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Design And Construction Defects In The Buildings Of Balakot (Pakistan) And Surrounding Areas In Relation To Earthquake Loading

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Abstract

This study is focused on identifying the design and construction faults in the structures constructed in Balakot (Pakistan) and surrounding villages in relation to their performance under seismic loading. In most of the cases it was observed that structures were either not designed or the seismic provisions of code were not completely followed in the design and construction. Size of structural members, especially columns in one direction, was much less than what is recommended by ACI-318 (chapter 21). In some cases the least lateral dimension of column was 4.5" giving slender column behavior. The materials used for concrete construction and their proportions were below required standards. Other construction faults are improper placement of reinforcement, unequal concrete cover in same members, poor concrete compaction and substandard formwork etc. Based on all this information it is concluded that major reason of structural collapse and damage of buildings during 8th October earthquake was the insufficient strength of vertical supporting members including columns, masonry walls, un-reinforced concrete walls and bonded or un-bonded rubble masonry walls. Most of the vertical supporting members had reasonable strength against gravity loads but not against the lateral loads. Based on this study some recommendations are proposed for the improvement of future construction.

Keywords

Balakot, Earthquake, Rubble Masonry.

1. Introduction

A major earthquake struck Azad Kashmir and Hazara Division of Pakistan on 8th October 2005. This natural disaster caused a wide spread damage. Large number of structures were either collapsed or damaged badly. There was a need to establish the flaws in the design and construction of the structures constructed in the earthquake hit areas. This research work is carried out as a part of National Volunteer Movement organized by Government of Pakistan. A group of 20 students and teachers from Civil Engineering Department U.E.T Lahore visited Balakot to participate in relief efforts. Besides relief work a detailed visit of the site was carried out, the failure of various buildings was duly recorded, photographic survey was completed and then the information was analyzed and compared with the famous foreign codes, such as ACI code and UBC. The major design and construction defects observed in the area are presented in the following sections.

2. Design And Construction Defects

2.1 Poor Construction Material

The requirements for proportioning concrete mixes are based on the philosophy that concrete should provide adequate durability, workability and strength along with economy. For concrete designed and constructed in accordance with ACI-318, fc’ should not be less than 2500 psi.

The concrete used in the suburb of Balakot was composed of poor aggregate material having significantly low cement-to-aggregate ratio. According to a mason, a mixture of fine and coarse aggregate is taken from some river-bed in Ghari Habibullah (Fig: 1). Three wheelbarrows of this mixture and one cement bag are mixed to prepare concrete.

Figure 1: Mixture Of Fine And Coarse Aggregate Used For Preparing Concrete

The local people believe that this gives a cement-to-aggregate ratio of 1:3 in the concrete. Actually one wheel barrow can have 4 cement bags so the cement-to-aggregate ratio becomes 1:12, the resulting concrete does not fall in the category of structural concrete. Fine and coarse aggregates were also not having any fixed proportion and a large variation is expected in concrete strength even within same structure or a structural member.

2.2 Slender Columns

According to ACI-318 (§ 21.4.1.1), for a frame member subjected to bending and axial load, the shortest cross sectional dimension measured on the straight line passing through the geometric centroid shall not be less than 12”. Furthermore ACI 21.4.1.2 states that the ratio of the shortest cross sectional dimension to the perpendicular dimension should not be less than 0.4. The column sizes observed in Balakot and other areas were 4.5” x 9”, 4.5” x 12” and 4.5” x 15”. These slender columns sufficiently reduced the strength of lateral force resisting system. When the earthquake struck, concrete frames exhibited large sways resulting in collapse of infill masonry and breaking of beam-column joint (Fig. 2). One important observation is that very few columns were found failing due to buckling; it indicates that columns had reasonable strength for gravity loads but not for lateral loads.

Figure 2: Concrete Frame Exhibiting Large Sway

2.3 Improper Detailing at Beam Column Joint for Shear

Due to inadequate shear reinforcement and improper development lengths at the joints, most of the failures initiated by joint rupture (Fig: 3 & 4). For a special moment resisting frame, spacing of transverse reinforcement, within two times the depth of member from face of joint, must not be less than one quarter of minimum member dimension (ACI-318, § 21.4.4.2). This means that, for a column having least lateral dimension 4.5”, the shear reinforcement should be # 3 @ 1” c/c. Even for intermediate moment resisting frame the limit for spacing is one-half of the minimum member dimension which means # 3 @ 2.25”c/c. The provided shear stirrups were either # 3 @ 9” c/c or # 3 @ 12 c/c.

Figure 3: Joint Failures Of Balakot Jamia Mosque

Figure 4: Large Sway In Frames

2.4 Insufficient Lap At Column Joints

Insufficient lap splices were commonly observed in frame structures. ACI-318 requires a minimum of 12” lap in any case. For a # 4 bar:

$$L_d = \left(\frac{f_y \psi_t \psi_e \lambda}{25\sqrt{fc'}} \right) d_b = \left(\frac{60000 \times 1.0 \times 1.0 \times 1.0}{25\sqrt{3000}} \right) 0.5 = 21.9"$$

For Class B splice, lap length comes out to be: 1.3 l_d = 1.3 x 21.9 = 28.47”.

Lap lengths observed in various structures in Balakot were ranging from 5” to 12”. A mosque in Pumbara village, about 8 km from Balakot city, lost its four minarets projecting from top story columns, which fell down due to insufficient lap length (Fig: 5). Lesser lap reduces strength proportionately. For instance if 5” lap is provided for # 4 (grade 60) steel bar, which requires 28.47” lap, the strength which can be developed is:

$$\frac{5"}{28.47"} \times 60000 = 10537\text{psi} = 0.176 f_y$$

Figure 5: Insufficient Dowels Lengths Left For Extension Of Mosque In Pambara Village

2.5 Non-Monolithic Beams And Slabs

It was frequently noticed that concrete frames and slabs were not cast monolithically (Fig: 6 & 7). Frames were constructed and slabs were placed above them resulting in weak connection between frame and slab. T-beam behavior could not be developed, reducing the effective cross sectional properties including moment of inertia and area. When the earthquake struck, the frames got separated from slabs and started swaying independently. This relative movement between frame and slab shattered overall stability of structures.

Figure 6: Frame Non-Monolith With Slab

Figure 7: A Frame Structure In Pambara, Ready For Placing Slab.

2.6 Inadequate Column Footing

The columns of a frame structure along the mountain slope of village Pambara (Fig. 8 & 9) were uprooted from foundation. Two things were clear from this type of failure:

- The depth of footing was much less, 1' to 1.5', which proved to be insufficient to provide resistance against over-turning.
- The footing was drastically under-sized. In some cases, a properly formed square or rectangular footing was not provided; instead only a lumped mass of concrete was used. The moment of inertia of footing was so less that it could not provide fixity to column and was not able to resist rotation, resulting in uprooting of column along with the foundation.

Figure 8: Inadequate footing of a slender column

Figure 9: Inadequate column footing

2.7 Improper Placement of Reinforcement

ACI-318, §7.5.1 states that reinforcement shall be accurately placed and adequately supported before concrete is placed and shall be secured against displacement. The structures observed in Balakot and surrounding area had improperly placed steel bars with uneven spacing and non-uniform clear cover (Fig: 10 & 11).

Figure 10: Steel Bars In Column With Uneven Cover And Improper Placement

Figure 11: Improperly Placed Steels Bars In A Beam

The bars, which were placed improperly, became ineffective and did not contribute in providing strength. So, poor construction material and improper placement of reinforcement resulted in overall low construction quality.

2.8 Un-reinforced Concrete Walls

The main mosque in Pambara had un-reinforced concrete walls. During the earthquake, few wall panels overturned as a whole and some of them suffered long shear cracks and broke into pieces (Fig: 12).

Figure 12: Un-Reinforced Concrete Wall Panels Collapsed Due To Earthquake

2.9 Bonded And Unbonded Rubble Masonry

Rubble masonry using undressed stones without bond is highly unsafe especially under lateral loading. Un-bonded rubble masonry is frequently used in outskirts of Balakot (Fig: 13). When this rubble masonry was subjected to earthquake it spread like loose soil and failed to provide required shear strength.

Even if bonded masonry had been used, it would also have not been appropriate because the stones used were uneven and arranging them in the form of wall could not ensure that they will behave as one unit like in a brick masonry wall.

Figure 13: Un-Bonded Rubbles Being Dressed To Make A Load Bearing Wall Structure.

2.10 Construction On Unstable Slopes

Any structure constructed on slope is more vulnerable compared with the others constructed on plane land. Such risk always existed for structures constructed on unstable slopes in Balakot city and its surroundings. In some cases the structures were quite safe but situated on unstable ground that failed during earthquake and the whole structure slipped down.

3. Conclusions

- In the earthquake hit areas, there were very few structures that were designed or supervised by any engineer or even a technical person.
- Seismic provisions of code were not fully satisfied even for those structures that were designed by engineers.
- Good construction material is not frequently available especially in outskirts of Balakot. People use poor construction materials, which is easily available at low cost.
- Poverty and lack of education are the two main reasons for the poor construction quality.

4. Recommendations

- Structural engineers should present some standard designs particularly for small houses, proposing some typical reinforcements, minimum size of columns, beams and foundation details etc.
- Some easy-to-understand guidelines for construction should also be prepared and distributed to the people in the form of pamphlets for the awareness of general public. These guidelines can also be displayed on signboards and banners in the earthquake affected areas.
- Training workshops can also be arranged for the masons and laborer to enhance their skills.

5. References

ACI Committee 318. (Jan 2005). "Building Code Requirements for Structural Concrete (ACI 318-05)". American Concrete Institute, Farmington Hills, MI.

Neville, A.M. (1995). *Properties of Concrete*, 4th edition, Pearson Education Asia Pte. Ltd, England.

Nilson *et al*. (2003). *Design of Concrete Structures*, 13th edition, M_cGraw Hill, New York, USA

Proceedings of the Earthquake Rehabilitation Conference, Islamabad, 18-19 Nov, 2005, NWFP UET Peshawar, HEC, Islamabad.