting on top of the beam is shown in table 4. The top surface area was found using SolidWorks measuring tool.

Table 2 – Calculating the distributed load on the beams

Beam ID	Area of top surface (m^2)	Total area (m^2)	Ratio	Distributed Load (N/m^2)
1-4	0.0135	2.11273	0.006	500.96
5-7	0.1725	2.11273	0.082	6401.20
8-13	0.05625	2.11273	0.027	2087.35
14-19	0.024375	2.11273	0.012	904.52
20-23	0.26437	2.11273	0.125	9810.34

Finally, using equations (1) and (2), the following stresses were found on the beams.

Note: Only the stresses on the C-section, small RHS and the middle RHS beam were found. The other beams had significantly less stress acting on them and as a result caused high inaccuracies in the error percentage.

Table 3 – Results for hand calculations

Beam	Stress (Hand Calculations) (MPa)
C-Section	22.62
Middle RHS beam	47.38
Small RHS	24.34

Appendix J –FEA Results

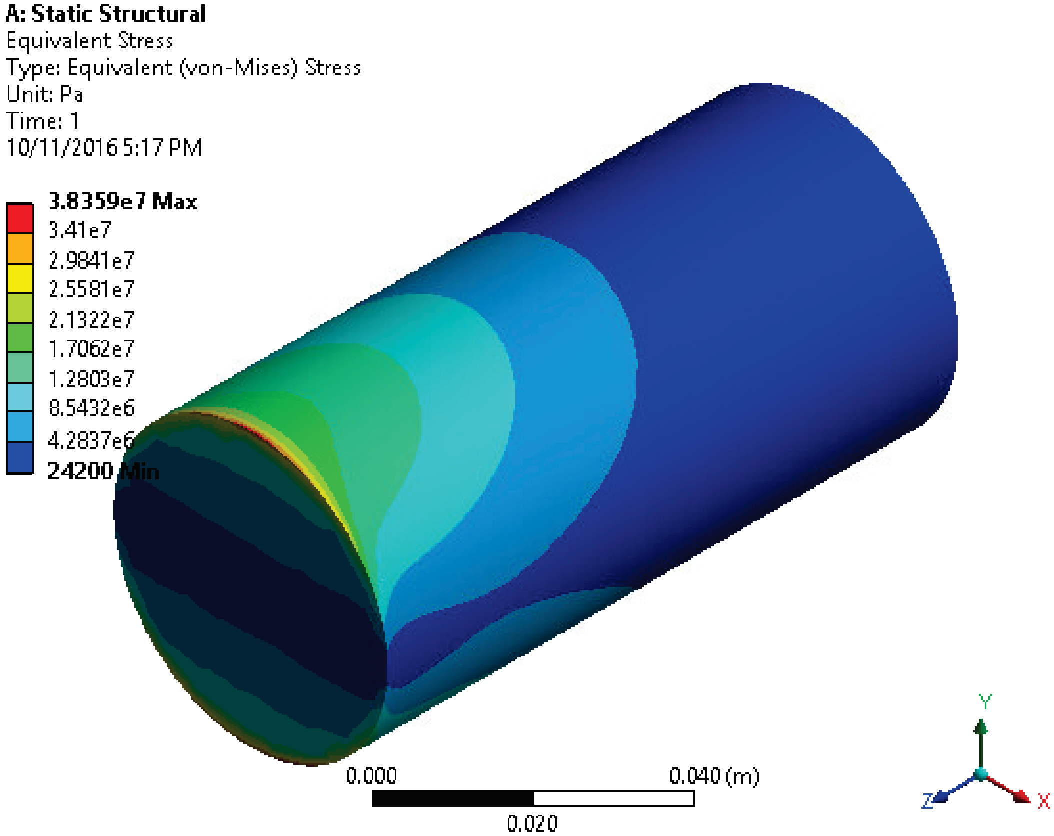


Figure 22: Stress on the lifting point (isometric view)

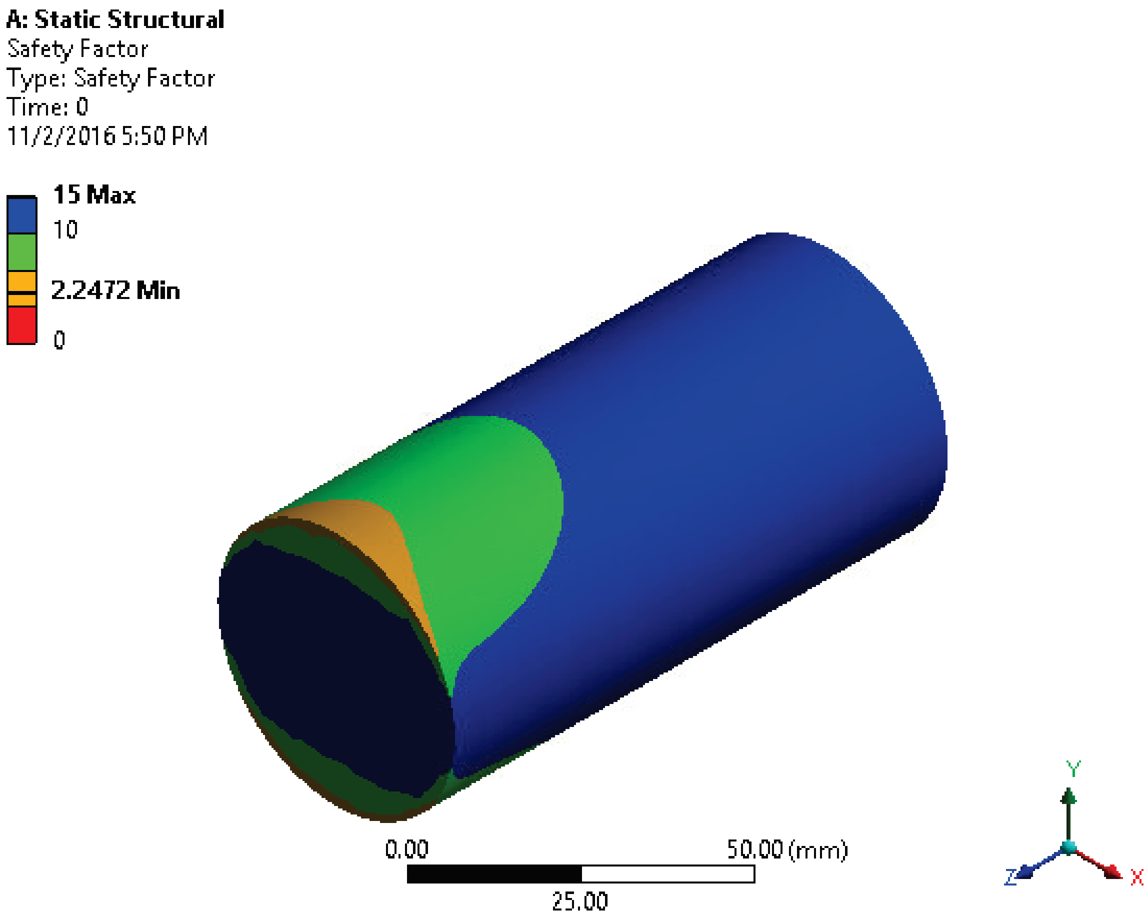


Figure 23: Safety factor for the fatigue life

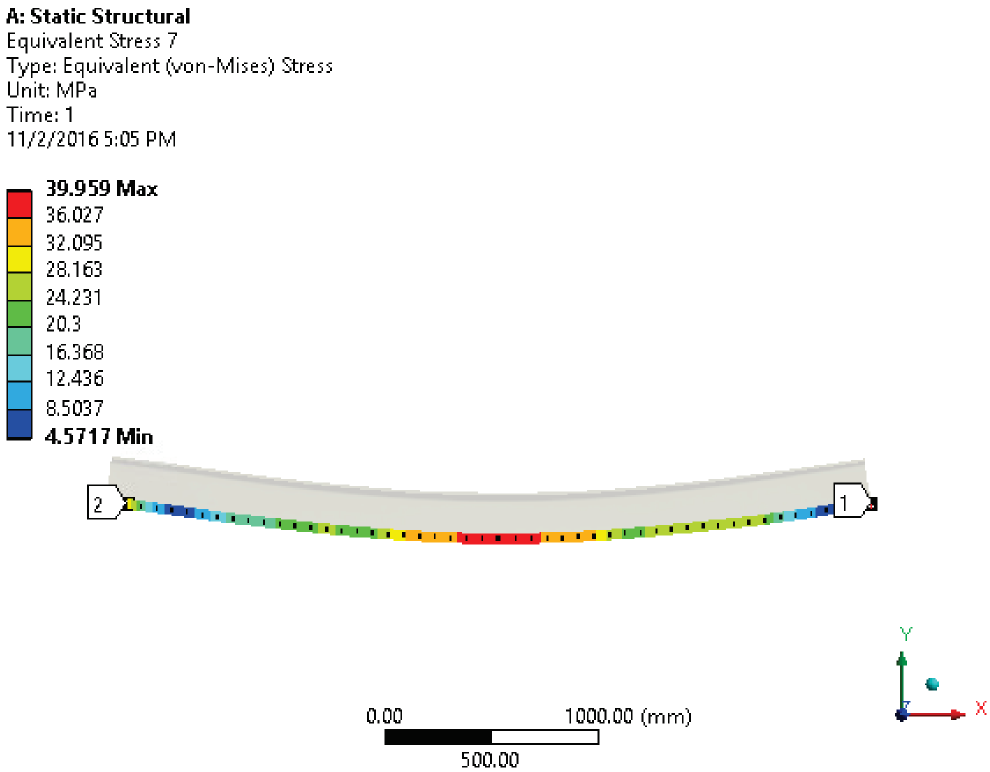


Figure 24: C-section beam stress

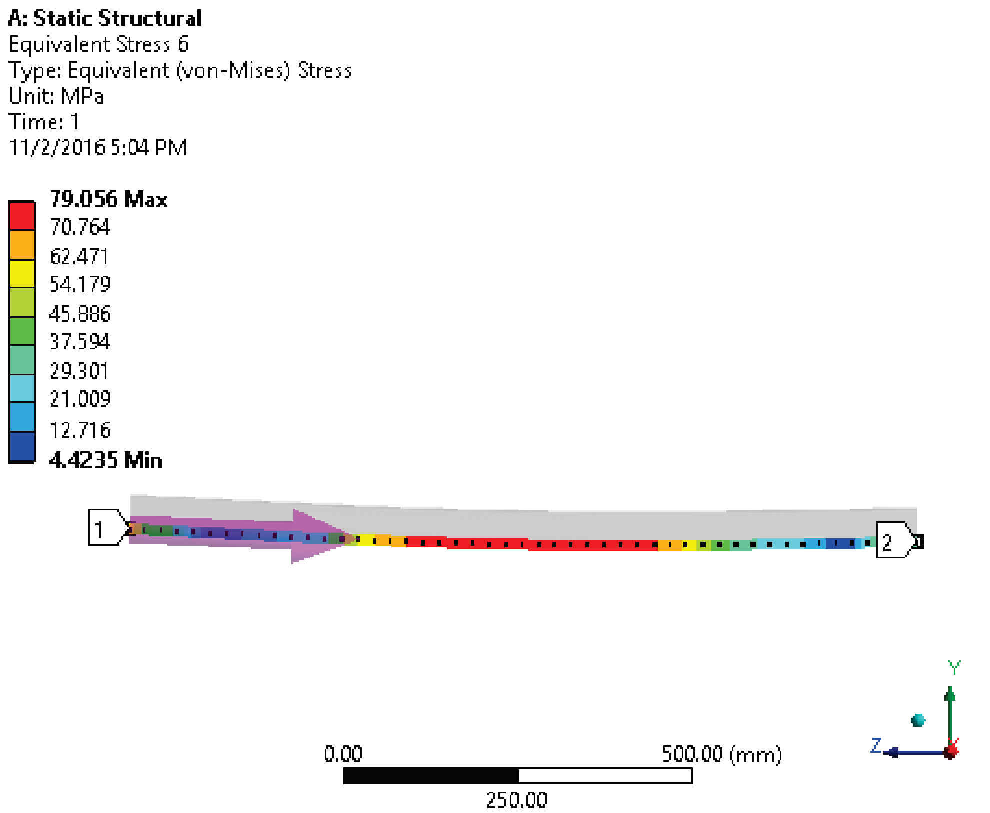


Figure 25: Stress on the small RHS beam

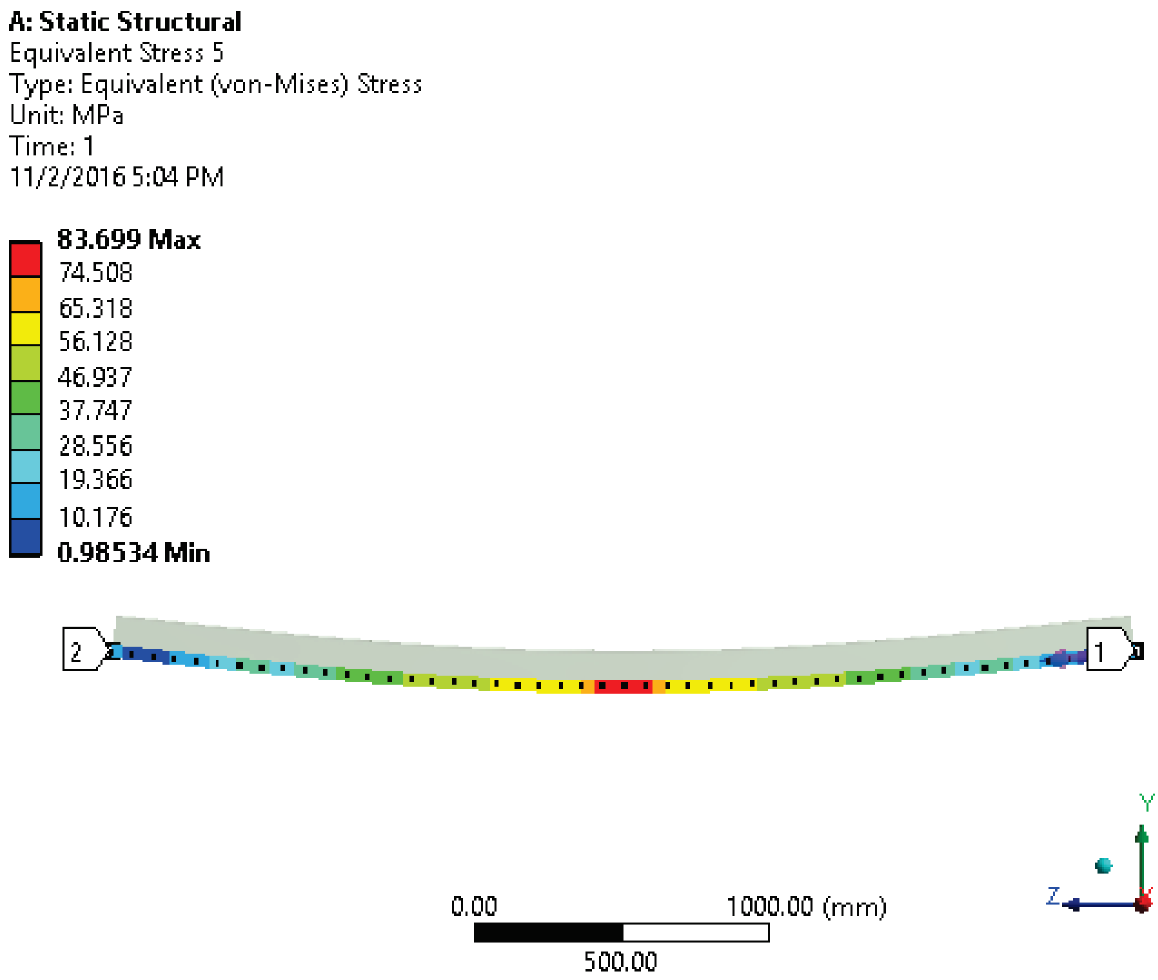


Figure 26: Stress on the middle member

Appendix K - Engineering Drawings

Contents:

- FRNSW000 – Weighing platform GA
- FRNSW100 – Steel structure arrangement
- FRNSW110 – Steel members
- FRNSW120 – Structure miscellaneous parts
- FRNSW130 – Mesh panels
- FRNSW200 – Load cell mount arrangement
- FRNSW300 – Jockey wheel arrangement