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October 20, 1991 Uttarkashi (India) earthquake

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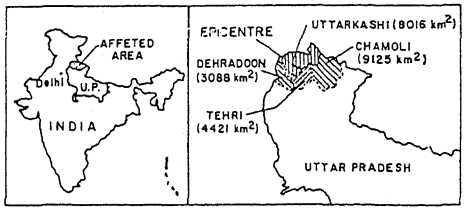
ABSTRACT: The Uttarkashi earthquake of October 20, 1991 had a Richter magnitude of 6.6, focal depth of 12 km and maximum MM intensity VIII+. In the Uttar Pradesh Himalayan hills it caused the death of 768 persons, injured 5066, fully destroyed 20 184 houses and damaged 74 714 more. The main contributor to this scenario was the prevailing type of construction, using field stone either dry packed or built with clay mud. Although the earthquake was not unexpected, code provisions had not been generally implemented. Buildings complying with such provisions underwent no more than minor cracking. Neither the administration nor the population were prepared for the calamity; rescue and relief operations were therefore carried out under very unfavorable conditions.

1 SEISMOLOGY

At 2:53 Indian Standard Time of October 20, 1991 a large area of North India was shaken for over 40 s by an earthquake of magnitude 6.6 on the Richter scale, in the Himalayas of Uttar Pradesh in the Uttarkashi District (fig 1), with focal depth of 12 km and MM intensity VIII+ in an epicentral region 30 by 40 km. (These parameters were established at a meeting in Dehradun (Proceedings of the Meeting of PI's, 1992) with basis on data from 26 stations including a strong-motion array.) New Delhi, some 300 km from the epicenter, was shaken with a MM intensity IV. Peak recorded ground accelerations were 0.3g horizontal at Uttarkashi and 0.29g vertical at Bhatwari close to the epicenter.

The main central thrust in the Himalayas lies about 40 km southwest of the epicenter.

The earthquake was not unexpected. Indeed the 1970 revision of Indian Standard (IS): 1893 classified the area in zone of MM VIII. A brief prelimiary report on this earthquake is given in EERI (1992)



(a) UTTAR PRADESH (INDIA) (b) AFFECTED DISTRICTS

Fig 1. Location map of districts

2 EARTHQUAKE EFFECTS

The earthquake left 768 persons dead and 5066 injured; 3095 cattle dead; 20 184 houses fully destroyed and 74 714 partially damaged; it caused the collapse of a 45.73-m span of a steel bridge at Ganeshpur, Gawana (fig 2), and 425 000 people in 2093 villages were adversely affected. There were numerous landslides in the area of strongest shaking.

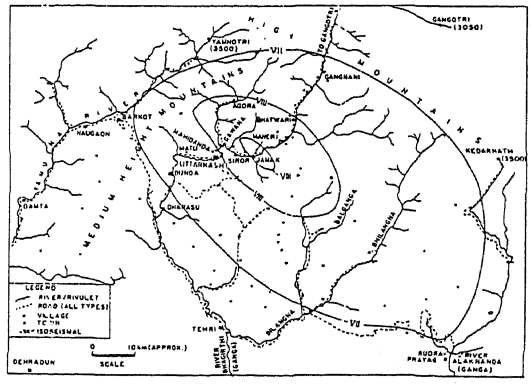


Fig 2. Location map of the worst affected villages

3 TYPES OF CONSTRUCTION AND CAUSES OF DAMAGE

The terrain of the severely affected area is hilly, elevations varying from 1200 m in the valley to more than 3000 m. Predominant wall materials are field stone with mortars of clay mud or lime-sand, and concrete blocks with lime or cement mortars. Old constructions are invariably in stone. Concrete block began to be used some 25 yr ago and only in government constructions, such as the colony buildings of the Manery hydroelectric project and those of the Indo-Tibetan Border Police (ITBP) at Mahindanda. Some houses of the richer people in towns like Uttarkashi have used red brick with 1:6 cement mortar.

Building types and their damage can be described as follows.

a) Rural stone houses. These vary from one to two storeys in height, room size being 2.5 m x 4 m on the average, the house having no separate space for bath or kitchen; intermediate floor of wood planks resting on wood logs or joists, and pitched roofs consisting of slates resting on wood purlins and round wood rafters. Wall thickness varies from 45 to 60 cm, the random stones either set in mud or dry packed. Storey height in ground floor, used for keeping cattle and sheep, is about 2.0 m, and the upper one, used for living of family, is about 2.4 m. As a family became affluent, they used reinforced concrete slab as floor and/or roof. Such houses suffered heavy to total damage in the epicentral area. The worst affected villages were Matly, Jamak, Hina, Natala, Ganeshpur and Gangori (A preliminary report..., 1992). Some constructions in other villages suffered partial or total collapse or various degrees of damage, the quantum of which decreased with increasing distance from the epicentral tract. Stone walls carrying reinforced concrete slabs also collapsed, along with the slabs burying the people underneath.

The causes of this unsatisfactory behaviour are well known: large mass and high stiffness attracting large seismic response to a near earthquake ground motion, very low shear and zero tensile strength of wall material, loose slate roofing, no binding of roof with walls, absence of "through" or bond stones, no integral action between perpendicular walls, no adhesion between the stones in the wall, etc.

b) Buildings in Uttarkashi Town. Here also the loss of lives and majority of heavy damage occurred in the old stone masonry buildings. The thick rubble masonry walls in lime or mud mortar were severely cracked and collapsed due to large inertial forces, improper bonding absence of "through" stones, and ageing. The District Court building and the residences of the District Magistrate and the Superintendent of Police and many private houses are examples of such construction. Even recently constructed buildings using random rubble masonry or concrete blocks with reinforced concrete slab floors and roofs cracked extensively and sometimes even partially collapsed. The fact that IS:4326 code provisions were not respected is responsible for this behaviour. Such was the case of the Girls' Intermediate College building.

Reinforced concrete framed buildings even up to five storeys showed excellent behaviour except for cracking in nonstructural filler walls. However, the upper storeys of State Bank of India building collapseddue to inadequate design, absence of overlaps in column bars while addingthe upper storeys to the first storey, and honeycombed concrete.

c) Maneri irrigation colony buildings. (Study of earthquake damage to departamental buildings situated at Maneri and Uttarkashi, 1991). Most of these buildings are two storeyed, constructed using cement concrete blocks load bearing walls in 1:6 cement-sand mortar, with reinforced concrete slab floors and pitched roof on wooden rafters with CGI sheet covering. These buildings were supposed to be temporary, meant for the Maneri hydroelectric project but have existed for more than 25 yr. They do not have reinforced concrete bands but were provided with one reinforcing bar at each corner of the building from foundation to roof level. Although Maneri is close to the severely damaged villages Jamak, Gangori and Ganeshpur, none of the 425 buildings collapsed and there was no loss of life. Corner bars did help greatly in keeping all of the buildings standing. The greatest damage was in the first storey in the form of star shape cracking going up to the corners. 37 of lower status buildings suffered very heavy damage.

d) Buildings constructed by Central Public Works Department, Government of India (Gupta et al, 1992). These buildings were constructed for the ITBP Complexes at Mahindanda and Matli. They generally consist of single and double storeyed load bearing walls 200 mm thick, made from cement concrete blocks laid in 1:6 cement-sand mortar. Foundation walls up to plinth level are in random rubble masonry with cement mortar. Due to heavy snowfall in Mahidanda, roofs are made sloping with either CGI sheet covering on wood purlins in reinforced concrete slab construction. All buildings are provided with the strengthening measures as per IS:4326-1976 in the form of lintel band, roof band and gable band applicable to seismic zone IV (MM VIII area) with importance factor of 1.0 (IS: 4326-1976, 1977). All these buildings have shown excellent performance except for minor cracking in the mortar joints, proving the efficacy of IS code provisions.

Similarly other colony buildings constructed more recently by the hydroelectric project at Joshiara and other places near Uttarkashi and satisfying IS: 4326 code requirements showed adequate performance during this earthquake.

4 RESCUE AND RELIEF

The district of Uttarkashi was the worst hit though the adjoining districts of Dehradun, Tehri-Garhwal and Chamoli (fig 1) had their share of damage. Owing to the extent of the disaster, besides the central and state ministers and highest government officials, the Chief Minister of Uttar Pradesh and the Prime Minister of India visited the region to assess the situation. They ordered the rescue and relief operations at much higher level than initially taken up by the district and divisional administrations. Ex-gratia payments were assigned to the injured and the next-of-kin to those who died. The scale of relief is described in A brief note on relief works... (1992).

Immediate and continued rescue work was carried out by the ITBP stationed at Mahidanda, situated a few kilometers from Uttarkashi. Five Indian Air Force helicopters started operation from day one and three more were added later for supply of rations and evacuating the severely injured victims to Dehradun where a relief cell was immediately established. Dehradun is a district headquarters well connected with Delhi and Lucknow (the state capital) by highways, rail and air, but about 150 km away from Uttarkashi by tortuous road (63 km as the crow flies). The Border-Roads Organisation quickly cleared the slides on the roads, major portions were cleared by October 23 and all of them by October 31. A military type bridge was erected at the site of the collapsed steel bridge to restore vehicular traffic by October 31. Tarpaulins and blankets were flown in to provide shelter and protection from rain and cold, a shelter camp established at Uttarkashi for those injured or displaced from their homes. A number of voluntary organisations established kitchens for supplying food and blankets to the needy. Teams from engineering institutions and government departments visited the area to assess the damage and its causes and gave suggestions for shelters and reconstruction of houses.

Many problems were encountered in rescue and relief work. The worst was the underdevelopment of the region, only one motorable access road in the critically devastated area which itself got blocked due to landslides at many points in a total length of about 50 km, and collapse of the bridge span mentioned earlier. The situation was worsened by the aftershocks which caused more land slips. Most initial rescue work was done by the surviving neighbours and men of ITBP moving around on foot from village to village. Some villages could be reached only several days after the earthquake, the rescuers being met with stench of dead persons and dead cattle. Local unavailability of ready made shelters or suitable material resulted into great effort, time and cost in transportation of such materials from Delhi and elsewhere. Effective transportation started by road only after the roads were opened. This took the initial few days which were crucial. The local administrative officers — the District Magistrate and the Superintendent of Police — were both under shock themselves because of personal tragedies. Too many visits of important persons led to diversion of attention of the officers involved in rescue and relief work. Relief in the form of tarpaulins, blankets and clothing poured from many nongovernmental and voluntary organisation but the distribution of such relief was mostly uncoordinated, the result being that some villages close to the highway received the bulk of the help in duplicate and triplicate while others in remoter places remained largely unserved for a long time.

5 RESTORATION

Of particular interest was the restoration of the Maneri irrigation colony buildings that did not collapse. All of them will be restored and repaired according the methodology suggested by the author (Arya, 1991b) in a note sent to all concerned, immediately after the earthquake. The repair and strengthening scheme included use of one or more of the following depending on the extent of damage: grouting of cracks with cement slurry; covering the cracks with welded wire-mesh/expanded metal on both sides of wall and plastering using 1:3 cement-coarse sand mortar; rebuilding out-of-plumb walls using temporary supports under the slabs in 1:4 cement-sand mortar; introducing external walls all round the building with steel mesh above the door and window lintels and covering it with micro-concrete, and introducing reinforced concrete bands in those walls which are rebuilt.

The restoration cost will on an average be less than 15% of the reconstruction cost of these buildings.

6 SHELTERS AND NEW HOUSES

Providing shelters to the persons displaced from their homes and reconstruction of houses became the most challenging problem in view of the time and transportation constraints. For shelters, the "Kedar hut" design (an iron hut with corrugated galvanized iron sheet cladding) earlier developed by Central Building Research Institute at Roorkee (Gauri hut and Kedar hut, 1991), was found feasible (fig 3). For house reconstruction, a two-story house of small size, ground floor for keeping cattle and upper floor for the family, which is the common living pattern of rural folk in the area, was designed by the architects of Uttar Pradesh Public Works Department, and seismic- protection measures were incorpora-

ted by the Earthquake Engineering Department of Roorkee University in accordance with IS: 4326-1976 (fig 4). A number of other designs, based on the ideas of the author (Arya, 1991c), making use of tubular steel framework inside, with usual stone wall wall cladding outside (fig 5), have also been developed by a voluntary organisation for adoption in the adopted villages. This approach has the merit of very fast construction of homes even in remote villages using the steel framework for stability against wind and earthquake and the stone wall, constructed as per local practice, which can only collapse outside the home. The scheme can also be used for retrofitting existing stone or adobe houses. Some voluntary organisations have *adopted whole villages for reconstruction of* houses and community buildings as donations. They are consciously making them earthquake resistant for the future. However, in the majority of the badly affected villages, the reconstruction activity is still to get started due lack of appropriate know-how and of skilled workmen, difficulties in transportation of heavy material, etc.

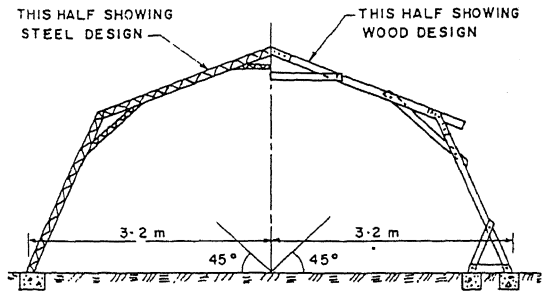
7 COSTS

The main brunt of the earthquake disaster had to be borne by the Uttar Pradesh State Government, which deployed large numbers of engineering and medical professionals in the area from within the state besides what initially could urgently come from ITBP and the army. The Central Government also provided substantial financial assistance in the relief and reconstruction measures.

The total assistance comes to about Rs 1350 million (US$ 52 million). Losses due to the destroyed and damaged houses will be several times more; hence the community itself has to bear a major share of the costs. Relief costs do not include reconstruction costs of government buildings, roads, bridges, etc, which will be met separately by the government. Insurance as such has little to contribute in the affected region. For such disasters in India only the central and state governments provide substantial assurance.

8 LESSONS LEARNED

Moderate earthquakes which have occurred recently in Himachal Pradesh, magnitude 5.5 (1986), **Assam**, magnitude 7.2 (1988), Bihar-Nepal, magnitude 6.5 (1988) and now Uttarkashi, magnitude 6.6 in Uttar Pradesh Himalayas, have clearly shown the vulnerability of large populations who will be threatened by *equal or larger earthquakes in the future.* Studies considering hypothetical repetition of major earthquakes, namely, 1905 Kangra earthquake of magnitude 8.0 in Himachal Pradesh (Arya, 1990), and 1934 Nepal-Bihar



SUCH FRAMES 2·5 - 3·0 m APART
PURLINS OF STEEL OR WOOD
SHEETING CGI OR AC
GOOD FOR HIGH WINDS AND 90 cm SNOW

Fig 3. Shelter designs ('Kedar' & 'Gauri' Kuti)

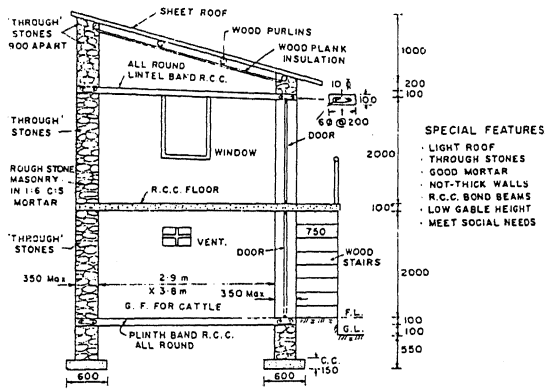


Fig 4. Two storey house with earthquake resistance

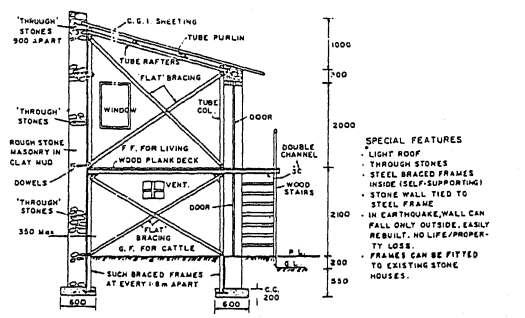


Fig 5. Tubular steel frame with stone wall cladding

earthquake of magnitude 8.4 in north Bihar (Arya, 1991a) have brought out that depending on the time of day or night and the season, such earthquakes will have the potential of killing about 300 000 people in Himachal

Pradesh or Bihar. Also in each future earthquake of magnitude 6.5, the average frequency of which is one every 11 years in the Uttar Pradesh Himalayas, the same order of losses or greater are likely to occur as during the present Uttarkashi earthquake (Arya, 1992).

Can something be done to reduce such losses in the future? All these areas are seismically well recognized and zoned in IS: 1893 since 1970 (IS: 1893-1970, 1971) as earthquake prone with maximum probable intensity classifications in Zone V with likely intensity of MM IX or more, and Zone IV with likely intensity of MM VIII. Also an earthquake resistant building construction code, IS: 4326, exists since 1967 dealing with brick, wood and stone masonry buildings, the provisions of which amply proved adequate in this earthquake. Therefore the answer is a definite "yes", the earthquake losses can be much reduced by two actions: (i) construction of buildings as per IS: 4326-1976, and (ii) preparation and implementation of a contingency plan to suit the needs of each seismic zone (Arya, 1992). Allocation of the necessary budgets to implement the program and its effective coordinated execution over a period of 5-10 yr will be necessary. The subelements of the program will be the following.

1. Awareness at various levels, demanding action from policy makers to the people
2. Microzonation within the macroseismic zones to prioritise the inputs so as to reduce costs
3. Preventive measures: earthquake resistance of all new constructions; retrofitting of existing constructions (priorities); safety analysis of critical installations, eg dams, power plants, hazardous industries, major bridges; preparedness for communication, rescue, relief, receipt and distribution, shelters, medical aid, etc; education and training at various levels

9 CONCLUSIONS

The main conclusions are that the earthquake occurrence was not unexpected, and its magnitude 6.6 and MM intensity VIII are consistent with the maximum values estimated in India Standard IS: 1893-1984 seismic zoning map. Not-too-expensive techniques are now available for earthquake resistant construction, such as in IS: 4326, IS: 4326-1976 (1977) and IAEE Guidelines (1986), using all types of materials like brick, stone, wood and even adobe. Time is needed to create the necessary awareness and implement these techniques in the hazard prone areas.

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