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Design Of Trusses With Light Gauge Cold Formed Steel Sections

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Abstract

The most complex component designed in light gauge framed residential structures are Roof trusses. In the design of light gauge cold formed metal trusses, the designer is meant to adhere to the requirements of Loading standards and steel design standards.

Designers need to ensure that all the loads and load combinations stipulated in NASH Standard Residential and Low-rise Steel Framing Part 1 Design Crieteria and AS 4055 are checked and that the support, restraint conditions are accurately considered in the analysis.Various loads, load combinations, wind pressure coefficients, restraint and support conditions will be discussed in this paper.

In the design of truss members, the requirement of AS/NZS 4600 should be strictly adhered. Effective length criteria for truss members is also discussed in this paper.This paper provides an illustrative example fo truss design using light gauge cold formed steel members.

In the construction of roof, lateral restraints are provided by battens and other secondary members. The integrity of these restraints are discussed in this paper.

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1. Introduction

While light framed structures have been used in residential construction for several decades, system developers and designers continually optimise and refine the design of components to achieve a high degree of economy as well as satisfy various architectural trends. One of the most complex components in typical framed residential structures is the roof. In cold formed steel construction, roof structures are mainly formed using roof trusses of various types. Indeed cold formed roof trusses are used not only with steel framed walls but also with different types of wall construction including solid brick construction.

Cold formed light gauge steel offers a number of superior features making it an attractive material for truss systems. Specifically, the strength, stiffness, quality and light weight features of cold formed steel trusses make them ideal for long spans. With availability of various sections and sizes, complex roof geometries could be easily achieved.

While trusses are structurally relatively simple, because of the complex sections used, numerous combinations of loads which need to be considered and the requirement for different roof trusses with different geometries in a house, it has become a common practice to use software programmes to analyse and design roof trusses. Indeed, this is not only common for steel trusses but also timber trusses. Many of the software systems for steel and timber trusses are developed for specific proprietary systems. Such software systems are specifically developed for use by manufacturers or fabricators without the aid of a structural engineer. The outputs from such softwares do require certification by an approved authority.

This paper highlights the main steps and assumptions involved in typical cold formed steel trusses. The listed steps and assumptions aim to assist structural engineers in designing such trusses and also provide certifiers with items for checking.

2. Typical truss roof system

Steel roof systems with cold formed high tensile steel can be provided to suit various types of roof construction like hips, gables, dutch gables, mansard, etc. Figure 1 shows a typical roof system and highlights typical terminology used. Depending on the shape of the roof, a variety of trusses can be used as shown in Figure 2. Due to the flexibility of roll forming of sections and the introduction of more sophisticated fabrication techniques, trusses with different cross sections are available as shown in Figure 3. Steel grades ranging from G300 to G550 are commonly available.

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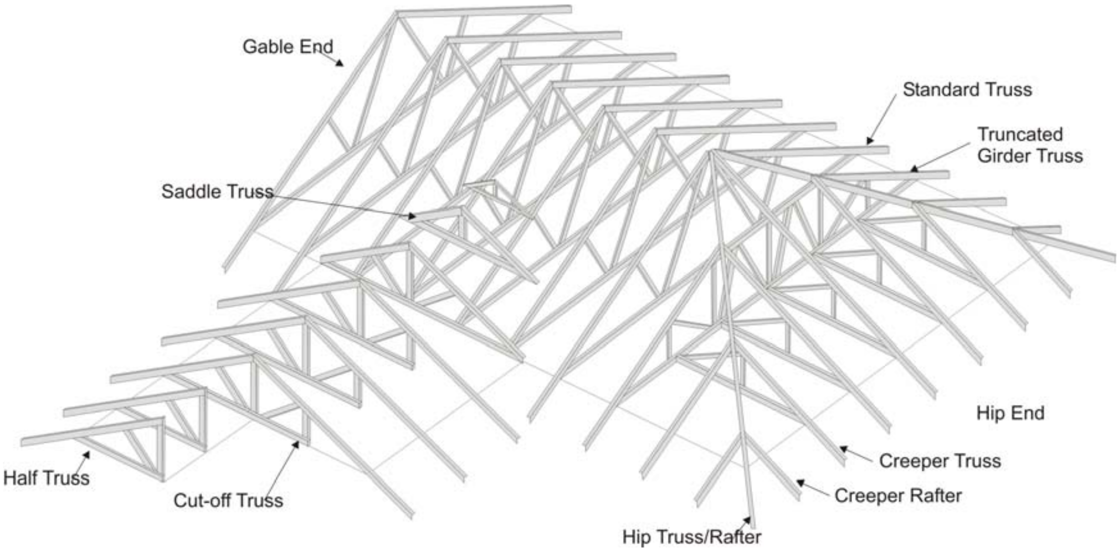

Figure 1: Typical Truss Roof System. Battens are not shown for clarity

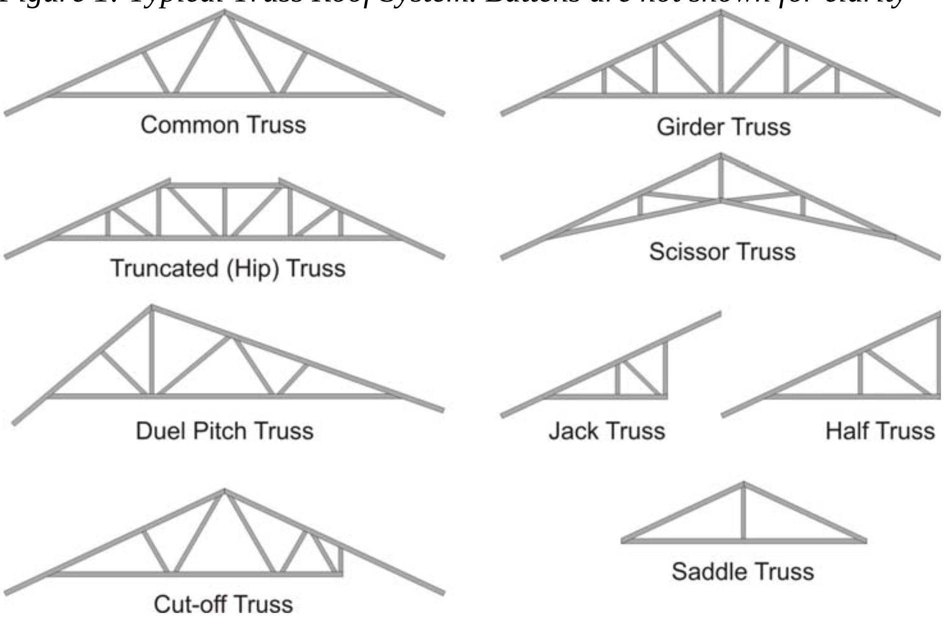

Figure 2: Typical roof trusses

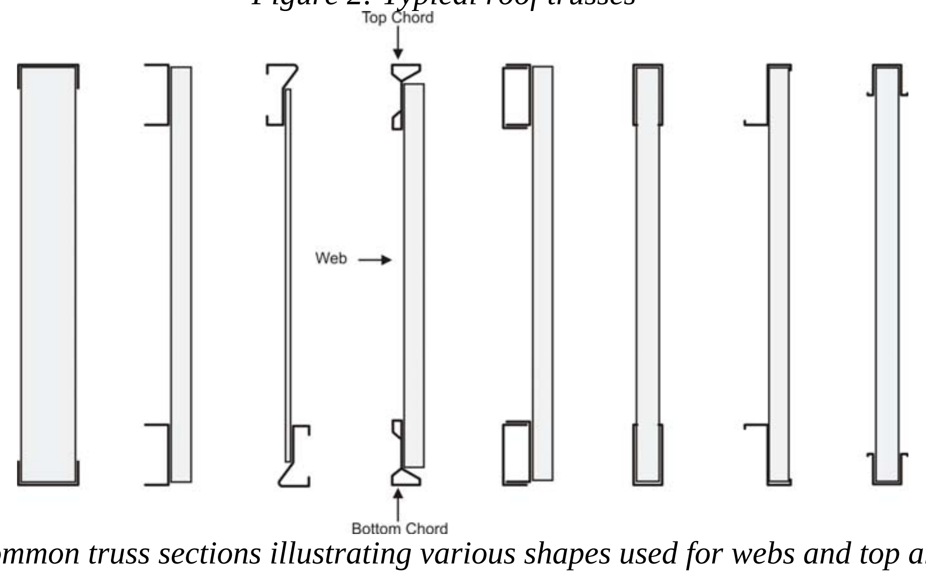

Figure 3: Common truss sections illustrating various shapes used for webs and top and bottom chords

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3. Actions on trusses

Permanent actions on roof trusses that need to be considered include self-weights of all structural components of the roof and the weights of all permanent fixtures such as solar panels, water tank, air conditioning plant etc. Imposed actions that need to be considered include a uniformly distributed load and a concentrated load of 1.1 kN (representing the weight of a person). The location of this concentrated load is often a critical design condition and should be carefully considered. It is not sufficient to only consider that this concentrated load is acting on nodal (panel) points of the truss. For example, the concentrated load should be considered at mid span of members and when there is an overhang, a load case should consider the application of the concentrated point load at a distance of 100mm away from the edge. Systematic software procedures or sound engineering judgment need to be employed to determine the worst case location for the application of the concentrated load along with other combinations of loads.

The NASH Standard for Residential Low-rise Steel Framing, Part 1: Design Criteria (NASH 2005) outlines a process by which a reduction factor can be obtained to account for load sharing between parallel top chord members.

In addition to the permanent and imposed actions, wind actions which could be either upward or downward depending on the roof shape and wind directions need to be included in the truss analysis. For cladding and immediate supports, both external and internal pressures should be considered together with localised pressures in accordance with AS 4055 (2006) or AS/NZS 1170.2 (2002).

During construction, in the absence of cladding, the battens and roof truss/rafter system will have to support the weight of the stacked roofing material and construction workers. Trusses may also have to support temporary scaffolds. To avoid possible rolling of trusses during construction, they should have temporary bracing.

Table 1 lists relevant load combinations for both strength and serviceability limit states. Table 2 provides a summary of the actions and corresponding design considerations for roof members.

Table 1: Load combinations for strength and serviceability limit states

Strength Limit States				
Load case	Dead Load	Live Load	Point Live Load	Wind Load*
1	1.2	1.5	0	0
2	0.9	0	0	1
3	1.2	0	0	1
4	1.2	0	1.5	0
Serviceability Limit States				
1	1	0	0	0
2	0	0	1	0
3	0	0	0	1

* Wind loads perpendicular and parallel to the ridge need to be considered.

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4. Design considerations for roof trusses

All roof system components including the truss, battens, cladding and bracing should be designed to act together to transfer all actions to appropriate supports.

For trusses, which are supporting ceilings, the application of wind internal pressure needs to be carefully considered. If the ceiling is fully sealed, the internal pressure will act on the ceiling plane. In other words, the internal pressure would act on the bottom chord and external pressure would apply to the top chord. However, if the ceiling is permeable then both external pressure and internal pressure would act on the top chord. The designer is required to apply a degree of engineering judgment in this situation. One possible suggestion is to design the whole truss for axial loads based on external pressure on the top chord and internal pressure on the bottom chord. However, for determining the local bending effects on the top chord, it might be prudent to include the bending effects of the internal pressure on the top chord.

It should be noted that the internal wind pressure coefficients can be reduced for structures that have shutters over openings. On the other hand, for unshuttered structures in cyclonic regions, there is an increase in the internal pressure coefficient for cyclonic regions as indicated in the NASH Standard.

5. Truss analysis

While sophisticated 3D computer programmes are becoming more widely available, for analysis of trusses, most designers opt for a conventional linear elastic 2D frame analysis. With such analysis, the axial forces, bending moments, shear forces and deflections are produced for all load combinations. However, a number of assumptions need to be considered and realized. It is often assumed that the axes of the truss members meet at the nodal points. When this condition is not realised, bending moments resulting from such eccentricities should be accounted for.

It is common construction practice that the top and bottom chords of the trusses are continuous over the nodal points. Thus the chord members experience axial and shear forces and bending moments. Therefore, they have to be design for combined actions. Web members on the other hand are often assumed to be pinned at both ends and are designed for axial forces only.

In most cases roof trusses are assumed to be simply supported. However, in some cases there could be additional supports provided when trusses are supported by load bearing walls below. Such intermediate supports may be considered as roller supports.

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Table 2: Actions and design considerations for roof members (NASH 2008)

MEMBER	ACTIONS			STRENGTH DESIGN		SERVICEABILITY DESIGN		
	G	Q	Wu	RESTRAIN	CRITERIA	G	Q	Ws
Roof Battens	Wt of roofing	1.1 kN	as per NASH Standard	Top: distance between fixing screws Bottom: distance between trusses or rafters	Bending under G+Q or W_u-G	L/300	L/150	L/150
Roof Rafters	Wt. of roof (and ceiling if carried by rafters)	0.25 kPa 1.1 kN	as per NASH Standard	Top: distance between battens	Bending under G+Q or W_u-G	L/300 Or 20 mm	L/250	L/150
Roof Trusses	Wt. of roof and ceiling distributed to top and bottom chord as appropriate	0.25 kPa 1.1 kN	as per NASH Standard	Top chord: distance between roof battens Bottom chord: distance between ceiling joists or battens Web members: Pinned at nodal points	Top and bottom chords: Combined compression (truss action) and bending (from UDL and concentrated load) Web members: Pinned ended members for compression and tension load capacities	Top chord L/300 Or 20 mm Bottom chord L/300	Top chord d/200 Top chord d/200 Bottom chord d/250	L/150
v Roof Trusses	Wt. of ceiling	1.1 kN	Internal pressure	Top: distance between trusses Bottom: fully restrained by ceiling	Bending under G or W_u -G	L/300 - L/500		L/200
Ceiling Joists	Wt. of ceiling		Internal pressure	as for batten	Bending under G or W_u-G	L/300 - L/500	L/300	L/200+

* For final design all combinations that are likely to produce the worst effects should be checked.

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6. Truss member design

6.1 Effective lengths

Effective lengths depend on the properties of the members and the specific physical details of heel, apex and node design. As a general guide, the following effective lengths are suggested.

For continuous chord members in compression and in-plane consideration, L_{ex} can conservatively be taken as the distance between panel points but can be reduced to 0.8 times the distance between panel points if there is sufficient rigidity at the nodal points. For out-of-plane consideration, L_{ey} can be generally taken as the distance between battens. For torsional consideration, L_{ez} is dependent on torsional stiffness of the members and the effective restraint provided by the battens. Tests may be performed to obtain the value of L_{ez} for various batten spacings. However, L_{ez} can be generally taken as 0.8 times the distance between panel points. The effective lengths for chord members in bending are summarized in Table 3.

For webs members in compression the effective lengths L_{ex}, L_{ey}, L_{ez} can be taken as the member length (L). Rigid connection details at each node may justify a shorter effective length for web members.

Table 3: Effective length for chord members in bending.

Condition	L_{ey} or L_{ez}
Restrained flange in compression	Distance between battens*
Unrestrained flange in compression	Distance between point of contraflexure (between panel points) Distance between panel point and point of contraflexure (at panel points)

** Clip-on battens are not assumed to provide restraint to chords unless test results show otherwise.*

6.2 Member capacities

The Australian Standard for Cold Formed Steel AS/NZS 4600 provides the process by which member capacities can be determined. The various capacity checks are summarized in Figure 4. If a computer program is used, it is possible to check all conditions but using engineering judgement it is possible to select the most likely critical conditions. These often are:

- web members are checked for axial capacities (tension or compression) only;
- chord members are usually checked for combined axial and bending capacities;
- for members with unstiffened webs, combined bending and shear could be critical.
- for members subject to concentrated load or reactions, bearing or combined bearing and bending could be critical

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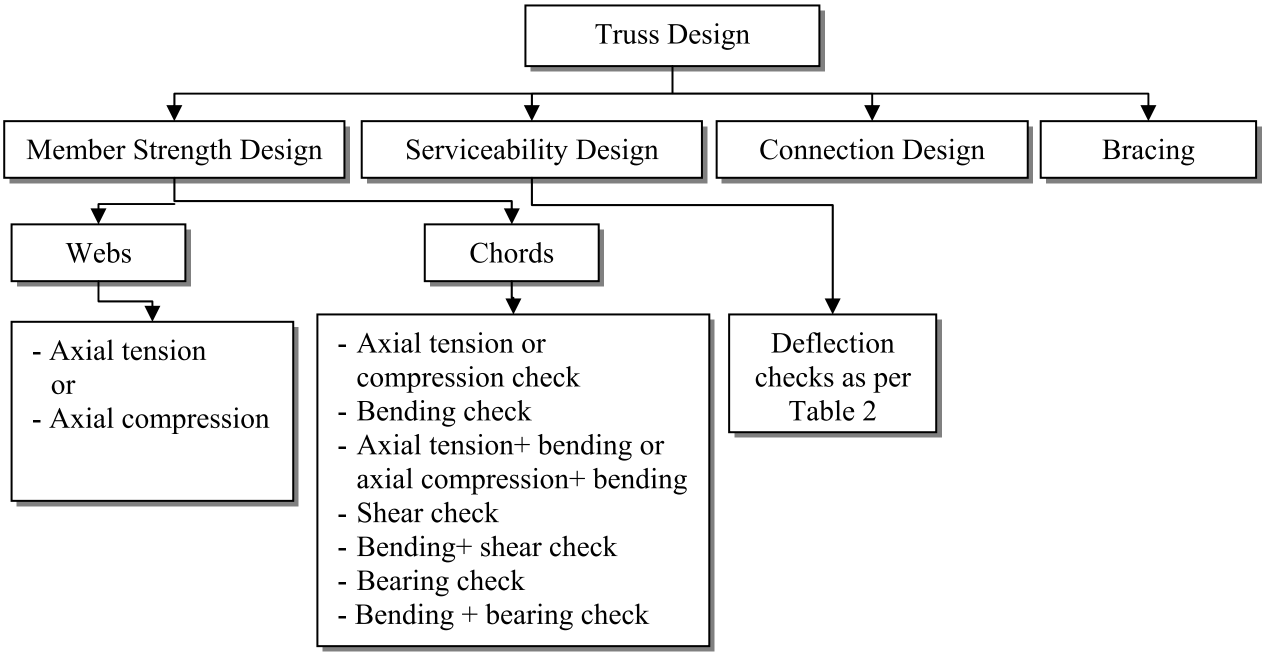


Figure 4: Summary of truss design checks

6.3 Connections

Typical truss connections are shown in Figure 5. The critical truss connections are those at the apex and heels. The connection between the top chords of a truss to the roof battens is critical in maintaining the fully restrained condition for the top chord. This condition is usually assumed in truss analysis. The total amount of restraints required between the apex and heel of a truss is approximately 10% of the maximum top chord compression force and is to be distributed among all chord-to-batten connections between these two points. This is based on AS/NZS 4600 requirements for lateral restraints. The connection capacities can be simply obtained by testing. AS/NZS 4600 also provides analytical models for determining the capacities for typical fasteners.

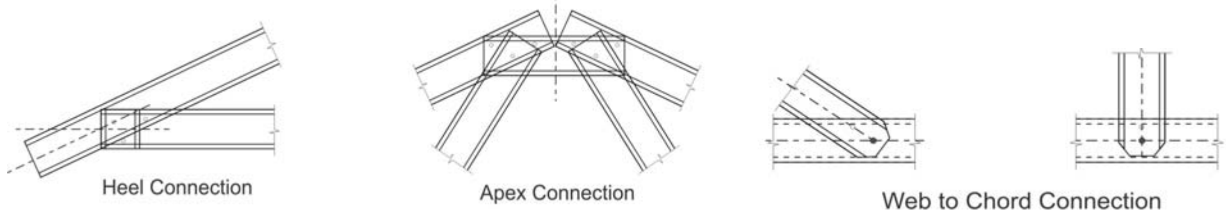


Figure 5: Typical truss connections

6.4 Bracing

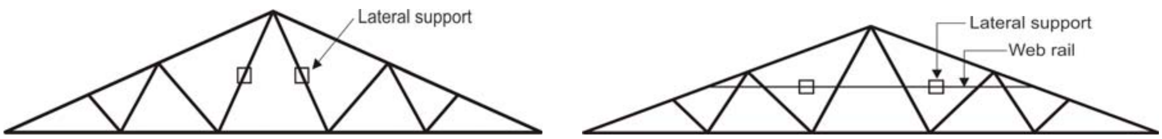
There are specific bracing items for trusses such as web bracing which reduce the effective length of the web members. However, there are other components such as the battens which in conjunction with cross strap bracing or lining provide dual functions. One is to provide bracing for the entire roof system so that it acts as one body to transfer lateral wind loads to the roof supports. The other is to provide restraint to the top and bottom chords which in turn reduce their effective lengths. Hence, the roof bracing can be broadly divided into four groups, namely; (a) Top chord bracing; (b) bottom chord bracing; (c) web bracing; and (d) lateral restraints to truss top chords.

Top chord bracing should be designed to transfer horizontal wind loads perpendicular to the span of trusses to the supports. In addition they are required to provide restraint to the roof battens or purlins that act as lateral buckling restraints to the top chords of the trusses when they are in compression.

Bottom chord bracing is required to restrain the bottom chords of trusses against lateral buckling. If ceiling battens are directly fixed to the bottom chords and do not allow movement, these battens may provide adequate restraint. For suspended ceilings, exposed ceilings or ceiling battens which allow movement of bottom chords, specific bottom chord restraint may be required.

It should be noted that the battens may be provided by a different contractor (eg., roofing contractor) to the truss supplier. Therefore, one should be aware if the provided battens and their connections satisfy the truss design intent.

For truss web members of longer lengths, their slenderness and therefore load capacity can be improved by boxing the section or by the provision of lateral restraints as shown in Figure 6. In Figure 6(a) the lateral restraint extends at right angles to the plane of the truss and along the building and is braced back to the ceiling or roof plane at each end of the building. This is suitable when the trusses are parallel to each other and the webs of the trusses line up. In Figure 6(b) the lateral support is provided by a web rail which in turn is braced by lateral restraints at right angles to the plane of the truss. This is suitable when trusses are parallel to each other but the webs of the trusses do not line up.



(a) (b)

Figure 6: Examples of web bracing

7. Illustrative example of Truss design (In accordance to AS/NZS 4600)

Input parameters (see figure 7):
Truss Span = 8 m
Truss Spacing = 1.2 m
Wind Speed (Strength) = 50m/sec (corresponding to N3)
Wind Speed (serviceability) = 32 m/sec (corresponding to N3)
Top chord batten spacing = 1200 mm
Bottom chord batten spacing = 600 mm
Dead load on top chord = 0.2 kPa
Live load on top chord =0.25 kPa
Dead load on bottom chord = 0.09 kPa
Truss web and chord material = C section 75 x 1.0, G550

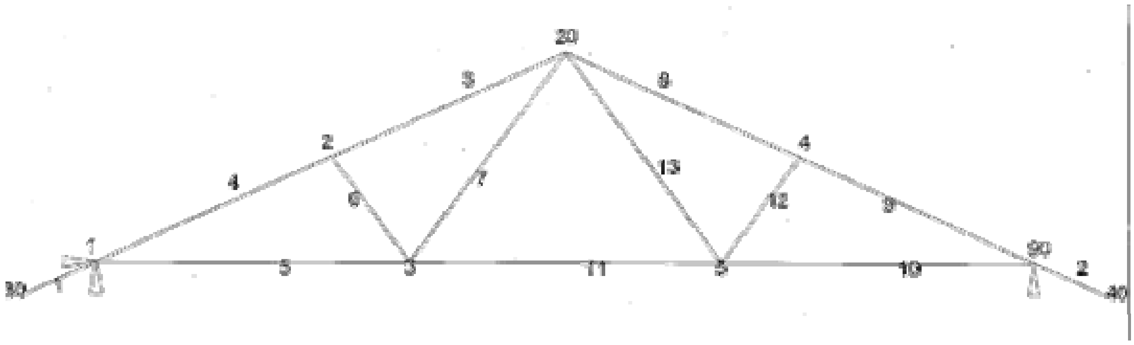


Figure 7:Example truss with node and member elements marked

Truss subjected to loading (see figure 8): 1.2(Dead Load) +1.5 (Live Load)

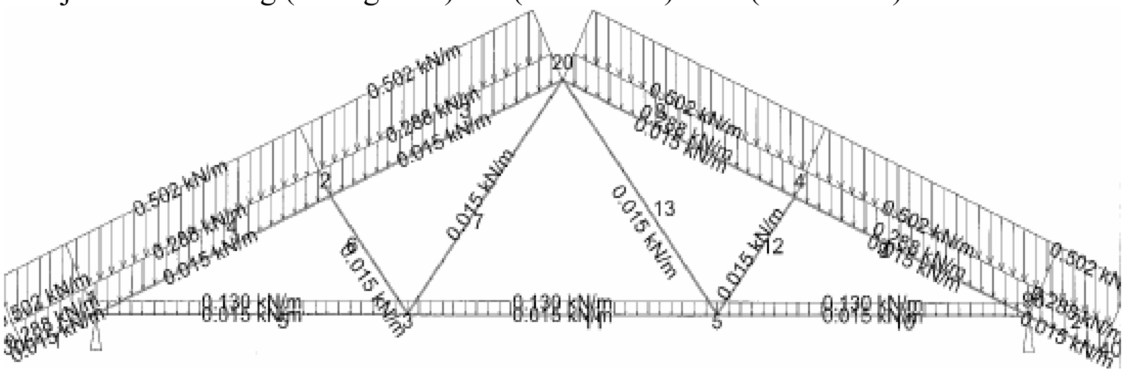


Figure 8:Example truss loading diagram

Design of Web element 7: This web element is subjected to tensile force
Axial Force = 2.45 kN (tension); Moment = 0 kN-m
Tension capacity of web ($\varphi_t N_t$) = 63.53 kN (in accordance to AS/NZS 4600)
Axial force (tension) < Tension capacity (safe)

Design of Web element 6: This web element is subjected to compressive force
Axial force = -1.91 kN (compression); Moment = 0 kNm
Length of web (L)= 1146 mm
Effective lengths of web; $L_{ex} = L_{ey} = L_{ez}$ = 1146 mm
Compression Section Capacity ($\varphi_c N_s$) = 44.19 kN
Member capacity (Torsional/Flexural-torsional) ($\varphi_c N_c$) = 17.25 kN
Member capacity (Distortional) ($\varphi_c N_c$) = 35.62 kN
Axial force (comp) < Compression capacity (section capacity/member capacity) (Hence OK)

Design of Top chord element 3 :
This chord element is subjected to combined Compressive force and Bending Moment
Axial force = -6.73 kN max (compression); Moment = 0.269 kNm max mid-span moment
Chord length (L) = 2206 mm

- Determination of compression capacity:

Effective lengths of chord; L_{ex} = 0.9*L = 1986 mm; L_{ey} = Batten distance = 1200 mm;
L_{ez} = 0.8*L = 1765 mm;
Compression Section Capacity ($\varphi_c N_s$) = 44.19 kN
Compression Member capacity (Torsional/Flexural-torsional) ($\varphi_c N_c$) = 8.55 kN
Compression Member capacity (Distortional) ($\varphi_c N_c$) = 35.62 kN
Axial force (comp) < Compression capacity (section capacity/member capacity) (Hence OK)

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- Determination of bending capacity:

Effective lengths of chord; L_{ey} = Batten distance = 1200 mm;
L_{ez} = Batten distance = 1200 mm (restrained flange is in compression)

Bending Section Capacity ($\varphi_b M_s$) = 1.581 kNm
Bending Member capacity (Lateral) ($\varphi_b M_b$) = 1.378 kNm
Bending Member capacity (Distortional) ($\varphi_b M_b$) = 1.349 kNm
Bending force < Bending capacity (section capacity/member capacity) (Hence OK)
Note: check also at panel point

- Combined bending and compression capacity:

Axial comp force/ comp capacity + Bending force/Bending capacity < 1 (Hence OK)

Note: Check for the most critical load combinations and most critical Axial force, Bending moment.
Shear, bending+shear, Bearing checks need to be performed for a complete design.
Bearing could be critical when members are subjected to concentrated loads/reactions

8. Concluding remarks

This paper outlined the basic features of roof trusses made of light gauge cold formed steel. The loads expected on typical residential roofs were discussed. Detailed lists of the expected actions along with relevant design criteria for serviceability and strength limits states were presented. The relevant load combinations were also summarised.

The paper detailed the process for designing typical roof trusses with an illustrative example. Typical industry practices were highlighted to provide general guidance to designers. In particular, the paper outlined typical assumptions related to effective lengths of chord and web members. This highlights the importance of adopting the correct effective length of determining the various member capacities.

It was emphasised that if a designer is not using a computer programme to carry out the analysis and design, he/she need to exercise a degree of engineering judgement to reduce the number of combinations and checks to be computed. The paper offered a number of suggestions in relation to the critical cases to be considered for the design of chord and web members.

The paper also emphasised the importance of ensuring that all parts of the roof system is correctly designed including the connections and bracing. It is also critical to ensure that the design assumptions and intent are materialised.

9. Acknowledgments

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