Reconnaissance Report

ON THE 21 AUGUST 1988 EARTHQUAKE IN THE NEPAL-INDIA BORDER REGION

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3. STRUCTURAL DAMAGE

3.1 Introductory Remarks

The outstanding characteristic of the structural damage caused by the 1988 Nepal-India Earthquake is that it was limited to clay or brick masonry buildings and to the so-called mud-stone buildings. Among the small number of wooden and reinforced concrete buildings that exist, we found no serious earthquake damage; there were no buildings constructed of steel in any of the damaged areas of India or Nepal. The next most important characteristic of the damage done by this earthquake is that the buildings affected were almost all rural houses (including small shops).

The structural damage done to brick masonry, mud-stone, wooden and reinforced concrete buildings is first discussed, then the seismic capacity of the structures or their structural elements is evaluated. Statistical data for Dharan Panchayat in Sunsari District, Nepal (one of the most severely damaged areas) as well as the actual damage done to civil structures there is reviewed.

3.2 Damage to Brick Masonry and Mud-Stone Buildings

3.2.1 Structure of brick masonry buildings

The dimensions of a typical Indian brick are 200x100x50mm and of a Nepalese brick 235x115x65mm. The Japanese standard, JIS R 1250, specifies 210x100x60mm as the dimensions for a clay brick. Burnt clay bricks in India or Nepal vary greatly in strength based on the place of production.

The typical method used to construct a brick masonry building is shown in Fig. 3.1. The exterior walls first are built up with cemented bricks, then wooden floor beams are laid across the space between the four walls. More bricks are arranged on these beams, and mud layered over them. Photo. 3.1 shows an interior view and Photo. 3.2 a cross section of the roof slab of a damaged house. For buildings of three or more stories, the usual brick floor slab with a mud layer is replaced by a brick floor slab reinforced with steel bars about 12mm in diameter. Photos. 3.3 and 3.4 show the details of the actual floor slab construction in another building. The transverse wooden floor beams can be seen in Photo. 3.3. In this building, thin wooden planks have been placed across the wooden beams, and a layer of bricks placed on the planks. Its exterior longitudinal brick wall is shown in Photo. 3.4; the ends of the transverse wooden floor beams penetrate the brick wall above the entrances. An important feature of this structural system is shown in...
3.2.2 Structure of mud-stone buildings

The stiffness of a staircase, even one of wooden construction, improves the stiffness of a building in the transverse direction and helps it to resist lateral load during an earthquake.

3.2.3 General description of the damage done

In rural regions of India and Nepal, what are called mud-stone buildings are common. Their construction is very simple: Stones piled up to form the exterior and interior walls are cemented with a clay-mud mortar. In the house under construction which we examined in Nepal, they were using clay mud without a reinforcing material. Photos. 3.5 through 3.7 show the construction process. Note that the mud mortar being mixed in the backyard (Photo. 3.7) contains no straw or cloth for reinforcement.

A mud-stone building typical of rural regions (Photo. 3.8) has been constructed at the Department of Earthquake Engineering, the University of Roorkee, India for use in experimental studies. A close-up of the mud-stone wall of a rural house partly damaged during the earthquake is shown in Photo. 3.9.

The damage done to clay brick masonry houses and to mud-stone houses was severe. The pattern of damage being the collapse of the brick masonry or mud-stone walls followed by the collapse of the heavily weighted floors and roof slabs made of clay bricks covered with a layer of mud. Because the ductility of the walls against lateral loading is poor, the collapse of such buildings may be abrupt thereby resulting in a large number of casualties.

The typical pattern of damage for brick masonry buildings is the collapse of the gable walls (Photos. 3.10 and 3.11). This pattern was seen at almost every site of damage in Nepal; but in damaged sections of Bihar State, India it was absent. One reason may be that the intensity of the shock experienced in the Indian area was not high enough to produce this kind of structural damage.

The typical damage pattern for brick masonry structures was seen in buildings of two or more stories, possibly because the gable walls of such buildings are exclusively self-supporting, there being no connecting seismic component. As shown, the wooden beams run transversely, and no specific seismic structural components are positioned to strengthen the gable wall. Therefore when out-of-plane lateral forces are applied in the longitudinal direction, the gable wall sloughs off (Photos. 3.10 and 3.11). Lack of stiffness in the floor slab system, in particular longitudinally, might cause major deformation during excitation and thrust the gable wall into an out-of-plane position.
Photo. 3.5 Construction of a mud-stone house in Dharan Bazaar; overall view

Photo. 3.6 Construction of a mud-stone house in Dharan Bazaar; cementing stones with mud-mortar

Photo. 3.7 Construction of a mud-stone house in Dharan Bazaar; mixing mud-mortar in the backyard

Photo. 3.8 A mud-stone building constructed for an experimental study at the University of Roorkee, India

Photo. 3.9 A mud-stone, rural house at Gajikha, Nepal partly damaged during the earthquake

Photo. 3.10 Typical pattern of damage to a brick masonry building produced by the earthquake; example 1

Photo. 3.11 Typical pattern of damage to a brick masonry building produced by the earthquake; example 2
3.2.4 Damage in the stricken areas

The damage done to buildings seen in the stricken areas visited during our field survey is summarized as follows:

(a) Patna and Darbhanga: Bihar State, India

(a.1) Patna

Patna, the capital of Bihar State, is located at the confluence of the Ganges and Sone Rivers about 860km east-southeast of Delhi. The distance of Patna from the reported epicenter of the earthquake is about 200km. Because the epicenter was far from the city, there was no serious damage done.

The main office of the State Government Secretariat, built in 1912 of brick masonry, is shown in *Photo. 3.12*. The only damage to this building was the cracking of its floor slabs and the peeling off of a small amount of plaster finish coating of a wall (*Photo. 3.13*).

(a.2) Darbhanga

Darbhanga is about 100km northeast of Patna. It and Madhubani, both district headquarters, are almost on a line from Patna to the reported epicenter. The distance to the epicenter from Darbhanga is 100km and from Madhubani 60km.

*Photo. 3.14* shows the damage done to a kiosk in the backyard of the District Headquarters Office. Shear cracks have appeared in its brick masonry walls and roof tiles have fallen, but the building has not collapsed. The District Headquarters Office has a large number of serious cracks in its brick masonry walls (*Photo. 3.15*), but it remains open for general business. Internal damage to the residence and to the office of the Civil Sergeant, Darbhanga District was severe (*Photo. 3.16*); both buildings have been closed.

Damage to an entrance of the dormitory at the Medical College Hospital is shown in *Photo. 3.17*. *Photo. 3.18* gives a close-up view. There are no reinforcing bars for the girders and beams, nor for the floor system composed of layers of bricks and mud. The building consequently is extremely heavy and has poor ductility for deformation. Numerous cracks have appeared within the dormitory in its transverse walls and in its longitudinal walls around the windows and doors. Note that the one-story buildings located less than 20m from the damaged dormitory show no exterior seismic damage, not even small cracks around their window frames (*Photo. 3.19*).
Photos. 3.20 and 3.21 show vividly the damage done by the earthquake in Darbhanga District.

(b) Kathmandu and Bhaktapur: Bagmati Zone, Nepal

(b.1) Kathmandu

Kathmandu is the capital of Nepal and headquarters of the Kathmandu District, Bagmati Zone, Central Sector. The reported epicenter was approximately 150km southeast of the city. Although a small number of injuries were reported in the newspaper, Rising Nepal, we found no structural damage caused by the 1988 Earthquake during our survey.

(b.2) Bhaktapur

Bhaktapur is the headquarters of Bhaktapur District, Bagmati Zone and is about 10km east of Kathmandu. The epicenter was about 140km east-southeast of this town.

The damage in Bhaktapur is concentrated in the old town which is spread over the hillside (Photo. 3.22). The buildings damaged by the 1988 Earthquake are those which were not affected by a previous one in January 1934. Buildings reconstructed after that earthquake have not been seriously damaged by recent earthquakes.

The typical damage pattern from the 1988 Earthquake, the collapse of gable walls, is present in Bhaktapur. Photos. 3.23 and 3.24 show such collapses. Photo. 3.25 shows a wall that has expanded in the out-of-plane direction and is indicative of the hazard of sudden collapse. These photographs also show the construction system used in brick masonry buildings. Bricks have been piled up and cemented to form an exterior wall that is almost 500mm thick by placing four bricks side-by-side. A wooden frame has been built in the longitudinal direction within the space formed. Photo. 3.23 shows wooden beams placed in the longitudinal wall. Note the wooden staircases positioned transversely.

(c) Gaighat, Udayapur District, Sagarmatha Zone, Nepal

Gaighat is located within the reported epicentral region of the 1988 earthquake about 35km north of the Mehandro Highway which runs almost due east-west along the foot of the Himalaya Mountains. Although the town is the headquarters of Udayapur District, it is very small.

Along the road to Gaighat we found a large number of liquefaction spots, and within the town several houses built of brick masonry or of stones cemented with mud-mortar
that showed seismic damage. Photos. 3.26 and 3.27 record some of the damage done in Gaighat; the former shows the typical collapse of the gable wall of a brick masonry farm house, and the latter the fallen wall stones of a mud-stone farm house. Both houses are two-storied, the upper story having a wooden frame. These wooden second stories were not seriously damaged. Inhabitants of a small village to the west of Gaighat told us that the shock was very frightening and that almost all the roof tiles were dislodged.

(d) Dharon, Sunsari District, Kosi Zone, Nepal

(d.1) Dharon Bazaar

Dharon Bazaar is located on the border between the Himalaya Mountains and the Terai, the plain at the foot of the mountains. Although Dharon is not the headquarters of the district, it is one of the largest bazaars for the exchange of products from the mountains and plain. It is about 75km east-northeast of the reported epicenter. Our observations of seismic damage indicate that the actual epicentral region, the center of maximum energy release of the 1988 earthquake, must have been located closer to Dharon or Dhankuta.

The newspaper Rising Nepal of September 15, 1988 gave the number of houses destroyed as 1,626, and the number partially damaged as 773. A total of 787 dangerous buildings were demolished by the Army or the Police. The estimated loss of property totaled 245.2 million Nepalese Rupees, the equivalent of U.S. $10 million.

Damage done to Dharon Bazaar is shown in Photos. 3.28 to 3.31. The nurses’ headquarters at Dharon Hospital (Photo. 3.28) has been reduced to a pile of bricks; whereas, the yellow-colored emergency ward next to it is without serious damage. Beyond the demolished nurses’ headquarters, an elevated reinforced concrete water tank stands undamaged. Examples of the total collapse of brick masonry houses are shown in Photos. 3.29 through 3.31. A pile of logs that had been wooden beams in a collapsed brick masonry house is shown in Photo. 3.31. The exposed ends of these logs have rotted with age, which may have been why this house collapsed.

(d.2) British Army Recruit Camp

The site of the British Army Recruit Camp is near Dharon Bazaar. Buildings within the camp, mostly single-story cement block structures, were damaged (Photo. 3.32). An administrative officer at the Camp informed us that the buildings were constructed to the seismic design specified in the U.K. code, but that their construction had not been certified by an appropriate engineer.
Photo. 3.28 Collapse of a brick masonry building; the nurses' headquarters, Dharan Hospital, Dharan Bazaar, Nepal

Photo. 3.29 A collapsed brick masonry house; example 1, Dharan Bazaar, Nepal

Photo. 3.30 A collapsed brick masonry house; example 2, Dharan Bazaar, Nepal

Photo. 3.31 A collapsed brick masonry house; example 3, Dharan Bazaar, Nepal

Photo. 3.32 Damage to a single-story block building in the British Recruit Camp, Dharan Bazaar, Nepal

Photo. 3.33 Shear failures in the short-span brick masonry wall of a special classroom, the Engineering College Campus, Tribhuvan University, Dharan Bazaar, Nepal

Photo. 3.34 Seriously and slightly damaged classroom buildings, the Engineering College Campus, Tribhuvan University, Dharan Bazaar, Nepal
Dhankuta District is north of Sunsari District. The town of Dhankuta Bazaar, its headquarters, is within the mountain area and 20km north of Dharan Bazaar. Between Dharan and Dhankuta, roads had to be closed at several places for reconstruction because of landslide damage.

Dhankuta Bazaar is spread over a gently sloping hill (Photo. 3.35). The typical damage done to gable walls of brick masonry constructions, is seen in Photos. 3.36 to 3.39. Almost every brick masonry building showed some seismic damage to its gable walls.

The damaged brick masonry buildings in Dhankuta Bazaar had all been roofed with thatch or corrugated iron sheets. Because these types of roofs are light in weight, the collapse of gable walls would be due to lateral forces produced from their own weights because such walls are constructed to be almost self-standing and are peeled off a building when lateral force is applied in the out-of-plane direction. Provided that such lateral force can be carried by wooden floor beams, longitudinal wall components, or both, gable walls of brick masonry buildings would not be seriously damaged.

Almost every building in Dhankuta Bazaar appears to have been harmed by the 1988 earthquake. The house shown in Photo. 3.40 does not look seriously damaged. Its exterior facade may have been reconditioned; the interior, however, shows large cracks in the walls (Photo. 3.41). The inhabitants told us that blocks of wall fell during the earthquake.

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(d.3) Engineering College Campus, Tribhuvan University

The Engineering College Campus of Tribhuvan University, Dharan is in the suburbs of Dharan Bazaar. It has several brick masonry buildings that are used for class rooms and laboratories. A single-story canteen was not damaged, but its two-story buildings, including the library, were. Serious shear failures are present in the short-span walls containing window frames (Photo. 3.33).

On this campus, buildings of identical construction are oriented in east-west and north-south directions. Our survey showed that serious damage was produced by excitation in the east-west direction. The intensity of east-west motion (parallel to the Himalaya Mountains and corresponding to the direction perpendicular to the probable subduction movement of the fault) would be higher than that of north-south motion (perpendicular to the Himalaya Mountains and parallel to the subduction movement of the fault). The building seen in the foreground of Photo. 3.34 has suffered no damage to its short-span walls; whereas, the one in the background has severe cracks in its east-west wall.

(e) Dhankuta, Dhankuta District, Kosi Zone, Nepal

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Another feature of the damage done at Dhankuta Bazaar can be seen in the public service buildings. Photo. 3.42 shows a pile of brick rubble, all that remains of Dhankuta Hospital. The white tents in the background were set up as temporary wards. The building that was used as a prison also was demolished.

(Biratnagar, Morang District, Kosi Zone, Nepal

Biratnagar, the headquarters of Morang District, is a large city with a population of more than 100,000; there is an airport in its suburbs. It is about 60km east-southeast of the epicentral region.

According to newspaper reports, there was damage done, but we found no signs of serious seismic damage within the city. Damage to a brick masonry single-story house is shown in Photo. 3.43. The collapse of its poorly constructed brick porch killed six persons.

3.3 Damage to Wooden Buildings

Wood frame is a typical type of rural house construction used in the damaged areas. During our field survey, we found most wooden houses to be undamaged.

Because the epicenter of the 1988 Earthquake was located far from the Indian area, the intensity of the shock was judged not to be so high as to cause damage to wooden houses there. In Nepal, the earthquake having occurred on the 21st of August and our field survey having been conducted from 10-12 October, many houses had been rebuilt or demolished prior to our arrival. We concluded from the exterior evidence available that wooden houses had not received serious structural damage.

Undamaged wooden houses at Gaighat within the reported epicentral region are shown in Photos. 3.44 and 3.45. The elevated story shown in Photo. 3.45 is not a recommended structural configuration in Japan. The collapse of the brick masonry and mud-stone houses in this area has been described in 3.2.4 (c), but their wooden second stories were undamaged. Another example of an undamaged wooden house is shown in Photo. 3.46; the tilt of its supporting columns is not believed to be the result of earthquake shock.

Possible reasons for the lack of structural damage are (1) The weight of a wooden building is light, therefore, the lateral force generated by the shock would be small because the floors and roofs of such houses are constructed of boards and thatch, or of boards and corrugated iron sheets; (2) Lateral force would be small because the fundamental periods of these wooden houses would be large owing to loose connections; whereas, the dominant period of motion should be small because the shock occurred within the near field; (3) The intensity of motion was not high enough to do structural damage to these wooden houses.
3.4 Damage to Reinforced Concrete Buildings

3.4.1 Structure of reinforced concrete buildings

There were few reinforced concrete buildings found within the damage areas surveyed. The most widely used method of construction for reinforced concrete buildings is a reinforced concrete frame with filled-in walls of brick masonry. We found no steel frame buildings during our field survey.

The Indian Standard for structural design includes seismic design provisions based on an ultimate strength design procedure [Ref.3.1]. These standards have been used exclusively for federal and state public buildings, not for small scale private construction. In Nepal, they are now establishing structural standards, but have also used established standards such as those of the U.K. or India. In most cases, structural designs against dead and live loads have been made without incorporating specific processes for lateral loads.

A typical reinforced concrete building under construction in an area damaged by the earthquake is shown in Photo. 3.47. It consists of reinforced concrete frames with filled-in walls constructed of clay bricks. This building will be two-stories high. The dimensions are about 20\times20cm for a column and about 10\times20cm for a girder. The quality of the concrete being used is not high. The reinforcing steel bars are cold-formed, deformed bars with diameters of about 0.5 inches. The tie bars used in the columns are spaced about 25cm apart. Another example of a typical reinforced concrete building is shown in Photo. 3.48.

A reinforced concrete building is being constructed for use as a ward at Dharan Hospital, where several brick masonry buildings were demolished (Photo. 3.49). Its construction has been interrupted for lack of funds. This building will be 36m long with 6 longitudinal spans and 18m wide with 3 transverse spans. The dimensions of the columns used are 36\times40cm. Three tensile reinforcing bars 0.75in(19mm) in diameter are positioned longitudinally and two bars transversely (Photo. 3.50). A Nepalese building engineer told us that they would construct brick masonry walls in the transverse direction. For reinforcement, the tie bars used in the columns in order to resist lateral loads are about 0.38in. (9mm) in diameter and spaced about 30cm apart.

3.4.2 Damage done in the stricken areas

No notable damage was seen in the few reinforced concrete buildings checked during our
field survey, which led us to conclude that the intensity of the shock was not great enough to damage a reinforced concrete building. But, because these constructions do not have great lateral strength, and have only a small amount of tensile reinforcement as well as an inferior ductility with only a small amount of shear reinforcement, their seismic capacities would not be sufficient to protect them from severe excitation. Should a shock with an intensity higher than that of 29 August 1988 be experienced, catastrophic damage leading to complete collapse similar to that observed for brick masonry buildings might well take place.

Summary of the survey of reinforced concrete buildings:

(a) Darbhanga, Bihar State, India

A two-story reinforced concrete building next to the Civil Sergeant’s brick masonry residence is shown in Photo. 3.51, the latter having had severe internal damage (Section 3.2.4 and Photo. 3.15). There was no notable damage to this 2-story building; moreover, a two-story reinforced concrete building next to the Civil Sergeant’s Office suffered no damage as judged from our exterior examination.

(b) Dharan Bazaar, Nepal

A ward of Dharan Hospital is shown in Photo. 3.52. At this place both the residence of the chief superintendent and the nurses’ headquarters (both constructed of brick masonry) collapsed completely, and here a ward that is under construction has been described (3.4.1). There was no structural damage, not even small cracks around window frames. A shear wall positioned longitudinally (Photo. 3.53) is not even slightly cracked. The partition wall constructed of brick masonry that is parallel to the reinforced concrete wall shows a long deep crack (Photo. 3.54) which indicates that the lateral force generated could be carried by the reinforced concrete shear wall. A two-story building used as the medical office showed slight damage to its exterior staircase (Photo. 3.55).

The two-story telecommunications office in Dharan, built with a reinforced concrete frame and a partially filled in brick masonry wall, is shown in Photo. 3.56. Our exterior examination showed that there was no external damage. The foreground of Photo. 3.56 shows the rubble of a nearby brick masonry building.

Private buildings (Photos. 3.57 and 3.58) showed no signs of seismic damage. Photo. 3.59 gives a close up of the top of a column. Generally, when subjected to a major earthquake, cracks form at the corners of such column-girder connections, but none are present.
Photo. 3.51 An undamaged reinforced concrete building located next to the Civil Sergeant's Residence, Darbhanga District, Darbhanga, Nepal

Photo. 3.52 An undamaged reinforced concrete ward at Dharan Hospital, Dharan Bazaar, Nepal

Photo. 3.53 A reinforced concrete shear wall positioned within the ward longitudinally, Dharan Hospital, Dharan Bazaar, Nepal

Photo. 3.54 Shear cracks in a brick masonry wall placed within the ward parallel to the undamaged reinforced concrete shear wall (Photo. 3.53), Dharan Hospital, Dharan Bazaar, Nepal

Photo. 3.55 The damaged two-story reinforced concrete medical office at Dharan Hospital, Dharan Bazaar, Nepal

Photo. 3.56 The telecommunications office, Dharan Bazaar, Nepal

Photo. 3.57 An undamaged reinforced concrete private home; example 1, Dharan Bazaar, Nepal

Photo. 3.58 An undamaged reinforced concrete private home; example 2, Dharan Bazaar, Nepal

Photo. 3.59 Close-up of the top of the column of a third reinforced concrete private home, Dharan Bazaar, Nepal

Photo. 3.60 An undamaged reinforced concrete private home, Dhankuta Bazaar, Nepal
There are a few reinforced concrete buildings in Dhankuta Bazaar, one of which is shown in Photo 3.60. No seismic damage was done to this house.

(d) Biratnagar, Nepal

A six-story hotel is being constructed in downtown Biratnagar. Photo 3.61 shows an exterior view of it. The frame is constructed of columns and beams of reinforced concrete with filled-in walls of brick masonry (Photo 3.62). The dimensions of the original columns are 12x12in (30x30cm). According to construction engineers at this site, because of cracking that took place during the earthquake, the columns for both the first and second stories have been enlarged to 60x60cm (compare Photos 3.63 and 3.62). The beams examined had a thickness of about 30cm, and the concrete floor slab a thickness of 10cm.

The arrangement of the reinforcing bars is seen at the top of the building (Photo 3.64), where the bars have been left exposed for possible future extension of the building; a common practice in the areas we visited in Bihar State, India and in Nepal. The arrangement of the tensile and shear tie reinforcing bars is shown. Six cold-formed tensile bars with diameters of about 0.5in(12mm) are positioned within a 30x30cm cross section. The ratio of this cross sectional area to the total column area ($A_p$) is about 0.0075. The shear reinforcing bars, about 4 to 5mm in diameter, are spaced 20cm apart. The shear reinforcement ratio ($p_s$) is approximately 0.0005.

3.5 Seismic Capacity of a Building in the Earthquake-damaged Area

3.5.1 Evaluation of seismic capacity

We evaluated the seismic capacity of a building in the area struck by the 1988 Earthquake in order to determine the intensity of ground motion during the shock. The results have been used to make recommendations for the improvement of the seismic capacities of buildings against future earthquakes.

As the buildings examined during our field survey constructed of brick masonry, mudstone, or a reinforced concrete frame with filled-in brick masonry walls have inferior ductility, we have been able only to estimate the strength of a building in our determination of its seismic capacity. Lack of other pertinent information, such as drawings of building plans...
and calculation notes, means that the evaluated strength is only roughly representative of the actual seismic capacity of a building.

### 3.5.2 Brick masonry and mud-stone buildings

**a) Brick masonry buildings**

The strength of this type of building generally can be determined from the strength of the cement or mud-mortar used. The compressive strength of a burnt clay brick taken from an existing brick masonry building constructed in Japan in 1914 is reported to be approximately 300kg/cm². The shear strength of its mortar made with cement-lime:sand (1:1:5) is in the range of 1.2-2.0kg/cm², but shear strength values fluctuate greatly with the type of mortar used. The respective compressive and shear strengths of a brick masonry wall of this Japanese building are 110-170kg/cm² and about 7kg/cm² with a deflection angle of $1.7 \times 10^{-3}$, this last value varying greatly with the amount of normal stress [(Ref.3.2)]. The ultimate shear strength of a brick masonry wall from another building in Japan has been reported to be about 3kg/cm².

The type of earthquake damage common to brick masonry buildings is the collapse of a gable wall in the out-of-plane direction. Let a gable wall be represented by a self-supporting panel of height $H$, length $L$ and thickness $t$ as shown in Fig. 3.2. And, let $w$ denote the unit weight of the brick masonry gable wall. The axial force, $N_o$, at the bottom of the wall is obtained from

$$N_o = wHLt$$  \hspace{1cm} (3 - 1)

Assuming that the rigidity of the wall is nearly infinite, we can estimate the overturning moment, $M_o$, at the bottom of the wall from Eq.(3 - 2).

$$M_o = cwH^3Lt/2$$  \hspace{1cm} (3 - 2)

in which $c$ is given by

$$c = a_o/G$$  \hspace{1cm} (3 - 3)

in which $a_o$ denotes the peak acceleration of the ground motion and $G$ the acceleration of gravity, 980cm/sec². Assuming that deformation at the cross-section is linear (following the Bernoulli-Euler approximation) and that the stress block at the cross section can be represented as linear, as shown in Fig. 3.3(a) (i.e., the stress-strain relation remains linear-elastic), we can obtain the fiber stress on the tensile end from:
\[
\sigma_k = \sigma_e + \sigma_t = \frac{N_k}{L_k} - M_k / (1 / 6 L_k^2) = \frac{wH - 2\omega H^2}{t}
\]

(3-4)

Suppose that the wall collapses in the out-of-plane direction when the fiber stress equals zero (i.e., the tensile strength of the cement or mud mortar would be zero), then coefficient \(c\) in Eq. (3-3) is given by

\[
c = \frac{\sigma_t}{3H}
\]

(3-5)

Substituting \(t = 45.7\) cm (18 in.) for the average thickness of the wall, and assuming each story of the building to be 3 meters high,

\[
c = 0.33 \times 45.7 / (300 \times n) = 0.05/n
\]

(3-6)

in which \(n\) is the number of stories in the building.

If we assume that the stress block at the bottom of the wall is rectangular (Fig. 3.3(b)), rather than triangular (Fig. 3.3(a)), coefficient \(c\) in Eq. (3-3) becomes

\[
c = \frac{r_s}{wH}
\]

(3-9)

in which \(r_s\) is the ultimate compressive strength of the brick masonry wall. Assuming that \(w\) equals 2ton/m\(^3\), and \(r_s\) equals 1000kg/cm\(^2\), and substituting \(t = 45.7\) cm and \(H = 300\) cm, we obtain the relation

\[
c = (1 - 6n/1000) \times 0.15/n
\]

(3-8)

Provided that our condition that a gable wall is self-supporting is realistic, Eq. (3-6) gives a possible minimum coefficient \(c\), and Eq. (3-8) a possible maximum coefficient.

When the shear capacity determines the strength of the wall, coefficient \(c\) is given by

\[
c = \frac{\tau_s}{wH}
\]

(3-10)

in which, \(\tau_s\) is the shear strength of the brick masonry wall. When \(\tau_s\) equals 1kg/cm\(^2\), \(w\) equals 2ton/m\(^3\), and \(H\) equals 300cm, coefficient \(c\) is given by

\[
c = 1.7/n
\]

(3-10)

The strength of the wall against the overturning moment in the out-of-plane direction is given by Eq. (3-6) or (3-8) depending on the stress distribution assumed, and the strength against the shear force is given by Eq. (3-10). Taking into account that the gable wall is fastened to a wooden roof and a floor slab framework, or to brick masonry walls positioned longitudinally, the strength of the wall against the overturning moment will be larger than that given by the above equations because the wooden framework would cramp the top of the wall against deflection. The seismic capacity of the wall against the shear force will be less than that given by Eq. (3-10) because a certain amount of lateral force is applied by both the roof and floor slab frames.

This quantitative discussion cannot be extended because we cannot evaluate the behavior of the wooden frames or walls in the longitudinal direction. The actual damage observed is evidence that the seismic capacity of a gable wall is determined from its resistance to the overturning moment which produces the out-of-plane deformation. The resulting coefficient \(c\) is 0.05-0.15 for \(n\) equal to unity, 0.025-0.075 for \(n\) equal to 2, and 0.017-0.05 for \(n\) equal to 3.

(c) Mud-stone buildings

For mud-stone buildings, a discussion similar to that made for brick masonry buildings holds true.

(b) Mud-stone buildings

In the British Army Recruit Camp at Dharan, Nepal, a group of reinforced block masonry buildings suffered seismic damage (described in 3.2.4). As shown in Photo. 3.32, cracks were generated along the joint mortar between the blocks.

We have several architectural drawings for these buildings that give the dimensions and the rough arrangement of the reinforcing bars. Because our observation of the damage done to the buildings revealed shear failure of the mortar joints between blocks, we can estimate the shear strength of a concrete block building in the transverse direction as follows:

Let the dimensions of a typical building in the Camp be 100ft by 22ft 4in (30.5 x 6.8m). Within that building, seven shear walls constructed of hollow concrete blocks 8in (20cm) thick are positioned transversely. The length of each wall is about 16ft 8in (5m). Suppose that the building has a set of seven shear walls; on the average one shear wall should support the lateral force, \(Q\), given by

\[
Q = \frac{wH - 2\omega H^2}{t} = \frac{wH - 2\omega H^2}{t}
\]
\[ Q = \dot{c} \times 30.5 \times 6.8 \times 1.3/7 \]
\[ = 30c \quad \text{(ton)} \quad (3 - 11) \]

in which \( c \) is the coefficient given by Eq. (3 - 3) when the weight of the building averages 1ton/m².

Suppose the shear strength of the concrete block masonry wall to be 1.5kg/cm² [Ref.3.3], then the maximum shear capacity of the wall, \( Q_{\text{max.}} \), is
\[ Q_{\text{max.}} = 1.5 \times 500 \times 20/2 \]
\[ = 7,500 \quad \text{(kg)} \quad (3 - 12) \]

by which, taking into account penetration for window frames and doors within the wall, we have estimated the effective cross-sectional area of the wall to be half that of the gross cross-sectional area. When the lateral load to the wall equals its maximum shear capacity, coefficient \( c \) is
\[ c = 7.5/30 = 0.25 \quad (3 - 13) \]

The assumed value of the shear strength of the block masonry wall or of the average weight of the building in Eq.(3 - 11) or (3 - 12) could produce a much lower coefficient \( c \) than the value given by Eq.(3 - 13).

The estimated coefficient \( c \) given by the Eq.(3 - 13) is larger than the actual value, if any, because the damage to concrete block masonry buildings seen in the Camp was not severe enough to produce the complete collapse of the joint mortar due to shear failure.

3.5.3 Reinforced concrete building

In Biratnagar, Nepal, a six-story reinforced concrete hotel is under construction (described in 3.4.2). This building has been reported to have had some cracks in its columns; therefore, the columns on both the first and second floors were enlarged from 12 to 24 in (30 to 60cm). We estimated the seismic capacity of the original building against lateral force.

The plan of the hotel shows a length of about 20 meters with 5 spans and a width of about 12 meters with 3 spans. As a result, each column on each story supports an average floor area of 10m². The arrangement of the reinforcing bars has been reconstructed from Photo. 3.63. There are three tensile bars, each with a diameter of about 13mm, and shear reinforcing bars positioned about 20cm apart. The following conditions were assumed in order to estimate the strength of a column; (1) The average weight of the building per unit area is 1.0ton/m² based on the floor slab at the top of the building being 10cm thick; (2) The yield strength of the cold-formed tensile bars is 4,000kg/cm², and (3) The compressive strength of the concrete, which we found to be lean, is 180kg/cm².

On this basis, the flexural capacity, \( M_y \), can be estimated as follows [Ref.3.4]:
\[ M_y = 0.8a_1 \sigma_y D + 0.5ND(1 - N/bD{\sigma}_y) \quad (3 - 14) \]

in which \( a_1 \) is the cross-sectional area of the tensile bar, \( \sigma_y \) the yielding strength of the reinforcing bar, \( D \) the depth and \( b \) the width of a column, \( N \) the axial force, and \( F_c \) the compressive strength of the concrete. Substitution of \( a_1 = 3.81cm^2, \sigma_y = 4000kg/cm^2, D = b = 30cm, N = 60ton \) and \( F_c = 180kg/cm^2 \) in the equation, gives a flexural capacity for a column on the first story of
\[ M_y = 9.3 \quad \text{(ton · m)} \quad (3 - 15) \]

Suppose the clear span of a first-story column to be 4m, then the lateral capacity of column \( Q_{\text{sy}} \) is
\[ Q_{\text{sy}} = 2M_y/H = 4.7 \quad \text{(ton)} \quad (3 - 16) \]

Provided that the dynamic amplification factors for this six-story building are assumed to be unity for the approximation in this estimation, the corresponding base shear coefficient obtained from the lateral capacity given by Eq.(3 - 16) is
\[ c = 4.7/60 = 0.08 \quad (3 - 17) \]

Based on the assumption that the shear strength is 9kg/cm² for concrete, the shear capacity of the column \( Q_{\text{sy}} \) is
\[ Q_{\text{sy}} = 8.1 \quad \text{(ton)} \quad (3 - 18) \]

This indicates that the seismic capacity of the column can be determined from the flexural capacity given in Eq.(3 - 16). Provided that half of any lateral force applied during the earthquake would be carried by the brick masonry walls that fill in the frame, the seismic capacity of the building would be twice as large (\( c = 0.16 \)) as the value given in Eq.(3 - 17).

3.5.4 Estimation of seismic intensity based on building responses

Our examinations of the apparent damage to and the evaluated seismic capacity of a building enabled us to estimate the probable seismic intensity of the ground motion in...
Table 3.1 Estimated seismic intensity during the 1988 Nepal-India Earthquake shock of 21 August 1988

<table>
<thead>
<tr>
<th>Place of Damage</th>
<th>Estimated Intensity (acceleration in gal)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhaktapur</td>
<td>20 - 50</td>
<td>Gable walls of 3-story high buildings collapsed but a large number of brick masonry buildings suffered no serious damage.</td>
</tr>
<tr>
<td>Gaighat</td>
<td>30 - 80</td>
<td>Brick masonry and mud-stone houses of 2-stories high were damaged. Wooden houses did not suffer serious damage.</td>
</tr>
<tr>
<td>Dharan Bazaar</td>
<td>80 - 250</td>
<td>A large number of brick masonry houses, 2-stories or higher, collapsed completely. Wooden houses and several reinforced concrete buildings suffered no serious damage.</td>
</tr>
<tr>
<td>British Army Recruit Camp, Dharan</td>
<td>125 - 250</td>
<td>Serious shear cracks appeared in one-story high concrete block buildings.</td>
</tr>
<tr>
<td>Dhankuta Bazaar</td>
<td>100 - 150</td>
<td>A large number of gable walls collapsed. A few gable walls that were one-story high collapsed; but, some 2-story high ones did not collapse even though serious cracks appeared.</td>
</tr>
<tr>
<td>Biratnagar</td>
<td>60 - 100</td>
<td>A 6-story reinforced concrete building suffered cracks but no serious damage. Some poorly constructed brick masonry houses were damaged.</td>
</tr>
</tbody>
</table>

Obviously, our estimate of the intensity must include a fair amount of variation because of the hypothetical assumptions made throughout the analysis. The estimated seismic intensity at selected points, expressed in terms of ground acceleration, is tabulated in Table 3.1.

3.6 Statistics on the Damage Done in Dharan Bazaar

To establish the distribution of the types of buildings damaged, we surveyed 500 houses in Dharan Town Panchyat, Sunsari district, Nepal, on the border between the hill area and alluvial plain, it being the place most damaged. The population is 118,218 and the number of houses about 20,000. The town is divided into 19 administrative wards. The data for the physical and human losses by ward for the 1988 earthquake, obtained from the Dharan administrative office, are tabulated in Table 3.2.

The total of lives lost in this town was 122, about one-sixth of the total earthquake-related deaths in Nepal. Collapsed buildings numbered 1671, about one-eighth of the total buildings destroyed in the country. A map of Dharan Bazaar, with ward numbers encircled is shown in Fig. 3.4. Dharan town hospital marked [H] (shown in Photos. 3.28, 3.52 and 3.53) is located in ward 4, and the British Army Recruit Camp (described in section 3.4.2) is in ward 18. Our basic area of research consisted of wards 1 to 5 (shaded in the figure) which make up the center of Dharan Bazaar, the most heavily damaged area in the town.

We checked the number of stories and the type of construction used for each house along the two main streets with the assistance of Ms. S. Mallo, Chief Engineer of the Nepalese Government, and Messrs. S. Sharma and J. Satyal, translators, and the residents. The numbers of collapsed, damaged and undamaged buildings classified by building material and the number of stories are shown in Table 3.3 and Fig. 3.5.

One-third of the buildings in these wards are constructed of brick masonry and one-third of wood. Engineered buildings of reinforced concrete and reinforced concrete filled-in brick walls make up about one-fourth of the total number of buildings. No mud-stone houses were found. Our information shows that more than 80% of the three-story brick masonry buildings, 50% of the two-story brick buildings, and 30% of the single-story brick buildings collapsed, but most of the wooden houses survived and no reinforced concrete buildings collapsed. This indicates that reinforced concrete buildings and reinforced concrete buildings with filled-in brick walls are relatively strong because of the rigidity of their floor slabs and that the frequency characteristics of the input ground motion might be much higher than the fundamental frequency of the wooden houses. Unfortunately, there is no available acceleration record for this area. Damage ratios for such hill areas as Sunsari, Dhankuta, Ilam and Panchthar districts, however, provide evidence for our supposition...
Table 3.2 Material and human loss caused by the 1988 Nepal-India Earthquake in Dharan Town Panchayat, Sansari District, Kosi Zone, Nepal

<table>
<thead>
<tr>
<th>Ward</th>
<th>Deaths</th>
<th>Damaged Houses</th>
<th>Damage Category</th>
<th>Loss Complete</th>
<th>Partial</th>
<th>Rs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>229</td>
<td>132</td>
<td>97</td>
<td>26385</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>179</td>
<td>68</td>
<td>111</td>
<td>27082</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>294</td>
<td>136</td>
<td>158</td>
<td>15028</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>185</td>
<td>86</td>
<td>99</td>
<td>27789</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>68</td>
<td>73</td>
<td>22</td>
<td>9235</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>156</td>
<td>54</td>
<td>102</td>
<td>14425</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>189</td>
<td>78</td>
<td>111</td>
<td>21688</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>304</td>
<td>30</td>
<td>325</td>
<td>15779</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>180</td>
<td>78</td>
<td>102</td>
<td>18690</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>174</td>
<td>54</td>
<td>120</td>
<td>10338</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>293</td>
<td>285</td>
<td>34</td>
<td>4057</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>191</td>
<td>44</td>
<td>147</td>
<td>15029</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>12</td>
<td>306</td>
<td>122</td>
<td>216</td>
<td>27071</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>10</td>
<td>278</td>
<td>276</td>
<td>2</td>
<td>17206</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>478</td>
<td>78</td>
<td>400</td>
<td>4884</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>161</td>
<td>34</td>
<td>127</td>
<td>14493</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>0</td>
<td>176</td>
<td>30</td>
<td>146</td>
<td>1748</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>6</td>
<td>156</td>
<td>30</td>
<td>117</td>
<td>6020</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>0</td>
<td>179</td>
<td>11</td>
<td>188</td>
<td>3414</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>123</td>
<td>1274</td>
<td>1973</td>
<td>2684</td>
<td>28867</td>
<td></td>
</tr>
</tbody>
</table>

Death Ratio = 122 x 100/118318 = 0.103%
Damage Ratio = 4275 x 100 / 20000 = 21.4%
Complete Damage Ratio = 1671 x 100 / 20000 = 8.4%
Rs. = Rupees

Table 3.3 Statistics on building damage in wards 1-5 in Dharan Bazaar

<table>
<thead>
<tr>
<th>Damage</th>
<th>Wood</th>
<th>Wood &amp; Brick</th>
<th>R/C</th>
<th>R/C Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1F</td>
<td>2F</td>
<td>1F</td>
<td>2F</td>
</tr>
<tr>
<td>Total Number</td>
<td>39</td>
<td>122</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>Collapsed</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>26</td>
</tr>
<tr>
<td>Half Collapsed</td>
<td>1</td>
<td>18</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>Cracked</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Tilted</td>
<td>1</td>
<td>28</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>No Damage</td>
<td>22</td>
<td>75</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>Collapse Ratio</td>
<td>10.0</td>
<td>4.1</td>
<td>14.7</td>
<td>32.1</td>
</tr>
<tr>
<td>Damage Ratio</td>
<td>26.9</td>
<td>30.5</td>
<td>67.6</td>
<td>80.2</td>
</tr>
</tbody>
</table>
Table 3.4 Damaged facilities and estimated monetary loss in Dharan Bazaar

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Facilities Damaged</th>
<th>Number of Damaged Buildings</th>
<th>Damage Category</th>
<th>Loss Amount 1000 Rs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Government Facilities</td>
<td>18</td>
<td>73</td>
<td>Complete</td>
<td>34</td>
</tr>
<tr>
<td>B. Semi-Governmental Offices</td>
<td>3</td>
<td>20</td>
<td>Partial</td>
<td>9</td>
</tr>
<tr>
<td>C. Educational Establishments</td>
<td>4</td>
<td>24</td>
<td>Complete</td>
<td>15</td>
</tr>
<tr>
<td>D. Schools</td>
<td>17</td>
<td>36</td>
<td>Partial</td>
<td>12</td>
</tr>
<tr>
<td>E. Hospitals and HealthOffices</td>
<td>12</td>
<td>32</td>
<td>Complete</td>
<td>3</td>
</tr>
<tr>
<td>F. Social Organization</td>
<td>3</td>
<td>5</td>
<td>Partial</td>
<td>3</td>
</tr>
<tr>
<td>G. Major Temples and Mosques</td>
<td>12</td>
<td>23</td>
<td>Partial</td>
<td>13</td>
</tr>
<tr>
<td>H. Private Houses</td>
<td>4278</td>
<td>1,671</td>
<td>Complete</td>
<td>2904</td>
</tr>
</tbody>
</table>

118,218 people effected by the earthquake

Rs. = Rupees

Table 3.5 Types of assistance received from Dharan Town Panchayat

<table>
<thead>
<tr>
<th>Item</th>
<th>Rs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>25000</td>
</tr>
<tr>
<td>Medicines</td>
<td>15000</td>
</tr>
<tr>
<td>Instruments</td>
<td>31000</td>
</tr>
<tr>
<td>Water Containers</td>
<td>101000</td>
</tr>
<tr>
<td>Food for Volunteers and Drivers</td>
<td>12400</td>
</tr>
<tr>
<td>Plastic</td>
<td>97000</td>
</tr>
<tr>
<td>Iron and Cotton Ropes</td>
<td>51100</td>
</tr>
<tr>
<td>Given to Ward Relief Committee</td>
<td>658000</td>
</tr>
<tr>
<td>Total</td>
<td>658000</td>
</tr>
</tbody>
</table>

Other help from Dharan Town Panchayat
(1) Exemption of registration fee for reconstruction
(2) Exemption of tax on construction materials

Table 3.6 Types of assistance received from the central and district governments

<table>
<thead>
<tr>
<th>Central Government</th>
<th>Cash Rice</th>
<th>Other Blanket/Tents</th>
<th>Corrugated Iron</th>
<th>Plastic</th>
<th>Relief Cash to Kin of the Dead</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18368800</td>
<td>2518.8 Quintal</td>
<td>200</td>
<td>791</td>
<td>1000 Rs./dead</td>
<td>122000 Rs.</td>
</tr>
</tbody>
</table>

Rs. = Rupees
On the assumption that the dimensions of a typical brick masonry building are 5×6m²; a unit, 3m story height; a wall thickness of 50 cm; an average weight of 1000kg/m²; and an ultimate shear stress of fired brick of 0.9 - 0.5kg/cm², the shear capacity of the first story is estimated to be 15 - 8.3 tons for a wall 350 cm long. The approximate respective total weights are 30, 60 and 90 tons for one-, two- and three-story buildings. As stated, half of the two-story and most of the three-story brick masonry buildings in Dharan Bazaar collapsed. Taking this into consideration and assuming a magnification factor of 1.5, the maximum acceleration of the ground motion was 150 - 60 cm/sec². The ultimate stress of adobe is about 0.3 -0.5 kg/cm², less than that for fired brick, but similar to the value for mud-stone; and, as it is similar to the values obtained from other estimations (see sections 2.3, 2.4, 2.5 and 3.4) it explains why severe damage was done to buildings of mud-stone construction.

The relation between the number of dead and the number of damaged buildings per ward is shown in Fig. 3.6. The ratio of deaths to collapsed houses, marked by circles, is roughly 10%. A detailed explanation is given in the next section.

The estimated value of lost property in Dharan Panchayat was 312 million Nepalese Rupees (equivalent to U.S. $13 million), about 90% representing the cost of damage to private houses (Table 3.4). According to the report by S.P. Gupta [Ref. 3.5], the total loss in Nepal amounted to 827 million Nepalese Rupees (U.S. $34 million). The monetary assistance received from Dharan Town Panchayat and the central government is tabulated in Tables 3.5 and 3.6. Relief cash to families of the dead from Sunsari District was 1000 Rs/dead person (U.S. $40).

3.7 Damage to Roads and Bridges in Nepal

There are two main roads in the earthquake-stricken area in Nepal; the Mehandro (East-west) Highway and the Dhankuta-Dharan-Jogabini road. Mehandro Highway is a blacktop-surfaced one lane road that runs along the border between India and Nepal. This road developed cracks at many locations (Fig. 3.7). Also, some culverts and bridges were reported damaged. We also visited Gehari Bridge, the only bridge on the highway which was so severely damaged that there was still a detour there at the time of our visit. This is a single span bridge constructed with three T-beams and a slab with a proper diaphragm. The roller shoe was dislodged (Photo. 3.65) because of the relative movement of the beams to the abutment, probably because the abutment tilted (Photo. 3.66).

The Dhankuta-Dharan section of the second road is a paved mountain road with several well designed bridges that were not damaged (Photos. 3.67 and 3.68). This road had been

Fig. 3.7 Damage to roads in the eastern development region of Nepal
Photo. 3.65 Displacement of the abut at Gehari Bridge, Nepal
Photo. 3.66 Tilting of an abutment at Gehari Bridge, Nepal
Photo. 3.67 Undamaged truss bridge
Photo. 3.68 Undamaged arch bridge
Photo. 3.69 Rockslide site undergoing restoration
Photo. 3.70 Road damaged by a landslide
Photo. 3.71 Retaining wall failure
closed for several days after the 1988 Earthquake because of landslides at several places. When we visited the sites, restoration work was still going on at many places. In the area 16 to 19 km from Dharan there were very large rock- and landslides caused by the earthquake (Photo. 3.69). Along the road 27 to 32 km from Dharan we had been informed that there were landslides that had been triggered by the earthquake but several had been caused by the heavy rains which followed the earthquake and which lasted for a few days (Photo. 3.70). As seen in this photograph the retaining wall has been constructed by the gavian method. Blocks 0.5 x 1 x 2.5m, composed of wire cages filled with rubble, have been laid zigzag. At several points along this road, where the Leoti Khola River flows alongside, the retaining wall for the embankment had moved into the river, and part of the road had been washed away (Photo. 3.71).

3.8 Discussion and Recommendations

The earthquake of 22 August 1988 produced catastrophic seismic damage in areas of northern Bihar State, India and the southeastern zone of Nepal, even though, as discussed earlier, the intensity of the shaking was moderate. It has been suggested by Indian authorities that heavy rainfall prior to the shock, which produced great flooding, may have weakened the mud-stone and brick masonry buildings which showed the greatest damage. The characteristic features of the typical types of construction found in the zones affected by the earthquake (listed below) may constitute the major reason for there having been catastrophic damage:

1. Heavy roofs or upper floor slabs constructed of a layer of bricks topped by a layer of mud.
2. Insufficient joint strength between the gable walls and such structural components as cross walls and wooden frameworks positioned perpendicular to those walls.
3. High rigidity of the unreinforced brick masonry or mud-stone construction, thereby producing an inferior ductility for lateral deformation.
4. Lack of stiffness in the framework of a building; in particular, in the floor slab. Therefore, an applied lateral force is not distributed properly to a stiffened frame that has a large resistance capacity.
5. Weak mortar composed of lean cement or mud-mortar used in the jointing of bricks and stones.
6. Lack of strength against lateral loading attributable to the inferior joint mortar used in the construction of a building.

The recommendations framed from the results of our field survey of the damage zones and our analytical examination of the observed damage are [Ref.3.6]

[1] Make buildings as light as possible. Use light materials such as wooden planks for floor slabs rather than bricks topped with a mud layer. Construct roofs of thatch or corrugated iron sheets instead of brick tiles cemented by a mud layer.

[2] Cramp the top of gable walls by using wooden or reinforced concrete roof bands, collar girders, or beams. It is advisable, and desirable, that gable walls and walls following the longitudinal axis of a building be fastened tightly together to form a rectangular wall box. A number of cross walls constructed within such a box will greatly improve the seismic capacity of a building.

[3] Place columns and collar beams made of reinforced concrete appropriately, wherever possible. Such columns and beams will improve both the strength of a brick masonry wall, owing to their confinement, and the ductility of the frame.

[4] Place horizontal braces in the planes of roof and floor slabs, or use appropriate joints to stiffen floor slabs when adding wooden planks. Placement of wooden braces diagonally in corners is a feasible and easy method for stiffening a floor slab frame. When the frames of a building are stiffened, lateral forces applied to the entire structure can be carried adequately by individual frames in proportion to their seismic capabilities.

[5] Improve the quality of the cementing mortar used in order to produce high joint strength. Avoid the use of structurally weak mud-mortar. The strength of a brick masonry building is determined by the strength of its joints; the greater the strength of the mortar, the greater the strength of the building against lateral loading during shaking. The addition of a tensile-fiber material (such as jute) to mud and to cement improves the strength of these mortars; but, use of a rich cement mortar is strongly recommended for the greatest strength. Neither a lean mixture of inferior mortar nor lime mortar should be used to cement the joints between bricks.

[6] Placement of reinforced concrete collar columns and girders appropriately spaced is necessary to give high strength to filled-in brick masonry walls within the reinforced concrete frame. Such strong reinforced concrete frameworks also should provide ductility against lateral deformation such that there will be no sudden, brittle collapse of the building when its ultimate seismic resistance is reached.
Section References


4. HUMAN LOSS AND EMERGENCY RESPONSES

4.1 Overview of Human Loss

In Nepal 14,964 dwellings were destroyed and 721 people killed [Ref.4.1]. In the State of Bihar, India, 25,093 houses collapsed (comparable to the Nepalese term "destroyed"), and 282 were killed according to the State Relief Commissioner. A comparison of the damage done and lives lost (Table 4.1) reveals that Nepal suffered more casualties, but had less damage to dwellings than Bihar. This suggests that

1. the criteria used in reports of dwelling damage were more strict in Nepal, and that
2. when they collapse, the two-story brick or adobe masonry dwellings common to the hill area of Nepal, are a greater threat to human life than the mostly single-story houses made of mud or brick that are found in Bihar.

An empirical equation used for Japanese earthquakes relates the number of dead, $D$, to the number of heavily damaged houses, $H$, [Ref.4.2].

$$D = 1.45 \cdot H^{0.35} \cdot F \cdot T \cdot A (4 - 1)$$

in which the fire occurrence factor, $F$, signifies 1.0 (major fire), 0.32 (moderate), 0.12 (small); and the time of earthquake factor, $T$, signifies 1.0 (night occurrence), 0.73 (day occurrence); and the year of earthquake factor, $A$, is 1.0 (before 1930), 0.96 (before 1955), and 0.22 (1956 or later). Assuming that there is no spread of fire, that the earthquake takes place at night, and that there is the present (or recent) environment, the equation is

$$D = 1.45 \cdot H^{0.33} \cdot 0.12 \cdot 1.00 \cdot 0.22$$

Inserting $H = 39,787$, the total of destroyed houses in Nepal plus the collapsed ones in Bihar, gives $D = 726$, a little less than the recorded fatalities. But, should an earthquake of magnitude 6.5 occur in Japan, it would not cause the destruction of thousands of dwellings. For example, the 1949 Imachi Earthquake of magnitude 6.4 caused the collapse of 290 dwellings and 10 fatalities; the 1962 Miyagi-ken-hokubu Earthquake of 6.5 demolished 340 dwellings and caused 3 fatalities; and the 1984 Nagano-ken-seibu Earthquake of 6.8 caused the collapse of 14 dwellings and 29 fatalities.

Regional and district distributions of damage to dwellings and of human casualties are shown in Figs. 4.1 and 4.2. The damage done to dwellings ranges from complete destruction to light cracks in Nepal and from complete collapse to minor damage in Bihar. The casualty index is the per district ratio of the total number of dead and injured per 10,000
Table 4.1 Casualties and dwelling damage in Nepal and Bihar State, India

<table>
<thead>
<tr>
<th></th>
<th>Nepal</th>
<th>Bihar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eastern Natural Disaster Relief Working Co-ord.</td>
<td>State Relief Commissioner</td>
</tr>
<tr>
<td>Dead</td>
<td>721</td>
<td>282</td>
</tr>
<tr>
<td>Injured</td>
<td>6,213</td>
<td>3,766</td>
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<tr>
<td>Dwellings</td>
<td>14,984 destroyed</td>
<td>25,093 collapsed</td>
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<tr>
<td></td>
<td>53,959 cracked/useless</td>
<td>46,389 major damage</td>
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<tr>
<td></td>
<td>24,496 cracked/repairable</td>
<td>77,842 minor damage</td>
</tr>
<tr>
<td></td>
<td>20,089 simple cracks</td>
<td></td>
</tr>
</tbody>
</table>

BIHAR STATE RELIEF COMMISSIONER

Nepal Eastern Natural Disaster Relief Working Co-ord. Committee

India Data: Bihar State Relief Commissioner


Fig. 4.1 Map of the affected region showing dwelling damage ratios

Fig. 4.2 Map of the affected region showing casualty ratios
census population. The data for Nepal is from the Eastern Natural Disaster Relief Working Coordination Committee [Ref.4.1] and those for India from the Bihar State Relief Commissioner. (See Appendices B-1, C-1 and C-2 for further detail.) The injured are those who received some type of treatment at hospitals or health centers and thus could be counted by local officials. Although the definition of injury varies in the two countries, the health systems appear to be equal. Therefore one can compare their human casualty ratios.

The area with the severest damage and the greatest concentration of casualties stretches northeast through the Sunsari, Dhankuta, Tehrathum and Panchthar districts in the Eastern Development Region of Nepal. These damaged areas are evidence that the epicenter reported by China (26.9°N, 87.1°E), as a little west of Dhankuta, is a better fit than the USGS reported epicenter (26.755°N, 86.61°E) located in Udayapur. The boundary for injuries (an index greater than 1) appears to extend southward into Bihar, but we have no damage information from Bhutan and Tibetan China.

4.2 Human Loss in Previous Earthquakes

4.2.1 The 1934 Bihar-Nepal earthquake

This was an earthquake of very large magnitude (8.4) that occurred along the Bihar-Nepal border at 14 hours 13 minutes Indian standard time on 15 January 1934. It devastated a similar, but certainly far larger region than the 1988 earthquake. The death toll in India was 7,000, the most badly damaged town of Munger having 1,260 fatalities out of a population of 22,000 (2.4% death) (The Hindustan Times, Aug. 28, 1988). Dividing the number of fatalities (1,260) by the 20,000 homeless, gives an estimate of 6% lethality (risk of death) for an occupant of a destroyed house was 7.0. The data for Nepal is from the Eastern Natural Disaster Relief Working Coordination Committee [Ref.4.1] and those for India from the Bihar State Relief Commissioner. (See Appendices B-1, C-1 and C-2 for further detail.) The injured are those who received some type of treatment at hospitals or health centers and thus could be counted by local officials. Although the definition of injury varies in the two countries, the health systems appear to be equal. Therefore one can compare their human casualty ratios.

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estimated to be 0.4-1.8% and the lethality risk about 1-2%. Of those killed in Nepal, 55% were men and 45% women. This gender ratio appears to be stable in the various regions.

The present population is about 2.2 times that of the 1930s in Bihar and about 2.7 times that in Nepal. We need to examine the return period for such great earthquakes because, should one occur again, the amount of damage done would be even greater. The standard of medical care, the information networks, and the transportation systems have all been improved; but, the workmanship seen in the construction of ordinary dwellings and their seismic strengths do not seem to have changed significantly. If there is to be improved disaster prevention in Nepal and India, records of the experienced earthquake intensity and damage distribution must be retrieved. This is feasible because at present one can still find and interview many people who lived through the great disaster of 1934.

4.2.2 The 1980 earthquake in far western Nepal

An earthquake of magnitude 6.5, similar in magnitude to the 1988 earthquake, occurred in far western Nepal in 1980 [Ref.4.6]. Its epicenter, determined by the University of Colorado, U.S.A., was at long. 81.3 E, lat. 29.3 N near Bajhang. It took place at 14:45 hours GMT, 20:30 hours local time. This earthquake killed 178 people and destroyed 40,000 houses in the districts of Darchula and Bajhang where the estimated maximum intensity was 8 (MM Scale). Table 4.3 gives the available damage statistics, but the data on the number of dead and wounded apparently is not complete. The highest damage ratio for houses is that for Bajhang (71%), and includes minor cracks. The second highest is for Darchula (46%) and does not include minor cracks. These maximum ratios are comparable to the figures for the 1988 earthquake. The area severely damaged in 1980, however, was smaller than that damaged in 1988, probably because of the shallower focal depth (18km) of the 1980 earthquake.

There being less human loss in 1980 (25% of the 1988 earthquake) in spite of the similar magnitudes is explained by the following factors:

1. A foreshock felt at 18:04 hours local time, 2.5 hours prior to the main event, warned people and kept them awake.

2. The 37 persons/km² population density of Darchula and Bajhang districts is far less than the 200 persons/km² of the Sunsari, Dhanakuta and Tehrathum districts of the Eastern Development Region (most severely hit in 1988).

---

### Table 4.4 Fatality distribution by age and sex, and the census population of Nepal

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Male Fatal</th>
<th>Male Fatal %</th>
<th>Male Pop. %</th>
<th>Female Fatal</th>
<th>Female Fatal %</th>
<th>Female Pop. %</th>
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<tr>
<td>0-4</td>
<td>56</td>
<td>18.0</td>
<td>15.5</td>
<td>25</td>
<td>11.9</td>
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<td>25.5</td>
<td>14.5</td>
<td>48</td>
<td>22.9</td>
<td>14.6</td>
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<tr>
<td>10-14</td>
<td>32</td>
<td>16.0</td>
<td>11.9</td>
<td>23</td>
<td>11.0</td>
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<td>8.3</td>
<td>19</td>
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<td>25-29</td>
<td>9</td>
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<td>7.4</td>
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<td>12</td>
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<td>6.8-0.9</td>
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<td>35-39</td>
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<td>1.0</td>
<td>6.0</td>
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<td>4.8</td>
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<td>2.9</td>
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<td>1.3</td>
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<td>1.2-3.2</td>
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<td>3.5</td>
<td>7</td>
<td>3.3</td>
<td>0.9-3.7</td>
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<td>-</td>
<td>-</td>
<td>121</td>
<td>-</td>
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<tr>
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<td>297</td>
<td>-</td>
<td>-</td>
<td>331</td>
<td>-</td>
<td>-</td>
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</table>
### 4.3 Factors Related to Human Loss

#### 4.3.1 Age and gender

At 04:54 hours Nepalese local time when the 1988 earthquake struck, most people were home sleeping, except for a few villagers in remote hill areas. Of the 114 respondents to the intensity questionnaire (reproduced in Section 2.4) 95% answered that they were indoors, and 5% outdoors. Only 3% answered that they were awake. This means that the initial conditions; i.e. the location of people and what they were doing was basically the same regardless of age or sex.

Form August 25 to 29 the newspaper Rising Nepal listed the names, ages and gender of 628 earthquake victims, who accounted for 87% of the total fatalities in Nepal (*Table 4.4*). The 52.7% for female fatalities is slightly higher than the value for males. Dividing these values by the percentages in the Population Census of 1981 [Ref.4.7], gives a risk that is about 15% higher for females than for males.

The age distribution in *Fig. 4.4* indicates that more than half of those killed were children under age 14. The fatality percentage divided by the population percentage (*Fig. 4.5*) gives the life-threatening indices. The higher risks seen for children and for the elderly among the adults agree with findings of other earthquake studies [Ref.4.8]. A comparison of the gender patterns shows a higher risk for male children, but a lower risk for males 30-39 years of age and those 60 and older. Because women of ages for motherhood have heavy family duties they may spend more time protecting children and therefore not be able to escape from collapsing houses. Also, elderly women may be physically weaker than males of the same age because of hard work during their youth and therefore have less chance of escape.

#### 4.3.2 Lethality of dwelling collapse

Ordinary dwellings in Nepal (discussed in Section 3.1) are mostly 2-story brick, stone or adobe masonry buildings cemented with weak mud mortar and having framed roofs. Timber frame dwellings located near destroyed masonry buildings showed only slight damage. Assuming that a fatality occurs only in a collapsed house, the lethality index, $L$, is given by

$$L = \frac{F}{C \cdot S}$$

in which $F$ denotes the number of fatalities, $C$ the number of collapsed houses, and $S$ the average size of a household.
the average size of a household (≈ 6). This equation represents the risk of an occupant of a collapsed house being killed, which we have called the lethality of dwelling collapse [Ref.4.9]. District indices for Nepal are plotted against the percentages of damaged houses in Fig. 4.6. The high lethality in Saptar (SPT) district is exceptional because of the small number of fatalities (13) and small amount of damage to dwellings (12). The high lethality (5%) in Sunsari (SNS) district, where 132 people died and 447 houses were destroyed, may be because many 2- and 3-story houses of brick masonry cemented with mud mortar were destroyed in the town of Dharan. Except for these two districts, the lethality index is fairly constant and unrelated to the ratio of damaged houses. The average for 15 districts, excepting Saptari, is 1.0%, and the standard deviation 1.3%.

In the town of Dharan there were 122 dead and 1,671 "completely damaged" houses. This latter figure does not agree with the district statistics given previously; that is, the "complete damage" for the town is about 4-fold the number of "destroyed" houses reported for the district. Therefore "complete" damage in Dharan seems to be a broadly defined term that includes unrepairable damage.

The lethality index also can be calculated from the ward-by-ward damage statistics for Dharan Bazaar that give the number of deaths, completely damaged houses, partially damaged houses and monetary loss (Table 3.2; Section 3.5). Because the number of houses and population per ward is not available, complete damage/(complete+partial) must be used as the damage severity index. On the assumption that all fatalities occurred in collapsed houses, Fig. 4.7 shows the relation of lethality to damage severity. We made an on-site damage survey along the two main streets running through wards 1, 2, 3, 4, and 5 (Fig. 3.4, map of Dharan; Section 3.5) which were the most badly damaged areas in the town. The data for wards 5 and 11 are suspicious because although most of the damage was "complete", only one fatality was counted. Data for ward 14 also are peculiar and questionable because monetary loss was moderate even though the amount of "complete" damage was the highest among the 19 wards. Excluding wards 5, 11, and 14, the relation is almost linear between Complete/Damage and Deaths/Complete Damage. The equation is

\[ L = F/(C \cdot D) \]

in which \( D \) denotes the total of completely and partially damaged houses. The correlation coefficient is 0.719. This linear relation indicates that

1. in the old central wards where 2- and 3-story brick and mud dwellings are the rule, building damage and loss of life were severe; whereas, in the peripheral, newly developed wards in which timber frame dwellings are common, damage was moderate.

Fig. 4.7 Relation of the lethality index to the dwelling damage severity index in Dharan Town Panchyat, Nepal

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Fig. 4.8 Relation of lethality to building type [Ref.4.9]
Sunseri and other Nepal districts are from the 1988 Earthquake, and Munger and K. V. (Kathmandu Valley) from the 1934 Earthquake
Other possibilities are that

2. even in this small town, the input motion (seismic intensity) differed according to local soil conditions. The degree of dwelling damage categorized as complete became greater with increasing input motion and constituted a greater threat to life.

3. the type of serious damage done to dwellings blocked evacuation routes to streets and backyards, thereby increasing the risk of injury or death and debris from collapsed houses created hazards in outside areas. The high population density in this town is responsible for this situation.

The lethality index ranges from 0 to 3%, the average being 1.5%. Taking into account that “complete” damage in this town is a very broad term, the index is actually about 5%.

Fig. 4.8 compares this value with estimations for other building types [Ref. 4.9]. The value for Sunsari (5%) is much lower than values for Turkey and China, but approximates the value for stone masonry buildings in the 1980 Italian earthquake. The estimates for Munger and the Kathmandu Valley (K.V.) in the 1934 earthquake fit the same line. Other Nepalese districts show 2% lethality, a value comparable to that for wood frame dwellings in Japan. Needless to say, the number of fatalities depends not only on the lethality index, but on the dwelling collapse ratio at a given seismic intensity as well.

The percent of damaged houses (average household members assumed to be 6) and the percent of casualties (death + injury) for 16 districts in Nepal and 13 districts in Bihar are plotted in Fig. 4.9. The linear relations are

\[ P_c = 0.0076 P_d + 0.047 \]  \hspace{1cm} (4-4)

\[ R = 0.609 \text{ and St. error } = 0.19 \] for Nepal, and

\[ P_c = 0.0032 P_d + 0.006 \]  \hspace{1cm} (4-5)

\[ R = 0.888 \text{ and St. error } = 0.008 \] for Bihar

in which \( P_c \) is the percent of casualties and \( P_d \) the percent of damaged dwellings.

The Nepal equation which applies to 0 to 50% damage gives a larger number of casualties than the Bihar equation which applies to 0 to 20% damage. A log-linear equation would better explain the relation between the two types of damage. The casualty ratio seems smaller than expected, probably because the count includes such moderate damage as cracked walls; whereas, the injuries counted were those serious enough to require medical treatment. The ratio of the injured to the dead ranges from 3 to 58, average 17.