The Chamoli Earthquake of March 29, 1999

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1. Introduction

A powerful earthquake measuring M = 6.8 on Richter scale struck near the city of Chamoli in Uttar Pradesh on 30 March 1999 at 12:35 A.M. IST. The epicentre of this earthquake was at 30.5? N and 79.3? E and was approximately 10 kilometres from the city. This earthquake caused damage upto intensity VIII on the MSK scale at locations near the epicentre. The earthquake caused deaths of approximately 100 people and injury to hundreds more. Most damage due to the earthquake has been concentrated in Chamoli and Rudra Prayag districts, besides minor effect in the Pauri Gerhwal district. The earthquake has affected more than 1250 towns and villages, and the total affected population exceeds 5 lakhs.

The two affected districts constitute a part of the former kingdom of Gerhwal, and are near the Holy shrines of Badrinath and Kedarnath. Since lakhs of people visit these shrines every year, extensive commercial activities have developed on the roads leading to these shrines. As a result, both the affected districts are relatively well developed and are prosperous. Almost all villages and towns are connected by telephones, and several hotels and tourist lodges are situated along the major highways. This region also has surplus electricity, and all towns and villages are supplied with electricity round the clock. Most towns and villages also have piped water supply system, wherein water is carried from mountains springs and streams to the homes.

The meizo-seismal region lies in the Gerhwal Himalayas and is close to the major Himalayan faults. In addition, several smaller faults criss-cross the region and the area is highly earthquake-prone. This region had earlier experienced a major earthquake measuring 6.6 on the Richter scale in 1991 (Uttarkashi earthquake) during which more than 800 people had perished. Large tremors have been recorded in this area frequently. As per the IS earthquake code (IS 1893-1984), the region has been placed in Seismic Zone V. This is the highest zone in the code and signifies regions with highest seismic hazard.

Due to the known high seismicity in the region, the area is also extensively instrumented. Separate seismic recording networks are maintained in this region by the Geological Survey of India, University of Roorkee and Wadia Institute of Himalayan Geology. The instrumentation network has been designed and implemented under the co-ordination of Department of Science and Technology so as to satisfy the different research requirements. At present, the processed strong motion data is not available and the ground motion characteristics are not known. It is interesting to note that a strong motion recorder at Roorkee, situated about 250 km from the epicentre, recorded the peak ground acceleration of 0.05g in the frequency range of about 2-3 Hz.

In this report, the evaluation of the performance of the post-earthquake activities, and the damage mechanisms of the structures have been discussed.

2. Rescue and relief operations

Most damage and destruction due to the earthquake is concentrated in Chamoli district, particularly in the areas surrounding the town of Chamoli. The district headquarters is located at Gopeshwar, about 10 km from Chamoli. Gopeshwar did not experience major damage due to the earthquake, and the entire district administration could be mobilised very quickly. Immediately following the earthquake, the power supply to the entire region was disrupted, and could be restored only about several hours. The telephone services were not generally affected and continued to function.

Rescue of the trapped people and extraction of the bodies were carried out by the affected people immediately following the earthquake. In most towns and all villages, there are no emergency services and no trained personnel were available for this purpose. Fortunately, the people were able to rescue hundreds of trapped victims of the earthquake. The injured were carried to the health centres from where they were referred to different hospitals as necessary.

Damage assessment teams were formed in the morning after the earthquake to carry out on-site surveys. Since the region is highly mountainous and inaccessible, information from different villages and towns could not be collected rapidly. This problem was further aggravated due to the very large number of landslides that had obstructed all major roads, some at several locations.

The government announced a relief package to the affected people, in which each family was promised Rs. 1000/-, 10 kg of food grains and one tent/tarpaulin in the first phase. This necessitated rigorous survey of the people in all affected villages so that the distribution of relief could be properly carried out. Due to the very large number of affected villages, the survey and relief distribution had not been completed upto one week after the earthquake.

The state government made use of central government forces very extensively for the relief operations. The national highways in the region are maintained by the Directorate General of Border Roads, who have their infrastructure located in the area. Due to the numerous landslides in the area, assistance of DGBR was found to be invaluable in removing the obstacles on other roads. The survey of the affected villages and distribution of relief materials was carried out with the assistance of the Army and Indo-Tibetian Border Police, who contributed about 500 people for the effort.

3. Building Construction Practice and damage mechanisms

The earthquake affected areas have several small townships along the major highways, while the rural areas located in the mountains away from the roads. Due to the extremely steep mountain slopes, the buildings are typically multi-tiered. In these constructions, the number of stories is not constant and varies. The portions facing the slope have fewer stories while the portion away from the slope has greater number of stories. This ensures that the roof of the building is kept at a fixed height. The entrance to the building may be provided at different levels so that several stories may have direct entrance from the outside.

Almost all constructions in the meizo-seismal area are non-engineered, i.e., designed and constructed without the assistance of qualified engineers. Among the non-engineered constructions, two distinct categories can be clearly identified depending on the date of construction. The first category consist of traditional stone masonry buildings that were generally constructed upto the early 1990s. Since the early 1990's there is a distinct shift in the construction technology from stone masonry structures to brick or concrete block masonry structures. The performance of the different types of constructions due to the earthquake has been discussed below.

3.1 Stone Masonry Buildings

The traditional constructions consist of tiled stone masonry construction. In these constructions, uncoursed flat stone blocks are stacked to form the load bearing walls. The wall is made of two separate sections, the outer and inner wythes, so that both surfaces are smooth. The space between the two wythes are filled with random stone rubble pieces. The total wall thickness is typically 60-90 cm while the wall height may range from 2 m on the walls facing the slope to upto 10 m on the walls away from the slope (facing the valley). It is interesting to note that very little mud mortar is used for these constructions, since the stone pieces are stacked very tightly.

Most relatively new constructions of stone masonry have used reinforced concrete cement roof that is directly resting on the load-bearing walls. Most very old constructions and some new stone masonry constructions have wood rafter roof supported on vertical wooden posts. The remaining structures have wood rafter roof supported directly on the walls. In all such constructions, the roof is relatively heavy and imposes tremendous lateral load on the wall or wooden posts.

Open strip foundation has been most commonly used in these constructions in which the wall itself is directly extended below the surface. The wooden posts, where used, are also embedded into soil along with the wall, and no special foundation for these have been reported.

Since the walls consist of stone masonry that are not bonded, these constructions are expected to perform very poorly during the earthquake. These structures were observed to behave as expected. The stone masonry structures were found to be damaged at large distances from the epicentre. In the meizo-seismal zone, most of these structures collapsed or were rendered unusable. The most common damage was due to the separation of wythes following which the walls tended to buckle. Where wood rafter roofs were used, partial cave-in of the roof along with the wall was also frequently observed. Most constructions using wooden post system for supporting roof where able to withstand the earthquake without collapse. However, the walls of these structures were also extensively damaged, and the structures where left unfit for occupation.

3.2 Brick/Concrete Block Buildings

Several relatively new buildings in rural as well as urban areas have used burnt brick masonry with mud mortar. Good quality of brick and sufficient water is not easily available in this region, and the bricks are transported from the plains. Most buildings in brick or cement blocks were relatively new, and where constructed during the last five years. The architectural configuration of these buildings where also similar to that of the stone masonry buildings. These constructions are designed and constructed by the local masons and typically do not utilise rigorous engineering inputs. These constructions are therefore non-engineered.

Most constructions of this type have single brick thick walls (about 230 mm thick) with cement mortar. The foundations are similar to those for stone masonry buildings described above. The new structures also frequently use reinforced concrete band at lintel and/or roof levels. In addition, these structures also frequently use vertical reinforcement at the corners of the building. In most constructions, reinforced concrete roof slab was directly resting on the wall.

Brick or concrete block masonry with cement mortar buildings, if designed and constructed properly, can perform adequately under ground shaking of moderate intensity. Infact, the IS codes explicitly recognise the importance of lintel band and these have been strongly recommended for all load-bearing constructions in Seismic Zones IV and V. Most well constructed buildings of this type performed very well. Infact, very few buildings with lintel band collapsed, and almost no loss of live was reported in these structures.

Several structures with lintel band that suffered damage during the earthquake were examined in detail. It was found that the damage could be attributed to the following main causes: (1) poor quality of concrete, (2) discontinuity in band due to break in the lintel band at some openings, and (3) improperly sized band incapable of taking the developed forces. Each of these situations signifies improper construction practice explicitly prohibited by the IS codes, and these damages do not indicate any deficiency in the recommended specifications.

It is interesting to note that several structures in the meizo-seismal area seemed to consist of reinforced concrete frame system with lintel band. Properly designed frame structures do not require an additional band at the lintel level, and their presence was surprising. Further evaluation into the construction practice revealed that the reinforced concrete beams and columns in most such structures were not designed to withstand lateral loads and joint moments. Infact, the reinforced concrete members in these structures were constructed simultaneously with the masonry portion, with the result that the reinforced concrete columns actually behave only as corner reinforcement in masonry constructions. The roof-level beams in these structures also behave as roof band since they rest directly on the masonry walls and do not transfer their load through the concrete columns. The performance of lintel band structures also includes the performance of these types of structures.

3. 3 Reinforced Concrete Frame Buildings

Very few constructions in the meizo-seismal areas were made of reinforced concrete frame systems. Most reinforced concrete frame structures have been constructed for different Central Government organisations such as the Department of Posts and Telegraphs, Indo-Tibetian Border Police, Defence services etc. These structures have been designed and constructed with the assistance of qualified engineering inputs and are therefore engineered constructions.

The properly designed and constructed RC frame structures did not experience any damage due to earthquake. Some RC structures developed cracks in the partition walls, particularly at the openings. However, these cracks were generally superficial and did not pose any threat to the safety of the structure, and did not decrease its ability to withstand similar ground motions in future.

4. Performance of Lifelines

4.1 Bridges

The earthquake affected area has several road and pedestrian bridges. Most of the road bridges are quite old, although some new bridges are also present. The old road bridges are typically constructed using steel truss that are fixed at both ends. The new road bridges have been designed using reinforced concrete box girders or I-sections. These bridges have used conventional support system consisting of rocker/roller mechanism. All old bridges and most new bridges are single span and therefore do not have piers. Some concrete multi-span bridges were found on the

National Highways, but they were far away from the meizo-seismal zone. None of the old steel truss bridges have been found to experience any damage. The concrete bridges have also not experienced any damage to either the deck or piers. In bearings of some bridges were inspected and were also found to be intact without any unusual movement. It can thus be concluded that all the road bridges where able to withstand the earthquake without any damage.

The widely spreadout villages are connected to the main roads through a wide network of pedestrian roads. These roads are usually paved with stone or concrete and are approximately 1 m wide. Since these roads cross several streams and rivers, several dozen pedestrian bridges have been provided wherever required. The pedestrian bridges are all cable suspended bridges with steel deck. The largest of cable suspended bridge was observed to be with approximately 60 m span, while several shorter bridges with spans of 15-20 m where also found. The cable suspended bridges are extremely flexible, and have very long fundamental time periods. These structures are therefore not expected to get damaged easily. The performance of these bridges was also found to be very good and no damage was observed in almost all bridges.

In one pedestrian bridge, lateral buckling to the bridge deck was observed. The cables were also found to have loosened in this bridge The most likely reason for loosening of the cables was due to shifting of the anchor block at one end, possibly due to slope instability of the embankment. It should be noted that this bridge was located in the centre of meizo-seismal area and several landslides had occurred in this region.

4.2 Water Supply Network

All cities and almost all villages in this area are served with piped water supply system. Most water supply lines are not buried, although they are sometimes buried upto 0.5 m deep if running parallel to roads. There where no damage reported to the water supply pipeline due to earthquake excitations.

In Chamoli and Gopeshwar, the water is supplied from springs that are located several kilometres from the town. The landslides following the earthquake severely disrupted the water supply system in both towns. This was due to the damage caused to some roads by falling rocks that also punctured and destroyed some segment of water supply pipelines. The restoration of water supply system was carried out by the concerned authorities on war footing, and flexible hoses were used to reconnect the pipelines. This was an extremely hazardous operation since small rock falls and landslides continued to affect the water supply system for several days after the earthquake. Most of the water supply lines were restored about 5 days after the earthquake.

4.3 Electricity and Telecommunication Network

The earthquake-affected area lost electrical power a few seconds after the earthquake struck the area. However, the electricity was quickly restored after about 12-18 hours. No damage to the electrical equipment has been reported or observed due to the earthquake, although the transmission system was affected in some portions due to landslides. The telecommunication system continued to function without any problems following the earthquake. Interestingly, the state government commandeered most STD lines for their own uses after the earthquake. This led to disruption of the long-distance phone system in several towns and villages in the meizo-seismal area.

4.4 Irrigation Network

The earthquake affected area also has an extensive minor irrigation network. The irrigation canals are typically 0.4 - 0.5 m wide and equally deep. These are lined with concrete. The total length of canal system in this area is estimated to be approximately 200 km. The lining of the canals had cracked at several locations. However, no disruption in the canal layout was caused due to the earthquake.

5. Discussions and Conclusions

The town of Chamoli and its surrounding areas experienced a severe earthquake on March 29, 1999. When compared to the last major earthquake in this area in 1991 (Uttarkashi earthquake), this earthquake did not result in very high casualty. The traditional buildings and other constructions in the affected areas were extensively damaged. However, the newer constructions that have used proposed earthquake-resistant elements suffered moderate to negligible damage.

Based on the observations during the damage survey, the following conclusions can be drawn:

1. The extent of damage caused by this earthquake was found to be very low for a magnitude 6.8 earthquake.

2. The rescue and initial relief was primarily carried out by the people themselves, although assistance was later provided by the government.

3. Ground fissures were observed at several locations. Most ground cracks were parallel to the slope contour and indicated incipient slope failure. At one location, ground cracks perpendicular to the slope contour was also observed. However, it was not possible to determine its cause.

4. The traditional construction practice using tiled stone walls with wooden post framing system has good capacity to withstand lateral loads without collapse. Several such structures were damaged but did not cause injury or deaths.

5. The traditional constructions using tiled stone load bearing walls behaved very poorly in the earthquake. Their performance is expected to very poor and the damage mechanisms were consistent with the known properties of such structures.

6. Masonry buildings with reinforced concrete lintel band behaved very well during the earthquake. Almost none of the well constructed buildings of this type experienced major damage. This clearly shows the suitability of this construction technology in earthquake-prone areas.

7. Most new constructions, even in rural areas, have used earthquake-resistant features. Even after Uttarkashi earthquake, large-scale training of local masons in earthquake-resistant construction technique was not carried out. Due to this reason, the widespread use of this technology has been very surprising. Discussions with local masons indicated very high awareness of earthquake-resistant elements based on their experience following the Uttarkashi earthquake. This situation following this earthquake clearly illustrates the importance of incorporating appropriate construction technology in order to minimise the impact of future earthquakes.