Full-Scale Experimental Study on the stability of Chords

of Cold-Formed Steel C-section Roof Trusses

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A thesis submitted in fulfilment of the requirements for the degree of

Master of Engineering **with Endorsement in Civil Engineering**

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ABSTRACT

The use of cold-formed steel (CFS) roof trusses is growing as a substitute for wood because of their advantages in quick fabrication, high strength-to-weight ratio, and lightweight nature [1]. However, the torsional buckling behaviour of these trusses remains inadequately understood. There have been experimental studies conducted for the behaviour of CFS roof trusses [2], wide-span roof trusses [1] and small-scale roof trusses [3]. The common failures in the previous studies of CFS roof trusses include distortion of heel plates, local buckling of the top chords [3] and flexural-torsional buckling becoming a concern in elevated temperatures [4]. The behaviour of CFS under loads applied away from the shear centre requires more testing due to its thin nature.

Through eight full-scale experiments, different truss configurations (back-to-back and linear), different lateral restraint spacing and internal support inclusions, this study investigates the structural behaviour of lipped channel (C-section) chords in CFS Howe roof truss assemblies. The experimental total load at failure exceeds factored predicted capacities by 12% and 34%, and factored design capacities by 34% and 60%, depending on lateral restraint spacing. Design equations, however, are conservative with predicted-to-experimental capacity ratios as low as 0.7 for wider spaced lateral restraints and 0.5 for closely spaced restraints. In 37.5% of cases, the design standards fail to predict the correct failure modes.

Observed failures during the experiments include lateral-torsional buckling, out-of-plane buckling, and inward torsional buckling. The single-channel linear truss system (face of web connected to back of chords) proved more robust than back-to-back system (back of web connected to back of chords), offering better torsional restraint and load-bearing capacity post-failure. Truss strength is enhanced by increased lateral restraints, but current design standards lack provisions for calculating member lengths with such restraints. Therefore, further research, including FEM analysis, is needed to address this gap and improve design accuracy.

Keywords: Cold-Formed Steel, CFS, truss, C section, bending, twisting, swaged, compression, tension, lateral torsional buckling, out-of-plane buckling, inward torsional buckling, roof, linear truss system, back-to-back system

PREFACE

This thesis is submitted in fulfilment of the requirements for the degree of Master of Engineering with Endorsement in Civil Engineering at the University of Waikato. The work in this thesis has not previously been submitted for a degree or a diploma at any other higher educational institution. To the best of my knowledge, the thesis does not contain any previously written or published material by another person except where due reference is made.

ACKNOWLEDGEMENT

First and foremost, I express my deepest gratitude to God for His everlasting grace, strength, guidance, and favour throughout this journey. His blessings have brought incredible individuals into my life, who supported me in completing this work.

To my parents and siblings (Senitiki, Varisila, Samuela and Losalini) whose unwavering support, prayers and encouragement have been a pillar of strength. A special tribute and dedication to my father who passed from this life during my studies, whose values, resilience, and wisdom continue to guide and inspire me every day.

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Special thanks to Kaitlin and Alice who helped me on some experiments at FrameCAD, my friends whose support has been very impactful during my studies, the lab technicians who helped me with my materials tests and the dedicated Masters and PhD students at the University of Waikato, whose assistance and camaraderie greatly enriched my experience during this journey.

Lastly, this work is a step toward giving back to the people who have shaped me. It is my hope that this research will contribute positively to the construction industry and the resilience of structures.

NOTATIONS

A_g	-	Gross area of the cross-section
A_n	-	Net area of the cross-section
A_e	-	Effective area at yield stress
C_b	-	Bending coefficient
CFS	-	Cold-Formed Steel
C-section	-	Channel Section
d_l	-	Depth of web element
E	-	Young's modulus
f_c	-	Critical buckling stress
FEA	-	Finite Element Analysis
FEM	-	Finite Element Modelling
f_{oc}	-	Least of elastic flexural, torsional, and flexural-torsional buckling stress
f_{ox}	-	Elastic buckling stress for flexural buckling about x-axis
f_{oy}	-	Elastic buckling stress for flexural buckling about y-axis
f_{oz}	-	Elastic buckling stress for torsional buckling
f_n	-	Critical stress
f_u	-	Tensile stress
f_y	-	Yield stress
G	-	Shear modulus

G	-	Dead Load
HWH	-	Hex Washer Head
I_w	-	Warping constant
J	-	Torsion constant
kg	-	kilograms
kN	-	Kilo Newtons
k_v	-	Shear buckling coefficient
k_t	-	Correction factor
l_{ex}	-	Effective length for x-axis
l_{ey}	-	Effective length for y-axis
l_{ez}	-	Effective length for torsional buckling
$l_{x,y}$	-	Buckling length
m	-	metres
m^2	-	Square metres
m^3	-	Cubic metres
m/s^2	-	metres per seconds squared
M*	-	Bending moment
mm	-	millimetres
mm^2	-	Square millimetres
mm^3	-	Cubic millimetres
M_b	-	Nominal member moment capacity

M_c	-	Critical moment
M_s	-	Nominal section moment capacity
M_o	-	Elastic buckling stress
MPa	-	Mega Pascals
M_y	-	Moment causing initial yield
N	-	Newtons
N*	-	Axial Tension Force / Compression Axial Force
N_c	-	Nominal member capacity
N_s	-	Nominal section capacity
N_t	-	Tensile capacity
Q	-	Live Load
r_o	-	Polar radius of gyration
$r_{x,y}$	-	Radius of gyration
s	-	seconds
t_w	-	Thickness of web element
V*	-	Shear force
V_v	-	Shear section capacity
x_o	-	Distance from shear to centroid
Z_c	-	Effective section modulus calculated at f_c
Z_e	-	Effective section modulus calculated at f_y
Z_f	-	Full unreduced section modulus

$\emptyset_b$	-	Capacity reduction factor for member bending
$\emptyset_c$	-	Capacity reduction factor for compression
$\emptyset_t$	-	Capacity reduction factor for tension
$\emptyset_v$	-	Capacity reduction factor for shear
λ_b	-	Slenderness ratio
λ_c	-	Slenderness factor

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Background

Cold-formed steel (CFS) has increased in demand for construction due to the sustainability in its properties. CFS trusses are being used for roof construction as it reduces construction time, is a lightweight material and increases the ease of transportation and delivery. In residential buildings, CFS roof truss designs are frequently utilized as cost-effective roof framing options [5]. While CFS is increasingly popular, the thin material can still create design problems which may not exist in other traditional building materials. This paper investigates the strength capacity of a 0.75mm thick cold-formed steel C-section Howe roof truss assembly subjected to gravity loads. The assembly is setup to test the linear truss system and the back-to-back truss system. There are eight (8) series of full-scale roof truss specimens investigated with different screw numbers at each joint of the truss assembly and the cold-formed steel open C section members are designed to suit extreme weather conditions. The truss assembly is placed on end supports only for 7 tests and 1 test includes an internal support together with the ends support. Similarly, there are 7 tests conducted for the linear truss system and 1 test for the back-to-back truss system. The variations of each test include the number of screws at joints, and the respective spacings between roof battens and ceiling battens. The impact of the lateral restraints applied on the truss is also investigated with how the truss reacts, and the type of failure experienced for each test series. The experimental test results capacity is also compared with the design and predicted capacities of the trusses.

1.2 Thesis Outline

The following is the outline of this Master of Engineering Thesis:

Chapter 1 introduces the background of the topic and outlines the contents of the thesis.

Chapter 2 reviews the current literature and related background research available for the cold-formed steel, cold-formed steel truss, timber truss, screw connections on truss, buckling on cold-formed steel truss. The research gap is also identified, and the research objectives will be summarized.

Chapter 3 entails the experimental methodology of the topic, the apparatus used, and the specifications of the specimen being tested.

Chapter 4 is a discussion and documentation of the results obtained from the experimental testing. The chapter entails the strengths of the different test series, type of failure experienced on each test series, the loading capacities and the deflection incurred.

Chapter 5 provides the design capacity truss and predicted capacity truss using the FrameCAD Structure software and shows the load diagrams, bending, shear and axial diagrams of both the design and predicted capacity of the truss. The chapter also includes the comparison of the test results against the design and predicted capacities.

Chapter 6 provides an overview of the conclusions of this study, the limitations of this study and the recommendations for future study.

Chapter 2 Literature Review

2.1 Introductory Remarks

This chapter presents an extensive literature review on the behaviour of cold-formed steel(CFS), CFS lipped channel sections, CFS Trusses.

2.2 Research on Cold-formed steel lipped channel section roof trusses

This chapter presents an extensive literature review on the behaviour of CFS lipped channel section, CFS lipped channel section trusses, CFS channel section roof trusses, linear truss system, back-to-back channel sections.

Several researchers have observed behaviours of cold-formed steel C-section roof trusses based on both concentrated panel point loads of the full-scale and small-scale experiments, and the computer-generated models. The Fink truss CFS C-section roof assembly test identified that the top chord member defined the strength performance requirements of a truss [2]. However, the shape of the truss, the web members locations, spacing and connection type can be further investigated for stability purposes if there are variations in the assembly.

A typical roof truss system consists of top chord members, bottom chord members and web members which are commonly comprised of C-sections that are resistant to loading in compression, tension, or combinations of these. The behaviours of the members are susceptible to connection failures and various forms of buckling [2].

2.3 Cold-Formed Steel Channel Section (C-Section) Applications

Cold-Formed Steel is used as steel racks for storage, corrugated sheets, roof systems, wall systems and structural members for trusses [6]. An analysis of the capacity of a CFS C-section Fink Truss assembly (**Figure 2-1**) that consists of web members placed diagonally between the top and bottom chords and wood sheathing is placed above the top flanges of the top chords in which the loads are applied [2]. Investigating the truss behaviour using both experimental testing and FEA method concluded that the top chord member of a truss defined the strength performance requirements of a truss [2]. The top chord experienced failure around connection points due to local rotation restraints which concluded that locations of maximum moment at top chord members should be investigated for axial compression while bottom chord members of a roof truss should be investigated for axial tension [2]. The investigation examines the stability of cold-formed steel trusses under the type of loading applied and relied on assumptions regarding boundary conditions; however, it does not discuss in depth about the failure mechanisms such as distortional buckling or lateral-torsional buckling which are critical in understanding the full behaviour under real-world conditions such as wind or seismic loads. To better anticipate the failure modes under various loading scenarios, more research is required to expand the assumptions on load conditions, boundary conditions and type of truss so it can cover more disaster-prone areas.

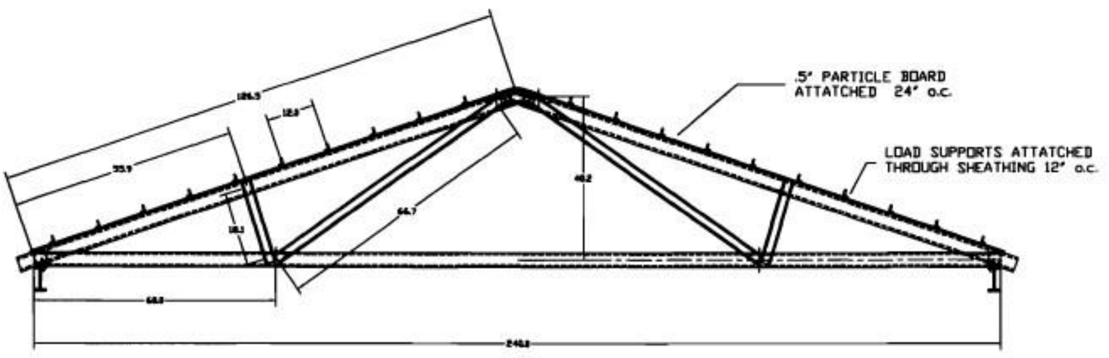


Figure 2-1: CFS Fink Truss analysed for behaviour [2]

An investigation on the interaction of local and distortional buckling was conducted for cold-formed steel lipped channel beams arranged in a back-to-back configuration [7]. This investigation included 3 different cross-sectional geometries with deeper webs and narrow flanges tested in a 4-point bending (**Figure 2-2**) configuration with lateral supports braced at loading points and simple supports as the boundary conditions [7]. The study also compared the results to the Eurocode design standards and AISI Direct Strength Method standards which showed safe predictions and all the tests showed that the beams failed by interaction of local and distortional buckling in the constant moment span [7]. The relationship with global buckling, such as lateral-torsional buckling is not thoroughly covered, despite the study's emphasis on the relationship between local and distortional buckling. In real-world situations where numerous buckling modes may occur simultaneously, more research could examine where these modes interact.

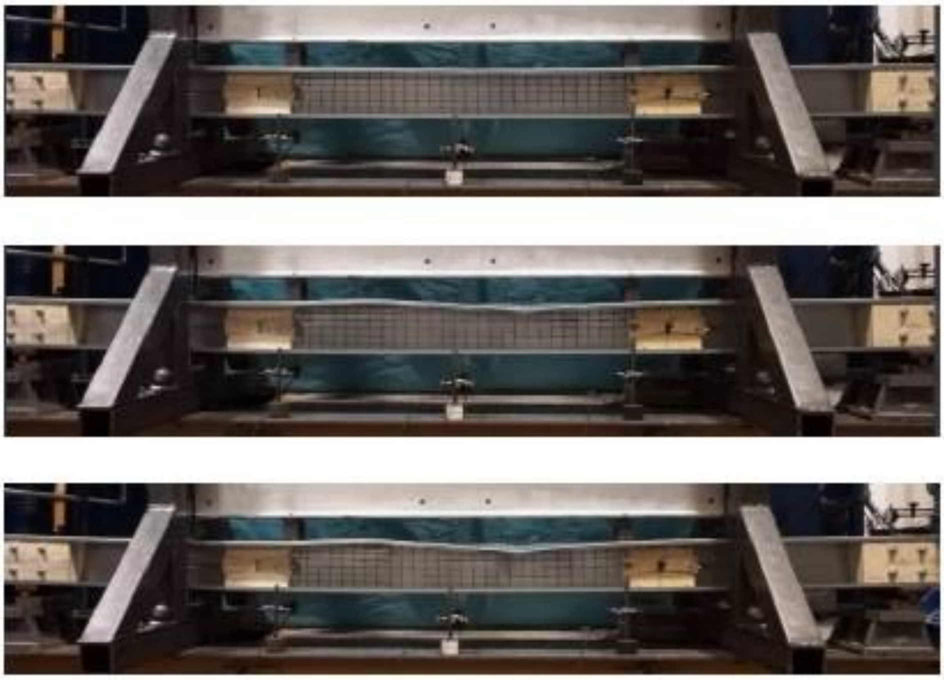


Figure 2-2: Progressive deformation of back-to-back lipped channel CFS beam in 4-point bending test [7]

2.4 Design Standards for Cold-Formed Steel Trusses

There are more than 20 countries in the world that have developed their own Design Standards and codes for Cold-Formed Steel which include Australia, United Kingdom and the United States of America [8]. The American Institute of Steel and Iron has updated about 6 of its design standards for Cold-Formed Steel, one of which is the AISI S100-16 (S2-20) 2020 edition: North American Specification for the Design of Cold-Formed Steel Structural Members, 2016 Edition with Supplement 1**.** The American Society of Civil Engineers distributes the SEI/ASCE Standard 8-02 [8]. In Australia, the design standard for Cold-Formed

Steel Structures is the AS/NZS4600:2018 while the AS/NZS5131 is used for Structural Steelwork. The standard for Steel Structures in New Zealand is the NZS 3404: 1997 – New Zealand Standard for Steel Structures, however, New Zealand also uses the same standard for Cold-Formed Structures as Australia [9]. In the Australian Cold-Formed Steel design standard, AS4600:2018, the analysis of a Cold-Formed Steel is carried out using the Direct Strength Method, under Clause 7.2 which involves a rational analysis called the Finite Strip *Method* [9]. The AISI [10] also uses Direct Strength Method to analyse cold-formed steel.

The design of a truss involves 5 steps which are: determining the profile of the truss and the spacing that is suitable for the structural conditions; determining the load and forces which include the unit loads, load combinations yielding line, truss reaction forces and member forces; determining the design factors for the material; calculating member stresses such as axial stress (tension/compression) and, bending and combined stress; calculating deflections and allowable deflections. There are 2 methods of calculation which can be used to determine the loads and forces; the first is Method of Joints which focuses on forces at each truss joint. By drawing a free body diagram of each connection point and starting the analysis from the supports, the sum of the horizontal and vertical forces can be found. The second method is Method of Sections which is an easier method when compared to Method of Joints because the full truss is not calculated. Separating the truss into sections or halving it allows for one side to be calculated and then this is mirrored onto the truss for the other side [11].

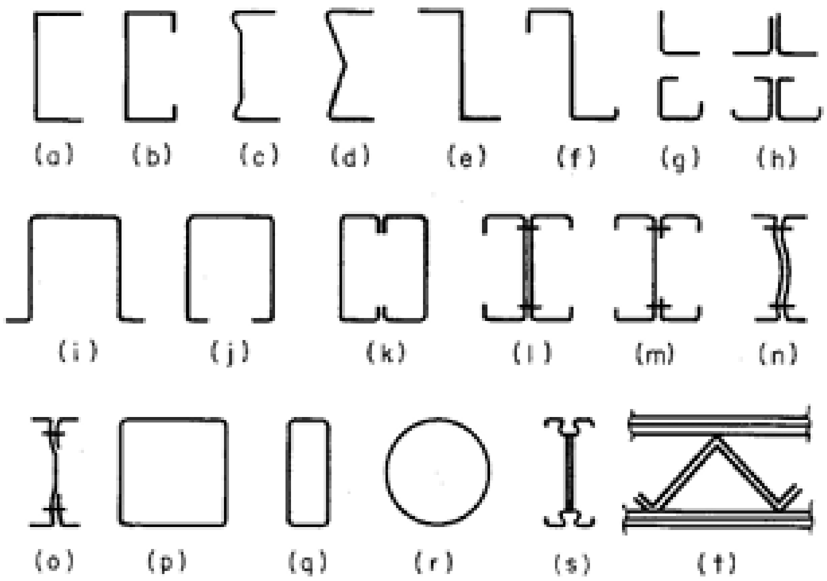


Figure 2-3: Cold-Formed Steel Sections [12]

There are a few differences between the Eurocode (EN1993), American (AISI S100) and Australian (AS4600:2018) standards for design cold-formed steel. In the tension capacity calculation, the EN1993[13] code ignores the net section fracture in its calculation whereas the AS4600[9] and AISI S100[10] code both account for the net section fracture and the bolt holes. For shear capacity, the AS4600 and AISI S100 codes integrate shear buckling in the design when using Direct strength method, however the EN1993 requires separate stiffeners in the design. AS4600 uses Direct strength method for flexural capacity, compression capacity and combines local, distortional, and lateral-torsional buckling for bending capacity, and EN1993 does not have a direct strength method to use for calculating these capacities.

2.5 Cold-Formed Steel Truss System

Trusses are made of a web of triangles which has Compression acting in the top chord and Tension acting in the bottom chord. The 3 main members of a truss (**Figure 2-4**) are the top chord, bottom chord, and web members. Typically, C sections or Z sections are used for these 3 main members of the truss. The triangular truss system solely acting in compression and tension makes it a rigid and suitable structure. Pin connections allow trusses to rotate with ease, and gusset plates are typically used to hold them together [11]. Analysis of a truss involves determining the external and internal forces acting on the joints, with compression acting inward towards the centre of a member and tension acting outwards towards the joints [11]. The cold-formed steel truss system works by applying loads directly on the joints instead of the members which enables the system to withstand the support load and allow sharing and transferring of loads.

Top chord: it is the top member of the truss framework which usually forms the shape of the truss for its purpose.eg. diagonal top chord members form the shape of a roof truss, and horizontal members form the shape of a flat roof truss, or a floor truss. The loads are normally applied along the top chord, at the joints where the web members are connected to the top chord.

Bottom chord: the bottom horizontal member of the truss framework. The supports are usually placed underneath the bottom chords and these locations are called bearing points. The bottom chords are connected to the web members along the internal panel points of the truss moving closer to the ridge of the truss and only meets the top chord at the end panel point or heel of the truss.

Web: it is the diagonal/ vertical members of the truss which is usually of shorter lengths than the top and bottom chord. The web member separates the top and bottom chord in the truss framework and its lengths at certain locations on the truss also helps form the shape of the truss.

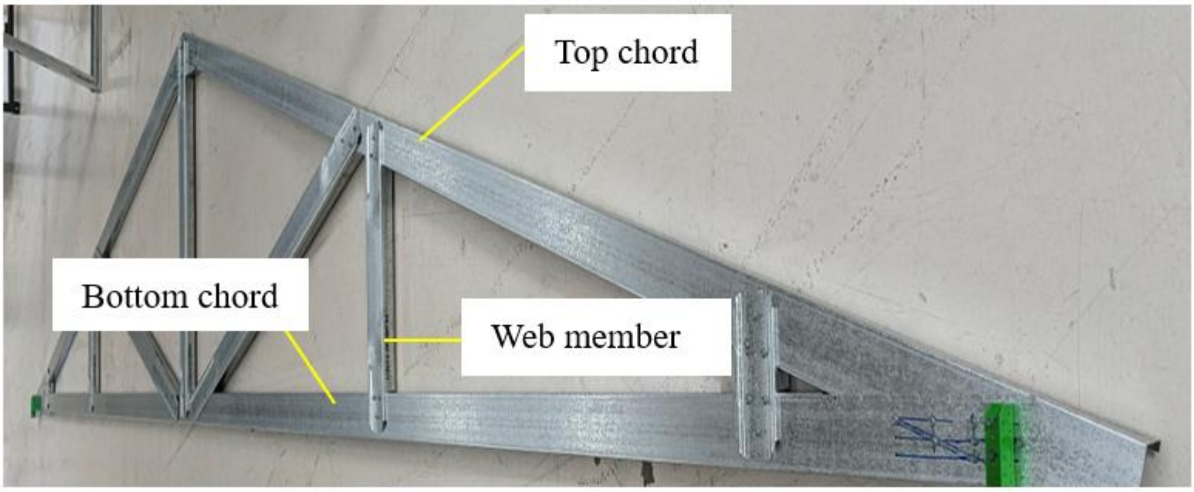


Figure 2-4: Typical Truss members

2.6 Cold-Formed Steel Truss Application in the Building Industry

The use of cold-formed steel trusses in the commercial, industrial, and residential sectors is expanding, as trusses are being used vastly from horizontal structures such as bridges to vertical structures such as single/multi-house dwellings, institutions, and recreational buildings [8]. Channel sections are usually joined by self-drilling screws in residential roof truss systems made of cold-formed steel. Both the bottom and top chords run continuously from heel to heel and from ridge to heel, respectively. The diagonal members are fastened between the top and bottom chords, and the roof surface is formed by traditional wood sheathing [2]. A study on investigating the behaviour and failure mechanisms of 23 small-scale cold-formed steel roof trusses was conducted under single point loading which showed that the top chord adjacent to the heel plate experienced local buckling. This is combined with the distortion of the heel plates due to inadequate stiffening. The limitation to the study is the investigation of methods of reinforcing the top chords to prevent local buckling [3]. A study on the reliability of cold-formed steel trusses which investigated 2 different types of truss profiles showed that the truss system has a greater system reliability than the individual component reliability [14]. The finite element modelling analysis can be conducted to analyse and compare with the test results [14]. Truss structures designed through reclaimed materials have a lower element capacity utilization and a higher mass which have less energy and carbon in comparison to structures made of new materials, however, the life cycle assessment still has some uncertainties[15]. Cold-formed steel trusses have also been used for disaster recovery construction, which is able to reduce the transportation costs, the construction time, and the labour costs in disaster areas. The imported CFS fabrication machine into a disaster area allows rapid fabrication of CFS building parts enabling faster construction in these remote areas which is better in comparison with construction through traditional materials [16].

2.7 Timber Truss System

Wood is a natural resilient material that is readily available for use in the construction industry. With a high ductility and low density, natural wood undergoes an easy process by drying and dressing of roughly sawn timber which gives timber better material properties before being used [17]. The extensive use of timber in the industry is mainly due to its high stiffness and strength [18]. Acquiring better optimization for timber truss requires design parameters of short lengths of intermediate members, a low span-depth ratio with a smaller cross section for its chord elements [17]. A study was undertaken for the comparison of weight efficiency of soft wood against carbon steel, concrete and carbon fibres by computing for tensile/compression efficiency ratio and deflection and buckling efficiency ratio [18]. The results showed that while softwood has a lower strength when compared to concrete and carbon steel, it has a higher efficiency for its members that are prone to buckling under compression [18]. The design criteria of a timber truss is designed to comply with a support span that does not exceed 12m, the truss spacings shall not exceed 1200mm for light roofs and 900mm for heavy roofs [19]. A study on the optimization of metal-plate connected plane timber trusses emphasizing on joint flexibility shows that in the numerical results, the higher timber trusses should be designed with a lower span/depth ratio, smaller cross-sections on the chord elements and smaller number of diagonal and vertical elements [17].

2.8 Screw Connections on Cold-Formed Steel Truss

Connections in cold-formed steel sections can be made in various ways which include blind rivet connections, nailing connections, clinching connections, powder actuated pin connections, self-tapping screw connections, spot welding connections, self-piercing rivet connections, and bolt connections [20]. The types of connections are based on its application and the type of cold-formed steel that need to be joined. The blind rivet connections, self-tapping screw connections and powder actuated pin connections are typically used for joining thin steel sections; spot welding is used for joining thin steel; whereas bolted connections are used for joining thicker cold-formed steel sections [20].

Screw connections in steel sections is a common type that is used due to the steel sections being very thin and this allows for rapid installation. The moment capacity of any connection should be close to or the same as the members which are connected to it as this ensures that the members carry the capacity instead of the joints [21]. Testing the different connection joints between conventional bolted moment end plate joints against gusset plate joints under a universal machine concluded that self-drilling screw joints achieves a great capacity while bolted moment end plate joints are unsuitable for thin cold-formed channel sections. Gusset plates are effective; however, it would need careful design and tests to be undertaken [21]. Assembling a full-scale truss model with varying number of connections at each joint is expensive and time consuming. There has been a number of research which compares the results of a few experimental testing against the Finite Element Modelling (FEM) analysis modelling, one of which concluded that thin plates with higher slenderness experiences more stiffness in the compressed and bent plate of the hat-section [22].

The study on the interaction of local buckling and distortional buckling of a cold-formed steel channel were setup in a back-to-back configuration where connectors are only provided over the supports and under loading points to prevent affecting the buckling pattern

[7]. The impact of various connection types and support conditions on buckling behaviour is not fully considered in this study. Additional research can be conducted on the influence of connections and support conditions in the buckling behaviour.

2.9 Cold-Formed Steel Roof Truss Behaviour

A study was conducted on the behaviour of cold-formed steel roof truss so it can be promoted as a better alternative for construction [2]. The test assembly for this study consisted of 2 x 20ft span Fink Truss made of cold-formed C-steel sections with an assumption that the radius of the CFS C-section is equal to its thickness. The top chord and bottom chord members are longer than the web members. This assembly is a replication of a cold-formed steel roof system with 4:12 roof pitch with 2 square foot tributary area/linear foot for each truss. Along the top chord length, a standard ½ inch flakeboard sheathing is attached using the 1.5 inches No. 12 self-drilling screws which are connected to the top flange at every 24 inches. The web member is attached across the top flange of the bottom chord at 8 feet from either ends of the test assembly which provided stability during construction and acted as a flooring or ceiling board. Each of the 9 different test assemblies for the study is subjected to several test cycles to create a consistent behaviour pattern. The strain measurements were used in later tests to identify specific member behaviour and the vertical deflection measurement was recorded during the initial testing [2]. The experiment concluded that the top chord is the most critical part of a cold-formed steel roof truss assembly. The types of failures occurring on the trusses were local buckling, rotational restraints and distortional buckling due to insufficient bracing [2].

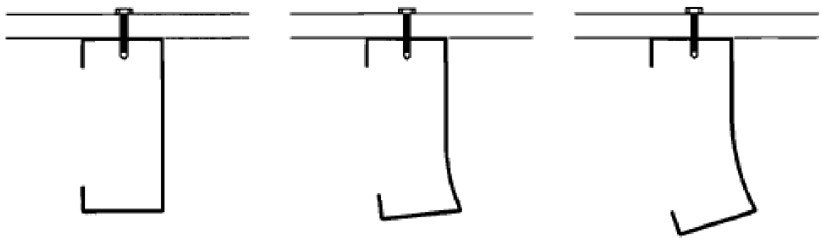


Figure 2-5: Cross sectional deformation on rotational restraint [2]

Further investigations were conducted about behaviours of the compression web members in cold-formed steel truss assemblies using 2 different test series [23]. The 28 test assemblies had an over-design of top and bottom chord to enable the web member to be the focal point of the assembly. The 1st test series used a Mitek Test Frame (**Figure 2-6**) which consists of a series of hydraulic jacks used to apply a simulated uniform gravity load to the top chord of the truss. A plywood sheathing of 18 inches width and ¾ inches thickness is attached to the top chord of the truss which provides a lateral bracing for the top chord. The sheathing is centred on the top chord and connected to the top flange by screws which are placed at a spacing of 12-inch intervals. The hydraulic jacks were screwed to the sheathing through stabilizer brackets extending 6 inches on either side of the hydraulic jacks [23].

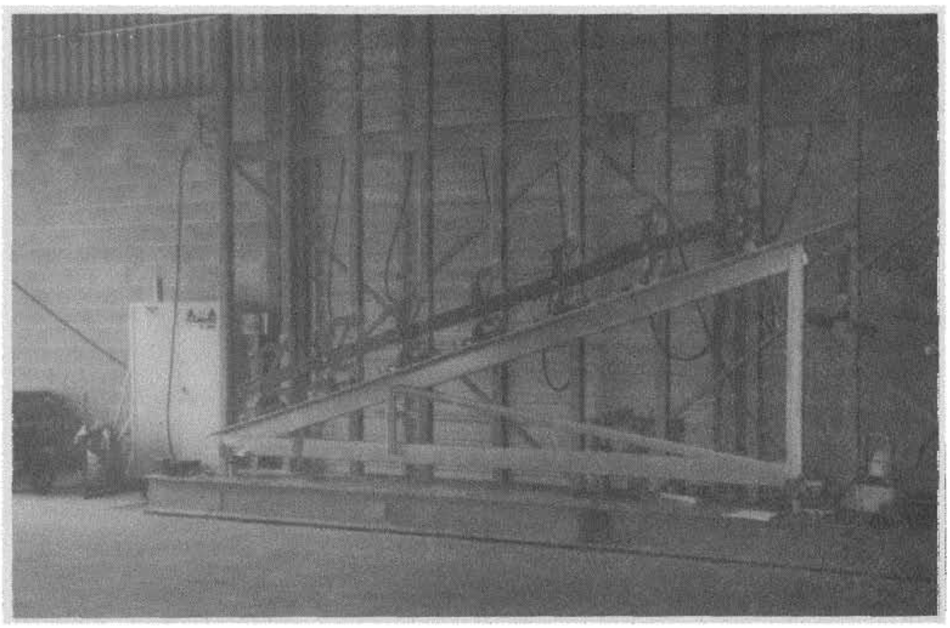


Figure 2-6: Mitek Test Frame Set Up [23]

The 2nd series test used the University of Missouri Rolla-Test Frame which followed the same technique used in the Mitek test frame; however, 6 self-drilling screws were placed at each web member connection for all the assemblies. The University of Missouri Rolla-Test Frame (**Figure 2-7**) consists of pneumatic cylinders which are spaced at 1 foot on the centre to apply a uniform gravity load on the top chord. Channel sections are connected to the bottom of the cylinders used to brace the top flange of the top chord and wooden surveying stakes are used to prevent lateral movement of the top chord. The bottom flange of the top chord is restrained using wire ties with number 20 self-drilling screws drilled through the bottom flange of the top chord which allows vertical deflection of the top chord while the bottom flange is held at a constant distance from support posts of the test frame. The use of bearing stiffeners, lateral bracing and wooden spacers prevent out of plane rotation and web crippling [23].

Figure 2-7: University of Missouri Rolla-Test Frame [23]

2.10 Parameters of Cold-Formed steel Truss

Cold-formed steel has become a better option for the truss system due to its sustainability in design and advantages in increasing rate of construction, preventing cutting down of trees, faster fabrication and construction which leads to reduced labour costs [1]. A full-scale testing of a 25m wide-span roof truss system was conducted and limited to testing for one location. The results showed that the 0.8mm thick channel section truss system did not meet the designed load capacity requirements which shows that trusses with longer spans should be investigated further [1]. Design standards do not offer design of systems such as trusses and only designs of components. In a comparison study of the behaviour of cold-formed steel trusses, the reliability of the truss system is much greater than the reliability of components[5]. A numerical investigation of cold-formed steel trusses with semi-rigid joints show that the rotational deformation is due to the elastic and plastic deformation experienced by bolt holes at the joints. The truss assembly has joined member stresses that usually influence the joint behaviour, and the triangulated shape of the truss will prevent or limit the initial rotational slippage. In accordance with the joint classification criterion in the Eurocode 3 criterion, all tested joints are of semi-rigid type with partial resistance[24].

2.11 Durability and Corrosion of Cold-Formed Steel Trusses

Durability and corrosion are an integral part of any building material that needs to be investigation. The study of corrosion in cold-formed steel members have not been thoroughly investigated as it is more focused on seismic performance and the calculation methods. Cold-formed steel has a higher yield strength than hot rolled steel due to the cold-formed effect which saves the steel between 10-15% [25]. The corrosion effects on various parts of cold-formed steel C-section purlins show that both the flat and the corner parts of the C-section purlins experience different fracture modes and characteristics. The strength reduction of the corner parts is higher than the flat parts due to the corrosion and concludes that the corrosion surface affecting the mechanical properties is related to the residual thickness of specimens. The corrosion effect is higher for thinner materials. These results show that corrosion test should be considered for the mechanical properties tensile test of cold-formed steel [26].

2.12 Truss Eccentricity

Positive eccentricity develops in the truss nodes of cold-formed steel truss sections due to technological factors which causes additional forces to be applied to the truss chords [27]. A series of tests to identify the behaviour of strain and deformation around eccentric joints was conducted due to the assumption that the usual method of structural dimensioning has a lower resistance when compared to an open cross-section truss joins that possesses high positive eccentricity and are located along compression chords [28]. Destructive tests were performed on 5 full-scale study models in order to identify the strains and forms of deformation of the hat-section walls around the eccentric joint [28]. The tests were limited to one wall thickness and the experimental research concluded that the plastic mechanism of failure occurred only in truss members with the loss of stability starting in the middle of the joint, however neither bolts nor holes for fasteners were destroyed [28].

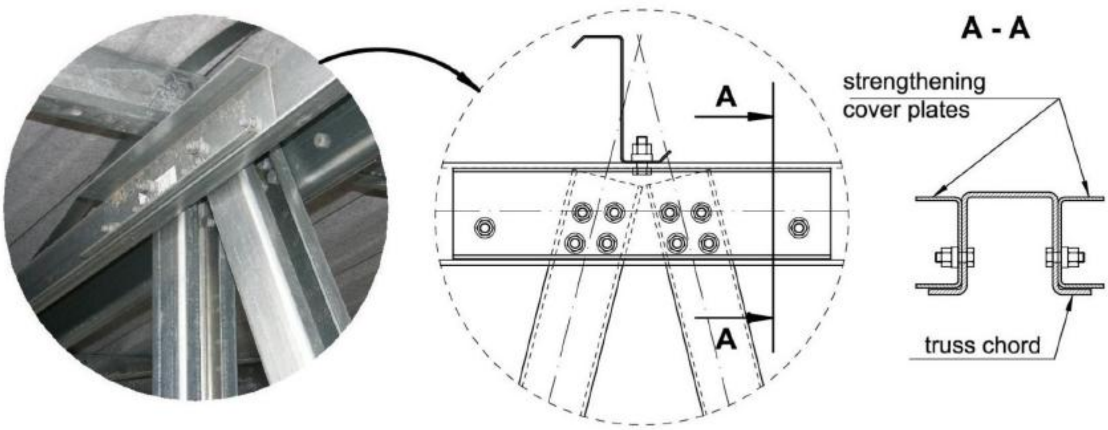


Figure 2-8: Strengthening cover plate on joint [27]

2.13 Distortional Buckling in Cold-Formed Steel of truss system

Local buckling, distortional buckling or lateral-torsional buckling are the 3 instabilities that typically cause failure in cold-formed steel beams [29]. When the compression flange of cold-formed steel joists, purlins, or girts is not constrained by attachment to sheathing or panelling, distortional buckling may be the main source of failure [29]. Experimental data on cold-formed steel beams with unbraced compression flange is limited which prompted a series of distortional buckling tests on C sections under bending [29]. The results showed that design standards for USA, Canada and North America address local buckling however provide unconservative strength estimates whereas the Direct Strength Method in the Australian/New Zealand standard provides methods for calculating distortional buckling with more accurate predictions [29]. Cold-formed steel beams feature open sections in which centroid and shear centre do not coincide [30]. Transverse loads being applied away from the shear centre causes torque and torsion causes warping in the beam due to the open structure of the sections of the beams [30]. The high strength-weight ratio of cold-formed steel allows the distortional mode of failure which causes the complex behaviour under fire conditions [31]. The 2 different steel strengths with varying thicknesses tested under ambient temperatures showed that the distortional buckling equations are accurate at ambient temperatures in the Australian and New Zealand standard, AS/NZS 4600 [31].

Distortional buckling is common in edge-stiffened sections like C and Z purlins and involve the rotation of the flange and lip around the flange-web junction [32]. There was a detailed study in storage rack columns on the distortional mode of buckling for cold-formed steel lipped channel sections in which rear flanges are attached to flange stiffening lips [33]. The theoretical and experimental evidence shows the minimal post-buckling strength in distortional buckling [33]. The test also shows distortional buckling occurs at lower stress than local buckling, however, adding stiffening lips to the channel to increase the distortional buckling strength may reduce the flexural-torsional buckling strength which makes the sections less-efficient [33].

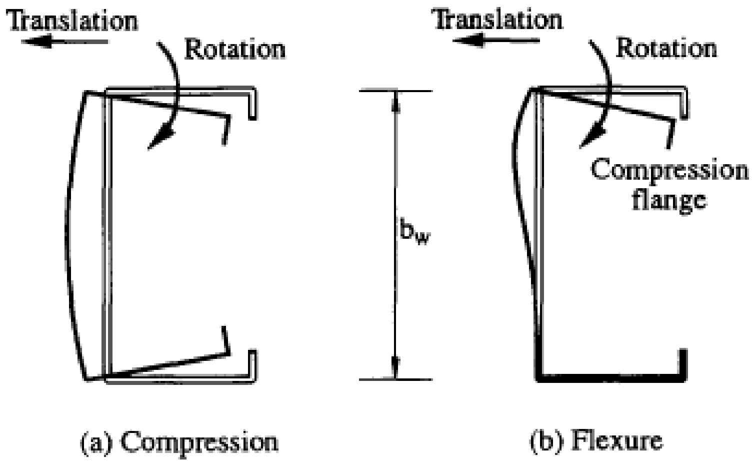


Figure 2-9: Distortional buckling mode [32]

2.14 Flexural-Torsional buckling in Cold-Formed Steel of truss system

The use of cold-formed steel for load bearing components has increased in recent years and the sections being made of thin material makes it prone to instabilities [34]. The investigations of these behaviours are important so there was an investigation in the flexural-torsional behaviour of cold-formed steel columns with arbitrary asymmetric cross sections under eccentric axial load [34]. This developed a formulation using the exact static stiffness matrix method to extract the differential equations for column buckling and also using the Wittrick-Williams algorithm to calculate the critical buckling loads for different types of cold-formed steel sections [34].

The current design standards lack sufficient guidelines for the fire design of cold-formed steel compression members that are subject to flexural-torsional buckling [35]. The European standards apply the same fire design recommendations to both hot-rolled and cold-formed steel compression members, despite the differences in their behaviour [35]. A study was conducted to test the theory in previous research which suggests that cold-formed steel design can be designed at ambient temperatures. The findings show that ambient temperature design standards are conservative [35].

Members are classified into 2 categories based on their torsional strength, which are warping torsion (Vlasov torsion) and pure torsion (St-Venant torsion) [36]. The thin steel open section characteristic of cold-formed steel withstand torsion mostly due to warping rigidity than pure torsional rigidity [36]. The experimental study shows that under warping-free and warping restraint conditions, the warping restraint causes a significant increase in strength [36]. The cold-formed steel sections also experience a combination of torsional and flexural buckling even under axial compression because of their lack of symmetry [36].

2.15 Local buckling in Cold-Formed Steel of truss system

Cold-formed steel compression members have thin walls, which makes local buckling a serious concern [37]. The limited investigations made on buckling behaviour of cold-formed steel compression under elevated temperatures provides a gap in knowledge [37]. An experimental and numerical study was conducted for testing cold-formed steel with varying thicknesses and grades under a series of local buckling tests [37]. The results when compared with design standards showed very conservative predictions [37].

There were 6 beams assembled from lipped channels in a back-to-back configuration and tested to investigate the interaction between local and distortional buckling [7]. The findings from the test showed that local and distortional buckling was simultaneously observed, however, there was no lateral-torsional buckling observed [7].

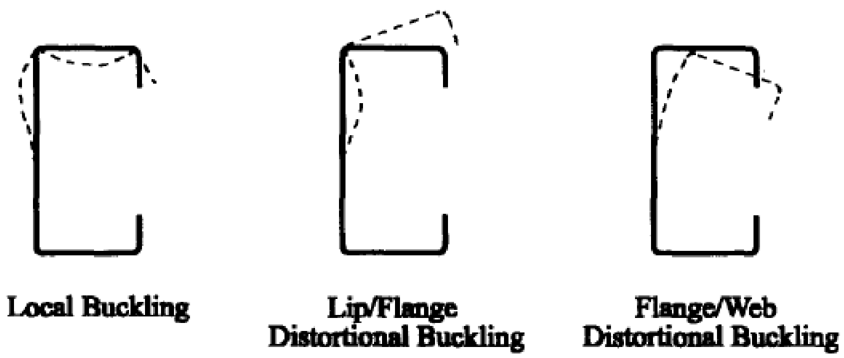


Figure 2-10: Local and short half-wavelength distortional buckling modes [38]

In cold-formed steel back-to-back channel beams that are connected to gusset plates through the webs, local buckling failure is experienced near moment resisting bolted connections [39]. The complex stress state originating from the transfer of both shear and bending moment through the web and the combination of shear lag effect causes this failure [39]. An investigation of the bolt group configuration and length, the thickness of the beam and the cross-sectional shape investigated with finite element models inclusive of material non-linearity, geometric imperfections and non-linear bolt bearing behaviour was conducted [39]. The results showed that the use of a longer bolt group, a thicker beam and introducing the load at the connection with a smaller eccentricity relative to the load causes an exponential decrease in the effect of local buckling [39].

2.16 Research Gaps

From the literature review that has been extensively assessed, there is a significant gap between researching the behaviours around the linear truss system and the back-to-back truss system. This can be further investigated if the truss type and load application is different to suit more realistic conditions. . This can be further investigated if the truss type and load application is different to suit more realistic conditions. The following are the research gaps identified from the literature review:

- Previous research is limited to trusses with particular geometry. Studying the behaviour of CFS roof truss can be expanded to trusses with various geometry and analysing the various lateral restraints along the top chord members.
- Previous research only investigates the behaviour when loads are applied above the top chords and both trusses are faced in the same direction which can be further investigated if the trusses are faced in opposite directions.
- The shape of the truss, the web members locations, spacing and connection type can be further investigated for stability purposes if there are variations in the assembly.

- Full scale tests and small-scale tests have been investigated for the behaviour of cold formed steel roof trusses; however, further research can be undertaken for truss systems with swaged notches on its members that reduce web member areas
- The design standards design members individually using conservative methods. Further analysis can be undertaken for calculating for systems such as truss systems.

2.17 Research Objectives

The objectives of this paper include:

- Investigating the strength capacity and performance of the full-scale 7m CFS Howe truss roof assembly by applications of gravity loads and variations of number of screws connected at each joint.
- Investigating the strength capacity and performance of the full-scale CFS 7m Howe truss roof assembly for a linear truss system and a back-to-back system.
- Investigating the type of failure that occurs on the linear truss and back-to-back system.
- Comparing the experimental results with the design and predicted capacities based on the design standards
- Determining the torsional stability of the chords of the truss assembly as longer members (chords) often fail in torsional buckling.

Chapter 3 Experiment Setup

3.1 Introductory remarks

This chapter discusses the test methodologies and procedures used on the cold-formed steel (CFS) trusses that were fabricated for the purpose of this study.

3.2 Material Properties

The Cold-formed steel used in fabricating the trusses for this study were provided by a manufacturing company, FrameCAD, which is based in New Zealand. The cold-formed steel coil is cut into required dog-bone coupon sizes using the wire Electrical Discharge Machining (EDM) machine at the University of Waikato Large Scale Lab. There were five (5) coupon samples extracted along the longitudinal lengths of the truss specimen and the tensile coupon tests were conducted using the 100kN Instron 9500 machine (**Figure 3-1**).

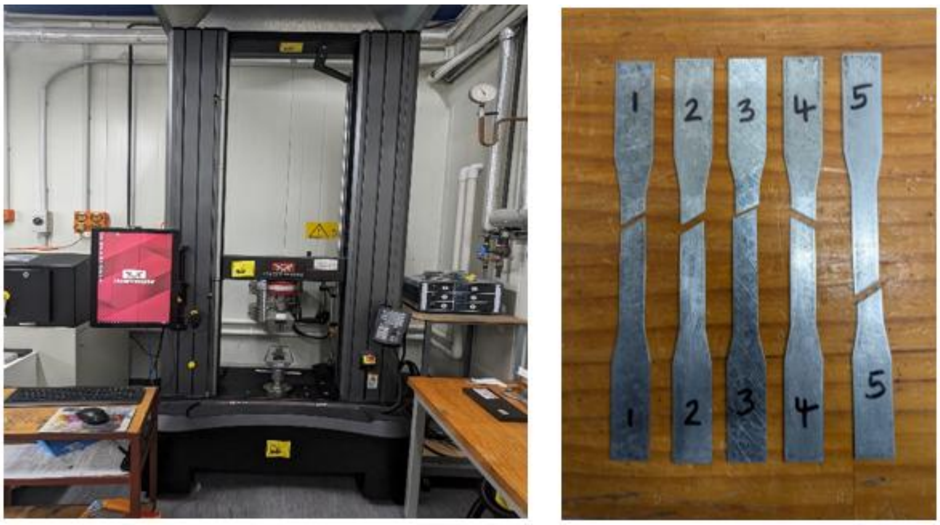


Figure 3-1: Instron Machine for Tensile Coupon Tests and Deformed Tensile coupons

The results from the 5 tensile coupon tests are shown in **Table 1**. A figure of dimension labels is shown in **Figure 3-2** and the stress-strain curve of results is shown in **Figure 3-3**. The varying thickness of each coupon ranges from 0.70mm to 0.76mm. The varying widths for each of the coupons range from 12.58mm to 12.86mm and the varying lengths range from 63.16mm to 67.89mm for the 5 coupons. The results from the tensile coupon tests showed that the maximum tensile stress (MPa) for the coupons ranged from 556MPa to 667MPa. An average of the Ultimate Tensile strength (MPa) for the 5 coupon tests showed that 600MPa is the average tensile strength for the material. The product data sheet of the material provided by the supplier shows that the yield stress of the material in the supplier's tests is 605MPa.

Table 1: Tensile Coupon Test Results

	Test	**1**	**2**	**3**	**4**	**5**	**Average values from 5 tests**
Test Parameters	**Width(mm)**	12.58	12.86	12.38	12.82	12.81	12.69
	Specimen Thickness(mm)	0.70	0.73	0.76	0.73	0.75	0.74
	Gauge Length(mm)	64.57	64.69	67.89	63.56	63.16	64.77
	Ultimate Tensile Strength (MPa), fu	667.76	600.27	556.46	594.39	581.92	600
	Yield Stress, fy	657.181	587.433	541.764	587.503	576.577	590.09
	Young's Modulus (E)	1989.7	1917.4	2182.5	2211.3	2034.1	2067.00

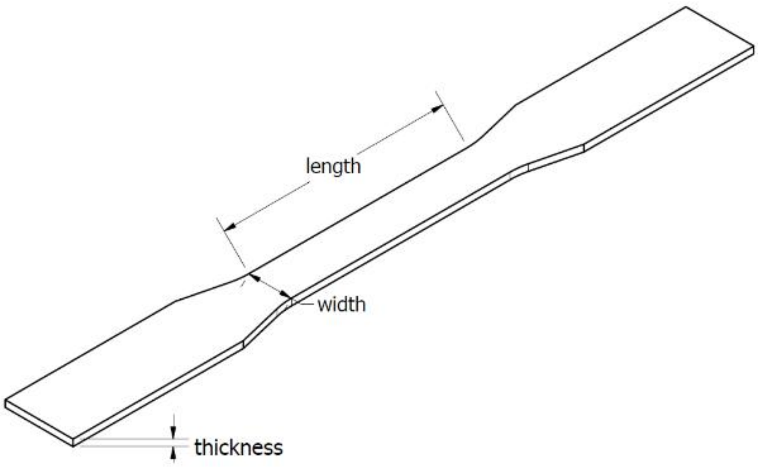


Figure 3-2: Tensile Coupon Dimension Labels

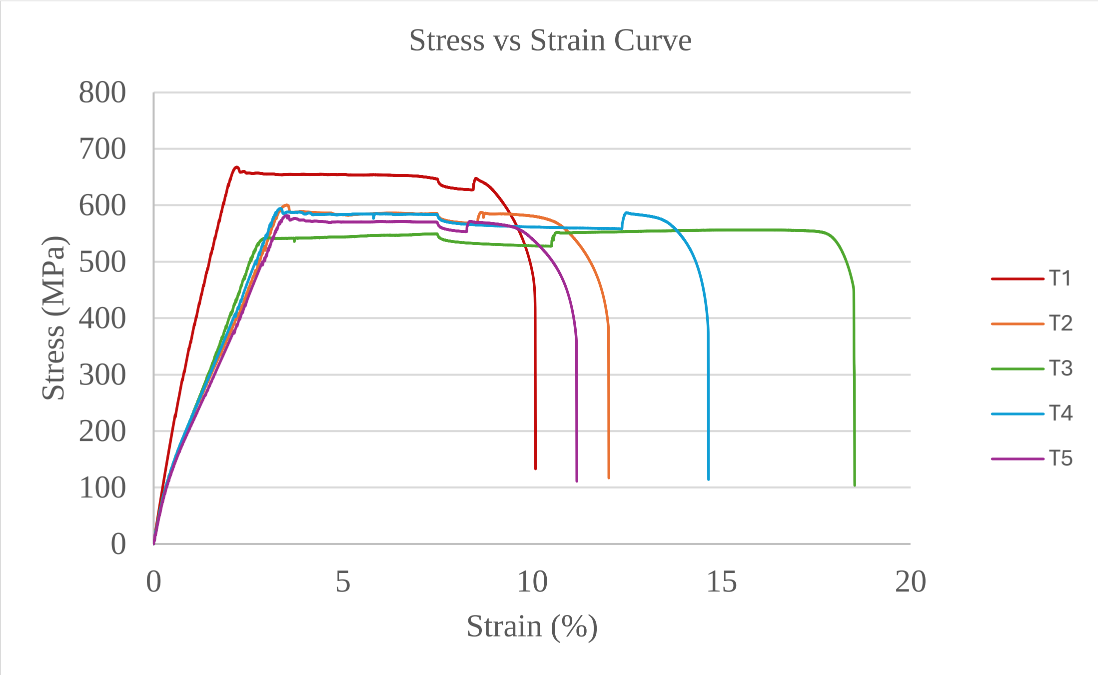


Figure 3-3: Stress vs Strain Curve of Tensile Test

The CFS C-section used for this test series consists of 41.00mm flanges with 11.00mm lip and a web of 89.00mm as shown in **Figure 3-4** below.

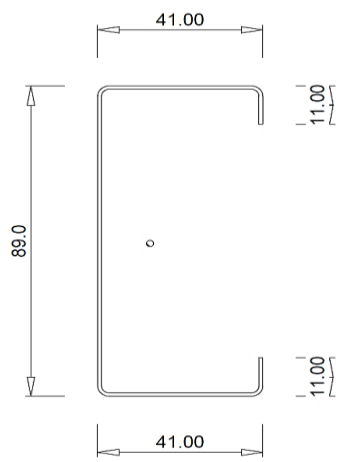


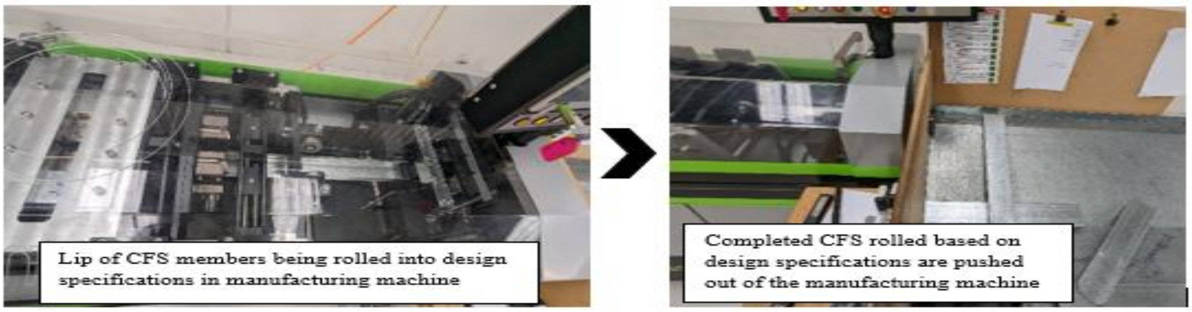
Figure 3-4: C-Section dimensions used for Truss Members

3.3 CFS Fabrication

The designs modelled on the FrameCAD structural software and screw connections designed on FrameCAD detailing software are eventually imported to a FrameCAD manufacturing machine. This manufacturing machine receives the detailed design and will begin to cut the respective members from the uploaded design. **Figure 3-5** shows the manufacturing machine used to manufacture the CFS design members used for this study. The manufacturing machine is very efficient as it can fabricate all the members of the 7m CFS truss within 10 minutes.

Figure 3-5: Manufacturing Machine used to cut steel sections for this study

The manufacturing machine has 5 parts which allows the designs to be accurately cut into its specifications (



). There is a screen on the manufacturing machine which shows the design that needs to be fabricated. The process of fabrication begins once the fabricator presses the start button on the screen of the manufacturing machine.

The CFS coil which is placed approximately 5m away from the machine is already inserted at the side of the entry point into the machine so it can be pulled easily by the machine. The machine starts to pull the flat CFS coil, and it firstly moves under a rectangular platform with 13 nodes that receives and reads the design specifications. This includes reading the lengths of the members to be cut, the order in which the members should be fabricated and the location of the screw holes for each member. The coil then moves onto the next part of the manufacturing process in the machine which consists of 5 rollers that bend the CFS and starts to form the open C section's web and flange member. The holes for the screws are also punched in its designed location. Once this is completed, the coil moves onto the last process in which the C section formed from the coil is further rolled to form the lip of the flange and the designed swage cuts are also bent and cut accordingly. The cold-formed C section is then pushed out of the machine once the entire process is completed, and the machine begins the entire process again with the next design member. While the screen for the machine shows the order of the member cuts for each design, it also shows which members have been completed and which members would be fabricated thereafter. The current member being cut will be shaded in green, the previously completed member will be shaded in grey and the next member to be cut will be shaded in blue colour. The manufacturing machine automatically stops operating once all the members of an uploaded design have been fabricated or otherwise the machine can also be stopped by the fabricator.

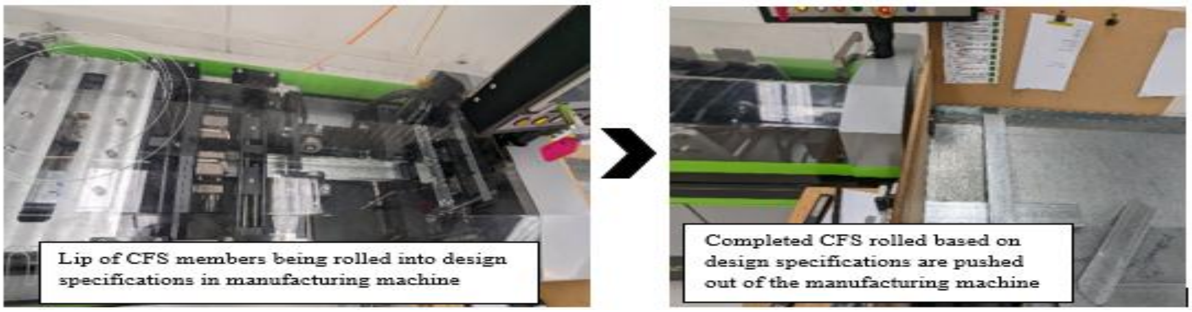


Figure 3-6: Cold-Formed Steel (CFS) being rolled through a manufacturing machine

3.4 Standard Experimental Arrangement

Each CFS truss designed to be studied in this experiment has a 7m (7000mm) length and 1.163m (1163mm) height with each member cut into a C-section from 0.75mm thick cold-formed steel. The 7m long truss is designed in the structural software and imported to the detailing software to decide the locations of the screw connections. Once this is completed, the detailed design is imported onto a manufacturing machine which roll-forms each member according to its specification.

Some of the CFS truss members are cut and swaged in certain areas of the section to allow it to be connected to other members using hexagonal head screws. **Figure 3-7** shows an example of one of these unique cuts in which a C-lipped section has the lip removed completely and one of the flanges reduced to a 7mm width. The figure also shows how a swaged cut looks on a C-section cold-formed steel.

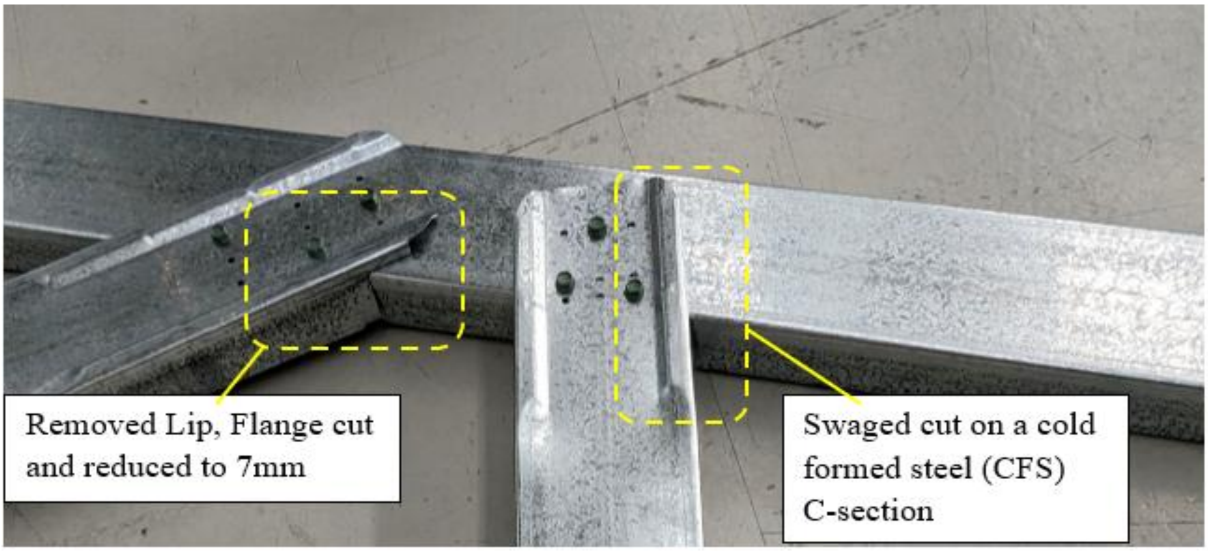


Figure 3-7: Removed lip and cut flange on CFS

Each of the CFS truss fabricated for the experiment testing consists of 11 members: 2 of these are top chord members, there is 1 bottom chord member and there are 8 web members. The members of the truss are connected using a minimum of 3 screws at each joint. A detail view of the typical dimensions of the 7m experiment truss is shown in **Figure 3-8**. The dimensions of each member of 1 truss are shown in an elevation view diagram in **Figure 3-9**.

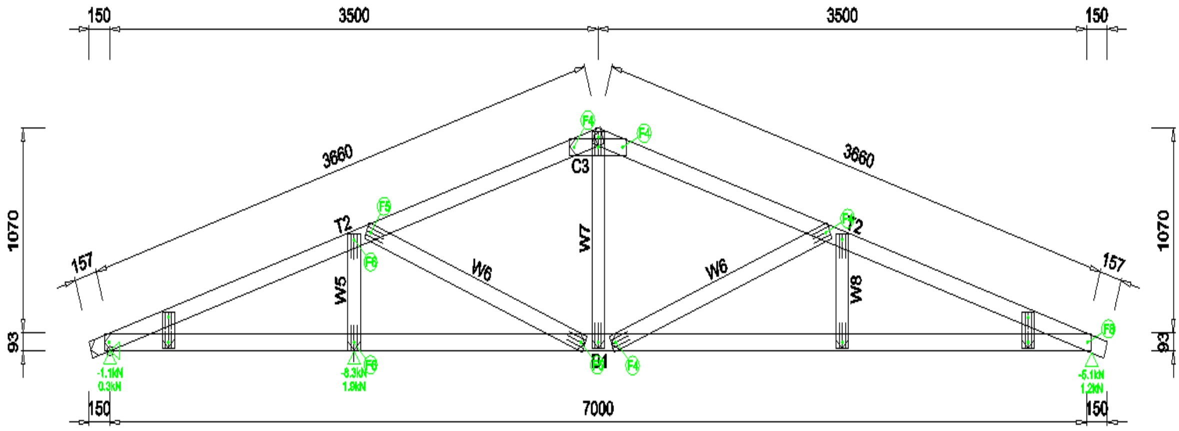


Figure 3-8: Detail of Experimental Truss in Design Software

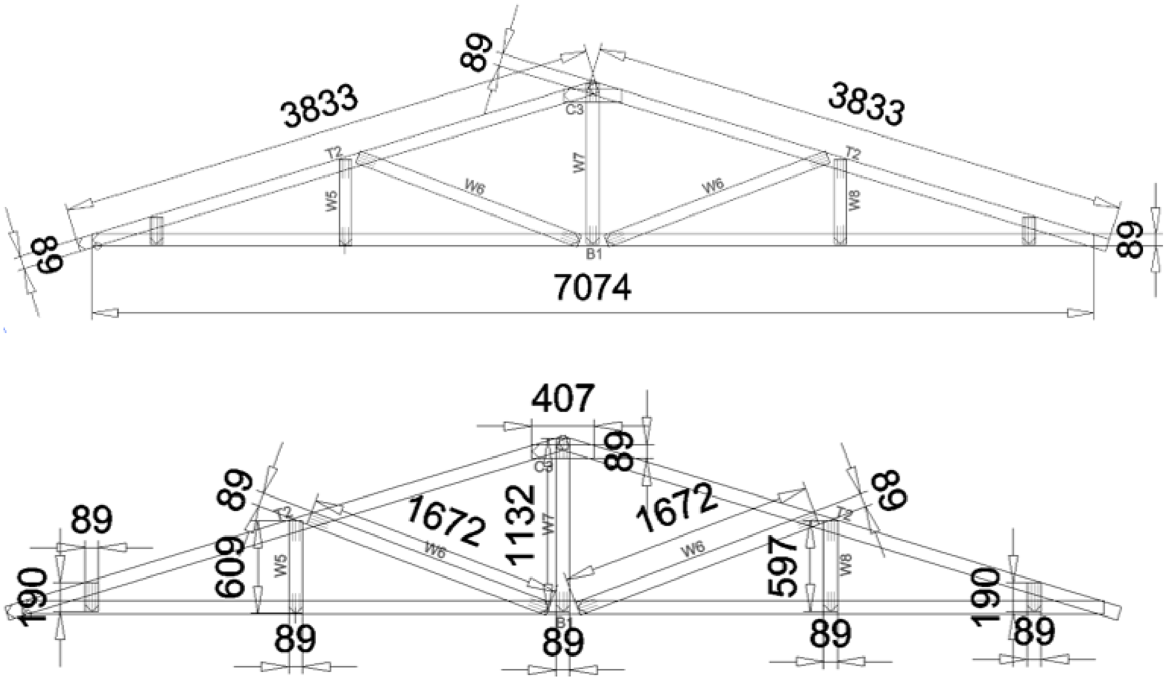


Figure 3-9: Truss Member Dimensions in Elevation View

3.5 Experiment Assembly Roof Truss with Support Frame

The 8 test experiments carried out in this study is held at the FrameCAD factory in which the CFS members are also fabricated. The pair of CFS roof trusses sit on top of a main support frame made of cold-formed steel (CFS) and timber which is about 880mm in height. The roof assembly is 1163mm in height at the ridge of the truss, and when the 880mm height of the main support frame is included, the total height of the test set up is 2043mm (2.043m). The pair of CFS trusses are separated by cross bracings in between the centre web member with typical roof elements above the top chords of both CFS trusses. The typical roof elements include roof battens, ridge cap, roof sheets and roof screws. There are ceiling battens which are installed underneath the bottom chord and the ends covered with cloth and clear wrapping to prevent injury during loading.

The loading of the assembly is made in such a way that the load acts on the top chord of the assembly. This is conducted by placing CFS made pieces above the roof sheets along the areas that are parallel to the locations of the roof battens. There are cables which are hung from the CFS made pieces and these are dropped down to near ground level and secured around CFS made pallets to hold them in place. The loads are placed onto the pallets at increments of 6 boxes per pallets until failure occurs. **Figure 3-10** shows a typical test assembly of the CFS roof truss sitting on top of the main support frame.

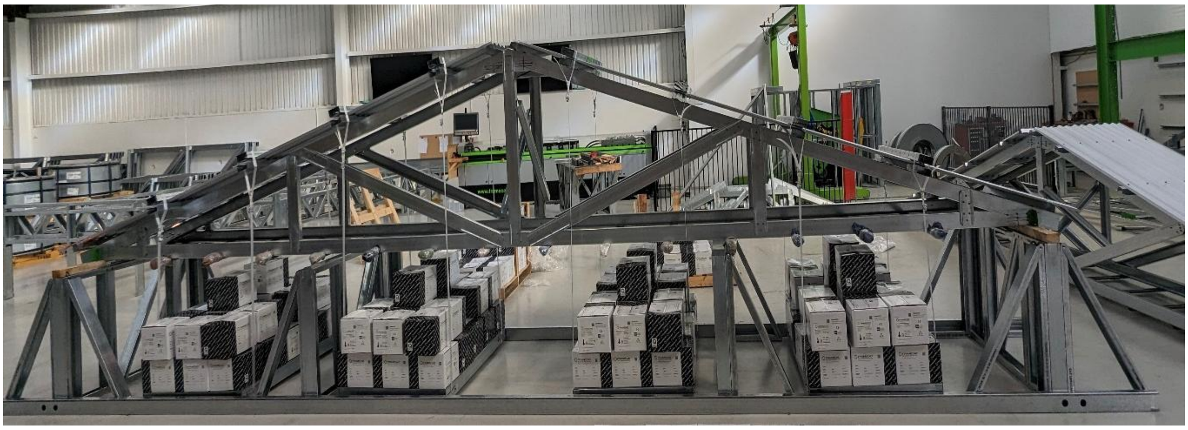


Figure 3-10: Typical Test Assembly with Loading

3.6 Roof Truss Assembly

Two Howe trusses, each measuring 7m in length and constructed using a new linear truss system are the standard specifications for the CFS roof truss system used in this study. As shown in **Figure 3-11** below, the typical arrangement of the experimental truss system includes trusses, roofing battens, ceiling battens, roof sheets.

The methodology of each test involves 2 CFS trusses being placed at 600mm spacing and 2No diagonal bracing installed in between the 2 trusses. Ceiling battens are connected to the bottom flange of the bottom chord of the truss at a 400mm spacing along its length. There are steel pieces that are fixed as cross bracings above the ceiling battens. The roof battens are connected to the top flange of the top chord of the truss at a spacing of 800mm spacing along the length. There are 2 corrugate iron roofing sheets of 4000mm length and 800mm width per sheet which are connected to the roof battens using standard roofing screws placed at 200mm spacing across the length of the roof battens. The loads for the CFS truss pair assembly tests are applied in sets. The loads consist of boxes of hexagonal head screws and any of these sets vary from 3 boxes per set to 6 boxes per set. Each of these boxes of screws weigh about 15.75kg and in later tests, 14.6kg boxes are also used and the boxes are applied continuously until the CFS truss pair assembly experiences failure.

Figure 3-11: Roof Truss Assembly Set up

The typical setup for one test comprises of the following: 2 cold-formed steel truss with each truss measuring at 7m length x 1.163m in height; 2 corrugated iron roof sheets consisting of 4m length x 0.8m width per sheet; 12 roof battens with each batten being 0.897m long by 0.09m wide; 14 ceiling battens which are 0.809m long and 0.065m wide; 1 ridge cap that is of 0.6m length and 0.1m width; about 48 standard roofing screws for the roof sheets; HWH Frame Fix DP screws for the joint connections; 2 steel cross bracings in between the trusses; 2 flat steel bracings, each of 1515mm long and 30mm wide, placed above 4 of the ceiling battens that are at the centre of the truss assembly; a main support frame made of cold-formed steel and timber in which the truss assembly is placed on during tests; CFS box sections placed above roof sheets in which cables are looped over to hang CFS load pallets underneath the truss assembly at a standard height above ground level and loads consisting of boxes of screws with an average total up to 3tonnes. The number of hexagonal head screws which is used to connect the truss members varies for each pair of trusses. The **Table 2** below shows the list of materials used for each test in this study.

Table 2: Standard Material List for CFS Truss Roof Assembly

Material	No. required	Dimensions	Spacing
CFS Truss	2	7m x 1.163m (LxH)	0.6m
Roof battens	12 (6 on each side)	0.897m x 0.09m (LxW)	0.8m
Ceiling battens	14 (7 on one side)	0.809m x 0.065m (LxW)	0.4m
Ridge cap	1	0.6m x 0.1m (LxW)	-
Roofing screws	72 (36 on each side)	Standard roof screws 0.014m x 0.035m	0.2m
Roofing sheets	2 (1 on each side)	4m x 0.8m(LxW), 0.55mm gauge	-
Cross bracings	2	1m x 0.93m	Centre between trusses
Screws on Truss	Minimum 3 (varies for each test)	10g, 18mm-19mm	-

3.7 Roof Sheets on Truss Assembly

There are 2 roof sheets which are placed above the pair of truss assembly along the lengths of either side of the top chords. Each roof sheet is 4000mm long and 800mm wide and is made of Corrugate 0.55 Zincalume. The pair of roof sheets are installed above the roof battens which are placed above the top chords of the pair of CFS truss assembly as shown in **Figure 3-12** below. There are 72 standard roof screws in total that are used for the roof sheets with 36 screws used to connect each roof sheet onto the roof battens (**Figure 3-12**). There are 6 rows of roof screws that are placed at 200mm spacing along the length of the roof battens and the spacing of each row of roof screws is the same as the 800mm spacing of the roof battens with each roof screw dimension being 35mm long and 14mm wide. The number of standard roof screws are increased from 72 to 120 for the tests conducted later during the study. This is due to the observations made from the early tests which caused the inclusion of more roof battens above the top chords of the truss assembly. With this increase, there are 60 standard roof screws on one roof sheet and 60 standard roof screws on the other roof sheet.

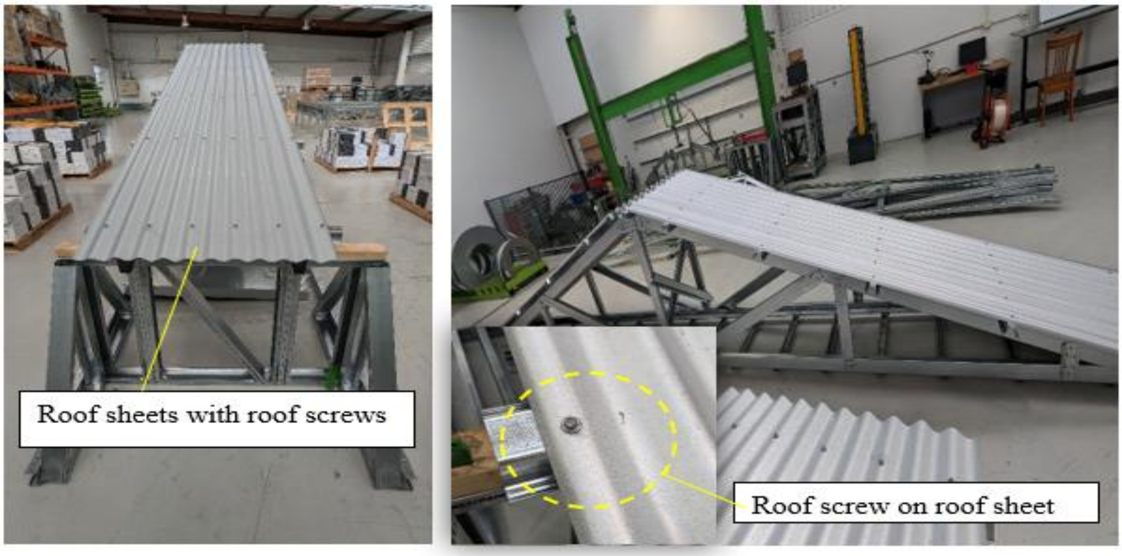


Figure 3-12: Roof sheets and roof screws on truss experiment

3.8 *Ridge Cap on Truss Assembly*

There is 1 roof batten which is used to simulate a ridge cap at the apex of the truss assembly, along the 0.6m spacing between the 2 trusses, where the two top chords of each truss are connected. The ridge cap is made of steel material, and its dimensions are 0.6m long and 0.1m wide. As shown in **Figure 3-13** below, the ridge cap is placed just between two roof battens and connected to the top chords of the truss assembly using 4 HWH Frame screws. The ridge cap is included in the test assembly after observations were made from the 1st test series set up. The roof sheets placed above the roof battens are not connected to the ridge cap which is at the apex of the truss assembly.

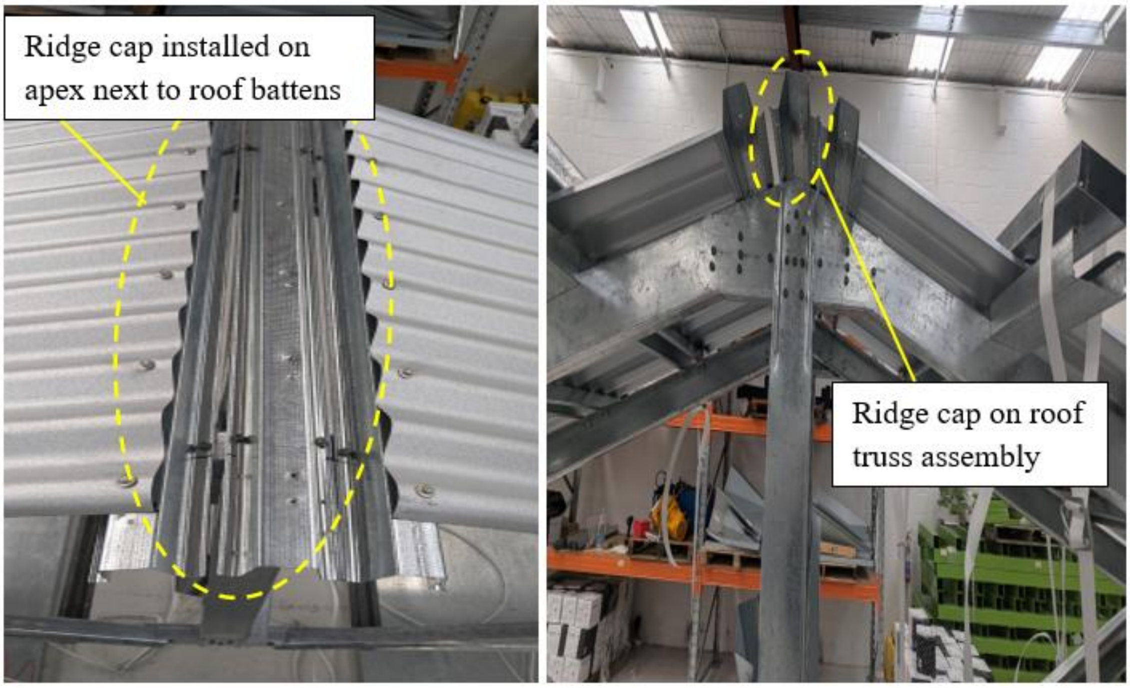


Figure 3-13: Ridge cap installation on roof truss assembly

3.9 Ceiling Battens below Bottom Chord

There are 14 ceiling battens placed at 400mm spacing underneath the bottom chords of the pair of CFS C-section trusses. The ceiling battens are perpendicular to the length of the bottom chords of the pair of CFS C-section trusses. From the centre of the CFS C-section trusses, there are 7 ceiling battens which are placed on either side of the trusses. Each ceiling batten is 809mm long and 64mm wide. The ceiling battens are made of steel and have a 2mm folding at the end of its open pentagonal sided shape. The 64mm width is the total of the 3 widths of 14mm per return edge and 36mm width of the base of the batten.

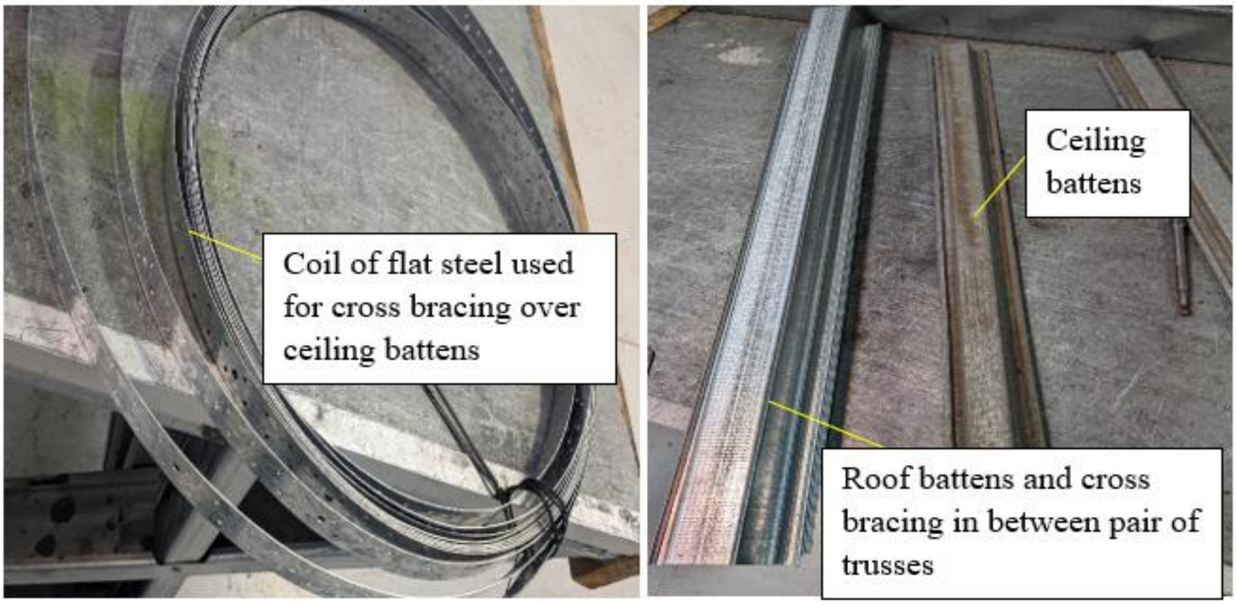


Figure 3-14: Coil of flat steel used for bracing, roof batten and ceiling batten

There are 4 hexagonal head screws that are used for each ceiling batten in which there are 2 screws connected on each side. In between the 4 ceiling battens located near the centre of the bottom chords of the truss assembly, there are 2 flat steel pieces of 1515mm long and 30mm wide which are used as cross bracing. A coil of the steel bracing used above the ceiling batten is shown in **Figure 3-14**. The edges of these steel pieces are screwed onto the ceiling battens at its edges and corners. The ceiling batten is placed at a spacing of about 400mm along the bottom chord. The ceiling batten connection to the bottom chord is shown below in **Figure 3-15**.

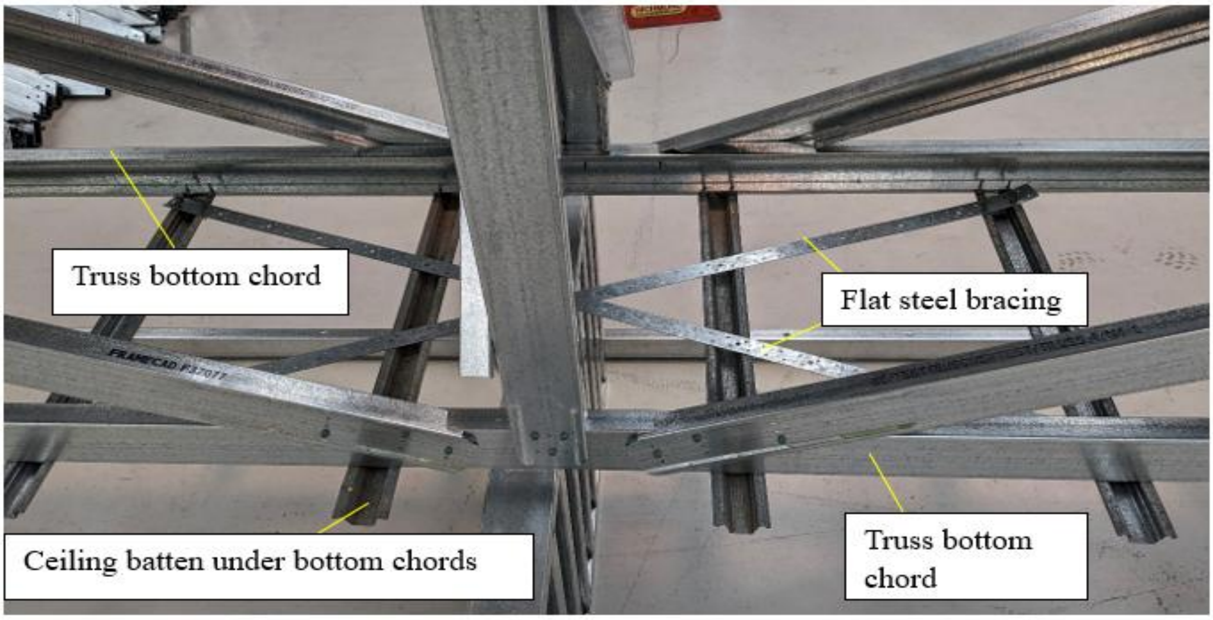


Figure 3-15: Ceiling batten under bottom chords of CFS Truss pair test assembly

3.10 Roof Battens below Top Chords

There are 12 steel roof battens used for the pair of open CFS C-section trusses which are placed underneath the roof sheets and above the top chords. The roof battens are perpendicular to the length of the top chords of the pair of CFS C-section trusses. Each roof batten is 897mm long and 90mm wide and there are 6 roof battens placed on each side from the centre of the pair of CFS trusses. The roof batten is placed at a spacing of 800mm. There is an overhang of 36mm for 11 roof battens and the 12^{th} roof batten has an overhang of 100mm. The roof battens are made of steel and have a 2mm folding at the end of its open pentagonal sided shape. The 90mm width is the total of the 3 widths of 20mm per return edge and 50mm width of the base of the batten. There are 4 hexagonal head screws that are used for each roof batten in which there are 2 screws connected on each side. The **Figure 3-16** shows the roof batten installation on the test assembly.

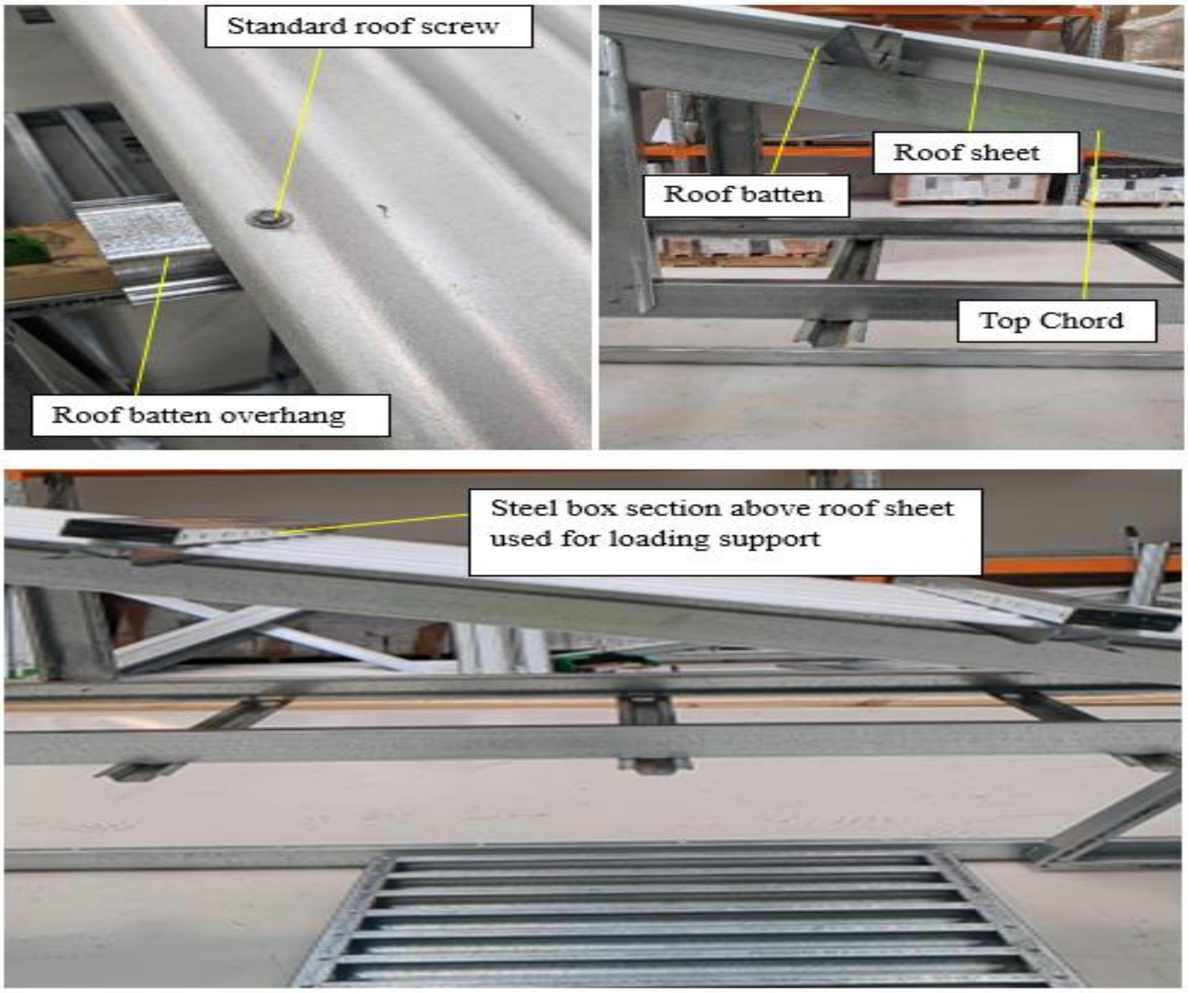


Figure 3-16: Roof Batten above Top Chords of CFS Truss pair test assembly

3.11 Support Frame for Truss Experiments

The pair of trusses inclusive of all the roofing elements used for testing are mounted on a supporting frame made of timber and cold-formed steel. The bottom chords of the pair of trusses are sitting on top of 2 pieces of dressed timber with dimensions of 1245mm x 70mm x 45mm. There is 1 timber placed on each side of the top of the main supporting frame which later increased to 2 pieces stacked on each side after the initial test as shown in **Figure *3-17*Figure *3-17*:** . The two pieces of stacked timber of equivalent dimensions are screwed together with 2 screws to prevent movement; each of the screw being used is 0.075m long and 0.014m wide. There are 2 multi fix brackets which are connected by 2 HWH Frame screws to the top piece of the stacked timber on the main support frame. The multi fix brackets are connected from the outer part of the stacked timber piece as shown in **Figure 3-18** and this prevents the CFS truss assembly from sliding off the width of the support frame. The extra screws that are used for the end supports of the truss assembly are connected to the CFS truss through the multi fix bracket. The timber pieces are placed on top of supporting frames made of cold-formed steel and the truss assembly rests on top of these timber pieces. The truss assembly is screwed to the timber pieces using multi fix brackets on all 4 sides of the assembly.

The support frame simulates a fixed support boundary condition on the truss assembly. The multi fix brackets ensures a fixed connection for both the heel of the truss assembly and the timber underneath the truss assembly. The fixed end support connections also aid in preventing the assembly to move sideways.

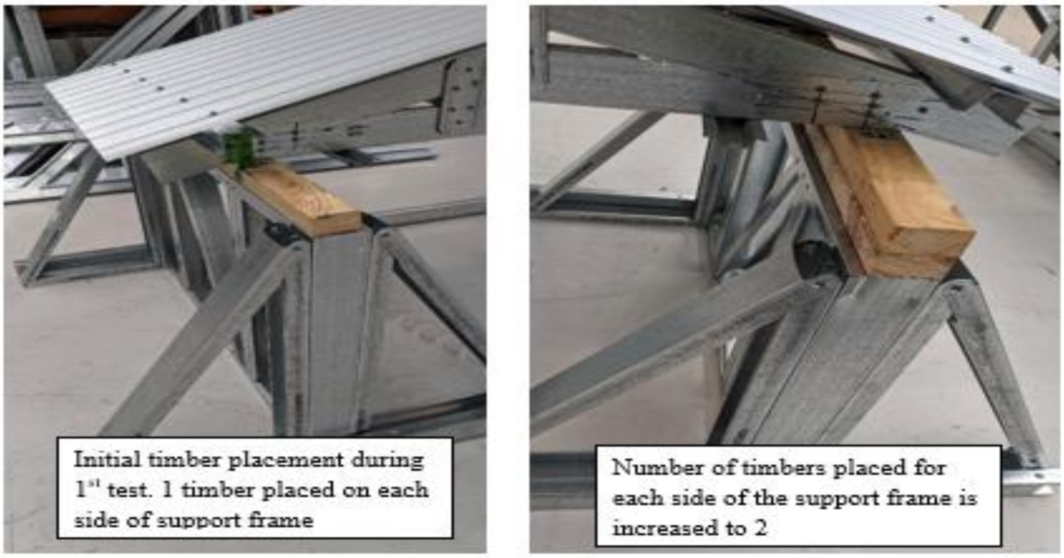


Figure 3-17: Timber placement on support frames for pinned end support of truss assembly

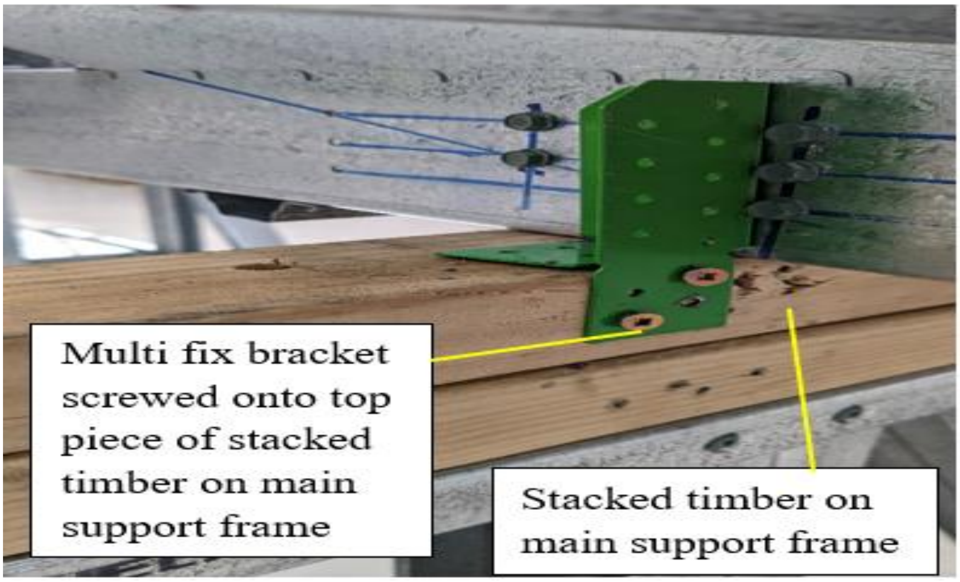


Figure 3-18: Multi fix bracket on top of stacked timber pieces of main support frame

The supporting frame consists of 9 open CFS C-section members joined together to form a rectangular box frame. There are 8 of these open CFS C-section members which are placed vertically and horizontally to form rectangular frames and the 8 open CFS C-sections are connected by 1 screw at each joint. The 8 CFS C-sections are placed in the following way: the 2 horizontally placed open CFS C-sections are the same length as the timber which is 1245mm; there are 2 open CFS C-section members which are placed vertically to separate the two horizontal members to form the ends of the rectangular frame; there are 4 open CFS C-section members which are placed in between the 2 vertical CFS C-sections at the ends of the frame; all 6 open CFS C-sections which are placed vertically are all of equal lengths of 800mm long; there is 1 open CFS C-section which is placed diagonally and is 860mm long.

There are 8 triangular pieces used as bracing for the main support frame in which the triangular braces are placed on each side of the end support frames. **Figure 3-19** shows the main support framework on one side of the test set up. Each of the triangular pieces are made of cold-formed steel (CFS) and consists of 3 open CFS C-sections of different lengths. The dimensions of 1 triangular piece when joined together is 470mm at the base, 790mm in height and the brace is 860mm long. The base of the triangular pieces used as bracing are leaned against single CFS C-section pieces which are 8m in length.

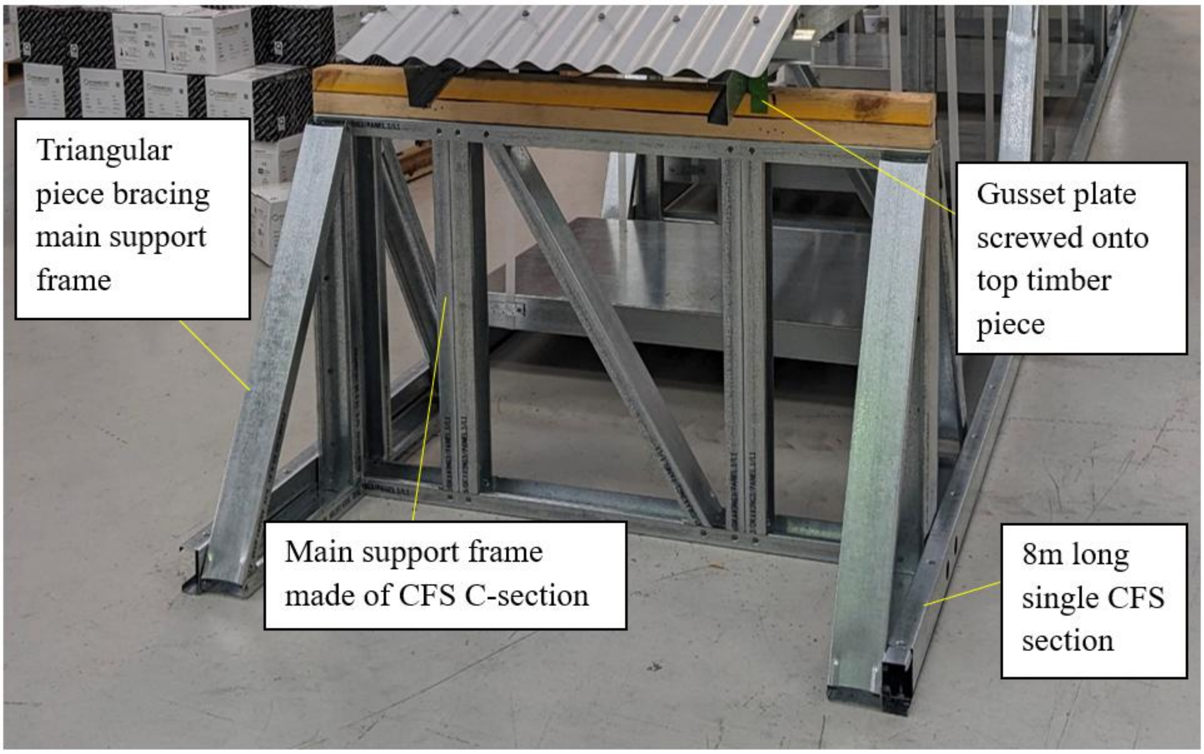


Figure 3-19: Main support framework on one side of test set up

There are 2 internal support frames which are also part of the main support framework. These two internal frames, however, are only placed in case there is a scenario where the pair of CFS trusses fail completely and the whole truss falls. During the tests, the pair of CFS truss assembly do not rely on the internal support frames for any support as the pair of CFS trusses are sitting on the timber pieces along the end support frames. The internal support frames are made of single CFS C-sections which consist of 2 triangular pieces placed on either end of a rectangular frame. The **Figure 3-20** shows the whole support framework which includes internal support frames.

Figure 3-20: Main Support framework for Truss Test

The support framework for the test assembly was further increased to a height of 1.045m after a few tests were conducted (**Figure *3-21***). An additional 200mm high CFS box section is placed above the original 0.8m cold-formed steel section and there is only 1 piece of 0.45m thick timber which is placed above the additional piece.

The new additional piece is made from 8 open channel sections joined together to form a rectangular box frame. There are 2 pieces of open cold-formed steel C-sections, each of 860mm length and 89mm width. There are 6 pieces of 200mm in length and 89mm width which are placed across the 860mm long open cold-formed steel C-sections, and these pieces are connected using the HWH Frame Fix DP screws or hexagonal head screws. Two of the 200mm long pieces are placed on either ends, facing inwards across the 860mm long pieces and each 200mm long piece is connected to the 860mm long pieces with 4 screws in total. The other 4 pieces of 200mm long open CFS C-sections are placed back-to-back along its webs and each piece is connected to the 860mm long pieces with 4 screws.

There are 4 flat plates which join the additional 8-piece open CFS box section to the original support frame. The flat plates are made of galvanized steel coated with green corrosion protection. These plates are placed on either sides of the support frame and 12 HWH Frame Fix DP screws or hexagonal head screws are used to connect the plates to both the original and additional CFS pieces.

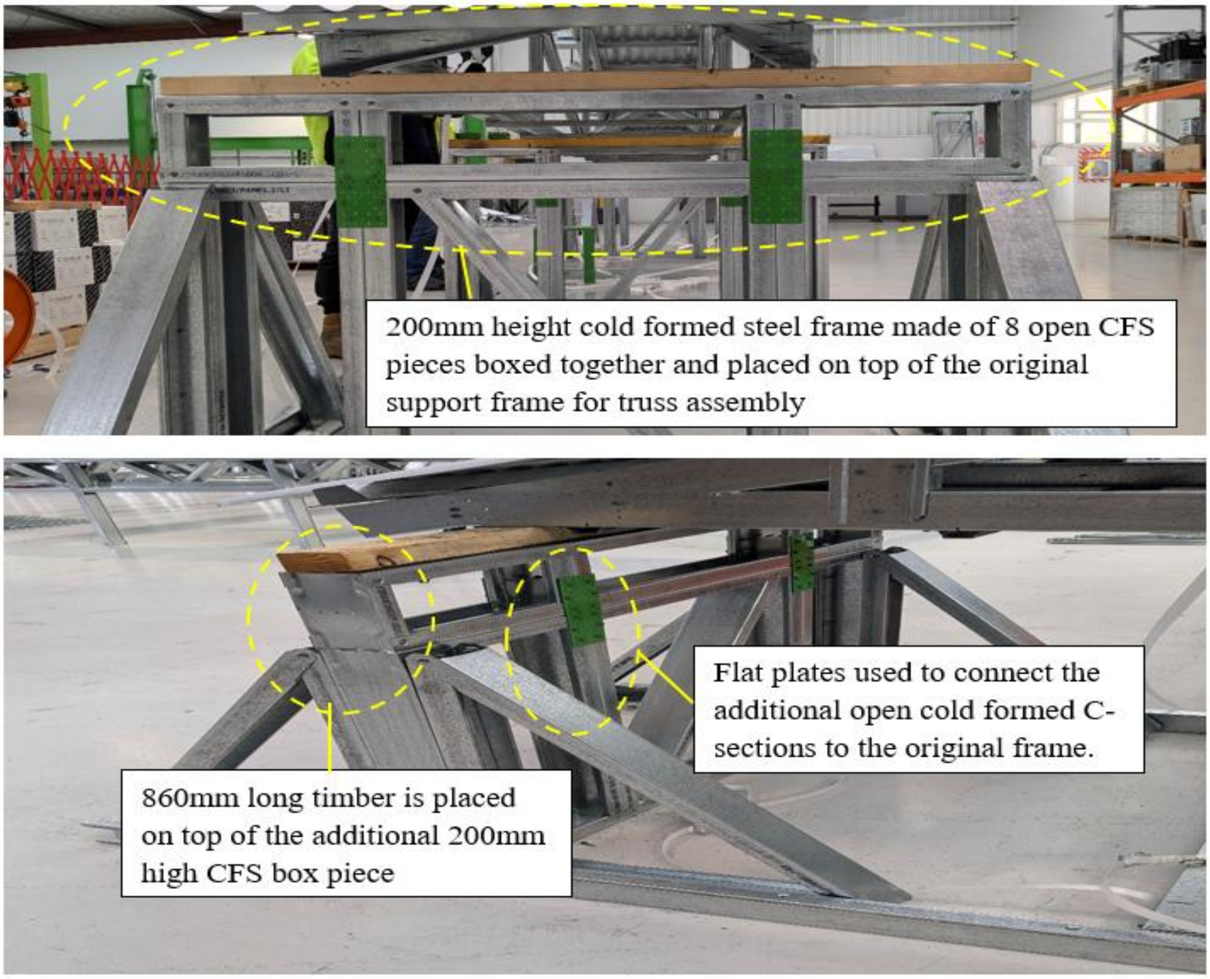


Figure 3-21: Additional open cold-formed steel C-section box piece on support frame

3.12 Load Supports on Test Assembly

The loads used on the test assembly are applied onto pallets that hang from CFS box sections placed above the roof sheets of the truss assembly. The CFS box sections are parallel to the roof battens under the roof sheets and directly above the locations of the roof screws (**Figure 3-22**). The box sections are made of 2 single channel cold-formed steel (CFS) C-sections which are connected by 12 HWH Frame Fix DP screws or hexagonal head screws. There are 6 of these HWH Frame Fix DP screws or hexagonal head screws on each side of the box CFS C-sections (**Figure 3-23**) and the dimension of the box CFS C-section is 1m long and 0.90m wide. Each single channel C-section has 6 holes across its length and each hole is about 34mm in diameter at a spacing of about 118mm.

The holes on the CFS box sections are located just above the location of the roof screws on the roof sheet so the box section will not hit the roof screws during the loading. The multi fix brackets next to the CFS box section assists in bracing the CFS box section so it does not slide off the roof sheet. The weight of each CFS box section with holes allows it to carry the hanging pallets and the box loads applied on the pallets until the truss assembly experiences failure.

Figure 3-22: CFS Steel Box Sections on Roof Sheets

Figure 3-23: Screw locations on CFS Box Sections

There are 4 pallets which are used to carry loads, and these pallets are hanging from the edges of CFS box sections. The pallets are hanging underneath at a certain height underneath the bottom chords of the pair of CFS truss assembly and the bottom of the pallet is about 110mm above the ground. There are 2 CFS box sections which are used to carry each hanging loaded pallet. The strap cables (**Figure 3-24**) used to hang the loaded pallets are made of 25mm width polywoven strap material and the cables hang from each side of the CFS box sections giving a total number of 4 cables hanging from the 2 CFS box sections per pallet.

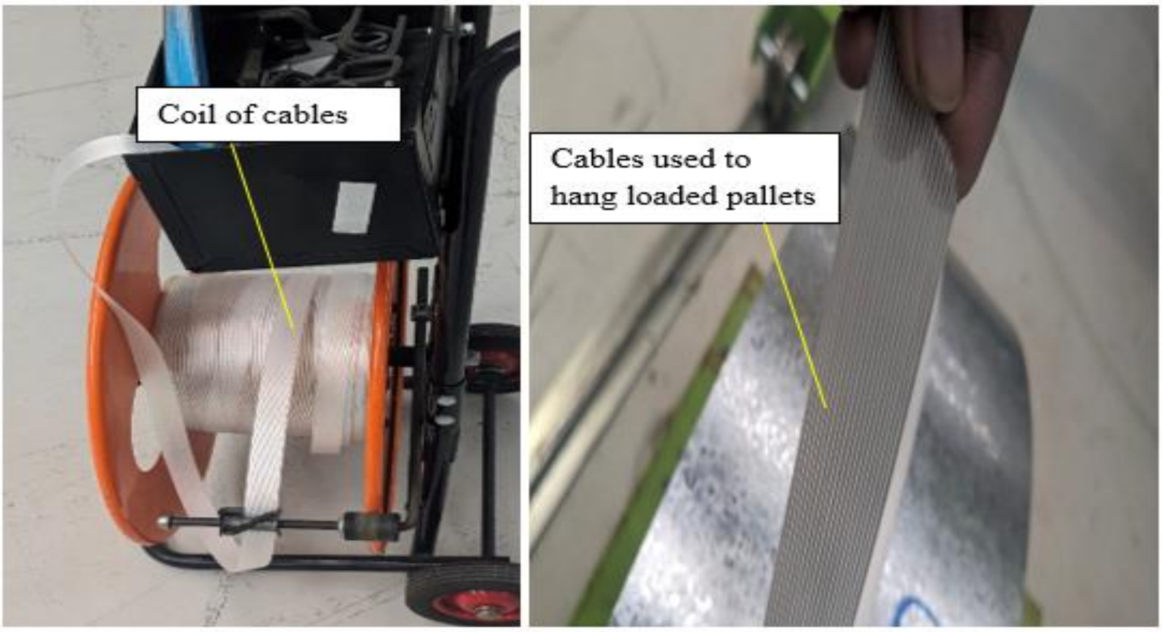


Figure 3-24: Cable material used for hanging loaded pallets

For each pallet, a long piece of strap cable is cut and both ends are looped over CFS box sections above the roof sheet before it is buckled together with a steel wire buckle. The buckle is placed underneath the roof batten (**Figure 3-25**). The apex height of truss including the CFS box sections on the roof sheets is 2.043m and since the CFS box sections are placed across the width of the roof at equal spacing, the length of cable used varies depending on the location of the CFS box section it is used for. There are 2 screws (1 on either side) which are placed on the CFS box section, and this is to prevent the cables from sliding off the CFS box sections. The inner edge of the cable is between 110mm – 135mm away from the face of the top chord of the truss before every test.

Figure 3-25: Loaded pallets hanging from CFS Box Sections

The pallets for the test are hanging underneath the pair of CFS truss roof assembly. There are 4 pallets used for the tests which are made of cold-formed steel. The dimension of each pallet is 1200mm long and 800mm wide and consists of 10 single channel C-section members that are 800mm in length which are placed horizontally in between 2 vertically placed single channel C-sections which are 1200mm in length (**Figure 3-26**). There are 4 screws connected on all sides of each joint between each horizontal and vertical CFS piece. There is 1 piece of flat CFS material of 1200mmx800mm dimensions that is placed on one side of the box section. The flat CFS piece creates a flat surface for the loads to be applied properly without sliding off.

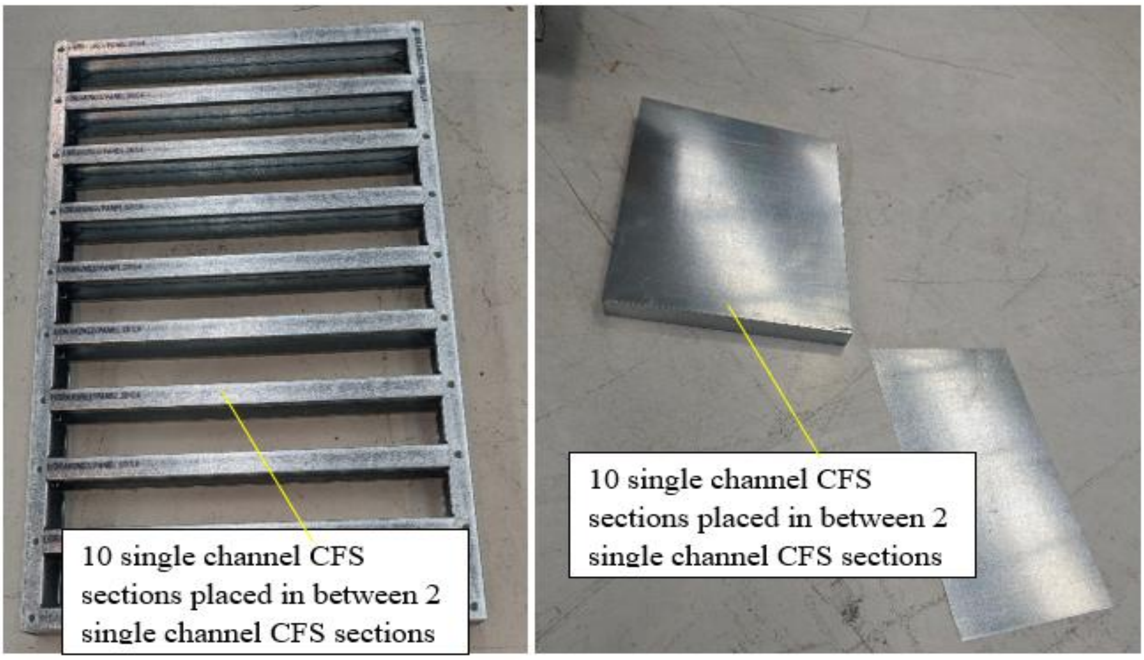


Figure 3-26: Load pallet for CFS Truss test

The cables carrying the load pallets are run underneath the load pallets along the width near its edges. There is a piece of steel screwed on each side of the pallet (**Figure 3-27**) that creates a gap for the cable to loop through it and then underneath the pallet. Each of these rectangular CFS pieces are connected on the side of the pallet with 2 screws and 2 washers on each side; the rectangular CFS pieces are connected on 4 sides of the CFS pallet. The loaded pallet is initially hanging at a height of 110mm from ground level to the bottom of the load pallet and it is approximately 150mm away from the inside edge of the CFS section on the base of the main support frame. The **Figure 3-28** shows the locations and distances of one of the hanging load pallets.

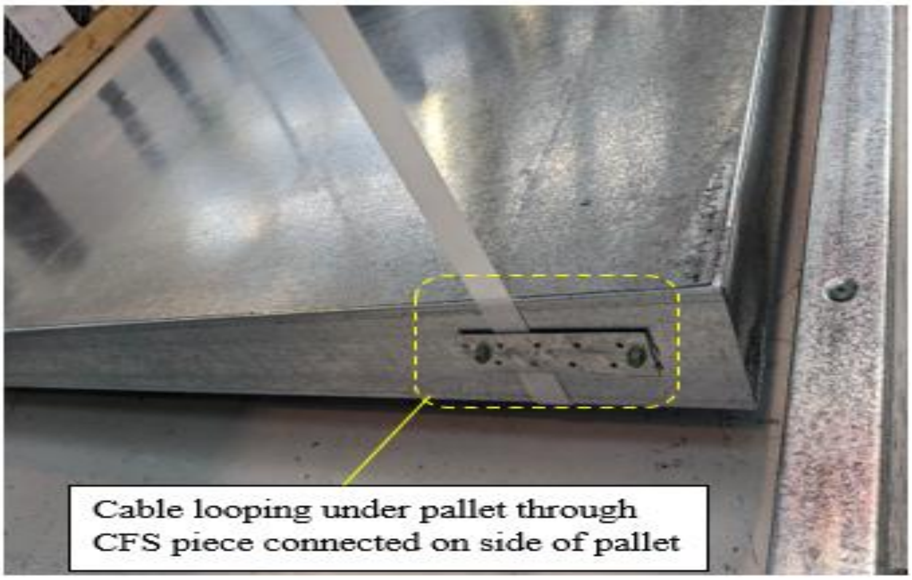


Figure 3-27: Rectangular steel pieces on side of load pallet used to hold cables

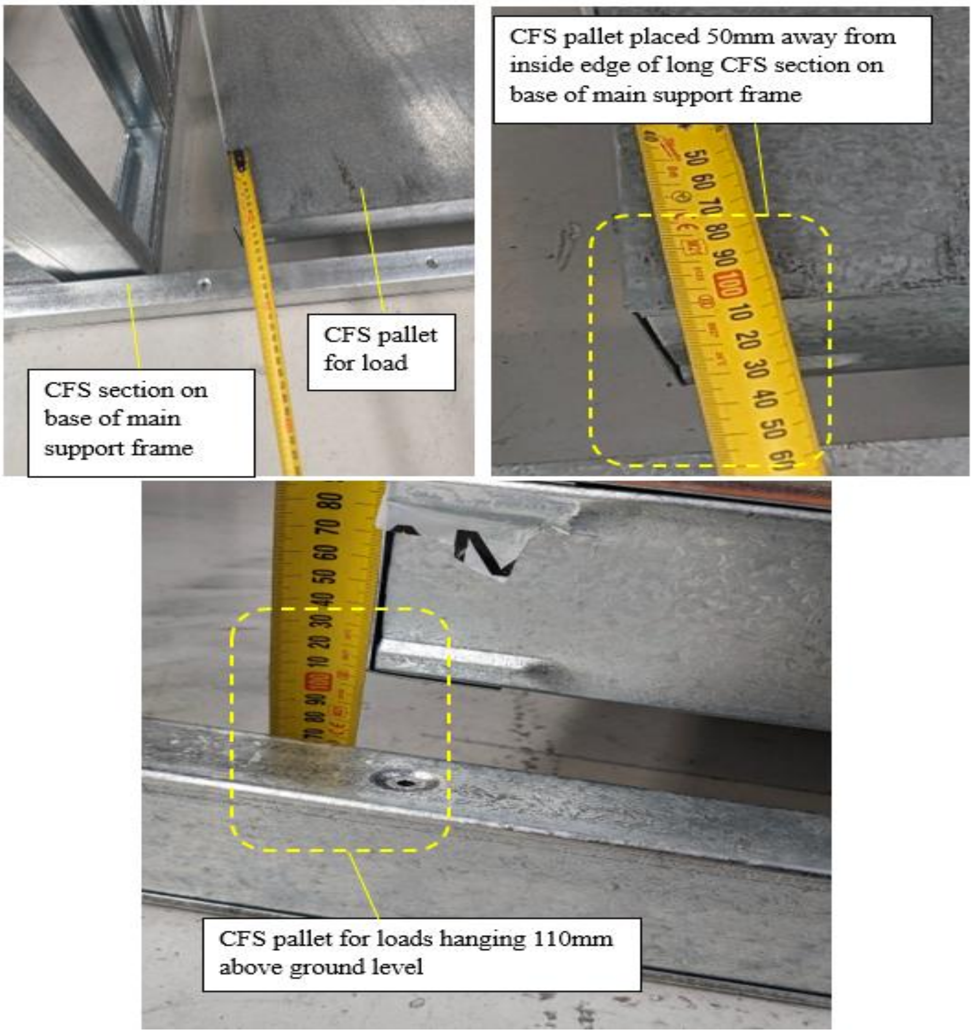


Figure 3-28: Distances of hanging load pallet

3.13 Safety for Test Procedures

Due to the size of the full-scale test and the materials being used, safety is an important aspect in ensuring that the tests are conducted smoothly. This is evident and especially crucial during the application of the incremental loads onto the CFS truss assembly during the tests. The ceiling battens are placed above or near the pallets which is a safety hazard due to the sharp edges around the ceiling battens and that the person(s) placing the loads onto the pallet will have to bend down to place the loads. This is mitigated by using pieces of cloth secured with clear wrapping which covers the protruding edge of the ceiling battens as shown in **Figure 3-29**.

The hanging cables that are placed over the CFS box sections on the roof is another potential safety hazard. The hanging cables drop down over the roof battens on the faces of the truss assembly of the roof battens before being fastened by a steel wire buckle. The area of the loop of the cable is smaller as it passes the roof battens and the weight of the load on the pallet can cause the loop to stretch faster as the cables are being pulled by down. This safety hazard is mitigated by placing an open C-section to cover the area around the protruding roof battens. The open C-section is also made of CFS, and its dimensions are 86.84mm wide,38.29mm thick and 200mm long with 12mm lip on the flanges. The **Figure 3-29** below shows the installation of the open CFS C-section over the protruding roof battens during the tests. Another safety measure placed on the test experiments are the screws placed near the end of the FS box sections placed on the roof sheets. These are installed to prevent the hanging cables from sliding off the CFS box sections as loads are being placed onto the pallets during the tests. A photo of one of these installed screws near the edge of the CFS box sections is also shown in **Figure 3-29**. There is a screw placed near the edge of the CFS box sections which is used to brace the cable strap and prevents the straps from sliding of the top of the CFS box section.

The manual load application of boxes impacts the pallets during the tests as the truss assembly pallets sway after loads are applied. The sway of pallets cannot be mitigated due to the space constraints between the pallets however this is instead minimized by ensuring that during load application, the loader avoids hitting the cable straps as the box loads are placed onto the pallets. The sway is manually stopped after loads are applied after which the mid-span deflection is then recorded. If the stress on the members causes a buckle sound, the loading ceases for a few seconds before load application continues. The method of manual application causes the stress to be distributed unevenly over the pallet area as each load pushes the pallet down. This is mitigated by ensuring that loads are not sliding on the pallet during application and for each row, loads are placed first at the centre and then the next loads are placed outside of the centre load.

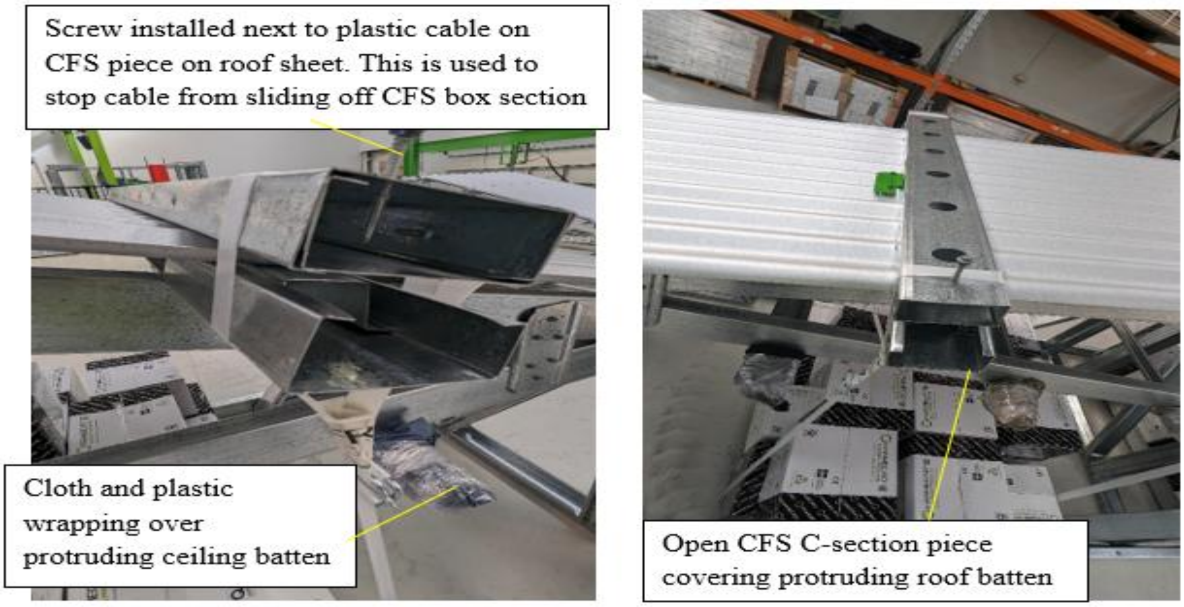


Figure 3-29: Safety measures during truss tests

3.14 Screw Connection at each Truss Joint

The assembly of the CFS truss involves initially placing one primary screw at each joint and the screws can either be a flathead screw of a hexagonal head self-drilling screw. These screws are connected through the web member of the truss where it meets the chord members. The screw is connected closest to the base of the web and flange of the C sections of the chords. Once the CFS truss is connected, then the secondary screws are placed accordingly for each experiment. However, all the CFS trusses used for this experiment are joined together using

HWH Frame Fix DP screws and a minimum of 3 screws is used at each joint. For the purposes of the experiment and trying to ensure that there is no local deformation or that there is no premature failure, there are extra screw connections around some of the joints and the locations vary for each test.

The HWH Frame Fix DP screws are also known as hexagonal head panel joiner framing screws. These are self-drilling screws that are made of galvanized steel. The HWH Frame Fix DP screw has a 1000hr Green E-coat, weighs about 10g (4.8mm diameter), consists of $\frac{5}{32}$ inch Hex Washer Head and 18mm-19mm in length. Both the primary screws and the HWH head screws weigh 10g (4.8mm diameter). A primary screw and a HWH Frame Fix DP screw is shown in **Figure 3-30**.

Figure 3-30: HWH Frame Fix DP screw and a primary screw

For each truss assembly, both trusses have different number of screws. The number of joints for each truss is the same which range from A-R when counted alphabetically from left to right. The trusses are placed opposite each other in the truss test assembly so Truss 1 will be from A-R when counted from left to right and Truss 2 will be counted as R-A when it is also counted from left to right on the same side as counting for Truss 1. This means that Joint A of Truss 1 is placed opposite of Joint R of Truss 2 and similarly, Joint B of Truss 1 will be placed opposite to Joint P of Truss 2 and Joint C of Truss 1 will be placed opposite to Joint Q of Truss 2. For the rest of the truss assembly, the joints are placed in order of the following: Joint D of Truss 1 is opposite Joint N of Truss 2, Joint E of Truss 1 is opposite to Joint O of Truss 2, Joint F of Truss 1 is opposite to Joint J of Truss 2, Joint G of truss 1 is opposite to Joint K of Truss 2, Joint J of Truss 1 is opposite to Joint F of Truss 2, Joint K of Truss 1 is opposite to Joint G of Truss 2, Joint L of Truss 1 is opposite to Joint M of Truss 2 and Joint M of Truss 1 is opposite to Joint L of truss 2. The Joint P of Truss 1 is opposite to Joint D of Truss 2 and Joint Q of Truss 1 is opposite to Joint E of Truss 2. The Joint R of Truss 1 is opposite to Joint A of Truss 2. The only Joints that match the opposite Joint letter is Joint H and Joint I of both trusses where Joint H of Truss 1 is opposite to Joint H of Truss 2 and Joint I of Truss 1 is opposite to Joint I of Truss 2. In the **Figure *3-31*** below is an example of some of the joints on a truss assembly in this study with the various number of screws on each joint.

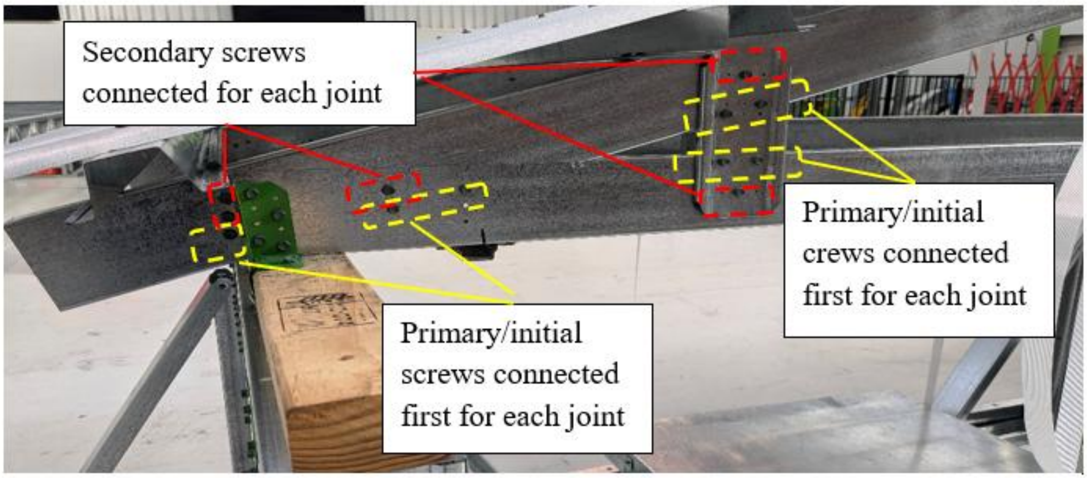


Figure 3-31: Example of joints with screws on the truss

3.15 Loads used on Tests

The loads applied onto the load pallets for the truss test assembly consists of boxes of HWH Frame Fix DP screws. The loads are calculated based on the NZS/AS1170.0:2002 and NASH AS2010 standards which equated there would be about 3 tonne worth of loading on the truss. This is then distributed further to match the available material to be used for the tests. The boxes of screws were the most appropriate available sources of loads that could be applied onto to the truss assembly without causing harm to the persons loading during the study. As shown in **Figure 3-32** below, each box of screw contains 5000 of these 10g(4.8mm diameter), 18mm-19mm HWH Frame Fix DP screws and one box of screws is about 400mm long, 160mm wide and 250mm high. Since there are 5000 screws per box, 1 box weighs about 15.75kg. During the test, each box is applied manually where a person carries the box and places it onto the load pallet of the CFS truss pair test assembly. In the later stages of the tests, some new boxes of a different weight are included due to availability of materials on the day and these new boxes weigh about 14.6kg (**Figure 3-33**).

Figure 3-32: 15.75kg box of screws which are applied as loads during the tests

Figure 3-33: 14.6kg box of screws also used for loading

There are 4 pallets used to carry the loads for the CFS truss pair assembly and at least 4 people are required to carry the boxes from the crates and onto the nearest 2 pallets in front of the crates. The crates with boxes placed at a distance from the truss assembly before a test begins is shown below in **Figure 3-34**.

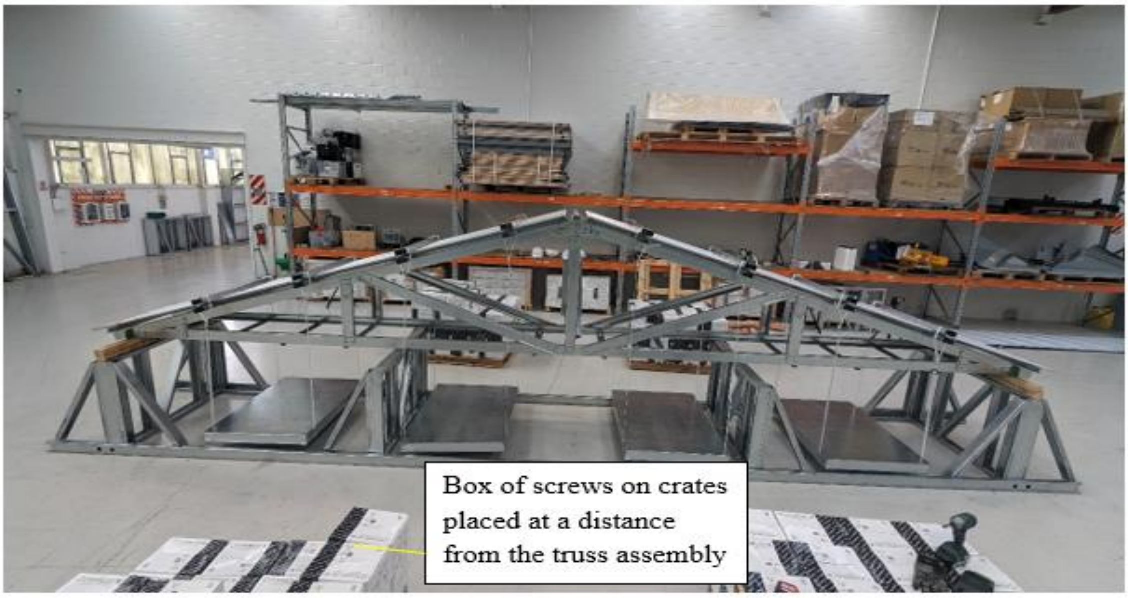


Figure 3-34: Box of screws on 4 crates at opposite sides of the truss assembly

The application of the load is carried out in sets of loads which vary from 3 boxes per loading to 6 boxes per loading. The 1st set of loads is placed at the centre of the pallets then its adjacent ends along the same centre row across the width of the pallet. Therefore, the 1st box of the 1st set of loads is placed at the centre, then 2 more boxes are placed on either side of the 1st box across the width of the pallet. The 1st set of 3 boxes are placed in such a way that the length of the box is placed in parallel to the width of the pallet (**Figure 3-35**). The next set of boxes are then placed in the same order across the width of the pallet; however, they are next to the 1st set of 3 boxes. The sets of loads are applied continuously on either side of each pallet to fill the entire length and width of the pallet. Once the full length and width of the pallet is filled, the next set of boxes are stacked on top of the 1st set of boxes on the base of the load pallet. On the 2nd stack of row of boxes, the order in which the set of boxes are applied is the same as the 1st stack of boxes. The box is placed at the centre and then the adjacent sides are filled with boxes, however the width of the box is parallel to the length of load pallet. The method of applying boxes onto the load pallet continues until the test assembly experiences failure on any of its members.

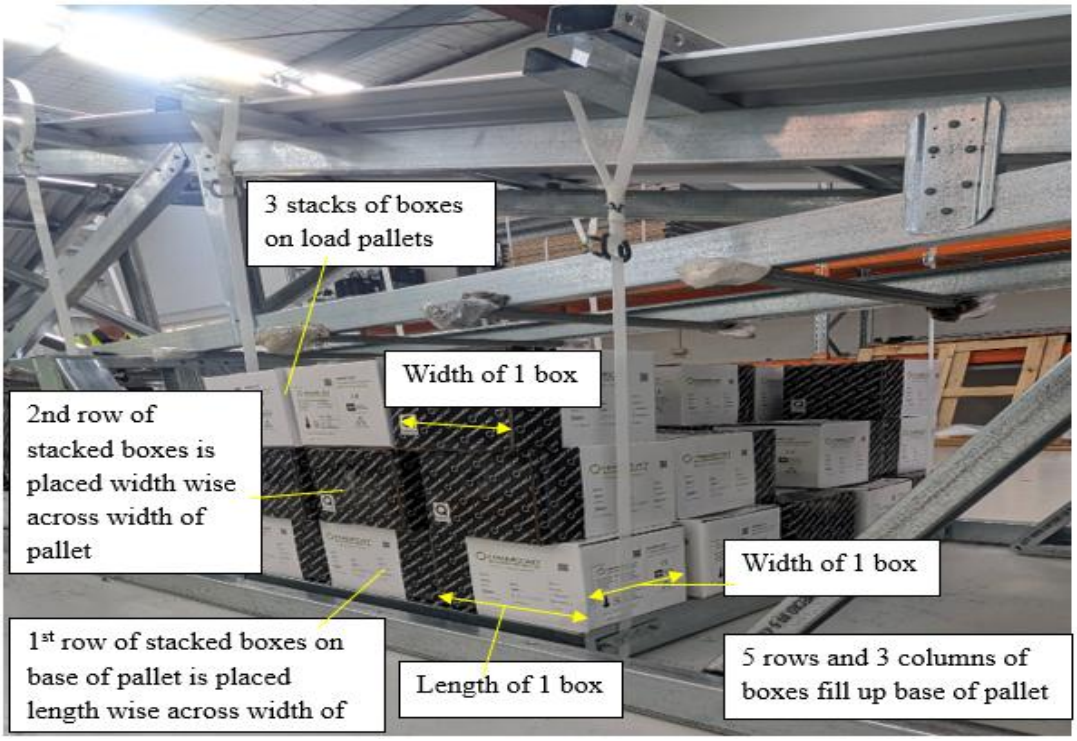


Figure 3-35: Boxes of screws stacked on load pallets of truss assembly

3.16 Data Collection

The data in this test series comprises of manual measurements, video camera recording and use of cameras. During the tests, camcorders are setup around the test area and are used to record the tests from start to finish. There are cameras and a phone used for photograph records of the tests, photographs of the truss joints and photographs of the end of the tests and any area that experiences failure. The deflection during the tests is measured manually with either the use of a long ruler from ground floor to the bottom of the bottom chord of the truss assembly or using a measuring tape. The deflection is measured at the same place after every loading which is at the mid-span of the truss assembly under Joint I of Truss 1. The pieces of the truss assembly are measured using measuring tape, vernier calliper where necessary. The information is recorded manually and transferred to a spreadsheet for an electronic copy.

3.17 Truss Configuration

All CFS trusses have a minimum of 3 screws at each joint and the number of screws in each truss assembly varies for both trusses. The joints of the truss are labelled from A-R to enable a clearer understanding of how many screws are connected to each joint as shown in **Error! Reference source not found.**. An elevation view of the truss assembly is shown in **Figure 3-37**.

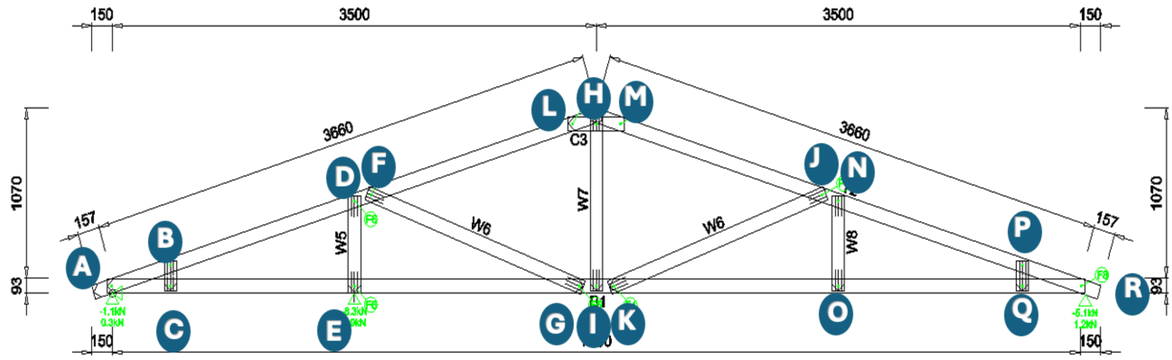


Figure 3-36: Labelling of each joint for the CFS Truss

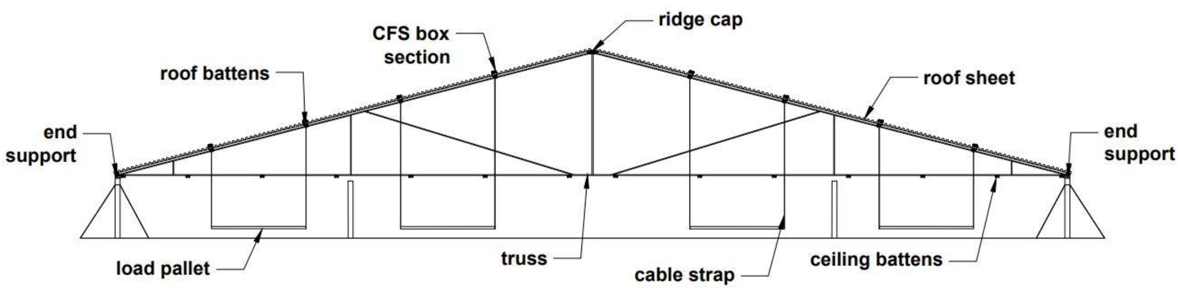


Figure 3-37: Elevation of truss assembly

Every truss has the same number of joints, which, when tallied alphabetically from left to right, range from A to R. In the trust test assembly, the trusses are arranged opposite to one another, so when counting from left to right, Truss 1 will be from A-R, and when counting from left to right, along the same side as counting for Truss 1, Truss 2 will be from R-A. As a result, Joint A of Truss 1 is positioned across from Joint R of Truss 2. Similarly, Joint B of Truss 1 is positioned across from Joint P of Truss 2, Joint C of Truss 1 is across from Joint Q of Truss 2. These continue for the remainder of the joints except for Joints H and I, in which Joint H of Truss 1 is across from Joint H of truss 2 and Joint I of Truss 1 is across from Joint I of Truss 2. The **Table 3** shows the number of screws of each joint for the 8 different test assemblies and the photos of the truss joint screws for each test assembly is shown in the **APPENDIX**. The **Figure 3-38** below shows an example of 3 joints in the truss each with a minimum of 3 screws.

Figure 3-38: Example of 3 joints in the truss each with a minimum of 3 screws

Table 3: Screws for each joint on Truss Assemblies

Number of Screws																
Test Number	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6		Test 7		Test 8	
Joint	Truss 1	Truss 2	Truss 1	Truss 2	Truss 1	Truss 2	Truss 1	Truss 2	Truss 1	Truss 2	Truss 1	Truss 2	Truss 1	Truss 2	Truss 1	Truss 2
A	7 screws, 3 on bracket	7 screws, 3 on bracket	7 screws, 4 on bracket	6 screws, 4 on bracket	5 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	5 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket
B	3	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3
C	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
D	3	3	3	3	4	4	3	3	3	6	4	4	3	3	3	3
E	3	3	3	3	3	3	3	3	3	6, 3 on bracket	3	3	3	3	3	3
F	3	3	3	3	4	4	3	3	5	6	4	4	4	4	4	4
G	3	3	3	3	4	3	3	3	5	6	5	3	4	4	4	4
H	6	6	7	6	7	7	7	7	7	7	7	7	8	8	8	8
I	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
J	3	3	3	3	4	4	3	3	6	5	6	4	4	4	4	4
K	3	3	3	3	3	3	3	3	6	5	6	3	4	4	4	4
L	4	4	6	4	6	6	5	5	4	4	5	2	6	6	6	6
M	4	4	6	4	6	6	5	5	4	4	5	2	6	6	6	6
N	3	3	3	3	4	4	3	3	6	3	6	4	3	3	3	3
O	3	3	3	3	3	3	3	3	6,4 on bracket	3	6	3	3	3	3	3
P	3	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3
Q	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
R	7 screws, 3 on bracket	7 screws, 3 on bracket	6 screws, 4 on bracket	7 screws, 3 on bracket	5 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	5 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket	6 screws, 4 on bracket
Total Number of Screws per Truss	73	73	79	73	83	84	76	76	93	92	92	74	83	83	83	83
Total Number of Screws for Truss Assembly	146		152		167		152		185		166		166		166	

3.18 Truss Test 1-Linear Truss System-800mm roof batten spacings

The 1st test assembly consists of 2 trusses with a total of 146 self-drilling screws where Truss 1 and Truss 2 each have 73 screws. Each truss is made of 2 top chords, 1 bottom chord and 8 web members and the truss is assembled following the Linear truss system which is based on the back-to-back truss system. However, the web member placement is changed where the face of the web member is connected onto the back of the top chords. i.e. the web member placement lies in the same plane and orientation as the chord members. The trusses are placed 600mm apart with 2 steel battens placed as cross bracings which separate the trusses. There are 12 roof battens connected to the top chords of the trusses with 2 roof sheets connected above the roof batten. The roof sheets have a total of 72 screws used to connect it to the roof battens. There are 14 ceiling battens are placed underneath the bottom chords of the trusses and there are 2 steel coils placed as cross bracings above the ceiling battens. The truss assembly is simply supported at the end joints and the truss assembly is placed above the main support frame at a height of 845mm. The **Figure 3-39** below shows the test assembly set up for Test 1.

Figure 3-39: Test 1 assembly set up

The **Table 4** shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 1. Each truss weighs 23.5kg and the total weight of the dead load (G) is 85.8kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons (kN), $Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ ^{m}/_{s^2}\right)}{1000N}$, the Dead Load of the Truss Assembly for Test 1 is 0.84kN.

Table 4: Truss Experiment Setup for Test 1

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.000	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.000	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.000	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.000	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.000	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.000	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.000	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.000	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.000	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.000	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.000	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		809	65	0.4	52585	0.05	21034	0.00002103	7850	-	-	0.2	14	2.3
Roof batten		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	12	3.0
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.001760	-	2	-	6.4	2	12.8

Cross brace between Truss	897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Steel Brace Coil on Ceiling Battens	1515	30	1	45450	0.05	45450	0.000045	7850	-	-	0.4	2	0.7
Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Steel brace	18	19	-	342	0.00	-	-	-	-	-	0.01	8	0.1
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	146	1.5
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.92	16	14.6
Roof Box Section Screws	18	19	-	342	0.00	-	-	-	-	-	0.01	96	1.0
			Weight Sum (2 Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)										***85.8***
			Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)										***0.84***

The labelling of the truss members (AH, HR, BC, DE, FG, HI, JK, LM, NO, PQ, AR) refers to the joints labelling shown in **Figure 3-36:** Labelling of each joint for the CFS Truss. The joints are labelled as such for convenience.

3.19 Truss Test 2-Linear Truss System-800mm roof batten spacings

The Test 2 assembly setup is similar to Test 1 assembly; however, Test 2 includes a ridge cap placed above the centre where both top chords meet at the ridge of the truss assembly. This ridge cap made of steel adds another lateral restraint to the truss assembly. The main support frame is also increased from 845mm to 890mm. For the test 2 assembly, there are 152 screws used for the trusses where Truss 1 has 79 screws and Truss 2 has 73 screws which is the same number used for Test 1, however, the joint H for Truss 1 has 7 screws as opposed to 6 screws used for the same joint in Test 1. Joint A for Truss 2 and Joint R of Truss 1 of this Test 2 assembly has 6 screws on the joint instead of 7 screws for the same joints and trusses of the Test 1 assembly. Joint A of Truss 1 in Test 2 has more screws than the same joint for Truss 1 in the Test 1 series. The **Figure 3-40** below shows the assembly set up for Test 2.

Figure 3-40: Test 2 assembly set up

The **Table 5** shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 2. Each truss weighs 23.5kg and the total weight of the dead load (G) is 85.5 kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons (kN), $Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ ^{m}/_{s^2}\right)}{1000N}$, the Dead Load of the Truss Assembly for Test 2 is 0.84kN.

Table 5: Truss Experiment Setup for Test 2

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00026	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00026	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00001	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00004	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00011	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00008	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00011	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00003	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00004	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00001	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00047	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00002	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00003	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00002	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00176	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Steel Brace on Ceiling Battens	1515	30	1	45450	0.05	45450	0.000045	7850	-	-	0.4	2	0.7
Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Steel brace	18	19	-	342	0.00	-	-	-	-	-	0.01	8	0.1
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	152	1.5
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***85.5***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.84***

3.20 Truss Test 3-Linear Truss System-800mm roof batten spacings

The test 3 assembly has 167 screws in which Truss 1 has 83 screws and Truss 2 has 84 screws. The number screws on the end support joints are less than the same joints for the Tests 1 and 2 however the number of screws for the inner joints towards the centre of the trusses have increased. The placement of the truss members in Test 3 is the same as Tests 1 and 2 which is using the Linear Truss system. There is a ridge cap included for test 3 but the steel coil braces that are placed above the ceiling battens have been removed. This arrangement remains for the rest of the test series conducted in this study. Similar to Tests 1 and 2, this test assembly consists of 12 roof battens and 14 ceiling battens; the main support frame of the assembly remains at a height of 890mm and **Figure 3-41** below shows the test assembly setup.

Figure 3-41: Test 3 assembly set up

The **Table *6*** shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 3. Each truss weighs 23.5kg and the total weight of the dead load (G) is 84.9 kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons (kN), $Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ ^{m}/_{s^2}\right)}{1000N}$, the Dead Load of the Truss Assembly for Test 3 is 0.83kN.

Table 6: Truss Experiment Setup for Test 3

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	167	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***84.9***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.83***

3.21 Truss Test 4-Back-to-back System-800mm roof batten spacings

The test 4 assembly consists of 152 screws in both trusses which is the same as the number of screws in the Test 2 series. There are 76 screws each in both trusses 1 and 2 and the internal joint screws are less than in Test 3. Each joint of Truss 1 has the exact number of screws as its opposite joint for Truss 2. The placement of web members in Test 4 differs from all the other tests in this study because Test 4 uses the back-to-back system which means that the back of the web member is connected to the back of the chord members. The web members for Joints L and M are the only ones arranged in a Linear Truss system similar to the previous tests. The height of the main support frame is 890mm similar to Tests 2 and 3 and **Figure 3-42** below shows the assembly setup of test 4.

Figure 3-42: Test 4 assembly set up

The **Table** *7* shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 4. Each truss weighs 23.5kg and the total weight of the dead load (G) is 84.7 kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons(kN), $Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$, the Dead Load of the Truss Assembly for Test 4 is 0.83kN.

Table 7: Truss Experiment Setup for Test 4

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	152	1.5
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***84.7***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.83***

3.22 *Truss Test 5-Internal Support inclusion-800mm roof batten spacings*

The Test 5 assembly has 185 screws for both trusses which is the highest when compared to all the tests in this study. Truss 1 has 93 screws and Truss 2 has 92 screws and the internal joints of the trusses have more screws than the previous tests conducted. Test 5 assembly differs from all the other tests in this study because it is the only test series which has an internal support in addition to the end supports of the assembly, however the truss member placement is following the Linear truss system. The internal support is located on Joint O of Truss 1 and Joint E of Truss 2; Joint O of Truss 1 has more screws than Joint E of Truss 2 at the internal support locations. The main support frame is increased from 890mm to 1045mm which remains for all future tests. There are 12 roof battens, and 14 ceiling battens used for the test and **Figure 3-43** below shows the test assembly setup for Test 5.

Figure 3-43: Test 5 assembly set up

The **Table 8** shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 5. Each truss weighs 24.1kg and the total weight of the dead load (G) is 86.4 kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons (kN), $Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$, the Dead Load of the Truss Assembly for Test 5 is 0.85kN.

Table 8: Truss Experiment Setup for Test 5

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
Extra CFS piece for internal support		295	89	0.75	26255	0.03	19691	0.00	-	-	2.15	0.6	1	0.6
									Weight Sum for 1 Truss Member					24.1
									Weight Sum for 2 Truss Members					48.2
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	14	0.4
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	185	1.9
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***86.4***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.85***

3.23 Truss Test 6-Linear Truss System-400mm roof batten spacings

The test 6 assembly consists of 166 screws in the 2 trusses where Truss 1 has 92 screws and Truss 2 has 74 screws. Test 6 assembly is simply supported at the ends of the trusses and there are more screws near Joints J, K, N & O of Truss 1 in comparison to the previous tests. The number of screws on the end support joints are the same as in Test 4 and the truss member placements for this test follow the Linear truss system. The number of ceiling battens used has reduced from 14 to 12 and the number of roof battens have increased from 12 to 20. A ridge cap is included which is similar to Tests 2, 3, 4 and 5 and there is no steel coil bracing above the ceiling battens which is the same for Tests 3, 4 and 5. The main support frame height is 1045mm and the **Figure 3-44** below shows the assembly setup for Test 6.

Figure 3-44: Test 6 assembly set up

The **Table 9** shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 6. Each truss weighs 23.5kg, and the total weight of the dead load (G) is 87.3kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons (kN), $Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$, the Dead Load of the Truss Assembly for Test 6 is 0.86kN.

Table 9: Truss Experiment Setup for Test 6

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	12	1.5
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	20	5.1
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	166	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	120	1.7
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***87.3***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.86***

3.24 Truss Test 7-Linear Truss System-400mm roof batten spacings

The test 7 assembly consists of 166 screws in total is used in the trusses in which Truss 1 and 2 both have 83 screws each. The truss assembly is simply supported at the end supports and all supports have the same number of screws. Joint H for both Truss 1 and 2 has the most screws compared to all the other test series. There are 20 roof battens, and 12 ceiling battens used in this test series. There is 1 ridge cap used, and no steel coil brace is placed above the ceiling battens. The web members placement follows the Linear Truss system similar to Tests 1,2,3,5 and 6. The height of the main support frame is 1045mm and **Figure 3-45** below shows the setup of the test 7 assembly.

Figure 3-45: Test 7 assembly set up

The **Table 10** shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 7. Each truss weighs 23.5 kg, and the total weight of the dead load (G) is 87.3 kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons (kN), $Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$, the Dead Load of the Truss Assembly for Test 7 is 0.86kN.

Table 10: Truss Experiment Setup for Test 7

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	12	1.5
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	20	5.1
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Multi Fix Brackets		114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3

HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	166	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	120	1.7
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***87.3***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.86***

3.25 *Truss Test 8-Linear Truss System-400mm roof batten spacings*

The test 8 assembly is setup in the same way as the test 7 assembly where there are 166 screws used for both trusses. Truss 1 and 2 both have 83 screws each and the arrangement and number of screws for each joint is the same for both trusses. The main support frame is at a height of 1045mm and there is 1 ridge cap used for the test series. There is no steel coil bracing placed above the ceiling battens and there are 20 roof battens, and 12 ceiling battens used for this test. The web placement for the truss is in the Linear Truss system, which is the same as Tests 1, 2, 3, 5, 6 and 7. The **Figure 3-46** shows the setup of the test assembly.

Figure 3-46: Test 8 assembly set up

The **Table 11** shows the details of the members of the truss assembly members and the amount of dead load calculated for Test 8. Each truss weighs 23.5 kg, and the total weight of the dead load (G) is 87.3 kg including all truss assembly members. With the use of the dead load formula and then converting it to kilonewtons (kN),

$$Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$, the Dead Load of the Truss Assembly for Test 8 is 0.86kN.

Table 11: Truss Experiment Setup for Test 8

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	1
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	12	1.5
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	20	5.1
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	166	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	120	1.7
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***87.3***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.86***

Chapter 4 Experimental Results

4.1 Summary of Test Results

4.1.1 *Loads Summary*

For the test series conducted in this study, the dead load values ranged between 0.84kN to 0.86kN. Tests 1 and 2 both have a dead load of 0.84kN each, Tests 3 and 4 both have a dead load of 0.83kN each, Tests 6,7 and 8 all have a dead load of 0.86kN each and Test 5 has a load of 0.85kN.

The dead loads for Tests 3 and 4 are the lowest and the dead loads for Tests 6, 7 and 8 are the highest. The variables for each test which adjusted the dead load values included the number of screws for each joint of the truss, the inclusion of the ridge cap, the exclusion of the steel coil brace and the additional steel section in Test 5. The dead load values being the highest for Test 6, 7 and 8 is due to the increase in number of roof battens and the decrease in number of ceiling battens. The weight of 1 truss remains as 23.5kg for all the tests except for Test 5 which is 24.1kg due to the internal support.

The live load of the test series ranged from 18kN to 29.98kN with the lowest live load applied on Test 2 and the highest live load found in test 8. Test 1 has a live load of 22.94kN, Tests 3 and 4 experience a live load of 20.47kN and 22.94kN respectively while Tests 5, 6 and 7 cater for live loads of 27.88kN, 29.12kN and 23.20kN, respectively. The total load applied for each test shows that Test 2 experiences the lowest total load of 18.83kN and Test 8 caters for the highest live load of 30.84kN. The total load for Test 1 is 23.78kN, Test 5 caters for a total load of 28.73kN, Tests 3 and 4 cater for total loads of 21.30kN and 23.77kN, respectively. Tests 6 and 7 are able to cater for a total load of 29.98kN and 24.05kN, respectively.

The height increases of the main support frame from 845mm to 890mm and eventually to 1045mm allowed for the pallets to be at a higher height above ground during load. The theory is that this can help delay the pallets from falling to the ground as the loads are incrementally applied. The variation for each test is based on the observations from the previous test.

The deflections for each test show that Test 6 and 8 both achieve the highest deflection at 27 mm. For the other test, the lowest deflection of 12 mm is achieved by Test 2, Test 5 achieves 15 mm deflection and Test 4 achieves 19mm deflection. A deflection of 21 mm is achieved for both tests 3 and test 7.

For the type of test conducted and the type of load application conducted, the human factor is affecting the mechanism of failure for this series of tests. The loads are incrementally applied; however, the time and method of load application can be factored to show inconsistencies which causes a different weight to apply stress on different areas of each pallet of the truss assembly.

The number of screws on the joints of the truss assembly and the arrangement of the screws also perform an integral role in the capacity of the truss assembly. The failures happening around the top chord member do not affect the screw connections. The rigidity of the screw connections prevented the deformations around the joints. At each joint, the screw spacings range between 15mm – 60mm with the primary screws connected near the web-flange edge where two members meet. The optimal spacing between screws at each joint allows for reduced stress concentrations of joints and better load distribution which are not affected during the failure in the tests. Test 1 faced failure around Joints H, L, M of both truss 1 and 2, however the rigidity of screw connections and the optimal spacing of the screws prevented failure around the joints despite the local failure on the top chord members.

4.1.2 *Failure Type*

There were 2 tests which did not experience any failure due to the pallets hitting the ground floor before any form of failure was produced. Tests 5 and 6 both do not display any failure as the pallets reached the ground floor after the loads were being applied. For test 5, the internal pallet (near Joints E, G of Truss 1) which was not beside the internal support had reached the ground floor upon the 13th loading at a live load of 24.8kN. For test 6, the internal pallet near Joints I, K of Truss 1 reached the ground floor upon the 15th loading at a live load of 29.1kN.

There are a few tests which experienced buckling failure during the test series. The tests 1, 2 and 3 which have the same arrangement of roof batten spacing of 800mm with 12 roof battens in total for each test either experience lateral-torsional buckling failure or inward distortional buckling. Test 1 experiences lateral-torsional buckling along the top chord near the joints D and F of Truss 1 on the 10^{th} loading at a live load of 22.94kN. Test 3 also experiences lateral-torsional buckling failure along the same area as Test 1; however, for Test 3, the truss assembly fails on the 8^{th} loading at a live load of 20.47kN. Test 2 experienced inward distortional buckling along the top chord near the joints D and F of Truss 1 and near joints J and N of Truss 2 after the 6^{th} loading at a live load of 18.00kN.

The 4^{th} test which is a back-to-back truss system experiences out-of-plane buckling along the same side of the top chords of both Truss 1 and 2 and causes the trusses to collapse during failure after the 10^{th} loading at a live load of 22.94kN. The test 7 experiences buckling downwards and out of plane along the top chord member of Truss 1. The top chord member near joint P which is closest to the end support of Truss 1 fails on the 9^{th} loading at 23.20kN. The test 8 has the same arrangement as test 7 which includes 20 roof battens, 12 ceiling battens, the same number of screws and screw locations on the truss assembly experiences failure around the top chord members near the Joints P and N of Truss 1 in the truss assembly. The top chord member buckles downwards and out of plane on the 16^{th} load at a live load of 29.98kN.

The following tests are excluded from comparison based on failure findings made during the test:

- Test 2 is not considered because the truss assembly was not checked properly before the test was conducted.
- Test 4 is a back-to-back system which experienced complete failure
- Test 5 is a linear system with an internal support of which the measured deflections did not fully show the capability of the internal support. The deflection becoming stagnant despite the increase in load indicates that the assembly may be undergoing a redistribution of the stress, however this current test remains inconclusive.
- Test 7 is not considered as the parts of the truss assembly were not installed properly and were already damaged before the test was conducted which influenced the results.

4.1.3 *Applied Load averages of 800mm and 400mm roof batten spacings linear truss system*

For the 800mm roof batten spacing truss assembly, the average total load and live load at failure is taken from Tests 1 and 3. The average live load of Test 1 and 3 is 21.70kN and the average live load at failure of 1 truss is 10.85kN. The average total load of Test 1 and 3 is 22.54kN and the average total load of 1 truss is 11.27kN. For the 400mm roof batten spacing truss assembly, the average total load and live load at failure is taken from Tests 6 and 8. The average total load of Test 6 and 8 is 30.41kN and the average live load of 1 truss is 15.20kN. The average live load of Test 6 and 8 is 29.55kN and the average total load of 1 truss is 14.77kN. These experimental loads will be compared with the design and predicted capacities in Chapter 5.

4.1.4 *Experimental results summary*

The following summarizes the findings of the test series conducted for the single channel linear truss system and single channel back-to-back system in this study:

- Lateral torsional buckling, out-of-plane buckling, inward torsional buckling are the common failures occurring on the truss assembly test series.
- The linear truss system has sufficient stiffness and strength to provide the required torsional restraint to chords.
- The linear truss system is still able to carry the remaining load capacity after the failure load has been reached on the truss. The failure experienced is the twisting of the top chord members and the supporting web members bending at its ends.
- The back-to-back system is not as strong as the linear truss system as it has less strength remaining after the failure load is reached on the truss assembly. The failure experienced is the full twisting of the top chord with deformation and screw slips of the ends of the supporting webs.
- The warping effects of both linear truss system and the back-to-back system seem to significantly determine the effective length. The closely spaced battens minimize warping which causes higher load capacities to be achieved than the capacities anticipated by design standard. The **Table 12** shows the test results summary for all 8-test series conducted under this study.

Table 12: Test Results Summary

Test Number	Dead Load (kN)	Live Load (kN)	Total Load (kN)	Deflection (mm)	Truss spacing per assembly (mm)	End Support	Internal Support	Number of HWH Screws per truss		Observation from Tests	Variables in each test
								Truss 1	Truss 2		
1	0.84	22.94	35.42	15	600	Yes	-	73	73	- **Truss 1-fails at the ridge Joint H, Joints L and Joint M.** (refer **Figure 4-12**) - Lateral torsional buckling occurs when the web and flange member of the top chord for Truss 1 buckles and twists inwards towards Truss 2 near Joints D and F of Truss 1. - **Truss 2- fails at the ridge Joint H, Joints L and Joint M.** (refer **Error! Reference source not found.**) - Truss assembly does not collapse/fall despite failure points around Joints H, L, M of - Trusses 1 and 2 and Near Joints D and F of Truss 1 at the web of the member. - Failure occurs on the top chord members. - Load manually applied by 4 people beginning at the centre of the pallets and moves outwards towards the edge at every set of loading. Loads spread to cover base of pallet and then stacked above each other - The pallets constantly sway with every set of loads applied.	- **no ridge cap** - **12 roof battens** - **14 ceiling battens** - steel brace coil above ceiling battens - 845mm main support frame height
2	0.84	18.00	28.00	12	600	Yes	-	79	73	- **Truss 1 – bottom flange of top chord near joint F and D buckling out of plane.** (refer **Figure 4-14**) - **Truss 2 – twist and buckle out of plane for bottom flange of top chord near joints J and N.** (refer **Figure 4-15**) - Inward distortional buckling of compression flange near Joints D and F of Truss 1 and Joints J and N of Truss 2. - Ripples appearing on web of members as 24th box is applied for each pallet during 4th load number. - Ridge cap inclusion above the top chords at ridge of truss pair prevented failure at the ridge connection joints. - Load applied manually by 8 people. - The right side of Truss 1 and left side of Truss 2 do not experience failure or bulging of the truss members. The failure occurs on the same side of the assembly for both trusses.	- **ridge cap added** - **12 roof battens** - **14 ceiling battens** - steel brace coil above ceiling battens - 890mm main support frame height
3	0.83	20.47	31.70	21	600	Yes	-	83	84	- **Truss 1- lateral torsional buckling occurs near joints D and F.** (refer **Figure 4-17**) - Bottom flange of top chord member near Joints D and F twists and buckles. - **Truss 2 - does not experience failure.** - Load manually applied by 4 people from centre base of pallet and outwards before being stacked on top of each other. - Failure area is still around the same area of Truss 1, the weight pulls on the loading stresses around the top flange since the loads are not placed at the shear centre. - More screws to be placed around D and F joints of Truss 1. - The spacing between the lateral restraints of roof battens may need to be increased.	- **ridge cap added** - **12 roof battens** - **14 ceiling battens** - 890mm main support frame height
4	0.83	22.94	35.41	19	600	Yes	-	76	76	- **Truss 1- out-of-plane buckling of top chord near Joints J, N.** (refer **Figure 4-18**) - **Truss 2- out-of-plane buckling of top chord near Joints D, F.** (refer **Figure 4-19**) - Top chord twists inwards and downwards along the same side of the truss assembly and happens simultaneously. - The truss collapsed on the right side of Truss 1 and left side of Truss 2. - Pallets fall to ground as a result of truss failure. - Load manually applied by 5 people from centre base of pallet and outwards before being stacked on top of each other. - The deflection is more than test 1 at the same number of boxes loading during failure however, the truss collapsed during this test and the pallet falling to the ground level stopped the full collapse.	- ridge cap added - 12 roof battens - 14 ceiling battens - 890mm main support frame height - **web members connected back-to-back against top chords and bottom chords**

5	0.85	27.88	42.84	15	600	Yes	Yes	93	92	- **No truss failure experienced in this test.** - **The internal pallet between the Joints E of Truss 1 and Joint O of Truss 2 touches** - **the ground at 37 boxes so loads were no longer applied on this pallet.** (refer **Figure *4-20***) - The pallet next to the internal support at Joint O of Truss 1 and Joint E of Truss 2 touches the ground at 39 boxes. - Loads were still applied until the pallet neat Joint A of Truss 1 and Joint R of Truss 2 reached 47 boxes and the pallet near Joint R of Truss 1 and Joint A of Truss 2 reached 53 boxes of loading. - Load manually applied by 4 people from centre base of pallet and outwards before being stacked on top of each other.	- main support frame height increased to 1045mm. - **Internal support frame included** - ridge cap added - 12 roof battens - 14 ceiling battens - web member connection same as Tests 1,2,3
6	0.86	29.12	44.71	27	600	Yes	-	92	74	- **No truss failure experienced in this test.** - **46 boxes load when pallet 3 fully hits the ground. Pallet 3 is near Joints I, K, O of Truss 1 and Joints E & G of Truss 2.** (refer **Figure *4-21***) - Other pallets do not hit the ground at 46 boxes loading. - Load manually applied by 5 people from centre base of pallet and outwards before being stacked on top of each other.	- main support frame height increased to 1045mm. - ridge cap added - **20 roof battens** - **12 ceiling battens** - web member connection same as Tests 1,2,3,5
7	0.86	23.20	35.82	21	600	Yes	-	83	83	- **Truss 1 - fails near Joint P of Truss 1.** (refer **Figure *4-22***) - The bottom flange of the top chord member buckles downwards and out of plane. - **Truss 2 - no failure.** - The left side of Truss 1 and both side of Truss 2 do not experience failure or bulging of the truss members. - Load manually applied by 4 people from centre base of pallet and outwards before being stacked on top of each other.	- main support frame height increased to 1045mm - ridge cap added - **20 roof battens** - **12 ceiling battens** - web member connection same as Tests 1,2,3,5,6
8	0.86	29.98	46.00	27	600	Yes	-	83	83	- **Truss 1 - fails near Joint P of Truss 1.** (refer **Figure *4-23*)** - The bottom flange of the top chord member buckles downwards and out of plane. - Failure occurs at same place as Test 7 however Test 8 number of boxes at failure is greater. - **Truss 2 - no failure.** - The left side of Truss 1 and both side of Truss 2 do not experience failure or bulging of the truss members. - Load manually applied by 5 people from centre base of pallet and outwards before being stacked on top of each other.	- main support frame height increased to 1045mm - ridge cap added - **20 roof battens** - **12 ceiling battens** - web member connection same as Tests 1,2,3,5,6,7

4.2 *Experimental Uncertainty*

There are a few uncertainties with the test experiments undertaken in this study which include the test design, test results, measurement methodology and imperfections in the truss assembly. The uncertainties in the test design consist of the boundary conditions, the loading applications, and the structural assumptions. The boundary conditions in this study include the end supports, cross bracings between the truss and the roof battens that act as lateral bracings. The lateral bracings and cross bracings prevent the assembly from moving sideways during the tests and rotating of the top chord members. The number of screws and multi fix brackets connected to the main support frame provide restraints at the truss ends roof truss assembly which can influence the torsional buckling behaviour. The test boundary conditions are made to replicate realistic boundary conditions and, in some instances, where the end supports are not fixed properly, the implications are observed in the test such as the outcome in Test 7. The replications of dynamic changes are subtle and difficult, but it is essential in understanding the behaviour of trusses in realistic conditions. In this study, the boundary conditions are resilient and prevent a global failure of torsional buckling for most of the tests. Boundary condition mitigation involves ensuring that the components utilized for boundary conditions in this study are not damaged and that the components are checked and replaced where necessary for the various tests.

The symmetry of load application and point of load application for this test produces a lot of uncertainty on the rate of spread of stress and the type of failure that will be produced. The human element influences the manual load application process, causing variations in how the load is delivered, with some loads being applied more quickly than others. Each load set causes different amounts of stress to act along the truss assembly region, which may have an effect on the buckling behaviour and, in certain tests, the grounding of the pallets prior to failure. The mitigation of varied load application during the tests is by ensuring that loads are applied at nearly the same time by the persons loading the boxes. i.e. variation of application is by seconds. The load application may not be exactly at the same time, but this test gives a more realistic view of how a truss assembly will be affected in comparison to load cell testing.

The structural assumptions of C-sections are based on how the members will react when loads are applied at the shear centre. In this study, the point of load application is outside the shear centre and the behaviour of the member during failure is different from the assumed behaviour. Realistic conditions in the physical test demonstrate that localized deformations caused by imperfectly uniform loading contribute to torsional buckling in a specific region. The increase in lateral restraints provide rigidity on the top chord members but the bends and warps around the members influence the torsional resistance.

The uncertainty in the test results consist of the various failures experienced throughout each test series. Some of the tests are able to fail around the same location, however, the failures occur at different live loads. There is not enough information available through the physical testing to identify the exact start point of failure on the truss assembly. The method of measurements of the study can be better recorded using mechanized forms along the top chord to identify the start point of buckling or the exact weight loading for the tests. In future tests, the deflection can also be measured at various points along the length of the truss assembly in addition to the midspan deflection. Also, a Finite Element Modelling (FEM) analysis can also be used to accurately predict where and how these experimental tests are experiencing failure.

The geometric imperfections of the physical test members can also be identified in affecting the critical load required for buckling during the tests and causing premature torsional failure. The out-of-plane distortions can occur during the screw connections between members. This slight warp out of the intended plane cause misalignment and may increase the likelihood of twisting and torsional buckling as higher stresses may be experienced in some members. The mitigation of these is adding more screws around certain joints that are near the failure region during the tests. The reduced spacings of lateral restraints in later tests also prevent increased buckling in the tests.

4.3 Load vs Deflection Comparison of Experimental Tests

The **Figure 4-1** shows the graph of live load (kN) against the deflection (m) for each of the 8-test series conducted in this study. The deflection for every loading in all 8 tests is measured at the mid-span of the truss assembly and the deflection measurement is always taken at the same location. The **Table 13** shows the tabulated values of the live load and deflection of each loading for each test.

All the tests achieve the same live load at the first loading except for test 5 which achieves that value at the 2nd loading because the number of boxes loading applied for each load was less than the other tests. Despite achieving the same live load of 4.4kN for the first loading for 7 out of 8 tests, the deflection of these 7 tests at this first loading is different. At the live load of 4.4kN, 3 out of the 7 tests achieve a deflection of 0.003m, 1 test which is the back-to-back truss system achieved a 0.001m deflection, the 3 other tests achieved 0.002m,0.004m and a 0.006m deflection, respectively. Test 5 achieves a deflection of 0.005m deflection when it reaches the 4.4kN live load during its 2nd loading. Tests 1 and 2 have the same deflection and live loads at every loading except Test 2 ends at 18kN with 0.012m deflection. At the 18kN live load, Test 1 achieves 0.011m deflection and loads are still applied until a failure is achieved at 22.9kN with 0.015m deflection. The tests achieve a live load of 8.8kN at one of the loadings, however the deflection of each test varies for the same live load, and this also occurs in other loadings where each test may achieve the same live load.

The linear truss system of test 1 shows the deflection is increasing gradually at a difference of 2mm for the first 4 loads and a difference of 1mm for the last 5 loads until failure which results in a linear graph to be produced from the results. The test 3 has a 4mm deflection difference for the first load and then increases by 6mm for the second loading despite the loading number being the same as the first loading. The deflection then averages for 3mm at every loading for the next 2 loadings then every 1mm for at least 3 loadings and then by 2mm for the last loading. In **Figure 4-2**, the comparison of Test 1 and 3 with the same setup of 800mm roof batten spacings shows that Test 1 has a more linear graph than Test 3. Test 1 is able to carry more live load at failure than test 3, however Test 3 includes a ridge cap in the truss assembly which prevented failure around the ridge area in comparison with Test 1. Test 1 and Test 3 both have the same number of live loads per loading until it differed when failure occurs for both tests. Test 3 carried more deflection which was observed from the 2nd loading application.

The Test 2 reaches a deflection of 12mm at failure in which the first load has a 3mm difference and then a difference of 2mm for the next 3 loads. The live loads of the first 4 loads have an average increase of about 5-6mm. The last 2 loads have a deflection difference of 1mm and an average live load increase of 1-2mm. The number of boxes per loading of Test 2 is the same as Tests 1 and 4.

Test 4, which is the back-to-back truss system, has the same number of boxes loading at every loading number and achieves the same live load at failure as test 1, however, as shown in the graph, the deflection difference only changes by 1mm after the 1st loading and then increases suddenly by 6mm after the 2nd loading. The deflection difference gradually returns to a 2mm difference for 2 loadings and then 1mm for the remaining loads until complete failure of the truss.

The test 5 linear truss system with an internal support has a deflection of 3mm for the 1st loading, then 2mm deflection for the next 3 loadings. A deflection of 1mm continues for the next 6 loads until the deflection does not change and the deflection remains at the same value afterwards when 6 more sets of loadings are applied. The amount of load of boxes applied at each pallet differs by the end of the test 5.

Tests 6, 7 and 8 have the same parameters of lateral restraints in the number of roof battens and ceiling battens. The loading boxes of Test 7 differs from other tests because of the different box sizes being used. The first 3 loads maintain the same live load as other tests and the deflection differences of these is 3mm. The change in weight of box loading when using a lighter box maintained about an average of 1.15kN increase in live load and about 1mm-2mm deflection until the last loading.

The test 6 shows that deflections for the first loading increases suddenly and then maintains an average between 1mm-2mm deflection difference upon each loading until the last loading is applied. The setup of test 8 is the same as test 7 where the loadings use 2 different weights of boxes. Test 8 results show an average of 2mm-3mm deflection difference at each loading for the heavier boxes and an average of 1mm-2mm difference in deflection at each loading of the lighter boxes. The lighter boxes have a live load difference of 1.72kN at each loading in comparison with test 7. In **Figure 4-3**, the comparison of Test 6 and 8 for the tests with 400mm roof batten spacings, the graph shows that Test 8 has a more consistent increase than Test 6 however both tests achieve the same deflection and around the same value of live load when failure is experienced on the truss assemblies.

The application of boxes for each loading onto every pallet affects the load distribution on the truss assembly. The human factor in these tests where the load application of each pallet is manually placed by persons that causes sway on the pallets. Another human factor is the sliding of box load on the pallets instead of placing on the pallets without sliding. The time taken to manually place each box load varies for each pallet as it depends on the rate in which the person loading carries the box and places it on the pallet. The type of truss system and the number of screws for the truss assembly also affect the deflection on the truss system. The increase in lateral restraints of roof battens for the later tests showed a longer load application capability for the tests. The measuring of the deflection at mid-span can be used by a machine instead of manual readings and deflections can also be measured at quarter span for future experiments/tests or research.

Table 13: Load vs Deflection Results for all Tests

Load Number	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6		Test 7		Test 8	
	Live Load (Q)	Deflection difference (m)	Live Load (Q)	Deflection difference (m)	Live Load (Q)	Deflection difference (m)	Live Load (Q)	Deflection difference (m)	Live Load (Q)	Deflection difference (m)	Live Load (Q)	Deflection difference (m)	Live Load (Q)	Deflection difference (m)	Live Load (Q)	Deflection difference (m)
0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
1	4.40	0.003	4.40	0.003	4.40	0.004	4.40	0.001	2.55	0.003	4.40	0.006	4.40	0.003	4.40	0.002
2	8.11	0.005	8.11	0.005	8.11	0.01	8.11	0.007	4.40	0.005	8.11	0.009	8.11	0.006	8.11	0.005
3	11.82	0.007	11.82	0.007	11.82	0.013	11.82	0.009	6.87	0.007	11.82	0.013	11.82	0.009	11.82	0.008
4	15.52	0.009	15.52	0.009	15.52	0.016	15.52	0.011	9.34	0.009	15.52	0.013	13.67	0.011	13.67	0.01
5	16.76	0.01	16.76	0.011	16.76	0.017	16.76	0.012	11.82	0.01	16.76	0.014	18.61	0.015	17.38	0.012
6	18.00	0.011	18.00	0.012	18.00	0.018	18.00	0.013	13.67	0.011	18.00	0.015	19.76	0.017	18.52	0.014
7	19.23	0.012			19.23	0.019	19.23	0.016	16.14	0.012	19.23	0.016	20.91	0.018	19.67	0.015
8	20.47	0.013			20.47	0.021	20.47	0.017	18.61	0.013	20.47	0.017	22.05	0.0195	20.82	0.016
9	21.70	0.014					21.70	0.018	19.85	0.014	21.70	0.019	23.20	0.021	21.96	0.017
10	22.94	0.015					22.94	0.019	21.09	0.015	22.94	0.02			23.11	0.018
11									22.32	0.015	24.18	0.022			24.25	0.02
12									23.56	0.015	25.41	0.024			25.40	0.021
13									24.79	0.015	26.65	0.026			26.54	0.022
14									26.03	0.015	27.88	0.027			27.69	0.024
15									27.27	0.015	29.12	0.027			28.84	0.025
16									27.88	0.015					29.98	0.027

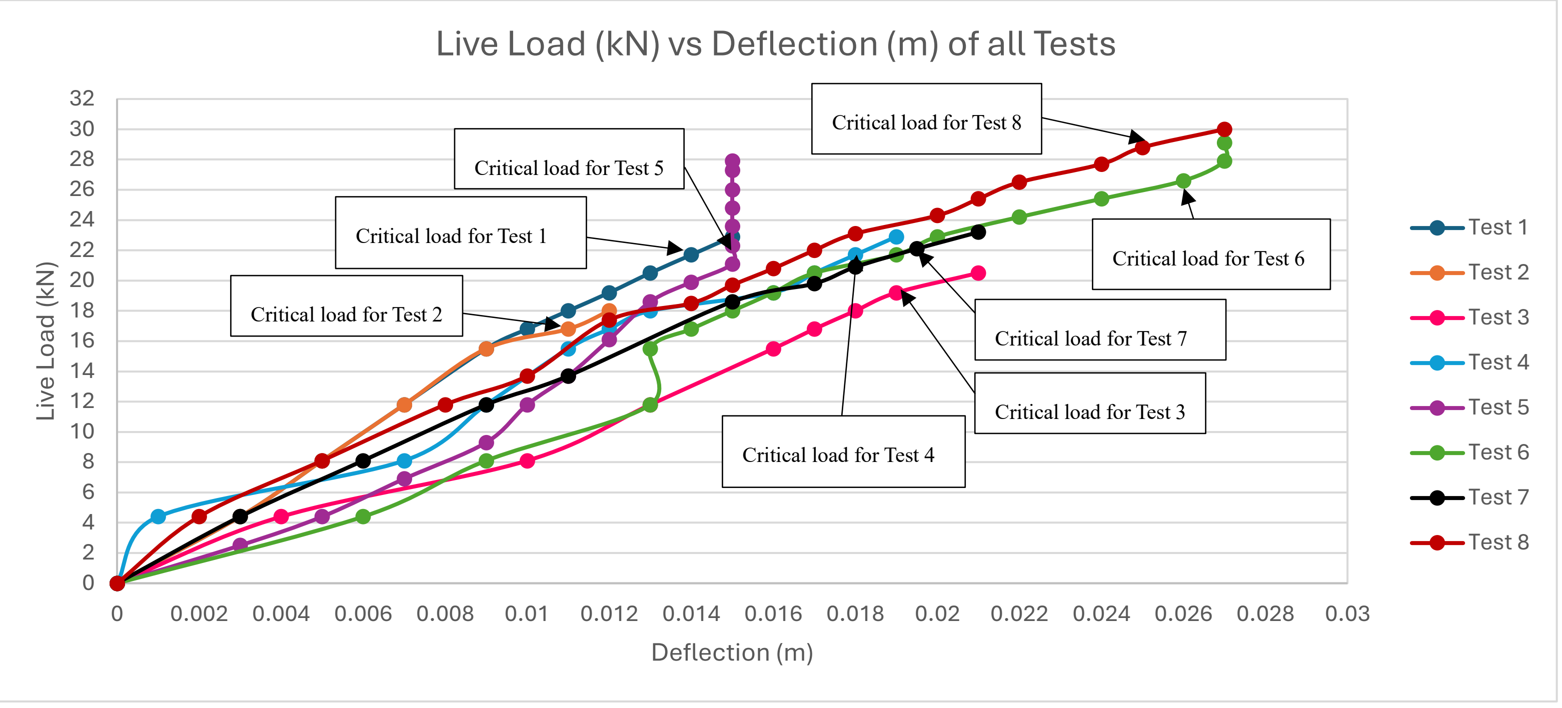


Figure 4-1: Load vs Deflection graph for all Tests

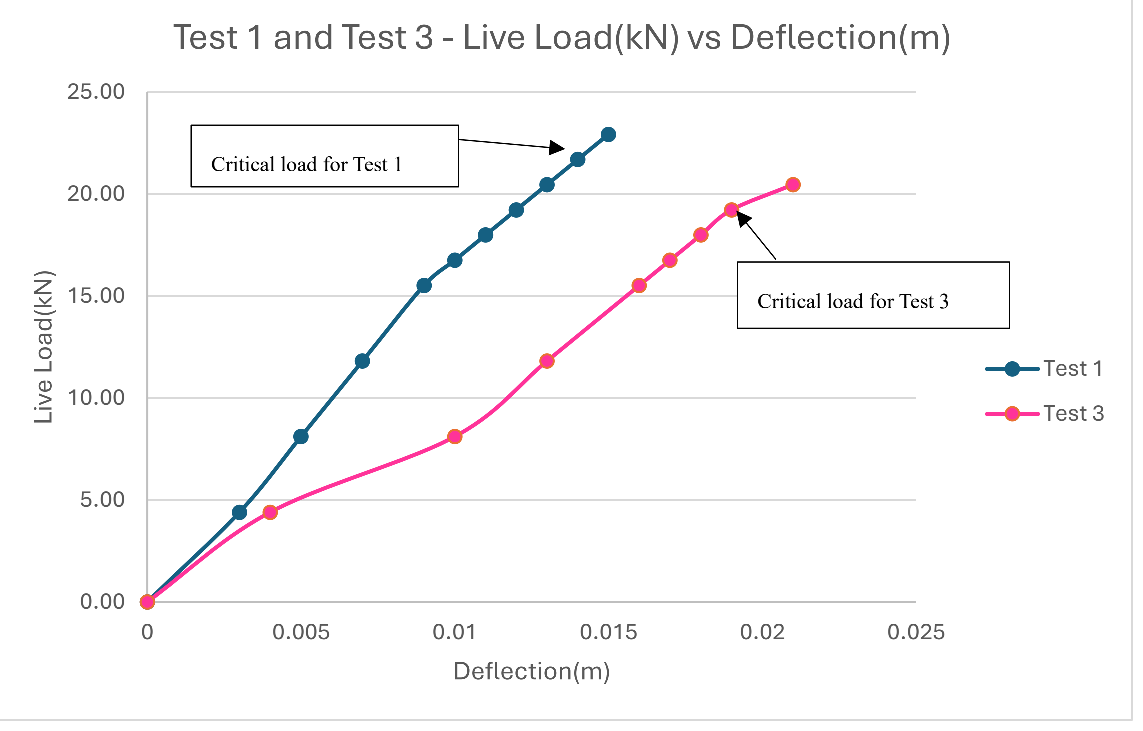


Figure 4-2: Test 1 and Test 3(800mm roof batten spacing) – Live Load(kN) vs Deflection(m) Graph

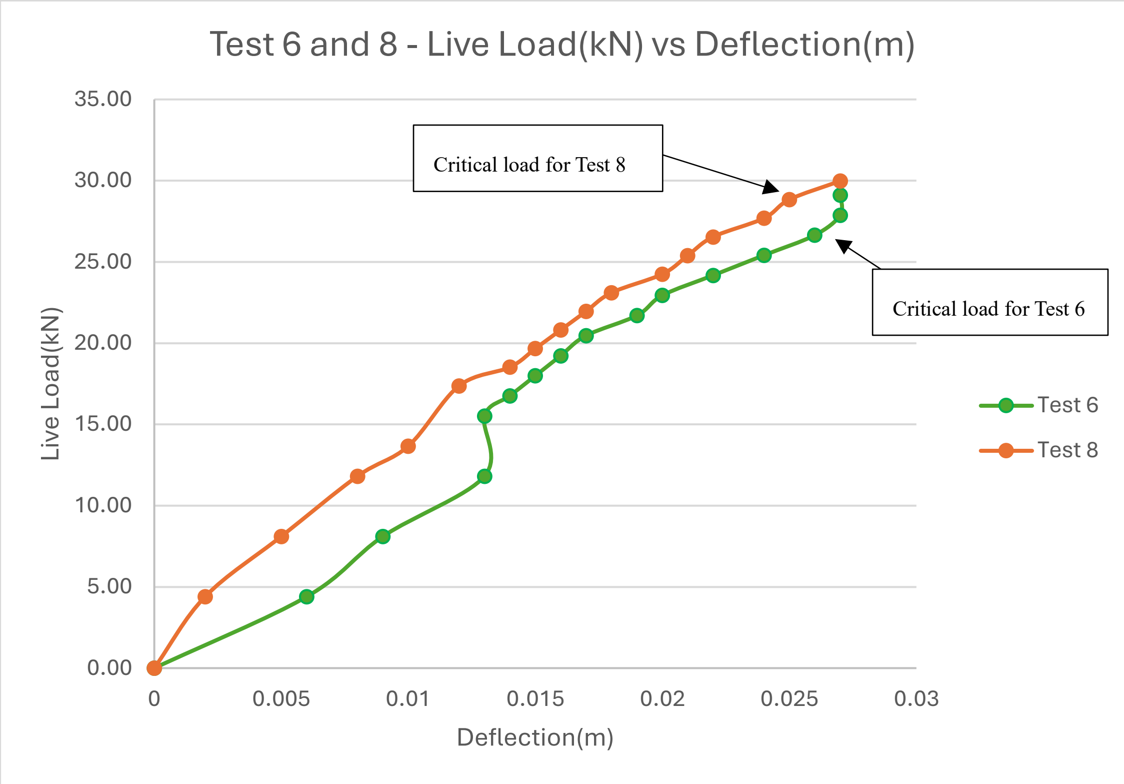


Figure 4-3: Test 6 and Test 8(400mm roof batten spacing) – Live Load(kN) vs Deflection(m) *Graph*

4.4 Test 1 Tabulated results and graph

The **Table 14** shows the dead load calculation of the truss assembly for Test 1 in which the Dead load (G) value is calculated to be 0.84kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The weight of each material used on the truss assembly is calculated using either the linear density, surface density or density of the material. The CFS material used in all the tests has a standard thickness of 0.75mm and a linear density of 1.15kg/m which is multiplied by the length of each of the 11 truss members to get the weight of each truss member. The CFS linear density is also multiplied by the length of the 16 roof box sections with holes made of CFS to get the weight of the roof box sections with holes. The area of each roof sheet is multiplied by the surface density of the material to get the weight of each of the roof sheets. The HWH roof screws and standard roof screws are multiplied by the weight of each screw to get the weight of the respective screws. The battens, braces and brackets are multiplied by the density of steel to get the weight of the materials. The truss members are added then multiplied by 2 since there are 2 trusses used for the assembly. Each truss weighs 23.5kg and the sum of both trusses is 47.0kg. The trusses are then added to all the other members that form the truss assembly for Test 1 which gives a value of 85.8kg as the weight of the truss assembly.

The **Table 15** shows the live load (Q) calculations of the truss assembly which includes the pallets and the number of boxes on each pallet at the end of the test. The pallet pieces which make up the box are made of CFS so the linear density of CFS is multiplied with the length of the 10 pallet pieces of 800mm in length. There are 2 of the 1200mm length pallet pieces which are also multiplied with the linear density. The volume of the flat steel plate made of steel is multiplied by the density of steel to get the weight of the flat steel plate. The sum of the weight of 10 CFS pallet pieces of 800mm long, the 2 CFS pallet pieces of 1200mm in length and the flat steel plate is calculated to be 17.6kg which is the weight of 1 pallet. Since there are 4 pallets, the weight of 4 pallets is 70.4kg. There are 36 boxes on each pallet when the truss experiences failure. Each box of screw used in test 1 is 15.75kg. The weight of the 36 boxes on 1 pallet is 567kg. The sum of the weight of boxes on all 4 pallets is 2268.0kg. The sum of 4 pallets and the weight of boxes per pallet is 2338.45kg. The sum of weight of boxes is multiplied by the acceleration due to gravity then converted to kiloNewtons to get the value of the live load (Q). The live load of the Test 1 at failure is 22.94kN which is calculated using the live load formula:

$$Live\ Load\ (kN) = \frac{weight\ sum \times acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of Test 1 is calculated using:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 1 is 23.78kN. The loads for the pallets are placed in increments of 6 boxes per loading for each pallet which occurred for 4 consecutive loading. The number of boxes per loading for each pallet are then decreased to 2 boxes per loading which occurred for 6 consecutive loadings until the truss experienced failure. The live load at each loading increased by almost 4kN in the first 2 loadings then averaged about 1kN-2kN for the remainder of the test until failure. The deflection at every loading is measured at the mid-span of the truss from the ground floor to the bottom of the bottom chord of Truss 1. The same location is used for every measure and for Test 1, the deflection averages between 2mm-3mm for the first 4 loadings and then maintains a 1mm deflection for the last 6 loadings until the assembly experiences failure. The Live Load vs Deflection graph of Test 1 is shown in **Figure 4-4**.

The key variables in Test 1 include the 14 ceiling battens underneath the bottom chords, the steel coil braces above the ceiling battens, the height of the main support frame at 845mm, the absence of a ridge cap above the centre of the top chords for both trusses and the 12 roof battens above the top chords. The 12 roof battens are connected on the flanges of the open channel section top chords. The trusses braced by the roof battens and roof sheets provide a lateral restraint to the assembly which prevents the truss from moving sideways during the test. The fixing of the end supports with the multi fix bracket screwed onto the main support frame provide a restraint for the assembly.

During the course of the test, the loads are placed beginning at the centre of the pallets and moves outwards towards the edge at every set of loading. Since 4 people are manually moving the loads, extra care is necessary to ensure that the boxes are placed precisely in the pallet area without causing stress on the assembly by avoiding sliding over the pallets or colliding with strap cables. Despite the extra care by manual placements, some of these cannot be prevented due to the space constraints around the pallet. While the loads are spread to cover the base of the pallet, they are also stacked above one another. The pallets constantly sway with every set of loads applied and are manually stopped before the mid-span deflection is measured by the use of a ruler or measuring tape.

There are ripples (bulging) which start to form on the back webs of the top chords near the Joint D and F of Truss 1 as the loads are applied. The top chord member eventually experiences failure near this location. The right side of Truss 1 and left side of Truss 2 do not experience failure or bulging of the truss members. The screw connections on the Trusses do not experience failure. The ridge of both Truss 1 and Truss 2 experience failure near the joints H, L and M which separates the top chords, however the top chords do not fall as the screws are still connected properly around these joints.

Table 14 : Dead Load of Test 1

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.000	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.000	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.000	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.000	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.000	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.000	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.000	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.000	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.000	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.000	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.000	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		809	65	0.4	52585	0.05	21034	0.00002103	7850	-	-	0.2	14	2.3
Roof batten		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	12	3.0
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.001760	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Steel Brace Coil on Ceiling Battens		1515	30	1	45450	0.05	45450	0.000045	7850	-	-	0.4	2	0.7

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Steel brace	18	19	-	342	0.00	-	-	-	-	-	0.01	8	0.1
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	146	1.5
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.92	16	14.6
Roof Box Section Screws	18	19	-	342	0.00	-	-	-	-	-	0.01	96	1.0
		Weight Sum (2 Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***85.8***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.84***

Table 15: Live Load of Test 1

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density(kg/m)	Density(kg/m^3)	weight(kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.76
	1200	800	0.75	960000	0.96	720000	0.0007	1	-	7850	5.65
Total weight of 1 pallet(kg)											17.6
Total weight of 4 pallets(kg)											70.4

Box weight calculations	Number of boxes	weight of 1 box (kg)	weight [boxes x pallet] (kg)
Pallet 1	36	15.75	567.0
Pallet 2	36	15.75	567.0
Pallet 3	36	15.75	567.0
Pallet 4	36	15.75	567.0
Total Sum of Boxes weight for 4 pallets			2268.0

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 2268.0kg + 70.4kg$$

$$= 2338.4kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/{}_{s^2}\right)}{1000N}$$

$$= \frac{2338.4\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 22.94kN}$$

Deflection per loading

Loading number	boxes per loading	box weight loading per pallet (kg)	box weight loading for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0.00	0.00	845	0.000
1	6	94.50	378	448.45	4.40	5.24	842	0.003
2	6	94.50	378	826.45	8.11	8.95	840	0.005
3	6	94.50	378	1204.45	11.82	12.66	838	0.007
4	6	94.50	378	1582.45	15.52	16.37	836	0.009
5	2	31.50	126	1708.45	16.76	17.60	835	0.010
6	2	31.50	126	1834.45	18.00	18.84	834	0.011
7	2	31.50	126	1960.45	19.23	20.07	833	0.012
8	2	31.50	126	2086.45	20.47	21.31	832	0.013
9	2	31.50	126	2212.45	21.70	22.55	831	0.014
10	2	31.50	126	2338.45	22.94	23.78	830	0.015
Total of boxes per pallet	36							

Total Deflection (mm) = 15.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.84 + 22.94$$

$$\boldsymbol{Total\ Load\ (kN) = 23.78kN}$$

Live Load (Q)	Deflection difference (m)
0.00	0.000
4.40	0.003
8.11	0.005
11.82	0.007
15.52	0.009
16.76	0.01
18.00	0.011
19.23	0.012
20.47	0.013
21.70	0.014
22.94	0.015

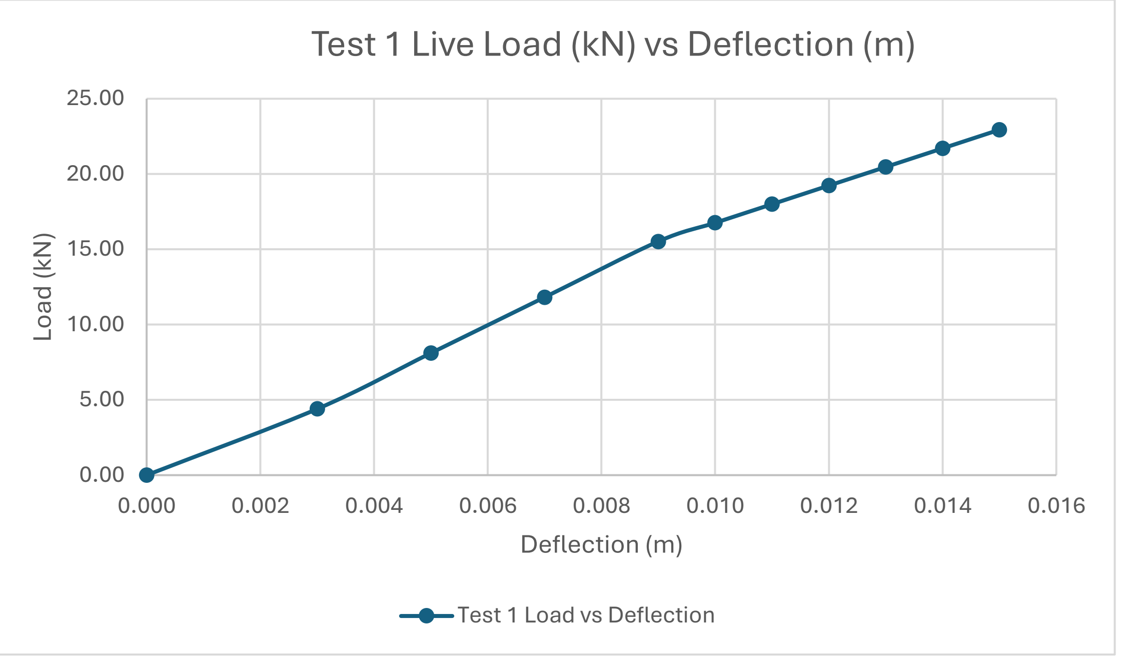


Figure 4-4: Test 1 Live Load (kN) vs Deflection (m) Graph

4.5 Test 2 Tabulated results and graph

The **Table 16** shows the dead load calculation of the truss assembly for Test 2 in which the Dead load (G) value is calculated to be 0.84kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The weight of 1 truss is the same as Test 1 which is 23.5kg and this is calculated from the individual weights of the 11 members of the truss. The length of the individual members is multiplied by the 1.15kg/m linear density of CFS. The sum of the 2 trusses used in the Test 2 assembly is 47.0kg. Since there are 79 HWH screws for Truss 1 and 73 screws for Truss 2, the 152 screws are multiplied by the weight of 1 screw to get the weight of all the HWH screws. Similar to Test 1, the weight of all the materials that form the truss test assembly setup is added to the weight of the 2 trusses which gives a total weight value of 85.5kg on the dead load.

Following the outcome of Test 1, there are key variables for Test 2 which is different from Test 1. There is a ridge cap which is added on the Test 2 truss test assembly to provide a lateral restraint on the ridge point of the top chords of both trusses. This additional ridge cap prevented failure around the Joints H, L, M of Truss 1 and 2 during the course of Test 2. The added piece only increased the dead weight on the dead load but did not change the final value of dead load (G). Truss 1 has more screws especially around Joints H, L and M, the same opposing Joints of Truss 2 have less screws. Joint A of Truss 1 has 1 additional screw on the bracket at the end support in comparison to Joint R of Truss 2. The height of the main support frame of the truss assembly is also increased by 45mm from 845mm to 890mm to provide more room above ground for the load pallets to hang. There are 8 people loading boxes for this test which is twice as many as Test 1.

The live load calculations for Test 2 truss assembly are shown in **Table 17**. The pallet material, dimensions and number of pieces used is the same for all 8 tests, so each pallet used is 17.6kg and the sum of weights for the 4 pallets is 70.4kg. There are 28 boxes loaded on each pallet when the truss assembly experiences failure. Since each box used in this test is 15.75kg, the weight of the 28 boxes on 1 pallet is 441.0kg and the weight of the 112 boxes loaded at failure on the 4 pallets is 1764.0kg. The sum of the weight of all the boxes loaded at failure and the weight of all 4 pallets is 1834.45kg. The live load is calculated using the sum of the weight of all the pallets and the number of boxes loaded on each pallet which is multiplied by the acceleration due to gravity and then converted to kiloNewtons (kN). The live load at failure for Test 2 is 18.00kN which is calculated from the formula below:

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of the Test 2 is calculated using the formula:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 2 is 18.83kN. The load application is the same as Test 1 where the first 4 loads consist of 6 boxes per pallet starting from the centre of the pallet. The loads per pallet then have 2 boxes per pallet for the next 2 loadings until failure is experienced. At 6 boxes per loading, the change in height is 2mm and 1mm when there are 2 boxes per loading and the assembly reaches a 12mm deflection at failure. There are ripples appearing on web of members as 24th box is applied for each pallet during 4th load number. The pallets sway as loads are applied and since the loading pace is faster than Test 1, the pallet sway is more and the spread of loads on the pallet occurs faster. The addition of a ridge cap above the top chords at ridge of truss pair prevented failure at those connection joints. The right side of Truss 1 and left side of Truss 2 do not experience failure or bulging of the truss members. The failure occurs on the same side of the assembly for both trusses The Live Load-Deflection graph of Test 2 is shown in **Figure 4-5**.

Table 16: Dead Load of Test 2

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00026	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00026	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00001	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00004	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00011	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00008	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00011	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00003	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00004	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00001	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00047	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00002	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00003	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00002	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00176	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Steel Brace on Ceiling Battens		1515	30	1	45450	0.05	45450	0.000045	7850	-	-	0.4	2	0.7

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Steel brace	18	19	-	342	0.00	-	-	-	-	-	0.01	8	0.1
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	152	1.5
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***85.5***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.84***

Table 17: Live Load of Test 2

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density (kg/m)	Density(kg/m^3)	weight (kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.76
	1200	800	0.75	960000	0.96	720000	0.00	1	-	7850	5.65

Total weight of 1 pallet(kg)	*17.6*
Total weight of 4 pallets(kg)	*70.4*

Box weight calculations	Number of boxes	weight of 1 box (kg)	weight [boxes x pallet] (kg)
Pallet 1	28	15.75	441.0
Pallet 2	28	15.75	441.0
Pallet 3	28	15.75	441.0
Pallet 4	28	15.75	441.0
Total Sum of Boxes weight for 4 pallets			1764.0

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 1764.0kg + 70.4kg$$

$$= 1834.4kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/{}_{s^2}\right)}{1000N}$$

$$= \frac{1834.4\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 18.00kN}$$

Deflection per loading

Loading number	boxes per loading	box weight loading per pallet (kg)	box weight load for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0.00	0.0	890	0.000
1	6	94.50	378	448.448	4.40	5.24	887	0.003
2	6	94.50	378	826.448	8.11	8.95	885	0.005
3	6	94.50	378	1204.448	11.82	12.65	883	0.007
4	6	94.50	378	1582.448	15.52	16.36	881	0.009
5	2	31.50	126	1708.448	16.76	17.60	879	0.011
6	2	31.50	126	1834.448	18.00	18.84	878	0.012
Total of boxes per pallet	28							

Total Deflection (mm) = 12.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.84 + 18.00$$

$$\boldsymbol{Total\ Load\ (kN) = 18.84kN}$$

Live Load (Q)	Deflection difference (m)
0	0
4.29	0.003
7.99	0.005
11.70	0.007
15.41	0.009
16.65	0.011
17.88	0.012

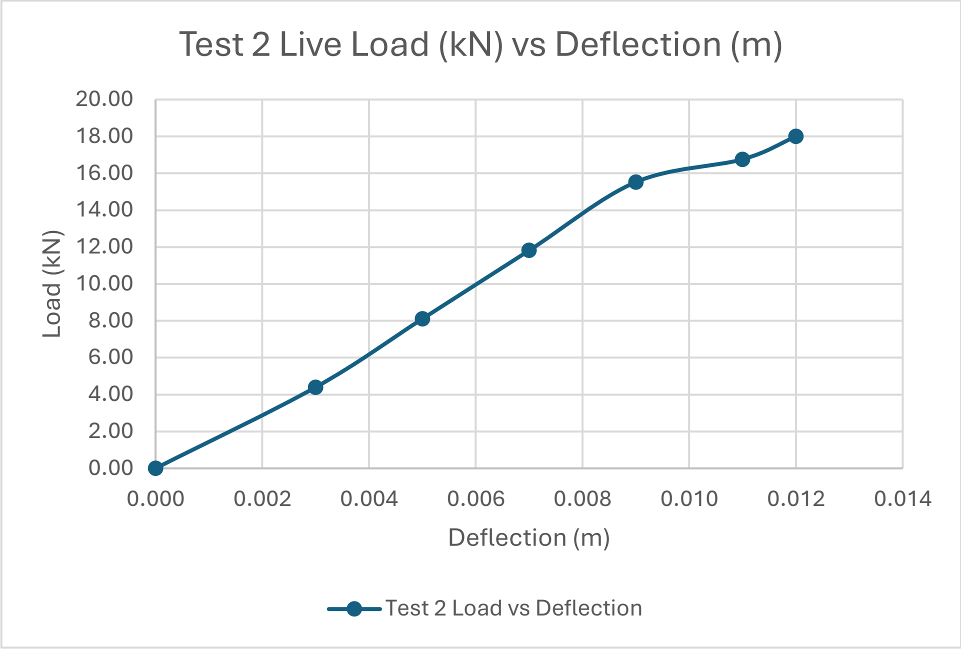


Figure 4-5: Test 2 Live Load (kN) vs Deflection (m) Graph

4.6 Test 3 Tabulated results and graph

The **Table 18** shows the dead load calculation of the truss assembly for Test 3 in which the Dead load (G) value is calculated to be 0.83kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/{}_{s^2}\right)}{1000N}$$

The truss arrangement is the same as previous tests 1 and 2 in which there are 11 CFS member of 0.75mm thickness so 1 truss weighs 23.5kg and both trusses weigh 47.0kg. The key variables in this test series are that there is no steel coil brace placed above the ceiling battens and the trusses have more screws compared to the previous tests. Truss 1 uses 83 HWH screws for all the joints, Truss 2 uses 84 HWH screws and the screws are connected from the back of the webs at each truss joint. Truss 1 has less screws connected to the truss at the end supports compared to Truss 2 and the previous tests completed. The 2 joints at the heels of each truss are connected to a multi fix bracket which is later connected with screws onto the end supports of the main support frame. The 167 HWH screws are multiplied to the weight of 1 screw to get the weight of the HWH screws used on the trusses. The number of roof battens remain as 12 and the ceiling battens remain as 14 which is the same as Tests 1 and 2. Test 3 also includes a ridge cap, and the main support frame height is 890mm which is the same as Test 2 however the loading of boxes is conducted by 4 people for this test which is the same as Test 1. The weight of all the materials that form the truss test assembly setup is added to the weight of the 2 trusses which gives a total weight value of 84.9kg on the dead load.

The live load calculations for Test 3 truss assembly are shown in **Table 19**. The pallet used is 17.6kg and the sum of weights for the 4 pallets is 70.4kg. There are 32 boxes loaded on each pallet when the truss assembly experiences failure. Since each box used in this test is 15.75kg, the weight of the 32 boxes on 1 pallet is 504.0kg and the weight of the 128 boxes loaded at failure on the 4 pallets is 2016.0kg. The sum of the weight of all the boxes loaded at failure and the weight of all 4 pallets is 2086.45kg. The live load is calculated using the sum of the weight of all the pallets and the number of boxes loaded on each pallet which is multiplied by the acceleration due to gravity and then converted to kiloNewtons (kN). The live load at failure for Test 3 is 20.47kN which is calculated from the formula below:

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of the Test 3 is calculated using formula:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 3 is 21.30kN. The loading method is the same as Test 1 and 2 which starts from the centre of the pallets and moves upward and outward towards the edge of the pallet, where there are 6 boxes per pallet for the first 4 loads, and then the boxes per pallet are decreased to 2 for each loading until the truss experiences failure. The roof battens and roof sheets provide a lateral restraint to the assembly which prevents the truss from moving sideways during the test. The fixing of the end supports with the multi fix bracket screwed onto the main support frame provide a restraint for the assembly. There was a sudden 6mm drop of the assembly after the 2nd loading but there is an average of 1mm deflection after most loadings and the test assembly experiences a deflection of 21.00mm at the failure. The Live Load-Deflection graph for Test 3 is shown in **Figure 4-6**. The area of failure is around Truss 1 and is near the same joints which experiences failure in Test 2, however the live load at the end of failure is more than Test 2. The load application is a factor that can be identified as causing the fluctuation of live load failure value, but the number of lateral restraints used may need to be changed. Tests 1, 2 and 3 are arranged in the linear truss system however for all tests, the load is not applied at the shear centre of the open channel sections of CFS so the failure may occur near the same places, but the mechanism of failure differs for all 3 tests. The truss assembly for Test 2 was not checked properly before the test was conducted which could have been a factor in the truss failure and for this reason, Test 2 is not considered for calculating the average load capacity values of the truss assembly with an 800mm roof batten spacing.

Table 18: Dead Load of Test 3

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	167	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***84.9***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.83***

Table 19: Live Load of Test 3

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density (kg/m)	Density(kg/m^3)	weight (kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.76
	1200	800	0.75	960000	0.96	720000	0.00	1	-	7850	5.65
Total weight of 1 pallet(kg)											*17.6*
Total weight of 4 pallets(kg)											*70.4*

Box weight calculations	Number of boxes	weight of 1 box (kg)	weight [boxes x pallet] (kg)
Pallet 1	32	15.75	504.0
Pallet 2	32	15.75	504.0
Pallet 3	32	15.75	504.0
Pallet 4	32	15.75	504.0
Total Sum of Boxes weight for 4 pallets			2016.0

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 2016.0kg + 70.4kg$$

$$= 2086.4kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/{}_{s^2}\right)}{1000N}$$

$$= \frac{2086.4\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 20.47kN}$$

Deflection per loading

Loading number	boxes per loading	box weight loading per pallet(kg)	box weight loading for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0	0	890	0.000
1	6	94.50	378	448.448	4.40	5.23	886	0.004
2	6	94.50	378	826.448	8.11	8.94	880	0.010
3	6	94.50	378	1204.448	11.82	12.65	877	0.013
4	6	94.50	378	1582.448	15.52	16.36	874	0.016
5	2	31.50	126	1708.448	16.76	17.59	873	0.017
6	2	31.50	126	1834.448	18.00	18.83	872	0.018
7	2	31.50	126	1960.448	19.23	20.06	871	0.019
8	2	31.50	126	2086.448	20.47	21.30	869	0.021
Total of boxes per pallet	32							

Total Deflection (mm) = 21.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.83 + 20.47$$

$$\boldsymbol{Total\ Load\ (kN) = 21.30kN}$$

Live Load (Q)	Deflection difference (m)
0	0.000
4.40	0.004
8.11	0.010
11.82	0.013
15.52	0.016
16.76	0.017
18.00	0.018
19.23	0.019
20.47	0.021

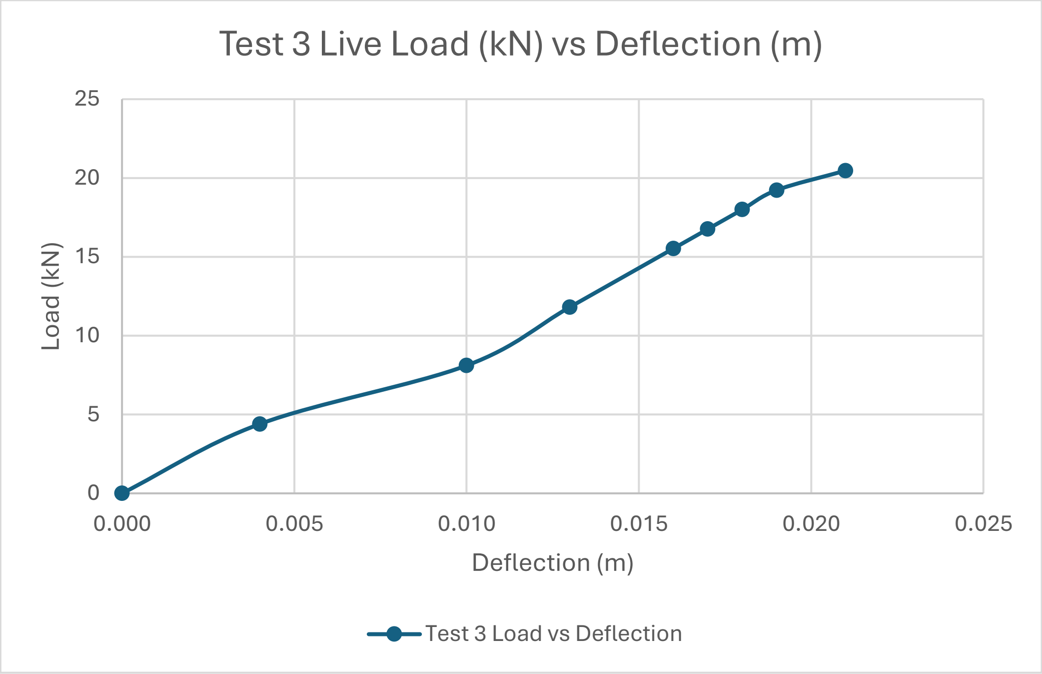


Figure 4-6: Test 3 Live Load (kN) vs Deflection (m) Graph

4.7 Test 4 Tabulated results and graph

The **Table *20*** shows the dead load calculation of the truss assembly for Test 4 in which the Dead load (G) value is calculated to be 0.83kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The arrangement of the truss members in this test 4 assembly follows the back-to-back truss system in which the back of the web members is placed against the back of the top chord and bottom chords of the trusses. The truss has the same number of members as the other tests of which there are 2 top chords, 1 bottom chord and 8 web members and all CFS truss members are of 0.75mm thickness. The weight of 1 truss is 23.5kg and the weight of both trusses is 47.0kg. The key variables in this test include the linear truss system, the removal of the steel coil brace above the ceiling battens, inclusion of the ridge cap. There are 14 ceiling battens, 12 roof battens and, 72 roof screws used in this test, which is the same as Tests 1, 2 and 3. The main support frame has a height of 890mm which is the same tests 2 and 3. There are 152 HWH screws used in both trusses and each truss has 76 HWH screws. The joints on Truss 1 have the same number of HWH screws as its opposite joint on truss 2. Similar with other tests, the number of screws around Joints H are more than the other joints on the truss.

The live load calculations for Test 4 truss assembly are shown in **Table 21** and the Live Load-Deflection graph is shown in **Figure 4-7**. The pallet used is 17.6kg and the sum of weights for the 4 pallets is 70.4kg. There are 36 boxes loaded on each pallet when the truss assembly experiences failure. Since each box used in this test is 15.75kg, the weight of the 36 boxes on 1 pallet is 567.0kg and the weight of the 144 boxes loaded at failure on the 4 pallets is 2268.0kg. The sum of the weight of all the boxes loaded at failure and the weight of all 4 pallets is 2338.4kg. The boxes per loading is the same as the previous tests 1, 2 and 3 in which there are 6 boxes per loading for the first 4 loads and then there are 2 boxes per loading until failure. The change in height for the first loading is 1mm and increases by a sudden 6mm before maintaining an average deflection of 1mm per loading until failure. The change in height is the same as test 2 during the 2nd loading of boxes in this test.

The live load is calculated using the sum of the weight of all the pallets and the number of boxes loaded on each pallet which is multiplied by the acceleration due to gravity and then converted to kiloNewtons (kN). The live load at failure for Test 4 is 22.49kN which is calculated from the formula below:

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of the Test 4 is calculated using the formula:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 4 is 23.77kN. The loads are placed beginning at the centre of the pallets and moves outwards towards the edge at every set of loading. While the loads are spread to cover the base of the pallet, they are also stacked above one another. During this test, the truss collapsed and the pallet falling to the ground level stopped the full collapse. Due to this, Test 4 is not considered for the averages of the capacities in the behaviour of the roof truss assembly with 400mm roof batten spacings.

Table 20: Dead Load of Test 4

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Multi Fix Brackets		114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3
HWH Screws on Roof battens		18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5

HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	152	1.5
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***84.7***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.83***

Table 21: Live Load of Test 4

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density (kg/m)	Density(kg/m^3)	weight (kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.8
	1200	800	0.75	960000	0.96	720000	0.00	1	-	7850	5.65
Total weight of 1 pallet(kg)											*17.6*
Total weight of 4 pallets(kg)											*70.4*

Box weight calculations	Number of boxes	weight of 1 box (kg)	weight [boxes x pallet] (kg)
Pallet 1	36	15.75	567.0
Pallet 2	36	15.75	567.0
Pallet 3	36	15.75	567.0
Pallet 4	36	15.75	567.0
Total Sum of Boxes weight for 4 pallets			2268.0

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 2268.0kg + 70.4kg$$

$$= 2086.4kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

$$= \frac{2338.4\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 22.94kN}$$

Deflection per loading

Loading number	boxes per loading	box weight loading per pallet (kg)	box weight for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0.00	0.00	890	0.000
1	6	94.5	378	448.448	4.40	5.23	889	0.001
2	6	94.5	378	826.448	8.11	8.94	883	0.007
3	6	94.5	378	1204.448	11.82	12.65	881	0.009
4	6	94.5	378	1582.448	15.52	16.35	879	0.011
5	2	31.5	126	1708.448	16.76	17.59	878	0.012
6	2	31.5	126	1834.448	18.00	18.83	877	0.013
7	2	31.5	126	1960.448	19.23	20.06	874	0.016
8	2	31.5	126	2086.448	20.47	21.30	873	0.017
9	2	31.5	126	2212.448	21.70	22.54	872	0.018
10	2	31.5	126	2338.448	22.94	23.77	871	0.019
Total of boxes per pallet	36							

Total Deflection (mm) = 19.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.83 + 22.94$$

$$\boldsymbol{Total\ Load\ (kN) = 23.77kN}$$

Live Load (Q)	Deflection difference (m)
0.00	0.000
4.40	0.001
8.11	0.007
11.82	0.009
15.52	0.011
16.76	0.012
18.00	0.013
19.23	0.016
20.47	0.017
21.70	0.018
22.94	0.019

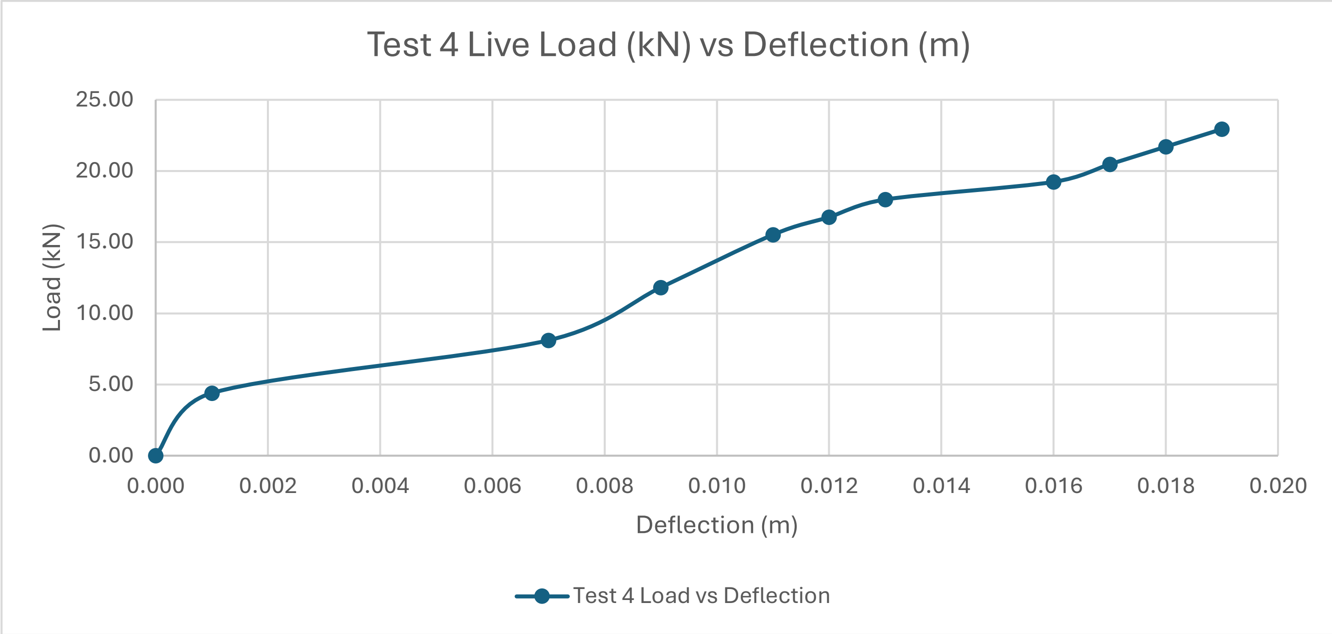


Figure 4-7: Test 4 Live Load (kN) vs Deflection (m) Graph

4.8 Test 5 Tabulated results and graph

The **Table 22** shows the dead load calculation of the truss assembly for Test 5 in which the Dead load (G) value is calculated to be 0.85kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The truss assembly in this test includes an internal support which is placed underneath Joint O of Truss 1 and Joint E of Truss 2. The weight of 1 truss in this assembly is 24.1kg due to the inclusion of an additional 295mm long CFS C-section member around the joint above the internal support. The weight sum of the 2 trusses in this assembly is 48.2kg. The key variable in this test assembly includes the internal support which then increases the number of HWH screws for the trusses. There are 14 ceiling battens, 12 roof battens, 1 ridge cap used in this test and there is no steel coil brace used above the ceiling battens. There are 185 HWH screws used in this test of which Truss 1 has 93 HWH screws and Truss 2 has 92 HWH screws. The end supports have the same opposing joint. i.e. Joint A of Truss 1 has 5 HWH screws on the truss and 4 screws connected on the multi fix bracket which is the same as its opposing Joint R on Truss 2. The Joint R of Truss 1 and Joint A of Truss 2 both have 6 screws each on the truss and 4 HWH screws on the multi fix bracket. For the internal joint supports, Joint O of Truss 1 has 6 HWH screws on the truss and 4 HWH screws on the multi fix bracket, however for Joint E of truss 2, there are 6 HWH screws on the truss and 3 HWH screws on the multi fix bracket. The main support frame of the truss assembly is increased to a height of 1045mm from 890mm following the outcome of Test 4. The weight of the dead load on the truss assembly is 86.4kg which includes the truss dead weight, the battens, roof sheets, screws, ridge cap, multi fix brackets, cross braces, roof box sections and extra CFS members.

The dimensions of the pallet pieces are the same as all other tests and the total number of boxes applied during the test is 176 which means the average number of boxes per pallet is 44 boxes. One of the inner pallets which is not supported by an internal support touches the ground during loading which eventually led to the discontinuation of Test 5. The internal pallet between the Joints E of Truss 1 and Joint O of Truss 2 touches the ground between the 12th and 13th loading at 37 boxes so loads were no longer applied on this pallet. The pallet next to the internal support at Joint O of Truss 1 and Joint E of Truss 2 touches the ground at 39 boxes, however, the pallets closest to both end supports did not touch ground and loads were still applied until the pallet neat Joint A of Truss 1 and Joint R of Truss 2 reached 47 boxes and the pallet near Joint R of Truss 1 and Joint A of Truss 2 reached 53 boxes of loading. The boxes applied during this test each weighed 15.75 kg and the total sum of the weight of boxes applied is 2772.0kg. The sum of the weights of the 4 pallets inclusive of the 2772.0 kg weight of boxes is 2842.4 kg.

The live load calculations for Test 5 assembly is shown in **Table 23** and the Live Load-Deflection graph is shown in **Figure 4-8**. The live loads are calculated using the sum of the weight of all the pallets and the number of boxes loaded on each pallet which is multiplied by the acceleration due to gravity and then converted to kiloNewtons (kN). The live load at failure for Test 5 is 27.88kN which is calculated from the formula below:

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of the Test 5 is calculated using the formula:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 5 is 28.73kN. The deflection at the end of test is 15mm in which there is an average of 2mm deflection per loading for the first 4 live loads and then there is a 1mm deflection per loading for the rest of the 9 live loads. The live loads increase from the 10th-16th loading however the deflection value remains at 15mm. This result is not a good reflection of how the truss assembly with internal support should behave so this test cannot be considered. Further tests of internal supports need to be conducted to observe the capacities in the behaviour of the roof truss assembly.

Table 22: Dead Load of Test 5

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
Extra CFS piece for internal support		295	89	0.75	26255	0.03	19691	0.00	-	-	2.15	0.6	1	0.6
									Weight Sum for 1 Truss Member					24.1
									Weight Sum for 2 Truss Members					48.2
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	14	1.7
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	12	3.0
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5

Multi Fix Brackets	114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	14	0.4
HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00						0.01	185	1.9
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	72	1.0
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***86.4***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.85***

Table 23: Live Load of Test 5

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density (kg/m)	Density(kg/m^3)	weight (kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.76
	1200	800	0.75	960000	0.96	720000	0.00	1	-	7850	5.65
Total weight of 1 pallet(kg)											*17.6*
Total weight of 4 pallets(kg)											*70.4*

Box weight calculations	Number of boxes	weight of 1 box (kg)	weight [boxes x pallet] (kg)
Pallet 1	47	15.75	740.3
Pallet 2	37	15.75	582.8
Pallet 3	39	15.75	614.3
Pallet 4	53	15.75	834.8
Total Sum of Boxes weight for 4 pallets			2772.0

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 2772.0kg + 70.4kg$$

$$= 2842.4kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

$$= \frac{2842.4\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 27.88kN}$$

Deflection per loading

Loading number	boxes per loading	box weight loading per pallet (kg)	box weight for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0.00	0.00	1045	0.000
1	3	47.25	189	259.448	2.55	3.39	1042	0.003
2	3	47.25	189	448.448	4.40	5.25	1040	0.005
3	4	63	252	700.448	6.87	7.72	1038	0.007
4	4	63	252	952.448	9.34	10.19	1036	0.009
5	4	63	252	1204.448	11.82	12.66	1035	0.01
6	3	47.25	189	1393.448	13.67	14.52	1034	0.011
7	4	63	252	1645.448	16.14	16.99	1033	0.012
8	4	63	252	1897.448	18.61	19.46	1032	0.013
9	2	31.5	126	2023.448	19.85	20.70	1031	0.014
10	2	31.5	126	2149.448	21.09	21.93	1030	0.015
11	2	31.5	126	2275.448	22.32	23.17	1030	0.015
12	2	31.5	126	2401.448	23.56	24.41	1030	0.015
13	2	31.5	126	2527.448	24.79	25.64	1030	0.015
14	2	31.5	126	2653.448	26.03	26.88	1030	0.015
15	2	31.5	126	2779.448	27.27	28.11	1030	0.015
16	1	15.75	63	2842.448	27.88	28.73	1030	0.015
Total of boxes per pallet	44							

Total Deflection (mm) = 15.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.85 + 27.88$$

$$\boldsymbol{Total\ Load\ (kN) = 28.73kN}$$

Live Load (Q)	Deflection difference (m)
0.00	0.000
2.55	0.003
4.40	0.005
6.87	0.007
9.34	0.009
11.82	0.01
13.67	0.011
16.14	0.012
18.61	0.013
19.85	0.014
21.09	0.015
22.32	0.015
23.56	0.015
24.79	0.015
26.03	0.015
27.27	0.015
27.88	0.015

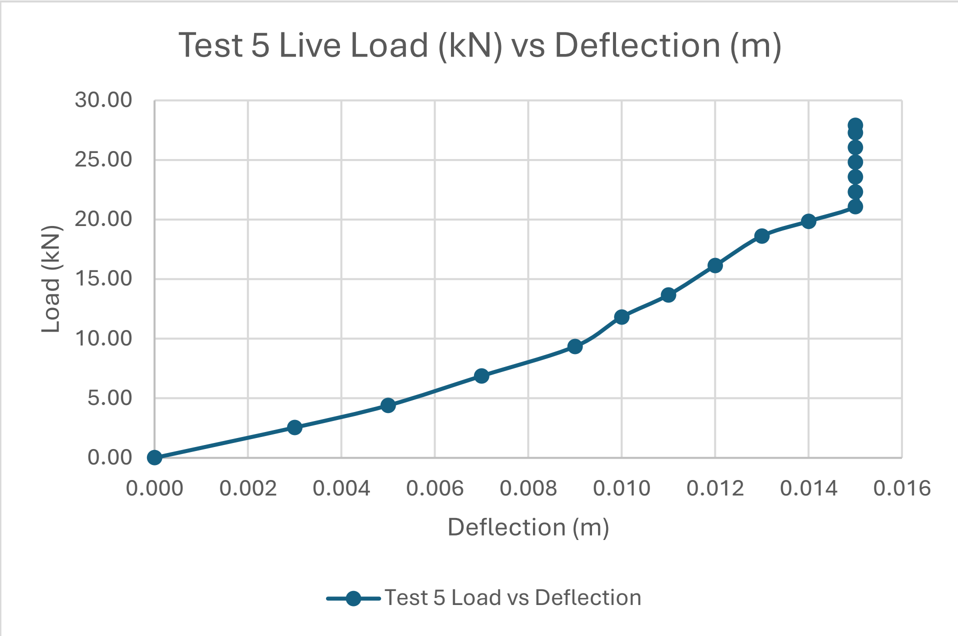


Figure 4-8: Test 5 Live Load (kN) vs Deflection (m) Graph

4.9 Test 6 Tabulated results and graph

The **Table 24** shows the dead load calculation of the truss assembly for Test 6 in which the Dead load (G) value is calculated to be 0.86kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The weight of 1 truss in this test assembly is 23.5kg which is the same as Tests 1, 2, 3 and 4 and the weight of both trusses is 47.0kg. The total number of HWH screws for both trusses is 166 in which Truss 1 has 92 HWH screws and Truss 2 has 74 HWH screws. The increase in number of screws is around the Joints H, L and M of Truss 1. The key variables in this test include an increase the number of roof battens and a decrease in the number of ceiling battens. There are 20 roof battens, 12 ceiling battens, 1 ridge cap, 2 steel pieces for cross bracing in between the trusses, 2 roof sheets used in this test and similar to tests 3,4 and 5, there is no steel coil bracing above the ceiling battens. Similar with other test series, the loads in this test are applied manually and incrementally placed at 6 boxes per loading then 2 boxes per loading until the end of the test. The main support frame height of the truss assembly remains at 1045mm. The weight of all the members that make up the truss assembly is 87.3kg when it is added to the 47.0kg weight of the trusses.

The setup of Test 6 is the same as tests 1,2,3 and 4 in which there is no internal support for the assembly. The pallet piece sizes are the same as previous tests so 1 pallet is 17.6kg and the sum of weights for the 4 pallets used in this assembly is 70.4kg. There are 46 boxes loaded on each pallet at the end of the test series and since each box is weighed at 15.75kg, each pallet consists of 724.5kg of boxes. The total sum of weight of boxes for the 4 pallets is 2898.0kg and when it is added to the 70.4kg pallets, the sum of weights for the 4 pallets inclusive of the total boxes on the pallets is 2968.4kg.

The live load calculations in **Table *25*** is calculated using the sum of the weight of all the pallets and the number of boxes loaded on each pallet which is multiplied by the acceleration due to gravity and then converted to kiloNewtons (kN). The live load at failure for Test 6 is 29.12kN which is calculated from the formula below:

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of the Test 6 is calculated using the formula:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 6 is 29.98kN. The Live Load-Deflection graph is shown in

Figure 4-9. The deflection suddenly increased by 6mm during the first loading and then increased by 3mm during the 2nd loading. The deflection remained the same for the 3rd and 4th loading and then maintained a 1mm deflection for the next 3 loadings. The deflection maintained an average of 1mm-2mm deflection for the remaining live loads until the end of the test. The deflection at the end of the test is 27.00mm. There is no failure experienced in this test, however the pallet 3 which is near Joints K & O of Truss 1 and Joints E & G of Truss 2 hits the ground at the box loading of 46 boxes.

Table 24: Dead Load of Test 6

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	12	1.5
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	20	5.1
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Multi Fix Brackets		114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3

HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	166	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	120	1.7
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***87.3***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.86***

Table 25: Live Load of Test 6

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density (kg/m)	Density(kg/m^3)	weight (kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.76
	1200	800	0.75	960000	0.96	720000	0.00	1	-	7850	5.65
Total weight of 1 pallet(kg)											*17.6*
Total weight of 4 pallets(kg)											*70.4*

Box weight calculations	Number of boxes	weight of 1 box (kg)	weight [boxes x pallet] (kg)
Pallet 1	46	15.75	724.5
Pallet 2	46	15.75	724.5
Pallet 3	46	15.75	724.5
Pallet 4	46	15.75	724.5
Total Sum of Boxes weight for 4 pallets			2898.0

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 2898.0kg + 70.4kg$$

$$= 2968.4kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/{}_{s^2}\right)}{1000N}$$

$$= \frac{2968.4\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 29.12kN}$$

Deflection per loading

Loading number	boxes per loading	box weight for each pallet (kg)	box weight for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0.00	0.00	1045	0.000
1	6	94.5	378	448.448	4.40	5.26	1039	0.006
2	6	94.5	378	826.448	8.11	8.96	1036	0.009
3	6	94.5	378	1204.448	11.82	12.67	1032	0.013
4	6	94.5	378	1582.448	15.52	16.38	1032	0.013
5	2	31.5	126	1708.448	16.76	17.62	1031	0.014
6	2	31.5	126	1834.448	18.00	18.85	1030	0.015
7	2	31.5	126	1960.448	19.23	20.09	1029	0.016
8	2	31.5	126	2086.448	20.47	21.32	1028	0.017
9	2	31.5	126	2212.448	21.70	22.56	1026	0.019
10	2	31.5	126	2338.448	22.94	23.80	1025	0.020
11	2	31.5	126	2464.448	24.18	25.03	1023	0.022
12	2	31.5	126	2590.448	25.41	26.27	1021	0.024
13	2	31.5	126	2716.448	26.65	27.50	1019	0.026
14	2	31.5	126	2842.448	27.88	28.74	1018	0.027
15	2	31.5	126	2968.448	29.12	29.98	1018	0.027
Total of boxes per pallet	46							

Total Deflection (mm) = 27.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.86 + 29.12$$

$$\boldsymbol{Total\ Load\ (kN) = 29.98kN}$$

Live Load (Q)	Deflection difference (m)
0.00	0.000
4.40	0.006
8.11	0.009
11.82	0.013
15.52	0.013
16.76	0.014
18.00	0.015
19.23	0.016
20.47	0.017
21.70	0.019
22.94	0.020
24.18	0.022
25.41	0.024
26.65	0.026
27.88	0.027
29.12	0.027

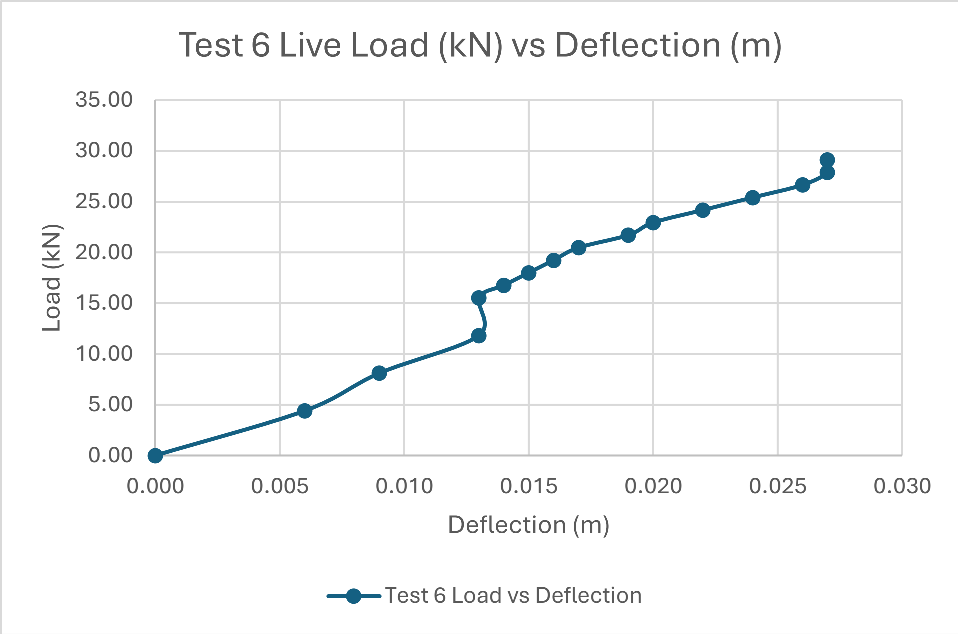


Figure 4-9: Test 6 Live Load (kN) vs Deflection (m) Graph

4.10 Test 7 Tabulated results and graph

The **Table *26*** shows the dead load calculation of the truss assembly for Test 7 in which the Dead load (G) value is calculated to be 0.86kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The weight of 1 truss is 23.5kg which consists of 2 top chords, 1 bottom chord and 8 web members similar to the tests 1,2,3,4 and 6. The sum of weight for both trusses is 47.0kg. The key variables in this test include cross braces between trusses, 12 ceiling battens, 20 roof battens, 1 ridge cap, no steel coil bracing above the ceiling batten. The main support frame of the assembly is the same as test 6 which is 1045mm. There are 166 HWH screws used on the trusses in which both trusses 1 and 2 have 83 screws each. Most of the screws are around Joints H, L and M for each truss. The test assembly is simply supported at the ends of the truss near the heel. Joint A of Truss 1 has 6 HWH screws and 4 HWH screws on the multi fix bracket which is the same on its opposite Joint R of Truss 2. This same arrangement occurs for Joint R of Truss 1 which has 6 HWH screws on the truss and 4 HWH screws through the multi fix bracket and Joint A of Truss 2 also has the same number of screws. The other joints of Truss 1 have the same number of HWH screws as its opposite joint on Truss 2. The weight sum of dead load on the assembly is 87.3kg which includes the weight of the ceiling battens, roof battens, different screws, ridge cap, cross bracing, multi fix brackets and the truss weights.

The size of the pallets used is the same as other 6 tests and the pallets each carried the weight of 29 boxes at the end of the test when the assembly experienced failure. There are 2 types of boxes used for this test; one box is 15.75kg and the other box is 14.6kg. Each pallet has 29 boxes weighing at 15.75kg and 8 boxes weighing at 14.6kg. There are 148 boxes on 1 pallet at the end of the test, so each pallet has 573.6kg of boxes and the weight of boxes on the 4 pallets is 2294.2kg. The weight sum of the 4 pallets and the weight of the boxes on the 4 pallets is 2364.6kg.

The live load calculations for Test 7 are shown in **Table *27*** and the Live Load-Deflection graph in **Figure 4-10**. The live loads are calculated using the sum of the weight of all the pallets and the number of boxes loaded on each pallet which is multiplied by the acceleration due to gravity and then converted to kiloNewtons (kN). The live load at failure for Test 7 is 23.20 kN which is calculated from the formula below:

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of the Test 7 is calculated using the formula:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 7 is 24.05kN. The deflection at the end of the test during failure is 21.00mm. The deflection has an average of 3mm for the first 3 loads and then 2mm and 4mm for the next 2 live loads during the application of the 15.75kg boxes. The assembly experienced a deflection of 1mm-2mm for the load applications of 14.6kg. The load application is the same as the other tests which are placed at the centre of the pallets and moves outwards towards the edge at every set of loading. While the loads are spread to cover the base of the pallet, they are also stacked above one another, and the pallets constantly sway with every set of loads applied. The left side of Truss 1 and right side of Truss 2 do not experience failure or bulging of the truss members. The roof battens closely placed together at around 400mm spacing instead of around 700mm spacing made a significant difference in the strength of the assembly however the setup of the truss assembly may be a factor in the failure as some of the test assembly parts need to be replaced. Due to this, Test 7 is not considered for the averages of the capacities in the behaviour of the roof truss assembly with 400mm roof batten spacings.

Table 26: Dead Load of Test 7

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	0.7
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	12	1.5
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	20	5.1
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Multi Fix Brackets		114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3

HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	166	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	120	1.7
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***87.3***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.86***

Table 27: Live Load of Test 7

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density (kg/m)	Density(kg/m^3)	weight (kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.76
	1200	800	0.75	960000	0.96	720000	0.00	1	-	7850	5.65
Total weight of 1 pallet(kg)											*17.6*
Total weight of 4 pallets(kg)											*70.4*

Box weight calculations	Number of boxes (18mm-19mm)	Number of boxes (16mm-16mm)	weight of 1 box (kg),18mm-19mm	weight of 1 box (kg),16mm-16mm	weight of 18mm-19mm boxes per pallet (kg)	weight of 16m-16mm boxes per pallet (kg)	weight [boxes x pallet] (kg)
Pallet 1	29	8	15.75	14.6	456.8	116.8	573.6
Pallet 2	29	8	15.75	14.6	456.8	116.8	573.6
Pallet 3	29	8	15.75	14.6	456.8	116.8	573.6
Pallet 4	29	8	15.75	14.6	456.8	116.8	573.6
Total Sum of Boxes Weight for 4 pallets							2294.2

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 2294.2kg + 70.4kg$$

$$= 2364.6kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

$$= \frac{2364.6\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 23.20kN}$$

Deflection per loading

Loading number	boxes per loading	box weight for each pallet (kg)	box weight for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0.00	0.00	1045	0
1	6	94.5	378	448.448	4.40	5.26	1042	0.003
2	6	94.5	378	826.448	8.11	8.96	1039	0.006
3	6	94.5	378	1204.448	11.82	12.67	1036	0.009
4	3	47.25	189	1393.448	13.67	14.53	1034	0.011
5	8	126	504	1897.448	18.61	19.47	1030	0.015
6	2	29.2	116.8	2014.248	19.76	20.62	1028	0.017
7	2	29.2	116.8	2131.048	20.91	21.76	1027	0.018
8	2	29.2	116.8	2247.848	22.05	22.91	1025.5	0.0195
9	2	29.2	116.8	2364.648	23.20	24.05	1024	0.021
Total of boxes per pallet	37							

Total Deflection (mm) = 21.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.86 + 23.20$$

$$Total\ Load\ (kN) = 24.05kN$$

Live Load (Q)	Deflection difference (m)
0.00	0
4.40	0.003
8.11	0.006
11.82	0.009
13.67	0.011
18.61	0.015
19.76	0.017
20.91	0.018
22.05	0.0195
23.20	0.021

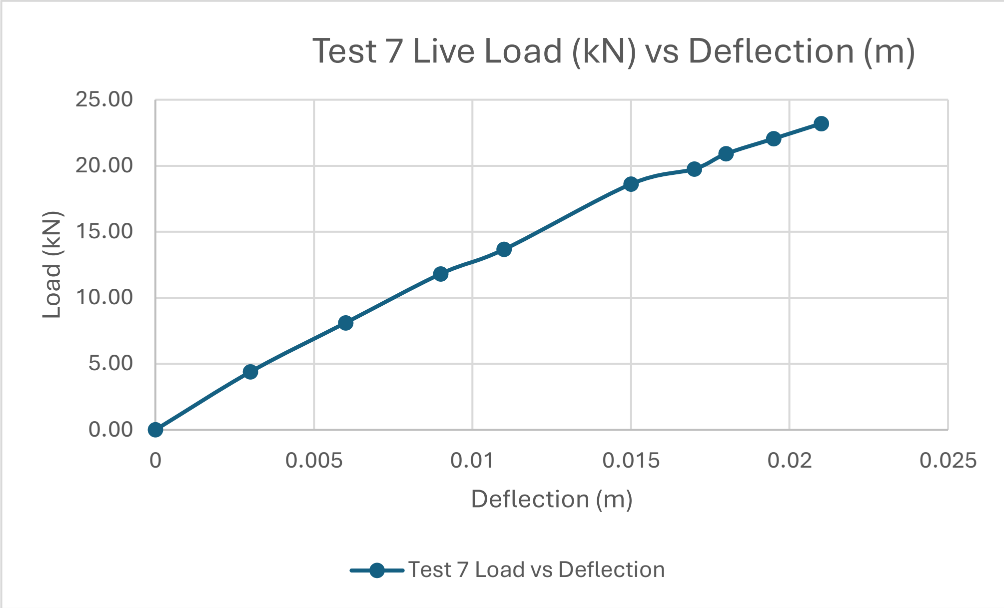


Figure 4-10: Test 7 Live Load (kN) vs Deflection (m) Graph

4.11 Test 8 Tabulated results and graph

The **Table 28** shows the dead load calculation of the truss assembly for Test 8 in which the Dead load (G) value is calculated to be 0.86kN using the dead load formula and then converting it to kilonewtons (kN). The dead load formula is below:

$$Dead\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/{}_{s^2}\right)}{1000N}$$

The arrangement of the test assembly for Test 8 is the same as Test 7. Each truss has 11 members of which the weight of 1 truss is 23.5kg and the weight of both trusses is 47.0kg. There are 12 ceiling battens, 20 roof battens, 1 ridge cap, no steel coil bracing above the ceiling battens, the steel cross bracings between the trusses, roof sheets and roof box sections above the roof sheets. The main support frame height is the same as tests 6 and 7 which is 1045mm. The truss is arranged following the linear truss system similar to tests 1,2,3,5,6 and 7. The number of HWH screws for both trusses is 166 which is the same as Test 7 and each truss has 83 screws. The dead load weight is 87.3kg which includes the trusses and the members that make up the truss test assembly. The key variable in this test is that the setup consists of using new multi fix brackets on the end supports, the roof box sections are removed and placed properly on the roof sheets. There are new screws used on the main support frame to connect it to the trusses.

The pallet dimensions are the same as all other series tests so 1 pallet is 17.6kg and the weight of 4 pallets is 70.6kg. There are 27 boxes weighing 15.75kg and 22 boxes weighing 14.6kg that is placed on each pallet in this test series by the end of the test. The weight of the 49 boxes on 1 pallet is 746.5kg and the weight of the 196 boxes on all 4 pallets is 2985.8kg. The weight sum of the 4 pallets and the 149 boxes is 3056.2kg.

The live load calculations in **Table 29** is calculated using the sum of the weight of all the pallets and the number of boxes loaded on each pallet which is multiplied by the acceleration due to gravity and then converted to kiloNewtons (kN). The live load at failure for Test 8 is 29.98kN which is calculated from the formula below:

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

The total load of the Test 8 is calculated using the formula:

$$Total\ Load\ (kN) = G + Q$$

Using the Dead load (G) and Live Load (Q) values calculated from the truss assembly test, the total load achieved for Test 8 is 30.84kN. The deflection at the end of the test during failure is 27.00mm and there is an average change in height of 2mm for the 15.75kg boxes and 1mm for the 14.6kg live loadings. The Live Load-Deflection graph is shown in **Figure 4-11**. The trusses braced by the roof battens and roof sheets provide a lateral restraint to the assembly which prevents the truss from moving sideways during the test. The fixing of the end supports with the multi fix bracket screwed onto the main support frame provide a restraint for the assembly.

The failure occurs around the same area as test 7, however, this test series is able to cater for more loadings until experiencing failure. The human factor of load application is a factor influencing the distribution of loads at every loading and the use of new multi fix brackets and screws on the main support frame, ensuring the roof box sections are placed properly and the truss test assembly setup for this series is also another factor which influences the strength of this test.

Table 28: Dead Load of Test 8

DEAD LOAD

Truss Members		Length (mm)	Width (mm)	Thickness (mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	Density of material (kg/m^3)	Surface Density (kg/m^2)	Linear Density (kg/m)	weight (kg)	No of items	weight for item on truss experiment(kg)
Top Chord	AH	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
	HR	3833	89	0.75	341137	0.34	255853	0.00	-	-	1.15	4.4	1	4.4
Web	BC	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
	DE	609	89	0.75	54201	0.05	40651	0.00	-	-	1.15	0.7	1	0.7
	FG	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	HI	1132	89	0.75	100748	0.10	75561	0.00	-	-	1.15	1.3	1	1.3
	JK	1672	89	0.75	148808	0.15	111606	0.00	-	-	1.15	1.9	1	1.9
	LM	407	89	0.75	36223	0.04	27167	0.00	-	-	1.15	0.0	1	0.0
	NO	597	89	0.75	53133	0.05	39850	0.00	-	-	1.15	0.7	1	1
	PQ	190	89	0.75	16910	0.02	12683	0.00	-	-	1.15	0.0	1	0.0
Bottom chord	AR	7074	89	0.75	629586	0.63	472190	0.00	-	-	1.15	8.1	1	8.1
									Weight Sum for 1 Truss Member					23.5
									Weight Sum for 2 Truss Members					47.0
Ceiling batten		600	65	0.4	39000	0.04	15600	0.00	7850	-	-	0.1	12	1.5
Roof batten		897	90	0.4	80730	0.08	32292	0.00	7850	-	-	0.3	20	5.1
Ridge cap		600	100	0.4	60000	0.06	24000	0.00	7850	-	-	0.2	1	0.2
Roof sheets		4000	800	0.55	3200000	3.20	1760000	0.00	-	2	-	6.4	2	12.8
Cross brace between Truss		897	90	0.4	80730	0.08	32292	0.000032	7850	-	-	0.3	2	0.5
Multi Fix Brackets		114	38	0.75	4332	0.00	3249	0.000003	7850	-	-	0.0	12	0.3

HWH Screws on Roof battens	18	19	-	342	0.00	-	-	-	-	-	0.01	48	0.5
HWH Screws on Ceiling battens	18	19	-	342	0.00	-	-	-	-	-	0.01	56	0.6
HWH Screws on Truss Joints	18	19	-	342	0.00	-	-	-	-	-	0.01	166	1.7
Roof Screws	65	-	-	-	-	-	-	-	-	-	0.01	120	1.7
Roof Box Section with web holes	796	90	0.75	71640	0.072	53730	0.00005	-	-	1.15	0.9	16	14.6
Roof Box Section Screws	-	-	-	-	-	-	-	-	-	-	0.01	96	1.0
		Weight Sum (Truss Members + Ceiling battens + Roof battens + Roof sheets + Roof Box Sections)											***87.3***
		Dead Load(G) = Weight Sum x Acceleration due to gravity (kN)											***0.86***

Table 29: Live Load of Test 8

LIVE LOAD

Pallet calculations	Length (mm)	Width (mm)	Thickness(mm)	Area (mm^2)	Area (m^2)	Volume (mm^3)	Volume (m^3)	No of items	Linear density (kg/m)	Density(kg/m^3)	weight (kg)
Pallet pieces	800	89	0.75	71200	0.07	53400	0.00	10	1.15	-	9.2
	1200	89	0.75	106800	0.11	80100	0.00	2	1.15	-	2.76
	1200	800	0.75	960000	0.96	720000	0.00	1	-	7850	5.65
Total weight of 1 pallet(kg)											*17.6*
Total weight of 4 pallets(kg)											*70.4*

Box weight calculations	Number of boxes (18mm-19mm)	Number of boxes (16mm-16mm)	weight of 1 box (kg),18mm-19mm	weight of 1 box (kg),16mm-16mm	weight of 18mm-19mm boxes per pallet (kg)	weight of 16mm-16mm boxes per pallet (kg)	weight [boxes x pallet] (kg)
Pallet 1	27	22	15.75	14.6	425.3	321.2	746.5
Pallet 2	27	22	15.75	14.6	425.3	321.2	746.5
Pallet 3	27	22	15.75	14.6	425.3	321.2	746.5
Pallet 4	27	22	15.75	14.6	425.3	321.2	746.5
Total Sum of Boxes Weight for 4 pallets							2985.8

$$Weight\ sum\ of\ 4\ pallets + boxes\ on\ 4\ pallets = 2985.8kg + 70.4kg$$

$$= 3056.2kg$$

$$Live\ Load\ (kN) = \frac{weight\ sum\ \times\ acceleration\ due\ to\ gravity\ \left(9.81\ {}^{m}/_{s^2}\right)}{1000N}$$

$$= \frac{3056.2\ \times 9.81}{1000}$$

$$\boldsymbol{Live\ Load\ (kN) = 29.98kN}$$

Deflection per loading

Loading number	boxes per loading	box weight for each pallet (kg)	box weight for 4 pallets (kg)	4 pallet weights + boxes (kg)	Live Load (Q)	Total Load (kN)	Deflection (mm)	Deflection difference (m)
0	0	0	0	0	0.00	0.00	1045	0
1	6	94.5	378	448.448	4.40	5.26	1043	0.002
2	6	94.5	378	826.448	8.11	8.96	1040	0.005
3	6	94.5	378	1204.448	11.82	12.67	1037	0.008
4	3	47.25	189	1393.448	13.67	14.53	1035	0.010
5	6	94.5	378	1771.448	17.38	18.23	1033	0.012
6	2	29.2	116.8	1888.248	18.52	19.38	1031	0.014
7	2	29.2	116.8	2005.048	19.67	20.53	1030	0.015
8	2	29.2	116.8	2121.848	20.82	21.67	1029	0.016
9	2	29.2	116.8	2238.648	21.96	22.82	1028	0.017
10	2	29.2	116.8	2355.448	23.11	23.96	1027	0.018
11	2	29.2	116.8	2472.248	24.25	25.11	1025	0.020
12	2	29.2	116.8	2589.048	25.40	26.25	1024	0.021
13	2	29.2	116.8	2705.848	26.54	27.40	1023	0.022
14	2	29.2	116.8	2822.648	27.69	28.55	1021	0.024
15	2	29.2	116.8	2939.448	28.84	29.69	1020	0.025
16	2	29.2	116.8	3056.248	29.98	30.84	1018	0.027
Total of boxes per pallet	49							

Total Deflection (mm) = 27.00mm

$$Total\ Load\ (kN) = G + Q$$

$$= 0.86 + 29.98$$

$$\boldsymbol{Total\ Load\ (kN) = 30.84kN}$$

Live Load (Q)	Deflection difference (m)
0.00	0
4.40	0.002
8.11	0.005
11.82	0.008
13.67	0.010
17.38	0.012
18.52	0.014
19.67	0.015
20.82	0.016
21.96	0.017
23.11	0.018
24.25	0.020
25.40	0.021
26.54	0.022
27.69	0.024
28.84	0.025
29.98	0.027

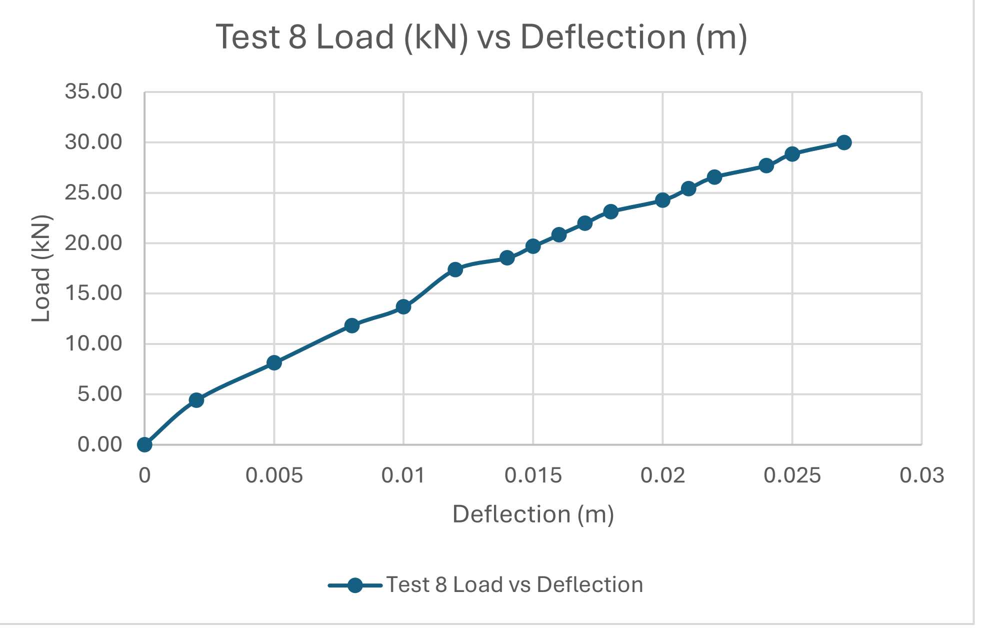


Figure 4-11: Test 8 Load (kN) vs Deflection (m) graph

4.12 Failure Mechanisms

4.12.1 800mm roof batten spacings Linear truss system

In the test 1 series, the truss assembly fails in 3 areas in which Truss 1 has 2 failure areas (**Figure 4-12**) and Truss 2 fails at 1 area particularly around the top chords of the trusses (**Figure 4-13:**). The web and flange member of the top chord for Truss 1 undergoes lateral torsional buckling when the member buckles and twists inwards towards Truss 2 near Joints D and F of Truss 1. The truss fails at the ridge Joint H, Joints L and Joint M of both Truss 1 and 2 along the web of these members as the member does not have top flange, top lip, only web and bottom flange and lip. At Joint L for Truss 1, the member buckles between the 2 columns of screw connections however the HWH screws are still fixed in place around these joints. The truss assembly does not collapse/fall despite failure points around Joints H, L, M of Trusses 1 and 2 and near Joints D and F of Truss 1 at the web of the member. The strength of the self-driven screw connection prevented the truss joints from separating at failure. The swaged sections with the bottom flange sitting underneath the top chord is able to carry the load applied however the lack of restraint at the ridge of the truss assembly caused the top chords to shift during failure.

The truss assembly experiences failure when the number of boxes for each pallet is 36 and at a live load of 22.94kN. The probable causes of failure for test 1 includes the human factor of load application, the point of load application and the exclusion of a ridge cap. The loading distribution and load timing of the test differs because it depends on how the load is applied. Since the loads are applied manually, the human factor affects the test. The loads are not all equally distributed during each load set which may cause a different weight to pull on each side of each pallet. The load is not applied at shear centre of C section but is applied on the flange of the members instead. The weight pull only causes lateral torsional buckling on the top chord member near the Joints D and F and causing the area to twist inward towards the centre of the truss. To further investigate for the strength of the trusses, the number of HWH screws need to be increased around ridge of Truss and a ridge cap may need to be included for lateral restraint. The number of HWH screws around Joints D and F also need to be increased to observe how the assembly will react.

Figure 4-12: Outward distortional and local buckling failure on Truss 1 of Test 1

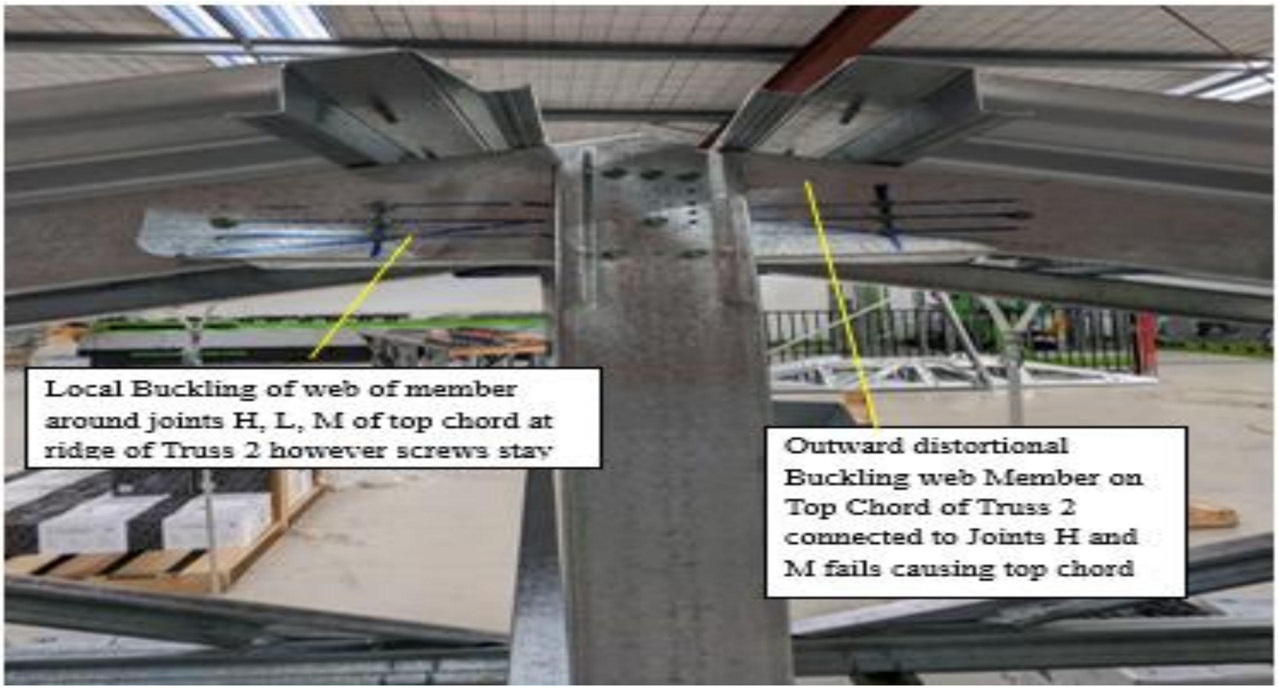


Figure 4-13: Outward distortional and local buckling failure on Truss 2 of Test 1

The failure areas around the test 2 series decreases by 22% than Test 1 and failure occurs when the number of boxes for each pallet is 28. The deflection at 28 boxes is 12mm however it was 11mm for the same number of boxes with Test 1. The failure in this test series only occurs on one side of the test assembly for both trusses. There is inward distortional buckling experienced on the same side of both trusses and around the same area of both trusses. The slenderness of the material together with its strength-weight ratio influenced the behaviour of the swaged C-sections which contributed to the failure experienced on the assembly and the strength of the self-driven screw connection prevented the truss joints from separating at failure. This failure is experienced along the top chords and on the compression flange near Joints D and F of Truss 1 (**Figure 4-14**) and Joints J and N of Truss 2 (**Figure 4-15**). For Truss 1, the bottom flange of top chord near joint F and D experiences out-of-plane buckling and Truss 2 experiences twist and buckle out of plane for bottom flange of top chord near joints J and N.

The load application and its position are the same for all tests. The probable causes of failure in this test are the human factor of load application, the inclusion of the ridge cap and the number of HWH screws used for truss joints near the failure areas. The assembly experiences failure at a live load of 18.00kN of which the human factor impacts the test as the number of people applying the loads are doubled from the first test. The distribution of load and sway of pallets increases at a faster rate than Test 1 and the loads are not applied at the same time. The inclusion of the ridge cap above the ridge points of both trusses played a significant role in improving the behaviour of the joints around the ridge area. The loads are not applied at shear centre of the C-sections and the rate of loading causes an increased gravity to pull from roof battens due to the applied loads push down on the compression flanges. In comparison with Test 1, the ridge area of the trusses does not fail due to the inclusion of the ridge cap and the increased HWH screws around the H, L, M joints of the trusses. An area of improvement that can be considered for future tests is to increase the number of screw connections near the failure joints.

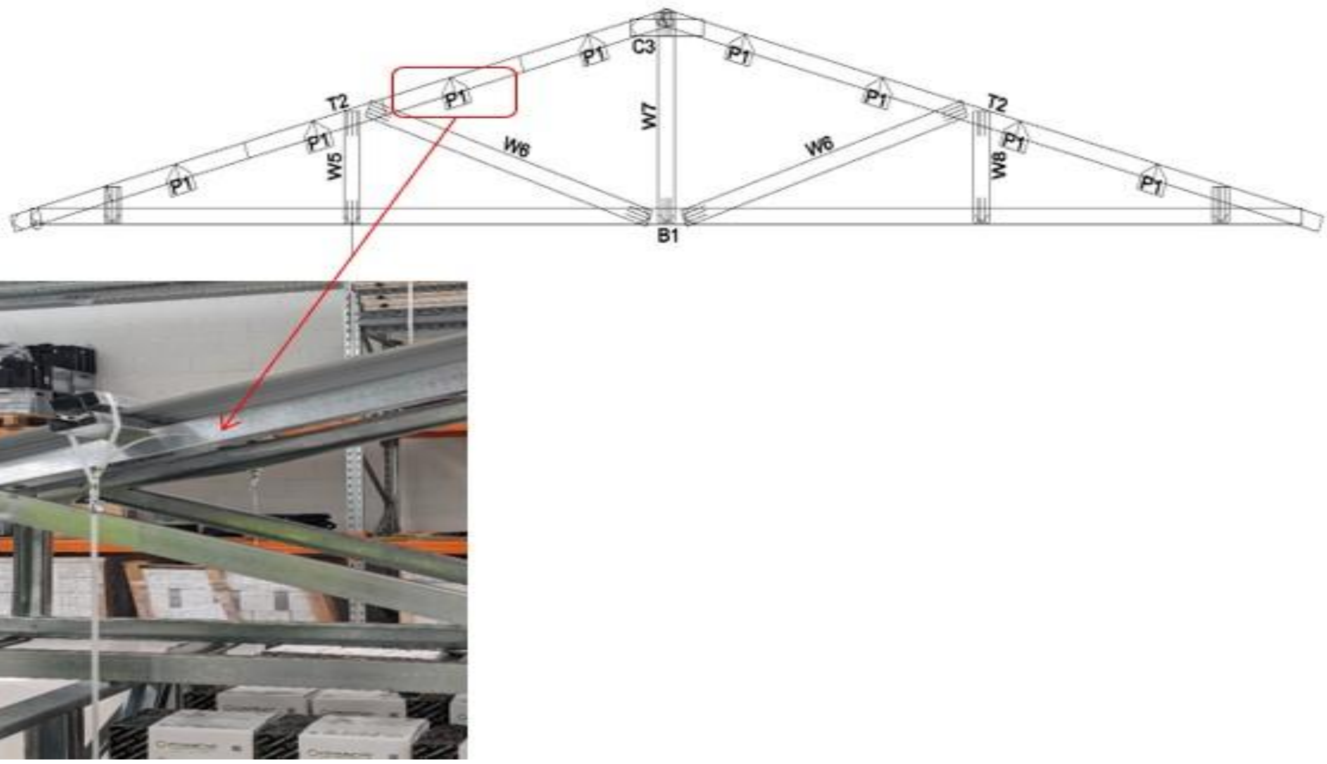


Figure 4-14: Failure on Truss 1 of Test 2

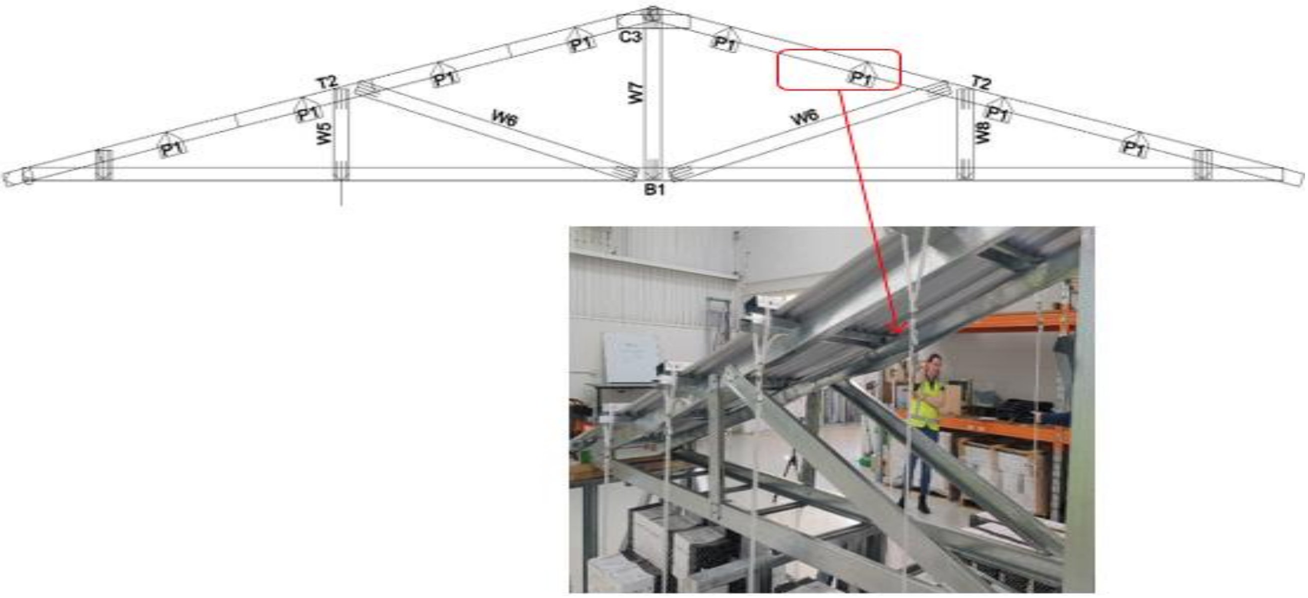
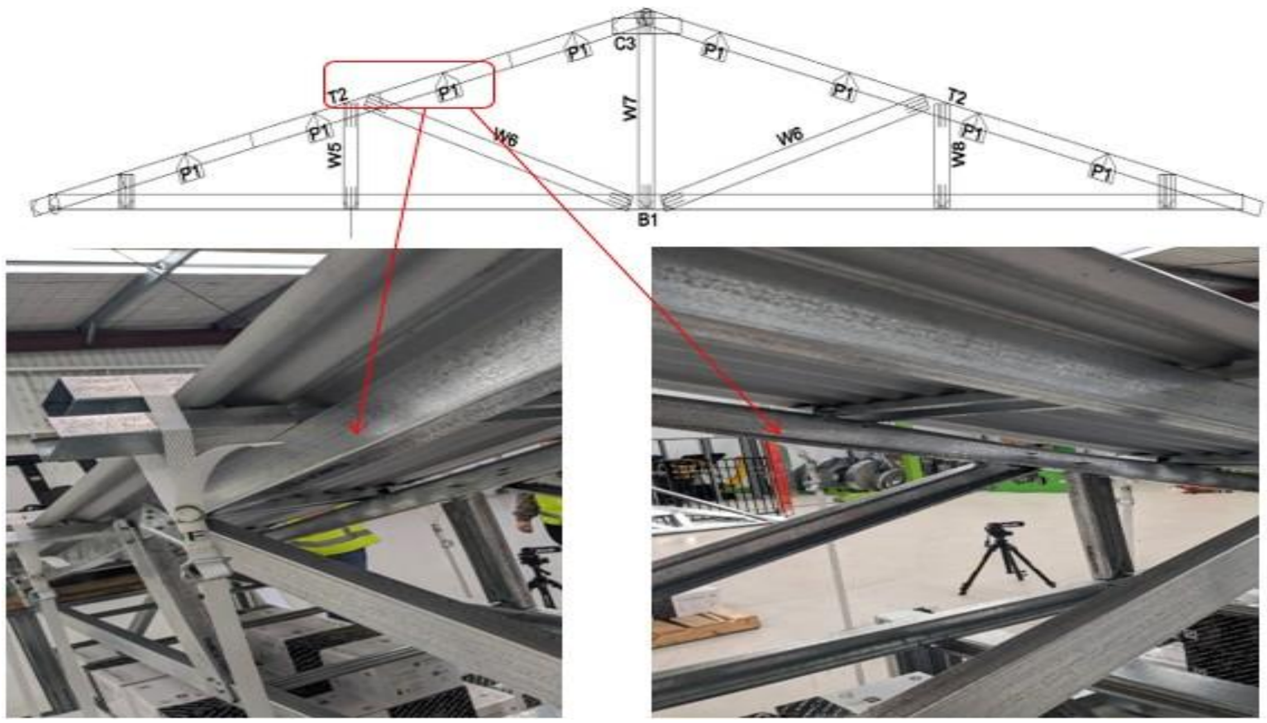


Figure 4-15: Failure on Truss 2 of Test 2

Figure 4-16: Inward distortional buckling and local buckling failures on Truss Assembly of Test 2

In test 3, the assembly fails at the top chord member near Truss 1 in which lateral torsional buckling occurs (**Figure 4-17**). The truss assembly experiences failure when the number of boxes for each pallet is 32. The bottom flange of the top chord twists and buckles downwards towards the centre of the truss assembly near the joints D and F of Truss 1. The failure area is similar to the failure area experienced in the test 1 series around the same joints on Truss 1 and the test assembly setup is the same as Test 2 however, the number of HWH screws used for the trusses is more than Tests 1 and 2.

The failure area is similar to Tests 1 and 2 but the mechanism of failure is different for all 3 tests. The possible cause of failure is from the decreased number of people applying the loads which causes a slower spread of stress on the loading areas and consequently, on the truss assembly. The weight pulls on the loading stresses around the top flange since the loads are not placed at the shear centre. To observe a change in the next test series, the number of HWH screws specifically around Joints D and F of Truss 1 and the opposite joints of J and N on Truss 2 may need to be increased. The spacing between the lateral restraints of roof battens may need to be decreased to observe how it can affect the truss assembly. The loads of the assembly are applied away from the shear centre of the C-section which can create a twist in the member leading to torsional deformation. The roof battens being placed on the compression flange of the C-section members of the top chords of the truss assembly act as lateral restraints which prevents rotation and twists along the members. So far, the restraints are preventing the full member failure at its current 800mm spacing but reducing these spacings further by adding more restraints can eventually reduce the lengths of twists and deformations experienced on the truss assembly.



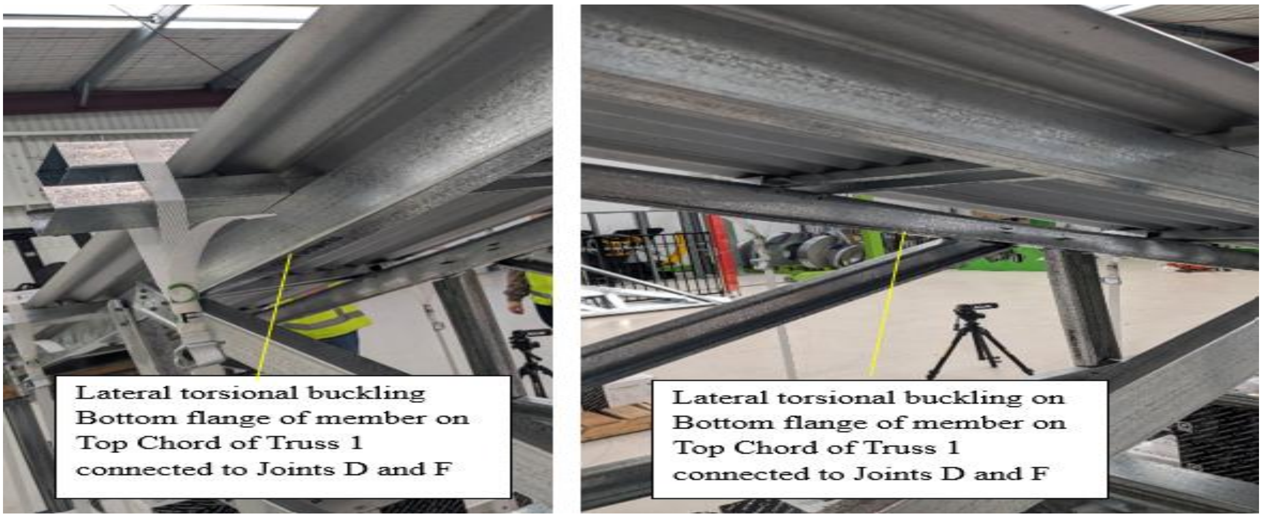


Figure 4-17: Lateral torsional buckling failure on Truss Assembly of Test 3

4.12.2 800mm roof batten spacings Back-to-back truss system

The 4^{th} test series, follows the back-to-back truss system and the assembly experiences complete failure when there are 36 boxes on each pallet. The failure is experienced on one side of the assembly which is different from the 3 tests previously conducted. The truss collapsed on the right side of Truss 1 (**Figure 4-18**) and left side of Truss 2 (**Figure 4-19**). The top chord twists inwards and downwards simultaneously along the same side of the truss assembly and the pallets fall to ground floor during failure.

The possible cause of failure for this test is the setup of the assembly. The failures occur on the top chords, loads are not applied at the shear centre, which is the same as the previous tests, however the back-to-back web member assembly on the truss causes a very different failure to be experienced on the truss assembly. The back-to-back system connection does not help with stiffening near the joints and is not as rigid. From observation, the face of the web members connecting to the top and bottom chords do not add any support on the top chord when the gravity load is pulled on the compression flanges of the top chords. In the linear truss system, the face of the web members connecting inward on the truss is able to distribute the loads applied on the assembly. The other possible cause of failure is the number of HWH screws on the joints of the truss. The number of screws per joint is meeting the minimum requirement of 3, however, these may need to be increased for the next test series.

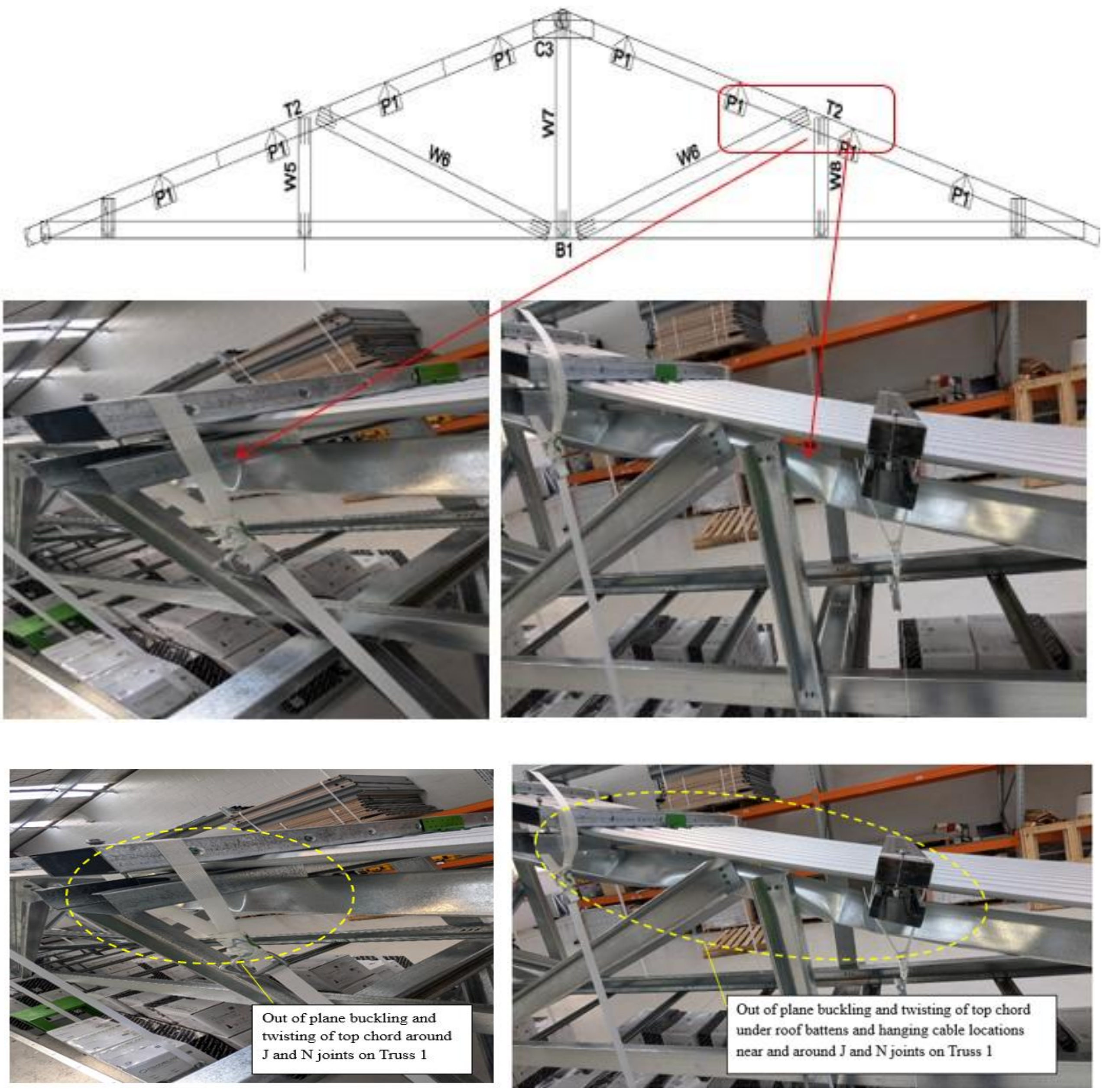


Figure 4-18: Out-of-plane buckling failure on Truss 1 of Test 4

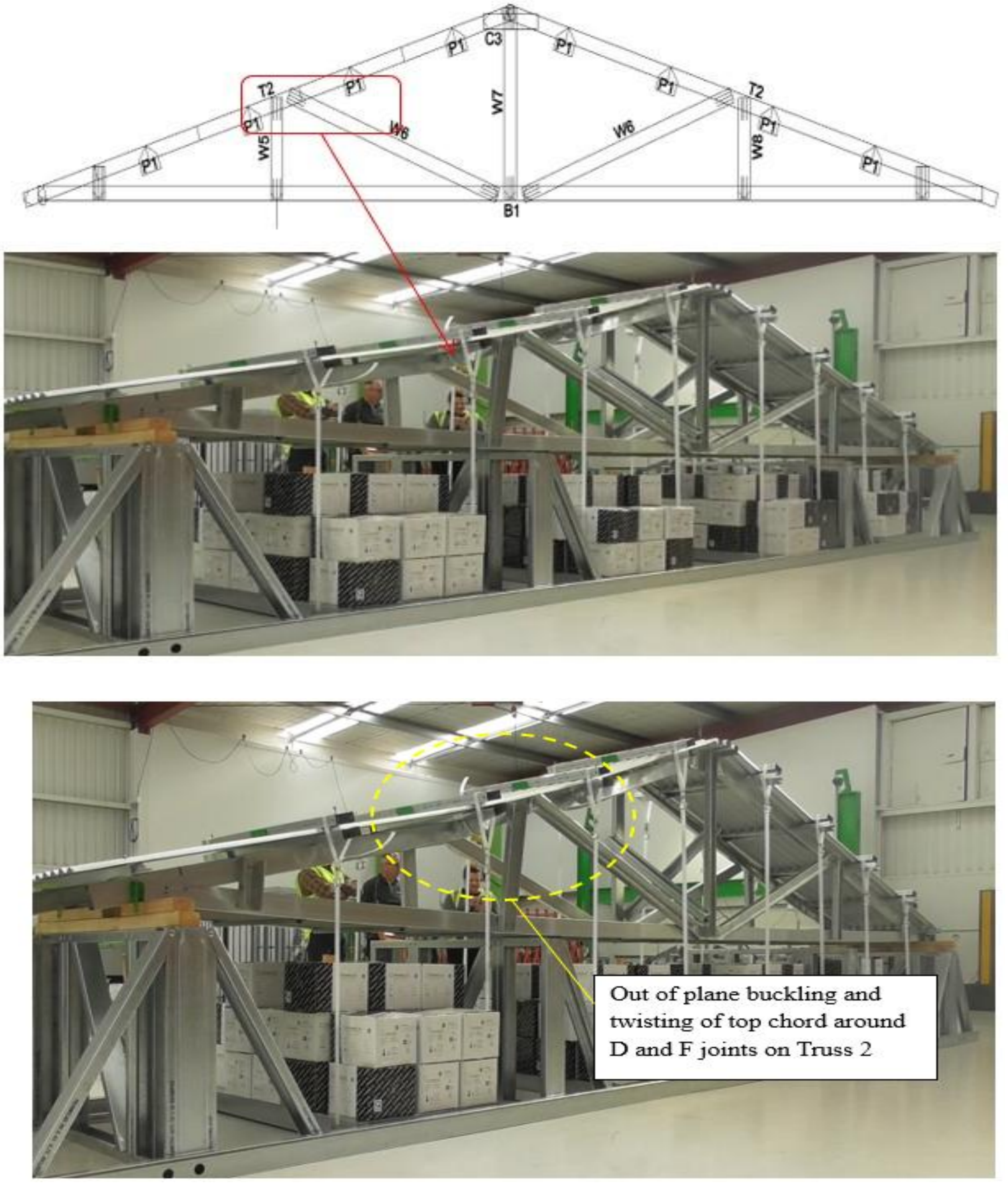


Figure 4-19: Out-of-plane buckling failure on Truss 2 of Test 4

4.12.3 800mm roof batten spacing Linear truss system with Internal support

The test 5 series is simply supported at the ends which is similar to other tests, however, test 5 includes an internal support which is underneath Joint O of Truss 1 and Joint E of Truss 2. Due to this internal support, the dead load is also increased and different from other tests because of an additional

CFS piece at the internal support area. There is no member failure on this test, however, the 1 of the pallets hit the ground floor at the 13th loading. The internal pallet next to the Joints E of Truss 1 and Joint O of Truss 2 touches the ground between the 12th and 13th loading at 37 boxes so loads were no longer applied on this pallet. The pallet next to the internal support at Joint O of Truss 1 and Joint E of Truss 2 touches the ground at 39 boxes, however, the pallets closest to both end supports did not touch ground and loads were still applied until the pallet neat Joint A of Truss 1 and Joint R of Truss 2 reached 47 boxes and the pallet near Joint R of Truss 1 and Joint A of Truss 2 reached 53 boxes of loading. Test 5 was eventually discontinued when the pallets went aground.

The possible cause of the end result experienced in this test can be linked to the internal support. There are extra HWH screws around joints and inclusions of multi fix brackets at the internal support which provided restraints for the truss members. While extra HWH screws are evident of providing additional restraints, the lateral restraints may need to be placed closer to observe if it has an impact on the truss behaviours.

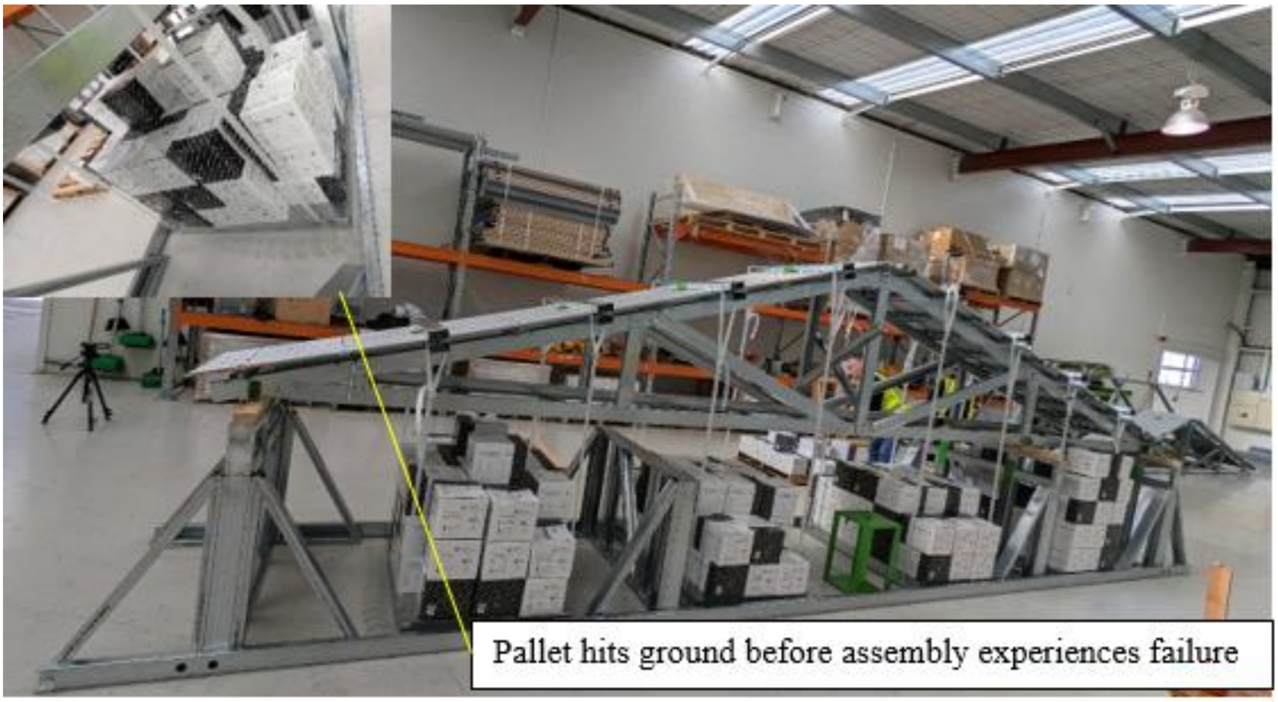


Figure 4-20: Pallet on ground at the end of Test 5

4.12.4 400mm roof batten spacing Linear truss system

In test 6 series, there is no member failure experienced on the truss assembly. The lateral restraint on this test assembly is different from tests 1 - 5 as the number of roof battens is increased, and the number of ceiling battens is decreased. The load application and location of load application is the same as other tests. For this test, 1 of the pallets hit the ground at 46 boxes of loading. The pallet which is between Joints K, O of Truss 1 and Joints E, G of Truss 2 fully hits the ground as the boxes are applied while other pallets on the truss assembly are still hanging.

The possible cause of no failure experienced during this test can be due to the load application where the manual application at various times causes the varying gravity to pull on the compression flanges. The gravity pull exists on the load and the polywoven elastic cable stretches until the pallet hits the floor. The increase in number of HWH screws where Truss 1 has more screws than Truss 2 can also be an additional factor. The decrease in spacing of the roof battens and the increased spacing of ceiling battens may also be an additional factor which prevents failure in the test series.

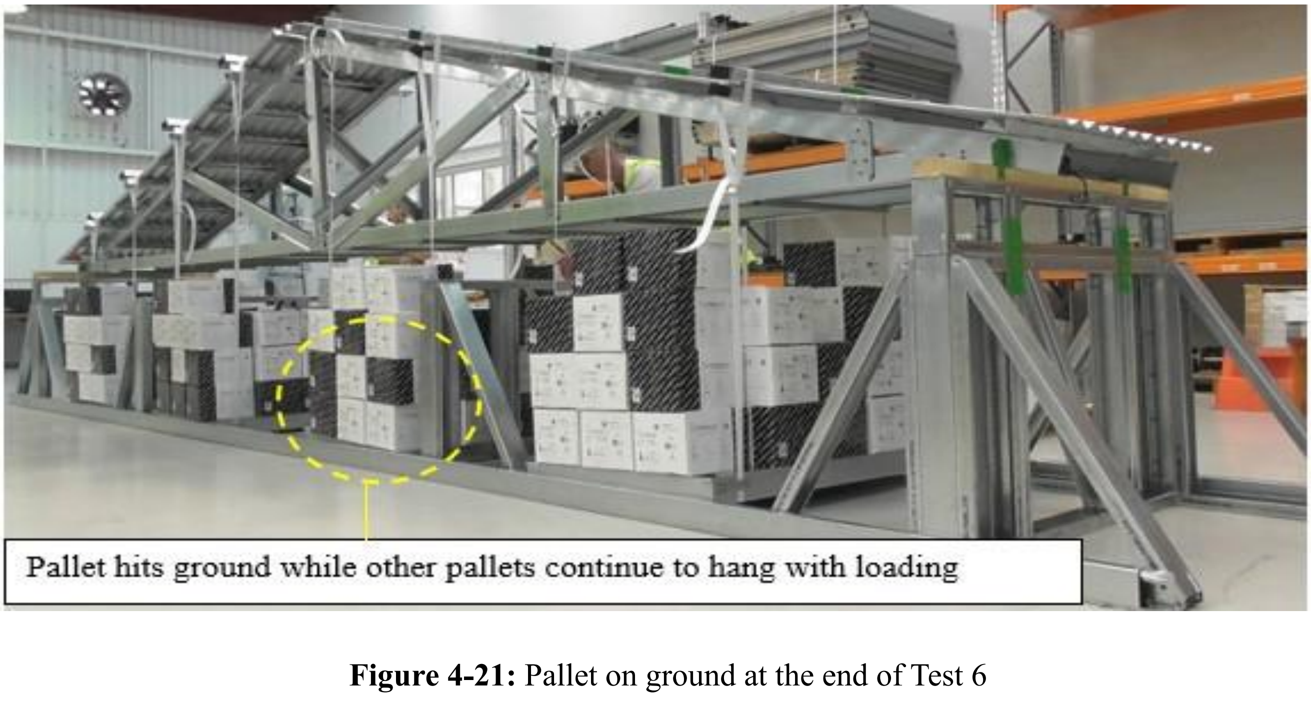
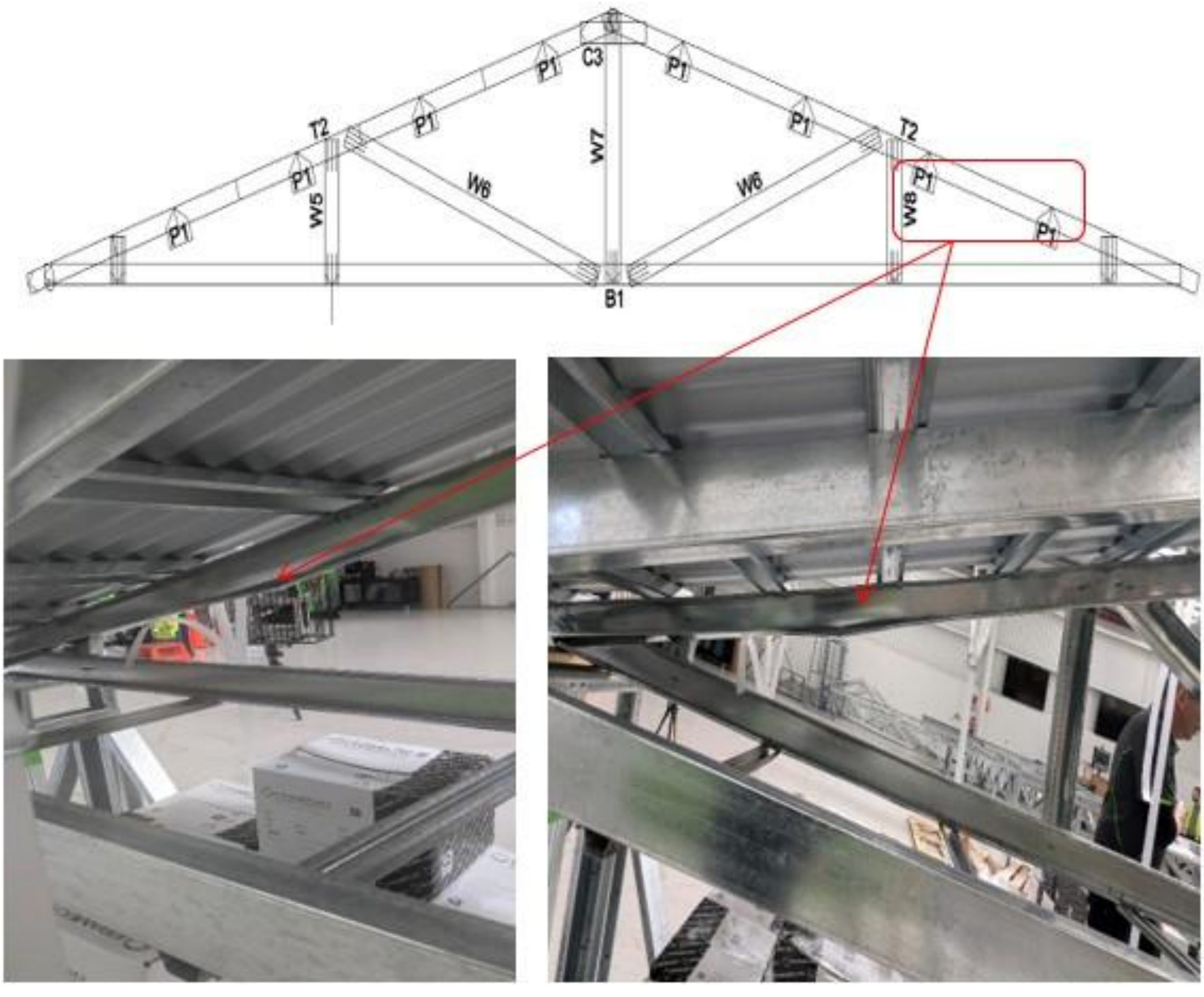


Figure 4-21: Pallet on ground at the end of Test 6

The test 7 series experiences failure when the number of boxes for each pallet is 37 and the area of failure is different from all tests previously conducted. The setup is the same as Test 6 in which the spacing of the lateral restraints on the top chords of the assembly is closer than the previous tests 1, 2, 3, 4 and 5. The truss fails near Joint P of Truss 1 where the bottom flange of the top chord member buckles downwards and out of plane. The number of HWH screws on the truss assembly is the same, however, both trusses have the same number of screws in comparison to test 6.

The test assembly setup may be the possible cause of failure in this test as the parts of the assembly may need to be replaced and installed properly. The end support brackets, and different screws need to be replaced and installed properly. The roof box sections need to be placed perpendicular across the roof sheets, so it does not move out of plane during loading. The polywoven strap cables need to be replaced with new due to wear and tear on previous cables used. The next test series can be improved by using new parts on the assembly while maintaining the same number of screws as Test 7 to compare the behaviour.



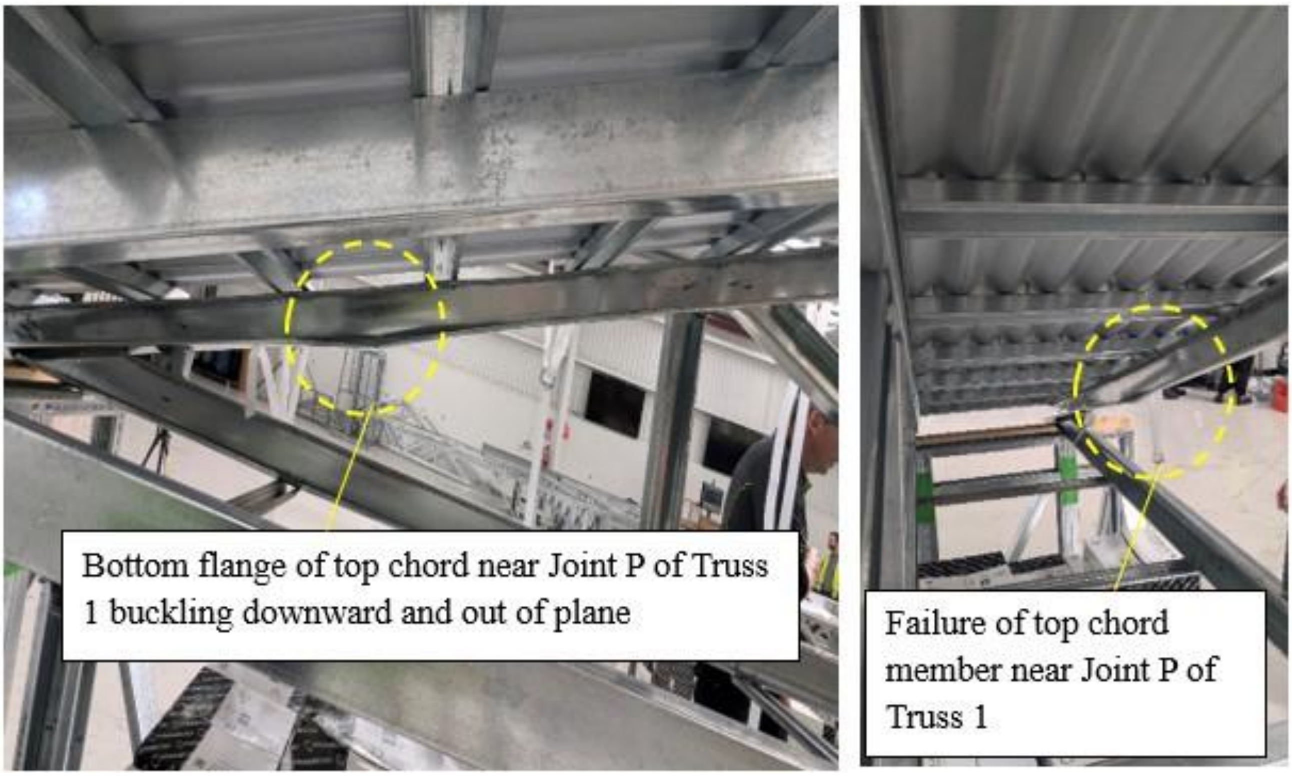


Figure 4-22: Distortional buckling failure on Truss 1 of Test 7

The setup of test 8 is the repetition of Test 7 in which the number of HWH screws on each joint of each truss in the test assembly is the same. The lateral restrains on the top chord members is the same as Tests 6 and 7 which has 20 roof battens. The truss assembly of test 8 series experiences failure when the number of boxes for each pallet is 49. The truss fails near Joint P of Truss 1 where the bottom flange of the top chord member buckles downwards and out of plane.

The possible cause of failure can be due to the loading distribution and different load timing of the test because it depends on how the load is applied. Since the loads are applied manually, the human factor affects the test. The loads are not all equally distributed during each load which may cause a different weight to pull on each side of each pallet. There are new parts used for this test assembly which is due to the observation made at the end of test 7. The positions of the multi fix brackets, the roof box sections placement, the truss assembly setup may have helped increase the live load at the end of the tests.

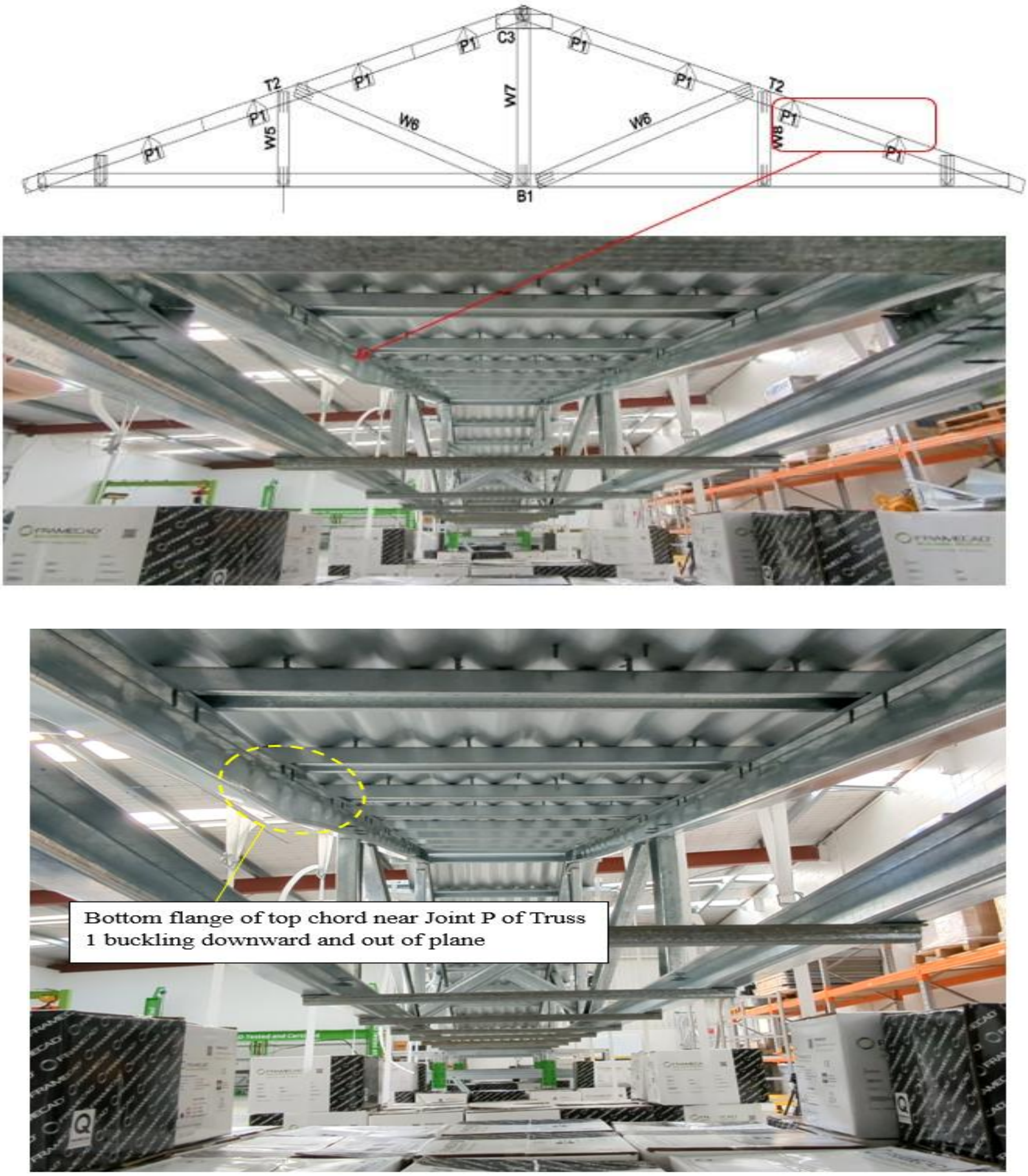


Figure 4-23: Distortional buckling failure on Truss 1 of Test 8

4.12.5 Swaged flange notched members

The swaged cut on the ends of web members (**Figure 4-24**) did not fail or cause any form of failure on the truss assembly. Despite the reduced length and strength of properties of the swaged web members, the experimental trusses only failed along the top chords by twisting and buckling inwards. The load application on the truss assembly ceased shortly after failing of the top chords and before any failure and before any failure was experienced on the swaged web members. From these experimental tests, it can be observed that the swaged web members performed its role by preventing the full collapse of the truss assembly.

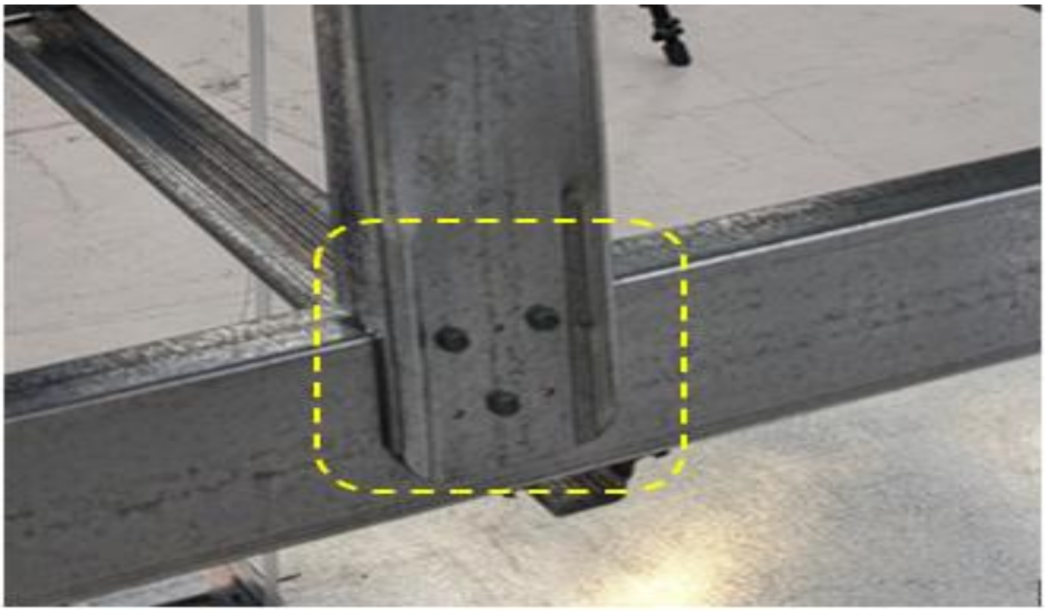


Figure 4-24: Swaged web member connected to chord member

Chapter 5 Comparison of Design, Predicted and Experimental Capacity of Truss

5.1 Introductory remarks

This chapter summarizes the unfactored design capacity and the unfactored predicted capacity of the Howe truss assemblies with roof battens at spacings of 800mm and 400mm. It also compares the design capacities, predicted capacities and actual capacities of the trusses. The design capacity shows the truss at a safe calculation of 100%, the predicted capacities show the truss at an expected failure of 120% and these are compared with the results from the experimental study. The comparison of the 3 different capacities should show how close the experimental results will be to the predicted capacity and the design results considering the realistic conditions included in the experiments. In the linear truss system arrangement of 800mm roof battens spacings the total load at failure during the experimental loading is 12% higher than the total load of the factored predicted capacity and 34% higher than the factored design capacity total load. When the lateral restraints of the same assembly arrangement are reduced to 400mm spacings, the total load at failure during the experimental loading is 34% higher than the total load of the factored predicted capacity and 60% higher than the factored design capacity total load.

The key difference between the design and predicted capacity is the design yield strength used. The design capacity uses the design yield strength value of 495MPa in accordance with AS standards. The predicted capacity uses the tensile strength and yield strength of 600MPa which is from the tensile coupon test results of the CFS material used in this study. The predicted capacity is expected to be closer to the experimental than the design capacity due to the use of the CFS material yield strength. The other expected outcome is the location of the failure area in the experiment being the same as the predicted capacity. The generation of failure in the predicted capacity is calculated using the compression and bending check to give the predicted truss failure capacity ratio of 120%. The compression and bending check sum are calculated from the following formula: $Compression + Bending$

$$\left(0.75 \times \frac{1}{0.85}\right) + \left(0.25 \times \frac{1.11}{0.9}\right) = 1.2\ \times 100\ = 120\%$$

The increase in yield strength from 495MPa in the design capacity to 600MPa in the predicted capacity showed that the member changed in bending strength while the compression remained the same. The bending strength changed from 1202Nm to 1335Nm which is an increase by 1.11. In a member, 75% is acting in compression and 25% is acting in bending. The capacity reduction factor for compression is 0.85 and the capacity reduction factor for bending is 0.9. The tension, compression and bending members of the sections for the design and predicted capacities of both the 400mm and 800mm roof batten spacing are calculated using the formulas in accordance with AS4600[9]. In the predicted capacities using the 600MPa tensile and yield strength, the values are reduced accordingly to 495MPa for the designs in accordance with the AS standards.

In the design, a 2D plane frame is used to analyse the truss frames of which the chords are modelled as continuous members, and the chord-chord connections are modelled as pin connections. The web members are modelled as pin-ended members which connect to the chords along the centreline of each member. Hence, any irregularity of the web member is specifically modelled. The axial load is not carried across the joints when a member completely crosses another and has flange cuts on both sides, as this is modelled as an axial release. The chord members are designed in accordance with the standards for moment, axial and shear forces derived from the plane frame analysis. The member effective lengths are calculated to account for torsion effects due to load application or support offsets in accordance with the standards. It is common practice to use an effective length factor of 0.85 and for narrow batten spacing or direct fix sheathing, this can be lowered to 0.75 [40].

The principle demonstrates that failure consists of a combination of compression and bending and this is based on the functions of the effective lengths (l_{ex} , l_{ey} and l_{ez}) which are critical parts of analysing buckling. The l_{ex} is for buckling in-plane, l_{ey} for buckling out-of-plane and l_{ez} is for twisting along the lengths. The web members provide restraints that prevent the system from moving upwards or downwards and from twisting. The roof battens provide a restraint that prevent the system from moving sideways. During the tests, it is identified that the increase in number of battens provide increased restraints which prevent the system from failing completely. The current standards however do not account for these increased lengths, and these can be further investigated through FEM modelling as the results in this study are not enough do not show the provisions of these. The design results for this study are shown in the **APPENDIX** and the formulas used for the designs is listed below:

Tension Capacity

Tension Section Capacity: $N^* \leq \emptyset_t N_t$

Tensile capacity of member for yield in gross section: $N_t = A_g f_y$

Tensile capacity of member for rupture in net section: $N_t = 0.85 k_t A_n f_u$

Capacity reduction factor: $\emptyset_t = 0.90$

Correction factor : k_t

Gross area of the cross-section: A_g

Net area of the cross-section: A_n

Yield stress in design: f_y

Tensile stress in design: f_u

Shear Capacity

Shear Section Capacity: $V^* \leq \emptyset V_v$

For $\frac{d_l}{t_w} \leq \sqrt{\frac{Ek_v}{f_y}}$: $V_V = 0.64 f_y d_l t_w$

For $\sqrt{\frac{Ek_v}{f_y}} \leq \frac{d_l}{t_w} \leq 1.415\sqrt{\frac{Ek_v}{f_y}}$: $V_V = 0.64 t_w^2 \sqrt{Ek_v f_y}$

For $\frac{d_l}{t_w} > 1.415\sqrt{\frac{Ek_v}{f_y}}$: $V_V = \frac{0.905Ek_v t_w^3}{d_1}$

Shear buckling coefficient : $k_v = 5.34$

Capacity reduction factor: $\emptyset_v = 0.90$

Depth of web element : d_l

Thickness of web element : t_w

<u>Compression Capacity</u>

Compression Section Capacity : $N^* \leq \emptyset_c N_s$

Capacity reduction factor: $\emptyset_c = 0.85$

$N_s = A_e f_y$

Effective area at yield stress : A_e

Compression Member Capacity : $N^* = \emptyset_c N_c$

$N_c = A_e f_n$

Effective area at critical stress : A_e

Critical stress : f_n

For $\lambda_c \leq 1.5$: $f_n = \left(0.685\lambda_c{}^2\right)f_y$

For $\lambda_c > 1.5$: $f_n = \left(\frac{0.877}{\lambda_c^2}\right)f_y$

Slenderness factor : $\lambda_c = \sqrt{\frac{f_y}{f_{oc}}}$

$$f_{oc} = \frac{1}{2\beta}\left[(f_{ox} + f_{oz}) - \sqrt{(f_{ox} + f_{oz})^2 - 4\beta f_{ox} f_{oz}}\right]$$

$$\beta = 1 - \left(\frac{x_o}{r_o}\right)^2$$

$$f_{ox} = \frac{\pi^2 E}{\left(\frac{l_{ex}}{r_x}\right)^2}$$

$$f_{oy} = \frac{\pi^2 E}{\left(\frac{l_{ey}}{r_y}\right)^2}$$

$$f_{oz} = \frac{GJ}{A_g r_{ol}^2}\left(1 + \frac{\pi^2 E I_w}{GJ l_{ez}^2}\right)$$

Distance from shear to centroid : x_o

Polar radius of gyration : r_o

Radius of gyration : $r_{x,y}$

Buckling length : $l_{x,y}$

Shear modulus : G

Torsion constant : J

Warping constant : I_w

<u>Bending Capacity</u>

Bending section capacity : $M^* = \emptyset_b M_s$

Capacity reduction factor for member bending capacity: $\emptyset_b = 0.90$

Capacity reduction factor for section bending capacity: $\emptyset_b = 0.95$

$M_s = Z_e f_y$

Effective section modulus calculated at f_y : Z_e

Bending member capacity : $M^* = \emptyset_b M_b$

$M_b = Z_c f_c$

Effective section modulus calculated at f_c : Z_c

Critical buckling stress : $f_c = \frac{M_c}{Z_f}$

For $\lambda_b \leq 0.60$: $M_c = M_y$

For $0.60 < \lambda_b < 1.336$: $M_c = 1.11 M_y \left[1 - \left(\frac{10\lambda_b^2}{36}\right)\right]$

For $\lambda_b \geq 1.336$: $M_c = M_y \left(\frac{1}{\lambda_b^2}\right)$

Slenderness ration : $\lambda_b = \sqrt{\frac{M_y}{M_o}}$

Moment causing initial yield : $M_y = Z_f f_y$

Elastic buckling stress : $M_o = C_b A_g r_{ol} \sqrt{f_{oy} f_{oz}}$

Bending coefficient : $C_b = 1$

5.2 *Design Capacity of Truss for 800mm roof battens spacings*

The truss design is calculated using the FrameCAD Structure software and following the Australian Design standards AS/NZS4600:2018[9]. The design calculations are completed for both truss assemblies with roof battens at respective 400mm and 800mm spacings. The design and predicted capacities of the truss with 800mm roof batten spacings uses the effective length factor values of $k_x = 0.85$, $k_y = 1.0$ and torsional length factor, $k_t = 0.85$.The design yield stress (f_y) and design tensile strength (f_u) is 495MPa in accordance with the G550 steel grade thickness in AS/NZS4600:2018 [9] and the design properties and capacities of the 495MPa strength is shown in **Table 30** below. The bending strength of the 495MPa C-section is 1202Nm and the compressive strength is 16.66kN.

Table 30: Properties and Capacities of 495MPa Yield Stress Design C-Section

Properties

Property	Value
Feed Width	186.9mm
Gross Area	140.2mm²
Gross Weight	1.155kg/m
Centroid Left	13.02mm
Centroid Top	44.13mm
Second Moment Ixx	179439mm⁴
Second Moment Iyy	33353mm⁴
Radius of Gyration rx	35.78mm
Radius of Gyration ry	15.42mm
Shear Centre X	32.82mm
Shear Centre Y	0.000mm
Polar Radius ro1	51.1mm
Torsion Constant J	26.29mm⁴
Warping Constant Iw	58849980mm⁶
Modulus Zx	4032mm³
Modulus Zy	1208mm³
Gross Area (Simple)	143.3mm²
Second Moment Ixx (Simple)	185497mm⁴
Second Moment Iyy (Simple)	34793mm⁴

Capacities

Property	Value
Shear Capacity Vv	4.395kN
Tension Capacity Nt	42.23kN
Compression Capacity Ns	29.36kN
Compression Capacity Nc	16.66kN
Bending Capacity Ms-	1380N.m
Bending Capacity Mb-	1202N.m
Bending Capacity Ms+	1380N.m
Bending Capacity Mb+	1202N.m
Bearing Capacity Rbe	1.877kN
Bearing Capacity Rbi	3.481kN
Effective Area Ae	102.0mm²
Effective Modulus Zx-	3083mm⁴
Effective Modulus Zx+	3083mm⁴
Euler Buckling Load Pe	252.7kN

In accordance with NASH AS2010 and using the Total Load formula: $Total\ Load\ (kN) = 1.2G + 1.5Q$, total design load of the truss with 800mm roof battens spacings is 8.36kN, the design dead load is 0.68kN and the design live load is 7.68kN which achieves the most optimised capacity of 100%. The design dead load (G) without any safety factor is 0.56kN and the live load (Q) without any safety factor is 5.12kN. The total design load of without any safety factor (G + Q) is 5.68kN. The 800mm roof batten spacing is applied along the top chords of the design truss where the point loads are located in the load diagram. The **Figure 5-1** below shows the load diagram of the design.

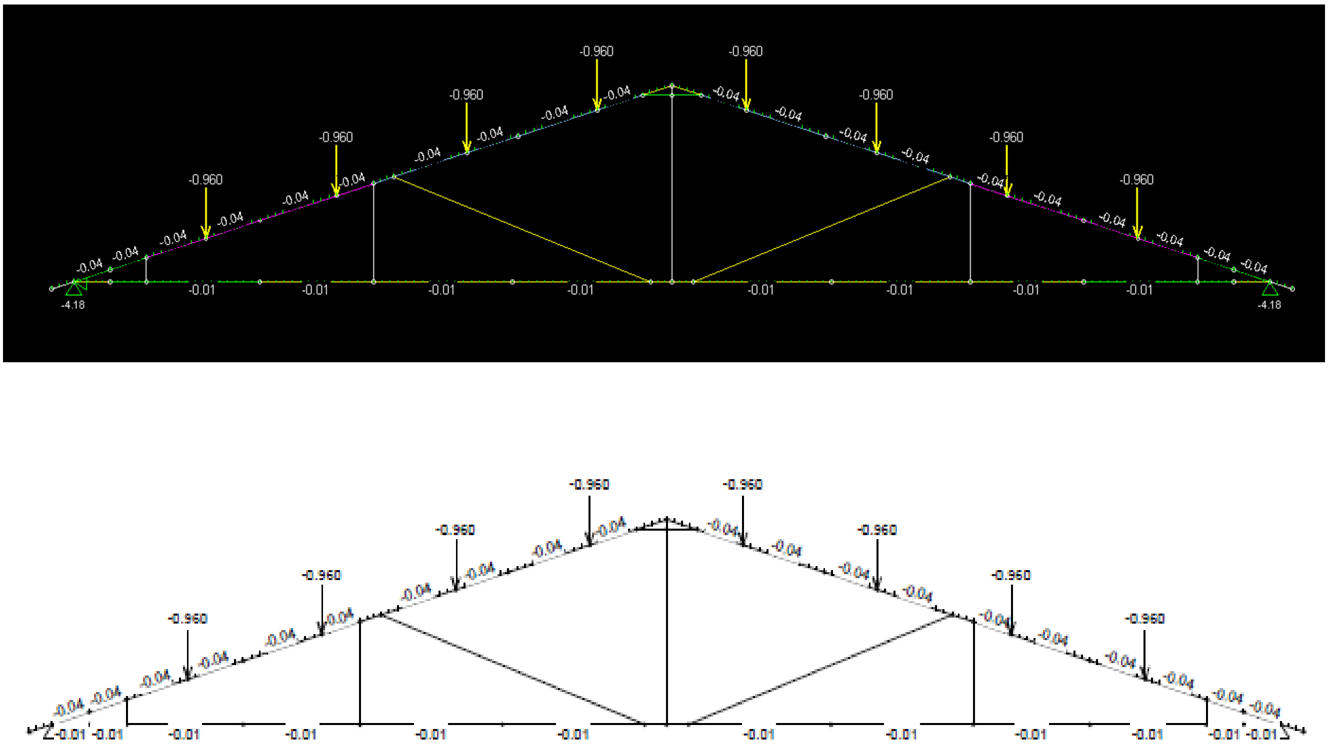
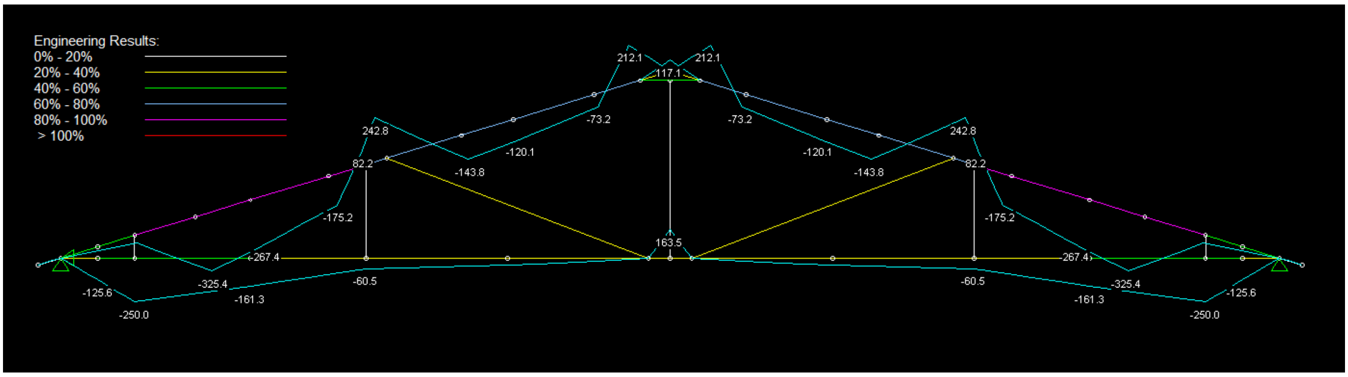


Figure 5-1: Load diagram of Truss Design Capacity with roof battens at 800mm spacing

The design truss shows that the member between Joint B and Joint D and Joint N and Joint P (purple lines in bending diagram shown on **Figure 5-2**) of the top chord is the area that will most likely fail first. The maximum bending moment of the design truss for roof batten spacings of 800mm is 242.8Nm which is calculated from the results using AS4600 [9] in the FrameCAD Structure software.



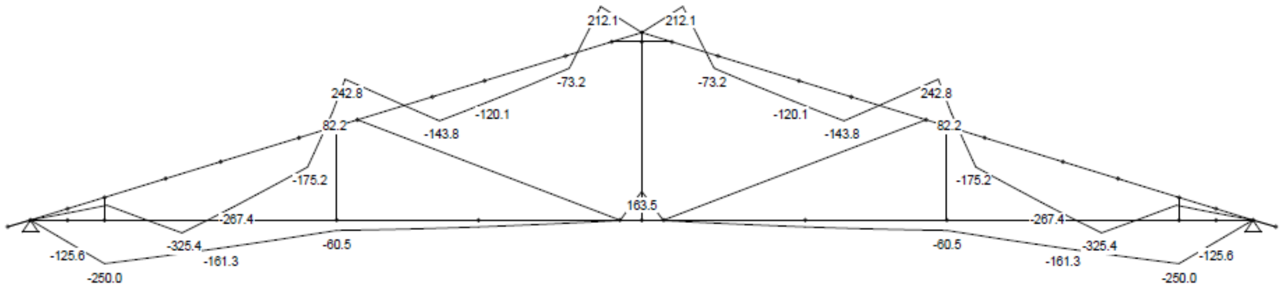


Figure 5-2: Bending diagram of Truss Design Capacity with roof battens at 800mm spacing

The maximum shear of the design truss for roof batten spacings of 800mm is 1.17kN which is calculated from the results using AS4600 [9] in the FrameCAD Structure software. The shear diagram of the design truss with roof battens placed at 800mm spacings is shown below in **Figure 5-3**.

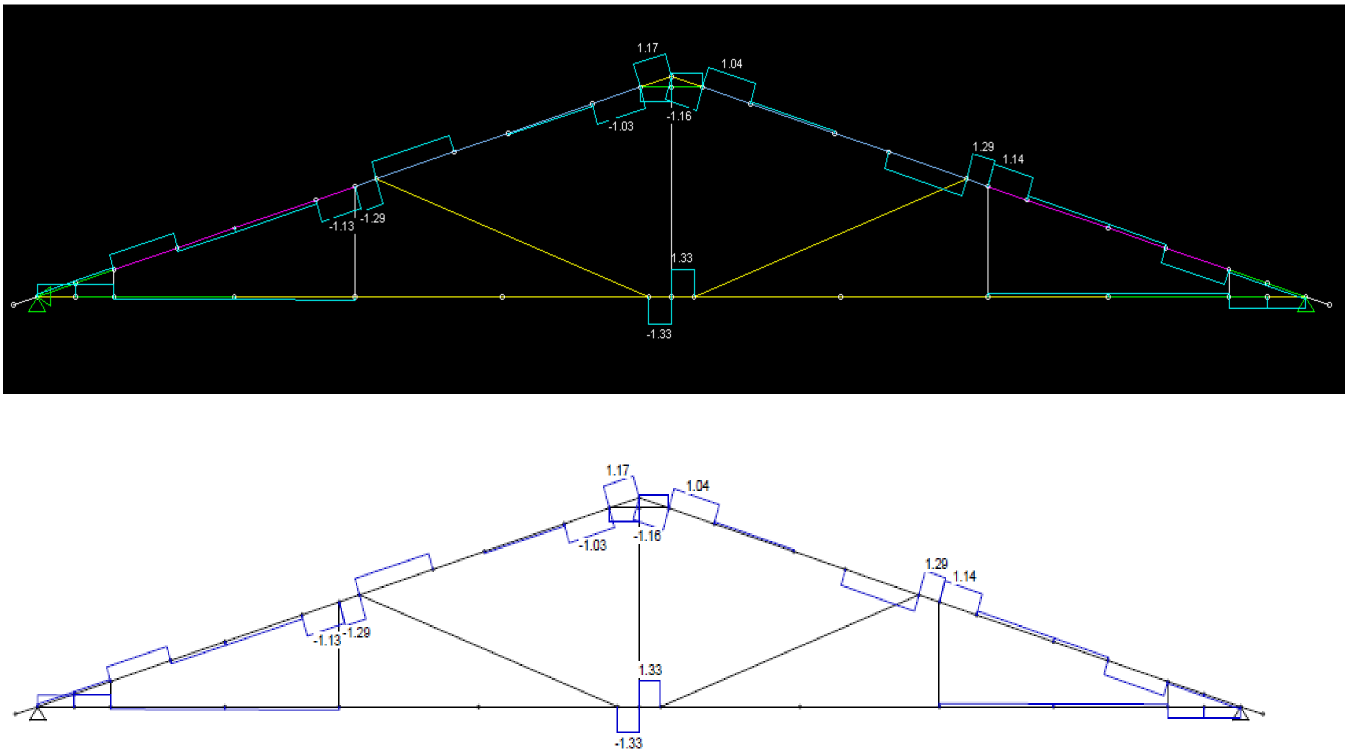


Figure 5-3: Shear diagram of Truss Design Capacity with roof battens at 800mm spacing

The maximum axial force of the design truss for roof batten spacings of 800mm is 12.06kN which is calculated from the results using AS4600[9] in the FrameCAD Structure software. The axial diagram of the design truss with roof battens placed at 800mm spacings is shown below in **Figure 5-4**.

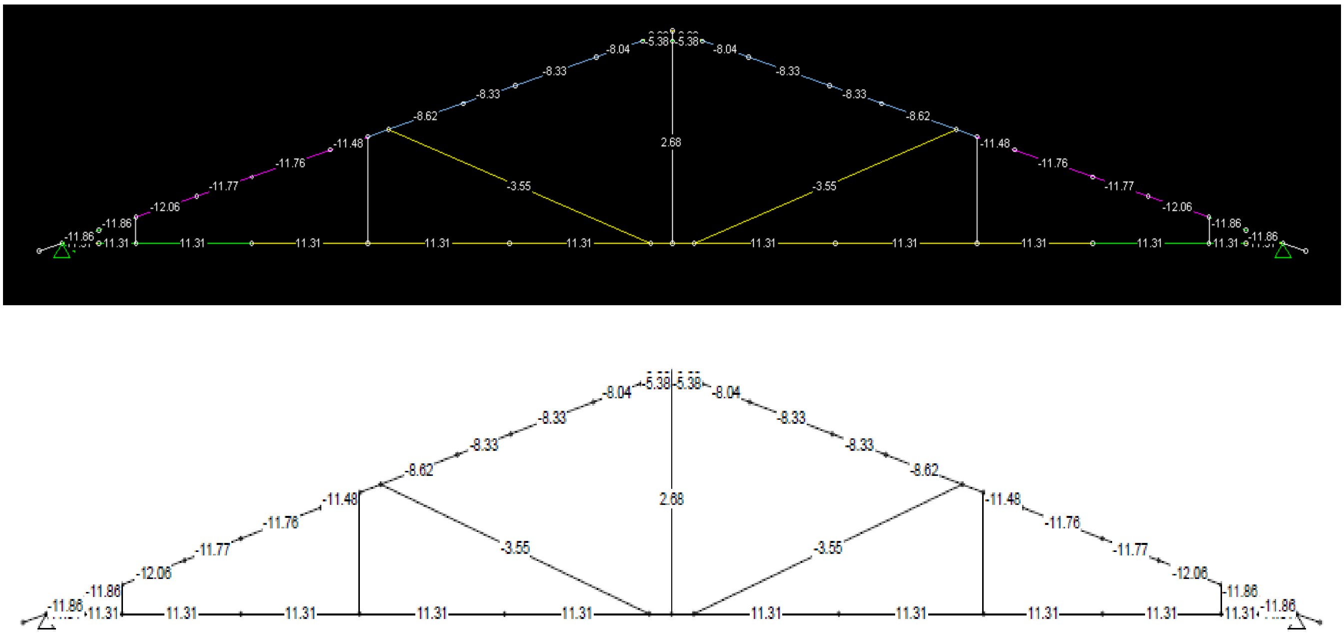


Figure 5-4: Axial diagram of Truss Design Capacity with roof battens at 800mm spacing

5.3 Predicted Capacity of Truss for 800mm roof battens spacings

The predicted capacity of the truss is calculated for the tensile strength 600MPa which is the material properties of the CFS used in this study. The use of 600MPa is necessary to view the difference in the capacities between a 495MPa section and a 600MPa section which enables the calculation of the expected failure of 120% in the predicted capacity.

This increase from 495MPa to 600MPa shows a significant change in the bending strength while the compressive strength remained the same. The bending strength of the 600MPa C-section is 1335Nm and the compressive strength is 16.66kN. Knowing this 120% expectancy failure, the yield strength and tensile strength in the predicted design is then reduced to 495MPa, as per the AS4600 standards and the loads in the predicted capacity are calculated for the 120% expectancy failure. The **Table 31** shows the properties and capacities of the 600MPa C-section used for the predicted truss calculations.

Table 31: Properties and Capacities of 600MPa Tensile Strength C-Section

Properties

Property	Value
Feed Width	186.9mm
Gross Area	140.2mm^2
Gross Weight	1.155kg/m
Centroid Left	13.02mm
Centroid Top	44.13mm
Second Moment Ixx	179439mm^4
Second Moment Iyy	33353mm^4
Radius of Gyration rx	35.78mm
Radius of Gyration ry	15.42mm
Shear Centre X	32.82mm
Shear Centre Y	0.000mm
Polar Radius ro1	51.1mm
Torsion Constant J	26.29mm^4
Warping Constant Iw	58849980mm^6
Modulus Zx	4032mm^3
Modulus Zy	1208mm^3
Gross Area (Simple)	143.3mm^2
Second Moment Ixx (Simple)	185497mm^4
Second Moment Iyy (Simple)	34793mm^4

Capacities

Property	Value
Shear Capacity Vv	4.395kN
Tension Capacity Nt	42.23kN
Compression Capacity Ns	32.80kN
Compression Capacity Nc	16.66kN
Bending Capacity Ms-	1531N.m
Bending Capacity Mb-	1335N.m
Bending Capacity Ms+	1531N.m
Bending Capacity Mb+	1335N.m
Bearing Capacity Rbe	1.877kN
Bearing Capacity Rbi	3.481kN
Effective Area Ae	102.0mm^2
Effective Modulus Zx-	2883mm^4
Effective Modulus Zx+	2883mm^4
Euler Buckling Load Pe	252.7kN

In accordance with NASH AS2010 and using the Total Load formula: $Total\ Load\ (kN) = 1.2G + 1.5Q$, the total predicted load at failure of the truss with 800mm roof battens spacings is 10.04kN the factored dead load is 0.68kN and the factored applied load at failure per truss is 9.36kN which meets the capacity of 120%. The design dead load (G) without any safety factor is about 0.56kN and the live load (Q) without any safety factor is 6.24kN. The total predicted load of without any safety factor (G + Q) is 6.82kN. The **Figure 5-1** below shows the load diagram of the design:

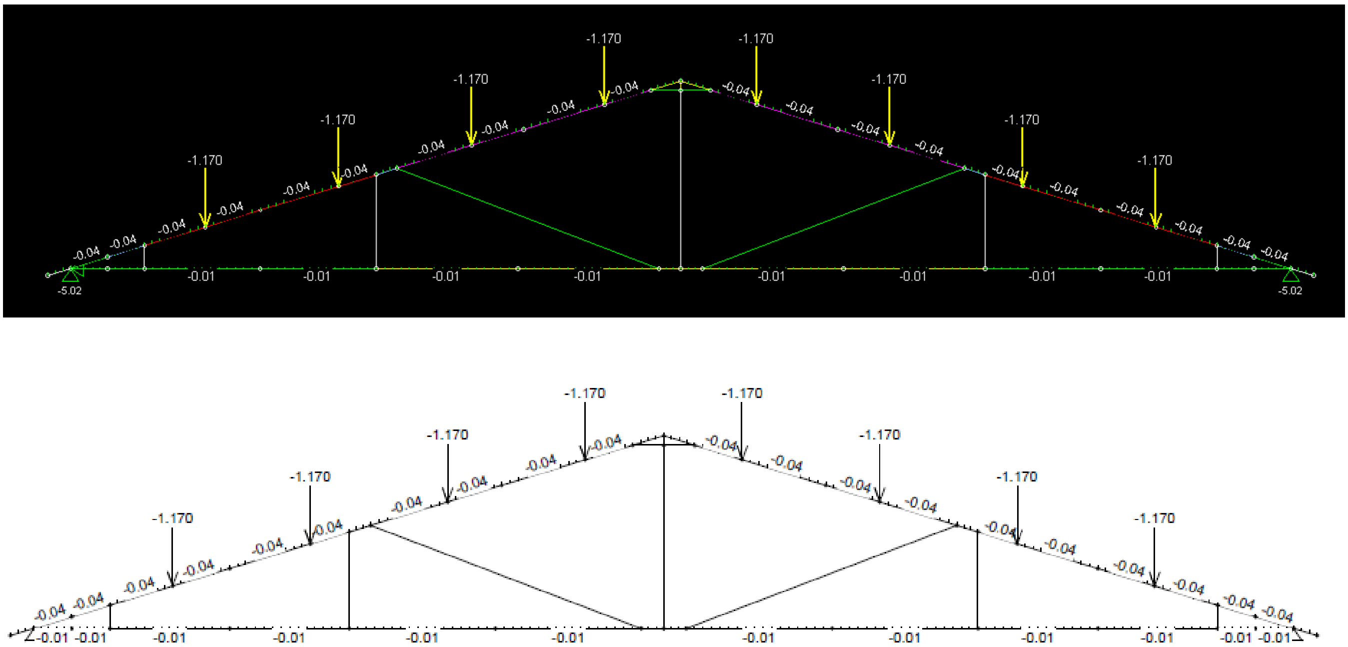


Figure 5-5: Load diagram of Truss Predicted Capacity with roof battens at 800mm spacing

Similar to the design calculations, the predicted capacity also shows that the member along the top chord between Joints B and D and Joints N and P (red lines in **Figure 5-6**) will most likely achieve failure. The maximum bending moment of the predicted capacity of the truss for the roof batten spacings of 800mm is 293.8Nm which is calculated from the results using AS4600 [9].

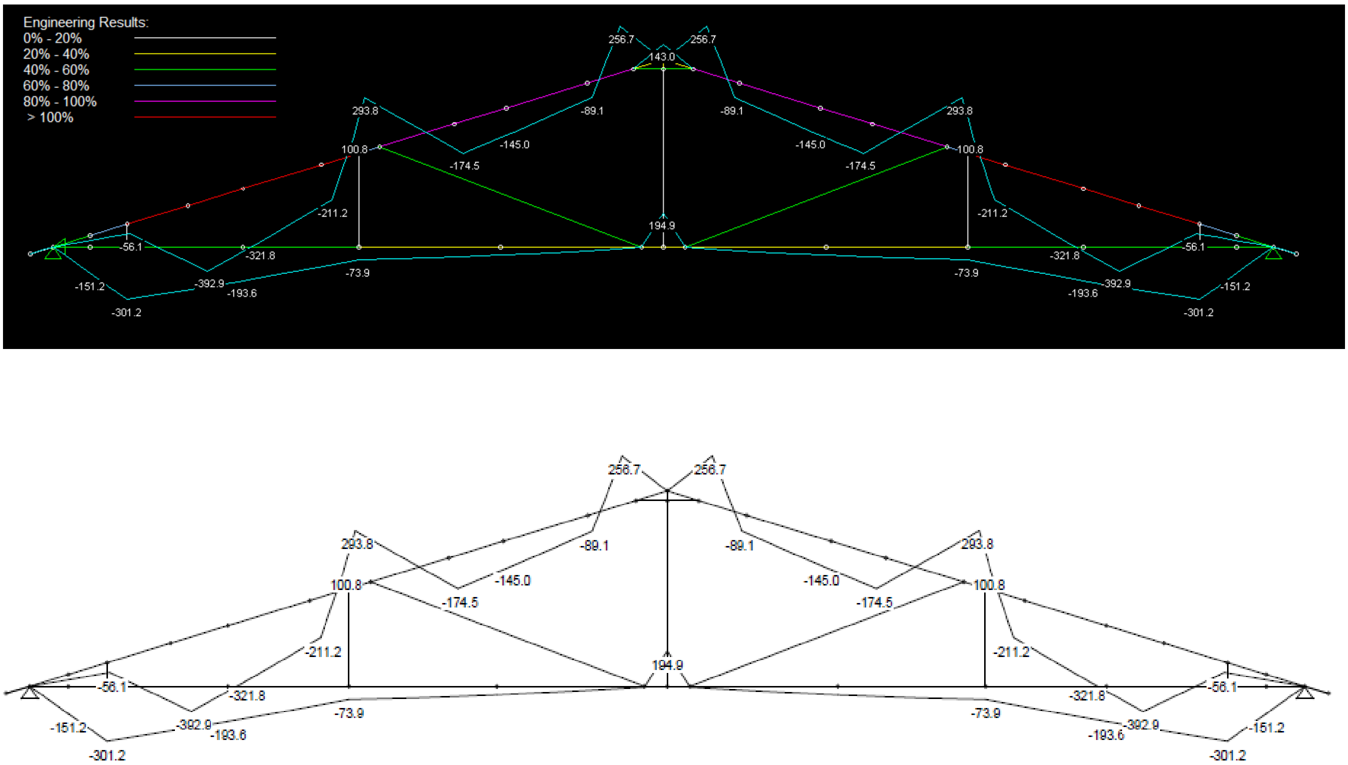
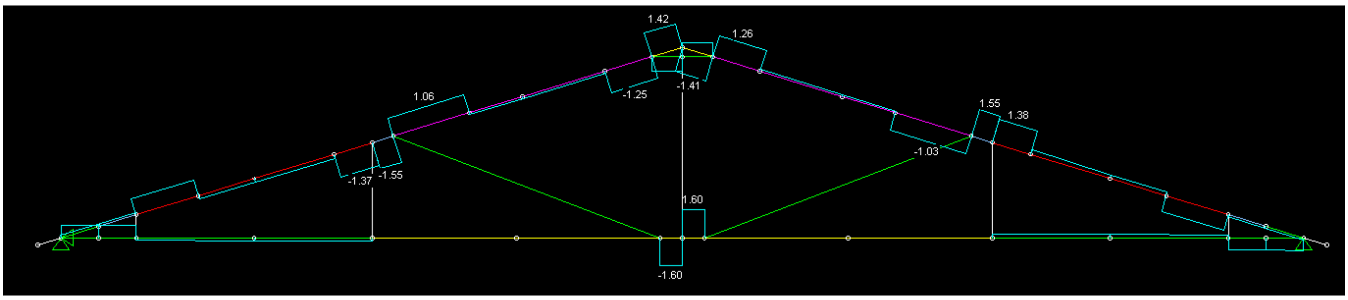


Figure 5-6: Bending diagram of Truss Predicted Capacity with roof battens at 800mm spacing

The maximum shear of the predicted capacity of the truss for roof batten spacings of 800mm is 1.55kN which is calculated from the results using AS4600 [9] in the FrameCAD Structure software. The shear diagram of the predicted capacity for the truss with roof battens placed at 800mm spacings is shown below in **Figure 5-7**.



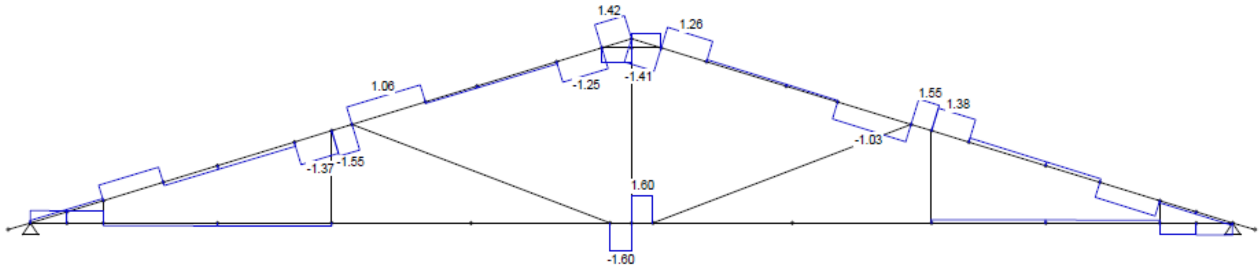


Figure 5-7: Shear diagram of Truss Predicted Capacity with roof battens at 800mm spacing

The maximum axial force of the predicted capacity truss for roof batten spacings of 800mm is 14.50kN which is calculated from the results using AS4600 [9] in the FrameCAD Structure software. The axial diagram of the design truss with roof battens placed at 800mm spacings is shown below in **Figure 5-8**.

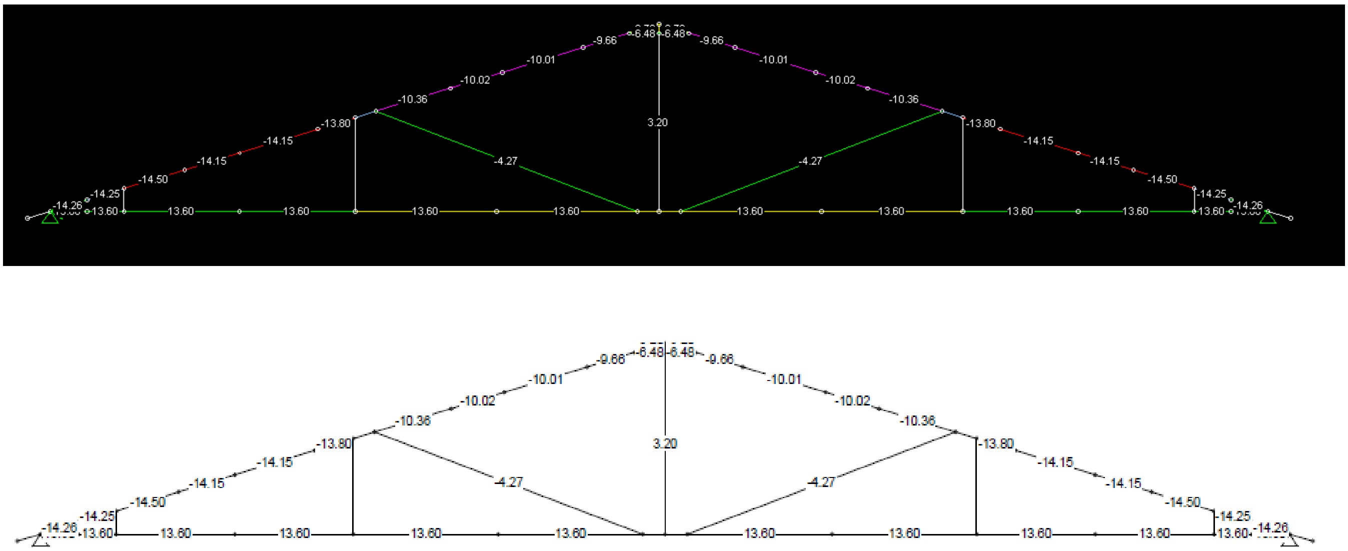


Figure 5-8: Axial diagram of Truss Predicted Capacity with roof battens at 800mm spacing

5.4 Design vs Predicted vs Experimental Capacity of Truss with 800mm roof batten spacings

The design total load per truss with 800mm roof batten spacings and with end supports only is 8.36kN. The predicted total load at failure per truss is 10.04kN where both design and predicted loads are using safety factors. The factored dead load for design and predicted capacity is 0.68kN. The factored live loads for design capacity are 7.68kN and 9.36kN for predicted capacity. The design and predicted capacity of dead load per truss without safety factors(G) is 0.56kN for both capacities. The live loads (Q) without the safety factors are 5.12kN for design capacity and 6.24kN for predicted capacity. The experimental total load per truss achieves an average of 11.27kN for end supports assembly. The average experimental dead load (G) per truss is 0.41kN and the average experimental live load (Q) per truss is 10.85kN. The total load of the truss assembly when compared between the unfactored design, unfactored predicted and actual experimental capacity shows that the applied load at failure of the predicted capacity and experimental capacity are nearly the same. The total load at failure during the experimental loading is 12% higher than the total load of the factored predicted capacity and 34% higher than the factored design capacity total load. The failures around the trusses are occurring around the truss joints D and F of 1 truss and between the joints J and N of the 2^{nd} truss. The failure area of the experiments is close to the same area as the predicted capacity, however for the experiments, the failure area is also including the top chord member closer to the ridge of the truss.

5.5 *Design Capacity of Truss for 400mm roof battens spacings*

The design loads for the truss with 400mm roof batten spacing is calculated using the design yield strength of G550 steel grade which is 495MPa. The design and predicted capacities of the truss with 400mm roof batten spacings uses the effective length factor values of $k_x = 0.75$, $k_y = 1.0$ and torsional length factor, $k_t = 0.75$. The total load calculated using the NASH AS2010 formula: $Total\ Load\ (kN) = 1.2G + 1.5Q$, the total design load per truss with 400mm roof battens spacings is 9.46kN and the design live load per truss is 8.824kN which achieves the most optimised capacity of 100%. The design dead load without any safety factor is 0.52kN and the live load without any safety factor is 5.88kN. The total design load of without any safety factor (G + Q) is 6.4kN. The 400mm roof batten spacing is applied along the top chords of the design truss where the point loads are located in the load diagram. The **Figure 5-9** below shows the load diagram of the design.

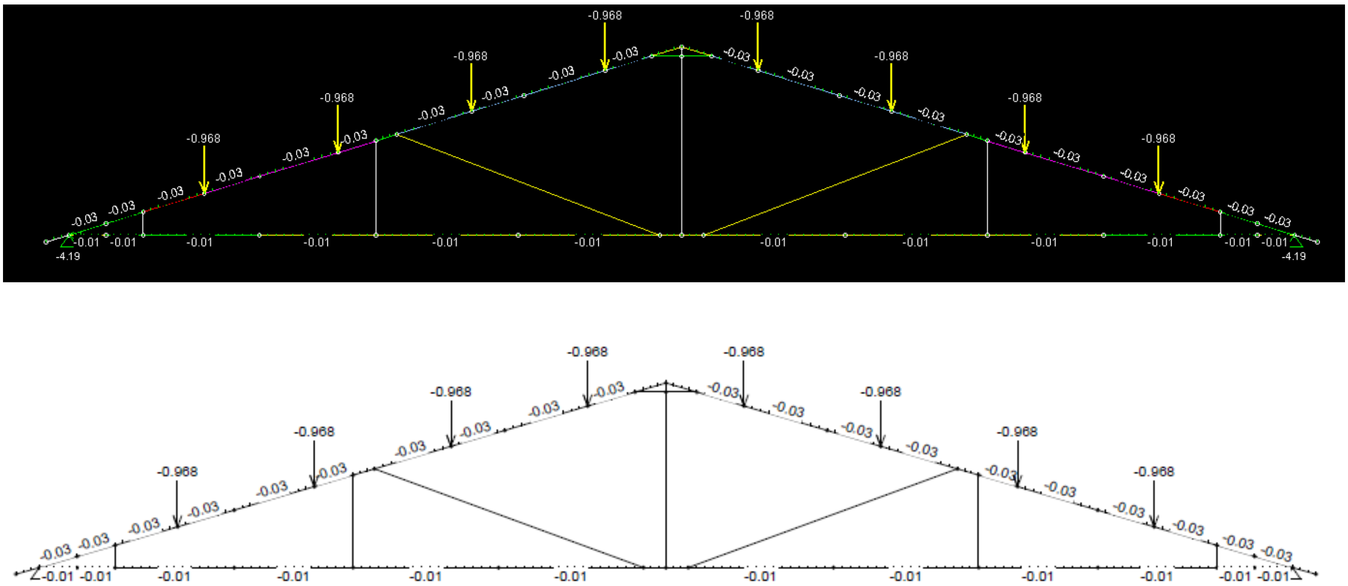


Figure 5-9: Load diagram of Truss Design Capacity with roof battens at 400mm spacing

The design shows that the member between Joint B and Joint D and Joint N and Joint P of the top chord is the area that will most likely fail first as illustrated in the bending diagram (red and purple lines) in **Figure 5-10**. The maximum bending moment of the design truss for the roof batten spacings of 400mm is 243.4Nm which is calculated from the results using AS4600 [9].

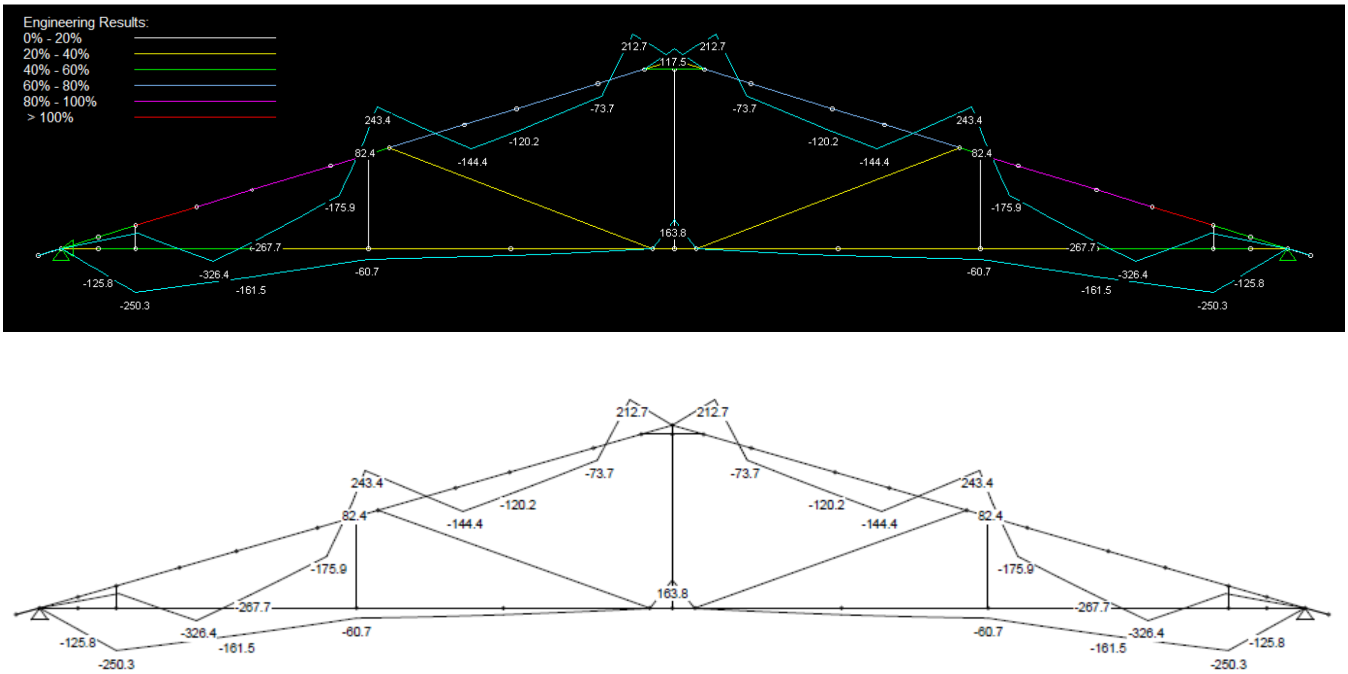


Figure 5-10: Bending diagram of Truss Design Capacity with roof battens at 400mm spacing

The maximum shear of the design truss for roof batten spacings of 400mm is 1.30kN which is calculated from the results using AS4600 [9] in the FrameCAD Structure software. The shear diagram of the design truss with roof battens placed at 400mm spacings is shown below in **Figure 5-11**.

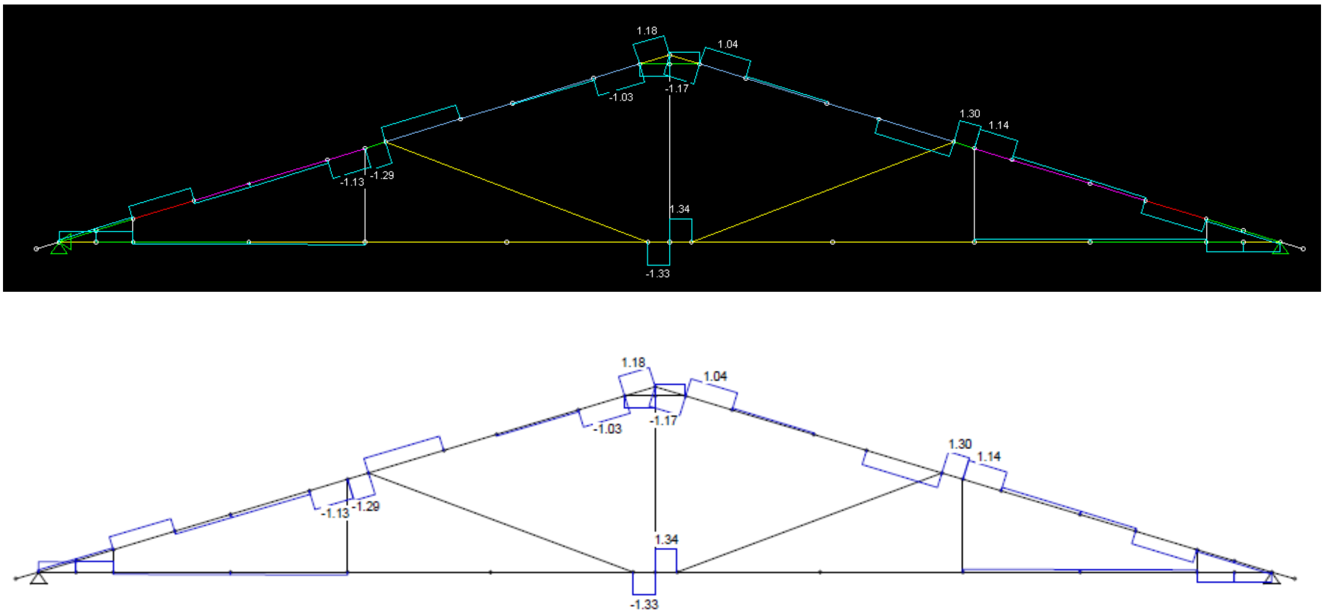
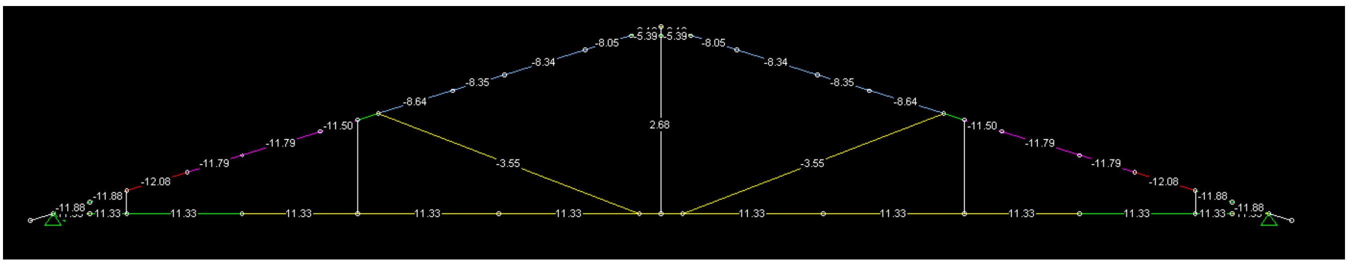


Figure 5-11: Shear diagram of Truss Design Capacity with roof battens at 400mm spacing

The maximum axial force of the design truss for roof batten spacings of 400mm is 12.08kN which is calculated from the results using AS4600 [9] in the FrameCAD Structure software. The axial diagram of the design truss with roof battens placed at 400mm spacings is shown below in **Figure 5-12**.



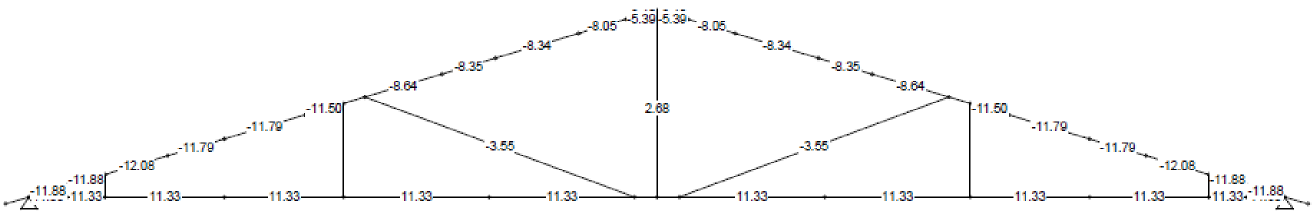


Figure 5-12: Axial diagram of Truss Design Capacity with roof battens at 400mm spacing

5.6 Predicted Capacity of Truss for 400mm roof battens spacings

The predicted capacity of the truss is calculated for the tensile strength 600MPa and in accordance with NASH AS2010, the Total Load formula: $Total\ Load\ (kN) = 1.2G + 1.5Q$, the total predicted load of the truss with 400mm roof battens spacings is 11.32kN and the applied factored load is 10.68kN which achieves the capacity of 120%. The dead load (G) and live load (Q) without factors of safety are 0.53kN and 7.12kN, respectively. The total predicted load of without any safety factor (G + Q) is 7.64kN. The **Figure 5-13** below shows the load diagram of the design.

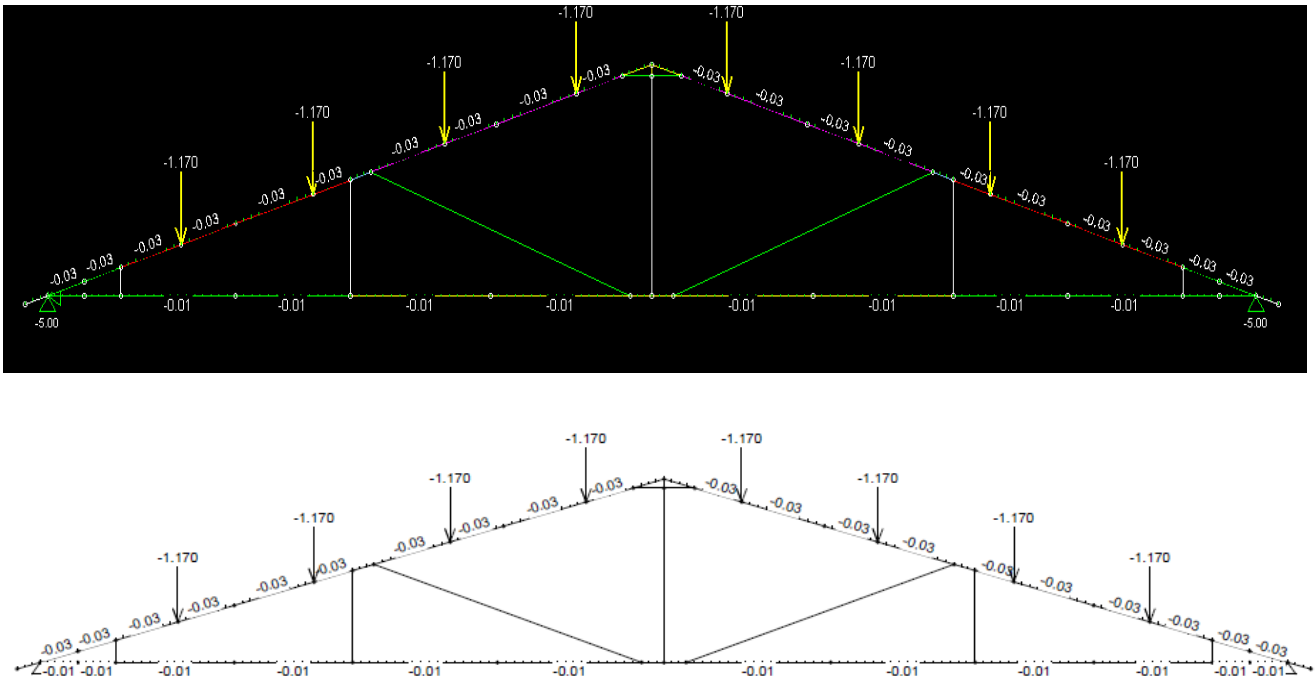


Figure 5-13: Load diagram of Truss Predicted Capacity with roof battens at 400mm spacing

The capacity calculations show that the top chord members between Joints B and D and Joints N and P of the truss would most likely experience failure first (red lines shown in **Figure 5-14**) at the predicted applied loads. The maximum bending moment of the predicted capacity of the truss for the roof batten spacings of 400mm is 292.6Nm which is calculated from the results using AS4600 [9].

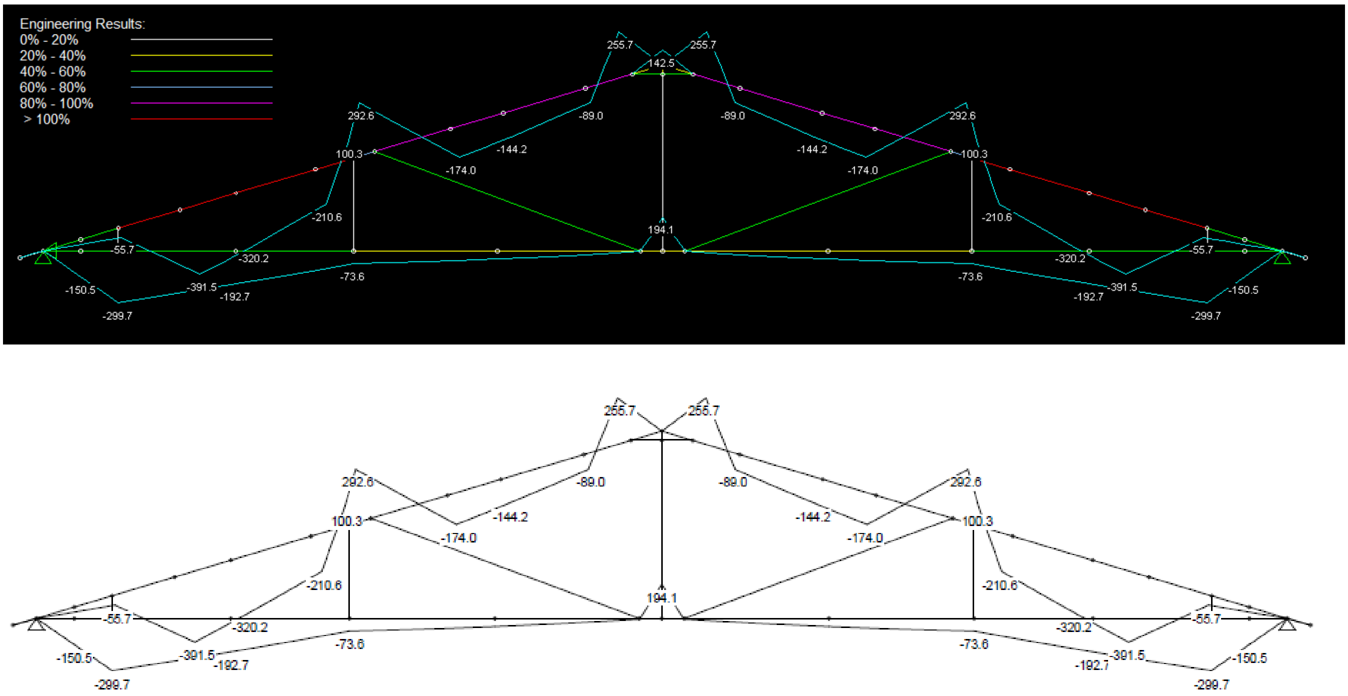
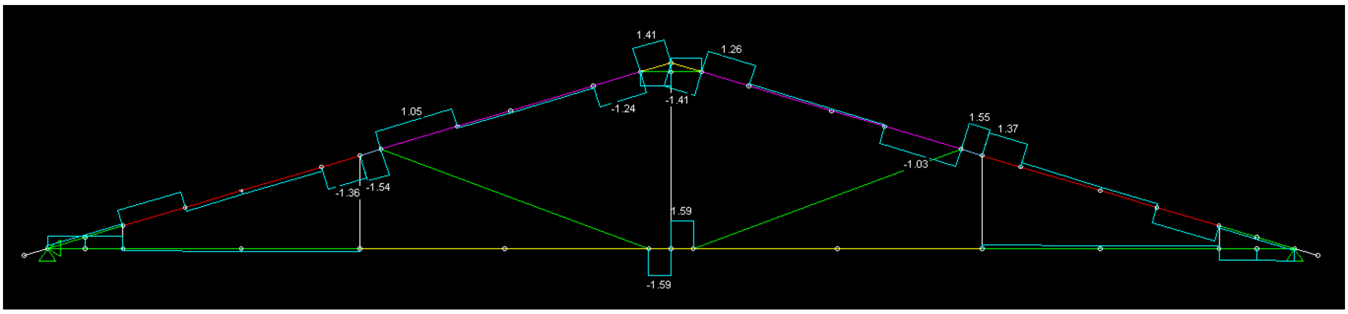


Figure 5-14: Bending diagram of Truss Predicted Capacity with roof battens at 400mm spacing

The maximum shear of the predicted capacity of the truss for roof batten spacings of 400mm is 1.55kN which is calculated from the results using AS4600 [9] in the FrameCAD Structure software. The **Figure 5-15** shows the shear diagram of the predicted capacity for the truss with roof battens placed at 400mm spacings.



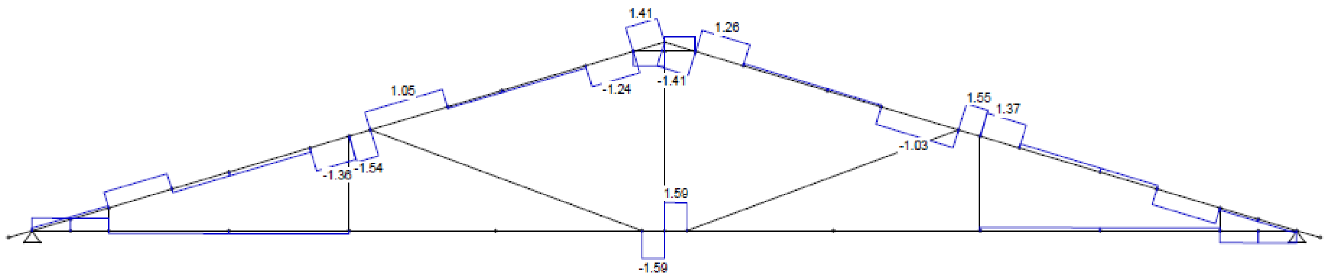


Figure 5-15: Shear diagram of Truss Predicted Capacity with roof battens at 400mm spacing

The maximum axial force of the design truss for roof batten spacings of 400mm is 14.43kN which is calculated from the results using AS4600 [9] in the FrameCAD Structure software. The **Figure 5-16** shows the axial diagram of the predicted capacity for the truss with roof battens placed at 400mm spacings.

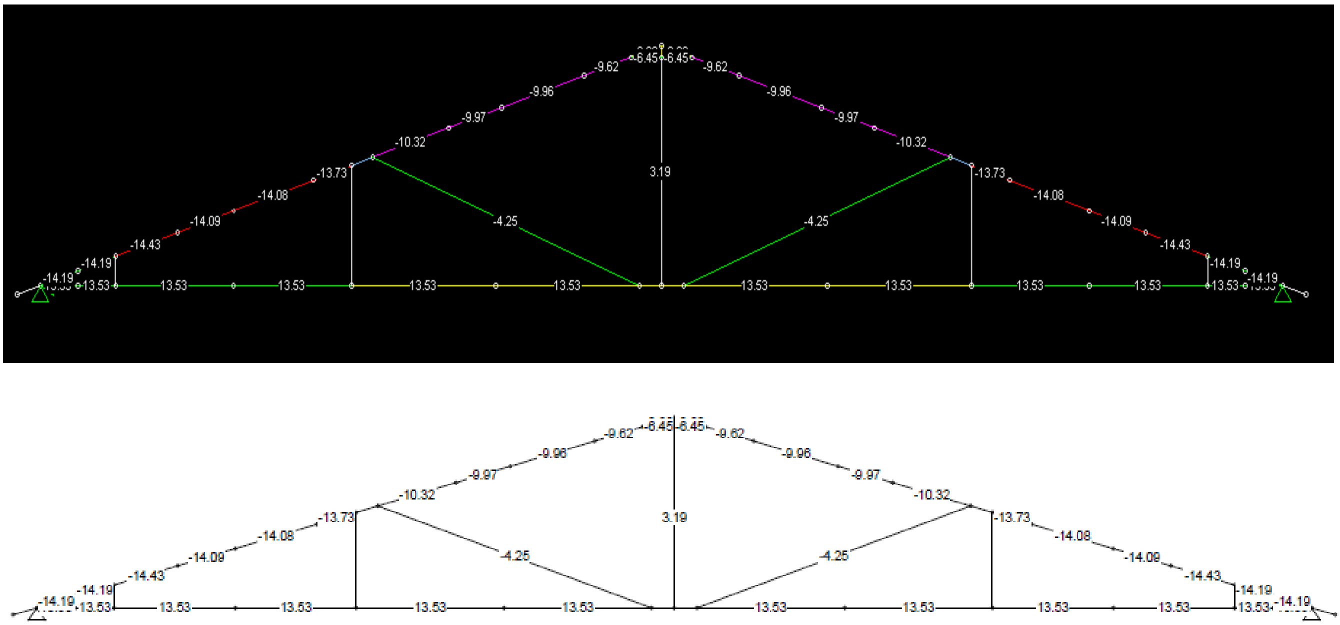


Figure 5-16: Axial diagram of Truss Predicted Capacity with roof battens at 400mm spacing

5.7 Design Capacity vs Predicted Capacity vs Actual Capacity of Truss with 400mm roof batten spacings

The design total load per truss with 400mm roof batten spacings and with end supports only is 9.46kN which meets the optimised capacity of 100%. The predicted total load at failure per truss is 11.32kN which meets the capacity of 120%, and both design and predicted loads are using factors of safety. The experimental total load per truss achieves an average of 15.20kN for end supports assembly. Without the use of safety factors, the design and predicted dead load (G) are respectively, 0.52kN and 0.53kN. The live loads (Q) without the safety factors are 5.88kN for design capacity and 7.12kN for predicted capacity. The factored design and predicted dead loads are 0.62kN and 0.63kN, respectively. The factored design and predicted live loads are 8.824kN and 10.68kN, respectively. The average experimental dead load (G) per truss is 0.43kN and the average experimental live load (Q) per truss is 14.77kN. The total load at failure during the experimental loading is 34% higher than the total load of the factored predicted capacity and 60% higher than the design capacity total load. The increase in lateral restraints on the trusses assists in increasing the applicable load that can be carried by the truss until failure is experienced. The area of failure experienced on the experiments occurs along the same area identified during the predicted capacity calculations. The design and predicted capacities are calculated to perfect conditions and includes safety factors whereas the experimental results are based on realistic conditions and factors that influence the results. The failures experienced in the experiments impact the outcome of the results which identifies that the design calculations are conservative based on the standards used.

5.8 Design Standards Recommendations

The comparison of the respective 800mm and 400mm roof batten spacings in the single channel linear truss assembly arrangement show the following about the current design standards:

- 800mm - the total load at failure during the experimental loading is 12% higher than the total load of the factored predicted capacity and 34% higher than the factored design capacity total load. Results are tabulated in **Table 32**, **Table 33** and **Table 34**.
- 400mm - When the lateral restraints of the same assembly arrangement are reduced to 400mm spacings, the total experimental load at failure is 34% higher than the total load of the factored predicted capacity and is 60% higher than the factored design capacity total load.

Table 32: Comparison of Factored Design, Factored Predicted and Experiment Capacities

	Factored Design	Factored Predicted	Experiment
800mm batten spacing			
Live Load (kN)	7.68	9.36	10.85
Total Load(kN)	8.36	10.04	11.27
400mm batten spacing			

Live Load (kN)	8.824	10.68	14.77
Total Load (kN)	9.46	11.32	15.2

Table 33: Ratio of Factored Predicted-Experiment and Factored Design-Experiment Capacity

	Factored Predicted-Experiment	Factored Design-Experiment
800mm batten spacing		
Live Load (kN)	0.862672811	0.707834101
Total Load (kN)	0.890860692	0.741792369
400mm batten spacing		
Live Load (kN)	0.723087339	0.597427217
Total Load (kN)	0.744736842	0.622368421

Table 34: Percentage Difference between Experiment- Factored Predicted and Experiment- Factored Design Capacities

	Factored Experiment-Predicted	Experiment-Factored Design
800mm batten spacing		
Live Load (kN)	15.91880342	41.27604167
Total Load (kN)	12.25099602	34.80861244
400mm batten spacing		
Live Load (kN)	38.29588015	67.38440617
Total Load (kN)	34.27561837	60.67653277

- The method of designing the strength of the single channel linear truss system can be calculated the same way as designing for the strength of the single channel back-to-back truss systems. The same formulas and procedures of individually designed members are used in accordance with the design standards.
- The strength of the truss system is increased when the number of roof battens are increased (i.e. reduces the spacings between the battens). The closely spaced battens prevent the twisting of the top chord members thus allowing for the truss system to cater for more applied loads. The current design standards do not have methods for calculating lengths of members with these types of increased restraints. This creates a gap in the design which can be further investigated. However, this current experimental data is not enough to show what provisions should be made for the effective lengths. The FEM analysis for this experimental study which could develop the sensitivity analysis to show the effective length factors and values is currently being completed by the University of Waikato.

Chapter 6 Conclusions, Limitations and Future Study

6.1 Conclusions

This research investigates the performance and the strength capacity of the 7m span truss assembly for a linear truss system and a back-to-back system. The testing also included an evaluation and verification of the design method. The conventional back-to-back truss system is the foundation for the linear truss system. The difference between the 2 systems is that the position of the web members is placed in the same orientation and plane as the chord members in the linear truss system. The load testing of the truss assembly is conducted to verify the capacities of the chord members and web members. The ends of the web members include the swage notches on the flanges which enable the installation of the web member over the chords to reinforce and stiffen the reduced area at the connections. The connections are more stable by positioning the screws in predrilled holes at the inner face of the chords. The truss frames are analysed on a 2D plane frame analysis using the FrameCAD Structural software in which the chords are modelled as continuous members and the connections between the chords are modelled as pin connections. The chord members are designed in accordance with industry standards for the moment, shear, and axial forces of the truss plane frame analysis. The web members are modelled as pin ended members that connect to the chords at the centreline of both members which results in any eccentricity of web members at panel points being explicitly modelled. The axial load is not transferred across the joints as an axial release is stimulated when a member fully crosses another and has flange cuts on both sides. The web member behaviour consideration in the chord design is important as the web members provide torsional and major axis lateral restraints to the chords. The findings of the full-scale Howe truss roof assembly testing using gravity loads is as follows:

- In the single channel linear truss system arrangement of 800mm roof battens spacings, the total load at failure during the experimental loading is 12% higher than the total load of the factored predicted capacity and 34% higher than the factored design capacity total load.

- In the single channel linear truss system arrangement reduced to 400mm roof battens spacings, the experimental total load at failure is 34% higher than the total load of the factored predicted capacity and is 60% more than the factored design capacity total load.
- Lateral torsional buckling, out-of-plane buckling, inward torsional buckling are the common failures occurring on the truss assembly test series.
- The linear truss system has sufficient stiffness and strength to provide the required torsional restraint to chords.
- The linear truss system is still able to carry the remaining load capacity after the failure load has been reached on the truss. The failure experienced is the twisting of the top chord members and the supporting web members bending at its ends.
- The back-to-back system is not as strong as the linear truss system as it has less strength remaining after the failure load is reached on the truss assembly. The failure experienced is the full twisting of the top chord with deformation and screw slips of the ends of the supporting webs.
- The warping effects of both linear truss system and the back-to-back system significantly determine the effective length. The closely spaced battens minimize warping which causes higher load capacities to be achieved than the capacities anticipated by design standards.

6.2 Limitations of the current study and future study

These are the limitations of the current study:

- The manual application of loads
- The manual measurements of the deflections conducted at mid-span only
- Only testing for ultimate limit state (ULS) capacity for the truss assembly
- The spacing between the trusses only tested for 600mm

The current study investigates the ultimate limit state (ULS) of truss design using manual loading and manual methods of measurements. The test gives a more realistic view of how the truss assembly will be affected. However, for comparison purposes, the future testing of this study can be extended to the following:

- Conducting the test using load cell testing
- Mechanized deflection measurements at both mid-span and increments along the truss span
- Testing for serviceability limit state (SLS) capacity of the truss
- Increasing the truss spacings to 1200mm to enable tests for heavy loaded trusses

REFERENCES

[1] S. Mohammad, M. Md Tahir, C. S. Tan, and P. N. Shek, "Experimental investigation on wide-span cold-formed steel roof truss system," *Appl. Mech. Mater.*, vol. 166–169, no. December 2014, pp. 1304–1307, 2012, doi: 10.4028/www.scientific.net/AMM.166-169.1304.

[2] M. M. Harper and A. R. LaBoube, "Behavior Of Cold-Formed Steel Roof Trusses," *Summ. Report, Dep. Civ. Eng. Univ. Missouri*, no. May, 1995.

[3] J. V. Wood and J. L. Dawe, "Small-Scale Test Behavior of Cold-Formed Steel Roof Trusses," *J. Struct. Eng.*, vol. 132, no. 4, pp. 616–623, 2006, doi: 10.1061/(asce)0733-9445(2006)132:4(616).

[4] S. Gunalan, Y. Bandula Heva, and M. Mahendran, "Flexural-torsional Buckling Tests of Cold-formed Steel Compression Members at Elevated Temperatures," *J. Constr. Steel Res.*, vol. 108, pp. 31–45, 2015, doi: 10.1016/j.jcsr.2015.01.011.

[5] M. Reda, T. Sharaf, A. ElSabbagh, and M. ElGhandour, "Behavior and design for component and system of cold-formed steel roof trusses," *Thin-Walled Struct.*, vol. 135, no. April 2018, pp. 21–32, 2019, doi: 10.1016/j.tws.2018.10.038.

[6] G. J. Hancock, T. Murray, and D. S. Ellifrit, *Cold-Formed Steel Structures to the AISI Specification*. 2001. doi: 10.1201/9780203907986.

[7] J. Ye, F. J. Meza, I. Hajirasouliha, J. Becque, P. Shepherd, and K. Pilakoutas, "Experimental Investigation of Cross-Sectional Bending Capacity of Cold-Formed Steel Channels Subject to Local-Distortional Buckling Interaction," *J. Struct. Eng.*, vol. 145, no. 7, 2019, doi: 10.1061/(asce)st.1943-541x.0002344.

[8] S. Systems, W. Yu, and D. S. Method, *6.1 Introduction*. 2005.

[9] L. Agreement and A. Standards, "AUS/NZS-4600, Cold-Formed Steel Structures," *Aust. New Zeal. Stand. Sydney (NSW, Aust.*, 2018.

[10] R. M. Schuster, "One north American standard for the design of cold-formed steel structures," *Proceedings, Annu. Conf. - Can. Soc. Civ. Eng.*, vol. 2002, pp. 1405–1414, 2002.

[11] F. P. Potter, "Timber Trusses," *Timber Des.*, pp. 147–166, 2017, doi: 10.4324/9781315733890-7.

[12] W. Yu, D. Ph, and J. Wiley, *CFS design*. 2000.

[13] R. J. Pope, "European developments in execution of steel structures," *J. Constr. Steel Res.*, vol. 46, no. 1–3, pp. 144–145, 1998, doi: 10.1016/S0143-974X(98)00019-4.

[14] A. M. Johnson, B. Smith, C. Moen, and C. Yu, "Experimental study on system reliability of cold-formed steel roof trusses," *Proc. Annu. Stab. Conf. Struct. Stab. Res. Counc. 2017*, 2017.

[15] J. Brütting, J. Desruelle, G. Senatore, and C. Fivet, "Design of Truss Structures Through Reuse," *Structures*, vol. 18, no. September 2018, pp. 128–137, 2019, doi: 10.1016/j.istruc.2018.11.006.

[16] R. Baehre, B.-K. He, G. Moreau, K. Sakae, E. R. Bryan, and T. Peköz, "The endless possibilities of Cold Formed Steel applications," *Appl. Abroad*, vol. 1, 1982.

[17] S. Šilih, M. Premrov, and S. Kravanja, "Optimization of timber trusses considering joint flexibility," *WIT Trans. Built Environ.*, vol. 85, pp. 615–623, 2006, doi: 10.2495/HPSM06060.

[18] R. Crocetti, "Large-Span Timber Structures," *Proc. World Congr. Civil, Struct. Environ. Eng.*, pp. 1–23, 2016, doi: 10.11159/icsenm16.124.

[19] S. New Zealand, *NZS-3604:2011, Timber-framed buildings*. Wellington: Stamdards Cpuncil, Private Bag 2439, Wellington 6140, 2011. [Online]. Available: https://www.standards.govt.nz/

[20] Y. H. Lee, C. S. Tan, S. Mohammad, M. Md Tahir, and P. N. Shek, "Review on cold-formed steel connections," *Sci. World J.*, vol. 2014, 2014, doi: 10.1155/2014/951216.

[21] J. E. Mills, "Knee joints in cold-formed channel portal frames: Problems and pitfalls," *Aust. J. Struct. Eng.*, vol. 13, no. 2, pp. 191–202, 2012, doi: 10.7158/S12-003.2012.13.2.

[22] M. Gordziej-Zagórowska, E. Urbańska-Galewska, and P. Deniziak, "Analysis of failure

mechanism in joints with positive eccentricity in CFS truss," *Materials (Basel).*, vol. 14, no. 22, 2021, doi: 10.3390/ma14226986.

[23] A. J. Riemann and R. A. Laboube, "Behavior of compression web members in cold- formed steel truss assemblies," 1996.

[24] D. Dubina and R. Zaharia, "Cold-formed steel trusses with semi-rigid joints," *Thin-Walled Struct.*, vol. 29, no. 1–4, pp. 273–287, 1997, doi: 10.1016/s0263-8231(97)00028-1.

[25] H. D. Craveiro, J. P. C. Rodrigues, and L. Laím, "Cold-formed steel columns made with open cross-sections subjected to fire," *Thin-Walled Struct.*, vol. 85, pp. 1–14, 2014, doi: 10.1016/j.tws.2014.07.020.

[26] Z. Zhang, S. Xu, and R. Li, "Comparative investigation of the effect of corrosion on the mechanical properties of different parts of thin-walled steel," *Thin-Walled Struct.*, vol. 146, no. August 2019, p. 106450, 2020, doi: 10.1016/j.tws.2019.106450.

[27] M. Gordziej-Zagórowska, E. Urbańska-Galewska, P. Deniziak, and Ł. Pyrzowski, "Truss Joint with Positive Eccentricity Experimental Research," *Civ. Environ. Eng. Reports*, vol. 25, no. 2, pp. 107–123, 2017, doi: 10.1515/ceer-2017-0023.

[28] M. Gordziej-Zagórowska, E. Urbańska-Galewska, and P. Deniziak, "Experimental investigation of joint with positive eccentricity in CFS truss," *Thin-Walled Struct.*, vol. 157, no. July, 2020, doi: 10.1016/j.tws.2020.106998.

[29] C. Yu and B. W. Schafer, "Distortional buckling tests on cold-formed steel beams," *Seventeenth Int. Spec. Conf. Cold-Formed Steel Struct. Recent Res. Dev. Cold-Formed Steel Des. Constr.*, vol. 132, no. April, pp. 19–45, 2005, doi: 10.1061/(asce)0733-9445(2006)132:4(515).

[30] B. P. Gotluru, B. W. Schafer, and T. Peköz, "Torsion in thin-walled cold-formed steel beams," *Thin-Walled Struct.*, vol. 37, no. 2, pp. 127–145, 2000, doi: 10.1016/S0263-8231(00)00011-2.

[31] E. Proceedings and I. Conference, "QUT Digital Repository : Tests of Cold-formed Steel

Compression Members at Elevated Temperatures . In,” *Thin-Walled Struct.*, vol. 2008, pp. 745–752, 2008.

[32] G. J. Hancock, “Design for distortional buckling of flexural members,” *Thin-Walled Struct.*, vol. 27, no. 1, pp. 3–12, 1997, doi: 10.1016/0263-8231(96)00020-1.

[33] G. J. Hancock, “Scholars’ Mine Scholars’ Mine Distortional Buckling of Steel Storage Rack Columns Distortional Buckling of Steel Storage Rack Columns,” 1984, [Online]. Available: https://scholarsmine.mst.edu/isccss/7iccfss/7iccfss-session7/2

[34] E. Ghandi and S. Esmaeili Niari, “Flexural-torsional buckling of cold-formed steel columns with arbitrary cross-section under eccentric axial load,” *Structures*, vol. 28, no. August, pp. 2122–2134, 2020, doi: 10.1016/j.istruc.2020.09.081.

[35] C. C. Weng, “Effect of Residual Stress on Cold-Formed Steel Column Strength,” vol. 117, no. 6, pp. 1622–1640, 1991.

[36] J. S. Rajkannu and S. A. Jayachandran, “Flexural-torsional buckling strength of thin-walled channel sections with warping restraint,” *J. Constr. Steel Res.*, vol. 169, p. 106041, 2020, doi: 10.1016/j.jcsr.2020.106041.

[37] S. Gunalan, Y. Bandula Heva, and M. Mahendran, “Local buckling studies of cold-formed steel compression members at elevated temperatures,” *J. Constr. Steel Res.*, vol. 108, pp. 31–45, 2015, doi: 10.1016/j.jcsr.2015.01.011.

[38] C. A. Rogers and R. M. Schuster, “Flange/web distortional buckling of cold-formed steel sections in bending,” *Thin-Walled Struct.*, vol. 27, no. 1, pp. 13–29, 1997, doi: 10.1016/0263-8231(96)00017-1.

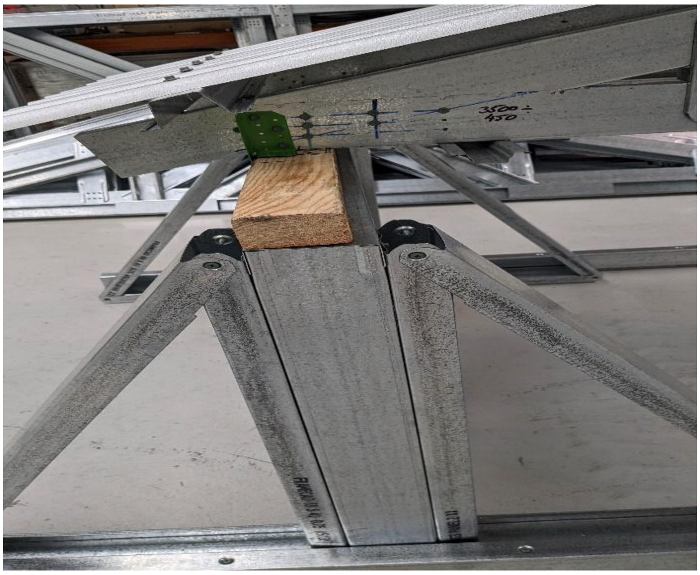
[39] S. M. Mojtabaei, J. Becque, and I. Hajirasouliha, “Local Buckling in Cold-Formed Steel Moment-Resisting Bolted Connections: Behavior, Capacity, and Design,” *J. Struct. Eng.*, vol. 146, no. 9, 2020, doi: 10.1061/(asce)st.1943-541x.0002730.

[40] AISI, "S240-15, North American Standard for Cold-Formed Steel Structural Framing," *Am. Iron Steel Inst.*, p. 204, 2015.

APPENDIX

Appendix A

Test 1 - Truss 1

Joint	Number of Screws	Photo
A	7 screws, 3 on bracket	
B	3	

C	3	
D	3	

E	3	
F	3	

G	3	
H	6	
I	3	

		
J	3	

K	3	
L	4	

M	4	
N	3	

O	3	
P	3	

Q	3	
R	7 screws, 3 on bracket	

Test 1 - Truss 2

Joint	Number of Screws	Photo
A	7 screws, 3 on bracket	

B	3	
C	3	

D	3	
E	3	

F	3	
G	3	

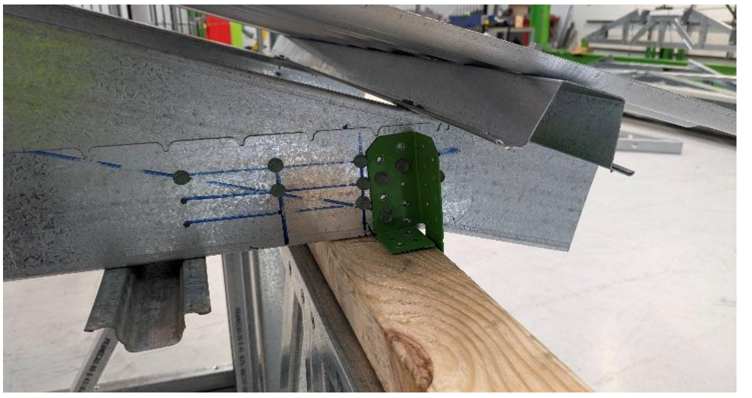
H	6	
I	3	

J	3	
K	3	

L	4	
M	4	

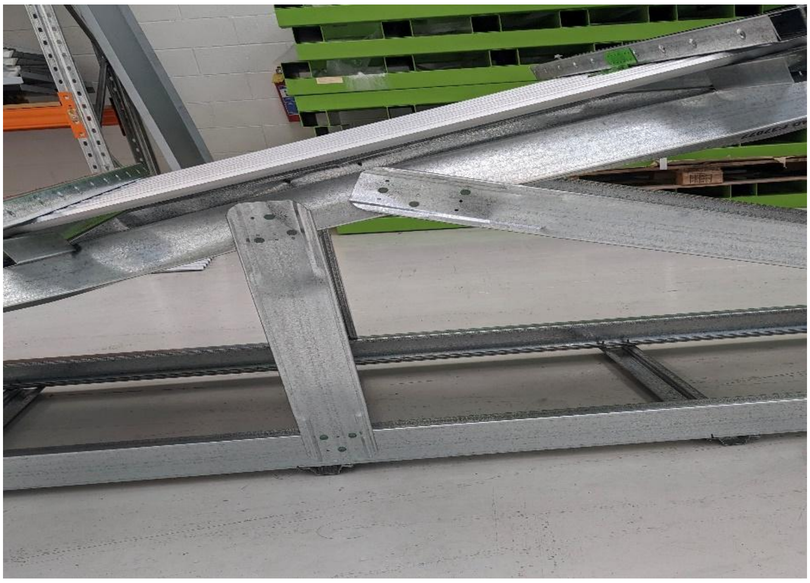
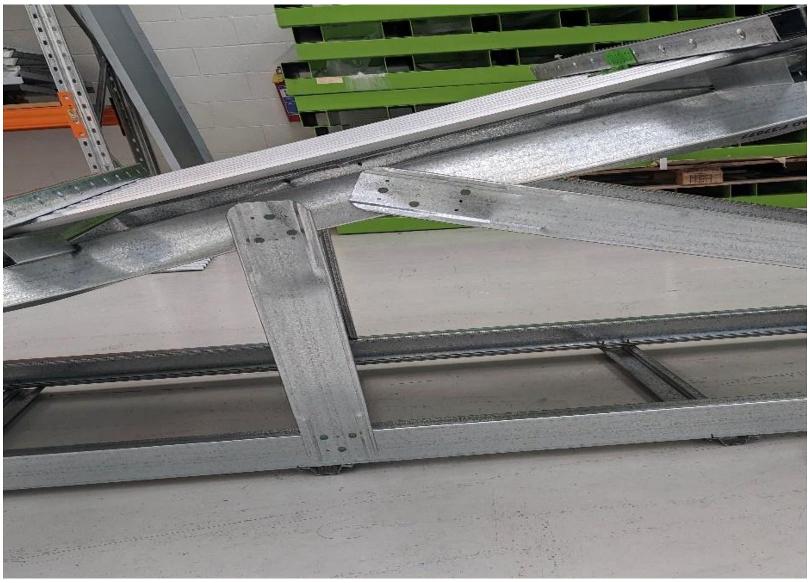
N	3	
O	3	

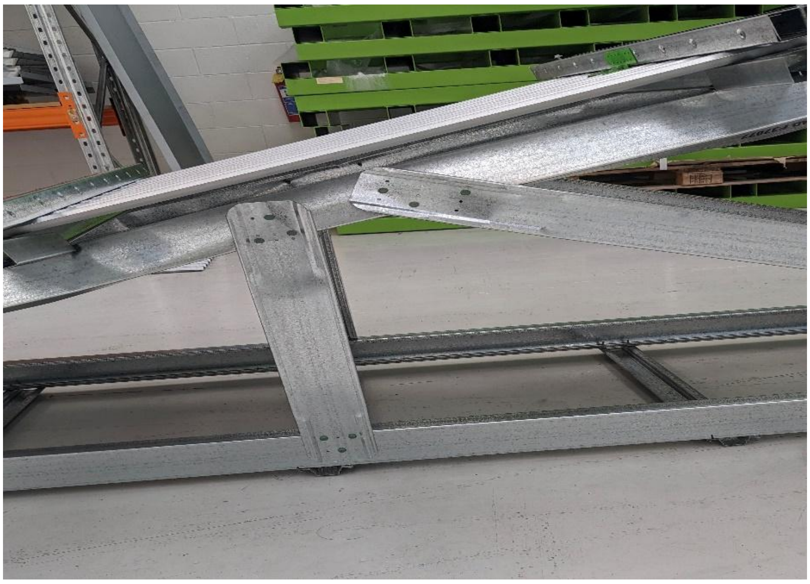
P	3	
Q	3	

R	7 screws, 3 on bracket	

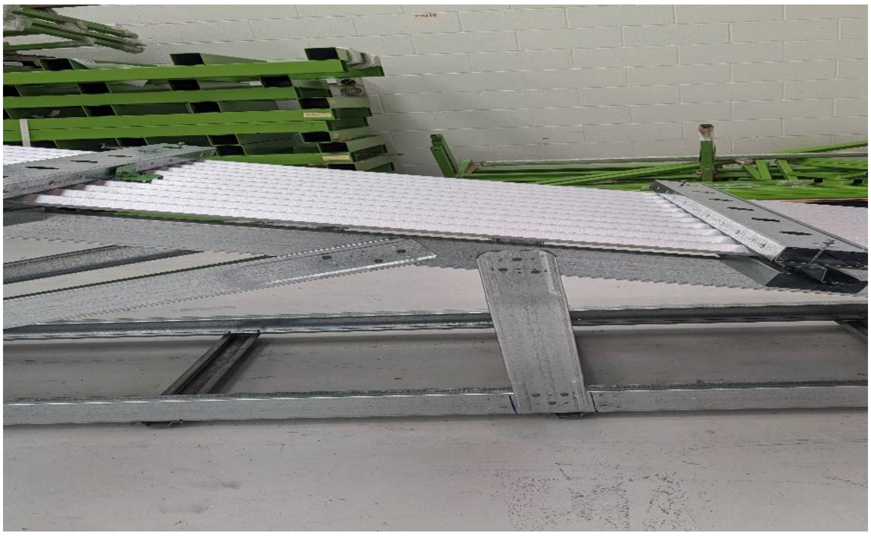
Test 2 - Truss 1

<u>Joint</u>	<u>Number of Screws</u>	<u>Photo</u>
A	7 screws, 4 on bracket	
B	3	

C	3	
D	3	
E	3	

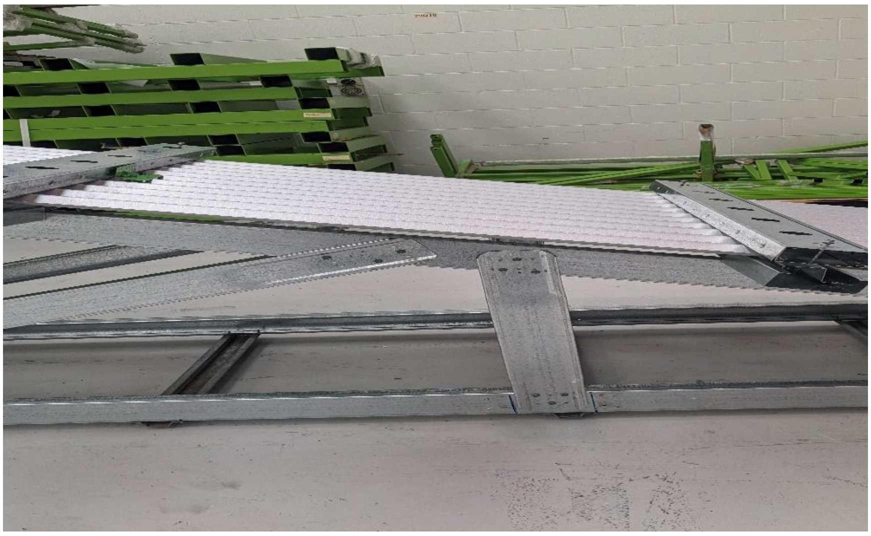
F	3	
G	3	

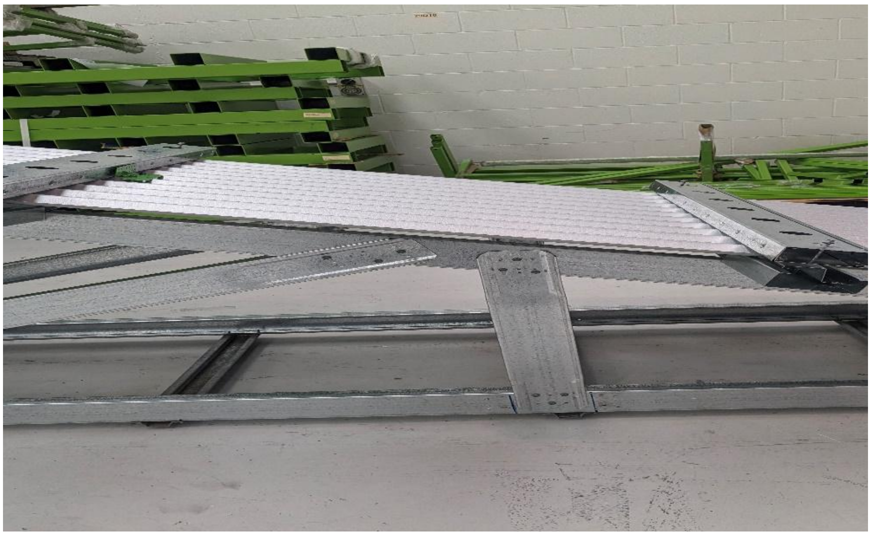
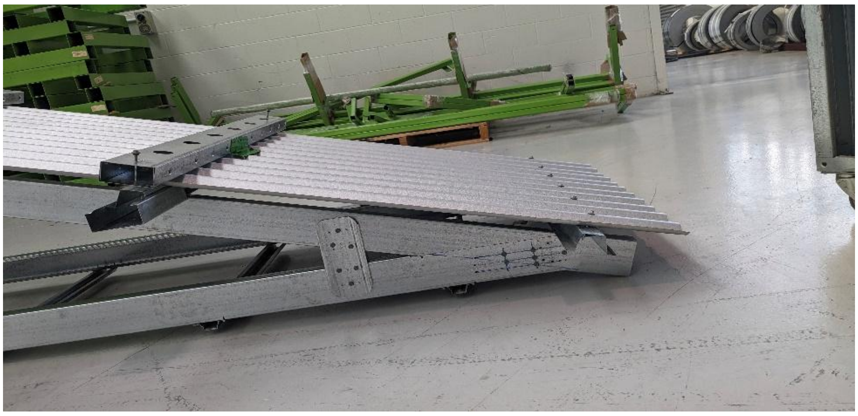
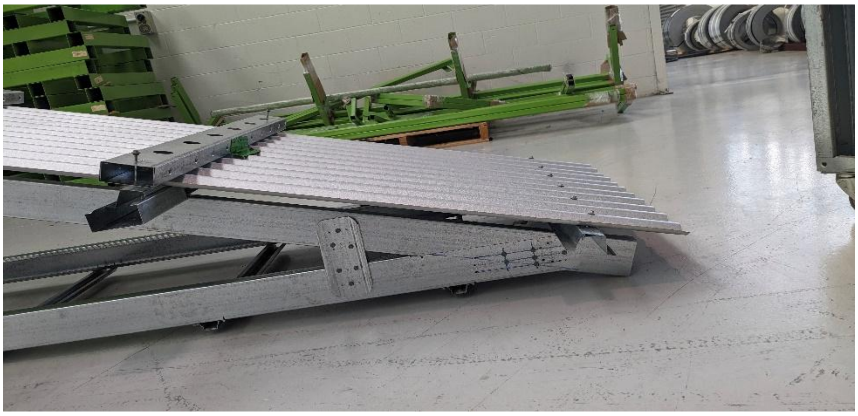
H	7	

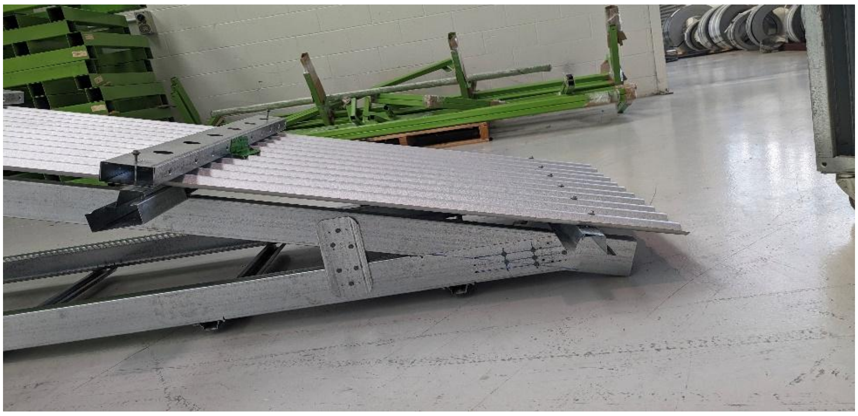
I	3	 .
J	3	

K	3	

L	6	

M	6	
N	3	

O	3	
P	3	
Q	3	

R	6 screws, 4 on bracket	

Test 2 - Truss 2

Joint	Number of Screws	Photo
A	6 screws, 4 on bracket	
B	3	

C	3	
D	3	
E	3	
F	3	

G	3	
H	6	

I	3	
J	3	

K	3	
L	4	

M	4	
N	3	

O	3	
P	3	
Q	3	

R	7 screws, 3 on bracket	

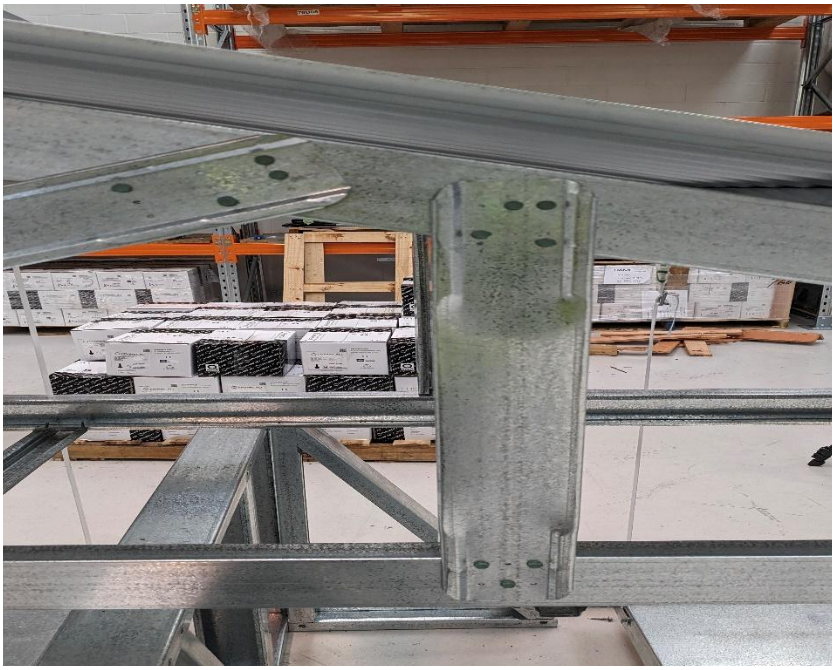
Test 3 – Truss 1

Joint	Number of Screws	Photo
A	5 screws, 4 on bracket	
B	4	

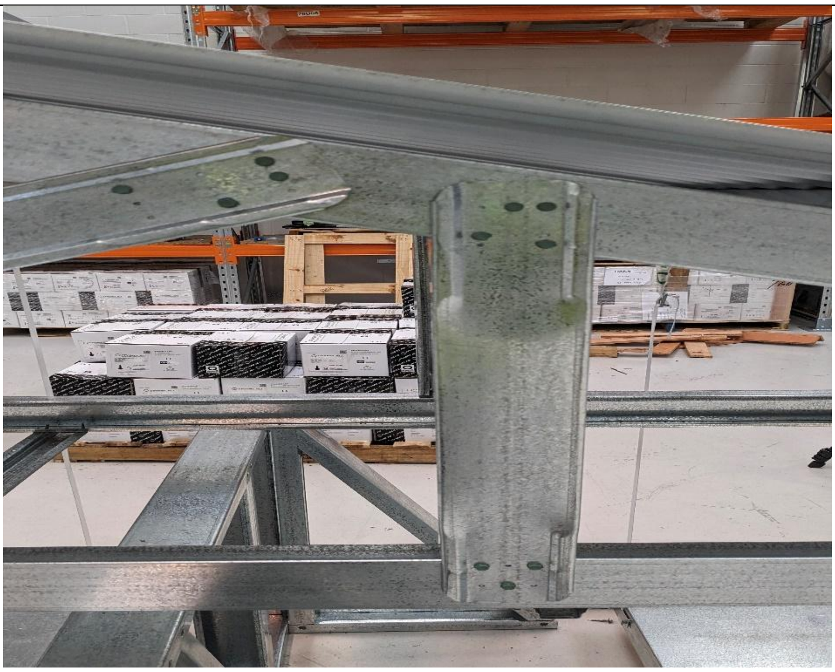
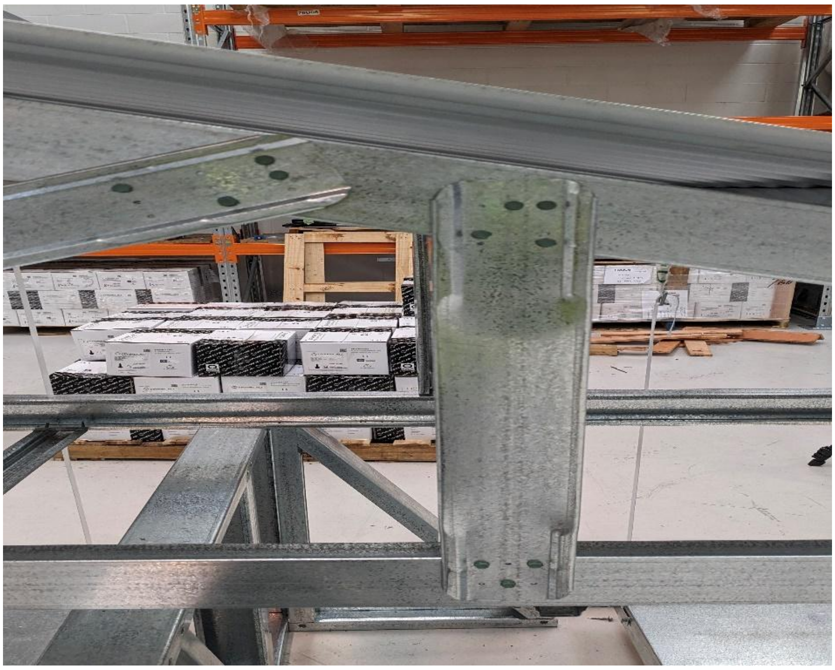
C	3	
D	4	
E	3	

F	4	
G	4	

H	7	
I	3	

J	4	
K	3	

L	6	
M	6	
N	4	

		
O	3	

P	4	
Q	3	
R	5 screws, 4 on bracket	

Test 3 – Truss 2

Joint	Number of Screws	Photo

A	6 screws, 4 on bracket	
B	4	
C	3	

D	4	
E	3	
F	4	

G	3	
H	7	

I	3	
J	4	

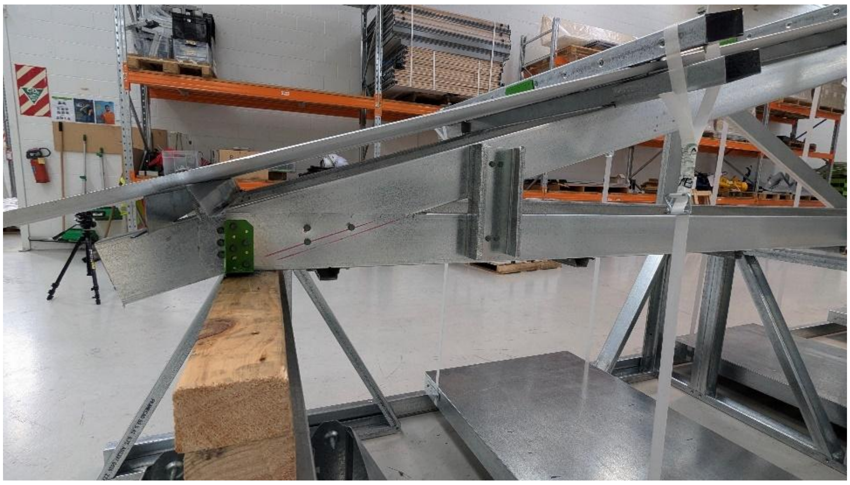
K	3	
L	6	

M	6	
N	4	
O	3	

P	4	
Q	3	
R	6 screws, 4 on bracket	

Test 4 – Truss 1

Joint	Number of Screws	Photo

A	6 screws, 4 on bracket	
B	3	
C	3	

D	3	
E	3	

F	3	
G	3	
H	7	

I	3	
J	3	

K	3	
L	5	

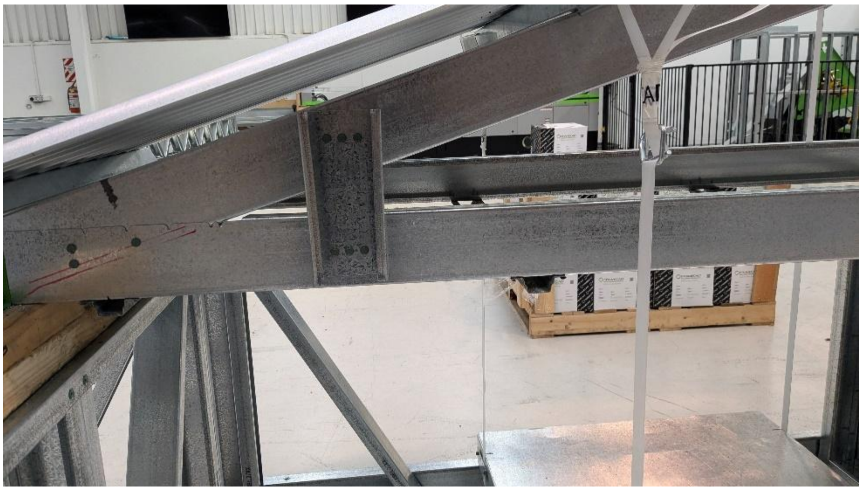
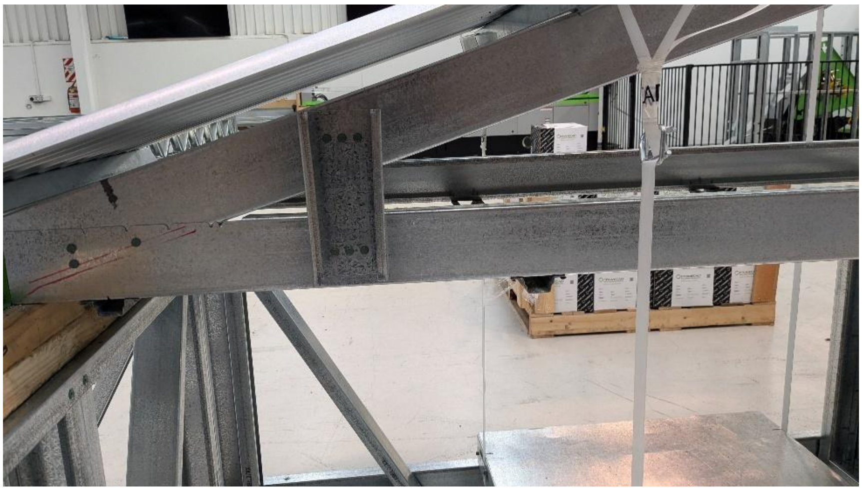
M	5	
N	3	

O	3	
P	3	

Q	3	
R	6 screws, 4 on bracket	

Test 4 – Truss 2

Joint	Number of Screws	Photo

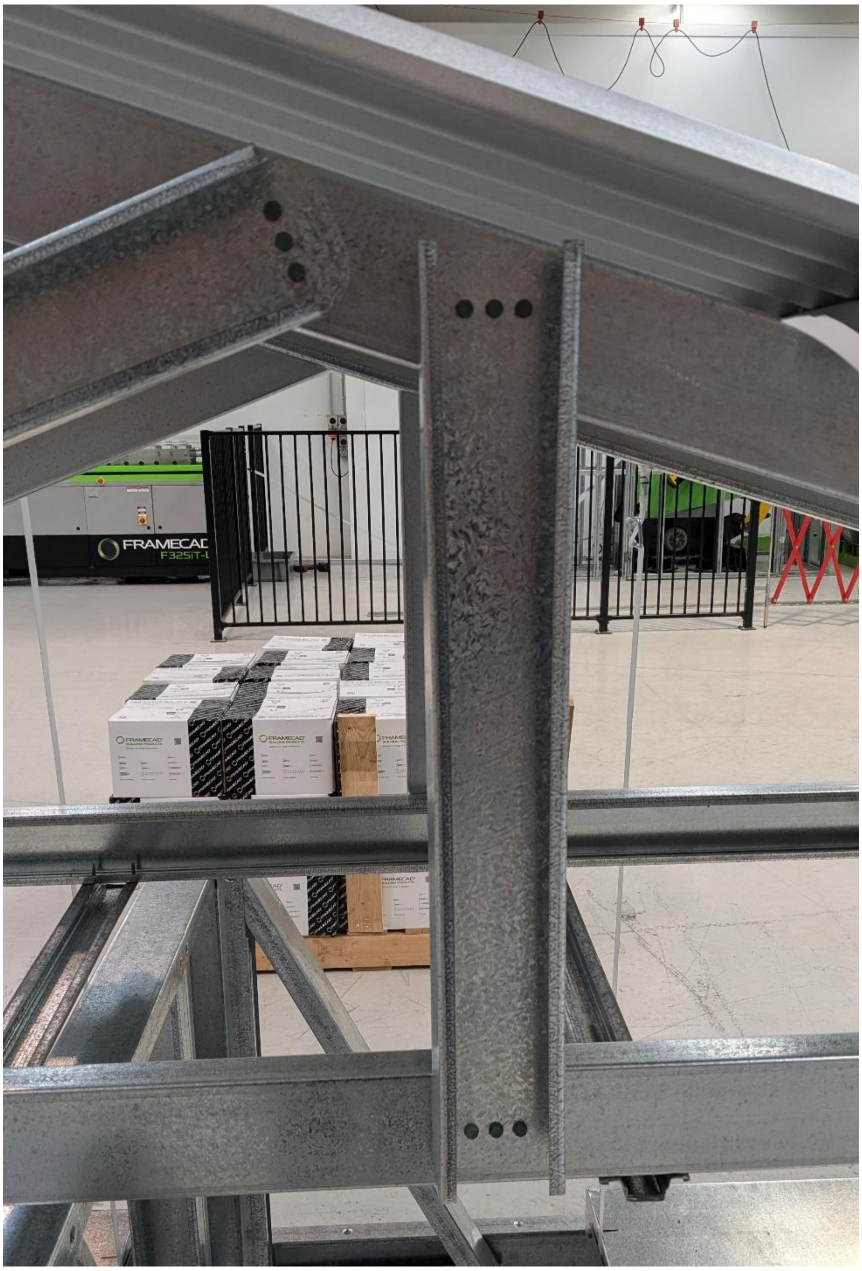
A	6 screws, 4 on bracket	
B	3	
C	3	

D	3	
E	3	

F	3	
G	3	

H	7	

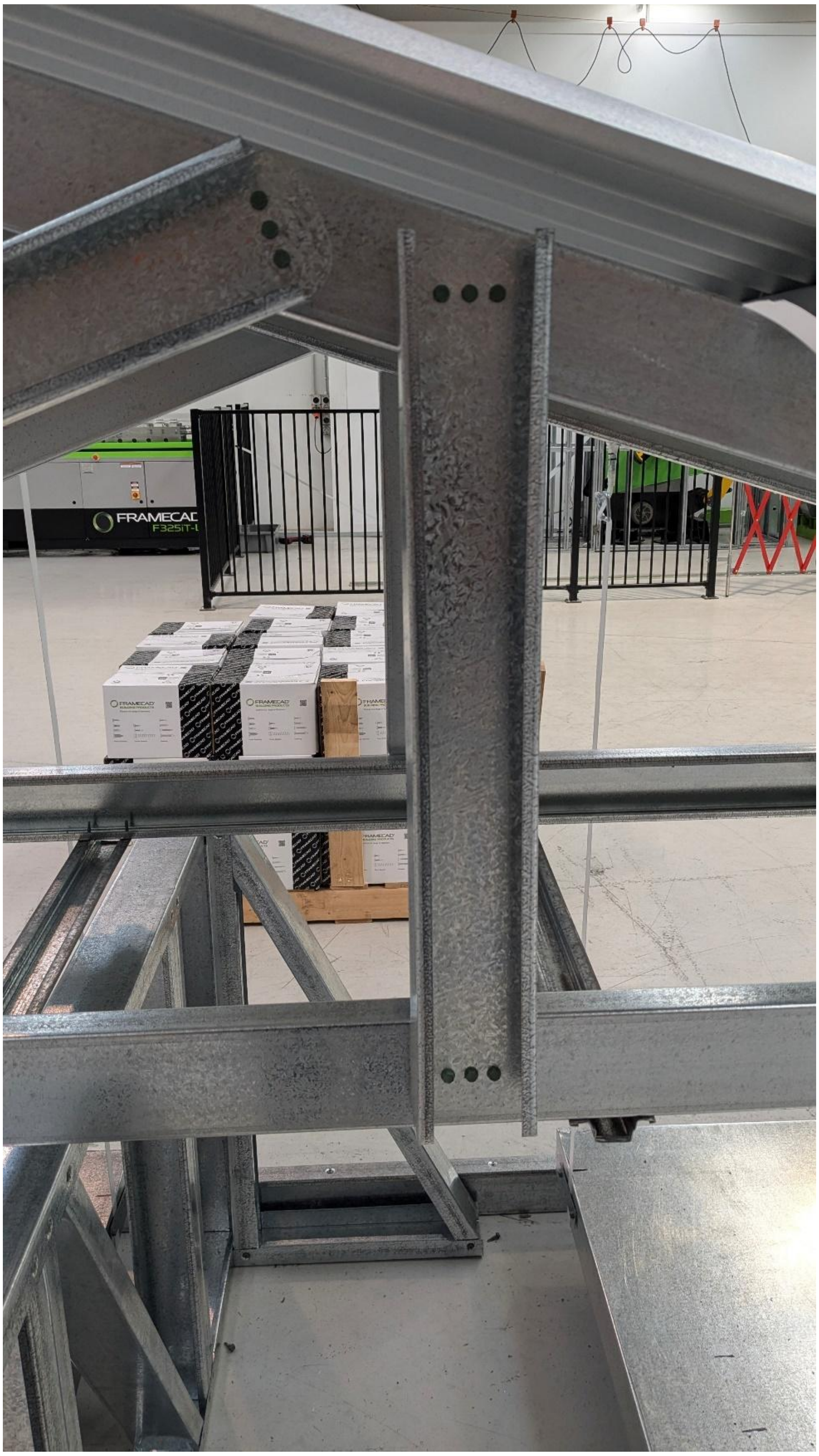
I	3	

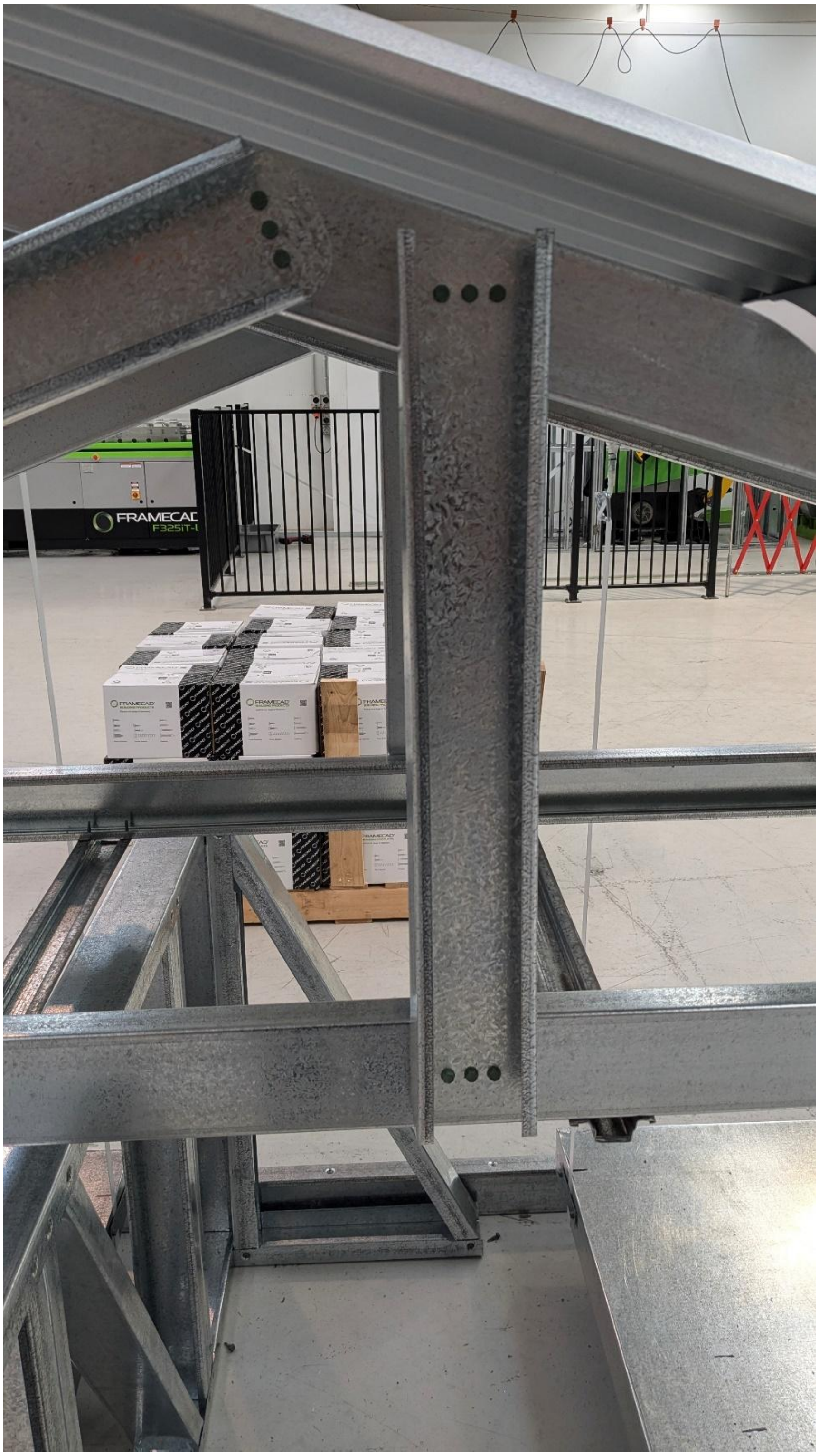
J	3	

K	3	

L	5	

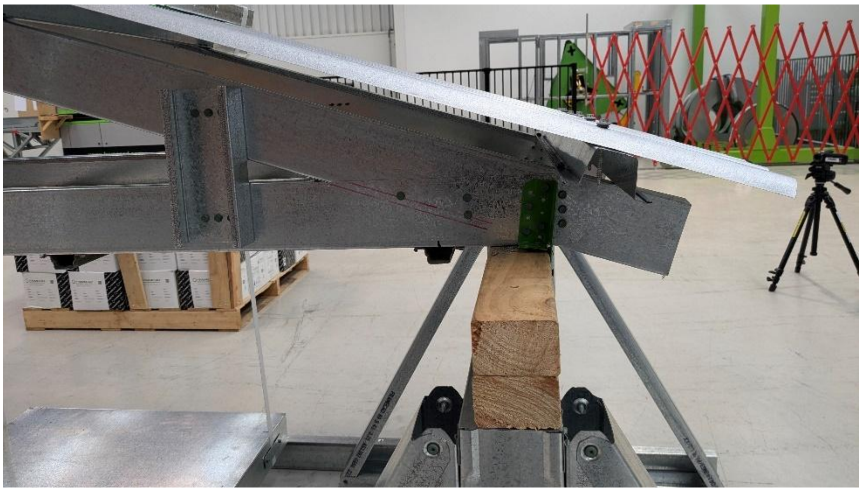
M	5	

N	3	

O	3	

P	3	

Q	3	

R	6 screws, 4 on bracket	

Test 5 – Truss 1

Joint	Number of Screws	Photo
A	5 screws, 4 on bracket	

B	3	
C	3	

<table>
<tr><td>D</td><td>3</td><td></td></tr>
<tr><td>E</td><td>3</td><td></td></tr>
</table>

F	5	
G	5	

H	7	

I	3	
J	6	

K	6	
L	5	

M	5	
N	6	

O	6	
P	3	

Q	3	
R	6 screws, 4 on bracket	

Test 5 – Truss 2

<u>Joint</u>	<u>Number of Screws</u>	<u>Photo</u>
A	6 screws, 4 on bracket	

B	3	
C	3	

D	3	

E	3	

F	3	

G	3	

H	7	

I	3	

J	3	

K	3	

L	5	

M	5	

N	3	

O	3	

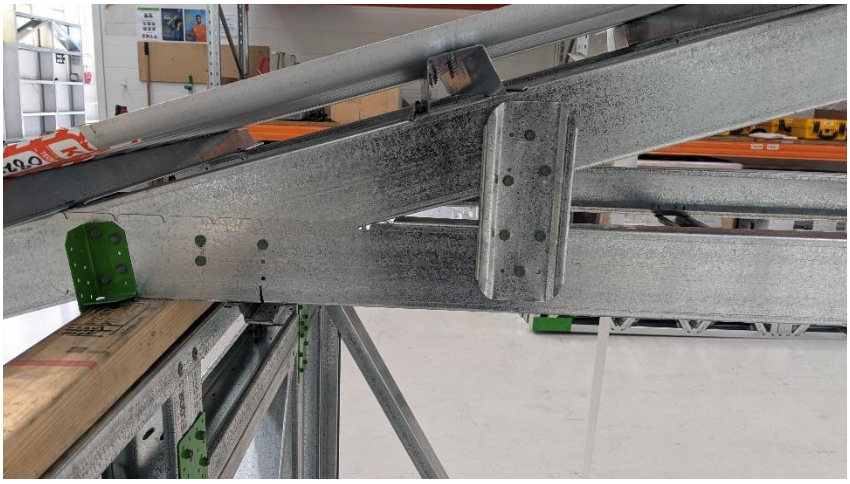
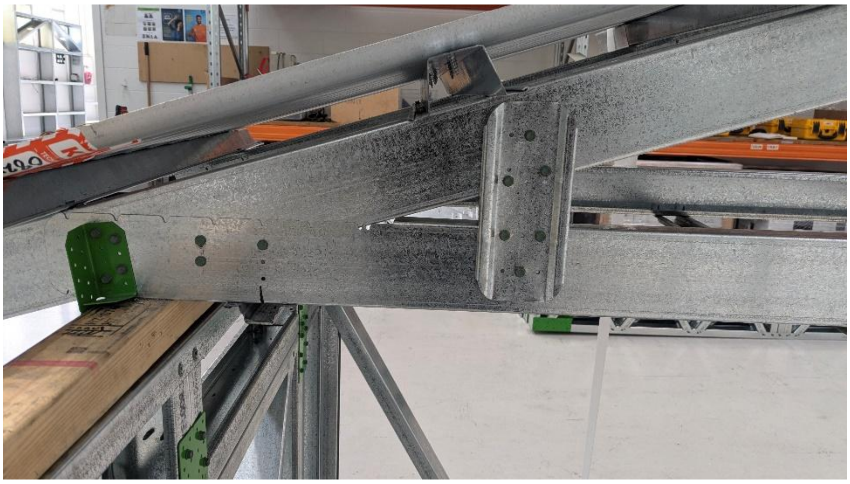
P	3	

Q	3	

R	5 screws, 4 on bracket	

Test 6 – Truss 1

Joint	Number of Screws	Photo
A	6 screws, 4 on bracket	

B	3	
C	3	
D	4	

		
E	3	

		
F	4	

		
G	5	

		
H	7	

		
I	3	

		
J	6	

		
K	6	

		
L	5	

		
M	5	

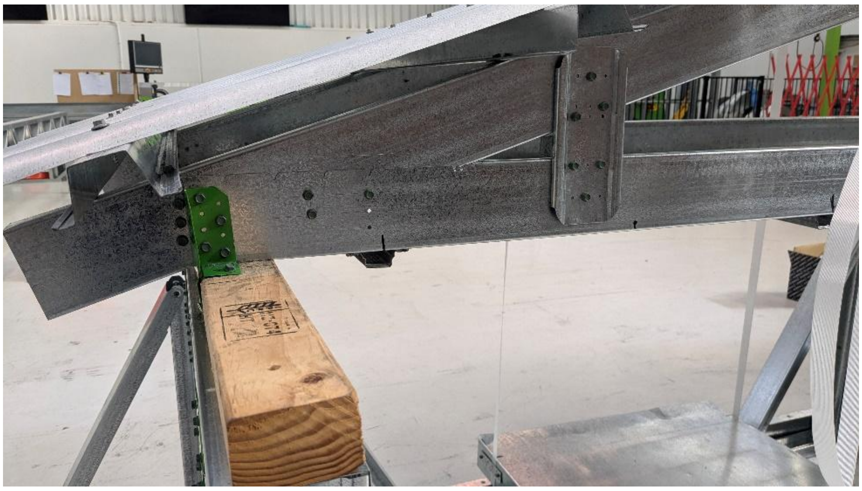
		
N	6	

		
O	6	

		
P	3	

		
Q	3	
R	6 screws, 4 on bracket	

Test 6 – Truss 2

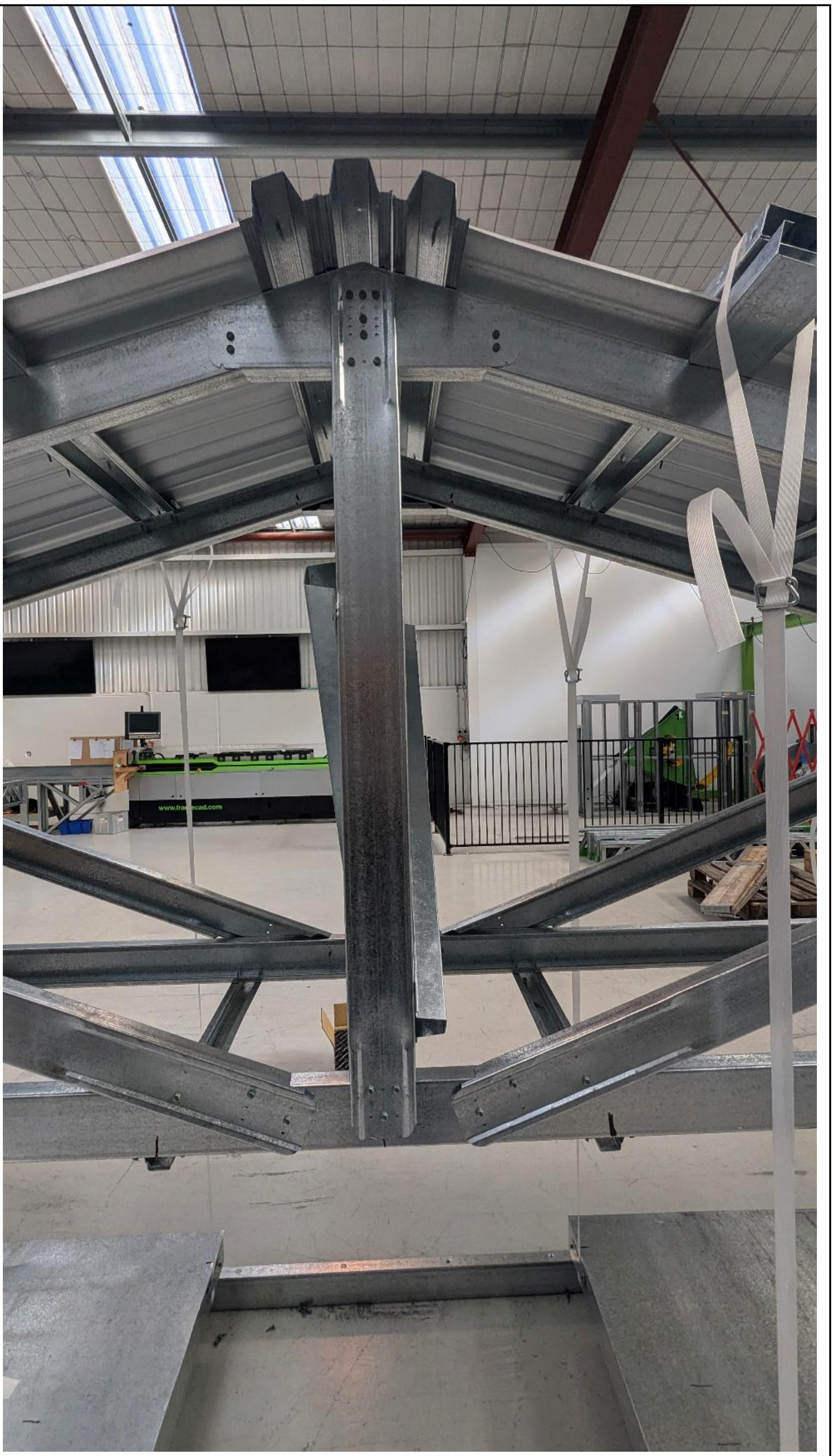
Joint	Number of Screws	Photo
A	6 screws, 4 on bracket	
B	3	
C	3	

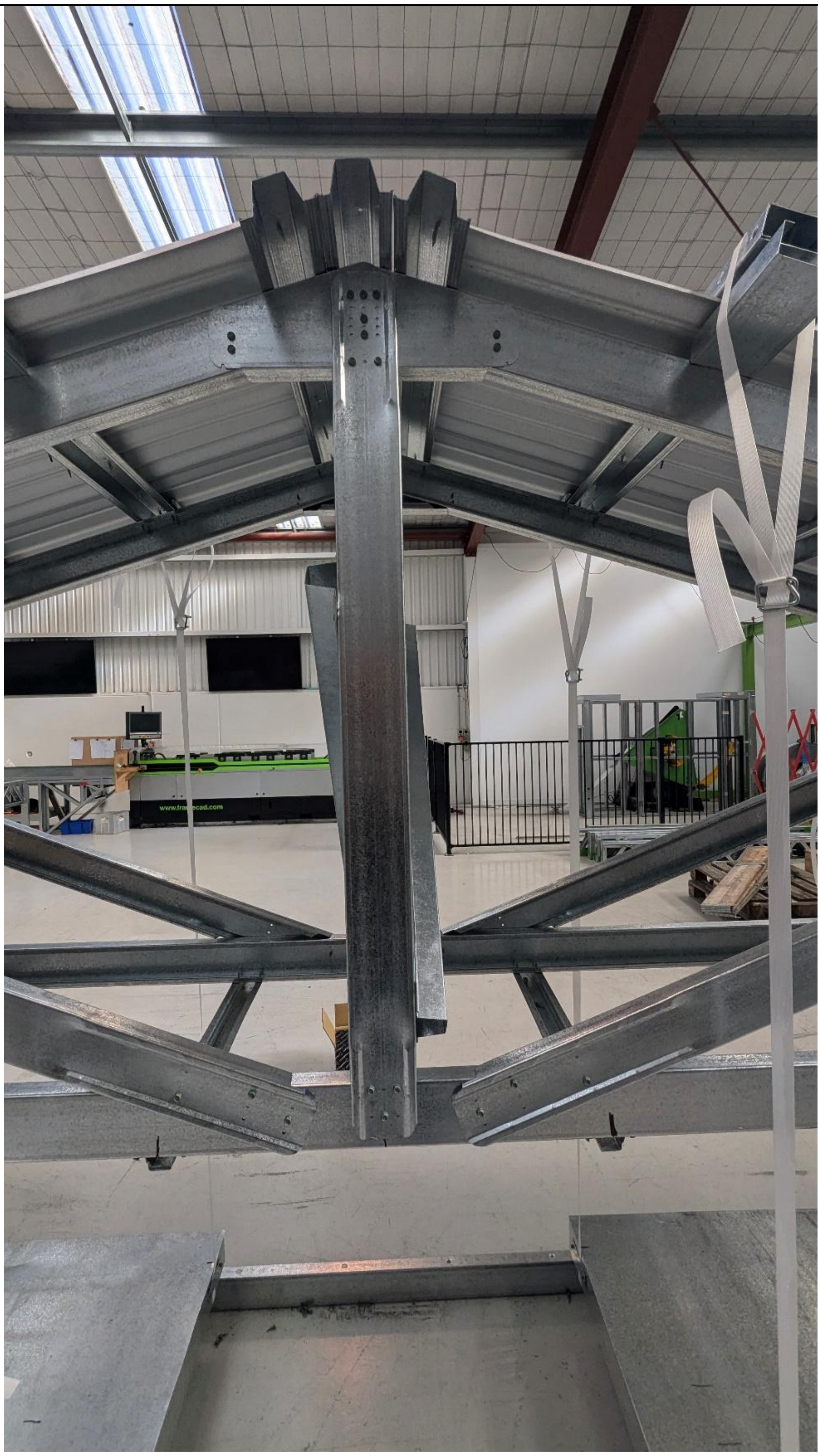
		
D	4	

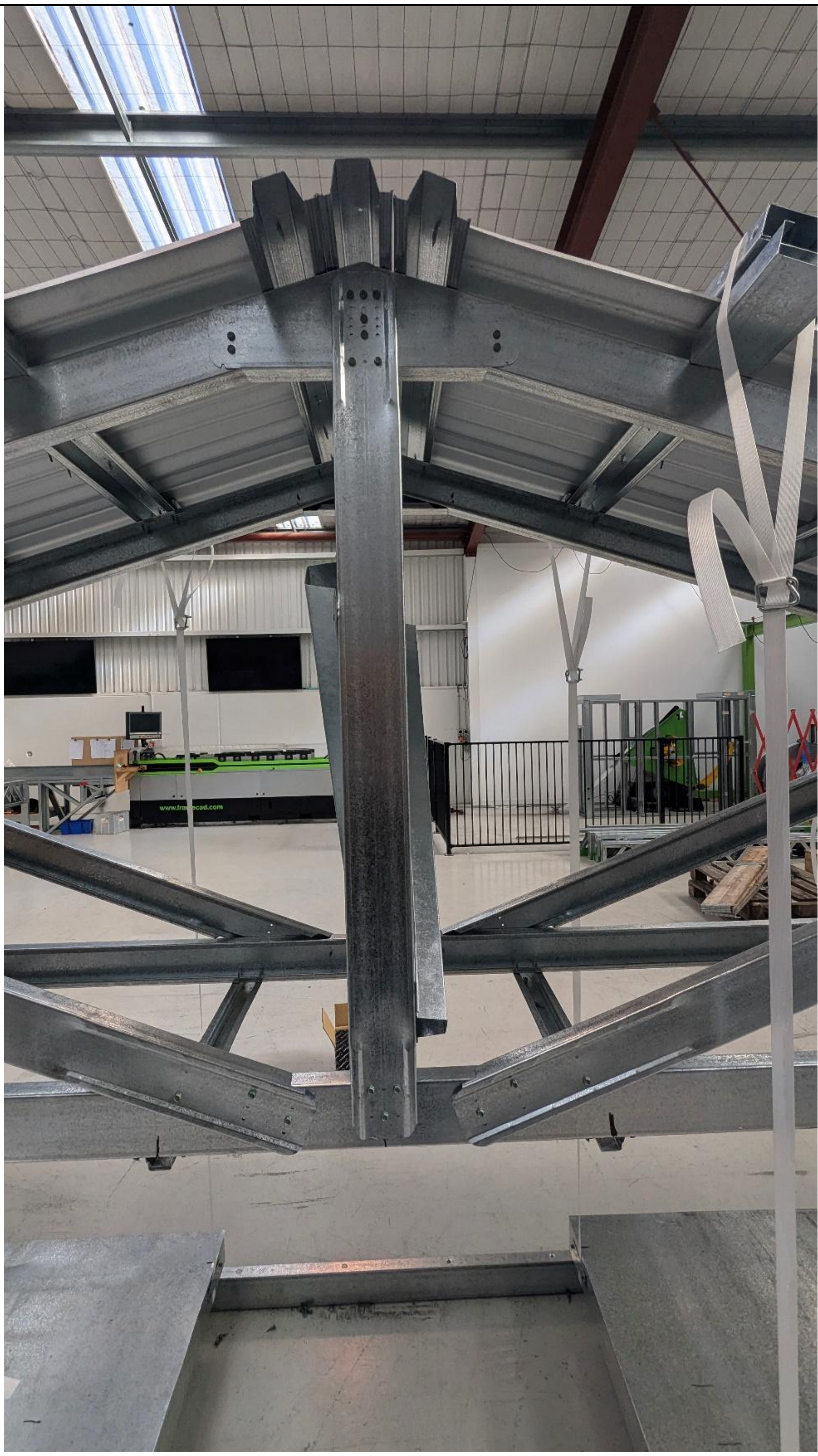
		
E	3	

		
F	4	

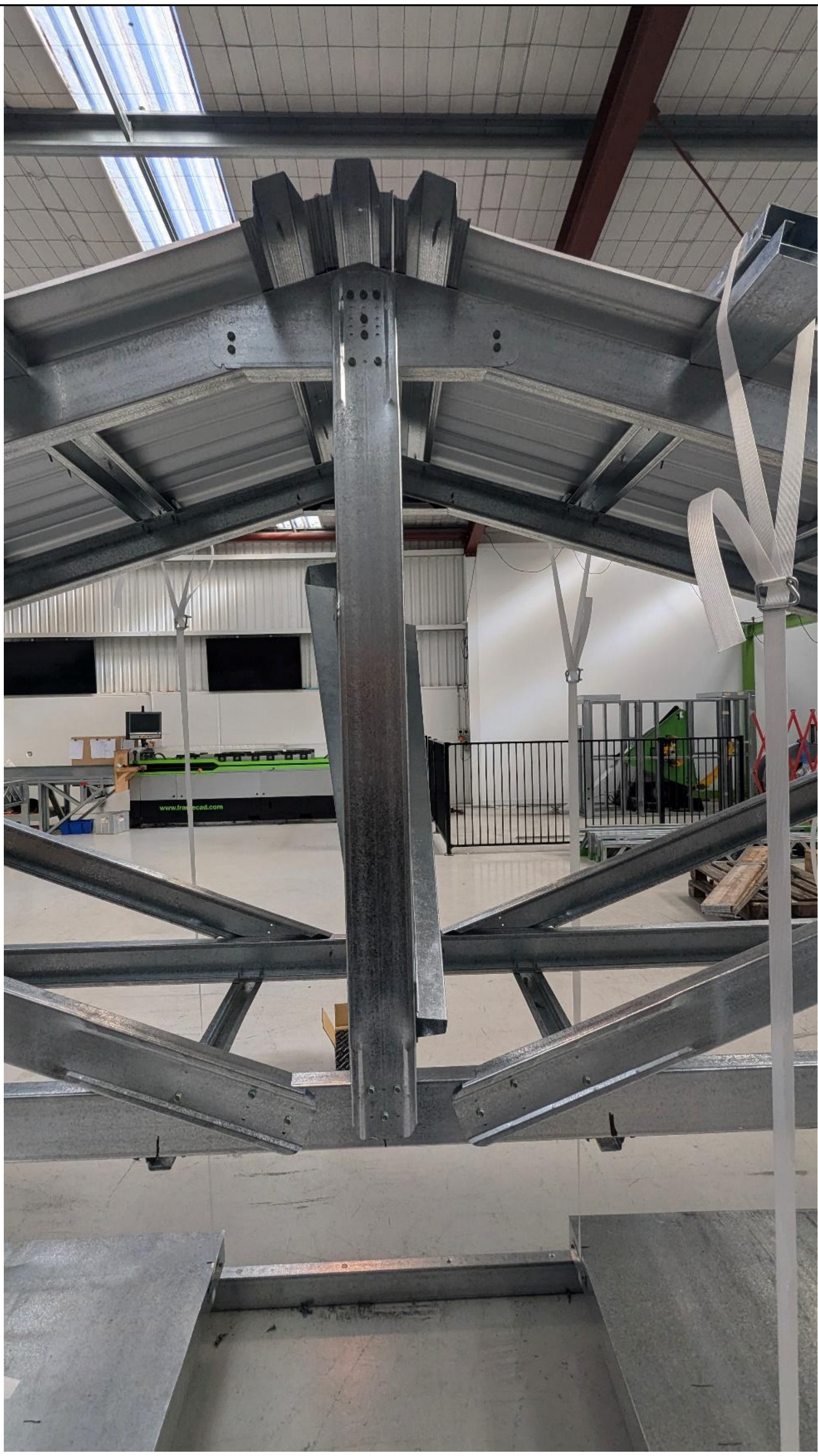
<table>
<tr><td></td><td></td><td>
</td></tr>
<tr><td>G</td><td>3</td><td></td></tr>
</table>

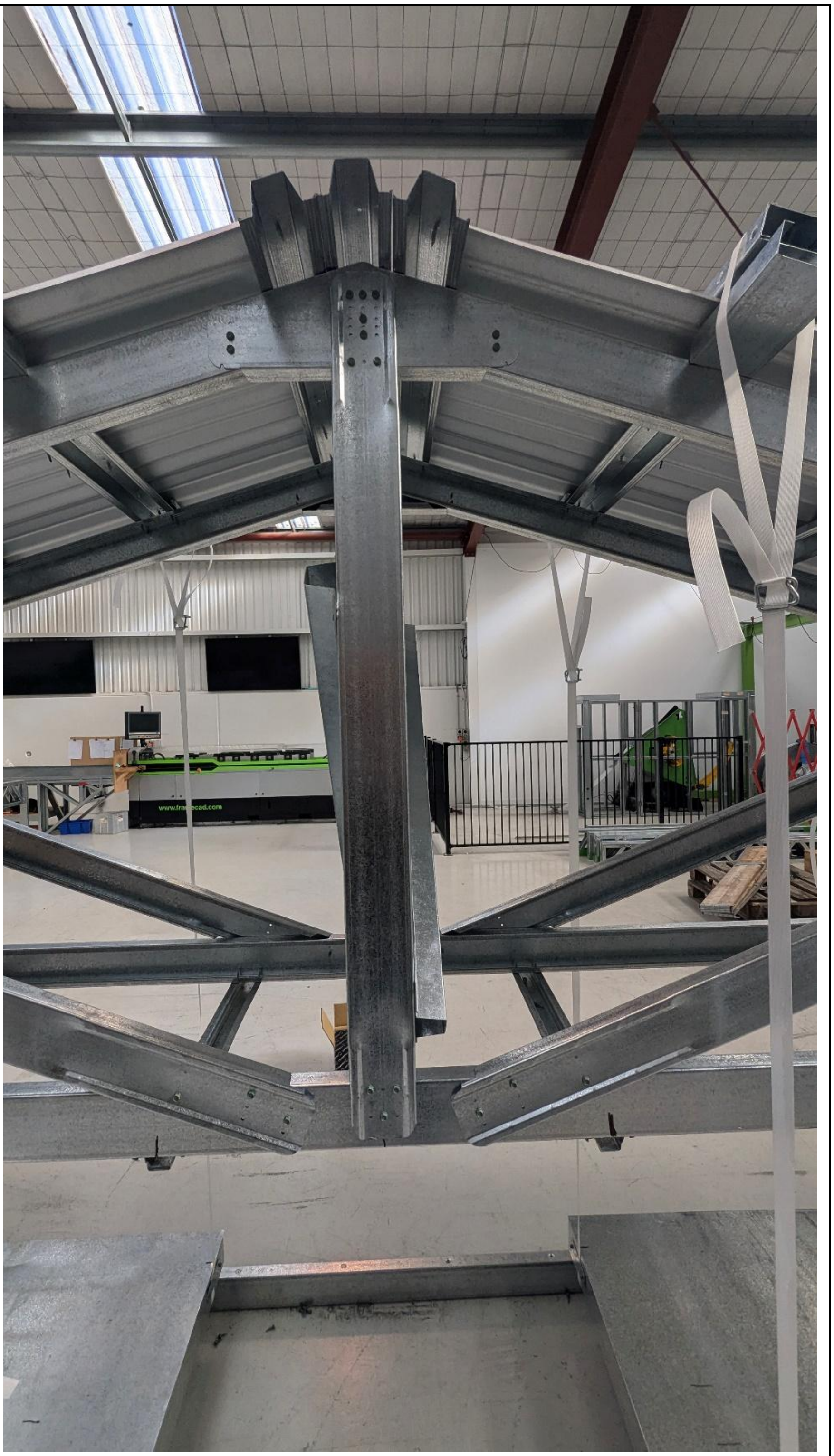
		
H	7	

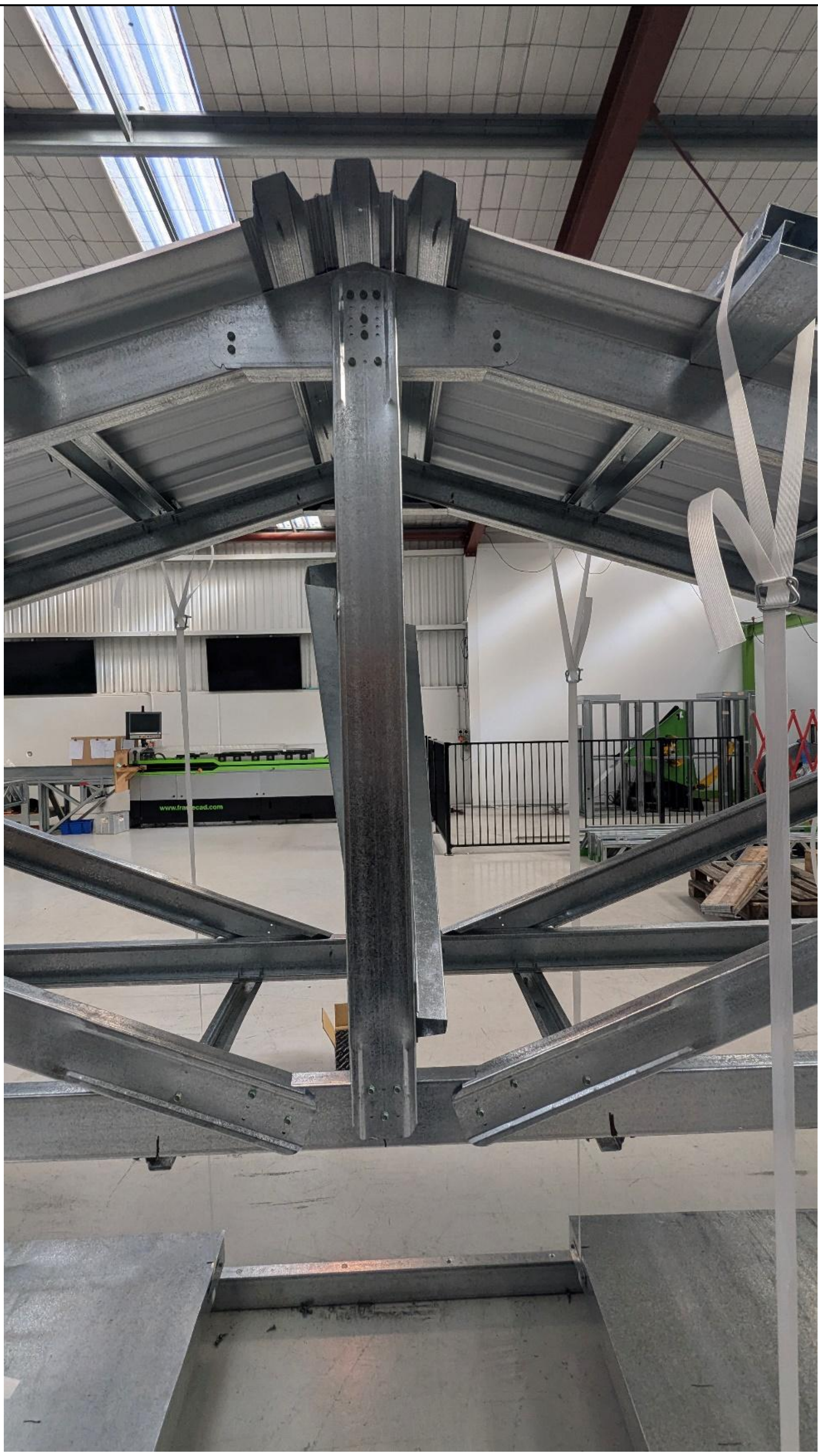
		
I	3	

		
J	4	

		
K	3	

		
L	2	

		
M	2	

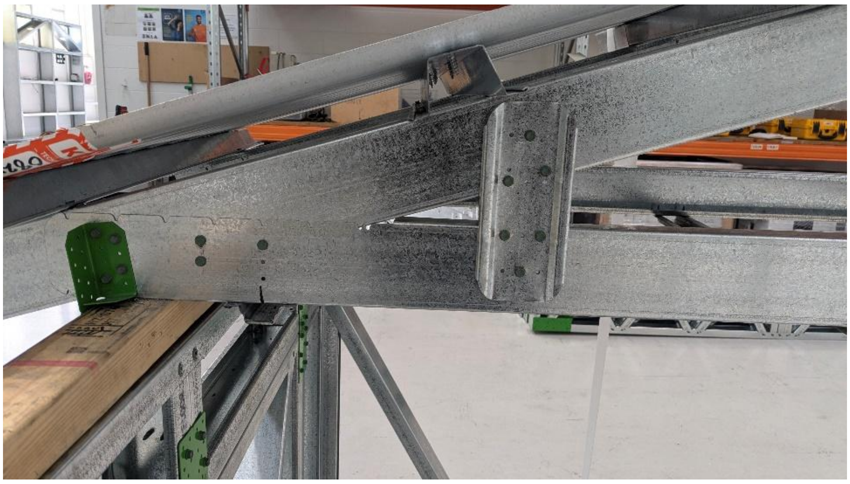
		
N	4	

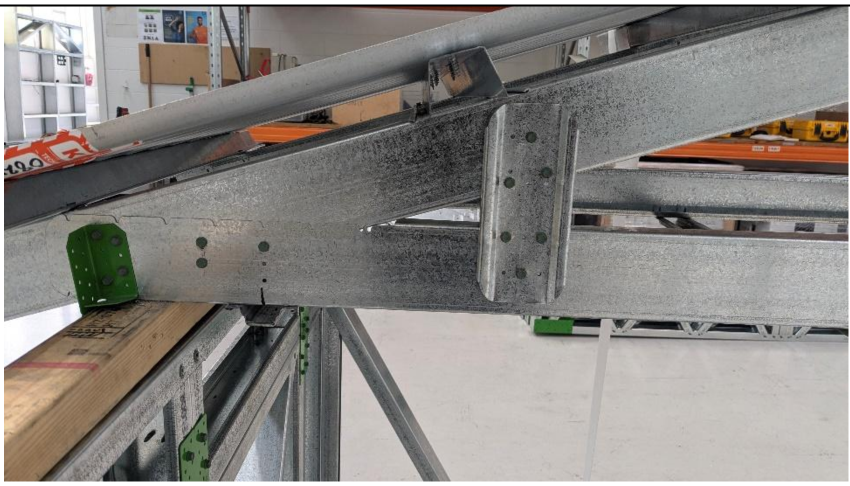
		
O	3	

		
P	3	

		
Q	3	
R	6 screws, 4 on bracket	

Test 7 – Truss 1

Joint	Number of Screws	Photo
A	6 screws, 4 on bracket	
B	3	
C	3	

		
D	4	

		
E	3	

		
F	4	

		
G	5	

		
H	7	

		
I	3	

		
J	6	

		
K	6	

		
L	5	

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>M</td><td>5</td><td></td></tr>
</table>

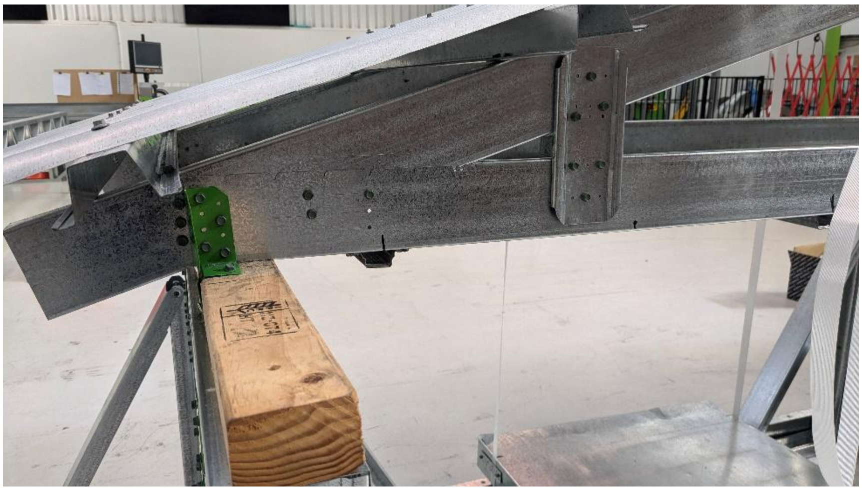
		
N	6	

		
O	6	

		
P	3	

		
Q	3	
R	6 screws, 4 on bracket	

Test 7 – Truss 2

<table>
<tr><th><u>Joint</u></th><th><u>Number of Screws</u></th><th><u>Photo</u></th></tr>
<tr><td>A</td><td>6 screws, 4 on bracket</td><td></td></tr>
<tr><td>B</td><td>3</td><td></td></tr>
<tr><td>C</td><td>3</td><td></td></tr>
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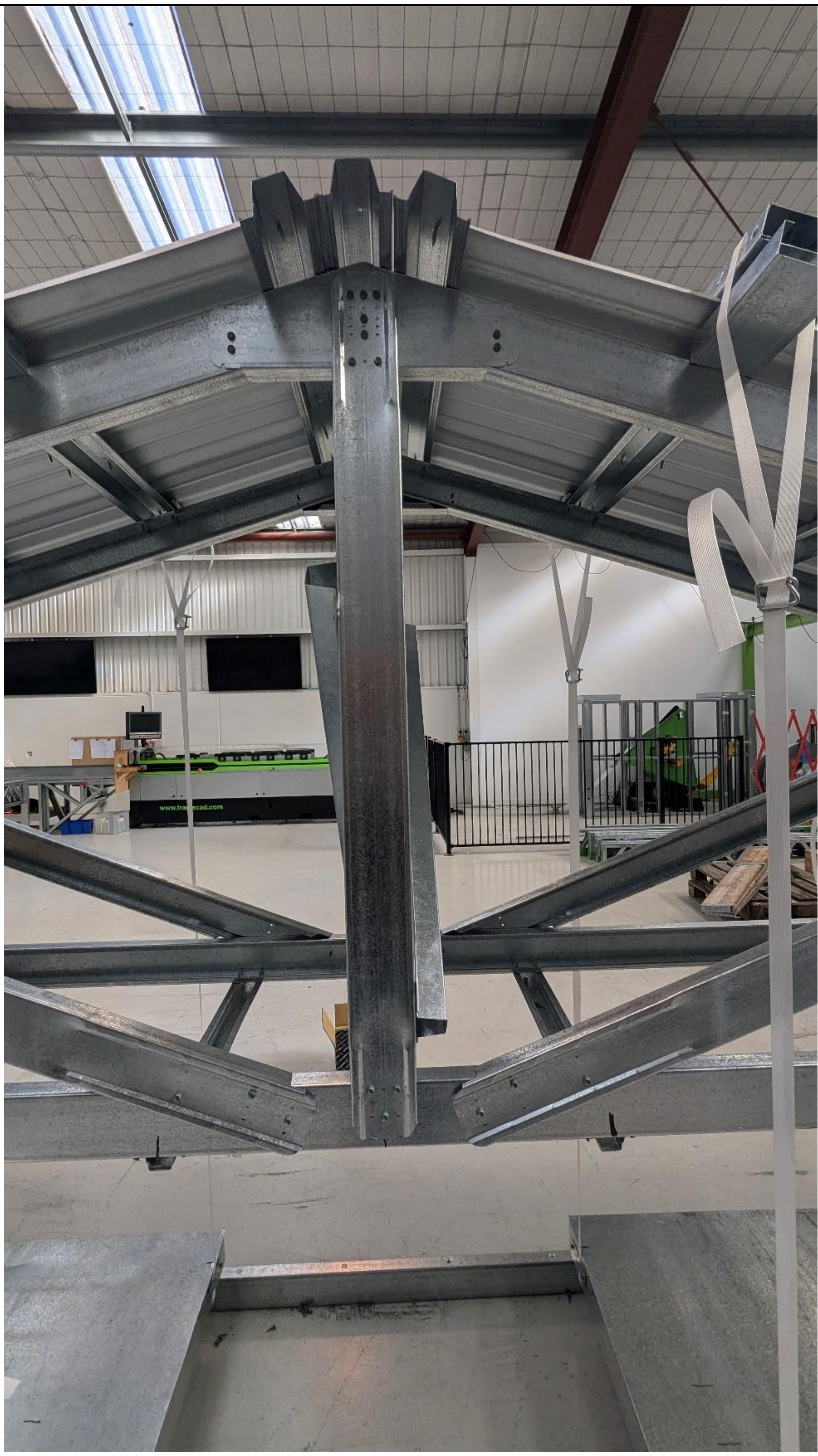
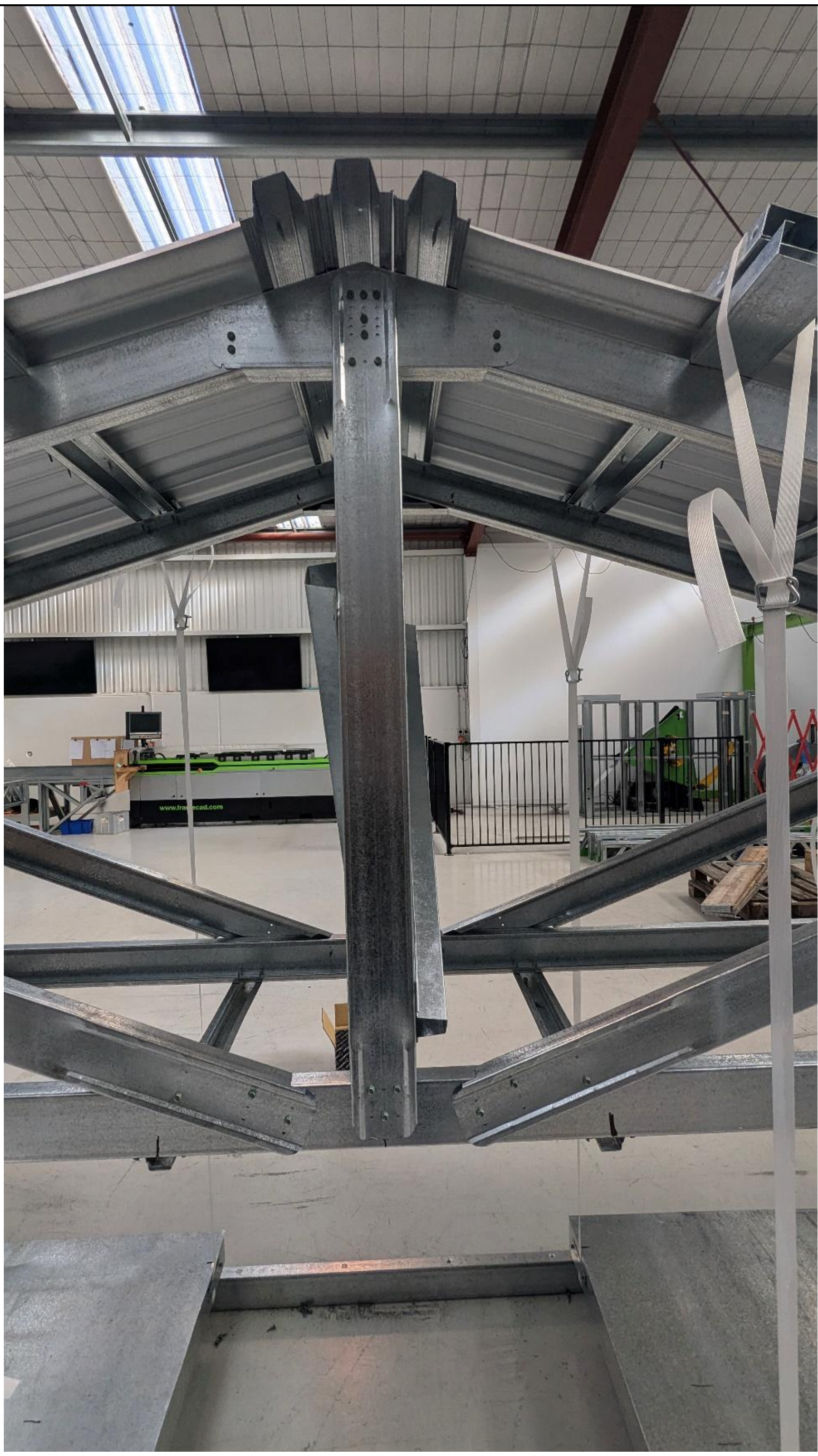
D	4	

		
E	3	

		
F	4	

		
G	3	

		
H	7	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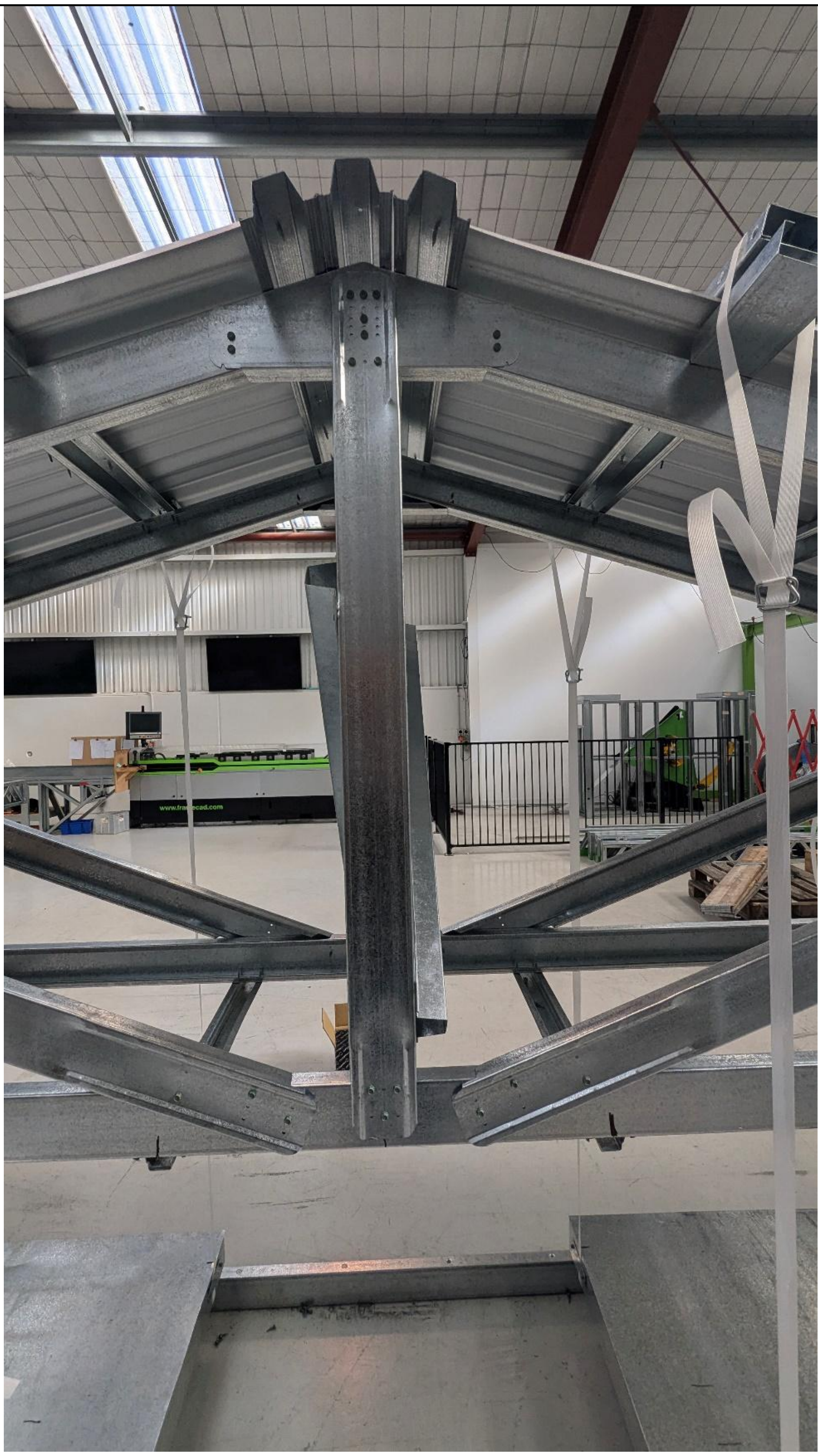
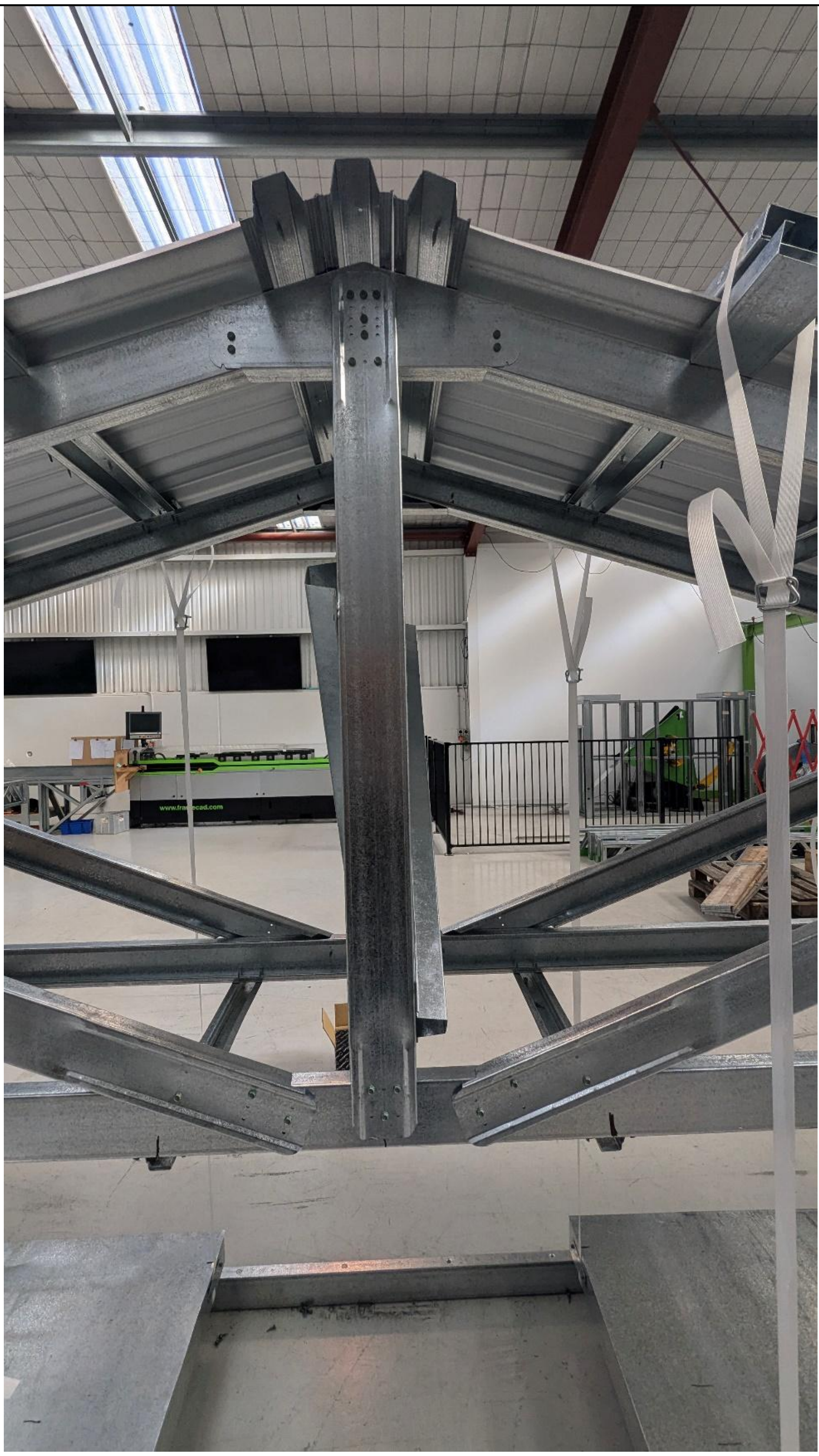
		
J	4	

		
K	3	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		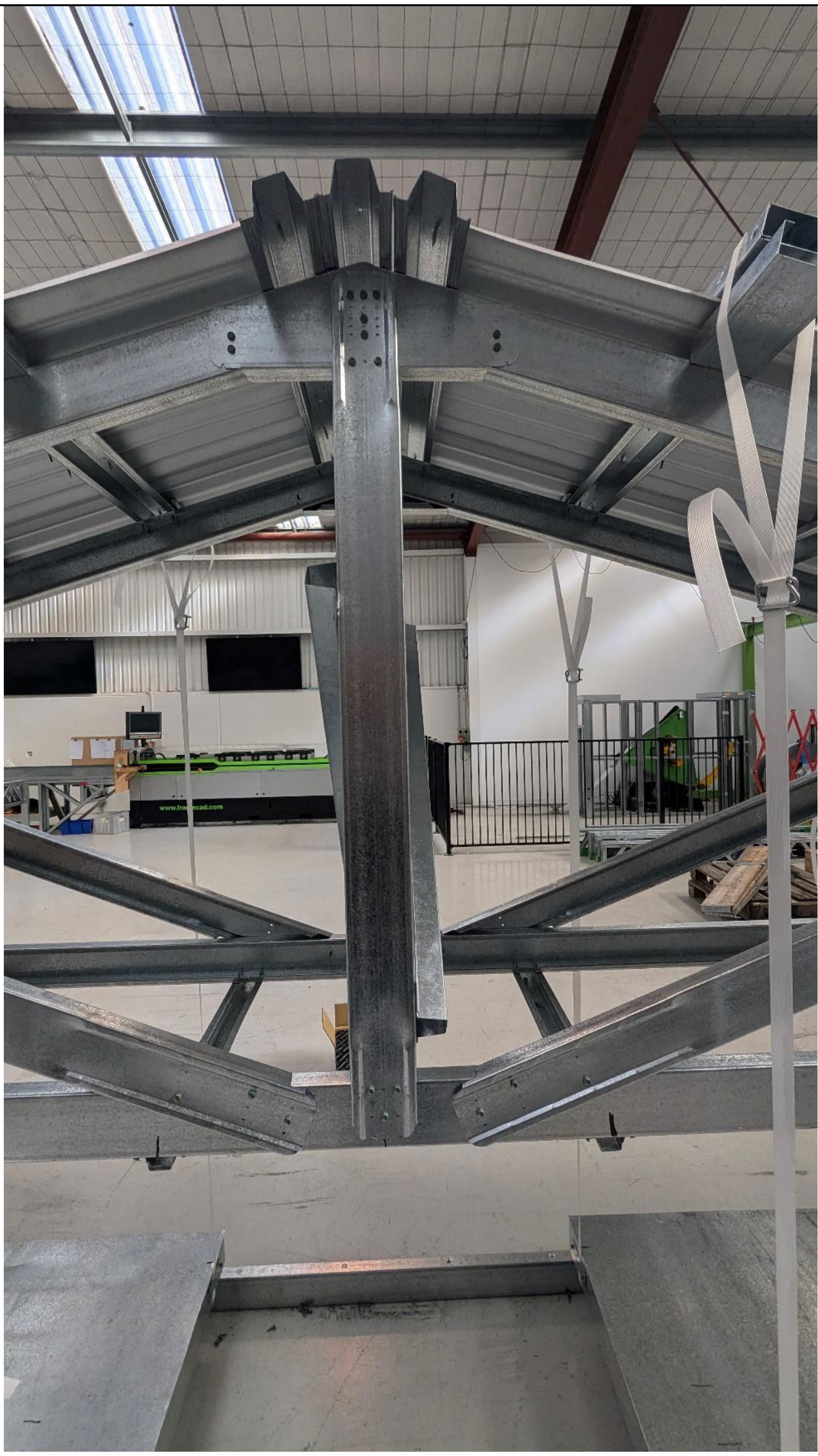
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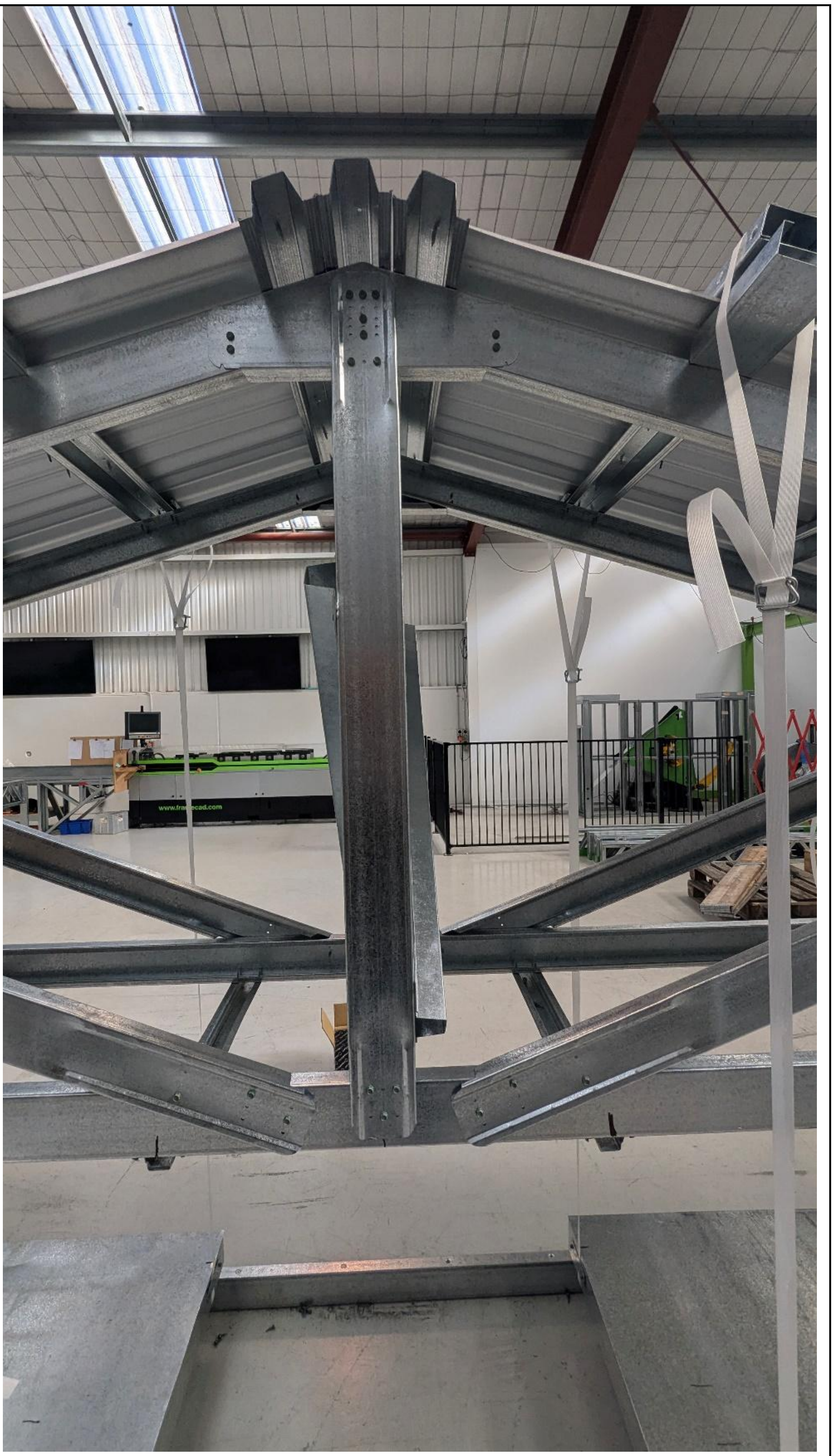
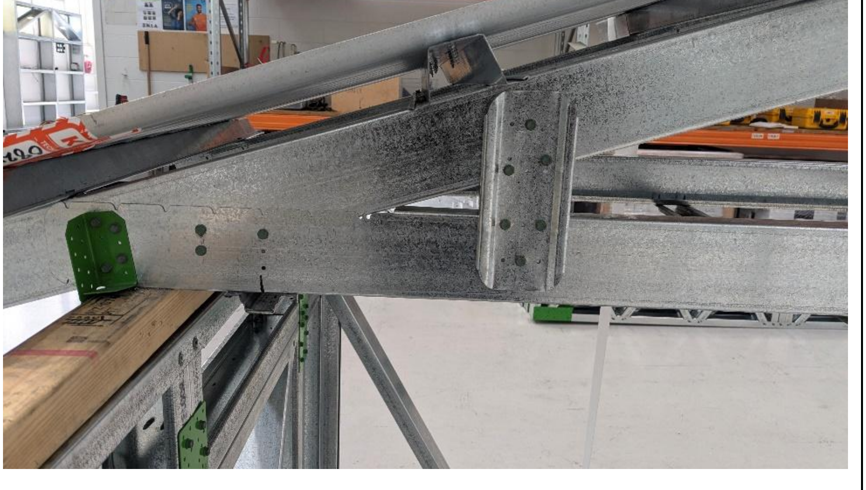
		
N	4	

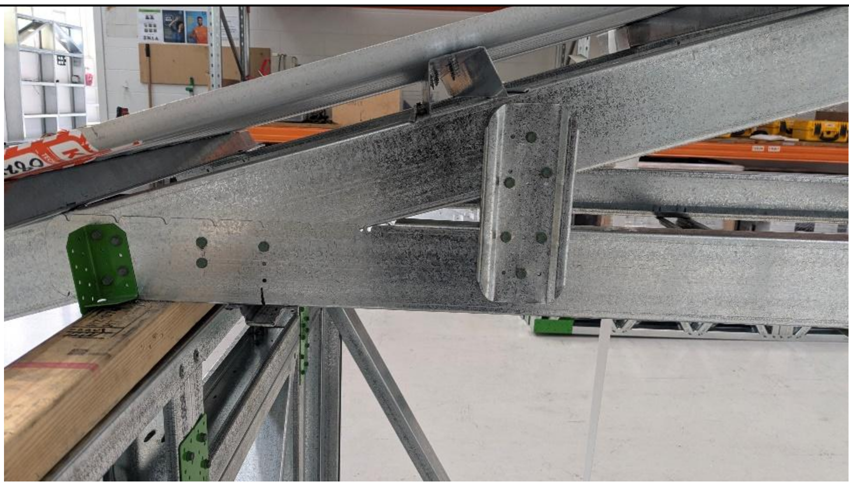
		
O	3	

		
P	3	

		
Q	3	
R	6 screws, 4 on bracket	

Test 8 – Truss 1

Joint	Number of Screws	Photo
A	6 screws, 4 on bracket	
B	3	
C	3	

		
D	4	

		
E	3	

		
F	4	

		
G	5	

		
H	7	

		
I	3	

		
J	6	

		
K	6	

		
L	5	

		
M	5	

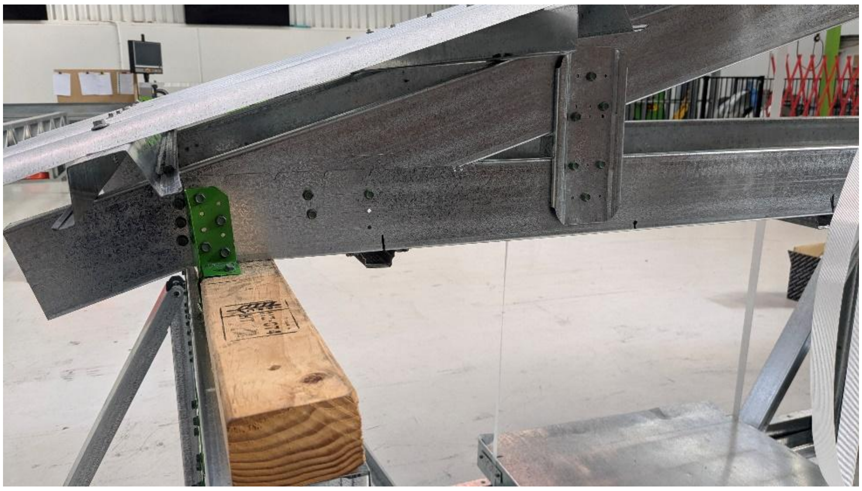
		
N	6	

		
O	6	

		
P	3	

		
Q	3	
R	6 screws, 4 on bracket	

Test 8 – Truss 2

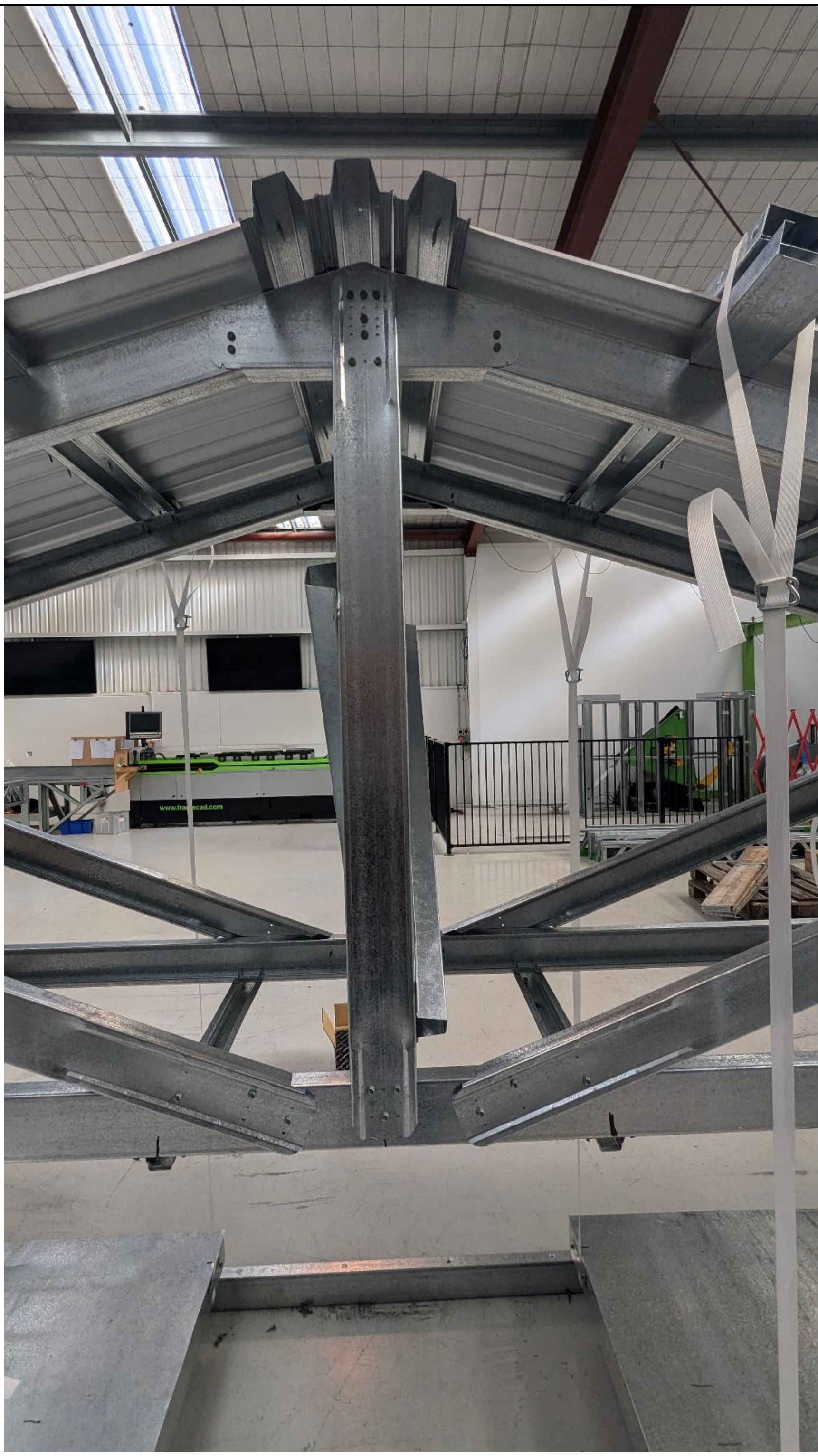
Joint	Number of Screws	Photo
A	6 screws, 4 on bracket	
B	3	
C	3	

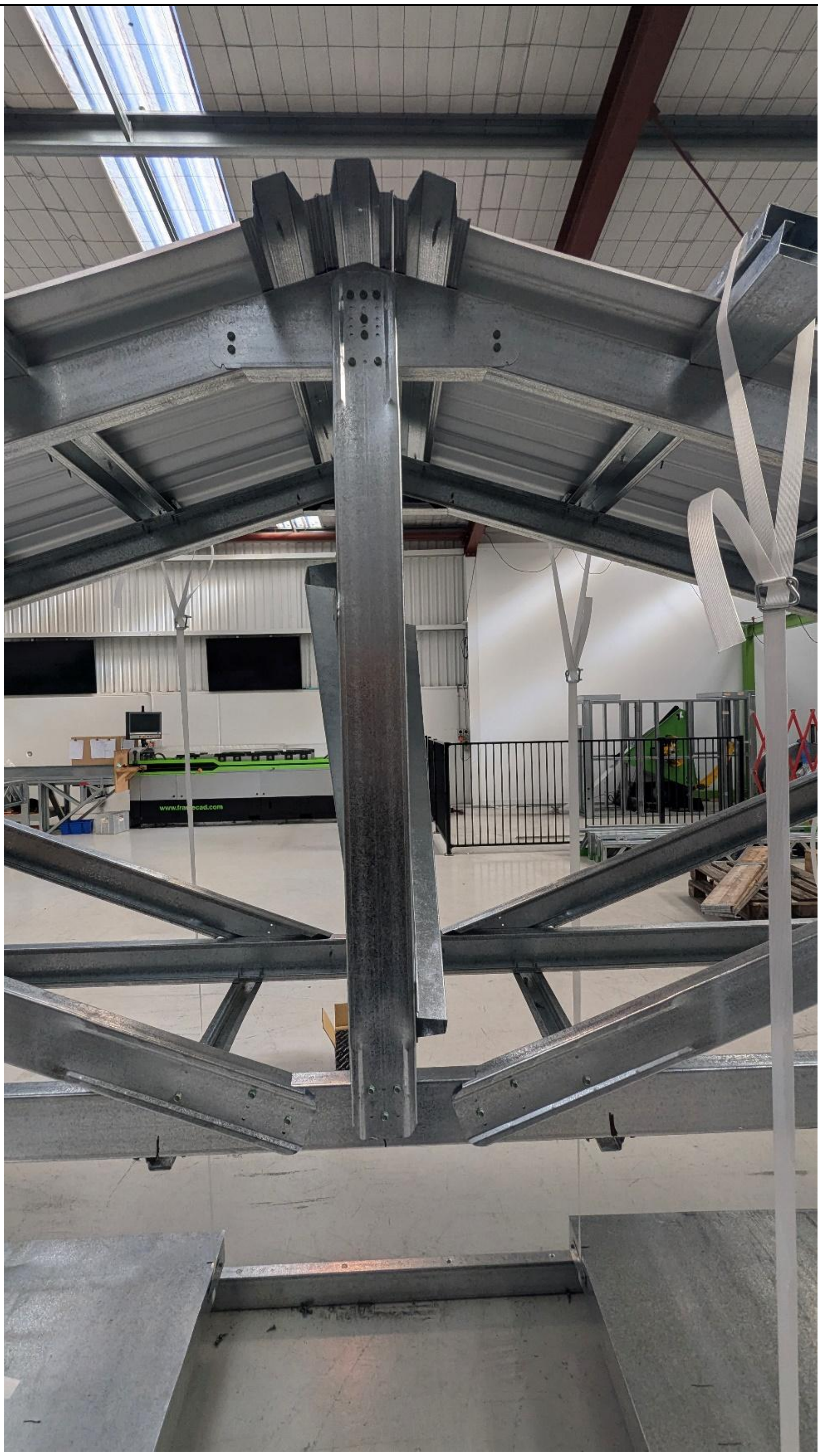
		
D	4	

		
E	3	

		
F	4	

		
G	3	

		
H	7	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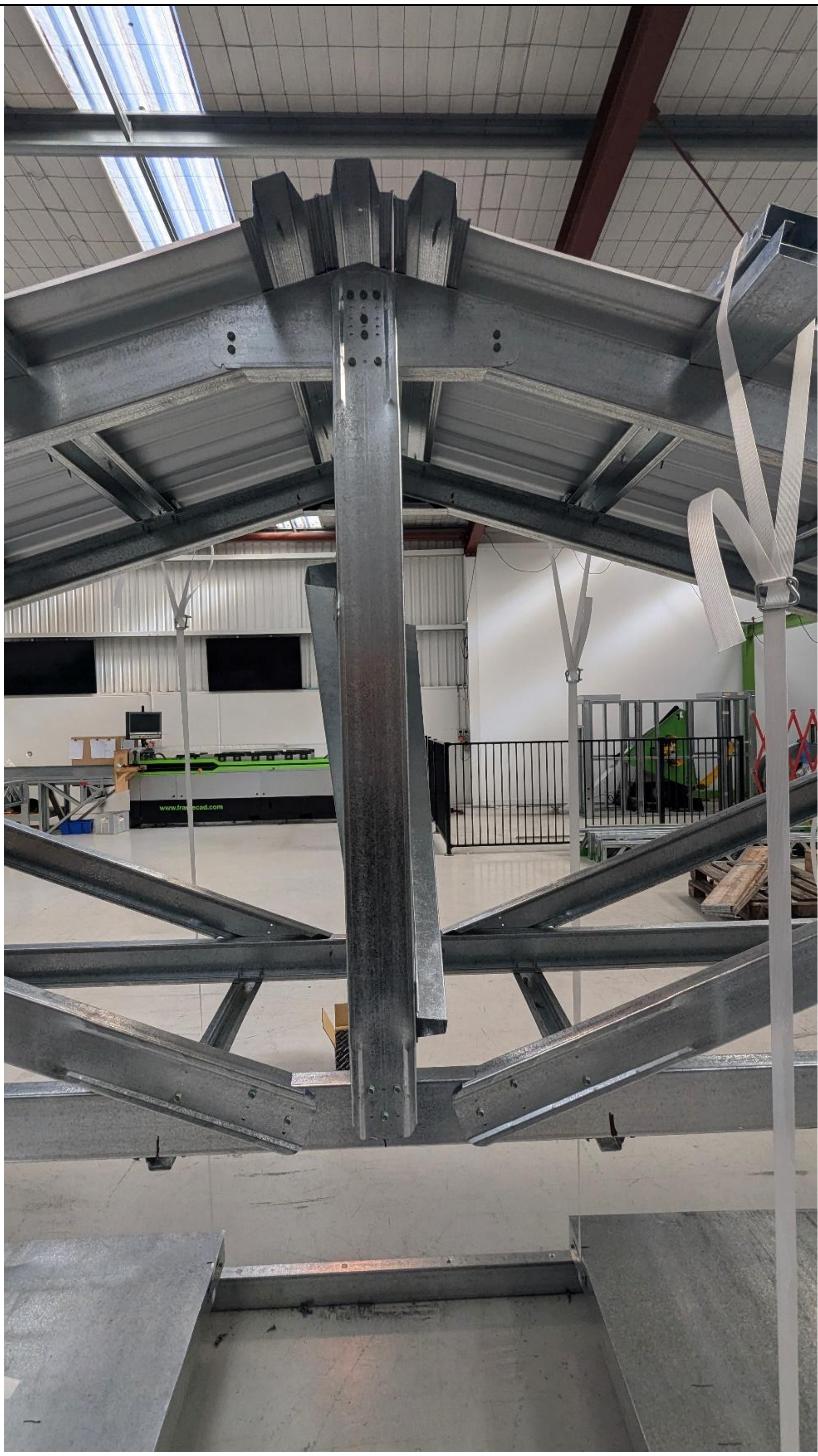
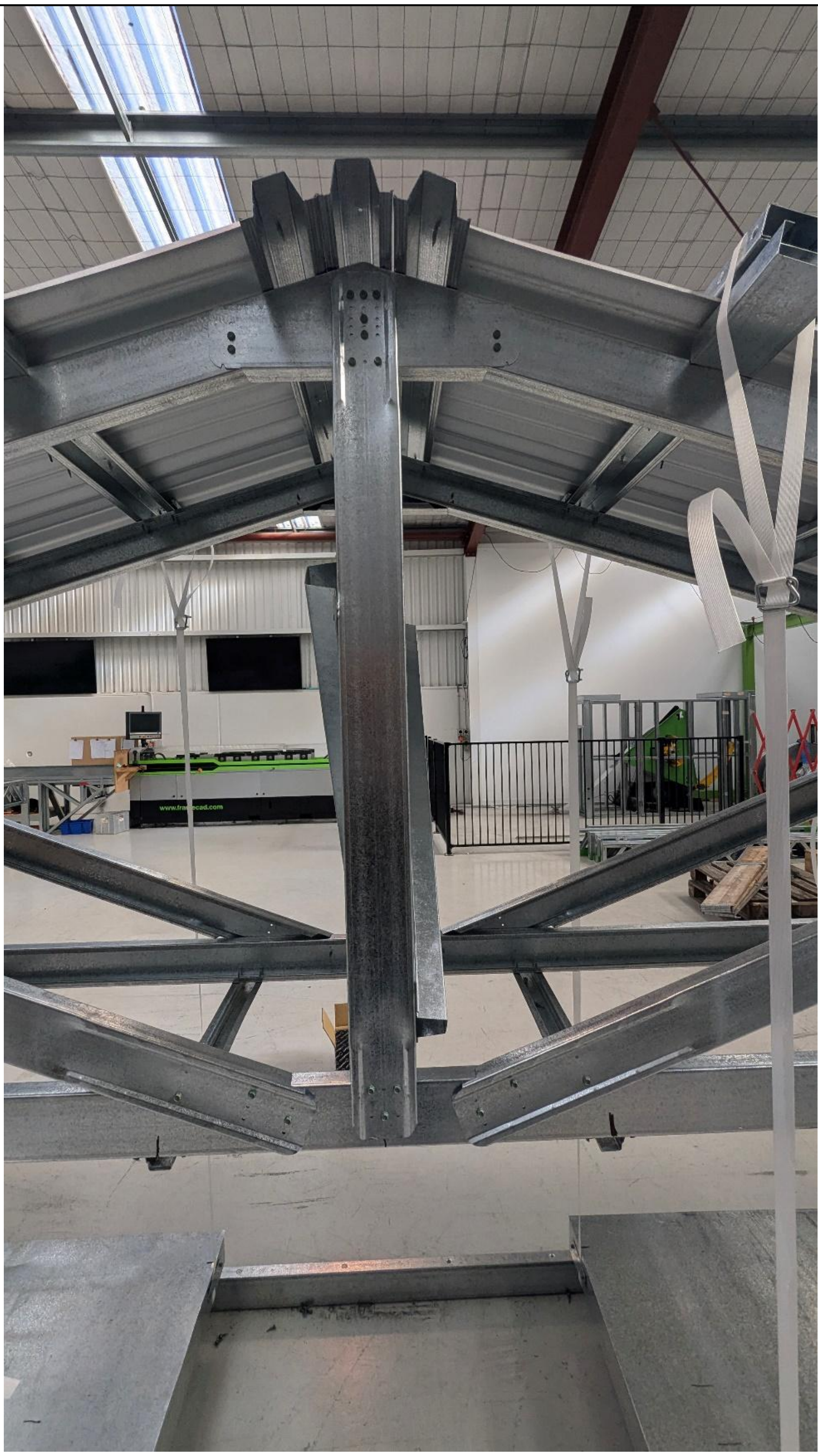
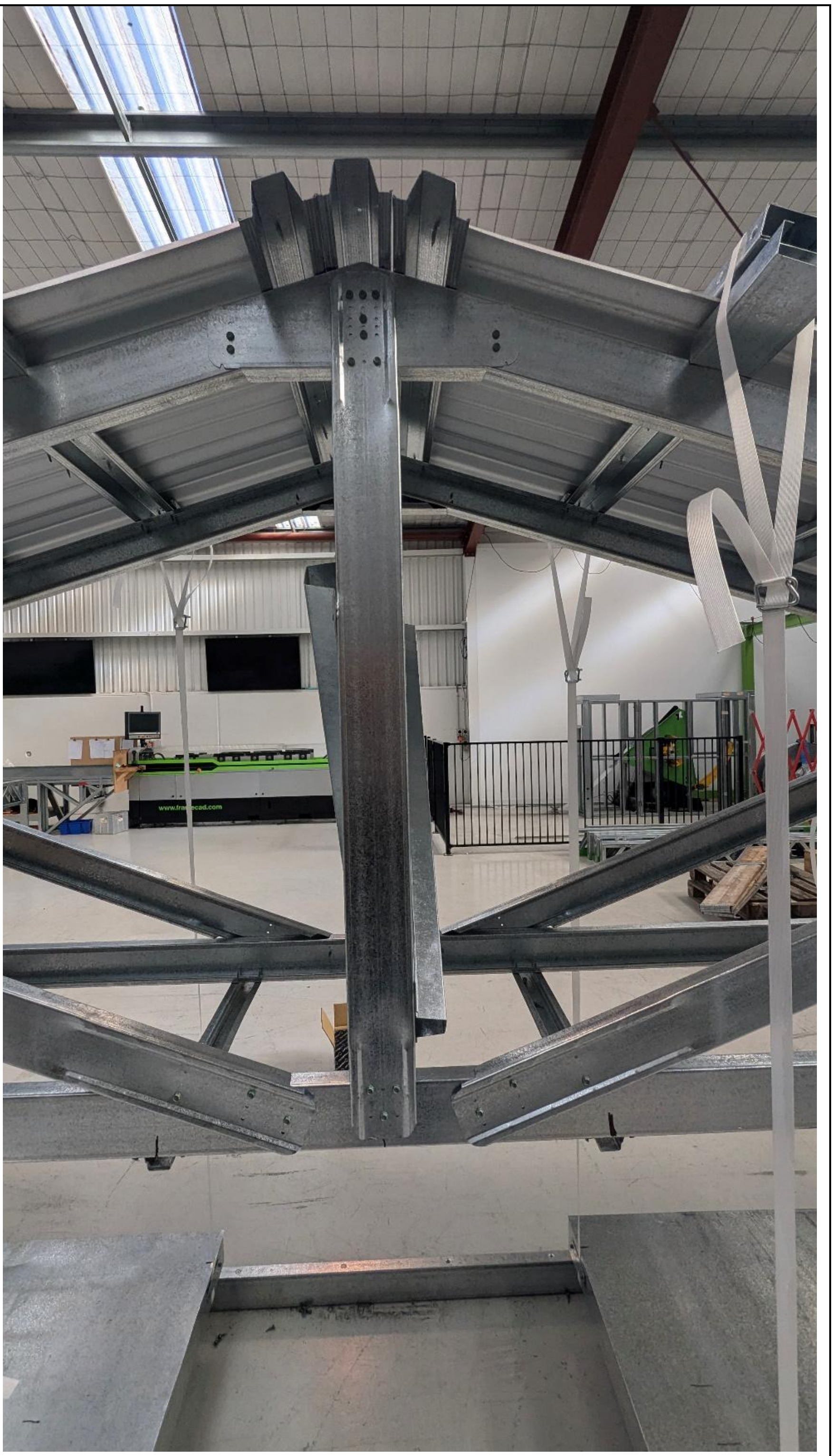
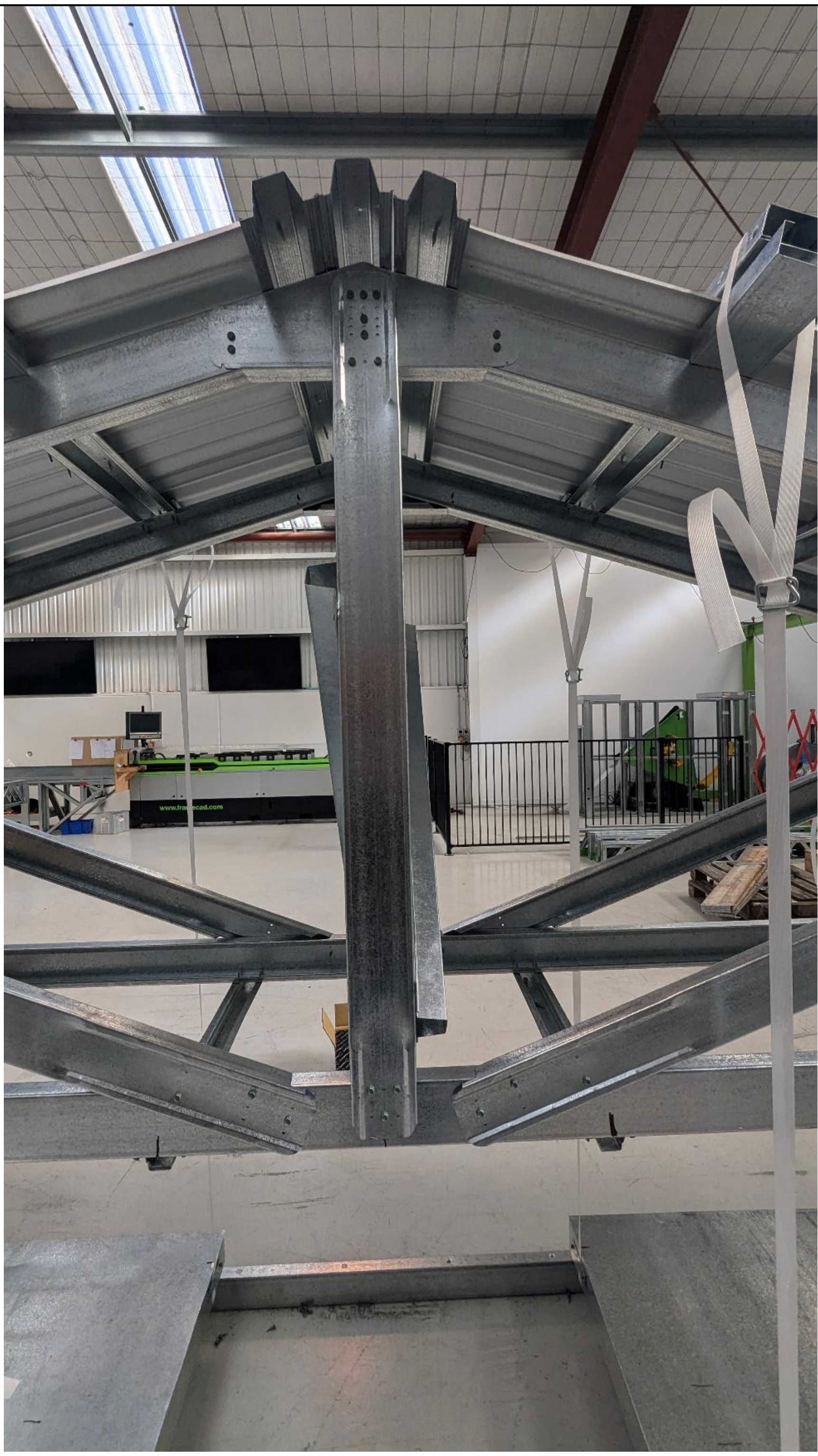
		
J	4	

		
K	3	

		
L	2	

		
M	2	

		
N	4	

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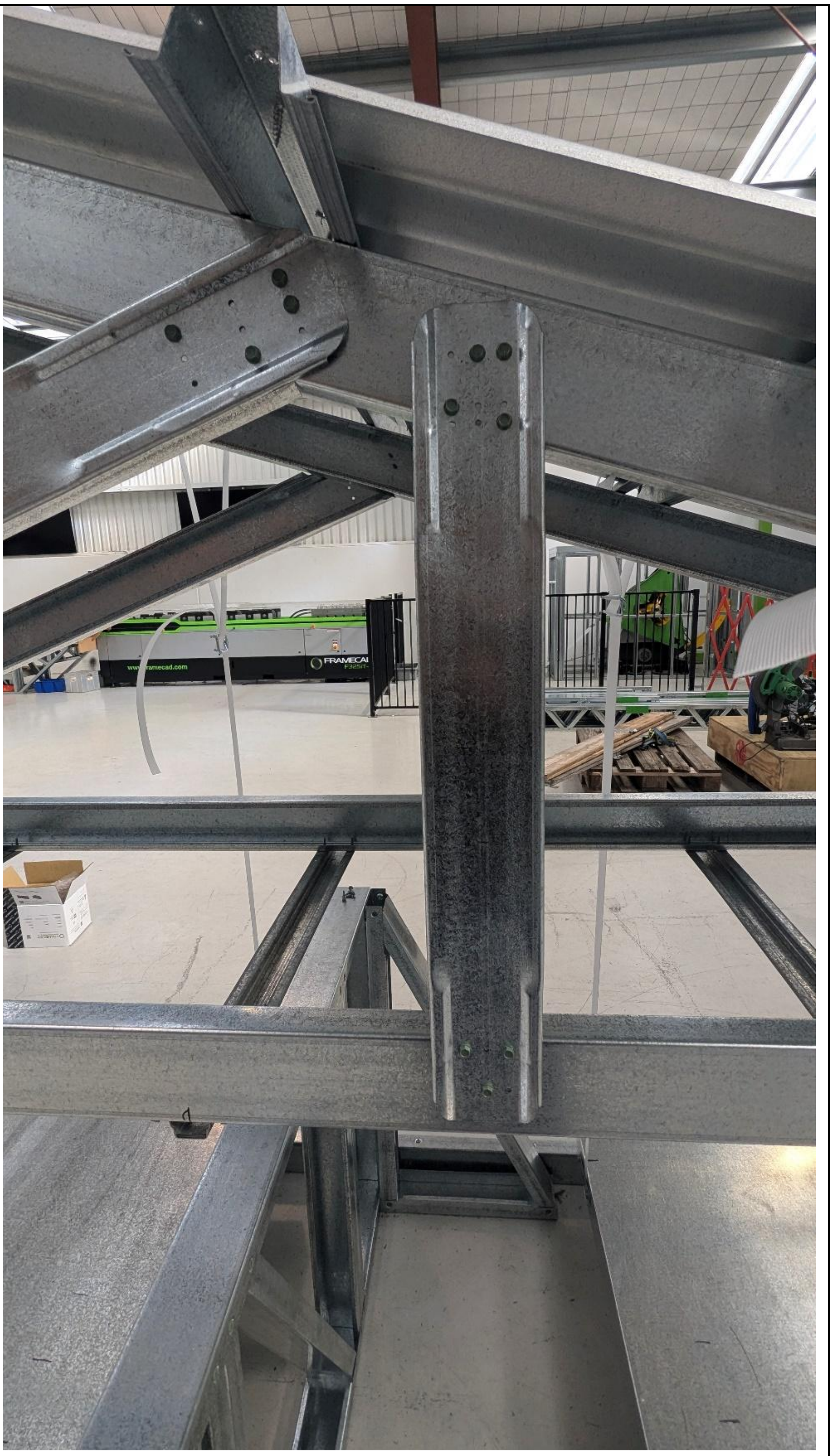
<tr><td></td><td></td><td>
</td></tr>
<tr><td>O</td><td>3</td><td></td></tr>
</table>

		
P	3	

		
Q	3	
R	6 screws, 4 on bracket	

Appendix B

800mm Design Truss

Node Results LC4 (1.2G + 1.5Q)

ID	X Displacment (mm)	Y Displacement (mm)	Resultant (mm)	Max X Reaction (kN)	Max Y Reaction (kN)	Joint Load (kN)	Joint Capacity (kN)
1	-0.33	1.09	1.14	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	-4.18	11.32	12.01
3	0.09	-1.86	1.86	0.00	0.00	0.00	0.00
4	0.45	-1.80	1.85	0.00	0.00	0.00	0.00
5	0.17	-3.55	3.56	0.00	0.00	0.71	4.61
6	0.89	-3.56	3.67	0.00	0.00	0.71	4.61
7	1.52	-6.2	6.3	0.00	0.00	0.00	0.00
8	0.44	-7.1	7.1	0.00	0.00	0.00	0.00
9	1.84	-7.7	7.9	0.00	0.00	0.00	0.00
10	1.90	-8.6	8.8	0.00	0.00	0.00	0.00
11	0.71	-8.6	8.7	0.00	0.00	0.15	4.61
12	1.82	-8.6	8.8	0.00	0.00	0.15	4.61
13	1.79	-8.7	8.9	0.00	0.00	3.55	4.61
14	1.84	-9.3	9.5	0.00	0.00	0.00	0.00
15	1.04	-9.3	9.3	0.00	0.00	0.00	0.00
16	1.82	-9.6	9.8	0.00	0.00	0.00	0.00
17	1.60	-9.4	9.5	0.00	0.00	0.00	0.00
18	1.44	-9.1	9.2	0.00	0.00	5.42	6.09
19	1.37	-9.2	9.3	0.00	0.00	3.55	4.61
20	1.41	-9.1	9.2	0.00	0.00	4.04	4.61
21	1.41	-9.2	9.3	0.00	0.00	2.68	4.61
22	1.41	-9.1	9.2	0.00	0.00	4.04	4.61
23	1.44	-9.2	9.3	0.00	0.00	3.55	4.61
24	1.37	-9.1	9.2	0.00	0.00	5.42	6.09
25	1.21	-9.4	9.4	0.00	0.00	0.00	0.00
26	0.99	-9.6	9.6	0.00	0.00	0.00	0.00
27	1.77	-9.3	9.4	0.00	0.00	0.00	0.00
28	0.97	-9.3	9.4	0.00	0.00	0.00	0.00
29	1.03	-8.7	8.7	0.00	0.00	3.55	4.61
30	2.10	-8.6	8.9	0.00	0.00	0.15	4.61
31	0.99	-8.6	8.7	0.00	0.00	0.15	4.61
32	0.91	-8.6	8.6	0.00	0.00	0.00	0.00
33	2.37	-7.1	7.5	0.00	0.00	0.00	0.00
34	0.97	-7.7	7.7	0.00	0.00	0.00	0.00

Node Results LC4 (1.2G + 1.5Q)

ID	X Displacment (mm)	Y Displacement (mm)	Resultant (mm)	Max X Reaction (kN)	Max Y Reaction (kN)	Joint Load (kN)	Joint Capacity (kN)
35	1.29	-6.2	6.3	0.00	0.00	0.00	0.00
36	2.64	-3.55	4.43	0.00	0.00	0.71	4.61
37	1.92	-3.56	4.04	0.00	0.00	0.71	4.61
38	2.73	-1.86	3.30	0.00	0.00	0.00	0.00
39	2.36	-1.80	2.97	0.00	0.00	0.00	0.00
40	2.81	0.00	2.81	0.00	-4.18	11.32	12.01
41	3.15	1.09	3.33	0.00	0.00	0.00	0.00

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node E	Segment Length (mm)	Design Lengtl (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
1	-2	3	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
2	3	5	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
3	5	8	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
4	8	11	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
5	11	15	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
6	15	19	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
7	19	21	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
8	21	23	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
9	23	27	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
10	27	30	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
11	30	33	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
12	33	36	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
13	36	38	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
14	38	-40	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
15	-1	2	136.2	136.2	800.0	115.8	800.0	115.8	0.00	-0.04	-0.01	TC
16	2	4	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
17	4	6	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
18	6	7	365.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
19	7	9	331.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
20	9	10	468.9	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
21	10	12	227.2	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
22	12	13	124.6	124.6	800.0	105.9	800.0	105.9	0.00	-0.04	-0.01	TC
23	13	14	448.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
24	14	16	313.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
25	16	17	486.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
26	17	18	275.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
27	18	-20	181.4	181.4	800.0	154.2	800.0	154.2	0.00	-0.04	-0.01	TC
28	-20	24	181.4	181.4	800.0	154.2	800.0	154.2	0.00	-0.04	-0.01	TC
29	24	25	275.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
30	25	26	486.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
31	26	28	313.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
32	28	29	448.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
33	29	31	124.6	124.6	800.0	105.9	800.0	105.9	0.00	-0.04	-0.01	TC

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node E	Segment Length (mm)	Design Lengtl (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
34	31	32	227.2	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
35	32	34	468.9	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
36	34	35	331.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
37	35	37	365.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
38	37	39	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
39	39	40	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
40	40	-41	136.2	136.2	800.0	115.8	800.0	115.8	0.00	-0.04	-0.01	TC
41	-5	-6	130.0	130.0	129.0	130.0	129.0	130.0	0.00	0.00	-0.01	WC
42	-11	-12	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
43	-13	-19	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
44	-21	-22	1019.1	1019.1	1072.0	1019.1	1072.0	1019.1	0.00	0.00	-0.01	WC
45	-22	-20	53.0	53.0	1072.0	53.0	1072.0	53.0	0.00	0.00	-0.01	WC
46	-23	-29	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
47	-30	-31	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
48	-36	-37	130.0	130.0	130.0	130.0	130.0	130.0	0.00	0.00	-0.01	WC
49	-18	22	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC
50	22	-24	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
1	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
2	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
3	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
4	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
5	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
6	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
7	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
8	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
9	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
10	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
11	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
12	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
13	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
14	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
15	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
16	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
17	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
18	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
19	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
20	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
21	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
22	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
23	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
24	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
25	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
26	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
27	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
28	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
29	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
30	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
31	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
32	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
33	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
34	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
35	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
36	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
37	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
38	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
39	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
40	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
41	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
42	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
43	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
44	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
45	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
46	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
47	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
48	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
49	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
50	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm^2)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm^3)	Zy (mm^3)
1	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
2	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
3	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
4	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
5	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
6	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
7	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
8	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
9	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
10	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
11	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
12	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
13	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
14	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
15	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
16	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
17	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
18	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
19	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
20	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
21	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
22	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
23	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
24	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
25	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
26	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
27	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
28	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
29	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
30	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
31	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
32	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
33	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
34	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm^2)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm^3)	Zy (mm^3)
35	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
36	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
37	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
38	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
39	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
40	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
41	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
42	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
43	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
44	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
45	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
46	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
47	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
48	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
49	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
50	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm^2)	Sec Mod Up (mm^3)	Sec Mod Dn (mm^3)
1	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
2	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
3	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
4	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
5	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
6	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
7	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
8	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
9	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
10	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
11	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
12	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
13	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
14	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
15	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
16	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
17	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
18	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
19	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
20	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
21	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
22	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
23	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
24	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
25	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
26	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
27	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
28	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
29	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
30	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
31	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
32	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
33	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm²)	Sec Mod Up (mm³)	Sec Mod Dn (mm³)
34	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
35	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
36	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
37	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
38	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
39	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
40	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
41	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
42	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
43	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
44	4.40	20.63	11.68	18.90	1430	1229	1430	1229	90.00	2975	2975
45	4.40	20.63	11.68	21.79	1430	1257	1430	1257	83.00	2737	2737
46	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
47	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
48	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
49	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
50	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
1	11.31	0.0	-63.0	-125.6	0.59	0.59	0.00	1.86
2	11.31	-125.6	-188.0	-250.0	0.59	0.58	1.86	3.55
3	11.31	-250.0	-207.2	-161.3	-0.12	-0.14	3.55	7.1
4	11.31	-161.3	-112.4	-60.5	-0.14	-0.16	7.1	8.6
5	11.31	-60.5	-52.8	-40.5	-0.01	-0.04	8.6	9.3
6	11.31	-40.5	-23.8	-2.6	-0.04	-0.06	9.3	9.2
7	7.99	-2.6	80.4	163.5	-1.33	-1.33	9.2	9.2
8	7.99	163.5	80.4	-2.6	1.33	1.33	9.2	9.2
9	11.31	-2.6	-23.8	-40.5	0.06	0.04	9.2	9.3
10	11.31	-40.5	-52.8	-60.5	0.04	0.01	9.3	8.6
11	11.31	-60.5	-112.4	-161.3	0.16	0.14	8.6	7.1
12	11.31	-161.3	-207.2	-250.0	0.14	0.12	7.1	3.55
13	11.31	-250.0	-188.0	-125.6	-0.58	-0.59	3.56	1.86
14	11.31	-125.6	-63.0	0.0	-0.59	-0.59	1.88	0.00
15	0.00	0.0	0.1	0.5	0.00	-0.01	1.09	0.00
16	-11.86	0.5	-12.5	-24.9	0.12	0.11	0.00	1.80
17	-11.86	-24.9	-36.6	-47.6	0.11	0.10	1.80	3.56
18	-12.06	-47.6	-187.4	-325.4	0.77	0.75	3.56	6.2
19	-11.77	-325.4	-297.1	-267.4	-0.17	-0.18	6.2	7.7
20	-11.76	-267.4	-222.7	-175.2	-0.18	-0.21	7.7	8.6
21	-11.48	-175.2	-46.9	82.2	-1.13	-1.14	8.6	8.6
22	-11.43	82.2	162.4	242.8	-1.29	-1.29	8.6	8.7
23	-8.62	242.8	48.2	-143.8	0.87	0.85	8.7	9.3
24	-8.33	-143.8	-132.6	-120.1	-0.07	-0.08	9.3	9.6
25	-8.33	-120.1	-98.2	-73.2	-0.08	-0.11	9.6	9.4
26	-8.04	-73.2	69.0	212.1	-1.03	-1.04	9.4	9.1
27	-3.09	212.1	105.8	0.0	1.17	1.16	9.1	9.1
28	-3.09	0.0	105.8	212.1	-1.16	-1.17	9.1	9.1
29	-8.04	212.1	69.0	-73.2	1.04	1.03	9.1	9.4
30	-8.33	-73.2	-98.2	-120.1	0.11	0.08	9.4	9.6
31	-8.33	-120.1	-132.6	-143.8	0.08	0.07	9.6	9.3
32	-8.62	-143.8	48.2	242.8	-0.85	-0.87	9.3	8.7
33	-11.43	242.8	162.4	82.2	1.29	1.29	8.7	8.6
34	-11.48	82.2	-46.9	-175.2	1.14	1.13	8.6	8.6

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
35	-11.76	-175.2	-222.7	-267.4	0.21	0.18	8.6	7.7
36	-11.77	-267.4	-297.1	-325.4	0.18	0.17	7.7	6.2
37	-12.06	-325.4	-187.4	-47.6	-0.75	-0.77	6.2	3.56
38	-11.86	-47.6	-36.6	-24.9	-0.10	-0.11	3.56	1.80
39	-11.86	-24.9	-12.5	0.5	-0.11	-0.12	1.81	0.00
40	0.00	0.5	0.1	0.0	0.01	0.00	0.28	1.09
41	-0.71	0.0	0.0	0.0	0.00	0.00	3.55	3.56
42	0.15	0.0	0.0	0.0	0.00	0.00	8.6	8.6
43	-3.55	0.0	-4.0	0.0	0.01	-0.01	8.7	9.2
44	2.68	0.0	0.0	0.0	0.00	0.00	9.2	9.1
45	4.04	0.0	0.0	0.0	0.00	0.00	9.1	9.1
46	-3.55	0.0	-4.0	0.0	0.01	-0.01	9.2	8.7
47	0.15	0.0	0.0	0.0	0.00	0.00	8.6	8.6
48	-0.71	0.0	0.0	0.0	0.00	0.00	3.56	3.56
49	-5.38	0.0	58.5	117.1	-0.67	-0.68	9.1	9.1
50	-5.38	117.1	58.5	0.0	0.68	0.67	9.1	9.1

Code Status LC4 (1.2G + 1.5Q)

ID	Shear (%)	Tension (%)	Comp Sec (%)	Comp Mem (%)	Bend Sec (%)	Bend Mem (%)	Shear + Bend + (%)	Tens + Bend + (%)	Comp+Bend Mem + (%)
1	13.5	26.9	0.0	0.0	8.8	10.0	16.1	35.7	8.8
2	13.4	26.9	0.0	0.0	17.5	19.9	22.0	44.4	17.5
3	3.2	26.9	0.0	0.0	17.5	21.3	17.8	44.4	18.1
4	3.6	26.9	0.0	0.0	11.3	13.7	11.9	38.2	11.7
5	0.8	26.9	0.0	0.0	4.2	5.4	4.3	31.2	4.6
6	1.3	26.9	0.0	0.0	2.8	3.6	3.1	29.8	3.1
7	30.4	19.0	0.0	0.0	11.4	13.0	32.4	30.5	11.4
8	30.4	19.0	0.0	0.0	11.4	13.0	32.4	30.5	11.4
9	1.3	26.9	0.0	0.0	2.8	3.6	3.1	29.8	3.1
10	0.8	26.9	0.0	0.0	4.2	5.4	4.3	31.2	4.6
11	3.6	26.9	0.0	0.0	11.3	13.7	11.9	38.2	11.7
12	3.2	26.9	0.0	0.0	17.5	21.3	17.8	44.4	18.1
13	13.4	26.9	0.0	0.0	17.5	19.9	22.0	44.4	17.5
14	13.5	26.9	0.0	0.0	8.8	10.0	16.1	35.7	8.8
15	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
16	2.7	0.0	38.9	46.8	1.7	2.0	3.2	1.7	48.5
17	2.5	0.0	38.9	46.8	3.3	3.8	4.1	3.3	50.0
18	17.5	0.0	39.5	76.7	22.8	25.9	28.7	22.8	99.8
19	4.2	0.0	38.6	74.9	22.8	25.9	23.1	22.8	98.0
20	4.8	0.0	38.6	74.8	18.7	21.3	19.3	18.7	93.8
21	25.9	0.0	37.6	73.0	12.3	13.9	28.7	12.3	85.4
22	29.4	0.0	37.5	45.1	17.0	19.3	34.0	17.0	61.5
23	19.9	0.0	28.3	60.7	17.0	19.5	26.2	17.0	78.0
24	1.9	0.0	27.3	58.7	10.1	11.6	10.2	10.1	68.9
25	2.5	0.0	27.3	58.6	8.4	9.7	8.8	8.4	67.2
26	23.7	0.0	26.4	56.6	14.8	17.1	28.0	14.8	71.7
27	26.7	0.0	10.1	12.2	14.8	16.9	30.6	14.8	26.6
28	26.7	0.0	10.1	12.2	14.8	16.9	30.6	14.8	26.6
29	23.7	0.0	26.4	56.6	14.8	17.1	28.0	14.8	71.7
30	2.5	0.0	27.3	58.6	8.4	9.7	8.8	8.4	67.2
31	1.9	0.0	27.3	58.7	10.1	11.6	10.2	10.1	68.9
32	19.9	0.0	28.3	60.7	17.0	19.5	26.2	17.0	78.0
33	29.4	0.0	37.5	45.1	17.0	19.3	34.0	17.0	61.5

Code Status LC4 (1.2G + 1.5Q)

ID	Shear (%)	Tension (%)	Comp Sec (%)	Comp Mem (%)	Bend Sec (%)	Bend Mem (%)	Shear + Bend + (%)	Tens + Bend + (%)	Comp+Bend Mem + (%)
34	25.9	0.0	37.6	73.0	12.3	13.9	28.7	12.3	85.4
35	4.8	0.0	38.6	74.8	18.7	21.3	19.3	18.7	93.8
36	4.2	0.0	38.6	74.9	22.8	25.9	23.1	22.8	98.0
37	17.5	0.0	39.5	76.7	22.8	25.9	28.7	22.8	99.8
38	2.5	0.0	38.9	46.8	3.3	3.8	4.1	3.3	50.0
39	2.7	0.0	38.9	46.8	1.7	2.0	3.2	1.7	48.5
40	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
41	0.0	0.0	6.0	2.5	0.0	0.0	0.0	0.0	2.5
42	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.7	0.0
43	0.2	0.0	30.4	35.0	0.3	0.5	0.4	0.3	35.4
44	0.0	13.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0
45	0.0	19.6	0.0	0.0	0.0	0.0	0.0	19.6	0.0
46	0.2	0.0	30.4	35.0	0.3	0.5	0.4	0.3	35.4
47	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.7	0.0
48	0.0	0.0	6.0	2.5	0.0	0.0	0.0	0.0	2.5
49	15.4	0.0	46.0	18.5	8.2	9.3	17.4	8.2	26.7
50	15.4	0.0	46.0	18.5	8.2	9.3	17.4	8.2	26.7

800mm Predicted Truss

Node Results LC4 (1.2G + 1.5Q)

ID	X Displacment (mm)	Y Displacement (mm)	Resultant (mm)	Max X Reaction (kN)	Max Y Reaction (kN)	Joint Load (kN)	Joint Capacity (kN)
1	-0.40	1.31	1.36	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	-5.02	13.61	0.00
3	0.10	-2.23	2.23	0.00	0.00	0.00	0.00
4	0.54	-2.16	2.22	0.00	0.00	0.00	0.00
5	0.21	-4.27	4.28	0.00	0.00	0.85	0.00
6	1.07	-4.28	4.41	0.00	0.00	0.85	0.00
7	1.83	-7.4	7.6	0.00	0.00	0.00	0.00
8	0.53	-8.5	8.5	0.00	0.00	0.00	0.00
9	2.21	-9.2	9.5	0.00	0.00	0.00	0.00
10	2.29	-10.3	10.5	0.00	0.00	0.00	0.00
11	0.86	-10.4	10.4	0.00	0.00	0.17	0.00
12	2.19	-10.4	10.6	0.00	0.00	0.17	0.00
13	2.15	-10.4	10.7	0.00	0.00	4.27	0.00
14	2.22	-11.2	11.4	0.00	0.00	0.00	0.00
15	1.25	-11.1	11.2	0.00	0.00	0.00	0.00
16	2.19	-11.5	11.7	0.00	0.00	0.00	0.00
17	1.93	-11.3	11.4	0.00	0.00	0.00	0.00
18	1.73	-11.0	11.1	0.00	0.00	6.53	0.00
19	1.65	-11.1	11.2	0.00	0.00	4.27	0.00
20	1.69	-10.9	11.0	0.00	0.00	4.86	0.00
21	1.69	-11.0	11.2	0.00	0.00	3.20	0.00
22	1.69	-10.9	11.0	0.00	0.00	4.86	0.00
23	1.73	-11.1	11.2	0.00	0.00	4.27	0.00
24	1.65	-11.0	11.1	0.00	0.00	6.53	0.00
25	1.45	-11.3	11.4	0.00	0.00	0.00	0.00
26	1.19	-11.5	11.6	0.00	0.00	0.00	0.00
27	2.13	-11.1	11.3	0.00	0.00	0.00	0.00
28	1.17	-11.2	11.3	0.00	0.00	0.00	0.00
29	1.23	-10.4	10.5	0.00	0.00	4.27	0.00
30	2.53	-10.4	10.7	0.00	0.00	0.17	0.00
31	1.19	-10.4	10.4	0.00	0.00	0.17	0.00
32	1.10	-10.3	10.3	0.00	0.00	0.00	0.00
33	2.85	-8.5	9.0	0.00	0.00	0.00	0.00
34	1.17	-9.2	9.3	0.00	0.00	0.00	0.00

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node E	Segment Length (mm)	Design Length (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
1	-2	3	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
2	3	5	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
3	5	8	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
4	8	11	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
5	11	15	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
6	15	19	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
7	19	21	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
8	21	23	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
9	23	27	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
10	27	30	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
11	30	33	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
12	33	36	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
13	36	38	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
14	38	-40	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
15	-1	2	136.2	136.2	800.0	115.8	800.0	115.8	0.00	-0.04	-0.01	TC
16	2	4	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
17	4	6	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
18	6	7	365.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
19	7	9	331.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
20	9	10	468.9	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
21	10	12	227.2	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
22	12	13	124.6	124.6	800.0	105.9	800.0	105.9	0.00	-0.04	-0.01	TC
23	13	14	448.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
24	14	16	313.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
25	16	17	486.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
26	17	18	275.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
27	18	-20	181.4	181.4	800.0	154.2	800.0	154.2	0.00	-0.04	-0.01	TC
28	-20	24	181.4	181.4	800.0	154.2	800.0	154.2	0.00	-0.04	-0.01	TC
29	24	25	275.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
30	25	26	486.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
31	26	28	313.8	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
32	28	29	448.2	1524.0	800.0	1295.4	800.0	1295.4	0.00	-0.04	-0.01	TC
33	29	31	124.6	124.6	800.0	105.9	800.0	105.9	0.00	-0.04	-0.01	TC

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node E	Segment Length (mm)	Design Length (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
34	31	32	227.2	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
35	32	34	468.9	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
36	34	35	331.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
37	35	37	365.1	1392.4	800.0	1183.5	800.0	1183.5	0.00	-0.04	-0.01	TC
38	37	39	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
39	39	40	222.3	444.6	800.0	377.9	800.0	377.9	0.00	-0.04	-0.01	TC
40	40	-41	136.2	136.2	800.0	115.8	800.0	115.8	0.00	-0.04	-0.01	TC
41	-5	-6	130.0	130.0	129.0	130.0	129.0	130.0	0.00	0.00	-0.01	WC
42	-11	-12	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
43	-13	-19	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
44	-21	-22	1019.1	1019.1	1072.0	1019.1	1072.0	1019.1	0.00	0.00	-0.01	WC
45	-22	-20	53.0	53.0	1072.0	53.0	1072.0	53.0	0.00	0.00	-0.01	WC
46	-23	-29	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
47	-30	-31	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
48	-36	-37	130.0	130.0	130.0	130.0	130.0	130.0	0.00	0.00	-0.01	WC
49	-18	22	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC
50	22	-24	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
1	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
2	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
3	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
4	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
5	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
6	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
7	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
8	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
9	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
10	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
11	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
12	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
13	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
14	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
15	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
16	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
17	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
18	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
19	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
20	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
21	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
22	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
23	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
24	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
25	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
26	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
27	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
28	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
29	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
30	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
31	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
32	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
33	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
34	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
35	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
36	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
37	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
38	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
39	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
40	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
41	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
42	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
43	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
44	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
45	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
46	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
47	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
48	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
49	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
50	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm^2)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm^3)	Zy (mm^3)
1	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
2	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
3	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
4	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
5	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
6	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
7	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
8	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
9	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
10	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
11	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
12	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
13	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
14	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
15	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
16	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
17	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
18	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
19	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
20	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
21	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
22	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
23	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
24	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
25	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
26	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
27	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
28	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
29	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
30	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
31	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
32	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
33	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
34	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm²)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm³)	Zy (mm³)
35	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
36	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
37	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
38	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
39	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
40	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
41	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
42	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
43	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
44	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
45	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
46	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
47	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
48	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
49	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
50	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm²)	Sec Mod Up (mm³)	Sec Mod Dn (mm³)
1	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
2	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
3	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
4	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
5	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
6	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
7	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
8	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
9	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
10	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
11	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
12	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
13	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
14	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
15	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
16	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
17	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
18	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
19	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
20	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
21	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
22	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
23	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
24	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
25	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
26	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
27	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
28	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
29	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
30	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
31	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
32	4.40	41.99	30.51	14.20	1430	1243	1430	1243	106.00	2947	2947
33	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm²)	Sec Mod Up (mm³)	Sec Mod Dn (mm³)
34	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
35	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
36	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
37	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2916	2916
38	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
39	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
40	4.40	41.99	30.51	25.34	1430	1257	1430	1257	74.00	2737	2737
41	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
42	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
43	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
44	4.40	20.63	11.68	18.90	1430	1229	1430	1229	90.00	2975	2975
45	4.40	20.63	11.68	21.79	1430	1257	1430	1257	83.00	2737	2737
46	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
47	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
48	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
49	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
50	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
1	13.60	0.0	-75.8	-151.2	0.71	0.71	0.00	2.23
2	13.60	-151.2	-226.4	-301.2	0.71	0.70	2.23	4.27
3	13.60	-301.2	-248.9	-193.6	-0.15	-0.17	4.27	8.5
4	13.60	-193.6	-135.2	-73.9	-0.17	-0.19	8.5	10.4
5	13.60	-73.9	-63.2	-47.9	-0.02	-0.04	10.4	11.1
6	13.60	-47.9	-28.2	-4.1	-0.04	-0.07	11.1	11.1
7	9.61	-4.1	95.4	194.9	-1.60	-1.60	11.1	11.0
8	9.61	194.9	95.4	-4.1	1.60	1.60	11.0	11.1
9	13.60	-4.1	-28.2	-47.9	0.07	0.04	11.1	11.1
10	13.60	-47.9	-63.2	-73.9	0.04	0.02	11.1	10.4
11	13.60	-73.9	-135.2	-193.6	0.19	0.17	10.4	8.5
12	13.60	-193.6	-248.9	-301.2	0.17	0.15	8.5	4.27
13	13.60	-301.2	-226.4	-151.2	-0.70	-0.71	4.29	2.23
14	13.60	-151.2	-75.8	0.0	-0.71	-0.71	2.26	0.00
15	0.00	0.0	0.1	0.5	0.00	-0.01	1.31	0.00
16	-14.26	0.5	-14.6	-29.1	0.14	0.13	0.00	2.16
17	-14.25	-29.1	-43.0	-56.1	0.13	0.12	2.16	4.28
18	-14.50	-56.1	-225.4	-392.9	0.93	0.91	4.28	7.4
19	-14.15	-392.9	-358.1	-321.8	-0.21	-0.22	7.4	9.2
20	-14.15	-321.8	-268.0	-211.2	-0.22	-0.25	9.2	10.3
21	-13.80	-211.2	-55.6	100.8	-1.37	-1.38	10.3	10.4
22	-13.74	100.8	197.2	293.8	-1.55	-1.55	10.4	10.4
23	-10.36	293.8	58.4	-174.5	1.06	1.03	10.4	11.2
24	-10.02	-174.5	-160.4	-145.0	-0.09	-0.10	11.2	11.5
25	-10.01	-145.0	-118.6	-89.1	-0.10	-0.13	11.5	11.3
26	-9.66	-89.1	83.3	256.7	-1.25	-1.26	11.3	11.0
27	-3.70	256.7	128.1	0.0	1.42	1.41	11.0	10.9
28	-3.70	0.0	128.1	256.7	-1.41	-1.42	10.9	11.0
29	-9.66	256.7	83.3	-89.1	1.26	1.25	11.0	11.3
30	-10.01	-89.1	-118.6	-145.0	0.13	0.10	11.3	11.5
31	-10.02	-145.0	-160.4	-174.5	0.10	0.09	11.5	11.2
32	-10.36	-174.5	58.4	293.8	-1.03	-1.06	11.2	10.4
33	-13.74	293.8	197.2	100.8	1.55	1.55	10.4	10.4
34	-13.80	100.8	-55.6	-211.2	1.38	1.37	10.4	10.3

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
35	-14.15	-211.2	-268.0	-321.8	0.25	0.22	10.3	9.2
36	-14.15	-321.8	-358.1	-392.9	0.22	0.21	9.2	7.4
37	-14.50	-392.9	-225.4	-56.1	-0.91	-0.93	7.4	4.28
38	-14.25	-56.1	-43.0	-29.1	-0.12	-0.13	4.28	2.16
39	-14.26	-29.1	-14.6	0.5	-0.13	-0.14	2.18	0.00
40	0.00	0.5	0.1	0.0	0.01	0.00	0.34	1.31
41	-0.85	0.0	0.0	0.0	0.00	0.00	4.27	4.28
42	0.17	0.0	0.0	0.0	0.00	0.00	10.4	10.4
43	-4.27	0.0	-4.0	0.0	0.01	-0.01	10.4	11.1
44	3.20	0.0	0.0	0.0	0.00	0.00	11.0	10.9
45	4.86	0.0	0.0	0.0	0.00	0.00	10.9	10.9
46	-4.27	0.0	-4.0	0.0	0.01	-0.01	11.1	10.4
47	0.17	0.0	0.0	0.0	0.00	0.00	10.4	10.4
48	-0.85	0.0	0.0	0.0	0.00	0.00	4.29	4.28
49	-6.48	0.0	71.5	143.0	-0.82	-0.83	11.0	10.9
50	-6.48	143.0	71.5	0.0	0.83	0.82	10.9	11.0

Code Status LC4 (1.2G + 1.5Q)

ID	Shear (%)	Tension (%)	Comp Sec (%)	Comp Mem (%)	Bend Sec (%)	Bend Mem (%)	Shear + Bend + (%)	Tens + Bend + (%)	Comp+Bend Mem + (%)
1	16.2	32.4	0.0	0.0	10.6	12.0	19.4	43.0	10.6
2	16.1	32.4	0.0	0.0	21.1	24.0	26.5	53.4	21.1
3	3.9	32.4	0.0	0.0	21.1	25.6	21.4	53.4	21.8
4	4.3	32.4	0.0	0.0	13.5	16.5	14.2	45.9	14.0
5	1.0	32.4	0.0	0.0	5.2	6.6	5.3	37.5	5.6
6	1.5	32.4	0.0	0.0	3.4	4.3	3.7	35.7	3.7
7	36.4	22.9	0.0	0.0	13.6	15.5	38.8	36.5	13.6
8	36.4	22.9	0.0	0.0	13.6	15.5	38.8	36.5	13.6
9	1.5	32.4	0.0	0.0	3.4	4.3	3.7	35.7	3.7
10	1.0	32.4	0.0	0.0	5.2	6.6	5.3	37.5	5.6
11	4.3	32.4	0.0	0.0	13.5	16.5	14.2	45.9	14.0
12	3.9	32.4	0.0	0.0	21.1	25.6	21.4	53.4	21.8
13	16.1	32.4	0.0	0.0	21.1	24.0	26.5	53.4	21.1
14	16.2	32.4	0.0	0.0	10.6	12.0	19.4	43.0	10.6
15	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
16	3.2	0.0	46.7	56.3	2.0	2.3	3.8	2.0	58.2
17	2.9	0.0	46.7	56.3	3.9	4.5	4.9	3.9	60.1
18	21.2	0.0	47.5	92.2	27.5	31.3	34.7	27.5	120.5
19	5.1	0.0	46.4	90.0	27.5	31.3	27.9	27.5	118.2
20	5.6	0.0	46.4	90.0	22.5	25.6	23.2	22.5	113.1
21	31.4	0.0	45.2	87.8	14.8	16.8	34.7	14.8	102.9
22	35.3	0.0	45.0	54.2	20.5	23.4	40.9	20.5	74.1
23	24.0	0.0	34.0	73.0	20.5	23.6	31.6	20.5	94.1
24	2.3	0.0	32.8	70.5	12.2	14.0	12.4	12.2	83.1
25	2.9	0.0	32.8	70.5	10.1	11.7	10.5	10.1	80.9
26	28.7	0.0	31.7	68.0	18.0	20.7	33.8	18.0	86.5
27	32.3	0.0	12.1	14.6	18.0	20.4	37.0	18.0	32.0
28	32.3	0.0	12.1	14.6	18.0	20.4	37.0	18.0	32.0
29	28.7	0.0	31.7	68.0	18.0	20.7	33.8	18.0	86.5
30	2.9	0.0	32.8	70.5	10.1	11.7	10.5	10.1	80.9
31	2.3	0.0	32.8	70.5	12.2	14.0	12.4	12.2	83.1
32	24.0	0.0	34.0	73.0	20.5	23.6	31.6	20.5	94.1
33	35.3	0.0	45.0	54.2	20.5	23.4	40.9	20.5	74.1

Code Status LC4 (1.2G + 1.5Q)									
ID	Shear	Tension	Comp Sec	Comp Mem	Bend Sec	Bend Mem	Shear + Bend +	Tens + Bend +	Comp+Bend Mem +
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
34	31.4	0.0	45.2	87.8	14.8	16.8	34.7	14.8	102.9
35	5.6	0.0	46.4	90.0	22.5	25.6	23.2	22.5	113.1
36	5.1	0.0	46.4	90.0	27.5	31.3	27.9	27.5	118.2
37	21.2	0.0	47.5	92.2	27.5	31.3	34.7	27.5	120.5
38	2.9	0.0	46.7	56.3	3.9	4.5	4.9	3.9	60.1
39	3.2	0.0	46.7	56.3	2.0	2.3	3.8	2.0	58.2
40	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
41	0.0	0.0	7.3	3.1	0.0	0.0	0.0	0.0	3.1
42	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0
43	0.2	0.0	36.5	42.1	0.3	0.5	0.4	0.3	42.5
44	0.0	15.5	0.0	0.0	0.0	0.0	0.0	15.5	0.0
45	0.0	23.6	0.0	0.0	0.0	0.0	0.0	23.6	0.0
46	0.2	0.0	36.5	42.1	0.3	0.5	0.4	0.3	42.5
47	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0
48	0.0	0.0	7.3	3.1	0.0	0.0	0.0	0.0	3.1
49	18.8	0.0	55.4	22.3	10.0	11.4	21.3	10.0	32.3
50	18.8	0.0	55.4	22.3	10.0	11.4	21.3	10.0	32.3

400mm Design Truss

Node Results LC4 (1.2G + 1.5Q)							
ID	X Displacment (mm)	Y Displacment (mm)	Resultant (mm)	Max X Reaction (kN)	Max Y Reaction (kN)	Joint Load (kN)	Joint Capacity (kN)
1	-0.33	1.09	1.14	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	-4.19	11.34	12.01
3	0.09	-1.86	1.86	0.00	0.00	0.00	0.00
4	0.45	-1.80	1.85	0.00	0.00	0.00	0.00
5	0.17	-3.56	3.56	0.00	0.00	0.71	4.61
6	0.89	-3.56	3.67	0.00	0.00	0.71	4.61
7	1.52	-6.2	6.4	0.00	0.00	0.00	0.00
8	0.44	-7.1	7.1	0.00	0.00	0.00	0.00
9	1.84	-7.7	7.9	0.00	0.00	0.00	0.00
10	1.90	-8.6	8.8	0.00	0.00	0.00	0.00
11	0.71	-8.6	8.7	0.00	0.00	0.15	4.61
12	1.83	-8.6	8.8	0.00	0.00	0.15	4.61
13	1.79	-8.7	8.9	0.00	0.00	3.55	4.61
14	1.85	-9.4	9.5	0.00	0.00	0.00	0.00
15	1.04	-9.3	9.3	0.00	0.00	0.00	0.00
16	1.82	-9.6	9.8	0.00	0.00	0.00	0.00
17	1.61	-9.4	9.5	0.00	0.00	0.00	0.00
18	1.44	-9.1	9.2	0.00	0.00	5.43	6.09
19	1.37	-9.2	9.3	0.00	0.00	3.55	4.61
20	1.41	-9.1	9.2	0.00	0.00	4.04	4.61
21	1.41	-9.2	9.3	0.00	0.00	2.68	4.61
22	1.41	-9.1	9.2	0.00	0.00	4.04	4.61
23	1.45	-9.2	9.3	0.00	0.00	3.55	4.61
24	1.38	-9.1	9.2	0.00	0.00	5.43	6.09
25	1.21	-9.4	9.5	0.00	0.00	0.00	0.00
26	1.00	-9.6	9.7	0.00	0.00	0.00	0.00
27	1.78	-9.3	9.5	0.00	0.00	0.00	0.00
28	0.97	-9.4	9.4	0.00	0.00	0.00	0.00
29	1.03	-8.7	8.8	0.00	0.00	3.55	4.61
30	2.11	-8.6	8.9	0.00	0.00	0.15	4.61
31	0.99	-8.6	8.7	0.00	0.00	0.15	4.61
32	0.92	-8.6	8.6	0.00	0.00	0.00	0.00
33	2.38	-7.1	7.5	0.00	0.00	0.00	0.00
34	0.97	-7.7	7.8	0.00	0.00	0.00	0.00

Node Results LC4 (1.2G + 1.5Q)							
ID	X Displacment (mm)	Y Displacment (mm)	Resultant (mm)	Max X Reaction (kN)	Max Y Reaction (kN)	Joint Load (kN)	Joint Capacity (kN)
35	1.30	-6.2	6.3	0.00	0.00	0.00	0.00
36	2.65	-3.56	4.44	0.00	0.00	0.71	4.61
37	1.93	-3.56	4.05	0.00	0.00	0.71	4.61
38	2.73	-1.86	3.31	0.00	0.00	0.00	0.00
39	2.37	-1.80	2.97	0.00	0.00	0.00	0.00
40	2.82	0.00	2.82	0.00	-4.19	11.34	12.01
41	3.15	1.09	3.33	0.00	0.00	0.00	0.00

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node E	Segment Length (mm)	Design Length (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
1	-2	3	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
2	3	5	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
3	5	8	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
4	8	11	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
5	11	15	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
6	15	19	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
7	19	21	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
8	21	23	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
9	23	27	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
10	27	30	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
11	30	33	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
12	33	36	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
13	36	38	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
14	38	-40	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
15	-1	2	136.2	136.2	400.0	115.8	400.0	115.8	0.00	-0.03	-0.01	TC
16	2	4	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
17	4	6	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
18	6	7	365.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
19	7	9	331.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
20	9	10	468.9	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
21	10	12	227.2	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
22	12	13	124.6	124.6	400.0	105.9	400.0	105.9	0.00	-0.03	-0.01	TC
23	13	14	448.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
24	14	16	313.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
25	16	17	486.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
26	17	18	275.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
27	18	-20	181.4	181.4	400.0	154.2	400.0	154.2	0.00	-0.03	-0.01	TC
28	-20	24	181.4	181.4	400.0	154.2	400.0	154.2	0.00	-0.03	-0.01	TC
29	24	25	275.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
30	25	26	486.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
31	26	28	313.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
32	28	29	448.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
33	29	31	124.6	124.6	400.0	105.9	400.0	105.9	0.00	-0.03	-0.01	TC

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node E	Segment Length (mm)	Design Length (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
34	31	32	227.2	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
35	32	34	468.9	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
36	34	35	331.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
37	35	37	365.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
38	37	39	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
39	39	40	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
40	40	-41	136.2	136.2	400.0	115.8	400.0	115.8	0.00	-0.03	-0.01	TC
41	-5	-6	130.0	130.0	129.0	130.0	129.0	130.0	0.00	0.00	-0.01	WC
42	-11	-12	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
43	-13	-19	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
44	-21	-22	1019.1	1019.1	1072.0	1019.1	1072.0	1019.1	0.00	0.00	-0.01	WC
45	-22	-20	53.0	53.0	1072.0	53.0	1072.0	53.0	0.00	0.00	-0.01	WC
46	-23	-29	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
47	-30	-31	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
48	-36	-37	130.0	130.0	130.0	130.0	130.0	130.0	0.00	0.00	-0.01	WC
49	-18	22	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC
50	22	-24	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
1	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
2	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
3	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
4	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
5	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
6	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
7	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
8	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
9	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
10	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
11	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
12	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
13	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
14	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
15	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
16	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
17	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
18	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
19	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
20	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
21	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
22	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
23	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
24	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
25	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
26	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
27	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
28	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
29	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
30	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
31	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
32	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
33	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
34	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
35	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
36	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
37	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
38	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
39	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
40	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
41	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
42	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
43	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
44	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
45	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
46	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
47	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
48	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
49	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
50	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm^2)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm^3)	Zy (mm^3)
1	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
2	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
3	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
4	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
5	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
6	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
7	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
8	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
9	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
10	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
11	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
12	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
13	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
14	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
15	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
16	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
17	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
18	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
19	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
20	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
21	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
22	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
23	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
24	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
25	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
26	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
27	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
28	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
29	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
30	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
31	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
32	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
33	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
34	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm^2)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm^3)	Zy (mm^3)
35	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
36	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
37	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
38	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
39	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
40	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
41	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
42	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
43	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
44	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
45	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
46	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
47	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
48	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
49	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
50	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm²)	Sec Mod Up (mm³)	Sec Mod Dn (mm³)
1	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
2	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
3	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
4	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
5	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
6	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
7	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
8	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
9	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
10	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
11	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
12	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
13	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
14	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
15	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
16	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
17	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
18	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
19	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
20	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
21	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
22	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
23	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
24	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
25	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
26	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
27	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
28	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
29	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
30	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
31	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
32	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
33	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm²)	Sec Mod Up (mm³)	Sec Mod Dn (mm³)
34	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
35	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
36	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
37	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
38	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
39	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
40	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
41	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
42	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
43	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
44	4.40	20.63	11.68	18.90	1430	1229	1430	1229	90.00	2975	2975
45	4.40	20.63	11.68	21.79	1430	1257	1430	1257	83.00	2737	2737
46	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
47	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
48	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
49	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
50	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
1	11.33	0.0	-63.0	-125.8	0.59	0.59	0.00	1.86
2	11.33	-125.8	-188.2	-250.3	0.59	0.58	1.86	3.56
3	11.33	-250.3	-207.4	-161.5	-0.12	-0.14	3.56	7.1
4	11.33	-161.5	-112.6	-60.7	-0.14	-0.16	7.1	8.6
5	11.33	-60.7	-52.9	-40.6	-0.01	-0.04	8.6	9.3
6	11.33	-40.6	-23.8	-2.6	-0.04	-0.06	9.3	9.2
7	8.01	-2.6	80.5	163.8	-1.33	-1.34	9.2	9.2
8	8.01	163.8	80.5	-2.6	1.34	1.33	9.2	9.2
9	11.33	-2.6	-23.8	-40.6	0.06	0.04	9.2	9.3
10	11.33	-40.6	-52.9	-60.7	0.04	0.01	9.3	8.6
11	11.33	-60.7	-112.6	-161.5	0.16	0.14	8.6	7.1
12	11.33	-161.5	-207.4	-250.3	0.14	0.12	7.1	3.56
13	11.33	-250.3	-188.2	-125.8	-0.58	-0.59	3.57	1.86
14	11.33	-125.8	-63.0	0.0	-0.59	-0.59	1.88	0.00
15	0.00	0.0	0.1	0.4	0.00	-0.01	1.09	0.00
16	-11.88	0.4	-12.4	-24.6	0.12	0.11	0.00	1.80
17	-11.88	-24.6	-36.3	-47.5	0.11	0.10	1.80	3.56
18	-12.08	-47.5	-187.7	-326.4	0.77	0.76	3.56	6.2
19	-11.79	-326.4	-297.7	-267.7	-0.17	-0.18	6.2	7.7
20	-11.79	-267.7	-223.1	-175.9	-0.18	-0.21	7.7	8.6
21	-11.50	-175.9	-47.0	82.4	-1.13	-1.14	8.6	8.6
22	-11.45	82.4	162.9	243.4	-1.29	-1.30	8.6	8.7
23	-8.64	243.4	48.4	-144.4	0.88	0.86	8.7	9.4
24	-8.35	-144.4	-132.9	-120.2	-0.07	-0.08	9.4	9.6
25	-8.34	-120.2	-98.3	-73.7	-0.08	-0.11	9.6	9.4
26	-8.05	-73.7	69.1	212.7	-1.03	-1.04	9.4	9.1
27	-3.10	212.7	106.2	0.0	1.18	1.17	9.1	9.1
28	-3.10	0.0	106.2	212.7	-1.17	-1.18	9.1	9.1
29	-8.05	212.7	69.1	-73.7	1.04	1.03	9.1	9.4
30	-8.34	-73.7	-98.3	-120.2	0.11	0.08	9.4	9.6
31	-8.35	-120.2	-132.9	-144.4	0.08	0.07	9.6	9.4
32	-8.64	-144.4	48.4	243.4	-0.86	-0.88	9.4	8.7
33	-11.45	243.4	162.9	82.4	1.30	1.29	8.7	8.6
34	-11.50	82.4	-47.0	-175.9	1.14	1.13	8.6	8.6

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
35	-11.79	-175.9	-223.1	-267.7	0.21	0.18	8.6	7.7
36	-11.79	-267.7	-297.7	-326.4	0.18	0.17	7.7	6.2
37	-12.08	-326.4	-187.7	-47.5	-0.76	-0.77	6.2	3.56
38	-11.88	-47.5	-36.3	-24.6	-0.10	-0.11	3.57	1.80
39	-11.88	-24.6	-12.4	0.4	-0.11	-0.12	1.81	0.00
40	0.00	0.4	0.1	0.0	0.01	0.00	0.28	1.09
41	-0.71	0.0	0.0	0.0	0.00	0.00	3.56	3.56
42	0.15	0.0	0.0	0.0	0.00	0.00	8.6	8.6
43	-3.55	0.0	-4.0	0.0	0.01	-0.01	8.7	9.2
44	2.68	0.0	0.0	0.0	0.00	0.00	9.2	9.1
45	4.04	0.0	0.0	0.0	0.00	0.00	9.1	9.1
46	-3.55	0.0	-4.0	0.0	0.01	-0.01	9.2	8.7
47	0.15	0.0	0.0	0.0	0.00	0.00	8.6	8.6
48	-0.71	0.0	0.0	0.0	0.00	0.00	3.57	3.56
49	-5.39	0.0	58.7	117.5	-0.68	-0.68	9.1	9.1
50	-5.39	117.5	58.7	0.0	0.68	0.68	9.1	9.1

Code Status LC4 (1.2G + 1.5Q)

ID	Shear (%)	Tension (%)	Comp Sec (%)	Comp Mem (%)	Bend Sec (%)	Bend Mem (%)	Shear + Bend + (%)	Tens + Bend + (%)	Comp+Bend Mem + (%)
1	13.5	27.0	0.0	0.0	8.8	10.0	16.1	35.8	8.8
2	13.4	27.0	0.0	0.0	17.5	19.9	22.0	44.5	17.5
3	3.2	27.0	0.0	0.0	17.5	21.3	17.8	44.5	18.1
4	3.7	27.0	0.0	0.0	11.3	13.7	11.9	38.3	11.7
5	0.8	27.0	0.0	0.0	4.2	5.4	4.3	31.2	4.6
6	1.3	27.0	0.0	0.0	2.8	3.6	3.1	29.8	3.1
7	30.4	19.1	0.0	0.0	11.5	13.0	32.5	30.5	11.5
8	30.4	19.1	0.0	0.0	11.5	13.0	32.5	30.5	11.5
9	1.3	27.0	0.0	0.0	2.8	3.6	3.1	29.8	3.1
10	0.8	27.0	0.0	0.0	4.2	5.4	4.3	31.2	4.6
11	3.7	27.0	0.0	0.0	11.3	13.7	11.9	38.3	11.7
12	3.2	27.0	0.0	0.0	17.5	21.3	17.8	44.5	18.1
13	13.4	27.0	0.0	0.0	17.5	19.9	22.0	44.5	17.5
14	13.5	27.0	0.0	0.0	8.8	10.0	16.1	35.8	8.8
15	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
16	2.7	0.0	38.9	41.9	1.7	2.0	3.2	1.7	43.5
17	2.5	0.0	38.9	41.9	3.3	3.8	4.1	3.3	45.1
18	17.6	0.0	39.6	76.8	22.8	26.0	28.8	22.8	100.0
19	4.2	0.0	38.6	75.0	22.8	26.0	23.2	22.8	98.2
20	4.7	0.0	38.6	75.0	18.7	21.3	19.3	18.7	94.0
21	26.0	0.0	37.7	73.1	12.3	14.0	28.8	12.3	85.6
22	29.5	0.0	37.5	39.5	17.0	19.4	34.0	17.0	55.9
23	19.9	0.0	28.3	60.8	17.0	19.4	26.2	17.0	78.0
24	1.9	0.0	27.4	58.8	10.1	11.5	10.3	10.1	69.0
25	2.4	0.0	27.3	58.7	8.4	9.6	8.7	8.4	67.2
26	23.8	0.0	26.4	56.7	14.9	16.9	28.0	14.9	71.7
27	26.8	0.0	10.2	10.7	14.9	16.9	30.6	14.9	25.1
28	26.8	0.0	10.2	10.7	14.9	16.9	30.6	14.9	25.1
29	23.8	0.0	26.4	56.7	14.9	16.9	28.0	14.9	71.7
30	2.4	0.0	27.3	58.7	8.4	9.6	8.7	8.4	67.2
31	1.9	0.0	27.4	58.8	10.1	11.5	10.3	10.1	69.0
32	19.9	0.0	28.3	60.8	17.0	19.4	26.2	17.0	78.0
33	29.5	0.0	37.5	39.5	17.0	19.4	34.0	17.0	55.9

Code Status LC4 (1.2G + 1.5Q)

ID	Shear (%)	Tension (%)	Comp Sec (%)	Comp Mem (%)	Bend Sec (%)	Bend Mem (%)	Shear + Bend + (%)	Tens + Bend + (%)	Comp+Bend Mem + (%)
34	26.0	0.0	37.7	73.1	12.3	14.0	28.8	12.3	85.6
35	4.7	0.0	38.6	75.0	18.7	21.3	19.3	18.7	94.0
36	4.2	0.0	38.6	75.0	22.8	26.0	23.2	22.8	98.2
37	17.6	0.0	39.6	76.8	22.8	26.0	28.8	22.8	100.0
38	2.5	0.0	38.9	41.9	3.3	3.8	4.1	3.3	45.1
39	2.7	0.0	38.9	41.9	1.7	2.0	3.2	1.7	43.5
40	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
41	0.0	0.0	6.0	2.5	0.0	0.0	0.0	0.0	2.5
42	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.7	0.0
43	0.2	0.0	30.4	35.0	0.3	0.5	0.4	0.3	35.5
44	0.0	13.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0
45	0.0	19.6	0.0	0.0	0.0	0.0	0.0	19.6	0.0
46	0.2	0.0	30.4	35.0	0.3	0.5	0.4	0.3	35.5
47	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.7	0.0
48	0.0	0.0	6.0	2.5	0.0	0.0	0.0	0.0	2.5
49	15.4	0.0	46.1	18.6	8.2	9.3	17.5	8.2	26.8
50	15.4	0.0	46.1	18.6	8.2	9.3	17.5	8.2	26.8

400mm Predicted Truss

Node Results LC4 (1.2G + 1.5Q)

ID	X Displacment (mm)	Y Displacement (mm)	Resultant (mm)	Max X Reaction (kN)	Max Y Reaction (kN)	Joint Load (kN)	Joint Capacity (kN)
1	-0.40	1.30	1.36	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	-5.00	13.55	0.00
3	0.10	-2.22	2.22	0.00	0.00	0.00	0.00
4	0.54	-2.15	2.21	0.00	0.00	0.00	0.00
5	0.21	-4.25	4.26	0.00	0.00	0.85	0.00
6	1.07	-4.26	4.39	0.00	0.00	0.85	0.00
7	1.82	-7.4	7.6	0.00	0.00	0.00	0.00
8	0.53	-8.5	8.5	0.00	0.00	0.00	0.00
9	2.20	-9.2	9.5	0.00	0.00	0.00	0.00
10	2.27	-10.2	10.5	0.00	0.00	0.00	0.00
11	0.85	-10.3	10.4	0.00	0.00	0.17	0.00
12	2.18	-10.3	10.5	0.00	0.00	0.17	0.00
13	2.14	-10.4	10.6	0.00	0.00	4.25	0.00
14	2.21	-11.2	11.4	0.00	0.00	0.00	0.00
15	1.25	-11.1	11.2	0.00	0.00	0.00	0.00
16	2.18	-11.5	11.7	0.00	0.00	0.00	0.00
17	1.92	-11.2	11.4	0.00	0.00	0.00	0.00
18	1.72	-10.9	11.0	0.00	0.00	6.50	0.00
19	1.64	-11.0	11.1	0.00	0.00	4.25	0.00
20	1.68	-10.9	11.0	0.00	0.00	4.84	0.00
21	1.68	-11.0	11.1	0.00	0.00	3.19	0.00
22	1.68	-10.9	11.0	0.00	0.00	4.84	0.00
23	1.73	-11.0	11.1	0.00	0.00	4.25	0.00
24	1.64	-10.9	11.0	0.00	0.00	6.50	0.00
25	1.45	-11.2	11.3	0.00	0.00	0.00	0.00
26	1.19	-11.5	11.5	0.00	0.00	0.00	0.00
27	2.12	-11.1	11.3	0.00	0.00	0.00	0.00
28	1.16	-11.2	11.2	0.00	0.00	0.00	0.00
29	1.23	-10.4	10.5	0.00	0.00	4.25	0.00
30	2.52	-10.3	10.6	0.00	0.00	0.17	0.00
31	1.19	-10.3	10.4	0.00	0.00	0.17	0.00
32	1.09	-10.2	10.3	0.00	0.00	0.00	0.00
33	2.84	-8.5	8.9	0.00	0.00	0.00	0.00
34	1.16	-9.2	9.3	0.00	0.00	0.00	0.00

Node Results LC4 (1.2G + 1.5Q)

ID	X Displacment (mm)	Y Displacement (mm)	Resultant (mm)	Max X Reaction (kN)	Max Y Reaction (kN)	Joint Load (kN)	Joint Capacity (kN)
35	1.55	-7.4	7.5	0.00	0.00	0.00	0.00
36	3.16	-4.25	5.3	0.00	0.00	0.85	0.00
37	2.30	-4.26	4.84	0.00	0.00	0.85	0.00
38	3.26	-2.22	3.95	0.00	0.00	0.00	0.00
39	2.83	-2.15	3.55	0.00	0.00	0.00	0.00
40	3.37	0.00	3.37	0.00	-5.00	13.55	0.00
41	3.77	1.30	3.98	0.00	0.00	0.00	0.00

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node E	Segment Length (mm)	Design Lengtł (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
1	-2	3	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
2	3	5	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
3	5	8	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
4	8	11	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
5	11	15	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
6	15	19	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
7	19	21	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
8	21	23	124.6	124.6	1200.0	105.9	1200.0	105.9	0.00	-0.01	-0.01	BC
9	23	27	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
10	27	30	812.7	1625.4	1200.0	1381.6	1200.0	1381.6	0.00	-0.01	-0.01	BC
11	30	33	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
12	33	36	665.8	1331.5	1200.0	1131.8	1200.0	1131.8	0.00	-0.01	-0.01	BC
13	36	38	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
14	38	-40	212.6	425.2	1200.0	361.4	1200.0	361.4	0.00	-0.01	-0.01	BC
15	-1	2	136.2	136.2	400.0	115.8	400.0	115.8	0.00	-0.03	-0.01	TC
16	2	4	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
17	4	6	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
18	6	7	365.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
19	7	9	331.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
20	9	10	468.9	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
21	10	12	227.2	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
22	12	13	124.6	124.6	400.0	105.9	400.0	105.9	0.00	-0.03	-0.01	TC
23	13	14	448.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
24	14	16	313.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
25	16	17	486.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
26	17	18	275.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
27	18	-20	181.4	181.4	400.0	154.2	400.0	154.2	0.00	-0.03	-0.01	TC
28	-20	24	181.4	181.4	400.0	154.2	400.0	154.2	0.00	-0.03	-0.01	TC
29	24	25	275.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
30	25	26	486.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
31	26	28	313.8	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
32	28	29	448.2	1524.0	400.0	1295.4	400.0	1295.4	0.00	-0.03	-0.01	TC
33	29	31	124.6	124.6	400.0	105.9	400.0	105.9	0.00	-0.03	-0.01	TC

Member Input LC4 (1.2G + 1.5Q)

ID	Node A	Node B	Segment Length (mm)	Design Length (Lx) (mm)	Restraint Length (Ly) (mm)	Eff Length x (KxLx) (mm)	Eff Length y (KyLy) (mm)	Eff Length t (KtLt) (mm)	X Force (kN/m)	Y Force (kN/m)	Self Weight (kN/m)	Usage
34	31	32	227.2	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
35	32	34	468.9	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
36	34	35	331.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
37	35	37	365.1	1392.4	400.0	1183.5	400.0	1183.5	0.00	-0.03	-0.01	TC
38	37	39	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
39	39	40	222.3	444.6	400.0	377.9	400.0	377.9	0.00	-0.03	-0.01	TC
40	40	-41	136.2	136.2	400.0	115.8	400.0	115.8	0.00	-0.03	-0.01	TC
41	-5	-6	130.0	130.0	129.0	130.0	129.0	130.0	0.00	0.00	-0.01	WC
42	-11	-12	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
43	-13	-19	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
44	-21	-22	1019.1	1019.1	1072.0	1019.1	1072.0	1019.1	0.00	0.00	-0.01	WC
45	-22	-20	53.0	53.0	1072.0	53.0	1072.0	53.0	0.00	0.00	-0.01	WC
46	-23	-29	1611.7	1611.7	1611.0	1611.7	1611.0	1611.7	0.00	0.00	-0.01	WC
47	-30	-31	537.1	537.1	537.0	537.1	537.0	537.1	0.00	0.00	-0.01	WC
48	-36	-37	130.0	130.0	130.0	130.0	130.0	130.0	0.00	0.00	-0.01	WC
49	-18	22	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC
50	22	-24	173.5	173.5	173.5	173.5	173.5	173.5	0.00	0.00	-0.01	RC

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
1	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
2	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
3	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
4	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
5	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
6	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
7	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
8	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
9	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
10	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
11	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
12	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
13	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
14	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
15	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
16	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
17	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
18	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
19	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
20	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
21	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
22	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
23	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
24	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
25	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
26	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
27	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
28	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
29	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
30	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
31	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
32	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
33	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
34	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Shape LC4 (1.2G + 1.5Q)

ID	Name	Profile	Height (mm)	Width (mm)	Lip (mm)	Radius (mm)	Thickness (mm)	Yield (MPa)	Tensile (MPa)
35	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
36	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
37	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
38	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
39	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
40	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
41	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
42	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
43	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
44	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
45	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
46	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
47	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
48	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
49	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495
50	89S41-075-550	LC	89.0	41.0	11.0	2.00	0.75	495	495

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm²)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm³)	Zy (mm³)
1	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
2	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
3	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
4	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
5	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
6	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
7	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
8	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
9	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
10	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
11	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
12	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
13	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
14	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
15	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
16	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
17	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
18	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
19	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
20	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
21	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
22	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
23	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
24	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
25	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
26	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
27	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
28	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
29	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
30	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
31	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
32	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
33	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
34	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Properties LC4 (1.2G + 1.5Q)

ID	Width (mm)	Area (mm²)	Weight (kg/m)	xc (mm)	yc (mm)	Ix (mm4)	Iy (mm4)	rx (mm)	ry (mm)	xo (mm)	yo (mm)	ro1 (mm)	J (mm4)	Iw (10E6mm6)	Zx (mm³)	Zy (mm³)
35	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
36	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
37	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
38	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
39	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
40	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
41	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
42	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
43	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
44	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
45	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
46	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
47	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
48	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
49	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182
50	182.9	139.44	1.108	12.9	44.1	178610	32794	35.8	15.3	32.5	0.00	50.9	26	57.02	4014	1182

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm²)	Sec Mod Up (mm³)	Sec Mod Dn (mm³)
1	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
2	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
3	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
4	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
5	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
6	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
7	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
8	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2737	2737
9	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
10	4.40	41.99	30.51	12.99	1430	1113	1430	1113	112.00	3241	3241
11	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
12	4.40	41.99	30.51	16.59	1430	1175	1430	1175	97.00	3098	3098
13	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
14	4.40	41.99	30.51	19.99	1430	1257	1430	1257	87.00	2741	2741
15	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
16	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
17	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
18	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
19	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
20	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
21	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
22	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
23	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
24	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
25	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
26	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
27	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
28	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
29	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
30	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
31	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
32	4.40	41.99	30.51	14.20	1430	1257	1430	1257	106.00	2761	2761
33	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737

Member Capacities LC4 (1.2G + 1.5Q)

ID	Shear (kN)	Tension (kN)	Comp Section (kN)	Comp Member (kN)	Bend Dn (Sec) (N.m)	Bend Dn (Mem) (N.m)	Bend Up (Sec) (N.m)	Bend Up (Mem) (N.m)	Eff Area (mm²)	Sec Mod Up (mm³)	Sec Mod Dn (mm³)
34	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
35	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
36	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
37	4.40	41.99	30.51	15.72	1430	1257	1430	1257	100.00	2749	2749
38	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
39	4.40	41.99	30.51	28.38	1430	1257	1430	1257	69.00	2737	2737
40	4.40	41.99	30.51	29.01	1430	1257	1430	1257	67.00	2737	2737
41	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
42	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
43	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
44	4.40	20.63	11.68	18.90	1430	1229	1430	1229	90.00	2975	2975
45	4.40	20.63	11.68	21.79	1430	1257	1430	1257	83.00	2737	2737
46	4.40	20.63	11.68	10.15	1430	825	1430	825	116.00	3513	3513
47	4.40	20.63	11.68	26.61	1430	1257	1430	1257	72.00	2737	2737
48	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
49	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737
50	4.40	20.63	11.68	29.01	1430	1257	1430	1257	66.00	2737	2737

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
1	13.53	0.0	-75.4	-150.5	0.71	0.70	0.00	2.22
2	13.53	-150.5	-225.2	-299.7	0.70	0.70	2.22	4.25
3	13.53	-299.7	-247.7	-192.7	-0.15	-0.17	4.25	8.5
4	13.53	-192.7	-134.6	-73.6	-0.17	-0.19	8.5	10.3
5	13.53	-73.6	-62.9	-47.7	-0.02	-0.04	10.3	11.1
6	13.53	-47.7	-28.1	-4.0	-0.04	-0.06	11.1	11.0
7	9.56	-4.0	95.0	194.1	-1.59	-1.59	11.0	11.0
8	9.56	194.1	95.0	-4.0	1.59	1.59	11.0	11.0
9	13.53	-4.0	-28.1	-47.7	0.06	0.04	11.0	11.1
10	13.53	-47.7	-62.9	-73.6	0.04	0.02	11.1	10.3
11	13.53	-73.6	-134.6	-192.7	0.19	0.17	10.3	8.5
12	13.53	-192.7	-247.7	-299.7	0.17	0.15	8.5	4.25
13	13.53	-299.7	-225.2	-150.5	-0.70	-0.70	4.27	2.22
14	13.53	-150.5	-75.4	0.0	-0.70	-0.71	2.25	0.00
15	0.00	0.0	0.1	0.4	0.00	-0.01	1.30	0.00
16	-14.19	0.4	-14.5	-28.8	0.14	0.13	0.00	2.15
17	-14.19	-28.8	-42.5	-55.7	0.13	0.12	2.15	4.26
18	-14.43	-55.7	-224.3	-391.5	0.93	0.91	4.26	7.4
19	-14.09	-391.5	-356.4	-320.2	-0.21	-0.22	7.4	9.2
20	-14.08	-320.2	-266.7	-210.6	-0.22	-0.24	9.2	10.2
21	-13.73	-210.6	-55.4	100.3	-1.36	-1.37	10.2	10.3
22	-13.68	100.3	196.4	292.6	-1.54	-1.55	10.3	10.4
23	-10.32	292.6	58.2	-174.0	1.05	1.03	10.4	11.2
24	-9.97	-174.0	-159.7	-144.2	-0.09	-0.10	11.2	11.5
25	-9.96	-144.2	-118.0	-89.0	-0.10	-0.12	11.5	11.2
26	-9.62	-89.0	82.9	255.7	-1.24	-1.26	11.2	10.9
27	-3.69	255.7	127.7	0.0	1.41	1.41	10.9	10.9
28	-3.69	0.0	127.7	255.7	-1.41	-1.41	10.9	10.9
29	-9.62	255.7	82.9	-89.0	1.26	1.24	10.9	11.2
30	-9.96	-89.0	-118.0	-144.2	0.12	0.10	11.2	11.5
31	-9.97	-144.2	-159.7	-174.0	0.10	0.09	11.5	11.2
32	-10.32	-174.0	58.2	292.6	-1.03	-1.05	11.2	10.4
33	-13.68	292.6	196.4	100.3	1.55	1.54	10.4	10.3
34	-13.73	100.3	-55.4	-210.6	1.37	1.36	10.3	10.2

Member Forces LC4 (1.2G + 1.5Q)

ID	Axial (kN)	Moment A (N.m)	Moment B (N.m)	Moment C (N.m)	Shear A (kN)	Shear C (kN)	Disp A (mm)	Disp C (mm)
35	-14.08	-210.6	-266.7	-320.2	0.24	0.22	10.2	9.2
36	-14.09	-320.2	-356.4	-391.5	0.22	0.21	9.2	7.4
37	-14.43	-391.5	-224.3	-55.7	-0.91	-0.93	7.4	4.26
38	-14.19	-55.7	-42.5	-28.8	-0.12	-0.13	4.26	2.15
39	-14.19	-28.8	-14.5	0.4	-0.13	-0.14	2.17	0.00
40	0.00	0.4	0.1	0.0	0.01	0.00	0.34	1.30
41	-0.85	0.0	0.0	0.0	0.00	0.00	4.25	4.26
42	0.17	0.0	0.0	0.0	0.00	0.00	10.3	10.3
43	-4.25	0.0	-4.0	0.0	0.01	-0.01	10.4	11.0
44	3.19	0.0	0.0	0.0	0.00	0.00	11.0	10.9
45	4.84	0.0	0.0	0.0	0.00	0.00	10.9	10.9
46	-4.25	0.0	-4.0	0.0	0.01	-0.01	11.0	10.4
47	0.17	0.0	0.0	0.0	0.00	0.00	10.3	10.3
48	-0.85	0.0	0.0	0.0	0.00	0.00	4.27	4.26
49	-6.45	0.0	71.2	142.5	-0.82	-0.82	10.9	10.9
50	-6.45	142.5	71.2	0.0	0.82	0.82	10.9	10.9

Code Status LC4 (1.2G + 1.5Q)

ID	Shear (%)	Tension (%)	Comp Sec (%)	Comp Mem (%)	Bend Sec (%)	Bend Mem (%)	Shear + Bend + (%)	Tens + Bend + (%)	Comp+Bend Mem + (%)
1	16.2	32.2	0.0	0.0	10.5	12.0	19.3	42.8	10.5
2	16.0	32.2	0.0	0.0	21.0	23.8	26.4	53.2	21.0
3	3.9	32.2	0.0	0.0	21.0	25.5	21.3	53.2	21.7
4	4.3	32.2	0.0	0.0	13.5	16.4	14.1	45.7	13.9
5	1.0	32.2	0.0	0.0	5.1	6.6	5.2	37.4	5.6
6	1.5	32.2	0.0	0.0	3.3	4.3	3.7	35.6	3.6
7	36.2	22.8	0.0	0.0	13.6	15.4	38.7	36.3	13.6
8	36.2	22.8	0.0	0.0	13.6	15.4	38.7	36.3	13.6
9	1.5	32.2	0.0	0.0	3.3	4.3	3.7	35.6	3.6
10	1.0	32.2	0.0	0.0	5.1	6.6	5.2	37.4	5.6
11	4.3	32.2	0.0	0.0	13.5	16.4	14.1	45.7	13.9
12	3.9	32.2	0.0	0.0	21.0	25.5	21.3	53.2	21.7
13	16.0	32.2	0.0	0.0	21.0	23.8	26.4	53.2	21.0
14	16.2	32.2	0.0	0.0	10.5	12.0	19.3	42.8	10.5
15	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
16	3.1	0.0	46.5	50.0	2.0	2.3	3.7	2.0	52.0
17	2.9	0.0	46.5	50.0	3.9	4.4	4.8	3.9	53.8
18	21.1	0.0	47.3	91.8	27.4	31.1	34.6	27.4	119.9
19	5.1	0.0	46.2	89.6	27.4	31.1	27.8	27.4	117.7
20	5.6	0.0	46.1	89.6	22.4	25.5	23.1	22.4	112.5
21	31.3	0.0	45.0	87.3	14.7	16.8	34.6	14.7	102.4
22	35.2	0.0	44.8	47.2	20.5	23.3	40.7	20.5	67.0
23	23.9	0.0	33.8	72.7	20.5	23.3	31.5	20.5	93.5
24	2.3	0.0	32.7	70.2	12.2	13.8	12.4	12.2	82.6
25	2.8	0.0	32.7	70.2	10.1	11.5	10.5	10.1	80.4
26	28.6	0.0	31.5	67.7	17.9	20.3	33.7	17.9	85.8
27	32.2	0.0	12.1	12.7	17.9	20.3	36.8	17.9	30.0
28	32.2	0.0	12.1	12.7	17.9	20.3	36.8	17.9	30.0
29	28.6	0.0	31.5	67.7	17.9	20.3	33.7	17.9	85.8
30	2.8	0.0	32.7	70.2	10.1	11.5	10.5	10.1	80.4
31	2.3	0.0	32.7	70.2	12.2	13.8	12.4	12.2	82.6
32	23.9	0.0	33.8	72.7	20.5	23.3	31.5	20.5	93.5
33	35.2	0.0	44.8	47.2	20.5	23.3	40.7	20.5	67.0

Code Status LC4 (1.2G + 1.5Q)

ID	Shear (%)	Tension (%)	Comp Sec (%)	Comp Mem (%)	Bend Sec (%)	Bend Mem (%)	Shear + Bend + (%)	Tens + Bend + (%)	Comp+Bend Mem + (%)
34	31.3	0.0	45.0	87.3	14.7	16.8	34.6	14.7	102.4
35	5.6	0.0	46.1	89.6	22.4	25.5	23.1	22.4	112.5
36	5.1	0.0	46.2	89.6	27.4	31.1	27.8	27.4	117.7
37	21.1	0.0	47.3	91.8	27.4	31.1	34.6	27.4	119.9
38	2.9	0.0	46.5	50.0	3.9	4.4	4.8	3.9	53.8
39	3.1	0.0	46.5	50.0	2.0	2.3	3.7	2.0	52.0
40	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
41	0.0	0.0	7.3	3.1	0.0	0.0	0.0	0.0	3.1
42	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0
43	0.2	0.0	36.4	41.9	0.3	0.5	0.4	0.3	42.3
44	0.0	15.5	0.0	0.0	0.0	0.0	0.0	15.5	0.0
45	0.0	23.5	0.0	0.0	0.0	0.0	0.0	23.5	0.0
46	0.2	0.0	36.4	41.9	0.3	0.5	0.4	0.3	42.3
47	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0
48	0.0	0.0	7.3	3.1	0.0	0.0	0.0	0.0	3.1
49	18.7	0.0	55.2	22.2	10.0	11.3	21.2	10.0	32.2
50	18.7	0.0	55.2	22.2	10.0	11.3	21.2	10.0	32.2