Shelter 3: Structural Assessment – Indonesia, Aceh

1.1 Introduction and Purpose

Arup was commissioned to carry out a structural review to assess and validate nine selected shelter designs for the IFRC. This document summarises the information gathered for and the key outcomes of the verification of the structural performance of Shelter 3, built by 7 members from the Red Cross movement including the Indonesian Red Cross, American Red Cross, Australian Red Cross, British Red Cross, Canadian Red Cross, Spanish Red Cross and the IFRC. The 33 implementing partners included international NGOs, national NGOs and government agencies. This assessment is based on the input documents listed in Appendix A.

Summary Information:

Disaster: Tsunami, 2004

Materials: Galvanised steel frame, steel sheet roofing, Radiata Pine/Douglas Fir or equivalent treated timber planks, steel foundation plates and anchors, door fixtures, nails, bolts and screws

Material source: The steel frames were manufactured regionally and the roof sheeting and timber imported internationally

Time to build: 1 day to construct the frame, 2 days minimum to clad the shelter

Anticipated lifespan: Minimum 5 years

Construction team: 4-5 people

Number built: 20,000

Approximate material cost per shelter: 4765CHF (2004)

Programme cost per shelter: 5100CHF (2004)

Shelter Description:

The structure consists of a cold rolled, hot dip galvanised steel frame with a pitched roof of 24.3 degrees and a raised floor. The height to the eaves is 2.8m and 4.15m to the ridge. The platform area of the shelter is 25m^2 with a cantilevering balcony at opposite sides front and back and a cantilevering roof covering the balconies. There are 6 columns fixed using column base plates nailed directly into the ground. Metal roof sheets are screwed to steel purlins spanning between primary roof beams. Limited lateral stability is provided by timber plank wall cladding fixed to timber studs that are in turn screwed to the steel frame. The floor consists of timber planks spanning between steel joists.

The shelter frame, tools and timber planks and studs were delivered as a ‘kit’. The timber planks and studs were delivered to site pre-cut and treated and the plywood supplied separately. Windows and gable materials were not provided in the kit to stimulate local markets. The shelter ‘kit’ was demountable and could be relocated easily. The durability of the shelter is good since the steel members are galvanised and the timber is treated.

1.2 Location and Geo-hazards

1.2.1 Location of Shelter

Aceh and Nias, West Sumatra, Indonesia

The shelters are located in districts including Aceh Barat, Barat Daya, Aceh Besar, Banda Aceh, Aceh Utara, Pidie, Simeulue, Biruen and Aceh Jaya. It has been assumed the shelters have been used in both mountainous and coastal locations on flat land.

1.2.2 Hazards

A summary of the natural hazards faced in the Aceh Province of West Sumatra are given below[1]:

- HIGH Earthquake Risk. A map from the Indonesian Design Code[2] suggests that the shelters are situated in an area with a high peak ground acceleration (PGA) of 0.25g for an earthquake return period of 500 years[3].
- LOW Wind Loading. Area not prone to tropical storms or cyclones. See Section 1.8.3 for wind loading details.
- HIGH Flood Risk. High rainfall and high run-off may lead to flash floods. The area is also prone to storms and lightning strikes.
- There is a high landslide risk due to earthquakes or flooding if shelters are located near potentially unstable slopes.
- Other hazards that will not be designed against include tsunami and volcanoes. There is precedence for devastating tsunamis in the region and a number of high risk active volcanoes. There is also a high risk of wildfires depending on the exact location.
- Tropical climate with consistent temperatures around 28 degrees average. High humidity and monsoons.

[1] See Appendix A, Reference 6.
[2] See Appendix A, Reference 7.
[3] In general a 475 year return period has been used with the code. The value used is therefore conservative.

1.3 Geometry

The geometry was determined using the drawings and photographic information provided, see Figure 1.1 for key members and levels.

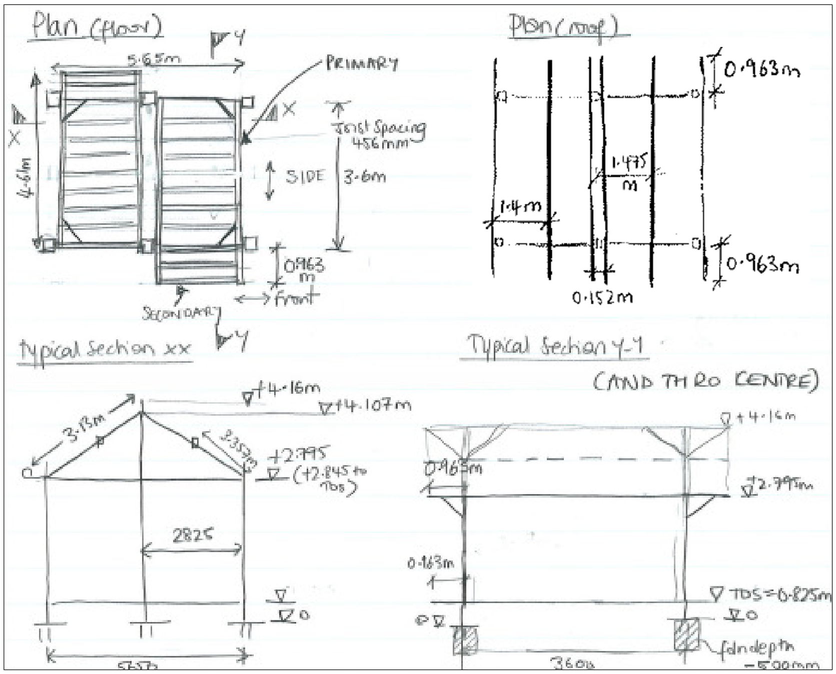


Figure 1.1 – Sketch of Geometry

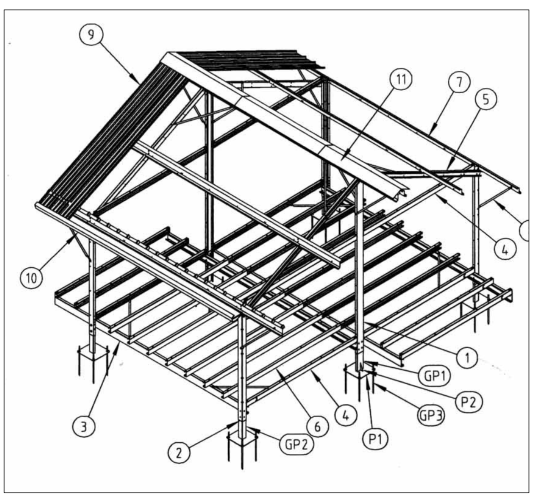


Figure 1.2 – Isometric Drawing of Shelter

The structure consists of a cold rolled, hot dip galvanised steel frame with a pitched roof of 24.3 degrees and a raised floor. The height to the eaves is 2.8m and 4.15m to the ridge and the frame is braced at roof level. The platform area of the shelter is 25m^2 with a cantilevering balcony at opposite sides front and back (see Figure 1.2). There are 6 columns laterally spaced at 2.83m and longitudinally spaced at 3.6m, fixed into the ground using column base plates and four anchor nails per column.

The covered area of the shelter is 31m^2 with a cantilevering roof at front and back to cover the balconies. Metal roof sheets are screwed to steel purlins spanning between primary roof beams. Limited lateral stability is provided by timber plank wall cladding fixed to timber studs that are in turn screwed to the steel frame. The floor consists of timber planks spanning 0.46m between steel joists. All fixings are simple steel bolted connections using two bolts.

1.4 Structural System

- Vertical loads are transferred from horizontal beams and purlins back to the corner columns which transfer the forces to the ground by bearing of the column base plates onto the soil.
- The structure has very little lateral stability since it has been assumed that the haunch and eaves braces and connections are simple connections and provide minimal portal frame action. There is no in plane bracing in the walls or roof only stabilising braces at the eaves. The metal roof decking will not as a diaphragm and nailed wooden planks do not provide a code compliant seismic or wind resistant lateral system. They do however provide some lateral resistance (see Figure 1.3).

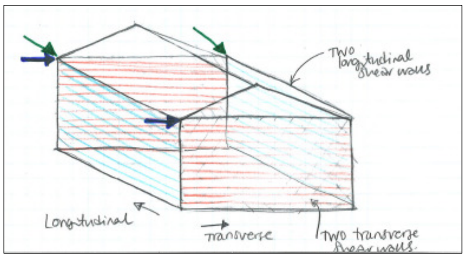


Figure 1.3 – Lateral Stability System

- Overturning and uplift on the foundations is resisted by the six anchor nailed base plates.

1.5 Member Sizes

The table below shows the member sizes that have been assumed for the structural assessment. These sizes have been based on information given in the drawings and Bill of Quantities referenced in Appendix A. The updated Bill of Quantities is given in Appendix B.

NO.	DESCRIPTION	DRAWING	SIZE	Q'TY /HOUS
GP1.	GUIDE POST FOUNDATION		400X400X625	2
GP2.	GUIDE POST FOUNDATION		400X400X625	4
GP3.	ANCHOR NAIL		#19X600	24
1.	CENTER POST		150X50X3790	2
2.	CORNER POST		100X100X2425	4
3.	RUNNER		150X50X4612.5	4
4.	JOIST VERANDA		100X50X2790	12
5.	GIRDLE		[illegible]	1
6.	JOIST		100X50X2872.5	14
7.	PURLIN		t2.0x246x5680	6
8.	BRACING		PIPE#25X1200	16
9.	ROOF PANEL		740X3440	16
10.	GUTTER		t0.5X457X4675	1
11.	TOP COVER ROOF		t0.5X458X2028	3

1.6 Materials

The frame, roof sheeting and timber planks were supplied internationally. The steel frame consists of cold formed hot dip galvanised steel members connected using bolts, with Douglas fir timber cladding fixed using screws. The roofing is galvanised steel sheeting and the floor plywood supplied separately to the rest of the shelter 'kit'.

1.6.1 Material Assumptions

Type	IFRC Specification	Arup Assumption	Comments
Galvanised Steel Members	Cold rolled, hot dip galvanised steel, JIS G3302, ASTM A653 M-95, minimum thickness 1.6, 2mm.	Cold rolled galvanised steel, yield strength 550N/mm^2, density 78.5kN/m^3.	All sections have been assumed to be 1.6mm thick and have been approximated to Albion sections of 450 N/mm^2 strength for analysis.
Galvanised Steel Foundations	Hot rolled steel sheet, hot dip galvanised finish, JIS G 3131, ISO3573 1986 3.	Assume galvanised steel, yield strength 275N/mm^2, density 78.5kN/m^3. Assume anchor nails are low strength S275 steel.	Foundation plates assumed to be 8mm thick from back calculation.
Timber Cladding and Flooring	Radiata Pine/Douglas Fir, Structural Grade, kiln dried and dressed 4 sides, 12.5% moisture content, H3 treated.	No. 2 Structural Grade Douglas Fir, density 530 kg/m^3, Young's Modulus 8274N/mm^2, bending strength 5.86 N/mm^2	160 x 20mm thick planks have been assumed.
Galvanised Steel Roofing Sheets	Hot dip aluminium/zinc coated sheeting. JIS G3321, ISO 9364.	Lightweight steel sheeting – low grade S275, weight 0.044kN/m^2.	0.55mm sheet thickness assumed.
Bolts	M12x25 and M14x30	M12 And M14 in low grade steel – S275.	
Screws	M5x19 hex screws	M5 screws in low grade steel – S275.	
Nails	None.	8d nails assumed.	

1.6.2 Cold Formed Galvanised Steel

The building frame has been fabricated using cold rolled, hot dip galvanised steel provided by Siam Steel International. Cold rolling is used to produce lightweight sections and work hardening and residual stresses from the process cause an increase in the yield strength at the expense of ductility and toughness. A yield strength for the steel of 550N/mm^2 has been assumed, based on the strength of similar products available in Indonesia from BlueScope Steel, one of the alternative companies that tendered for the job. In practice the members have been conservatively checked using load tables provided by Albion Sections for members with a strength of 450N/mm^2.

1.7 Codes, Standards and References

General

The IBC (International Building Code) 2009 has been used as a basis for the design checks on the shelters since it is widely accepted worldwide, particularly for extreme loading cases such as earthquakes or strong winds. Other codes have been referenced where appropriate or where the IBC is thought to be less applicable. This included the Eurocodes and local codes where appropriate.

Other references used:

- Standards referred to by IBC 2009 including: ASCE 7-10 (2010), NDS for Wood Construction, ACI 318 for Concrete, and AISC for Steel.
- UBC 1997 Volume 2 for preliminary wind calculations.
- BS5950-5: 1998, Structural use of steelwork in building – Code of practice for design of cold formed thin gauge sections.

1.8 Loads

1.8.1 Dead Loads

- Self-weight of structural materials applied in accordance with the densities specified in Section 1.6.1.

1.8.2 Live Loads

- For IBC compliancy live loads of 1.92kN/m^2 on the ground floor and 0.96kN/m^2 on the roof should be applied[1]. In this case however, no live load is assumed on the roof since there will be no maintenance access or snow/volcanic/sand load so it is not applicable. The live load allowance for the ground floor has been reduced to 0.9kN/m^2 since this represents a more realistic loading situation.

[1] 'International Building Code', ICC, 2009 – Table 1607.1.

1.8.3 Wind Loads

- The wind loads have been calculated using the method given in the Indonesian design code[1]. This specifies a minimum standard pressure to be used in coastal locations for normal height construction modified by a pressure coefficient depending on the building type. The following values were used:

Wind pressure for areas up to 5km from the coast – 2.1.3.2 (2)	p = 0.4kPa
Wind coefficients assuming a closed building or a building with an opening on one side – 2.1.3.3, Figure 1 (1) and (2)	Varies for each case on each surface

- Modifying the wind pressure by the pressure coefficients gives a maximum uplift pressure of 0.4kPa in the partially enclosed case and a maximum lateral force on the structure of 10.2kN in the transverse direction. Local knowledge of higher wind speeds must be taken into account by using higher design pressures for specific shelter locations where necessary.

[1] Refer to Appendix A, Reference 7.

1.8.4 Seismic Loads

- Seismic loads have been considered in accordance with the IBC[1] using a short period design acceleration based on the UBC methodology. Stiff soil has been assumed (soil category D or Site Class D). The design response acceleration was determined using the PGA detailed in Section 1.2.2.

Assume Site Soil Category D[2] (20.3-1) and use PGA (Z) in UBC Table 16-Q	$C_a = 0.32$
Assume structure response in 0.5-1.5s period (UBC 16-3) to get S_{DS}	$S_{DS} = 2.5C_a = 0.8g$
Assume risk category I (Table 1.5-1 low risk to human life in event of failure) in Table 11.6-1	Seismic Design Category D
Importance factor assuming risk category I – Table 1.5-2	$I_e = 1.0$
Assume no codified seismic lateral system – Table 12.2-1[3]	R = 1.5

The equivalent lateral force procedure has been used to calculate horizontal loads for design. The resulting base shear is only 4.4kN due to light weight of the materials used.

[1] 'ASCE 7-10 – Minimum Design Loads for Buildings and Other Structures', Chapters 11&12.
[2] In locations where liquefaction is a risk the Site Soil Category should be changed accordingly for seismic design.
[3] Bracing and connections are not considered sufficient to resist lateral loads, but some resistance is provided by nailed timber cladding.

1.9 Calculation Plan

1.9.1 Design Methodology

The performance of each shelter has been assessed by checking that the structure as assumed from the information provided is safe for habitation. Relevant codes and standards have been used as the baseline for identifying appropriate performance/design criteria, but the structure has been checked against code requirements: if variations from this were made, assumptions and reasoning for lower factors of safety and alternative standards have been justified. Logical reasoning has therefore been used where necessary and upgrades suggested in order for the shelter to meet these criteria.

Assumptions:

For this shelter one structural case has been considered – the structure is enclosed and the roof and wall covering has sufficient strength to transmit wind loads to structural members without damage. Seismic loads will act on the structure from its own self-weight but wind loads will govern.

1.9.2 Structural Checks

For a summary of the checks performed to assess the building, refer to Appendix C.

2 Results of Structural Assessment

2.1 General Key Findings

I. All members perform adequately under vertical and seismic loads, but a lateral stability system must be provided in the form of properly nailed plywood walls with intermediate steel stud locations or in plane bracing in the walls to resist both lateral seismic and wind loads. Steel bracing should also be added in the plane of the roof.

II. The bearing pressure beneath the column base plate is unacceptable for all load cases. Under dead loads alone the bearing pressure slightly exceeds the acceptable limits for the firm clay soil assumed; it is unknown whether settlement has been observed in practice.

III. In the seismic case there is no overall uplift due to overturning or sliding of the foundations. Under wind loads the overall uplift on the columns of 1.93kN exceeds the pullout capacity of the anchor nails in the soil, and the overall lateral load exceeds the shear resistance of the base plates and anchors. An alternative foundation solution with more uplift capacity and shear resistance such as screw in ground anchors is therefore required[1].

IV. The roof sheeting, purlins and primary roof beams are adequate under wind loads but the bending capacity of the columns is exceeded and the timber wall cladding should be increased from standard to structural No. 2 grade in order to span between columns. The floor boards, joists and primary floor beams are adequate under all loading.

3 Conclusions and Recommendations

3.1 Assumptions

- The maximum allowable floor live load is $0.9kN/m^2$, which is appropriate for lightweight shelter design, and it has been assumed that the roof of the structure will not be subjected to loading from volcanic ash, sand or snow.
- A stiff soil type (see Site Class D, ‘2009 International Building Code’, ICC, February 2009) has been assumed in analysis of the structure. For sites where liquefaction may be a hazard (near river beds, coastal areas with sandy soils and high water tables), the shelters could be seriously damaged if soil liquefies in an earthquake but such damage is unlikely to pose a life safety risk to occupants.
- All fixings and connections are of sufficient strength to transmit forces between members.

---

[1] Alternative forms of ground anchor may be required depending on specific site conditions, for example screw in anchors cannot be used in rock.

3.2 Conclusions

Performance Analysis	
The performance of the frame under gravity loads alone is adequate. The foundations must be upgraded to prevent the settlement of the column bases into the soil. Bracing is required in the walls and roof to improve the lateral stability and make the structure safe.	
Hazard	**Performance**
Earthquake – HIGH	Currently damage to the shelter is expected due to the low resistance to lateral loads provided by the timber cladding. Bracing or suitably nailed plywood should be used to improve the lateral stability and prevent failure in the event of an earthquake. The foundations should also be changed to prevent settlement. The structure is lightweight and relatively flexible so will pose a low risk to life if damaged.
Wind – LOW	The shelter does not perform well under wind loads. In addition to the provision of wall and roof bracing, an alternative foundation solution is required to prevent settlement, uplift and sliding under wind loads. The column size should also be increased.
Flood – HIGH	The shelter has a raised floor to prevent damage but no specific checks against standing water have been made.

Notes on Upgrades:

In many cases it has been upgraded through the addition of porch structures, partitions and extensions but the main shelter structure has remained unaltered. In instances where the occupants were provided with permanent housing the shelter was used as an extension to this, a second home, or a shop.

The performance of this shelter would be significantly improved for a relatively small cost by the provision of intermediate studs and nailed plywood shear walls and in plane roof bracing.

If the shelter is adequately braced, the foundations modified and the column sizes increased, the roof or walls of the shelter can be upgraded with materials of a similar weight to those already in use. Upgrading the shelter with heavier materials must be planned for in advance and the appropriate foundation upgrades made. Upgrading the shelter with masonry or other very heavy materials is not recommended as they will attract high seismic loads causing the structure to perform poorly in an earthquake. Collapse of a heavy roof or unreinforced masonry walls poses a serious risk to the life safety of the occupants.

Watch-its for drawings: ‘Change or Check’

A. CHANGE: Improve lateral stability by upgrading the walls using ½” thick structural grade plywood with vertical framing spaced at 600mm and nailed 24/16 span rated 4-ply plywood with maximum 150mm on centre nail spacing (see I.1). In this case header and primary floor beams would also require strengthening. Alternatively, walls could be braced in-plane with diagonal steel bracing.

B. CHANGE: Provide in-plane bracing in the roof to increase lateral stability.

C. CHANGE: Modify the foundations to Type 1 of Type 2 (see C.1) depending on soil type to prevent settlement of shelter.

D. CHANGE: Use Type 1, 4 or 5 foundations (see C.1) to increase uplift and sliding resistance depending on soil type and wind loads.

E. CHANGE: All column sizes should be increased in accordance with design to local wind pressures.

F. CHECK: Fasten roof sheet to purlins using screws spaced at appropriate intervals (see C.3).

G. CHECK: In areas known to have high local wind pressures adequate foundations and member sizes must be provided to account for this.

H. CHECK: Do not upgrade using masonry or cement blocks due to risk to life safety and increase in seismic force attracted to the structure.

I. CHECK: The design and detailing of all connections is critical to the stability of the structure and should be checked for individual cases.

J. CHECK: Check that the soil type for the shelter location is stiff, otherwise design foundations accordingly.

Appendix A – Source Information

1. 'Transitional shelter Task Group Summary information – Transitional shelter data sheet Indonesia', CT & JA, December 2010.
2. 'Installation Manual: Transitional Shelter for Aceh', Siam Steel, 2005.
3. 'Transitional Shelter for Aceh: Parts List, Installation Tooling and Parts List', Siam Steel International, November 2005.
4. Relevant photos and drawings including DWG-14_RC-00-001 KD-House, Siam Steel International, 15th November 2005.
5. 'Transitional Shelter Process in Aceh and Nias', Corinne Treherne IFRC, January 2007.
6. 'Natural Hazards in Aceh', Yasir Khokher & Ziggy Lubkowski Arup, November 2009.
7. 'Standar Nasional Indonesia: SNI 03-1726-2003', Bandung, Juli 2003

Appendix B – Bill of Quantities

The table of quantities below is for the materials required to build the shelter. It does not take into account issues such as available timber lengths and allowances for spoilage in transport and delivery.

Item (Dimensions in mm)	Material Spec.	No.	Total	Unit	Comments
Structure - Foundations					
Guide post foundation 1 (400x400x8thk plate, 625 centre column stub)	Steel 1	2	2	pieces	
Guide post foundation 2 (400x400x8thk plate, 625 corner column stub)	Steel 1	4	4	pieces	
Anchor nails (19 dia. x 600)	Steel 1	24	24	pieces	
Main Structure					
Centre columns (150x50x1.6, L=3.79m)	Steel 2	2	7.58	m	
Corner columns (100x100x1.6, L=2.425m)	Steel 2	4	9.70	m	
Primary floor beams (150x50x1.6, L=4.613m)	Steel 2	4	18.45	m	
Roof truss beam (100x50x1.6, L=3.205m)	Steel 2	4	12.82	m	
Primary roof beams (100x50x1.6, L=2.79m)	Steel 2	4	11.16	m	
Bracing (25 dia. x 1.6thk, L=1.2m)	Steel 2	16	19.20	m	
Secondary Structure					
Floor edge joists (100x50x1.6, L=2.79m)	Steel 2	8	22.32	m	
Main floor joists (100x50x1.6, L=2.873m)	Steel 2	14	40.22	m	
Roof purlins (246x2, L=5.68m)	Steel 2	6	34.08	m	
Covering – Wall, Roof and Floor					
Roof panels (740x3440)	Sheet 2	16	40.73	m^2	
Timber wall planks (160x20, L varies)	Timber 3	-	44.60	m^2	Supplier to decide lengths required
Timber studs (3.79 or 2.42m)	Timber 3	6	17.28	m	
Timber floor planks (160x20, L varies)	Timber 3	-	26.10	m^2	
Fixings					
Guttering (457x0.5thk, L=4.675m)	-	1	4.68	m	
Roof flashing (458x0.5thk, L=2.028m)	-	3	6.08	m	
Bolt + nut + 2 washer (M12x25)	Bolts	172	172	pieces	
Bolt + nut + 2 washer (M14x30)	Bolts	28	28	pieces	
Hex Screw (M5x19)	-	90	90	pieces	
Nails (8d)	Nails	-	-	-	Quantity to suit fixing recommendations
Tools Required					
Taper Punching Tool, 3-14mm diameter	-	2	2	pieces	
Big Hammer	-	1	1	piece	
Carpenter Hammer	-	2	2	pieces	
Screw Driver	-	2	2	pieces	
Tape Measure, 5m	-	1	1	piece	
Plumb Bob + 50m gut	-	1	1	piece	

Water Level ~30cm	-	1	1	piece	
Sockets, No. 17 and 22	-	2	2	pieces	
Spanner, No. 17 and 22	-	4	4	pieces	
Knitted Gloves	-	2	2	pieces	
Bag	-	1	1	piece	
Multipurpose heavy duty spade	-	1	1	piece	
Hand saw, 18” length	-	1	1	piece	
Ladders	-	2	2	pieces	

Appendix C

Calculation Plan

1) Loading

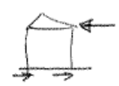
The steel members have been checked using strength design to BS5950-5 and relevant load tables. The loads described in Section 1.8 have therefore been combined using the load factors given in the IBC (International Building Code) 2009, Section 1605.2.1.The timber members have been checked using allowable stress methods in accordance with the NDS for wood construction. The loads described in Section 1.8 have therefore been combined using the un-factored load cases described in the IBC (International Building Code) 2009, Section 1605.3.1.

2) Foundations

   a. Bearing pressure

   b. Uplift

   c. Base Shear



The effect of overturning must be included in the vertical force calculations.

3) Stability

   a. Overturning

   b. Transverse Stability – key members: columns, primary beams and bracing

   c. Longitudinal Stability – key members: columns, primary beams and bracing

4) Primary Members

Check members for a combination of vertical and lateral loads, including columns, beams and bracing. Check foundation base plates and anchor nails for all load cases.

5) Secondary Members

Check members for a combination of vertical and lateral loads, including roof sheeting, purlins, floor boards, joists and wall cladding.

6) Fixings – check key connections using bolt details provided. Connections will be assumed to be pinned, including at column bases.