Garhwal Earthquake of Oct. 20, 1991

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Introduction

On October 20, 1991, at 2.53 a.m. local time, an earthquake occurred in the Garhwal Himalayas in northern India. The earthquake caused strong ground shaking in the district of Uttarkashi, Tehri, and Chamoli in the state of Uttar Pradesh (*Figure 1*). Official information indicates that population of about 307,000 in 1,294 villages were effected; 768 persons died while 5,066 were injured. In addition the earthquake claimed 3,096 head of livestock. As many as 42,400 houses were damaged. The roads between Uttarkashi and Gangotri were disrupted. A four-member team from Civil Engineering Department of the Indian Institute of Technology, Kanpur conducted a survey of the significantly affected areas during October 27 to November 4. The team members were Dr. Sudhir. K. Jain, Dr. R. P. Sigh, Dr. V. K. Gupta, and Mr. Amit Nagar.

Seismological Data

The magnitude of the earthquake was assigned as 6.1 by the Indian Meteorological Department (IMD) based on body wave data. The USGS assigned a surface wave magnitude of 7.1. There was confusion about epicenter of the earthquake, with preliminary estimates by IMD indicating its location close to Almora, about 170 km from Uttarkashi.

However, no damage occurred in and around Almora. Based on the damage pattern, the epicenter is believed to be located somewhere in the Uttarkashi and Bhatwari region. Calculations on magnitude and epicenter by IMD are under revision.

Uttarkashi lies in the main Alpine Himalayan belt, one of the most earthquake prone regions of the world. Crustal instability in this belt is ascribed to the movement of the Indian plate towards the Eurasian plate at the rate of about 50mm per year. Besides several local faults, two prominent thrusts tending northwest to southeast, from the conspicuous tectonic features.

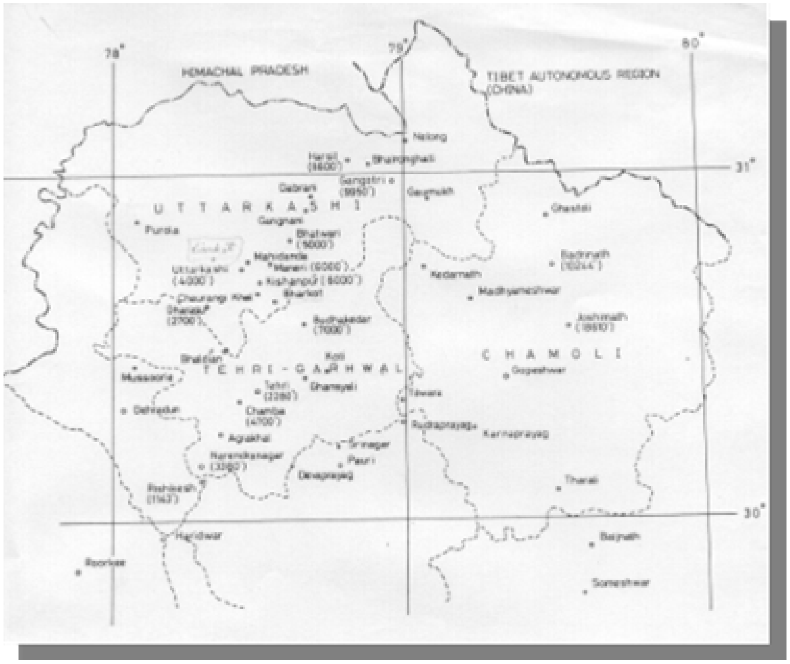

Figure 1: Map of the affected area

This earthquake has provided excellent strong motion records. The area is instrumented with a number of SMA's (photographic film type, supplied by kinematics) and structural response recorders (SRR) operated by the University of Roorkee. Maximum horizontal acceleration of 0.03 g and maximum vertical acceleration of 0.04 g were recorded.

Intensity of Shaking

The intensity of shaking was moderate. The maximum intensity was VIII on the Modified Mercalli (MM) scale at Budhakedar, Krishanpur, Maneri, Uttarkashi, Mahinanda, and Bhatwari. Tehri, Ghansyali, and Gongotri had a shaking of MMI VII. Information from other sources indicate that Pauri, Karnaprayag and Gopeshwar also experienced shaking of MMI VII.

The seismic code in India divides the country into five seismic zones (I to V). Tehri and Chamoli are in zone V and Uttarkashi is in zone IV. The preamble of the code suggests that the expected MMI broadly associated with zones I to V is: V (or less), VI, VII, VIII, and IX (above), respectively. Thus the Uttarkashi and its neighborhood experienced a design level earthquake.

Buildings

Damage to rural dwellings (random rubble stone masonry supporting a heavy roof) was extensive in areas of maximum shaking. Even in developed areas, most

privately owned buildings and older government owned buildings were build without seismic provisions.

Uttarkashi has a number of three and four story reinforced concrete (RC) framed buildings which sustained damage. Shear-cracks developed in the ground floor columns of two story Post Office Building in Uttarkashi built in 1985-86 by engineers of the Department of Post and Telegraphs. The strong floor beams in the frame forced the yielding into ground-story columns. The weaker roof beams sustain flexural hairline cracks while the supporting second story columns were damaged.

Figure 2 shows the State Bank building in Uttarkashi. During the earthquake, the upper two stories collapsed on the first story. Informations from the local residents revealed that the building was first constructed as one story only; the upper two story was added subsequently. The beams has only two normal rebars on the top face near the column joint and those were incorrectly placed.

Figure 2: State Bank Building at Uttarkashi

Most government buildings, both offices and residences, are one or two story buildings with load bearing walls and sloping roofs. Older construction is of Unreinforced random rubble stone masonry which performed very poorly. The newer construction is of Unreinforced concrete block masonry and usually include a RC band at lintel level.

The ITBP Paramilitary Campus at Mahidanda consists a large number of two story residential buildings with load bearing walls of concrete masonry. All have

RC lintel bands, but no roof bands or gable bands. The construction is about 10 years old. The damage to buildings consisted of (I) diagonal cracks below window sills, (ii) damage at the connection between masonry walls and RC roof slabs, (iii) in buildings with corrugated iron sheet roofs, damage at seat of purlins on the gable end walls, and (iv) damage to walls supporting roofs at different heights at either end (*Figure 3*). Roof and gable bands would have prevented damage of types (ii), (iii), and (iv) above.

Figure 3: Damage to wall supporting Split Level roof - ITBP campus, Mahidanda.

The Maneri Hydel power project colony campus has two-storey buildings with concrete block masonry bearing walls, of poorer quality construction than that seen on the ITBP campus. Many buildings were damaged beyond repair. Damage consisted of (I) severe damage to gable walls (*Figure 4*), and (ii) diagonal cracks in ground story walls.

Figure 4: Damage to Gable Wall -Maneri Hydel Project Colony

Roads

Roads in the area were extensively damaged due to failure of slopes, retaining walls, and bridges. The Uttarkashi-Harsil-Nelong road link was completely disrupted for several days due to large number of landslides and the collapse of a major bridge. The Uttarkashi-Lumgaon road link was lost due to collapse of embankment on the approach road to the bridge at Kishanpur.

Numerous massive landslides took place on the Uttarkashi-Harsil road, particulary on a 42 km stretch between Uttarkashi and Bhatwari. The stretch is believed to be the area of most intense shaking. While landslides on this route are common in rainy seasons, many of the landslides caused by the earthquake were totally new. Deep fissures on the road caused by the earthquake pose a potential threat of slope failure in the near future. Fissures were most prominent on the Maneri to Bhatwari stretch. A few landslides also took place on the Uttarkashi-Lumgaon route and on Ghansyali-Koti road.

Retaining walls in the area consist of random rubble stone masonry. These are either "dry" with no mortar, or "banded" with horizontal and vertical bands of masonry in cement mortar at regular intervals in the otherwise dry wall. Many of

these walls collapsed on Uttarkashi-Harsil road. The number of such collapses was higher in the Maneri-Bhatwari segment.

On the Uttarkashi-Lumgaon route, the approach road to a bridge near the village of Kishanpur is on an embankment about 8.0m high with retaining walls in "banded" stone masonry. The walls on both sides of the approach road collapsed leading to failure of the embankment. The reduced road width was adequate only pedestrians. Vehicular traffic was disrupted for more than 10 days. The RC T-beam bridge at this location, spanning 18m, suffered shear cracks in the main girders near the support, the flexural cracks near the quarter span.

The Gawana Bridge is a 56.0 m span steel truss bridge build in 1974. It is located at 6km from Uttarkashi towards Maneri. The entire bridge came off the abutments and fell into the river (*Figure 5*) causing the entire area beyond Uttarkashi to be cut off from the rest of the country. Inadequate design of the bearings and anchor bolts as well as absence of any suitable means of preventing the span from falling off the supports were responsible for the damage.

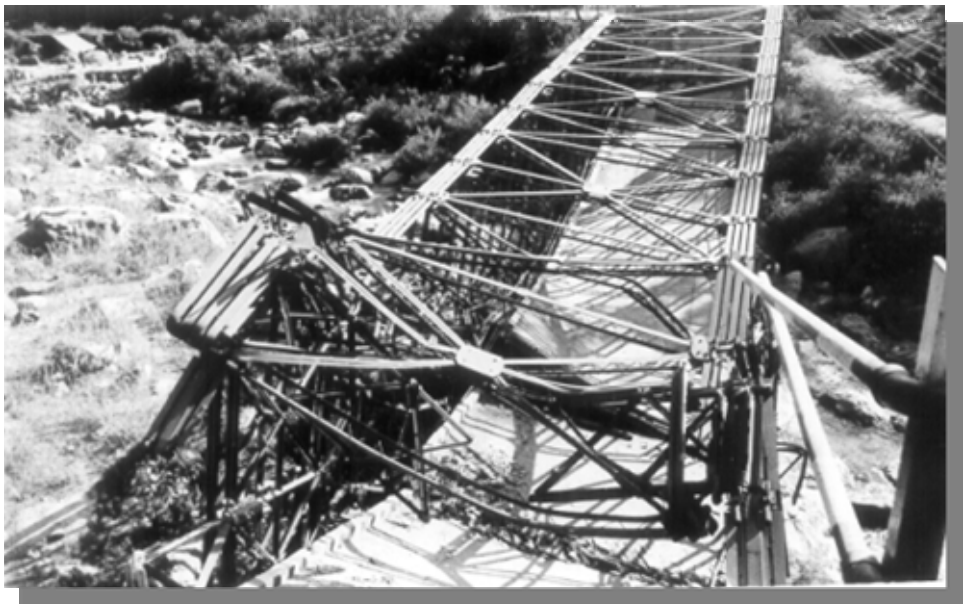

Figure 5: Collapsed Gwana bridge

The area has a number of pedestrian suspension bridges that cross the River Bhagirathi. The main tower and the anchors blocks are of Unreinforced stone masonry. Five of these bridges were damaged, four of them in the Maneri-Bhatwari region. Cracks in the tower and anchor blocks were typical of damage sustained.

The peak horizontal ground acceleration in the region was about 0.30 g. The Indian codes specifies the design seismic force for bridges in the range of 0.05 to 0.075 g for zone IV. This is obviously inadequate. It is hoped that the bridge failures caused by this earthquake will provide the necessary impetus to revise the code.

Other Lifelines

Landslides damaged numerous electric and telephone poles. The area beyond Bhatwari was still without power and without telephone link 10 days after the earthquake.

The diversion dam at Maneri which feeds water through a tunnel to the Tilot power house at Uttarkashi suffered no damage. However the telephone link between the dam and the power house snapped, and power generation had to be stopped.

Rescue and Relief

With the road network disturbed, rescue and relief became extremely difficult. Immediate rescue was provided by the army and paramilitary forces. The Border Roads Task Force did a very commendable job by clearing the Uttarkashi-Harsil road quickly. However the restoration of the Uttarkashi-Lumgaon road by the state Public Works Department was rather slow, and the work on restoration of approach road to the bridge at Kishanpur was still in progress on November 1.

During the initial response stage some relief material was air dropped to the villages. Once the road network was restored , the area was flooded by relief material . However, there are numerous villages accessible only on foot; the relief materials could not reach such villages and ended up being distributed amongst the villages on the roadside. There appeared to be a lack of appropriate leadership at the village level. While many administrators and politicians are experienced in the handling of flood relief work, it appears that earthquake relief poses a rather difficult task for which they have no prior experience or training.

Conclusions

The earthquake caused strong ground shaking over a large area with worst effects suffered in Uttarkashi-Bhatwari region. Damage was observed in Unreinforced masonry buildings as well as RC frame structures. Good construction performed much better than poor quality construction. The need for RC roof and gable bands in masonry buildings was clearly underlined by the performance of buildings at the ITBP campus at Mahidanda. The damaged Post Office building, which was designed and constructed in the formal manner, may

provide some useful insight after detailed analysis. There was enormous loss due to landslides and collapse of retaining walls. The failure of Gowana bridge needs to be studied. This may trigger revision of the Indian code.

Acknowledgements

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