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Low cost Earthquake resistant house using Cold Formed Steel [CFS] member - A Case Study

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Abstract—The occurrence of earthquakes destroys the adobe houses and historical monuments and leave thousands of people injured and homeless. Such catastrophe is neither unexpected nor surprising because every single earthquake that occurs in developing countries where construction with earth is common , leaves similar sequel of destruction, economic loss, injuries and deaths. Earthen building are particularly vulnerable to earthquakes because of the low strength and fragile behavior of there walls. Inhabitants of earthen houses in the seismic areas of the worlds, most of them poor, therefore live under unacceptable risk.

This research work is mainly focused on developing a design of small size, low cost and earthquake resistant house. CFS member are recommended as the main structural elements with lightweight roofing system. Earthquake resistance is ensured by analyzing the structure on Staad-Pro for a seismic activity of zone 4. The behavior of structure is found satisfactory under the earthquake loading. An estimate of cost is also presented which shows that it is an economical

Keywords—Earthquake, Low Cost House, Cold Formed Member

1. Introduction

The major earthquake of last ten year has left a great food for thought for civil engineers to improve the design practice and quality of construction to withstand the natural disasters. Engineers are working at individual and organizational level to meet such challenges. This research work is a part of the same process. A design of simple-to-construct small residential building is presented which has capability to meet the strength and serviceability requirements of a major seismic activity.

Cold Formed member (CFS), a material recommended by AISI-97, is proposed for this house. CFS performs excellently due to its strength. This will be a very economical option for temporary and permanent construction for the years to come. Shortly after the earthquake this design was proposed, keeping in mind the cost efficiency, availability of materials, quick time of fabrication and flexibility of extension and portability.

No level of earthquake preparedness can guarantee that an earthquake will not damage a building. Structures cannot be completely earthquake-proof, but good seismic design will minimize structural damage, and the most importantly, safeguard the lives of the occupants during a major seismic event. Seismic resistance is best achieved by following modern building codes and standards and in large or complex buildings, using the services of a professional structural engineer.

2. Cold Formed Member [CFS]

The use of cold formed steel member in building construction began in the 1850 in both United States & Great Britain. However, such steel members were not widely used until 1940 i.e. after the research sponsored by AISI at Cornel University under the direction of George winter in year 1939. The thickness of steel sheets used in cold formed structure is usually 1 to 3mm & it is formed at room temperature .Due to these quality this is also called as Light gauge steel member. The method of manufacturing is important as it differentiates these products from hot rolled steel sections. Normally, the yield strength of steel sheets used in cold-formed sections is at least 280 N/mm2.

Cold-formed steel structural members are shapes commonly manufactured from steel plate, sheet or strip material. The manufacturing process involves forming the material by either press-braking or cold roll-forming to achieve the desired shape. Press-braking is often used for production of small quantity of simple shapes. Cold roll-forming is the most widely used method for production of roof, floor and wall panels. It is also used for the production of structural components such as Cees, Zees, and hat sections. Sections can usually be made from sheet up to 60 inches (1.5m) wide and from coils more than 3,000 feet (1,000m) long.

3. Causes of Failure During Eartquake

In majority of cases, it was observed that structures were neither designed by following seismic provisions of code nor the construction was completely carried out accordingly. Size of structural members, especially columns in one direction, was much less than what is recommended by IS-1893. In some cases the least lateral dimension of column was 114 mm giving slender column behavior. Materials used for concrete construction and their were well below the required standards. Other construction faults were improper placement of reinforcement, unequal & insufficient concrete cover in same members, poor concrete compaction and substandard form work etc. Based on all this information, it is concluded that major reason of structural collapse and damage of residential and institutional buildings during earthquake was the insufficient strength of vertical supporting members

Figure 1: Collapsed house in earthquake with heavy roofing.

Figure 2: Thick layer of mud collapsed in earthquake

members including columns, masonry walls, un-reinforced concrete walls and bonded or un-bonded rubble masonry walls (Figures 1, 2, 3 and 4)

1. FEATURES OF PROPOSED HOUSE

The principal material for this house is CFS. It consists of metal panels placed side by side connected with girts using bolts (Figures 5). CFS is selected because it is recommended by AISI as a very good option for making small size houses. Furthermore, all the constituent materials are easily available in market; the panels are lightweight, which are easy to cast, transport and assemble. The system has been designed with the do-it-yourself concept in mind. Back to back C section are used for column and rafter and single Z section are used for girts & purlins (Figures 8).

Figure 3: Corner joint failure of bonded masonry in earthquake

Figure 4: Typical corner joint failure of a house in earthquake

1.1 RESISTANCE AGAINST EARTHQUAKE

Resistance against earthquake is the primary requirement for any structure. This house is modeled using Staad-Pro, software based on finite element method, and its response under the seismic activity of zone four is checked. Pseudo static analysis is carried out with earthquake forces applied along both the principal directions. Building connections are considered as hinges at support and fixed at eave and ridge.CFS member is defined as column and rafter in Staad-Pro. Final Stresses in software especially at joints, displacement and sway due to earthquake are carefully noted for various load combinations. Some of the important Information related to analysis and design is presented below.

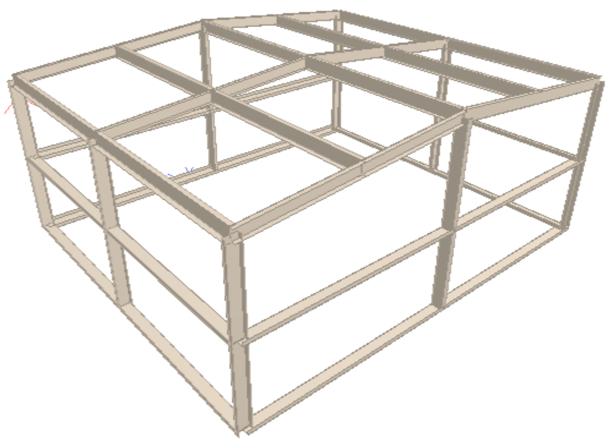

Figure 5: Three dimensional Model of house

1.1.1 Geometry of Building

A architectural plan of 2BHK is prepared in such a way that to fulfill the functional requirement of building such as Bedroom, Kitchen, toilet and bathroom (Figures 6). The orientation of column is select in such a way that it does not interfere with functional requirement of building (Figures 7).

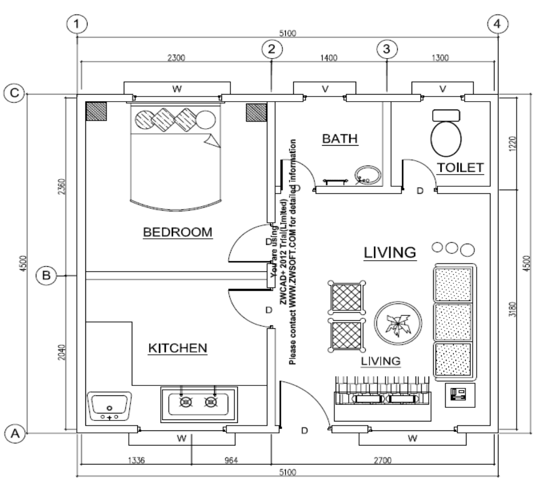

Figure 6: Architectural Plan

Size of House =7.0mx7.0m

Eave Height of House =3.0m

Roof Slope = 1:10

Sidewall Bay Spacing = 2 @ 3.5m

Endwall Bay Spacing = 2 @ 3.5m

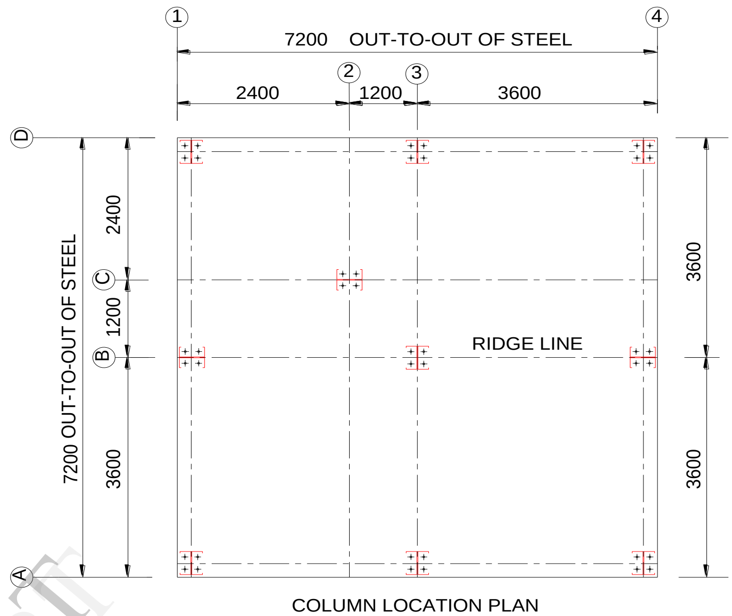

Figure 7: Location of Steel Column

1.1.2 Loading Parameter for Analysis of Building

Dead Load =0.15 kN/m2

Live Load =0.57 kN/m2 (Table 3.1)

Wind Speed = 44 m/sec. (Nagpur)

Wind Pressure =0.84 kN/m2 (Table 5.2(b).)

Earthquake Zone = IV

Building Condition:
Building Design as Enclosed = +/- 0.25
(As per MBMA)

Deflection Limit of Building:
Sway of Frame = H/100
Vertical Deflection of Frame =L/180
Loading Combinations:

1. DL+LL
2. DL+WL

3. DL+EQ

Section Used for Analysis of Column and Rafter:

After the selection of basic parameters of building we need to select the section size for Design of Frame.

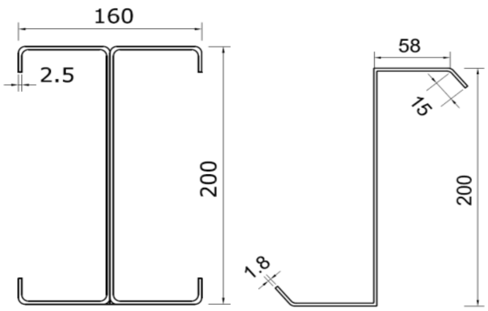

Figure 8: Profile of Steel column , Girts and Purlins

4.1.3 Analysis Output

Following results are the maximum out of all combinations.

Dead Load Reaction = 2.34kN

Live Load Reaction = 7.22kN

Maximum Bending Moment =8.31kN-m

Maximum Shear Force =9.03kN

Sway under Earthquake = 25.0mm < 35.0mm (OK)

Critical Stresses envelopes in frame are well below than strength of CFS member. Further, the deflection under gravity loads and sway under earthquake are also working.

4.2 Flexibility of Extension

Flexibility of extension and ease of alteration are two of the important features. Although this house is proposed as a 2BHK room but the design has flexibility to add row houses etc. Adding more and more frames at the suitable location makes the extension very simple. This small unit can be extended to build a field hospital, combined residence, messing facility and a warehouse etc.

4.3 Light Roofing System

One of the major causes of damage during earthquake was heavy roofs. During earthquake the weak vertical supports could not survive and came down with thick layer of mud, burying everything under it. Lightweight roofs are better than heavier ones because they:

- Generate lesser forces
- Cause less damage if they fall.

The roof system of this proposed house consists of GI corrugated sheets with member of cold formed rafter & purlin. Every CFS member is strongly coupled with panels by bolted steel fixtures. Bracing connect to rafter and column member. Wooden trusses, which have been in common use, are deliberately avoided as they are comparatively heavier and cause more damage to life and property in case of collapse.

4.4. Foundations

Total service load reaction is 9.56kN which yields a foundation size of 650mm x 650mm for a net allowable bearing capacity of two tons/ft2[200 kPa]. Column is proposed as 230mm x 230mm RCC block with 250mm total depth. Total foundation depth is proposed as 450mm. The connection between foundation blocks and column is developed by anchor bolt of 16mm diameter with 230mmx230mm base plate section.

4.5. Openings

Doors can be located at any desired position. It is just a matter of removing panel and fit the door jamb and header with connection bolt and the door opening is ready. Panels with windows and ventilators can also be cast but it is recommended to have ventilators in roof.

5. Tentative Cost

It can be confidently said that cost will not cross rupees 181474/-, which means it is rupees 345/- per square foot. The cost can also be quoted as rupees 7910/- per foot length with a width of 22′-11″ [7.0m]. As stated previously, this structure can be easily extended so the approximate cost for any size can be easily calculated.

6.Conclusion:

The main objective of this research work is that it its behavior under a major seismic activity is satisfactory. It can bear the shock with little or no damage. Catastrophic failure will be avoided in any case thus minimizing the loss of life and property.

This structure is not only be suitable for temporary use but for permanent construction as well. Multiple or repetitive uses makes the structures viable with unmatched saving from conventional or classical structure .For such pre-fabricated CFS members even erection shall be done manually without using cranes and other machineries. Time required to construct such buildings shall be a distinct advantage in case of calamities shelters specially and other structures also.

Most important advantage of the designed structure is that it shall be 100% salvaged or reused because of its ease of dismantling.

Table 1: Estimated cost of proposed house

Components	Weight of Coldformed steel members. (kg)	Cost of Coldformed steel members. (Rs)
Primary Members (Column and Rafters)	**764**	**35908**
Secondary members (Purlins and Girts)	**1043**	**49021**
Roof and Wall sheeting	**670**	**26130**
Connection Plates and Base Plates	**75**	**7500**
Secondary (Trims & Flashing)	**599**	**26955**
Anchor Bolts	**40**	**2000**
Gutter (RM)	**52**	**20000**
Downspouts (RM)	**19**	**3800**
Cemnet Bags(Nos.)	**13**	**4200**
Sand (m3)	**0.88**	**780**
Crush(m3)	**1.77**	**1880**
Steel	**77.5**	**3300**
Total weight of the building (Kg)		**181474**

It is concluded that in the emergency scenario of economic development, cold-formed steel product has a good future and promise.

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