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

Research Report on Natural Disasters,
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Natural Disaster Science

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1. INTRODUCTION

The Trans-Himalaya Range formed by the collision of the Eurasian and Indian Plates is still being effected by the movement of these plates. Many earthquakes have occurred along the Indus-Tsangpo Suture (ITS) Zone and in its southern area. The earthquake (1988 Nepal-India Earthquake) we investigated took place in the Nepal-India border region at latitude 26.755°N, longitude 86.616°E in the early morning (4:39 Indian; 4:54 Nepalese time) of 21 August 1988 (23:09:10.3, 20 August Greenwich time). This earthquake experienced in the southeastern zone of Nepal close to the border of the State of Bihar, India registered 6.6 on the Richter Scale according to the U.S. Geological Survey. Its focal depth was assumed to be 57 km [Ref.1.1].

In Bihar State, 282 persons died and 3766 were injured. In Nepal, 721 persons died and more than 5000 were injured. As it was a near field earthquake, the methods used to construct residential buildings may account for the many deaths even though the earthquake was not particularly destructive. One hundred fifty thousand houses in Bihar State and one hundred thousand in Nepal collapsed partially or completely. Most of the damaged houses had been constructed of stone cemented with mud mortar, or of unburnt or burnt brick masonry.

Our research group was sent by the Ministry of Education, Science and Culture of Japan to survey the damage done by this earthquake. We left Japan on 2 October 1988 and stayed in India from 3 to 7 October, at Roorkee, New Delhi and in the damaged areas of Patna and Darbhanga in Bihar State. We then continued on to Nepal where we stayed from 7 to 13 October and visited the Kathmandu, Bhaktapur, Morang, Sunsari and Dhankuta districts.

An outline map of the area surveyed is given in *Fig.* 1.1. The symbol * marks the epicenter of the earthquake near Udayapur, Sagarmatha Zone about 150km southeast of the Nepalese capital of Kathmandu. Three other groups also surveyed the area concerned; one each from the University of Roorkee, the Asian Institute of Technology, and the United States Geological Survey.

1.1 General Description of the Damage Done by the Earthquake

As the magnitude of this earthquake was less than 7 on the Richter scale, most damage took place in areas around the reported epicentral region in the northern part of Bihar State, India close to the border with Nepal and in the southeastern zone of Nepal along the Himalaya Mountains close to the border with India. Damage to the structural systems of buildings was limited to nonengineered types of rural housing constructed of clay bricks

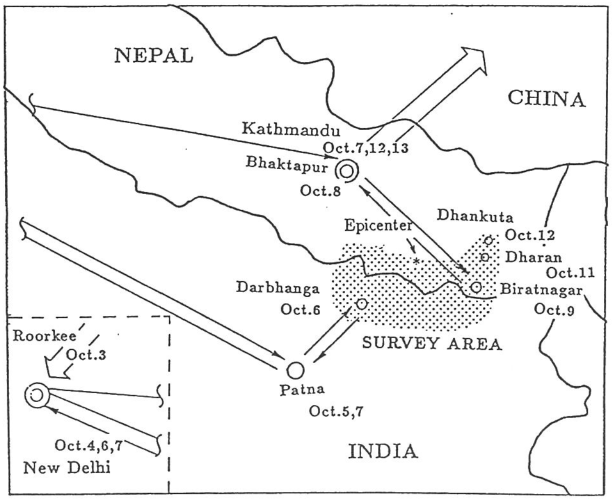


Fig. 1.1 Outline map of the survey area

Photo. 1.1 Typical rural houses in Nepal (a) Mud-stone house in the Kathmandu Valley

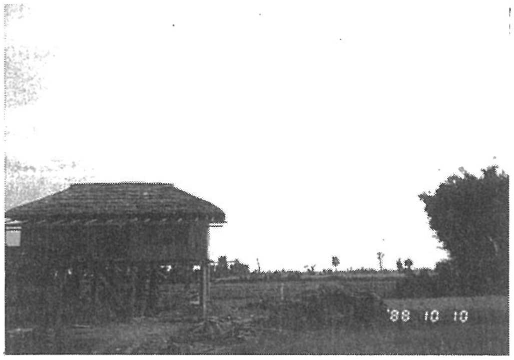


Photo. 1.1 Typical rural houses in Nepal (b) Wooden house in Biratnagar

Photo. 1.2 A survey team member interviewing inhabitants near Udayapur

or of stones cemented with mud mortar, the seismic qualities of which are judged to be poor. The number of engineered buildings is very limited in these areas, but we found no major structural damage done to engineered buildings made of reinforced concrete with or without filled-in brick masonry walls.

(a) Damage in Bihar State, India

Bihar State, located along the Ganges River is adjacent to the states of West Bengal, Orissa, Madhya Pradesh and Uttar Pradesh and the border with Nepal. Its total area is about 174,000 km^2, and its population approximately 70,000,000 (about 10 percent of the total Indian population) according to the census of 1981. Bihar is divided into 39 administrative districts. It is one of India's least developed states.

The nearly complete damage statistics provided by the Relief Commissioner, Government of Bihar show that 282 persons were killed, 3,766 injured and 149,334 houses damaged (Appendix B). The most severely damaged districts were Darbhanga, Madhubhani and Saharsa close to the border with Nepal, and Munger on the Ganges riverbed. No damage was reported in any of the other states of India.

There was no available estimate of economic loss of property for this earthquake, but a total of 5.4 million in Indian Rupees, equivalent to about U.S. $0.4 million was paid out by the State Government and the Relief Fund.

(b) Damage in the southeastern region of Nepal

Nepal has an area of approximately 141,000km^2 and a population of about 16,000,000. The country is divided into five regions; the Far Western, Mid-western, Western, Central and Eastern Regions. These regions are comprised of 14 zones that are subdivided into 75 administrative districts.

Damage was concentrated in the Eastern Region. According to data received from Ms. S. Malla, Chief Engineer of the Building Section of the Nepalese Government and Dr. S. P. Gupta [Ref.1.2], the number of deaths was 721, serious injuries 2450 and slight injuries 4879. Collapsed houses totaled 53816, and the number of buildings damaged 52357. We have summarized the damage statistics based on the above-information and the casualty figures given in the newspaper Rising Nepal of August 27, 1988 (Appendix C). Casualty data alone show that most seismic damage took place in the Eastern Region and a few districts in the Kathmandu Valley in the Central Region. The major damage seems to have been concentrated within districts of the Mechi(Panchthar, Ilam), Kosi(Dhankuta, Tehrathum, Bajhpur, Sunsari), and Sagarmatha (Udayapur, Khotang) Zones.

Signs of liquefaction were present in many places along branches of the Ganges River in Nepal and of landslides along the Dhankuta-Dharan-Jogbani road in the mountain area.

1.2 Background of the Construction of Rural Housing

According to J. M. Boch-Isaacson [Ref.1.3], traditional architectural design in the Himalaya area is categorized by three topographic/climatic belts; the tropical Terai, the subtropical/temperate hills, and mountain areas. In the Terai, at Biratnagar, Darbhanga and elsewhere, structures must protect humans from the heat and from the heavy rainfall of the tropical monsoonal climate. Wooden houses with thatched roofs, or wood and stone houses have been the most common and inexpensive forms of housing until recently. Balconies and verandas are added to provide comfortable places to sit, work, and sleep. Some houses have been built on wooden pilings to elevate them above the damp and to keep out snakes and other unwelcome guests. The prosperous build their homes of brick roofed with thatch. Floors in the Terai buildings are made of layers of dry hay and clay and are springy, soft and dry.

More than fifty percent of the inhabitants of Nepal live in the hill area. The hill houses in Dhankuta and elsewhere must protect their inhabitants from a wide range of weather conditions (rainfall, snow, wind, etc.). Stone is therefore the most common building material, although in some areas large unfired bricks are used. Roofs are covered with heavy clay-mud slabs and require a substantial timber under structure to support the weight. Random rubble masonry composed of rough stones is very common, the stone-bearing walls sometimes being half a meter thick. Houses seldom are more than two stories high and have verandas. Mud is moulded in wooden floor/ceiling frames to form an unfired layer that is as thick as the walls in the mountain areas. These stone, unfired brick, and brick masonry houses are now being replaced by wooden ones because of the cheaper cost and ease of construction. Typical rural houses seen in Nepal are shown in *Photo.* 1.1.

1.3 Summary of the Survey Report

This research report consists of three sections:

1) Seismic activity and the intensity of the ground motion

After the discussion of the tectonics in the vicinity of the Himalaya Range and the history of earthquakes in India and Nepal, we give an estimation of the fault zone of this earthquake made from post-earthquake records obtained from the Department of Mines and Geology of Nepal and from our survey of actual geological conditions. The intensity of ground motion near the epicentral area also is discussed in terms of assumed fault parameters and the geological condition of the surface layer.

We prepared a questionnaire that asked inhabitants how their houses responded to the earthquake shock. More than one hundred answers were obtained in the stricken areas of India and Nepal. A team member is shown in *Photo.* 1.2 interviewing inhabitants near Udayapur, the epicenter of this earthquake. The intensity distribution estimated from their information has been compared with the distribution derived from seismographic data. In addition, based on results of laboratory tests done on sand specimens collected from riversides where liquefaction occurred during the earthquake, we could estimate the maximum acceleration near the epicenter.

2) Structural damage

Most of the houses in Bihar State, India and in Nepal are built of brick masonry or mud-stone. The typical types of damage done to these structures are shown and the causes discussed in terms of the structural materials used. The strengths of the brick masonry, reinforced concrete, concrete block and mud-stone buildings in the effected areas were estimated and compared with the actual damage seen. Little damage was done to structures such as bridges or to water and electricity lifelines. To determine the distribution of the various types of buildings, we surveyed five hundred houses in Dharan Panchayat, Sunsari district, one of the most severely damaged areas in eastern Nepal. Results show that most two- and three-story structures built of brick masonry collapsed; whereas, few of the wooden houses were severely damaged. On the basis of our survey and the analytical results obtained we present recommendations for the anti-seismic designs of non-engineered structures.

3) Human loss and emergency responses

Regional distributions of casualties are presented and compared with those for previous earthquakes. Factors related to human loss, such as age distribution, damage to homes, and the intensity distribution are discussed. The relation of the death ratio to the building damage ratio also is compared. Relief Commissions were established in both India and Nepal after the 1988 Earthquake; their activities and the work done by some hospitals are reported. Measures for emergency rescue at the hospitals as well as the injury pattern were surveyed in detail. The Rising Nepal and Hindustan Times, influential English language newspapers in Nepal and in India carried reports on the earthquake and its aftermath.

We report the trends in the quantity and quality of earthquake-related articles published. Relief funding, and the distribution of materials are summarized in Appendices B and C.

In summation, we have proposed recommendations for the mitigation of earthquake disasters in the areas surveyed. Appendix D lists all the reference materials.

Section References

[1.1] Preliminary Determination of Epicenters, Monthly Listing, U.S. Department of the Interior/Geological Survey, National Earthquake Information Center, August 1988.

[1.2] Gupta, S. P. : Report on Eastern Nepal earthquake, 21 August 1988 — Damage and Recommendations for Repairs and Reconstruction, Asian Disaster Preparedness Center, Asian Institute of Technology, Bangkok, Thailand, 1988.

[1.3] Boch-Isaacson, J. M. : Architecture & Construction Management in the Highland and Remote Areas of Nepal, Sahayogi Press, Kathmandu, Nepal, 1987.

2. SEISMIC ACTIVITY AND THE INTENSITY OF GROUND MOTION

2.1 History of the Himalaya Formation

Tectonic activity in Asia often is cited as the consequence of the current continental collision of India and Eurasia. Historical changes in the formation of the Himalaya Range are shown in *Fig.* 2.1. [Ref.2.1]. During the Jurassic to early Cretaceous Period, the Tethys Sea separated Eurasia and India. In the late Cretaceous Period, the two plates started to collide and the Tethys Sea became narrow and shallow. Today a trace of that sea can be seen at the Indus-Tsangpo Suture (ITS) and in the Himalaya Range, the upheaval of which has been accompanied by the formation of many faults including the Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT). The MCT is regarded as having been more active in the early phase, the MBT assuming the role of an active thrusting and convergence zone later. A typical bird's-eye view of the Himalaya region is shown in *Fig.* 2.2.

Continental reconstructions show there has been a steady convergence of India and Eurasia since the late Cretaceous, but also suggest that their collision rate after the Eocene has decreased by one half (*Figs.* 2.3 and 2.4)[Ref.2.2]. Nevertheless, at least 1500 kilometers of crustal shortening must have been caused by deformation solely within the continental lithosphere. Seismic data, including the spatial distribution of earthquakes, associated fault plane solutions, and surface deformation, as well as geologic evidence of recent tectonic activity reported in the literature and seen on Earth Resources Technology Satellite (ERTS) photographs, indicate that deformation covers a broad zone that extends as far as 3000km northeast of the Himalayas.

Geologic, seismic, and gravity data show a northward underthrusting of the Indian subcontinent beneath the Himalayas. Although the Himalayas are composed of slivers of the ancient Indian subcontinent and there no longer is active subduction in the Indus suture zone, several aspects of the underthrusting of India beneath the Himalayas are similar to the subduction of the oceanic lithosphere at island arcs. Unlike the island arcs, where the length of the deep seismic zone gives a measure of the rate of subduction, no intermediate or deep earthquakes have been reliably located in the Himalayas [Ref.2.2].

2.2 Geology and Tectonics

The Himalaya orogeny, extending more than 2500km from Kashmir in the northwest to Arunachal in the northeast of India and having a width of 200 ~ 300 km, is characterized by four physiographic provinces; the Tibetan Sedimentary Zone, the Central Crystalline

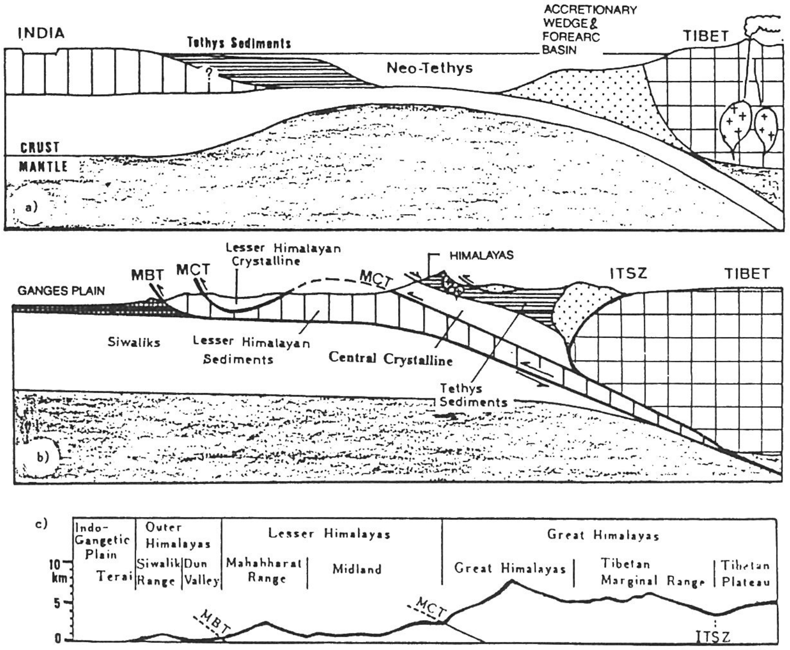


Fig. 2.1 Historical changes in the formation of the Himalaya Range [Ref.2.1]

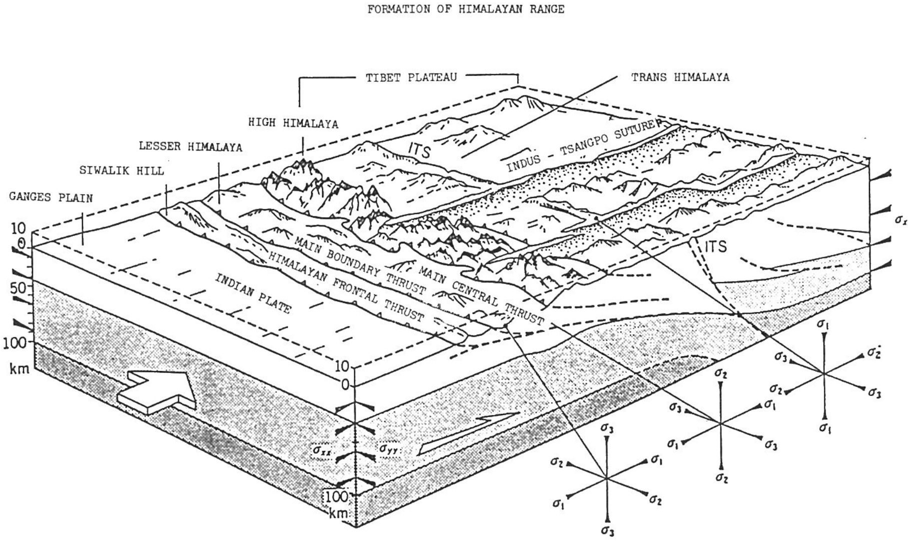
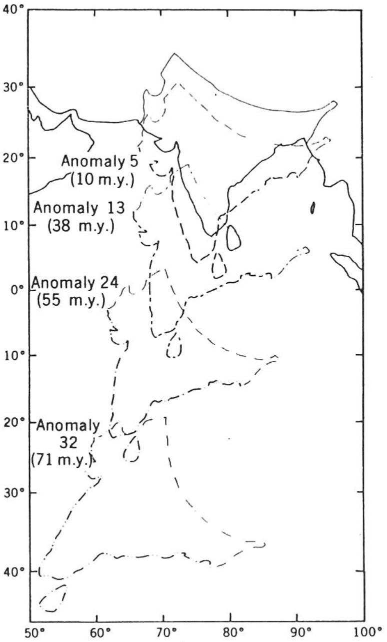


Fig. 2.2 Bird's-eye view of a section of the Himalaya Range [Ref.2.1]



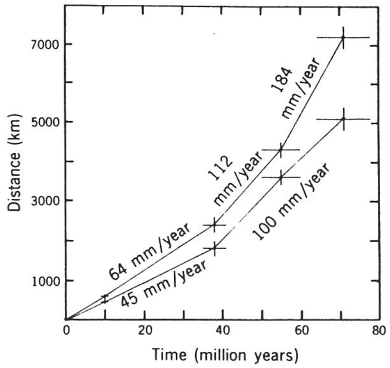
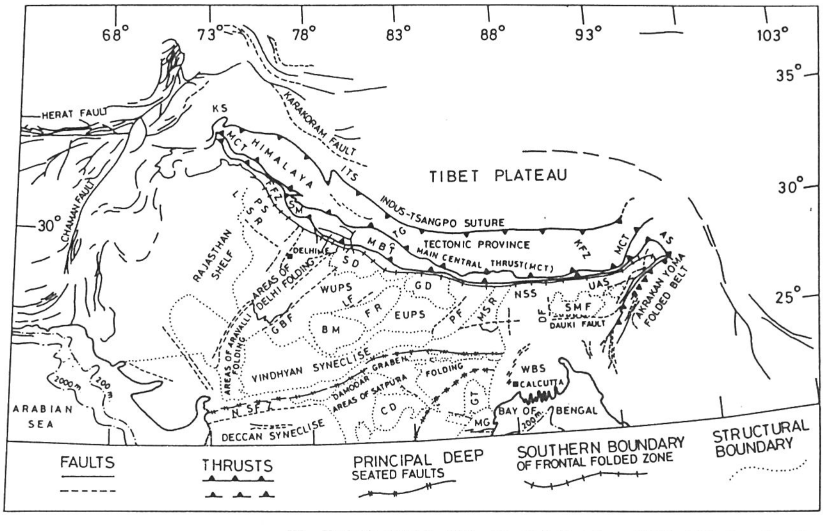


Fig. 2.4 Distance of the northeast and northwest tips of India from their present positions as a function of time [Ref.2.2]

Fig. 2.3 Position of India with respect to Eurasia during different periods [Ref.2.2]



KS—Kashmir syntaxis, *FFZ*—Frontal Folded Zone, *MBT*—Main Boundary Thrust, *MCT*—Main Central Thrust, *IST*—Indus Suture Thrust, *TG*—Takhola Graben, *KFZ*—Kangto Fracture Zone, *AS*—Assam Syntaxis, *PS*—Punjab Shelf, *SM*—Simla, *SD*—Sarda Depression, *GD*—Gandak Depression, *PF*—Patna Fault, *MSR*—Monghyr Saharsa Ridge, *NSS*—Northern Shillong Shelf, *UAS*—Upper Assam Shelf, *SMF*—Shillong Massif, *DF*—Dhubri Fault, *EUPS*—East Uttar Pradesh Shelf, *FR*—Faizabad Ridge, *WUPS*—West Uttar Pradesh Shelf, *BM*—Bundelkhand Massif; *GBF*--Great Boundary Fault, *NSFZ*—Narbada Son Fracture Zone, *CD*—Chattisgarh Depression, *GT*—granitoids, *MG*—Mahanadi Graben, *WBS*—West Bengal Shelf.

Fig. 2.5 Generalized tectonic map of the Himalaya area and adjoining regions [Ref.2.3]

Zone, the Lesser Himalayan Zone and the Siwalik Belt (*Fig.* 2.1). The southernmost unit, the Siwalik Belt (outer Himalaya), consists of folded and faulted Siwalik molasse sediments of Miocene age which form the low hills that rise in front of the plains of the Sindhu-Ganges basin. The lesser Himalaya is composed of a mountain belt having an average elevation of about 2000m and is made up of fossiliferous Riphean sediments overridden by several thrust sheets which have traveled from north to south in response to the geodynamic processes that gave birth to the Himalayas. The next province, the great Himalaya, is made up of crystalline rocks which form a tectonic slab. The highest mountain ranges are present in this province and have an average elevation of 6000m. Further to the north lies the Tethtyan Himalaya province with fossiliferous sediments ranging in age from late Precambrian to Cretaceous. This is bordered further north by an ophiolite and melange suite associated with the suture of India and Eurasia beyond which lies the Trans-Himalaya geological province. The main tectonic features of the Himalayas and adjoining regions are shown in *Fig.* 2.5.[Ref.2.3]

There is a gently dipping thrust [Ref.2.4] plane under the Sindhu-Ganges plains, the sub- and lesser Himalayas. This is the detachment surface, which coincides with the upper surface of the subducting Indian lithosphere, and great earthquakes occur along this thrust plain. The MBT and MCT, which dip steeply near the surface, flatten out at depth and merge with this detachment surface.

The Sindhu-Ganges plain is a frontal depression filled with sediments and alluvium. It is subdivided into sub-basins by NE-SW tending subsurface ridges and faults that extend northeastward from the Peninsular region in the south. This foredeep has its deepest sections in the Sarda and Gandak depressions which are separated by the Bundelkand Ridge. The deepest parts are at the northern edge near sub-Himalaya and are characterized by sedimentary strata about 8 $\sim$ 10km thick [Ref.2.5]. The Sarda depression is terminated on the west by the Delhi-Hardwar Ridge beyond which the Punjab shelf extends further westward. The sedimentary thickness in the Punjab shelf region is much less where the basement dips gently and reaches a depth of about 2km near the edge of the sub-Himalaya. The eastern margin of the Gandak depression is demarcated by the NE-tending Monghyr-Saharsa Ridge. Further eastward the Shillong Massif interrupts the continuity of the foredeep.

The syntaxial bends in the Himalaya tectonic zone on the western and eastern extremities are areas of complex tectonics. General geological outlines of India and Nepal are shown in *Figs.* 2.6 and 2.7 [Ref.2.6].

Seismic activities that have taken place in the Himalaya region since 1897 [Ref.2.3] are shown in *Fig.* 2.8. The year of occurrence is noted near the respective epicenter zones. Shaded areas in brackets denote large earthquakes and the number of lives lost in these earthquakes. The major intermediate focus earthquakes are shown by triangles, those of

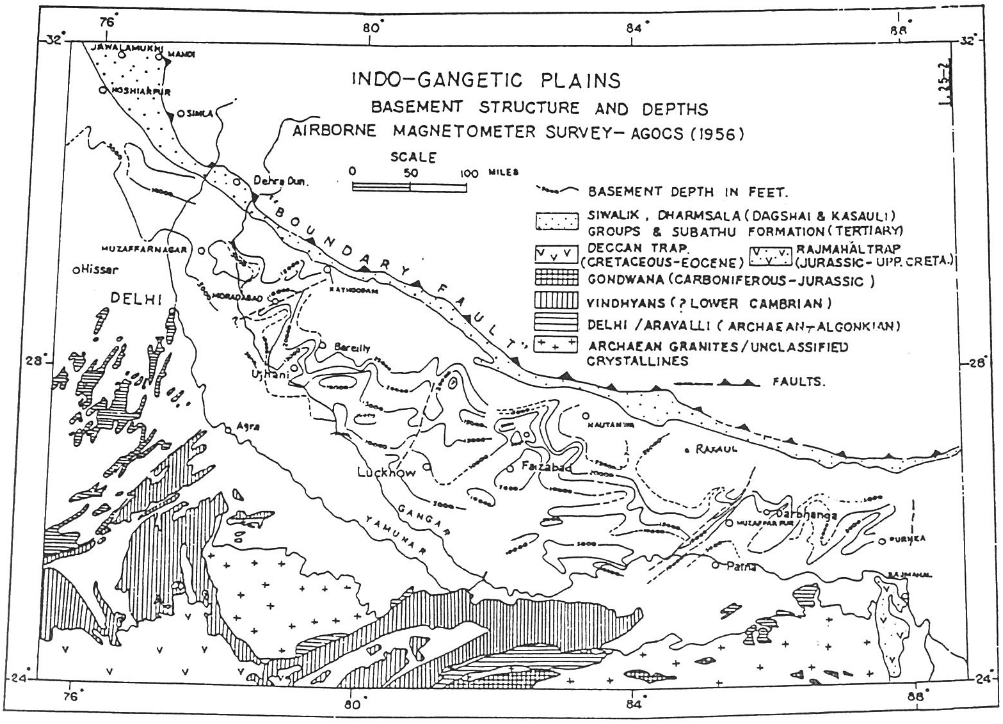


Fig. 2.6 Geological map of India

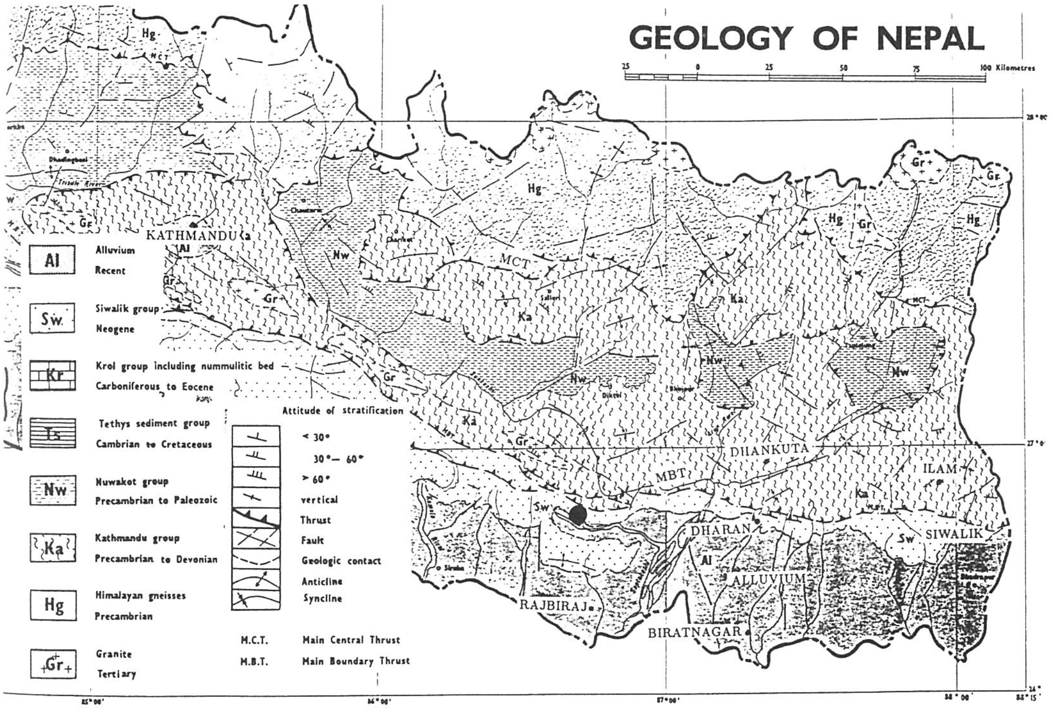


Fig. 2.7 Geological map of Nepal

smaller magnitude by dots. The thick lines with triangles denote the thrust systems in the Himalaya tectonic zones; (initials denote) KH-Kashimir Himalaya, GKH-Garhwal Kumaon Himalaya, EH-Eastern Himalaya, MCT-Main Central Thrust, MBT-Main Boundary Thrust, SGD-Sindhu Ganges Depression, and ND-New Delhi.

2.3 Theoretical Estimation of the Intensity of Ground Motion

Because of the lack of strong motion records near the epicentral region of the 1988 Nepal-India Earthquake, the maximum intensity of the ground motion has been estimated theoretically. The simplest way to estimate maximum ground motion is to use an attenuation law which includes the tectonic characteristics and local geological conditions of the region. As there is no appropriate attenuation law applicable to the region, we first estimated the peak acceleration at the bed rock level then used the amplification factor of the surface ground and the damping effect of the traveling path. Results show that the contour of the estimated peak accelerations obtained by considering the amplification and damping effect is in good agreement with the peak accelerations estimated from the questionnaire data.

A multi-variable regression analysis that includes the magnitude of the earthquake, the epicentral distance, and the parameter that expresses the site condition was made in order to investigate the attenuation of peak ground motions. Many regression equations (attenuation laws) have been proposed [Refs.2.7,2.8], but the regression curve is affected by the characteristics of the data base used. Although the numbers of observed earthquakes are increasing, consistent data that show homogeneous distributions of the epicentral distance and magnitude are rare, especially over a short distance and for a large magnitude. Estimates of peak acceleration from these attenuation laws, therefore, are unrealistic in the region near the source because the epicentral distance is not an adequate parameter by which to express the distance between the source region and the site.

To avoid this defect, we have developed a simplified analytical procedure with which to estimate the attenuation of peak ground motion that takes into account the fault extent. Peak acceleration near the fault region is expressed as a function of the fault parameters and the relative collocation between the fault and the observation site [Ref.2.9].

To account for the fault extent, a large event must be synthesized from small events that occur in part of the fault plane. A method first was proposed by Harzell [Ref.2.10] that used a relatively simple formula; improvements to his method have been made [Refs.2.11,2.12]. We have used Irikura's revised model [Ref.2.13] which is based on the idea that slips occurring on the fault plane during a large event can be replaced by the spatial distribution of slips that take place during small events. Therefore, high frequency components can be

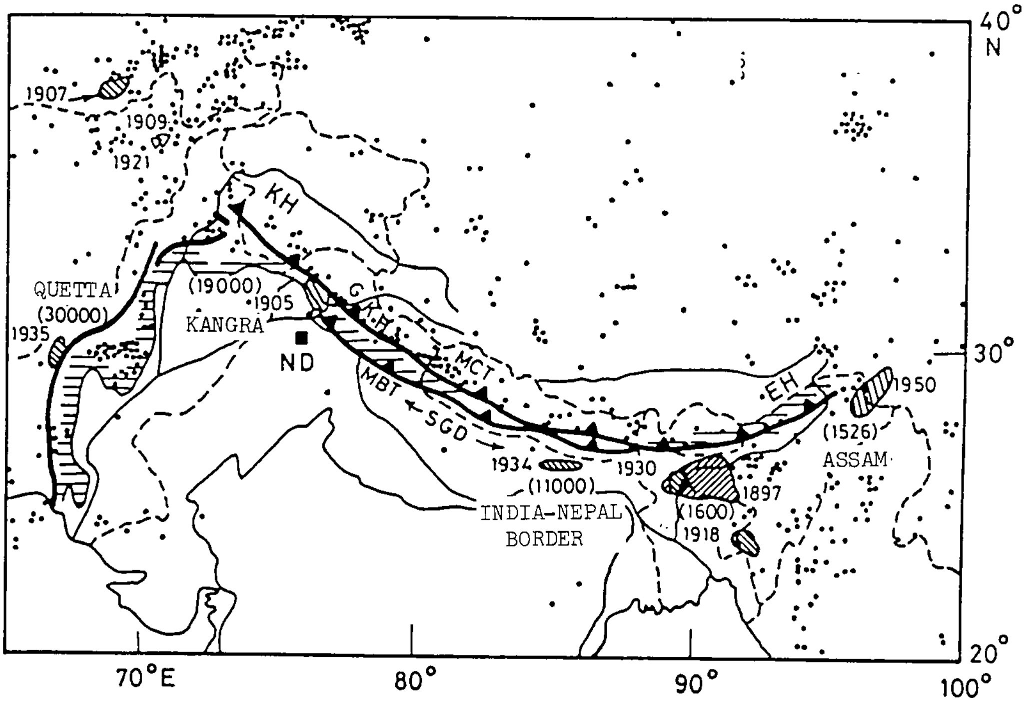


Fig. 2.8 Meizoseismal areas of great earthquakes in the Himalaya region since 1897 [Ref.2.3]

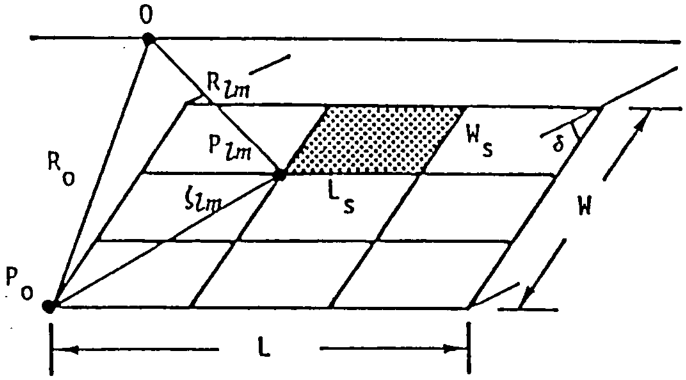


Fig. 2.9 Fault model

generated adequately.

The equation of superposition is transformed into a frequency domain to obtain the power spectrum of the large event. The expectation of peak ground motion thus can be evaluated in terms of the three spectral moments.

As a wave propagates through soil, its amplitude attenuates because of inertial friction. This effect is expressed by the dimensionless quantity Q which, in general, depends on the frequency. Many equations have been proposed to express the frequency dependence of the Q-values in Japan [Refs.2.14,2.15]. Iwata and Irikura [Ref.2.16] obtained the Q-value of the shear wave from the 1983 Nihonkai-Chubu Earthquake by using an inversion method.

The effect of the site also is important when predicting surface ground motion. Having assumed seismic bed rock for which the shear wave velocity is about 3km/sec, we then needed the amplification factor between the deep bed rock and ground surface. Midorikawa et al. [Ref.2.17] defined the relation between geological conditions and the amplification factor for the value of peak acceleration of deep seismic bed rock. We also have taken into account the damping effect of the propagation path and the amplification effect of the surface ground in order to obtain a realistic peak acceleration.

2.3.1 Method for predicting peak acceleration

A fault mode of the Haskell type has been assumed in this analysis. The model is described by a rectangular fault with five factors: the fault length, L; the fault width, W; the rise time, τ ; the final offset of dislocation, D; and the rupture velocity, v_r. Assuming small events caused by the dislocation of small parts on the fault, we can synthesize a large event by superposing these small events taking into account the time delay caused by the rupture propagation. *Fig.* 2.9 shows the fault model. The fault plane is divided into n elements, each of which corresponds to the area of a small event.

In Irikura's revised model [Ref.2.13], the motion of a large event $g_L(t)$ at observation point O is expressed by the motion of a small event $g_s(t)$ as

$$g_L(t) = \sum_{l=1}^{N_L N_D} \sum_{m=1}^{N_W} g_{slm}(t - t_{lm}) \qquad (2-1)$$

in which N_L ,N_W and N_D are the number of subdivisions that correspond to fault length, fault width and dislocation. We assume the relation $N_L = N_W = N_D = n = \sqrt[3]{M_{0L}/M_{0S}}$, in which Mo_L and Mo_S are seismic moments for the large and small events. t_{lm} is the time delay related to the wave propagation.

Earthquake motion due to a small event and its Fourier transform can be written

$$g_S(t) = \frac{R_{\theta\phi}}{4\pi\rho v_s^3} \cdot \frac{S(t)}{R_{lm}} \qquad (2-2)$$

$$G_S(f) = \frac{R_{\theta\phi}}{4\pi\rho v_s^3} \cdot \frac{S(f)}{R_{lm}} \qquad (2-3)$$

in which $R_{\theta\phi}$ is the radiation pattern, ρ the density of the medium, $S(t)$ the source time function and $S(f)$ the source spectrum. Multiplying the Fourier transform of $Eq.(2-1)$ by the conjugate of $G(f)$, we can express the power spectrum of the earthquake motion of a large event as

$$P_L(f) = \frac{2}{T}\left(\frac{R_{\theta\phi}}{4\pi\rho v_s^3}\right)^2 S(f)S^*(f)\left(\sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{-i2\pi f t_{lm}}/R_{lm}\right)\left(\sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{i2\pi f t_{lm}}/R_{lm}\right) \quad (2-4)$$

in which T is the duration of the stationary part of the ground motion and $*$ indicates the conjugate complex.

Once the power spectrum of the large event is given, the expectation of the peak ground motion, A_{max}, can be established from Kiureghian's formula [Ref.2.18]

$$A_{max} = p\sqrt{\lambda_0}, \qquad p = f(T, \nu_e, \lambda_0, \lambda_1, \lambda_2) \qquad (2-5)$$

in which p is the peak coefficient and λ_i $(i = 0, 1, 2)$ the spectrum moments of zero and of the first and second orders, and ν_e is the reduced ratio of the zero-crossing.

$Eq.(2-4)$ can be easily extended to multiple fault rupture mechanisms. If the fault is composed of two fault planes and the time delay due to rupture propagation from one to another fault is assumed to be t_0 , the power spectrum of the multiple fault is

$$P_L(f) = \frac{2}{T}\left(\frac{R_{\theta\phi}}{4\pi\rho v_s^3}\right)^2 (S_1(f)S_1^*(f)XX^* + S_1(f)S_2^*(f)XY^*$$
$$+S_2(f)S_1^*(f)YX^* + S_2(f)S_2^*(f)YY^*) \qquad (2-6)$$

in which

$$X = \sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{-i2\pi f t_{lm}}/R_{lm}, \qquad Y = \sum_{l=1}^{n^2}\sum_{m=1}^{n} e^{i2\pi f (t_{lm}+t_0)}/R_{lm}$$

The expectation of peak acceleration can be obtained from $Eq.(2-5)$

Attenuation of the peak acceleration is effected strongly by the rupture process and the direction of the observation site. For a single fault plane we can calculate the expectation of peak accelerations using $Eqs.(2-4)$ and $(2-5)$. The values of each parameter; starting point of rupture, dip angle and direction of the observation point, are given in *Fig.* 2.10

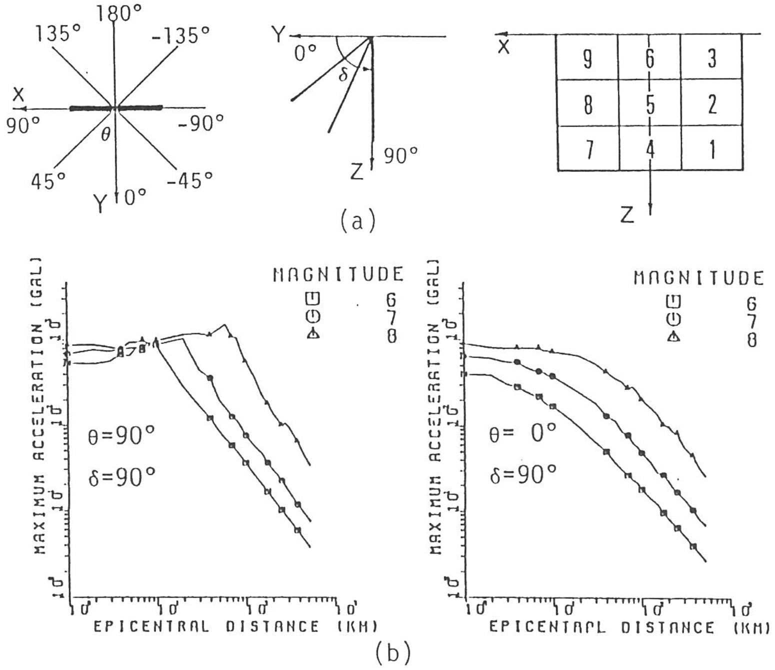


Fig. 2.10 Classification of parameters and attenuation of peak acceleration for magnitudes 6, 7 and 8 (Starting point of rupture: element 1)

Table 2.1 Fault parameters of the 1988 Nepal-India Earthquake

	strike(°)	dip(°)	slip(°)
P-wave	221	36	14
	120	82	125
USGS	217	54	-10
	312	82	-144
HRV	230	23	2
	137	89	113

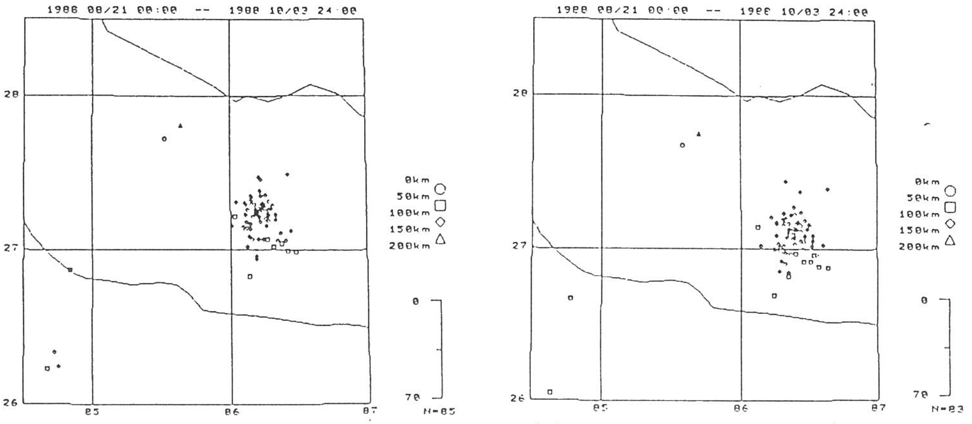
(*a*). The attenuations for magnitudes 6, 7 and 8 are shown in *Fig.* 2.10 (*b*) (dip angle $\delta = 90°$). In each section of the figure, peak acceleration has the upper bound. When the observation point is placed on the fault line ($\theta = 90°$), peak acceleration has a constant value for the range of distance that coincides with the length of the fault.

2.3.2 The source mechanism and intensity at.the base rock

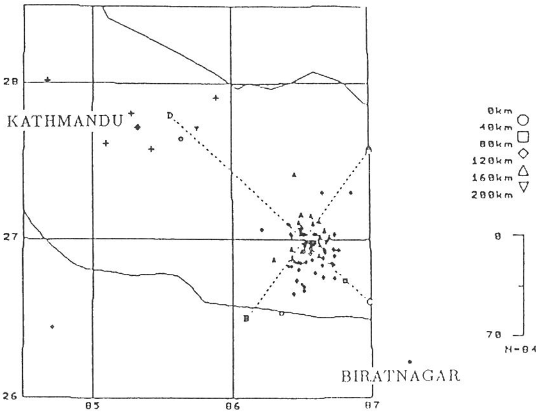
On the basis of the preliminary report of the U.S.G.S. [Ref.2.19] three source mechanisms have been proposed for the 1988 Nepal-India Earthquake (*Table* 2.1). In each model two planes (the fault plane and its auxiliary) are identified. To determine the actual fault plane we can use the distribution of the after shocks. We collected the P an S wave arrival times of 97 microearthquakes which were recorded at five stations after the main shock up to 3 October 1988 with the aid of Dr. M. R. Pandey, the Department of Mines and Geology of Nepal. *Fig.* 2.11 (*a*), (*b*), (*c*) shows the epicenter distribution of these 97 microearthquakes. The upper and lower curved lines represent the Nepalese borders between China and India. The positions of the observation stations are shown by the symbol +. We assumed P wave velocities of 6.0, 6.5 and 7.0 km/sec to derive figures (*a*), (*b*) and (*c*). Because the location of the main shock given in *Table* 2.1 supports a P wave velocity of 7.0 km/sec, the hypocentral depths of the microearthquakes projected in the A-B and C-D sections in *Fig.* 2.11 (*c*) are shown in *Fig.* 2.12 (*a*), (*b*). The distribution of the microearthquakes in the A-B section is relatively homogeneous; whereas, in the C-D section it is concentrated on the surface with a dip angle of 50 $\sim$ 60 degrees. This supports dislocation of the fault with a strike angle of 217 degrees and a dip angle of 54 degrees (U.S.G.S model). We assumed these values and a slip direction of 0 degrees in the following analyses.

The hypocenters of most microearthquakes are distributed from a depth of 80 to 125km. The large earthquakes that occur in this region are related to a north dipping detachment fault that constitutes the plate tectonic boundary between India and Asia (*Fig.* 2.1). According to the Seeber model [Ref.2.4], this detachment lies no more than 20 km below the region concerned. The accuracy of definition for the focal depth is not as good as for the main shock (57 km) because we used only data recorded at the five stations and the hypocenters of the microearthquakes were outside of this network. This suggests that the 1988 earthquake may have been unrelated to the detachment. Because the relative position of hypocenters can be obtained from microearthquakes with reliable accuracy, we selected the dip angle of 54 degrees.

The contours of the estimated peak accelerations during the 1988 Nepal-India Earthquake obtained by our method are shown in *Fig.* 2.13. The magnitude of the earthquake was 6.6. We assumed a seismic moment of 2.2×10^{26} dyne cm. Although the estimated

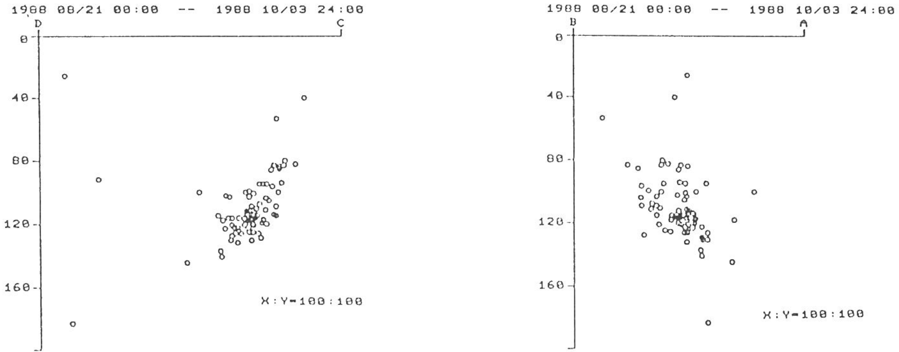


(a) P-wave velocity 6.0km/s (b) P-wave velocity 6.5km/s



(c) P-wave velocity 7.0km/s

Fig. 2.11 Epicenters of microearthquakes
in Nepal and India
from 21 August to 3 October, 1988



(a) CD section (b) AB section

Fig. 2.12 Distribution of microearthquake depth in Nepal and India
from 21 August to 3 October, 1988

values were at the base rock level, they could be modified by considering the amplification effect produced by the soft surface deposit and the damping effect of the propagation path.

2.3.3 Adoption of the path and site effects

PATH EFFECT In $Eqs.(2-4)$ and $(2-6)$, we consider only the radiation damping proportional to the reciprocal of the distance, $1/R$. However, we must take into account the damping produced by the inertial friction of the material, the Q-value, in order to approach the real phenomena. From the spatial decay of the propagating wave, the exponentially decaying equation of $G(x)$ is defined as follows [Ref.2.20]:

$$G'(f) = G(f)exp\left[\left\{-\frac{\pi f}{cQ}\right\}R_{lm}\right] \qquad (2-7)$$

in which $G(f)$ is the Fourier transform of earthquake motion as in $Eq.(2-3)$, c the wave propagation velocity, and Q the Q-value.

The frequency-dependent Q-values for the full logarithmic scale are given in *Fig.* 2.14 for the Japanese archipelago. The gradients are steep in the northern part and gentle in the southern part. The material characteristics of the lithosphere and the global tectonic condition along the Japanese archipelago may differ from those in the India-Nepal region. The Sindhu-Ganges depression, however, is assumed to be a replica of the trench systems associated with the front of the island arc systems at the subduction zones. We can approximate the Q-value for this region with the average line obtained for the straight lines in the figure. The equation is

$$\log Q^{-1} = -\log f - 2 \qquad (2-8)$$

The effect of inertial damping can be incorporated by substituting $Eq.(2-8)$ into $Eq.(2-7)$ and multiplying it by $G(f)$ of $Eq.(2-3)$.

SITE EFFECT The amplification effect of the surface ground also is needed to make an accurate prediction of the intensity of the surface ground motion.

Midorikawa [Ref.2.17] studied the correlation between geological conditions and shear wave velocities and defined the amplification factor based on geological conditions. The amplification factors, α, are defined as follows:

$\alpha_1 = 5.5$	(Quaternary)	
$\alpha_2 = 4.0$	(Quaternary Extrusives)	
$\alpha_3 = 5.0$	(Neogene to Quaternary)	$(2-9)$
$\alpha_4 = 3.5$	(Neogene)	
$\alpha_5 = 2.5$	(Pre-neogene)	

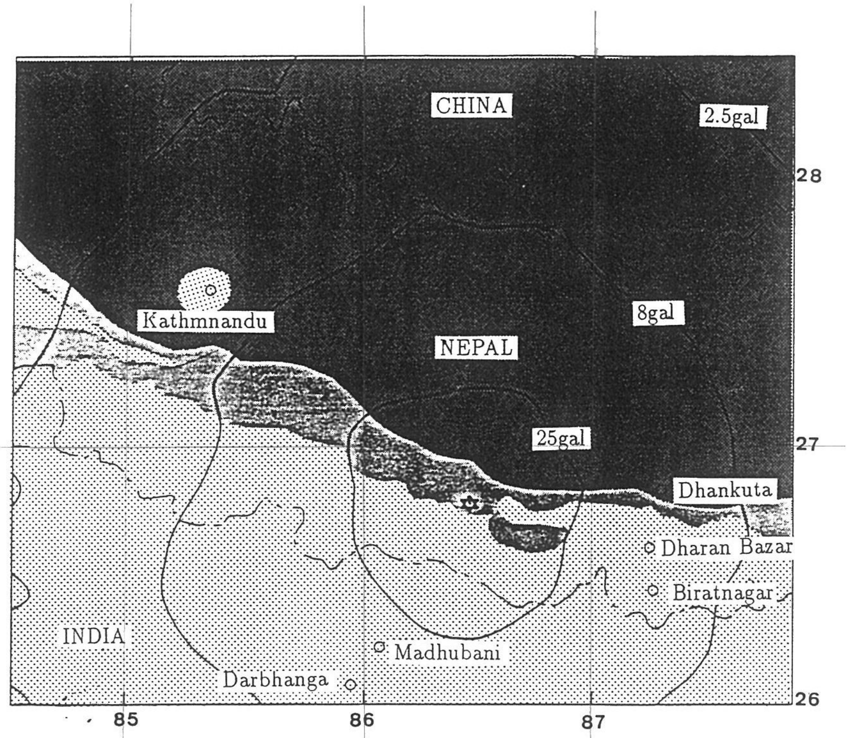


Fig. 2.13 Contours of maximum acceleration at bed rock level in Nepal and India from 21 August to 3 October, 1988

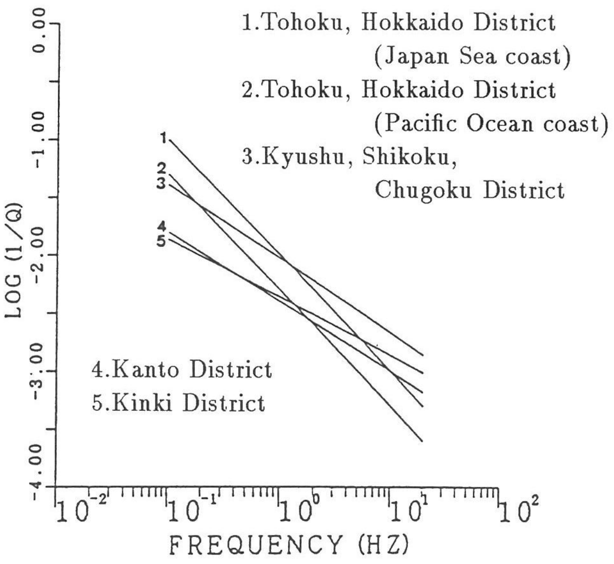


Fig. 2.14 Frequency-dependent Q-values in Japan

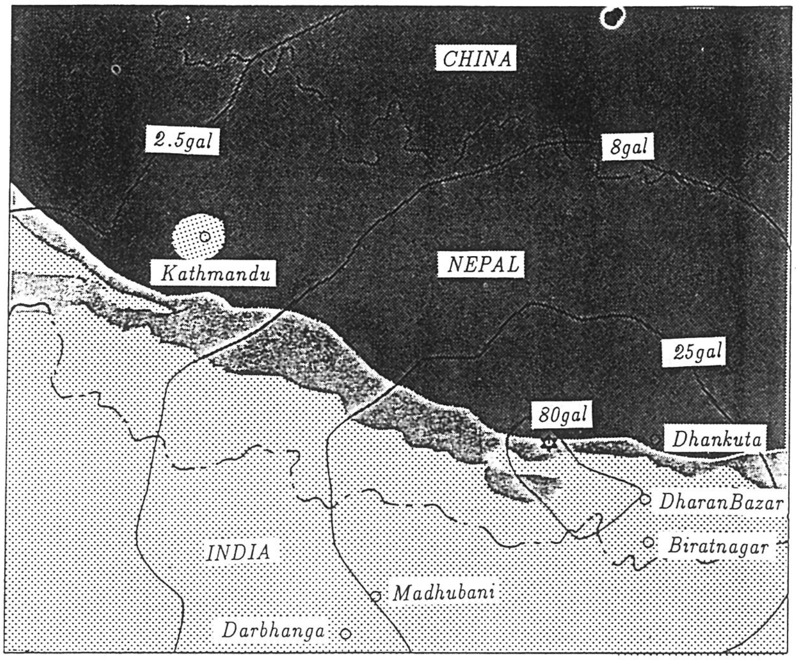


Fig. 2.15 Contours of maximum acceleration in the 1988 Nepal-India Earthquake. Fault rupture is assumed to have started at the right edge of the fault

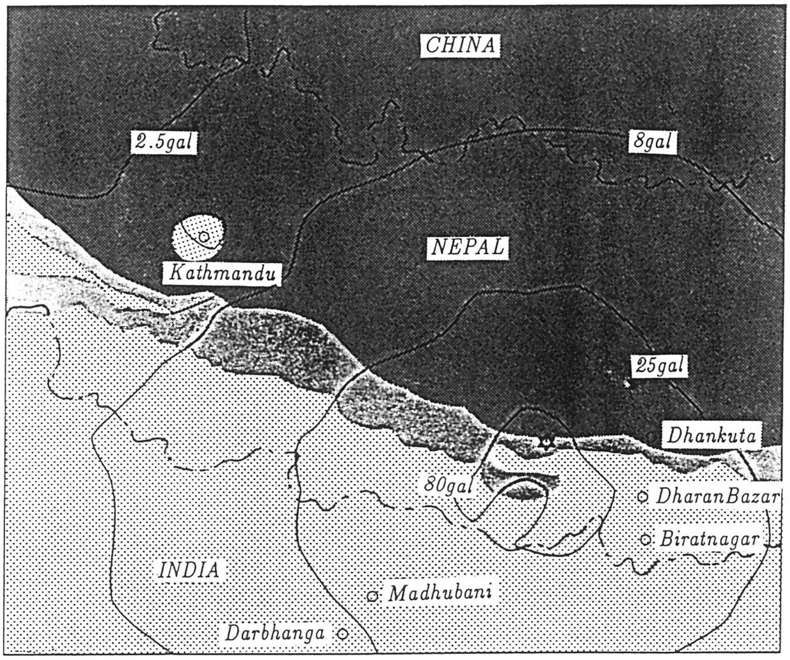


Fig. 2.16 Contours of maximum acceleration in the 1988 Nepal-India Earthquake. Fault rupture is assumed to have started in the middle of the fault

We can obtain the expected peak accelerations at ground surface by multiplying one factor of *Eq.*(2 – 9) by the maximum acceleration at the bed rock, A^{surf}_{max}:

$$A^{surf}_{max} = \alpha_i \cdot A_{max} \qquad (i=1\sim5) \qquad (2-10)$$

The geological conditions in the India-Nepal region are shown in *Figs.* 2.6 and 2.7. We assigned an amplification factor of $\alpha_i (i = 1 \sim 4)$, given in *Eq.*(2 – 9), to each site.

2.3.4 Distribution of maximum acceleration

The estimated values for the peak accelerations in the 1988 Nepal-India Earthquake, taking into account the damping of the traveling path and the amplification factor at ground surface, are shown in *Figs.* 2.15 and 2.16. The fault parameters are the same for both figures, but the starting point of rupture on the fault differs. In *Fig.* 2.15 we assumed that rupture started from the left edge of the fault and was propagated homogeneously to the right edge. In *Fig.* 2.16 rupture started in the middle of the fault and was propagated homogeneously in both directions. In comparison with *Fig.* 2.13, the peak accelerations are larger as a whole and the contour of the estimated peak acceleration expands to outer space.

2.4 Estimated Intensity from Questionnaires

2.4.1 Survey method

Use of a detailed questionnaire study to evaluate seismic intensity has the following advantages; it can be employed where there has been no earthquake data recorded by instruments, and it requires no installation and maintenance, as do seismographs. A number of detailed studies have been made using the questionnaire and wide-range applications reported by Ohta et al. [Ref.2.21].

Ohashi et al. [Ref.2.22] developed an intensity questionnaire based on the Modified Mercalli (MM) intensity scale which has been used to investigate California earthquakes. Taking into account the time of day of the Nepal-India earthquake (early morning) and the environment, 26 of the original 34 questions could be used. (See Appendix A-1 for the English version.) Hindi and Nepali versions of the questionnaire also were prepared, but we mostly used the English version. The items on human response, movement of indoor objects, and damage to structures cover an intensity range of approximately 2 to 9 on the MM scale (*Table* 2.2).

During our field survey in the stricken areas of Bihar and Nepal, the native guides interviewed local people regarding their experiences and observations during the earthquake.

Table 2.2 Intensity questionnaire items and the categories of responses

Question	Intensity Coefficients Based on MM Scale							
No Item	2	3	4	5	6	7	8	9
8 Awakened			·Few	·Many	·All			
9 Vibration		·Light	·Moderate	·Strong	·Violent			
10 Duration	·Sudden	·Short		·Long		·Very long		
11 Frightened		·Not		·Little	·Quite		·Panic	
12 Human behavior					·Exit			
13 Moving			·Easy		·Difficult	·Couldn't	·Fell down	
14 Animals				·Uneasy	·Ran out			·Ran,cry
15 Hanging objects		·Slight	·A lot		·Fell			
16 Windows,dishes			·Rattle	·Swung/brk		·Broke		
17 Liquids		·Little	·Lot	·Spill				
18 Shelf items			·None	·Few	·Many	·All		
19 Furniture			·No	·Slight	·Overturn	·Damage		
20 Walls				·Fine crk	·Plst fell	·Large crk	·Collapse	
21 Chimneys				·No damage	·Small crk	·Fell	·Most fell	
22 Stone,brck wall				·No damage	·Small crk	·Big crk	·Collapse	
23 Ground Cracks				·No damage		·Few	·Many	·Numerous
No. of Categories	1	5	8	15	12	9	6	2

Table 2.3 Sites of the questionnaire survey and preliminary intensity estimations

Sites	Abbr.	No.of cases	"Average"intens.		"Maximum"intens.		Epicentral dist, km
			mean	st.dev.	mean	st.dev.	
Dharan	DHR	16	6.16	0.53	8.25	0.66	70
Dhankuta	DKT	6	5.76	0.53	7.50	0.76	82
Biratnagar	BRT	11	5.76	0.42	8.27	0.62	72
Udayapur	UDY	8	5.94	0.64	7.75	0.66	18
Lalitpur	LLT	8	4.85	0.66	6.75	1.20	173
Bhaktapur	BKT	5	5.30	0.23	7.40	0.80	165
Kathmandu	KTM	45	4.96	0.34	6.67	1.01	175
Patna	PTN	7	4.85	0.38	6.57	1.29	181
Darbhanga	DRB	7	6.11	0.32	8.43	0.73	86
Total		113	5.39	0.68	7.32	1.16	-

Epicenter: 26.7N, 86.6E

In the Kathmandu Valley English questionnaires were distributed and collected with the assistance of the branch office of a Japanese corporation.

The number of cases collected and the epicentral distance for each location (Dharan, Dhankuta, Biratnagar, Udayapur, Lalitpur, Bhaktapur, and Kathmandu in Nepal; Patna and Darbhanga in Bihar State, India) are listed in *Table* 2.3. The nine sites (113 cases) have been divided into 5 sites (48 cases) in the relatively near field (distance less than 86 km) where serious damage occurred and 4 sites (65 cases) in the far field (distance more than 160km) where property damage and casualties were rare, except for Bhaktapur. Appendix A-2 gives the statistics (frequency distribution) for the two groups.

2.4.2 Calculations

Using the tentative intensity coefficients given in *Table* 2.2, we made two intensity calculations for each case; "average" intensity A and "maximum" intensity M :

$$A = \sum_j C(j, Q(j))/N \qquad (2-11)$$

and

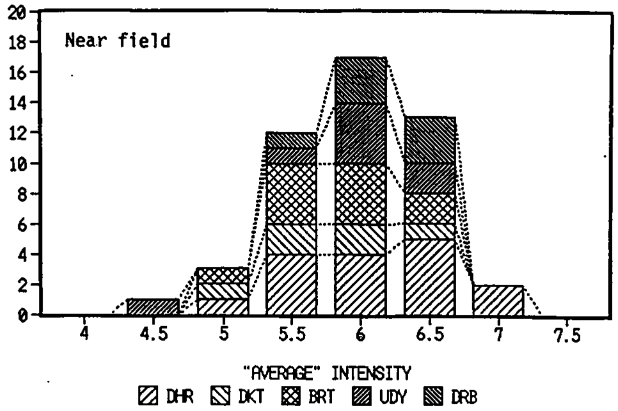
$$M = MAX[C(j, Q(j))] \qquad (2-12)$$

in which $C(j, Q(j))$ is the intensity coefficient of item j, $Q(j)$ the response category to item j, and N the number of effective responses. Results are given in *Table* 2.3. The "maximum" intensities naturally are 1.5- to 2-fold the "average" values.

Distributions of the "average" intensity in the near and far field survey sites are given in *Fig*. 2.17. The mean intensity for the near field locations (6.0) is much higher than that for the far field (5.0). This agrees with our field observations and the various damage data collected. The attenuation of the estimated intensity across the epicentral distance is shown in *Fig*. 2.18. The intensity at Udayapur (nearest the epicenter) is not higher than at the other 70 to 80km-distant near field locations, in terms of the focal depth of 57km.

An intensity estimation of 5 on the MM scale seems reasonable for Kathmandu and Patna and approximately corresponds to a PGA (Peak Ground Acceleration) of 20-30 Gals and an intensity of 3 on the JMA (Japan Meteorological Agency) scale, as noted from the following definition taken from the questionnaire [Ref. 2.22]:

Scale 5 Felt outdoors; direction estimated. Sleepers awakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.



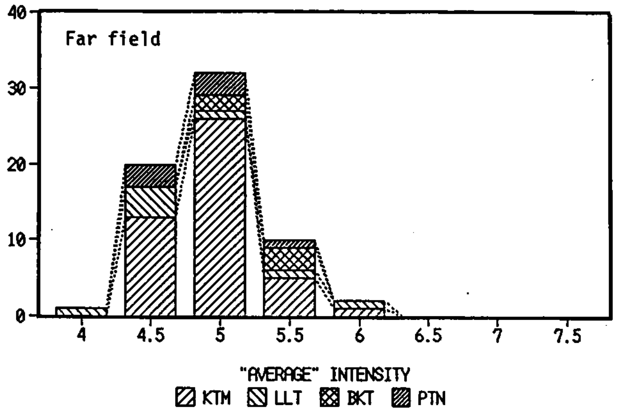


Fig. 2.17 Distributions of "average" intensities for near and far field locations

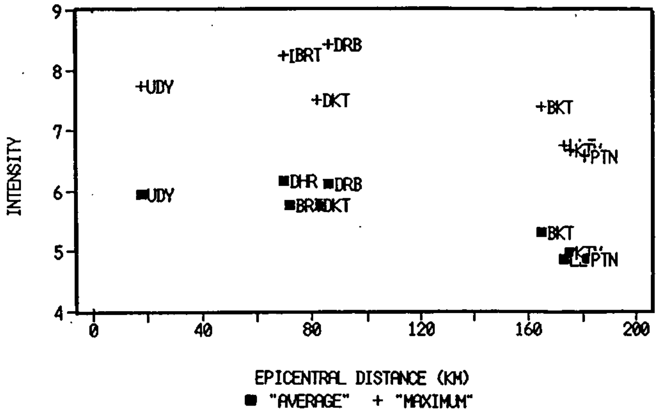


Fig. 2.18 Attenuation of "average" and "maximum" intensities along the epicentral distance

The intensity in the most heavily damaged areas of Dharan Bazaar and Dhankuta may have been at least 7 on the MM scale, corresponding to about 100 Gal and 5^- on the JMA scale. This is higher than the value estimated by the "average" method of the questionnaire because our observations of the local masonry buildings and dwellings show they should belong to masonry D (weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally) on the MM scale.

Scale 7 Difficult to stand. Felt by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

If we take into account that some masonry D-type dwellings not only had cracked but had partially collapsed and that liquefaction took place in wet lands, the intensity may even have been 8 (MM).

The tendency for the "average" intensities calculated from the questionnaire data to be smaller than those calculated from field observations also is found in the study of California earthquakes[Ref. 2.21]. The probable reasons for this discrepancy are

1. Engineers and seismologists tend to look for the existence of the severest damage during field investigations of seismic intensity rather than considering the lack of damage to other structures of similar type or the ratio of damage occurrence.
2. The MM intensity scale definition has not been statistically examined nor revised on the basis of actual field observations of the damage done by earthquakes. More field data is needed to establish more accurate intensity coefficients for the various item categories.

2.5 Estimation of Intensity from Liquefaction

The area we investigated is a grain field in Nepal, and the alluvium consisted of the flood plain deposit of the Sapta Kosi River, a tributary of Ganges River. Most of the land is used as rice fields. A few farmers' houses located at the site of sand ejection were seriously damaged by the disruption which caused sinking of columns and uneven settling. Sand and water reportedly gushed out near the epicentral regions (Gaighat and Motigada). *Photo.* 2.1 shows typical sand ejection over the ground surface. Because of the presence of a cohesive soil layer near the surface, liquefied sand was ejected from a hole-shaped channel at a weak spot in the surface layer.

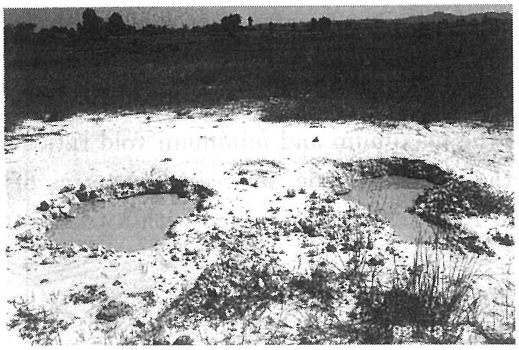


Photo. 2.1 Sand ejected through hole-shaped channels in a rice field

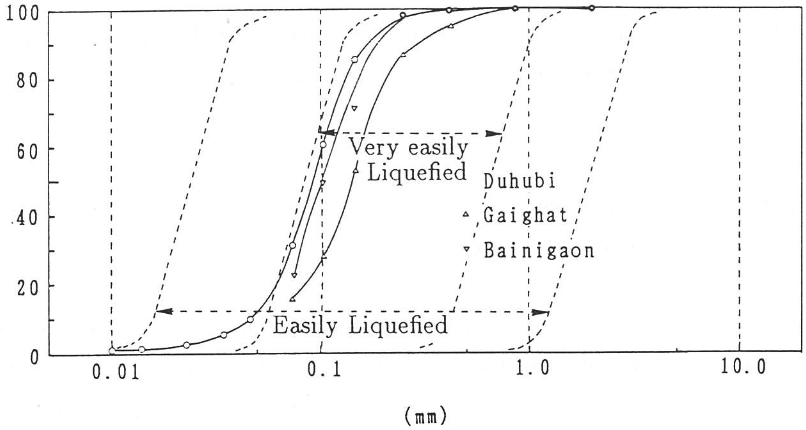


Fig. 2.19 Grain size distribution curves for local sand samples from areas effected by the 1988 Nepal-India Earthquake

Table 2.4 Physical properties of local sands

	Gaighat	Bainigaon	Duhubi
G_s	2.650	2.651	2.688
e_{max}	1.199	1.141	1.303
e_{min}	0.649	0.559	0.663

We sampled ejected sand at three points (Gaighat, Bainigaon and Duhubi) and took samples back to the laboratory. Results of a sieve analysis are shown in *Fig.* 2.19. The grain size distributions of all the samples are in the range of very easily liquefied as defined in the Japanese Technical Standards for Port and Harbor Facilities and its Commentary. The specific gravity and the maximum and minimum void ratios of each sample are given in *Table* 2.4. The internal friction angle, expressed in terms of relative density for the samples from each site in *Fig.* 2.20, was obtained with a triaxial test apparatus.

2.5.1 Simple analysis of liquefaction

The maximum stress ratio,τ_{max}/σ'_v, induced by earthquake loading is expressed by the simple formula [Ref.2.24]

$$\frac{\tau_{max}}{\sigma'_v} = \frac{\alpha_{max}}{G} \cdot r_d \cdot \frac{\sigma_v}{\sigma'_v} \qquad (2-13)$$

in which σ_v is the total and σ'_v the effective vertical overburden pressures at the depth in question, and the stress reduction coefficient, r_d , is given by the empirical formula;

$$r_d = 1 - 0.015z \qquad (2-14)$$

in which z is the depth in meters. In $Eq.(2-13)$, α_{max} is the maximum horizontal ground acceleration and G the acceleration of gravity.

The cyclic strength, $\tau_{max,l}/\sigma'_v$, to be compared against the induced maximum stress ratio, can be determined from the following formula, on the basis of cyclic triaxial shear test data expressed in terms of the cyclic stress ratio, $\sigma_{dl}/(2\sigma'_0)_{20}$ required to cause 5% double amplitude axial strain in 20 cycles;

$$\frac{\tau_{max,l}}{\sigma'_v} = \frac{0.9}{0.55}\frac{1+2K_0}{3}(\frac{\sigma_{dl}}{2\sigma'_0})_{20} \qquad (2-15)$$

in which $\tau_{max,l}/\sigma'_v$ denotes the maximum strength, σ_{dl} the amplitude of axial stress and σ'_0 the initial confining stress under triaxial loading conditions. K_0 is the coefficient of earth pressure at rest. The value, 0.55, in $Eq.(2-15)$ is a factor to account for the effect of the irregular nature of changes in shear stress with time during an earthquake. The factor 0.9 was incorporated in $Eq.(2-15)$ to allow for changes in the direction of the shear stress applied on the horizontal plane during an earthquake.

To estimate the cyclic strength of in situ sand deposits from the N-values of the standard penetration test, the empirical correlations between these values have been established. On

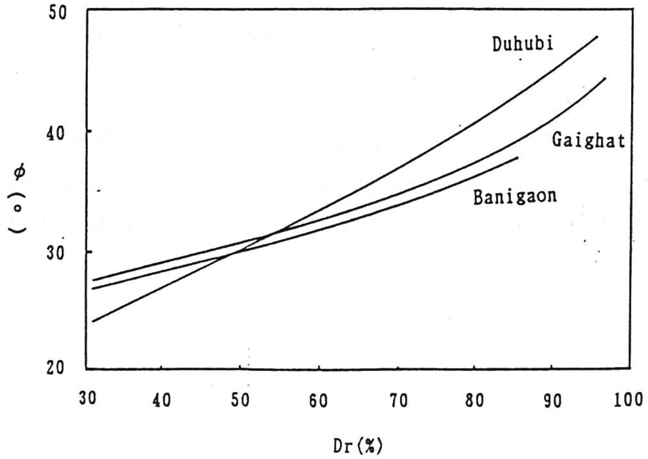


Fig. 2.20 Internal friction angle of the sand samples in Fig. 2.19 in terms of relative density

Table 2.5 Estimation of maximum accelerations (Gal) from liquefaction analyses made at three points

		Gaighat	Bainigaon	Duhubi
D_r (%)	50	126	117	119
	40	116	109	99
	30	103	97	81
Lowest Intensity		75	77	75

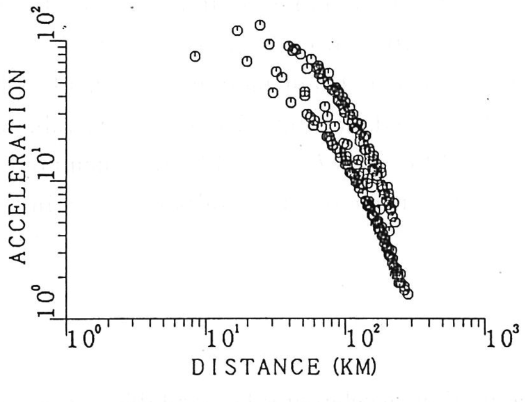


Fig. 2.21 Attenuation characteristics of theoretically calculated maximum accelerations

the basis of test data for undisturbed sand samples taken mainly from alluvial deposits in Japan, Tatsuoka et al. [Ref.2.25] proposed the following formula;

$$(\frac{\sigma_{dl}}{2\sigma'_0})_{20} = 0.0882\sqrt{\frac{N}{\sigma'_v + 0.7}} + 0.225 \log \frac{0.35}{D_{50}} \qquad (2-16)$$

in which D_{50} is the mean grain size and σ'_v the effective overburden pressure in kgf/cm^2. Evaluation of liquefaction potential can be made in terms of the factor of safety, F_l, defined by

$$F_l = \frac{\tau_{max,l}/\sigma'_v}{\tau_{max}/\sigma'_v} \qquad (2-17)$$

2.5.2 Intensity estimation

If the factor of safety exceeds 1.0 the possibility of liquefaction becomes very high. Assuming that $F_l = 1$ is the threshold value for liquefaction of the sand layer, the value of α_{max}/g can be calculated from *Eqs*.(2−13), (2−15) and *Eq*.(2−16). Because we could not collect standard penetration test data in the affected areas, we used the following formula for the internal friction angle and N-value;

$$\phi = \sqrt{12N} + 20 \qquad (2-18)$$

As seen in *Fig*. 2.20, the internal friction angle is a function of relative density. Based on field investigations conducted after past earthquakes, sand layers with homogeneous grain size distribution usually have a relative density of less than 50 percent. For estimating the maximum intensity of ground shaking at a site where liquefaction took place, we assumed three relative densities; 50, 40 and 30 percent. The lowest value represents loosely deposited sand. A depth of 5m and a ground water level of 0m also were assumed. The estimated maximum acceleration at each site is given in *Table* 2.5. Based on soil and seismic data for when there is or is not liquefaction in the field, it has been reported that liquefaction is rarely seen for a sand element with a τ_{max}/σ'_v value of less than about 0.15 [Ref.2.26]. Substituting this value into *Eq*.(2 − 13), we calculated the lowest estimate of maximum acceleration at each of three points; results are given in the bottom row of *Table* 2.5.

2.6 Discussion

There were no strong motion accelerographs available for areas 70 to 80 kilometers from the epicenter. We therefore calculated the theoretical distribution of the maximum

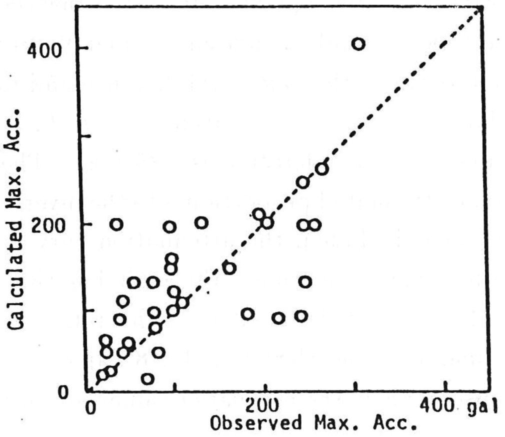


Fig. 2.22 Comparison of calculated and observed maximum accelerations for 8 Japanese earthquakes

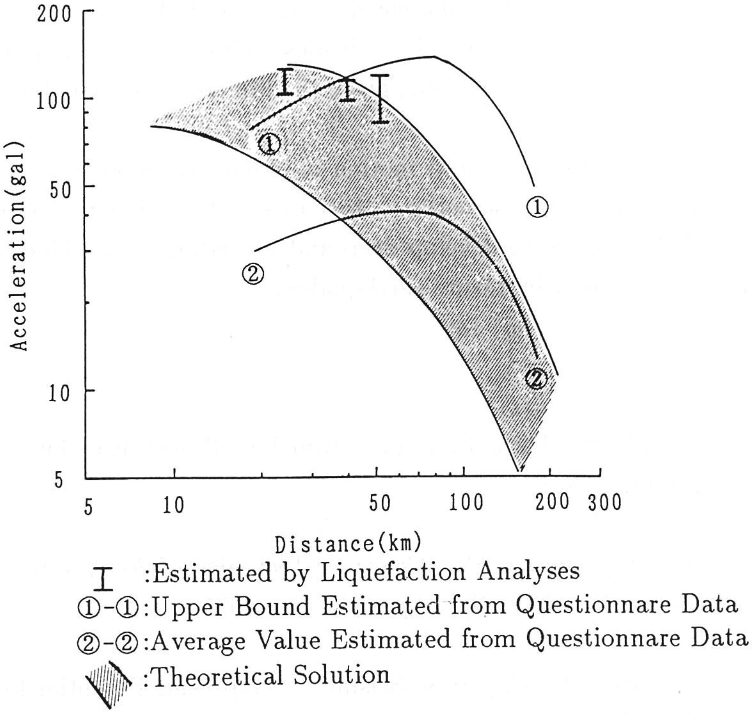


Fig. 2.23 Comparison of maximum ground intensities obtained by several methods

accelerations in the region near the earthquake source. To draw the contour lines we divided this region into 208 square meshes and calculated the maximum acceleration at each grid of the lattice. The relation between the epicentral distance and maximum acceleration for each grid for the case shown in *Fig.* 2.16 is given in *Fig.* 2.21. At about an epicentral distance of 25 km the maximum acceleration is 125 Gal. The overall tendency is for maximum acceleration to be attenuated proportional to the inverse of the distance. Because the effect of the fault extent is included, the attenuation curves have upper bounds near the source region, and the range is, at most, the fault length. To check the validity of estimating the intensity of ground shaking with our theoretical method, we compared the calculated and observed maximum accelerations for 8 Japanese earthquakes (*Fig.* 2.22). Although there is some discrepancy, the estimated values are in good agreement with the observed values.

A comparison of the intensity of ground shaking obtained by calculation, liquefaction analyses, and from the questionnaire datas is given in *Fig.* 2.23. The estimated average value from the questionnaire data gives too low an intensity for a short epicentral distance, but shows good agreement as the epicentral distance increases. The values obtained from liquefaction analyses also support our theoretical results. In order to procure a detailed intensity distribution for the severely damaged area, we would have to take into account the local topography, soil profile and soil conditions. This, however, requires long range data acquisition and was beyond our scope, given the limited time available for our team's investigations.

Without quantitative data on ground motion it is usually impossible to evaluate the earthquake-resistant capacities of structures. Instrumentation of strong accelerographs is most urgently needed if we are to develop deep understanding of the kinds of damage to structures that may be caused by future earthquakes.

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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 200×100×50mm and of a Nepalese brick 235×115×65mm. The Japanese standard, JIS R 1250, specifies 210×100×60mm 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

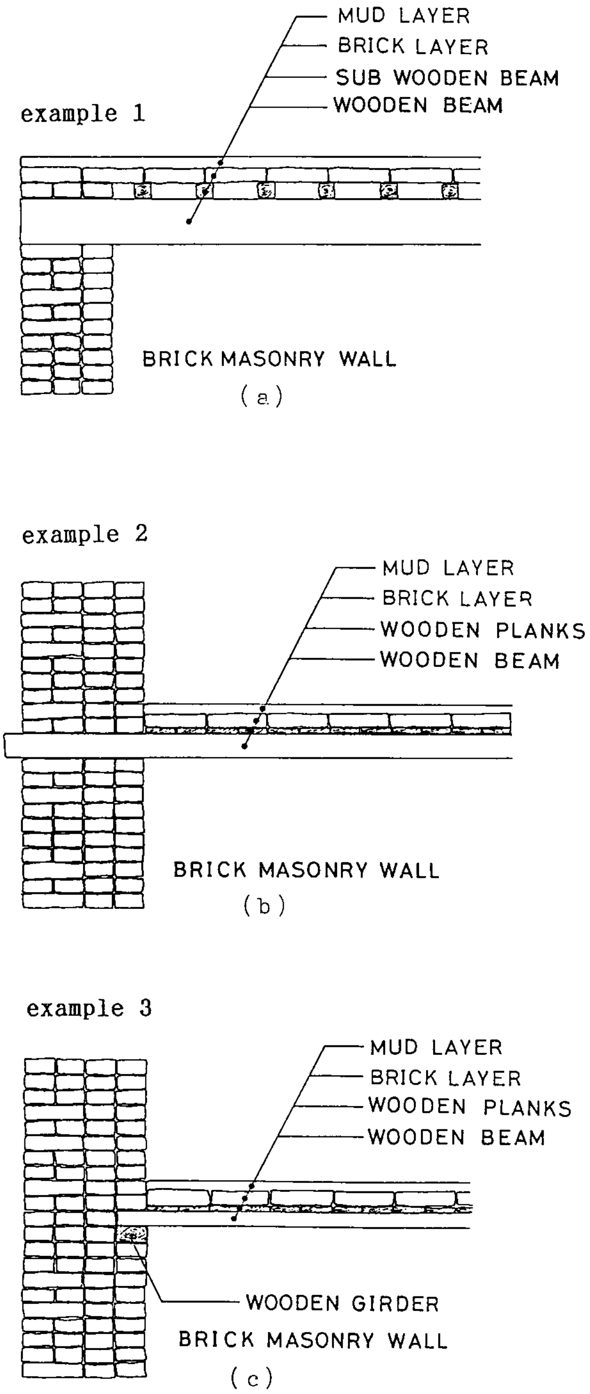


Fig. 3.1 Typical construction of a brick masonry building

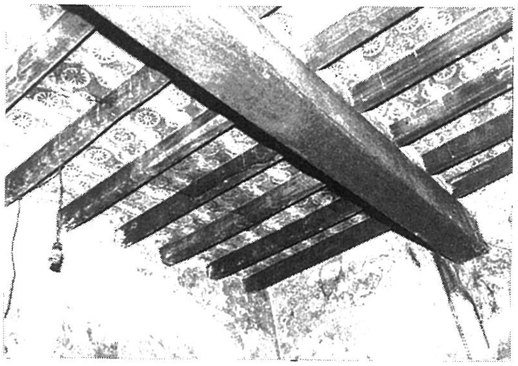


Photo. 3.1 Interior view of the floor slab system of a damaged brick masonry house

Photo. 3.2 Cross-sectional view of the floor slab system of the same damaged brick masonry house

Photo. 3.3 Interior view of the floor slab system of a brick masonry building

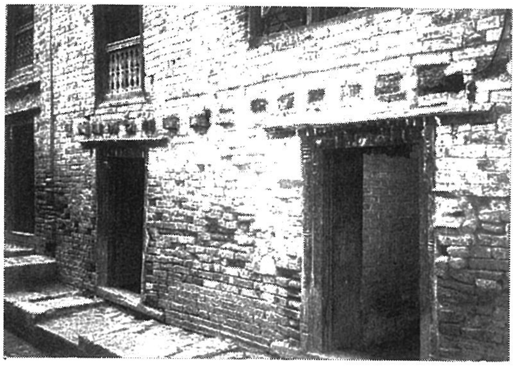


Photo. 3.4 Exterior view of the floor slab system of the same brick masonry building

Photo. 3.3; the staircase positioned along the transverse axis of the building. 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.

3.2.2 Structure of mud-stone buildings

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.

3.2.3 General description of the damage done

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.

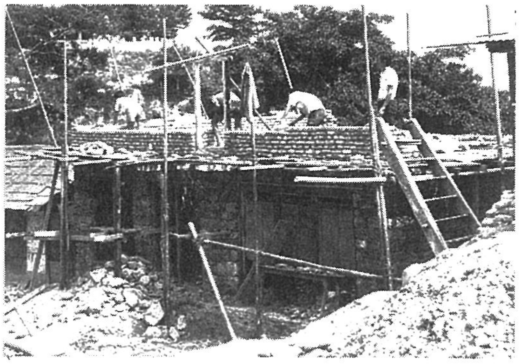


Photo. 3.5 Construction of a mud-stone house in Dharan Bazaar; overall view

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

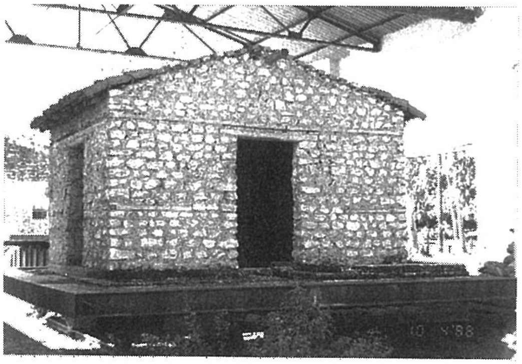


Photo. 3.8 A mud-stone building constructed for an experimental study at the University of Roorkee, India

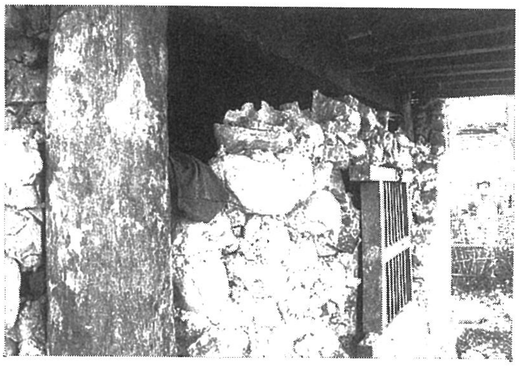


Photo. 3.9 A mud-stone, rural house at Gaighat, Nepal partly damaged during the earthquake

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 Madhubhani, 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 Madhubhani 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).

Photo. 3.12 The State Government Secretariat Main Office, Patna, India

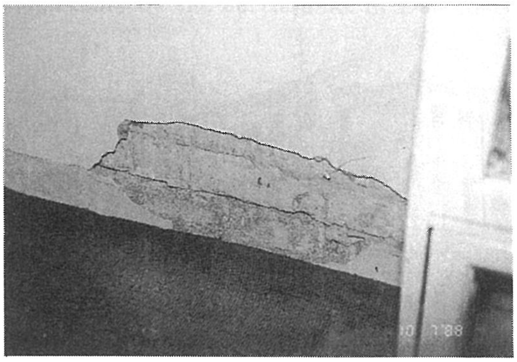


Photo. 3.13 Peeling off of the finish on a wall in the State Government Secretariat Main Office, Patna

Photo. 3.14 A damaged kiosk in the backyard of the Darbhanga District Headquarters Office, Darbhanga, India

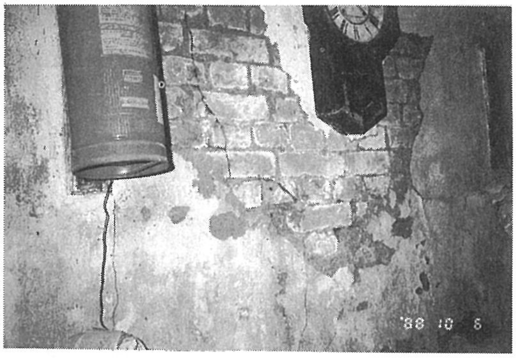


Photo. 3.15 Cracks on the brick masonry wall in the Darbhanga District Headquarters Office, Darbhanga

Photo. 3.16 The damaged Civil Sergeant's Residence, Darbhanga District, Darbhanga

Photo. 3.17 The damaged Medical College Hospital, Darbhanga

Photo. 3.18 Close-up of a cross-sectional view of the damaged Medical College Hospital, Darbhanga

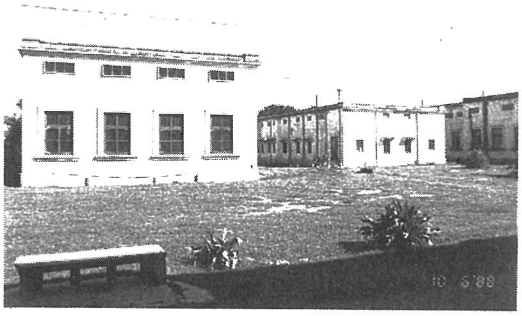


Photo. 3.19 Undamaged buildings located close to the damaged Medical College Hospital, Darbhanga

Photo. 3.20 Damage in the Darbhanga area, view 1 (courtesy of the Building Construction Department, Government of Bihar)

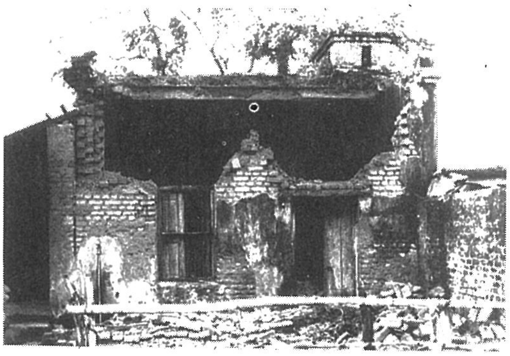


Photo. 3.21 Damage in the Darbhanga area, view 2 (courtesy of the Building Construction Department, Government of Bihar)

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 effected 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

Photo. 3.22 Damage zone in the old town, Bhaktapur

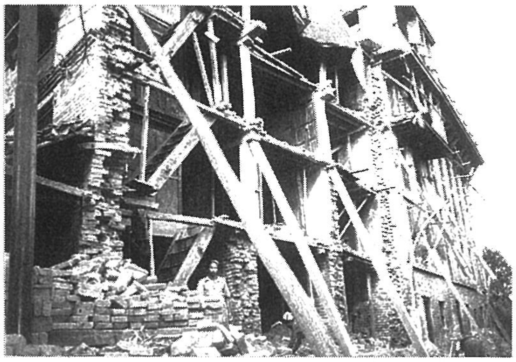


Photo. 3.23 Collapse of the gable wall of a brick masonry building; example 1, Bhaktapur, Nepal

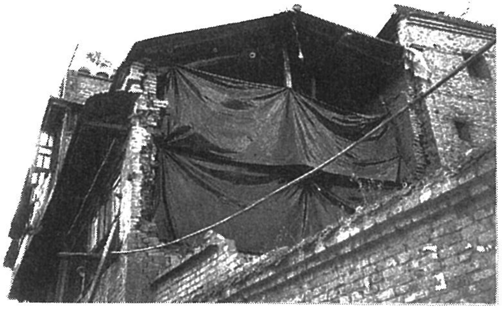


Photo. 3.24 Collapse of the gable wall of a brick masonry building; example 2, Bhaktapur, Nepal

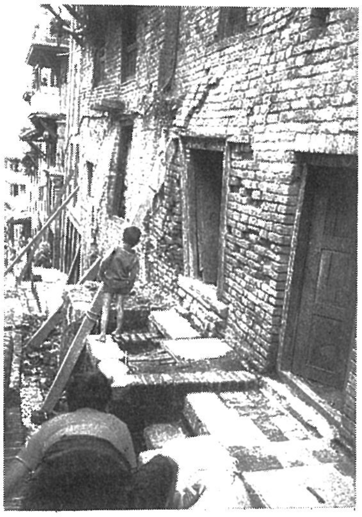


Photo. 3.25 The expanded wall of a brick masonry building, Bhaktapur, Nepal

Photo. 3.26 A damaged brick masonry farm house, Gaighat, Nepal

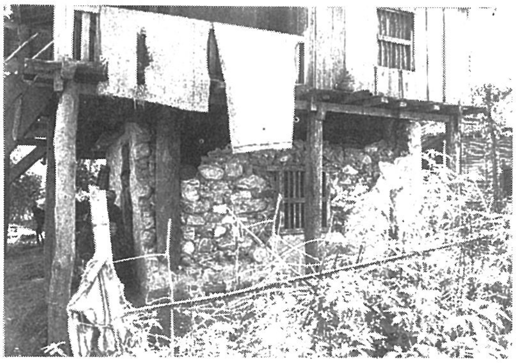


Photo. 3.27 A damaged mud-stone farm house, Gaighat, Nepal

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) Dharan, Sunsari District, Kosi Zone, Nepal

(d.1) Dharan Bazaar

Dharan Bazaar is located on the border between the Himalaya Mountains and the Terai, the plain at the foot of the mountains. Although Dharan 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 Dharan 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 Dharan Bazaar is shown in *Photos*. 3.28 to 3.31. The nurses' headquarters at Dharan 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 Dharan 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

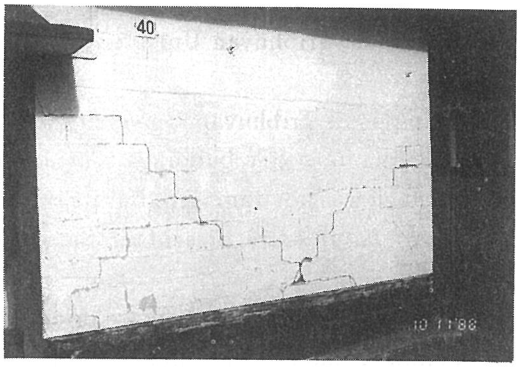


Photo. 3.32 Damage to a single-story block building in the British Recruit Camp, Dharan Bazaar, Nepal

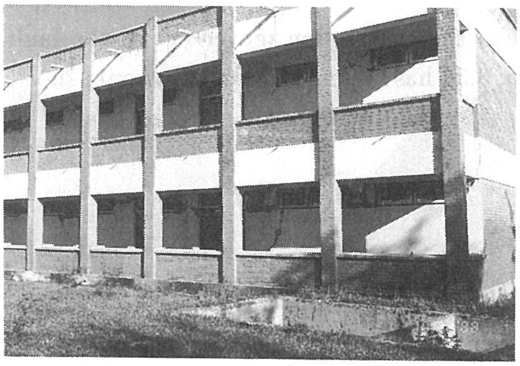


Photo. 3.33 Shear failures in the short-span brick masonry wall of a special classroom, the Engineering College Campus, Tribhuvan University, Dharan Bazaar, Nepal

Photo. 3.34 Seriously and slightly damaged classroom buildings, the Engineering College Campus, Tribhuvan University, Dharan Bazaar, Nepal

(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

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.

Photo. 3.35 Damage zone in Dhankuta Bazaar, Nepal

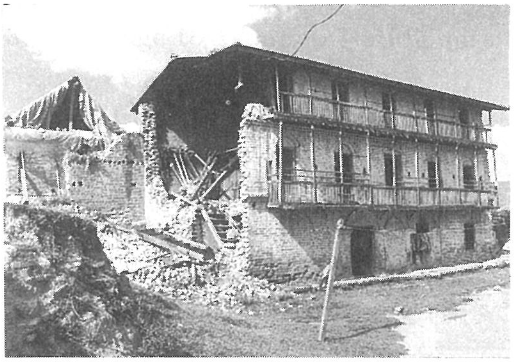


Photo. 3.36 Damage to the gable wall of a brick masonry building; example 1, Dhankuta Bazaar, Nepal

Photo. 3.37 Damage to the gable wall of a brick masonry building; example 2, Dhankuta Bazaar, Nepal

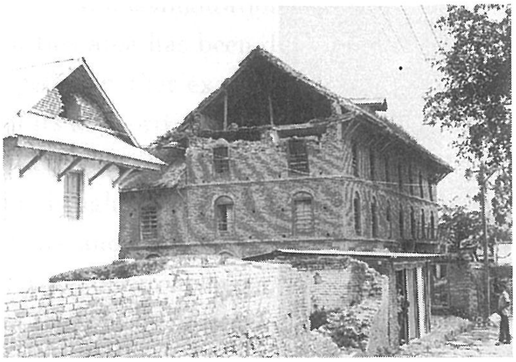


Photo. 3.38 Damage to the gable wall of a brick masonry building; example 3, Dhankuta Bazaar, Nepal

Photo. 3.39 Damage to the gable wall of a brick masonry building; example 4, Dhankuta Bazaar, Nepal

Photo. 3.40 Exterior view of a rural brick masonry house, Dhankuta Bazaar, Nepal

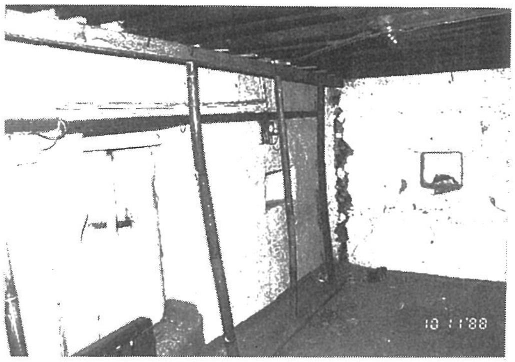


Photo. 3.41 Interior view of the same damaged rural brick masonry house, Dhankuta Bazaar, Nepal

Photo. 3.42 The completely collapsed Dhankuta Hospital, Dhankuta Bazaar, Nepal

Photo. 3.43 A collapsed single-story brick masonry house in Biratnagar, Nepal (photo taken by a resident just after the shock)

Another feature of the damage done at Dhankuta Bazaar can be seen in the public service buildings. *Photo.* 3.42 shows of 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.

(f) 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

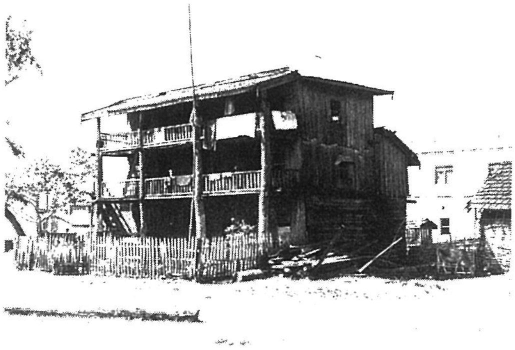


Photo. 3.44 An undamaged rural wooden house; example 1, Gaighat

Photo. 3.45 An undamaged rural wooden house; example 2, Gaighat

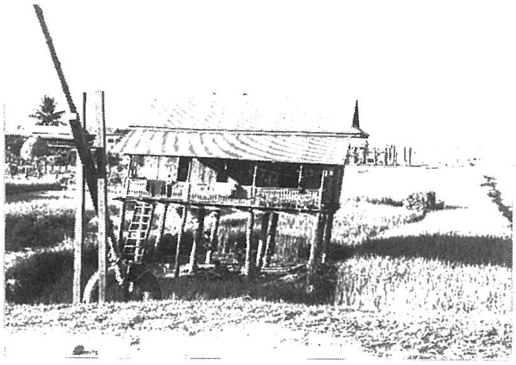


Photo. 3.46 An undamaged rural wooden house; example 3, near Biratnagar, Nepal

whose seismic capacities we had concluded were not great.

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 20×20cm for a column and about 10×20cm 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 36×40cm. 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

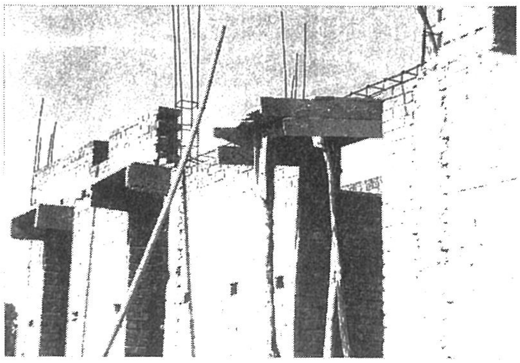


Photo. 3.47 A reinforced concrete building under construction in Bihar State, India

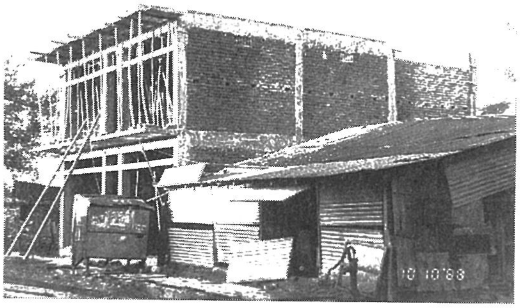


Photo. 3.48 A reinforced concrete building under construction in Biratnagar, Nepal

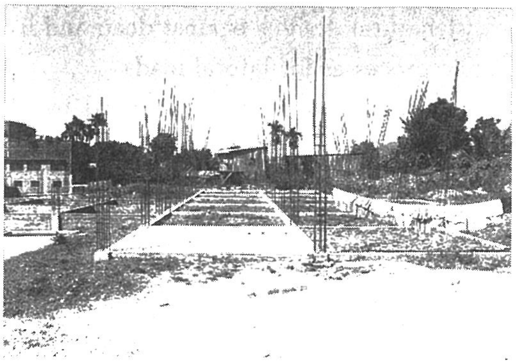


Photo. 3.49 A reinforced concrete building under construction at Dharan Hospital, Dharan Bazaar, Nepal

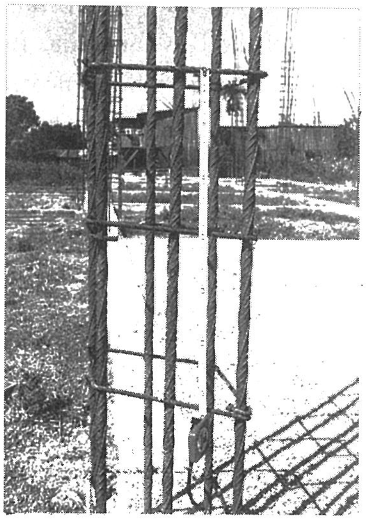


Photo. 3.50 Reinforcement of the steel bars in the building under construction at Dharan Hospital, Dharan Bazaar, Nepal

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 20 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

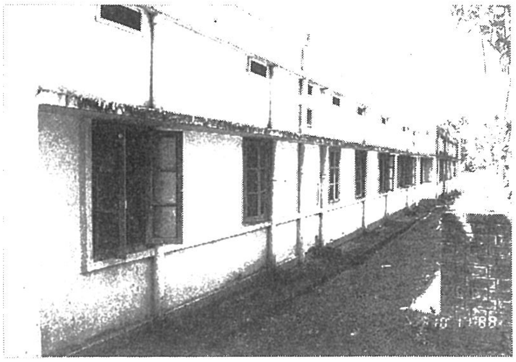


Photo. 3.52 An undamaged reinforced concrete ward at Dharan Hospital, Dharan Bazaar, Nepal

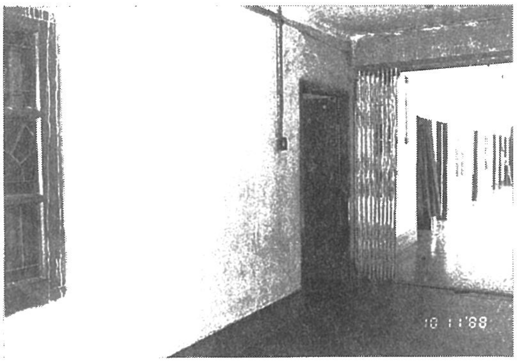


Photo. 3.53 A reinforced concrete shear wall positioned within the ward longitudinally, Dharan Hospital, Dharan Bazaar, Nepal

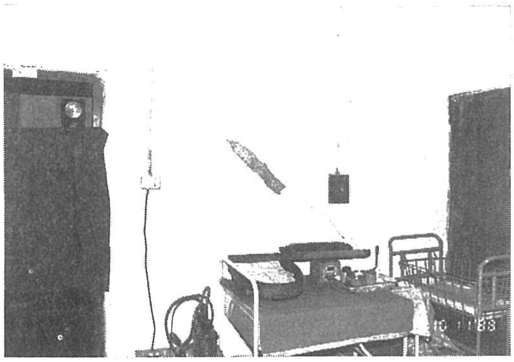


Photo. 3.54 Shear cracks in a brick masonry wall placed within the ward parallel to the undamaged reinforced concrete shear wall (Photo. 3.53), Dharan Hospital, Dharan Bazaar, Nepal

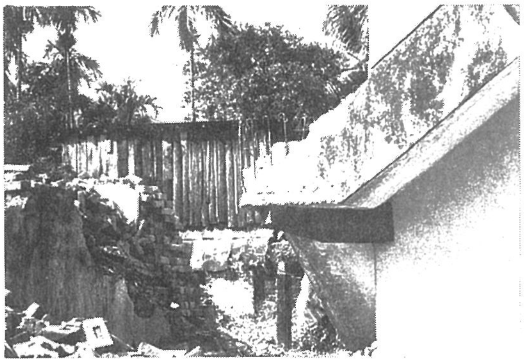


Photo. 3.55 The damaged two-story reinforced concrete medical office at Dharan Hospital, Dharan Bazaar, Nepal

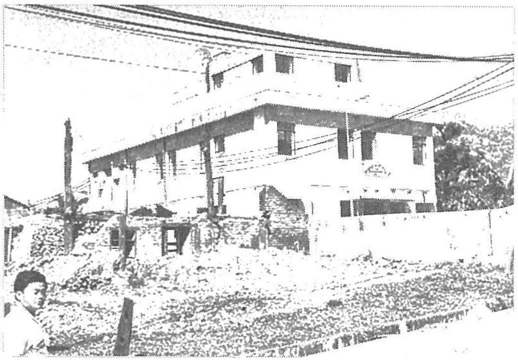


Photo. 3.56 The telecommunications office, Dharan Bazaar, Nepal

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

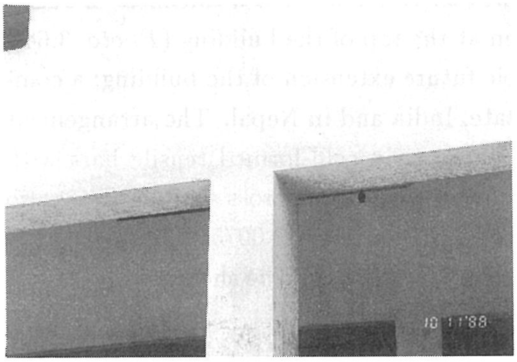


Photo. 3.59 Close-up of the top of the column of a third reinforced concrete private home, Dharan Bazaar, Nepal

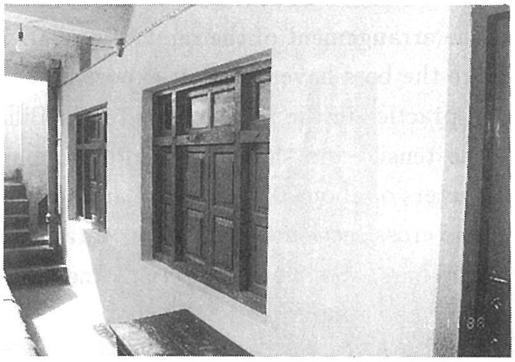


Photo. 3.60 An undamaged reinforced concrete private home, Dhankuta Bazaar, Nepal

here.

(c) 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 12×12in (30×30cm). 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 60×60cm (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 30×30cm cross section. The ratio of this cross sectional area to the total column area (p_g) 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

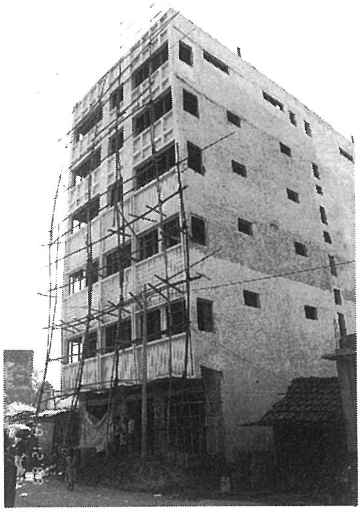


Photo. 3.61 Exterior view of the six-story hotel under construction at Biratnagar, Nepal

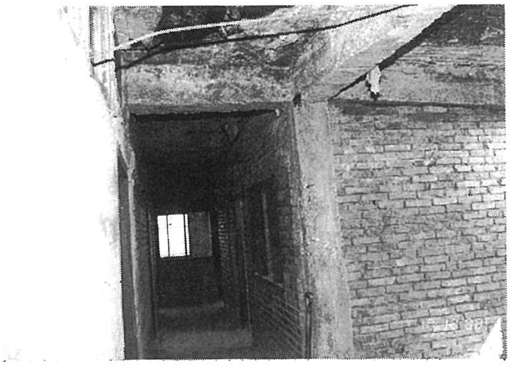


Photo. 3.62 Interior view of the six-story hotel under construction at Biratnagar, Nepal

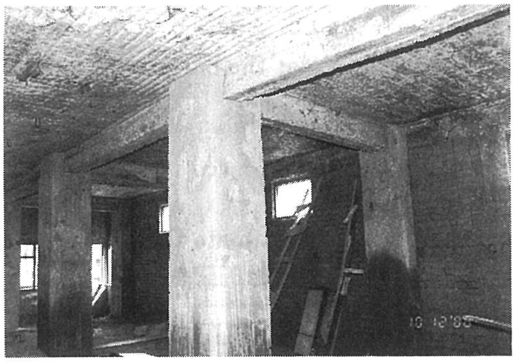


Photo. 3.63 Enlarged columns on the first and second story levels of the six-story hotel under construction at Biratnagar, Nepal

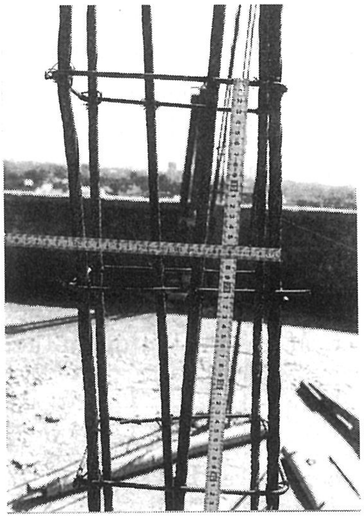


Photo. 3.64 Arrangement of the reinforcing bars for a column of the six-story hotel under construction at Biratnagar, Nepal

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/cm^2. The shear strength of its mortar made with cement:lime:sand (1:1:5) is in the range of 1.2-2.0kg/cm^2, 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/cm^2 and about 7kg/cm^2 with a deflection angle of 1.7×10^{-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/cm^2.

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

$$N_o = wHLt \qquad (3-1)$$

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 $Eq.(3-2)$.

$$M_o = cwH^2Lt/2 \qquad (3-2)$$

in which c is given by

$$c = a_o/G \qquad (3-3)$$

in which a_o denotes the peak acceleration of the ground motion and G the acceleration of gravity, 980cm/sec^2. 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:

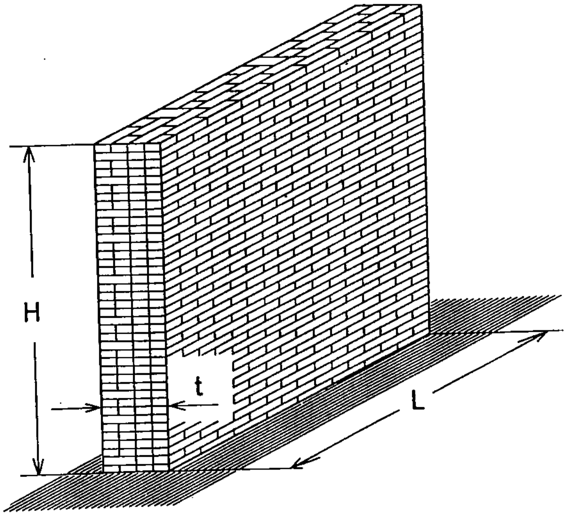


Fig. 3.2 Analytical model of a gable wall represented by a self-supporting panel

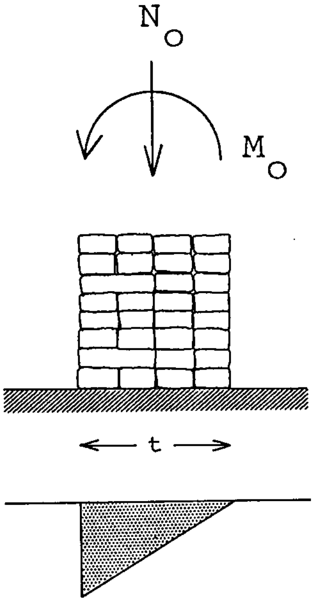


Fig. 3.3(a) Triangular stress-block at the bottom of a gable wall that corresponds to the linear elastic condition

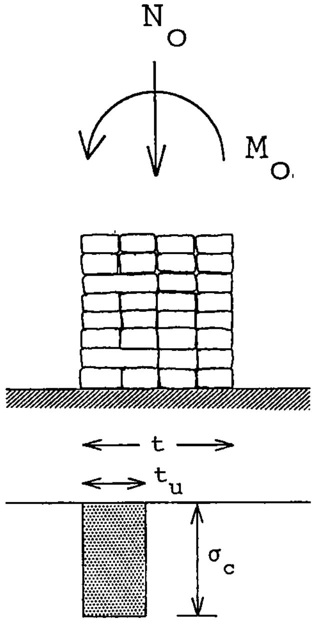


Fig. 3.3(b) Rectangular stress-block at the bottom of a gable wall that corresponds to the ultimate condition

$$
\begin{aligned}
\sigma &= \sigma_o + \sigma_b \\
&= N_o/(Lt) - M_o/(1/6Lt^2) \\
&= wH - 3cwH^2/t \qquad (3-4)
\end{aligned}
$$

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

$$c = t/(3H) \qquad (3-5)$$

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

$$
\begin{aligned}
c &= 0.33 \times 45.7/(300 \times n) \\
&= 0.05/n \qquad (3-6)
\end{aligned}
$$

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

$$c = t/H(1 - wH/\sigma_c) \qquad (3-7)$$

in which σ_c is the ultimate compressive strength of the brick masonry wall. Assuming that w equals 2ton/m^3, and σ_c equals 100kg/cm^2, and substituting $t = 45.7$cm and $H = 300n$cm, we obtain the relation

$$
\begin{aligned}
c &= (1 - 6n/1000) \times 0.15/n \\
&\simeq 0.15/n \qquad (3-8)
\end{aligned}
$$

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

$$c = \tau_s/(wH) \qquad (3-9)$$

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

$$c = 1.7/n \qquad (3-10)$$

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.

(b) Mud-stone buildings

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

(c) Concrete block 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 (30.5×6.8m). 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

$$
\begin{aligned}
Q &= c \times 30.5 \times 6.8 \times 1.0/7 \\
&= 30c \quad \text{(ton)} \qquad (3-11)
\end{aligned}
$$

in which c is the coefficient given by $Eq.(3-3)$ when the weight of the building averages 1ton/m^2.

Suppose the shear strength of the concrete block masonry wall to be 1.5kg/cm^2 [Ref.3.3], then the maximum shear capacity of the wall, $Q_{max.}$, is

$$
\begin{aligned}
Q_{max.} &= 1.5 \times 500 \times 20/2 \\
&= 7,500 \quad \text{(kg)} \qquad (3-12)
\end{aligned}
$$

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

$$
c = 7.5/30 = 0.25 \qquad (3-13)
$$

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 10m^2. 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/m^2 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/cm^2; and (3) The compressive strength of the concrete, which we found to be lean, is 180kg/cm^2.

On this basis, the flexural capacity, M_y, can be estimated as follows [Ref.3.4];

$$M_y = 0.8 a_t \sigma_y D + 0.5 N D (1 - N/bDF_c) \qquad (3-14)$$

in which a_t is the cross-sectional area of the tensile bar, σ_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 $a_t = 3.81\text{cm}^2$, $\sigma_y = 4000\text{kg/cm}^2$, $D = b = 30\text{cm}$, $N = 60\text{ton}$ and $F_c = 180\text{kg/cm}^2$ in the equation, gives a flexural capacity for a column on the first story of

$$M_y = 9.3 \quad (\text{ton} \cdot \text{m}) \qquad (3-15)$$

Suppose the clear span of a first-story column to be 4m, then the lateral capacity of column Q_{my} is

$$Q_{my} = 2M_y/H = 4.7 \quad (\text{ton}) \qquad (3-16)$$

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

$$c = 4.7/60 = 0.08 \qquad (3-17)$$

Based on the assumption that the shear strength is 9kg/cm^2 for concrete, the shear capacity of the column Q_{sy} is

$$Q_{sy} = 8.1 \quad (\text{ton}) \qquad (3-18)$$

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

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

the areas damaged during the earthquake. 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 Panchayat, 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. Malla, 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 that 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, Sunsari District, Kosi Zone,Nepal

Population	118218
No. Houses	20000
No. Wards	19

Ward	Deaths	Damaged Houses	Damage Category		Loss
			Complete	Partial	1000 Rs.
1	20	229	132	97	28585
2	8	179	68	111	27592
3	23	294	136	158	15529
4	11	185	86	99	27790
5	1	95	73	22	9230
6	5	136	34	102	14251
7	8	189	78	111	21688
8	2	364	39	325	15379
9	7	180	78	102	18690
10	3	174	54	120	16398
11	1	293	259	34	4627
12	0	191	44	147	13029
13	12	338	122	216	27871
14	10	278	276	2	17268
15	3	478	78	400	4906
16	2	161	34	127	14492
17	0	176	30	146	1748
18	6	156	39	117	6020
19	0	179	11	168	3414
Total	122	4275	1671	2604	288507

Death Ratio = 122*100/118218 = 0.108%
Damage Ratio =4275*100/ 20000 = 21.4%
Complete Damage Ratio =1671*100/20000 = 8.4%
Rs. = Rupees

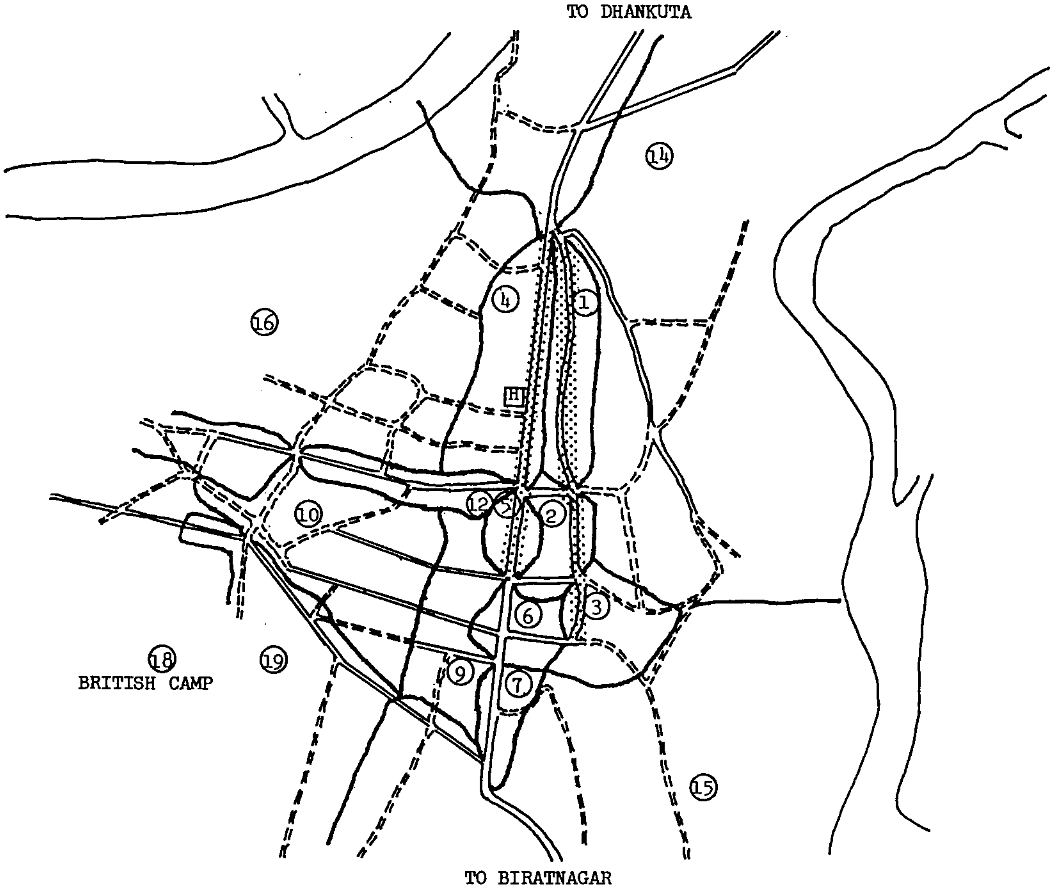


Fig. 3.4 Map of Dharan Bazaar

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

Damage	Wood 1F	Wood 2F	Wood & Brick	Brick 1F	Brick 2F	Brick 3F	R/C Brick 1F	R/C Brick 2F	R/C Brick 3F	R/C 1F	R/C 2F	Total
Total Number	30	122	34	28	103	31	15	30	6	29	53	481
Collapsed	3	5	5	9	58	26	1					107
Half Collapsed	1	16	10	1	24	3	1	5			1	62
Cracked	1		7	1	7		6	16	3	1	6	48
Tilted	3	26	1									30
No Damage	22	75	11	17	14	2	7	9	3	28	46	234
Collapse Ratio	10.0	4.1	14.7	32.1	56.3	83.9	6.7	0.0	0.0	0.0	0.0	%
Damage Ratio	26.6	38.5	67.6	39.2	86.4	93.5	53.3	70.0	50.0	3.4	13.2	%

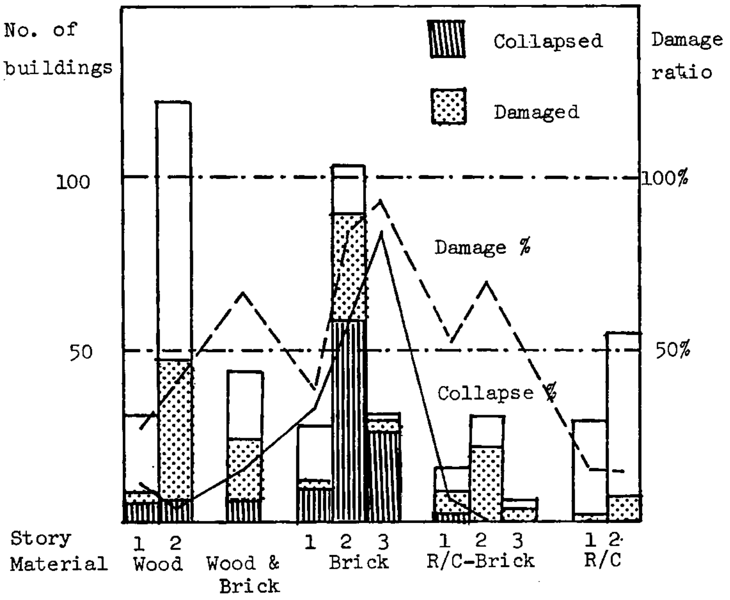


Fig. 3.5 Damage classified by the construction material and number of stories of a building

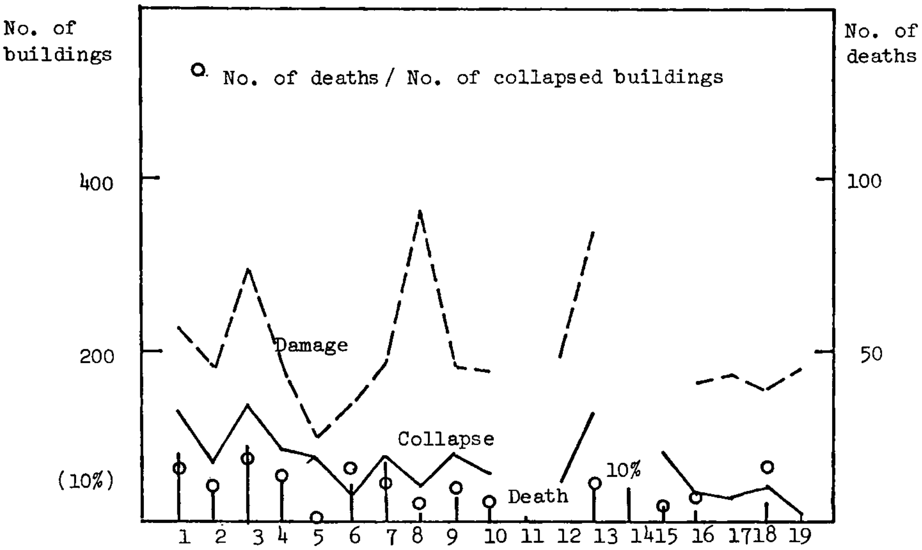


Fig. 3.6 Numbers of collapsed and damaged buildings and deaths per ward, in Dharan Town Panchayat

Table 3.4 Damaged facilities and estimated monetary loss in Dharan Bazaar

Category	Number of Facilities	Number of Damaged Buildings	Damage Category		Loss Amount 1000 Rs.
			Complete	Partial	
A. Government Facilities	18	73	34	39	4,625
B. Semi-Governmental Offices	3	20	0	20	2,370
C. Educational Establishments	4	24	15	9	11,239
D. Schools	17	36	12	24	2,514
E. Hospitals and Health Offices	-	13	-	-	1,561
F. Social Organization	3	5	3	2	140
G. Major Temples and Mosques	12	23	13	10	1,405
H. Private Houses		4,275	1,671	2,604	288,507

118,318 people effected by the earthquake

Rs. = Rupees

Table 3.5 Types of assistance received from Dharan Town Panchayat

Item	Rs.
Rice	350000
Medicines	25000
Instruments	15000
Water Containers	21000
Fuel	101000
Food for Volunteers and Drivers	15000
Plastic	7500
Iron and Cotton Ropes	12400
Given to Ward Relief Committee	57000
Stationary and Other goods	51100
Total	655000

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

Central Government	Cash	1898000 Rs.	
	Rice	2516.8 Quintal	(1 quintal=112 Lb)
	Other Blanket/Tents	205	
	Corrugated Iron	200 Binding	(1 bind.=15 sheets)
	Plastic	791	
Sunsari District Panchayat	Relief Cash to Kin of the Dead	1000 Rs./dead	
	Total	122000 Rs.	

Rs. = Rupees

(see section 4.1).

On the assumption that the dimensions of a typical brick masonry building are $5 \times 6\text{m}^2$; a unit, 3-m story height; a wall thickness of 50 cm; an average weight of 1000kg/m^2; and an ultimate shear stress of fired brick of 0.9 - 0.5kg/cm^2, 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/sec^2. The ultimate stress of adobe is about 0.3 -0.5 kg/cm^2, 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.

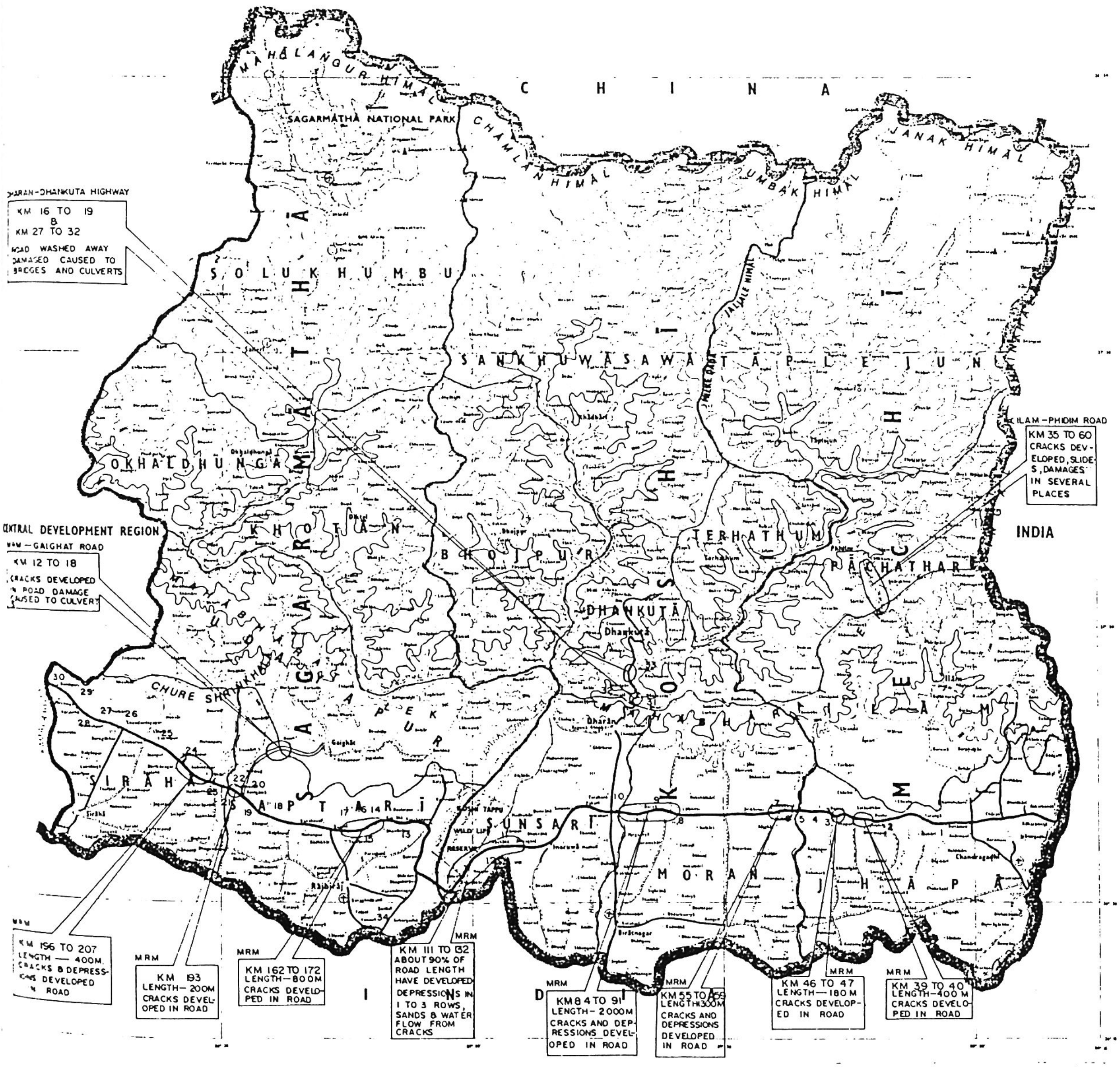
The relation between the number of dead and the number of damaged buildings per ward is shown in *Fig.* 3.6. The ratio of deaths to collapsed houses, marked by circles, is roughly 10%. A detailed explanation is given in the next section.

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



ARAN-DHANKUTA HIGHWAY

KM 16 TO 19
&
KM 27 TO 32
OAD WASHED AWAY
DAMAGED CAUSED TO
BRIDGES AND CULVERTS

CENTRAL DEVELOPMENT REGION

MRM — GAIGHAT ROAD

KM 12 TO 18
CRACKS DEVELOPED
IN ROAD DAMAGE
CAUSED TO CULVERT

ILAM — PHIDIM ROAD

KM 35 TO 60
CRACKS DEVELOPED, SLIDES, DAMAGES
IN SEVERAL
PLACES

MRM

KM 196 TO 207
LENGTH — 400M.
CRACKS & DEPRESSIONS DEVELOPED
IN ROAD

MRM

KM 193
LENGTH — 200M
CRACKS DEVELOPED IN ROAD

MRM

KM 162 TO 172
LENGTH — 800M
CRACKS DEVELOPED IN ROAD

MRM

KM 111 TO 132
ABOUT 90% OF
ROAD LENGTH
HAVE DEVELOPED
DEPRESSIONS IN
1 TO 3 ROWS,
SANDS & WATER
FLOW FROM
CRACKS

MRM

KM 84 TO 91
LENGTH — 2000M
CRACKS AND DEPRESSIONS DEVELOPED IN ROAD

MRM

KM 55 TO 59
LENGTH 1300M
CRACKS AND
DEPRESSIONS
DEVELOPED
IN ROAD

MRM

KM 46 TO 47
LENGTH — 180 M
CRACKS DEVELOPED IN ROAD

MRM

KM 39 TO 40
LENGTH — 400 M
CRACKS DEVELOPED IN ROAD

NB.- KILOMETRE CHAINAGE STARTS FROM KAKARVITTA FOR MAHENDRA RAJ MARG (M.R.M.) FROM DHARAN FOR DHARAN DHANKUTA AND FROM RAJBIRAJ FOR RAJBIRAJ – KUNAULI.

Fig. 3.7 Damage to roads in the eastern development region of Nepal

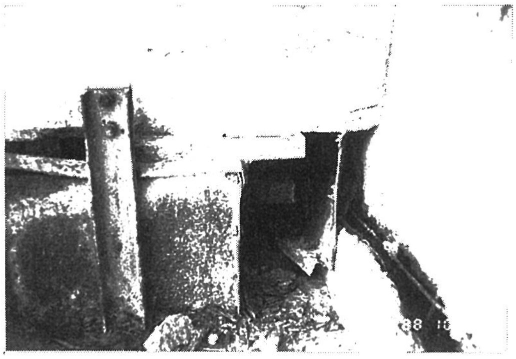


Photo. 3.65 Displacement of the shoe at Gehari Bridge, Nepal

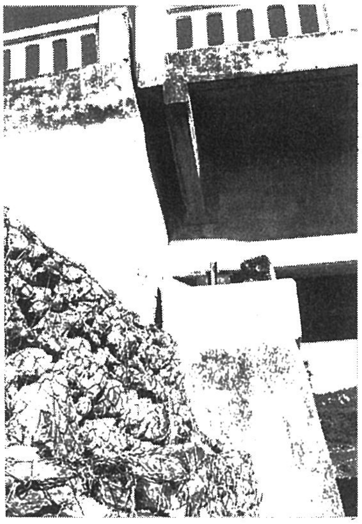


Photo. 3.66 Tilting of an abutment at Gehari Bridge, Nepal

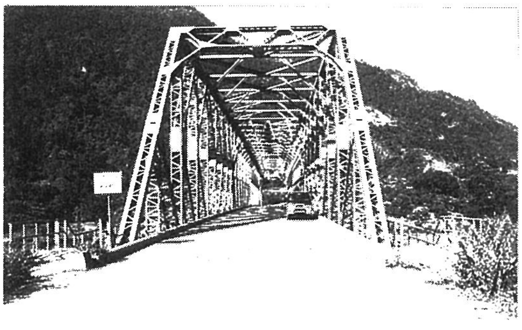


Photo. 3.67 Undamaged truss bridge

Photo. 3.68 Undamaged arch bridge

Photo. 3.69 Rockslide site undergoing restoration

Photo. 3.70 Road damaged by a landslide

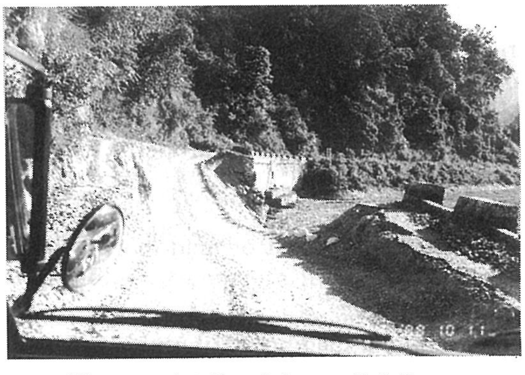


Photo. 3.71 Retaining wall failure

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 effected 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

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[3.2] Technical Report on The Structural Performance of The Tokyo Station Building, JR Technical Research Institute, Kokubunji, Tokyo, March 1988 (in Japanese).

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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].

$$D = 1.45 \cdot H^{0.93} \cdot F \cdot T \cdot A \qquad (4-1)$$

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

$$D = 1.45 \cdot H^{0.93} \cdot 0.12 \cdot 1.00 \cdot 0.22$$

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 Imaichi 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

	Nepal Eastern Natural Disaster Relief Working Co-ord. Committee	Bihar State Relief Commissioner
Dead	721	282
Injured	6,213	3,766
Dwellings	14,964 destroyed 33,959 cracked/useless 24,496 cracked/repairable 20,089 simple cracks	25,093 collapsed 46,399 major damage 77,842 minor damage

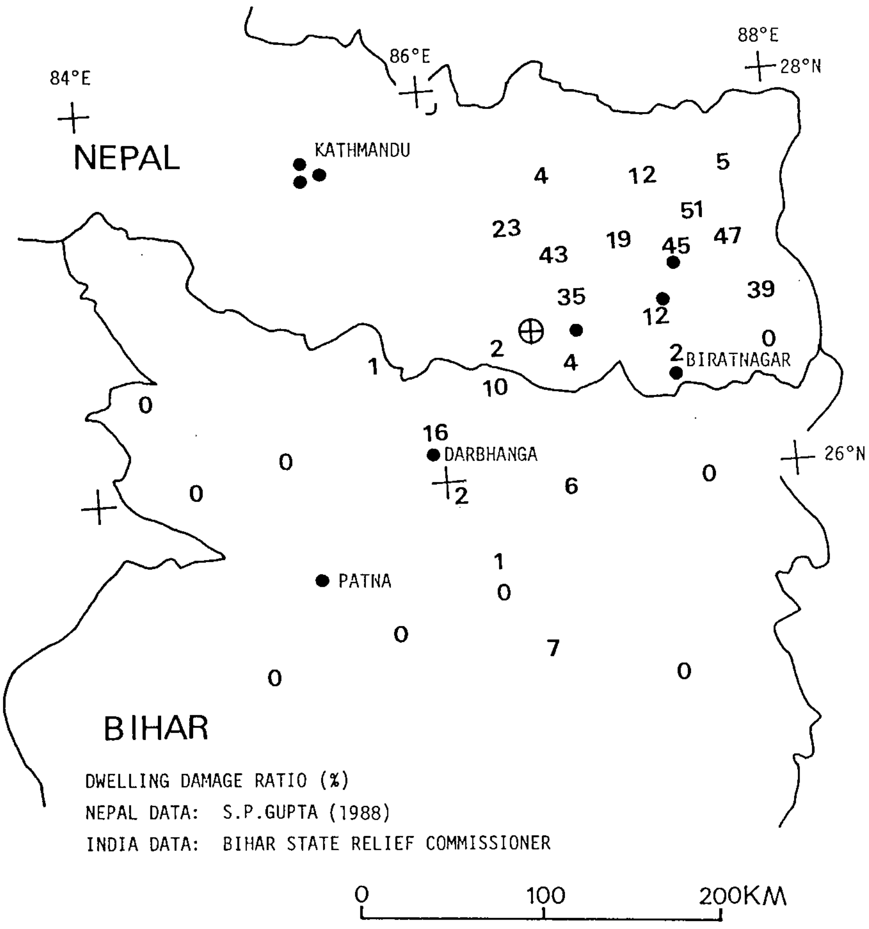


Fig. 4.1 Map of the affected region showing dwelling damage ratios

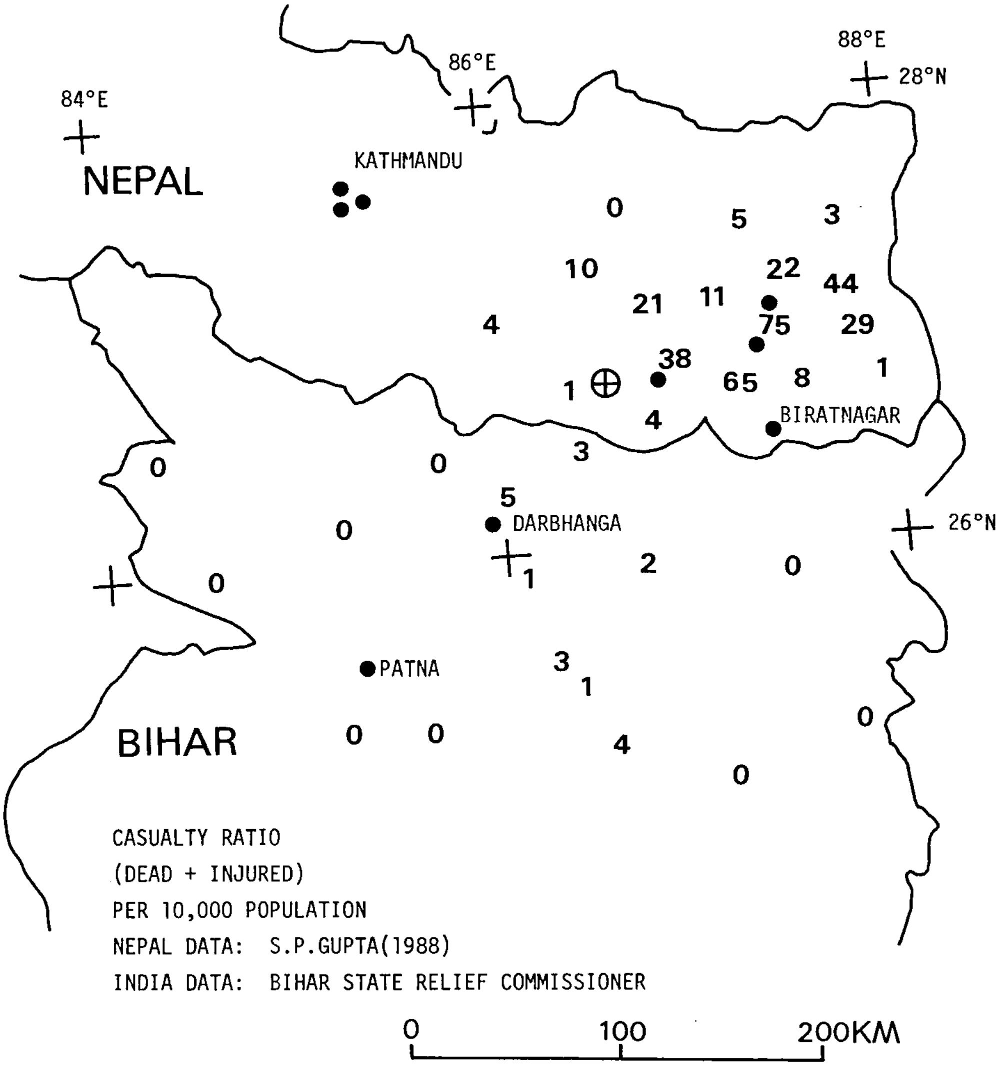


Fig. 4.2 Map of the affected region showing casualty ratios

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,86.616°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 52,000 (2.4% dead) (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 collapsed (or heavily damaged and unrepairable) dwelling in Munger. A large number of seismological and geological reports are available for this earthquake that were compiled by Officers of the Geological Survey of India [Refs.4.3, 4.4].

Recently, Pandey and Molnar (1988) examined damage records for the 1934 earthquake in Nepal and made a good statistical summary of the structural damage and fatalities by region [Ref.4.5]. As *Table* 4.2 indicates, 8,519 Nepalese were killed and 207,740 houses and buildings damaged, of which 81,000 (39%) were completely flattened. Overall, the average lethality was about 2% in Nepal. The distribution of fatalities is shown on the Nepalese map in *Fig.* 4.3. In the Kathmandu Valley, where 19% of the dwellings were completely destroyed, 39% much damaged, and 27% slightly damaged, the fatalities numbered 4,296, about 1% of the population. Average lethality for an occupant of a destroyed house was approximately 6%, comparable to the estimation for Munger, Bihar. In the Eastern Mountainous Region (presently the Okhaldhunga and Bhojpur districts), the fatality ratio was

Table 4.2 Houses destroyed and casualties in the 1934 Earthquake, Nepal [Ref.4.5]

Region	DAMAGED HOUSES				CASUALTIES		
	Complete destruct.	Much fracture	Slight fracture	Total	Men	Women	Total
KATHMANDU VALLEY							
Kathmandu	725	3735	4146	8606	254	225	479
Outskt.of Kathmandu	2892	4062	4267	11221	79	166	245
Patan	1000	4170	3860	9030	250	297	547
Outskirts of Patan	3977	9442	1598	15017	871	826	1697
Bhaktapur	2359	2263	1425	6047	433	739	1172
Outskt.of Bhaktapur	1444	1986	2388	5818	65	91	156
Totals	12397	25658	17684	55739	1952	2344	4296
EASTERN MOUNTAINOUS							
East No 1	9628	19391	-	29019	163	193	356
East No 2	4687	10738	-	15425	52	43	95
East No 3	21107	15548	-	36655	330	527	857
East No 4	15048	5	-	15053	698	899	1597
Dhankuta	6623	15120	-	21743	162	154	316
Sindhuli Gadhi	3486	3154	-	6640	51	58	109
Udayapur Gadhi	1052	3917	-	4969	295	257	552
Ilam	2316	3112	-	5428	41	51	92
Totals	63947	70985	-	134932	1792	2182	3974
WESTERN MOUNTAINOUS							
West No 1	582	1720	-	2302	4	6	10
West No 2	186	461	-	647	0	1	1
West No 3	19	65	-	84	0	1	1
West No 4	8	1	-	9	0	1	1
Chisapani Gadhi	-	18	1266	1284	25	27	52
Palpa	-	3	-	3			
Totals	795	2268	1266	4329	29	36	65
TERAI(PLAIN)							
Western Terai	-	4	6	10	0	0	0
Chitwan	-	-	-	-	-	-	-
Birgunj	3654	854	2546	7054	16	28	44
Sariati & Mahattari	-	4323	268	4591	31	20	51
Sirha & Saptari	87	428	-	515	17	23	40
Biratnagar	13	1	64	78	13	36	49
Jhapa	-	-	-	-	0	0	0
Totals	3754	5610	2884	12248	77	107	184
Totals for Nepal	80893	104521	21834	207248	3850	4669	8519

Table 4.3 Damage statistics for the July 1980 Earthquake in far western Nepal [Ref.4.6]

District	Affected pancha-yat	Houses collap-sed	Houses cracked	Houses cracked (minor)	Dead	Wounded (human	Popu-lation 1981	Density per sq.kms
Darchula	26	4135	2743	-	24	-	90218	38.9
Baitadi	41	1257	1949	-	22	236	179136	117.9
Dandeldhura	-	-	120	-	-	-	86853	56.5
Bajhang	35	6137	6380	2200	-	-	124010	36.2
Bajura	19	419	654	1199	-	-	74649	34.1
Achham	46	781	1227	1583	-	-	185212	110.2
Doti	30	82	225	1395	-	-	153135	75.6
Total	197	12817	13298	6377	46	236		

Note: Casualty data are apparently incomplete.

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 aseismic 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/km^2 population density of Darchula and Bajhang districts is far less than the 200 persons/km^2 of the Sunsari, Dhankuta and Tehrathum districts of the Eastern Development Region (most severely hit in 1988).

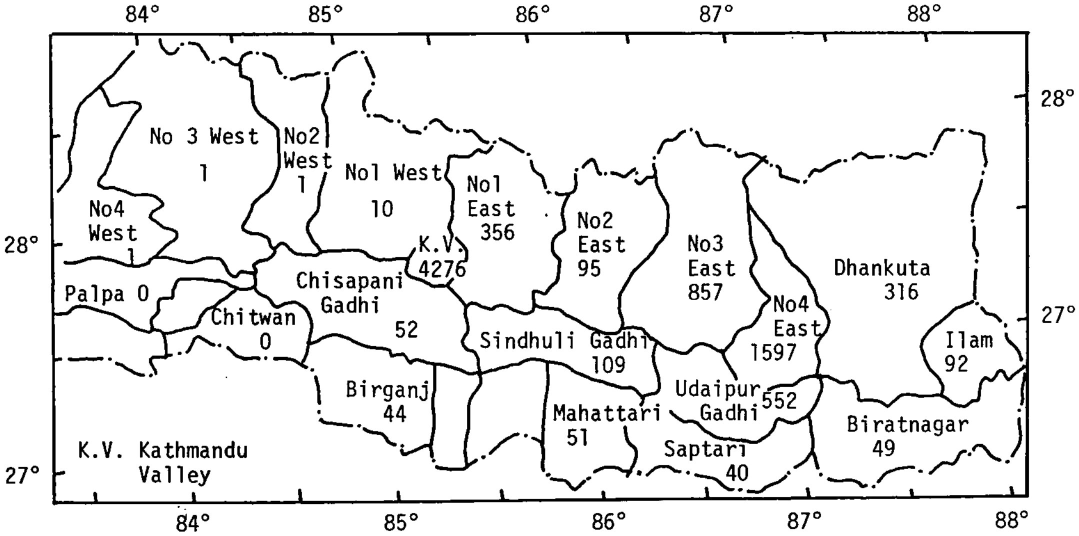


Fig. 4.3 Location of stricken districts and the number of fatalities in Nepal caused by the 1934 Bihar-Nepal Earthquake [Ref.4.5]

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

Age group	MALE				FEMALE			
	Fatal cases	Fatal %	Pop %	Fat.%/ Pop.%	Fatal cases	Fatal %	Pop %	Fat.%/ Pop.%
0-4	36	18.0	15.5	1.2	25	11.9	15.3	0.8
5-9	51	25.5	14.5	1.8	48	22.9	14.6	1.6
10-14	32	16.0	11.9	1.3	23	11.0	10.8	1.0
15-19	16	8.0	9	0.9	14	6.7	8.6	0.8
20-24	15	7.5	8.3	0.9	19	9.0	9.5	1.0
25-29	9	4.5	7.4	0.6	10	4.8	8.1	0.6
30-34	1	0.5	6.1	0.1	12	5.7	6.9	0.8
35-39	2	1.0	6	0.2	10	4.8	5.9	0.8
40-44	6	3.0	4.9	0.6	6	2.9	5.1	0.6
45-49	6	3.0	4.3	0.7	6	2.9	3.9	0.7
50-54	7	3.5	3.8	0.9	8	3.8	3.4	1.1
55-59	2	1.0	2.4	0.4	1	0.5	2.2	0.2
60-64	5	2.5	2.5	1.0	8	3.8	2.4	1.6
65-69	3	1.5	1.3	1.2	8	3.8	1.2	3.2
70-74	2	1.0	1.1	0.9	5	2.4	1.0	2.4
75+	7	3.5	1	3.5	7	3.3	0.9	3.7
unknown	97	-	-	-	121	-	-	-
total	297				331			

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.

From 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

$$L = F/(C \cdot S) \qquad (4-2)$$

in which F denotes the number of fatalities, C the number of collapsed houses, and S

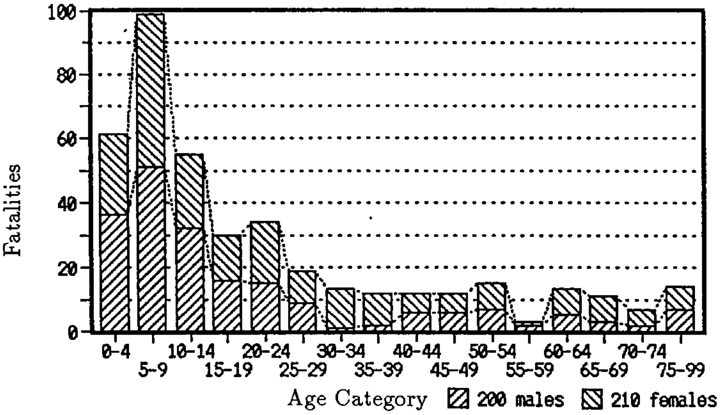


Fig. 4.4 Number of fatalities by age and sex in Nepal

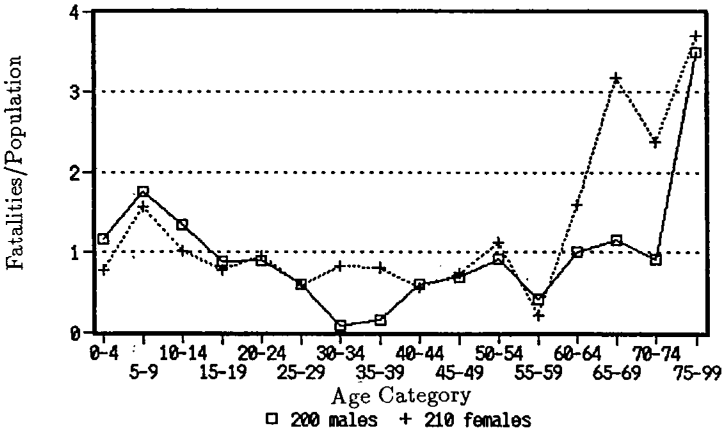
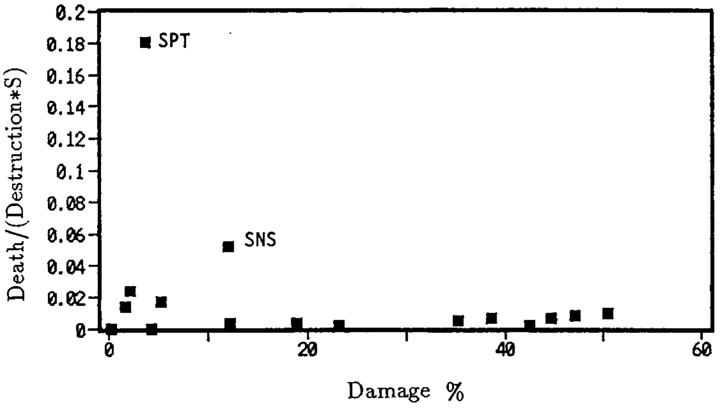


Fig. 4.5 Ratio of fatalities divided by the total population shows the risk of fatality by age and sex in Nepal



S: average size of a household

Fig. 4.6 Relation of the lethality index (number of dead/number of occupants in destroyed dwellings) to the percent of damage in Nepal the average size of a household ($\simeq 6$). 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 Saptari (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

$$\begin{aligned} L &= F/(C \cdot 5.9) \\ &= 0.0484(C/D) \qquad (4-3) \end{aligned}$$

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.

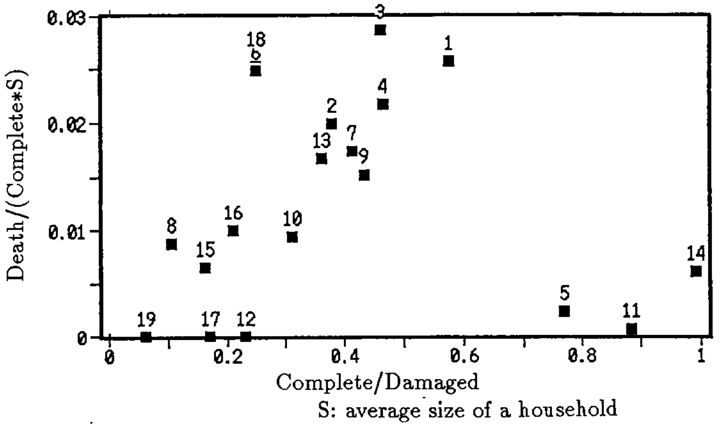


Fig. 4.7 Relation of the lethality index to the dwelling damage severity index in Dharan Town Panchayat, Nepal

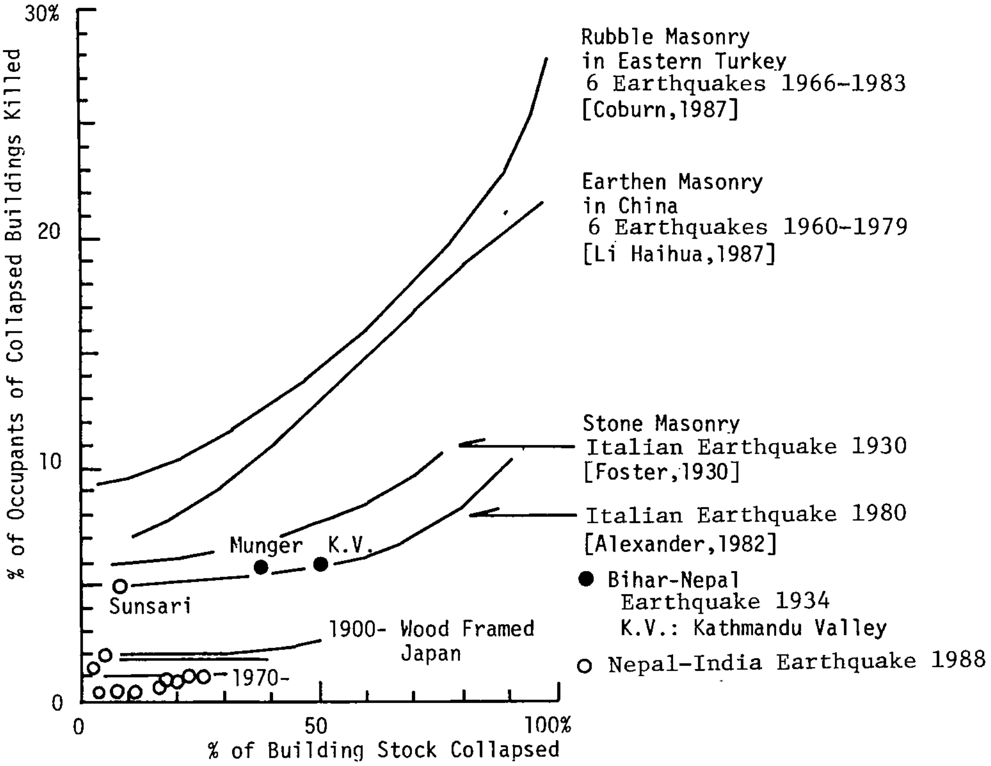


Fig. 4.8 Relation of lethality to building type [Ref.4.9]
Sunsari and other Nepal districts are from the 1988 Earthquake,
and Munger and K. V. (Kathmandu Valley) from the 1934 Earthquake

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 1% 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

$$P_c = 0.0076P_d + 0.047 \qquad (4-4)$$

$R = 0.609$ and $St.error = 0.19$ for Nepal, and

$$P_c = 0.0032P_d + 0.006 \qquad (4-5)$$

$R = 0.888$ 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.

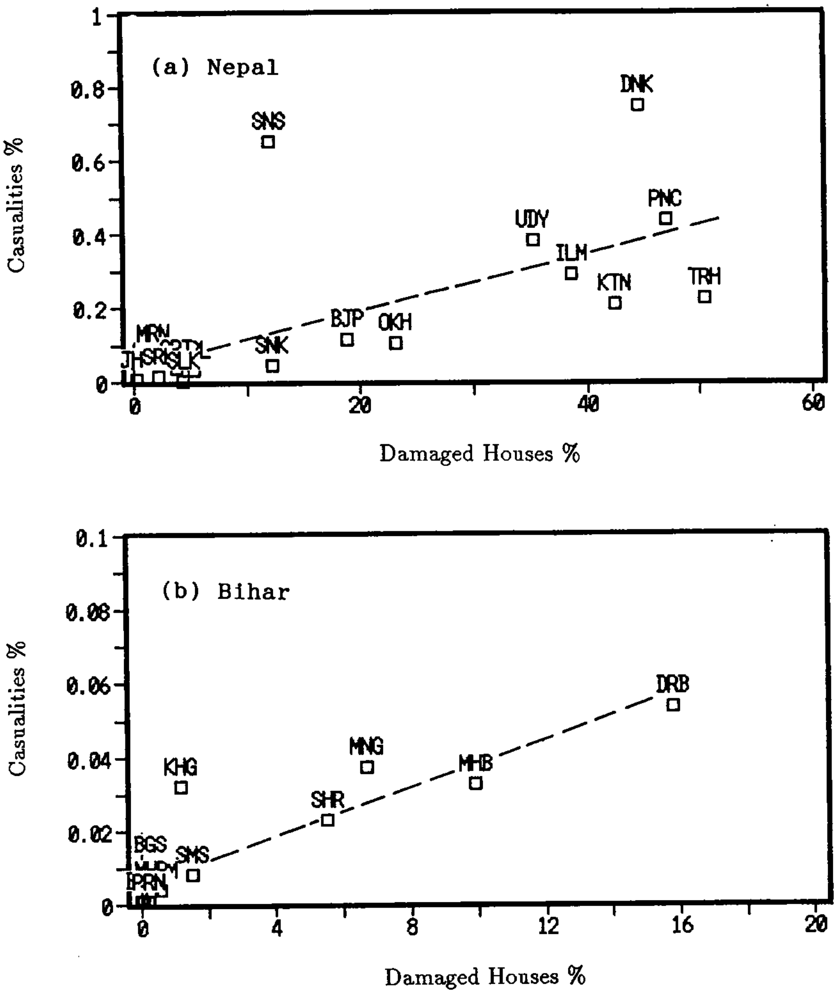


Fig. 4.9 Relation of the dwelling damage ratio to the casualty ratio for Nepal and Bihar State, India

4.4 Emergency Medical Responses

4.4.1 Immediate damage assessment

The extent of earthquake damage must be evaluated quickly if there are to be quick responses that ensure rescue, medical aid, food and shelter. The official death tolls, revised daily, were reported in the Rising Nepal and Hindustan Times newspapers (*Fig.* 4.10). Day 1 denotes 21 August when the earthquake took place. It took about 7 days in Nepal (where 708 people were killed) and 9 days in Bihar (where 281 people were killed) to determine the total number of fatalities. The difference seems to be related to there being better telephone communication, a more enthusiastic survey, and less administrative formalities in Nepal than in Bihar.

Changes in the official figures for the 9 districts most badly damaged in the Eastern Development Region of Nepal are shown in *Fig.* 4.11. Fatality assessment was rapid in some districts but slow in others. Some surveys were finished on the 3rd day, others not until the 7th day. The remoteness of a district or the extent of damage (total number of deaths) do not satisfactorily explain this difference.

4.4.2 Kosi Zonal Hospital

Kosi Zonal Hospital in Biratnagar is primitive by modern standards but is the largest health care facility in the Eastern Development Region of Nepal. Officially it has 100 beds, but in actuality there are 140 beds and 22 medical doctors. It accepted 560 patients after the earthquake. *Table* 4.5 gives the number of patients by district and gender and shows that there were almost equal numbers of male and female patients. From *Table* 4.4, we know that the number of fatalities did not significantly differ for the two sexes; therefore, we conclude that injured males and females had comparable opportunities for treatment at the hospital.

Almost half of the patients (45.7%) came from the Morang district in which the hospital is located although the 30 lives lost recorded for that district is a moderate figure (4 % of the total for Nepal). The distance to Biratnagar from each stricken district was a major factor in determining the number of patients (*Fig.* 4.12). Another important factor, naturally, was the number of human casualties in a district (*Fig.* 4.13). It is difficult to determine what the complex effect of these two factors was because Sunsari and Dhankuta districts, which had the highest human loss, are relatively close to Biratnagar, Morang district. The following linear equation is derived with the correlation coefficient $R = 0.71$:

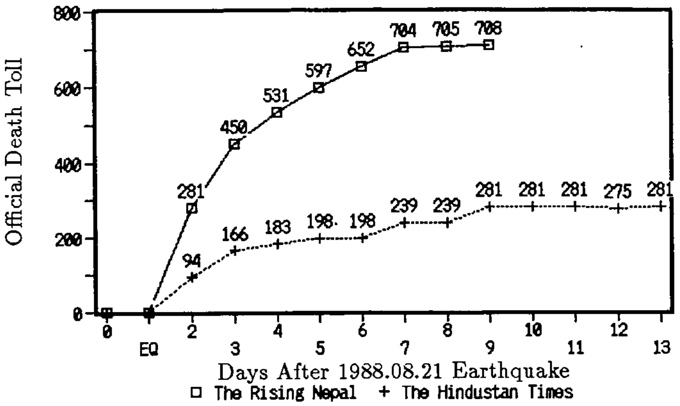


Fig. 4.10 Change in the official death toll with time (days) after the 1988 Nepal-India earthquake

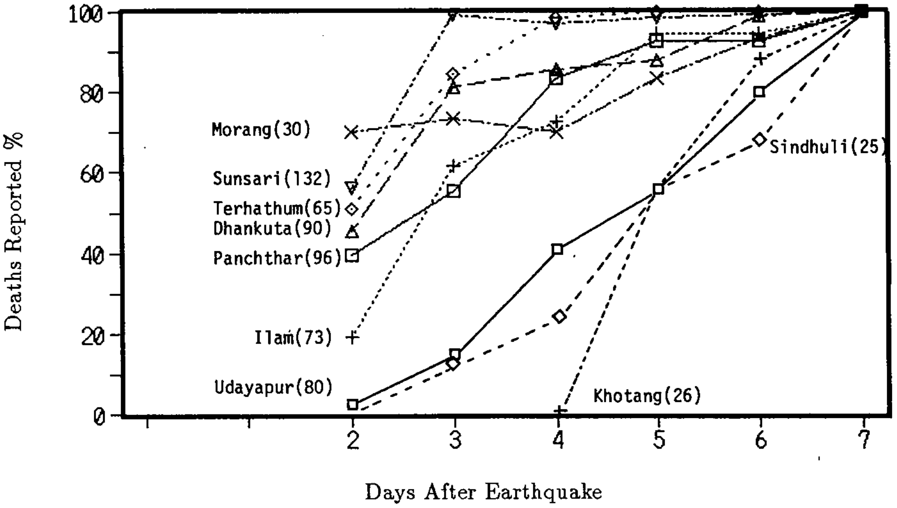


Fig. 4.11 Number of days taken to total the number of deaths in the effected districts of Nepal.
Numbers in parentheses give the fatalities in each district.

Table 4.5 Patients admitted to the Kosi Zonal Hospital (21 August to 10 October)

Zone	District	Male	Female	Total	%
Mechi	Taplejung	1	0	1	0.2
	Panchthar	17	21	38	7.0
	Jhapa	7	11	18	3.3
	Ilam	7	5	12	2.2
Kosi	Dhankuta	4	3	7	1.3
	Bhojpur	7	3	10	1.8
	Morang	131	116	247	45.7
	Sunsari	42	44	86	15.9
Sagar-matha	Okhaldhunga	4	2	6	1.1
	Udayapur	35	27	62	11.5
	Siraha	6	8	14	2.6
	Khotang	16	22	38	7.0
Janakpur	Sindhuli	0	2	2	0.4
Total		277	264	541	100.0

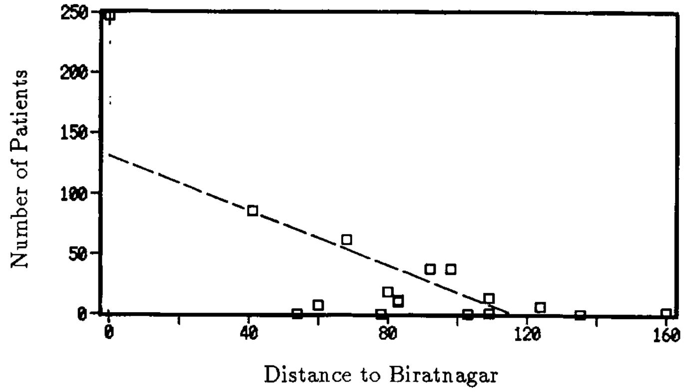


Fig. 4.12 Relation of the number of patients admitted to Kosi Zonal Hospital by district to the distance from the hospital

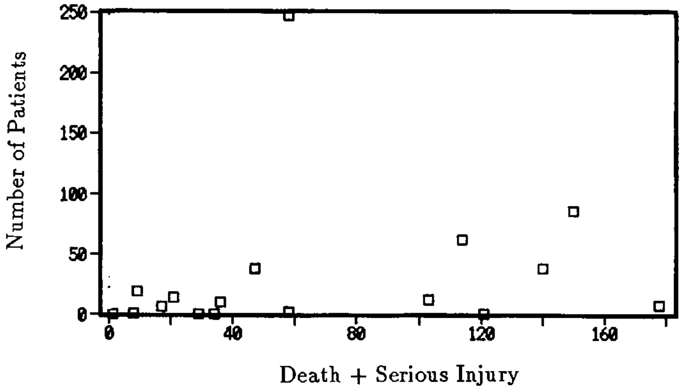


Fig. 4.13 Relation of the number of patients admitted to Kosi Zonal Hospital by district to the number of casualties

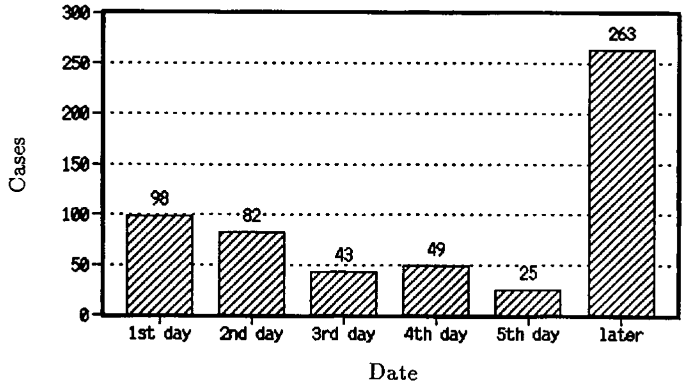


Fig. 4.14 Dates of patient arrival at Kosi Zonal Hospital

$$P = 131 - 1.15S \qquad (4-6)$$

in which P is the number of patients and S the distance to Biratnagar (Kosi Zonal Hospital). This shows the mixed effect of these two factors.

Dates of arrival at Kosi Zonal Hospital are shown in *Fig.* 4.14. The injured from nearby towns and villages came in during the first few days, but more than half of those treated arrived on the 6th day or later. This is because they had been referred from smaller district health centers or had been transported by helicopters from remote mountain villages. The Rising Nepal (Aug. 28) reported, "171 persons (31 from Khotang, 21 from Ilam, 24 from Udayapur, 36 from Panchthar, and 42 from Dhankuta) [who are] seriously wounded have been airlifted to Kosi Zonal Hospital by helicopters of the Royal Nepal Army." The paper reported on Sep. 2, "The number of severely injured persons airlifted to Biratnagar had reached 276 till Wednesday [Aug. 31] evening."

The types of injury (*Table* 4.6) incurred were mostly fractures of various parts of the body, the majority of fractures being those of the upper and lower limbs. This is a reasonable pattern of injury as most casualties were caused by the destruction of houses; it does not differ from patterns for previous earthquakes.

4.4.3 Dharan Hospital

Dharan District Hospital (25 beds) with 2 doctors, 2 medical assistants, and 3 nurses is little more than a maternity unit and cottage hospital. The city of Dharan has a population of 118,218 and 20,000 households; 122 people were killed and 4,275 houses damaged (1,671 completely and 2,604 partially). The 2-story house of the hospital superintendent was damaged beyond repair and the 1-story hospital ward had cracked walls (see Section 3.2.4).

Right after the earthquake, 1 local doctor and 1 medical assistant came in to help. Two hours later, 1 doctor and 2 medical practitioners, (1 from Indian Camp and 1 from Kathmandu) came in. Seven volunteers joined from the British Camp. Three medical students came from the Teaching Hospital in Kathmandu. The Rising Nepal (Aug. 24) reported "A six-member advance team of Health Professionals for Social Responsibility, Nepal, headed by an assistant lecturer of the T.U. [Tribhuvan University], Institute of Medicine left for Dharan-Bijayapur, Biratnagar and Dhankuta to extend medical relief assistance." A Japanese team (1 surgeon, 1 pediatrician, 1 nurse) joined later.

Nineteen people were brought in dead. During the first 24 hours after the earthquake, 700 patients were recorded. Totally 1,359 injury cases were recorded, of which 39 were admitted to indoor beds, 85 put into tents, 15 critical cases referred to Kosi Zonal Hospital, and 86 referred to the British Camp Hospital. The superintendent estimates that 800 additional

Table 4.6 Types of injury treated at the Kosi Zonal Hospital

Type of injury	cases	%
head injury (most died)	41	7.3
chest injury	35	6.3
spinal fractures	52	9.3
pelvic fracture	12	2.1
femur fracture	16	2.9
fracture of other bones & multiple injuries	404	72.1
Total	560	100.0

Table 4.7 Casualties and treatment in Dharan

	Ayurvedic inst.	Dharan hospital	British Army hosp.	Total
Number of People registered in hospital	96	1055	893	2044
Retun after treatment	96	1053	819	1968
Under treatment		2	67	69
Died in hospital			7	7

Remarks		
	Treated by Red Cross	70
	Health expedition, health pos	128

Ayurvedic: India traditional medicine

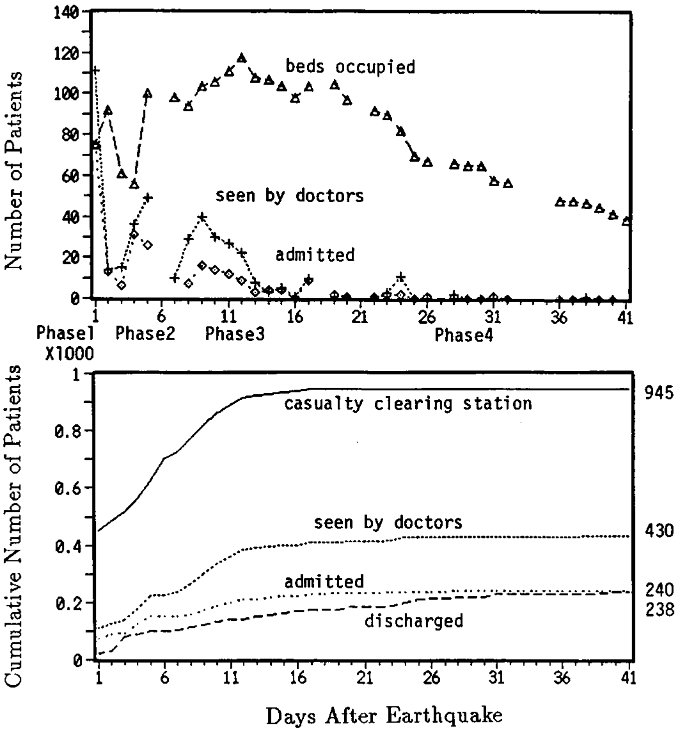


Fig. 4.15 Response of the British Army Recruit Camp Hospital in Dharan Bazaar in the days after the earthquake

patients who were given first aid were not recorded due to extreme confusion. As to the type of injuries treated, 10-15% included head and spinal injuries and pelvic fracture; the remainder were cuts and fractures of limbs.

The number of earthquake casualties treated in the town according to the Dharan Town Panchayat (administrative unit) is given in *Table* 4.7. Dharan Hospital and the British Army Hospital had comparable numbers of patients, but the latter accepted more serious injuries. Not all the casualty cases were from Dharan itself, some were from other towns and villages.

4.4.4 The British Army Recruit Camp Hospital

The British Army Hospital in Dharan also played a very important role in treating earthquake injuries. The camp facilities, mostly single-story, concrete block masonry buildings showed moderate cracking (Ref. Section 3.2.4, *Photo.* 3.32). The water supply system (an 8-km pipeline from the hill) was damaged but repaired in a few days. Fortunately the sewage system was not damaged.

This hospital normally has 72 beds, 4 doctors and a 105-member medical staff. Their emergency response has been well summarized by Headquarters British Gurkhas Nepal [Ref.4.10]. Within 4 days, 250 emergency beds were added in tents with extra toilets and water supply. From UK-Hongkong Hospital, 2 doctors, 7 specialists and 57 nurses arrived to give assistance. The Rising Nepal (Aug. 25) reported, "A medical team comprised of 14 males and 5 females along with medicines arrived Kathmandu Wednesday [Aug. 24] by British Royal Air Force Hercules aircraft."

The hospital erected a tented Casualty Clearing Station on the first day at the gate of the Camp, so that the flow of patients could be controlled (triage). In all, this hospital took 884 injuries, of which 256 were hospitalized, 515 received treatment and were released, and 8 died. Also, 89 major and 223 minor operations were performed. As for the types of injury, the British Gurkhas report says, "most were fractures and crush injuries with virtually no traumatic amputations or severe cuts requiring blood". The Rising Nepal (Aug. 29) reported, "29 persons were airlifted to British-Gurkha Camp hospital of Dharan by Royal Nepal Army helicopters."

The change in the numbers of patients by day after the earthquake is shown in *Fig.* 4.15. The first peak appears on the day of the earthquake (Phase 1 - the mass casualty situation) because of the immediate inflow of casualties from the town of Dharan. It took several days for the second peak representing patients arriving from the hill areas (Phase 2 - Consolidation: Days 1 to 5). Movement of casualties was hampered by landslides on the 52-km Dharan to Dhankuta road, and helicopters had to be called in. There was a similar situation at Kosi Zonal Hospital (*Fig.* 4.14). During Phase 3 (Expansion: Days 6 to 24) 117 beds were occupied at the peak. It took about 12 days before the treatment or admission of new patients ended. Phase 4 (Rehabilitation/ Discharge) started on day 24 when the reinforcement team returned to Hong Kong.

4.4.5 Darbhanga Medical College Hospital

The district of Darbhanga with a population of 2 million reported 83 fatalities and 992 injuries (Bihar State Relief Commissioner). Darbhanga Medical College Hospital (DMCH) with 100 beds admitted 225 patients and discharged 250 patients after giving them first aid on the day of the earthquake (the Hindustan Times, Aug. 22). Four doctors and a dozen nurses worked without water or power for an entire day. A third-year medical student suffered a spinal injury while trying to rush down the stairs of the old hostel (*Photo.* 3.17) at DMCH when the staircase collapsed; he was buried in its debris. He was airlifted to Patna Medical College (The Hindustan Times, Aug. 24).

According to the interview with the Civil Surgeon of Darbhanga, DMCH admitted about 600 earthquake-related patients, of which 3 were brought in dead, 6 died in the DMCH, 40 were still being treated in the hospital as of Oct. 6, 1988, and the rest had been discharged. Before the earthquake the Hindustan Times (Sep. 16) reported that the DMCH had been flooded and its sanitary conditions were poor .

4.5 Earthquake-related Articles in Newspapers

4.5.1 Topics of the articles

The treatment of earthquake news in the newspapers reveals the social, political and economic impact of the disaster in the society or country hit. Proper release of information through the mass media on the extent of damage and available public assistance helps those who are effected respond to the emergency and aids in a smooth recovery from the earthquake.

The Rising Nepal is one of the most influential English newspapers in Nepal. The Hindustan Times is published both in Patna, the state capital of Bihar, and in Delhi, so that it covers local news well. Both papers were read carefully to obtain the earthquake-related articles published from August 22 to September 30 [Refs. 4.11 and 4.12].

The Nepalese articles have been classified according to topic (*Fig.* 4.16). The topics emphasized are "Provisions, Medicine" (distribution of relief materials), "Medical Care"

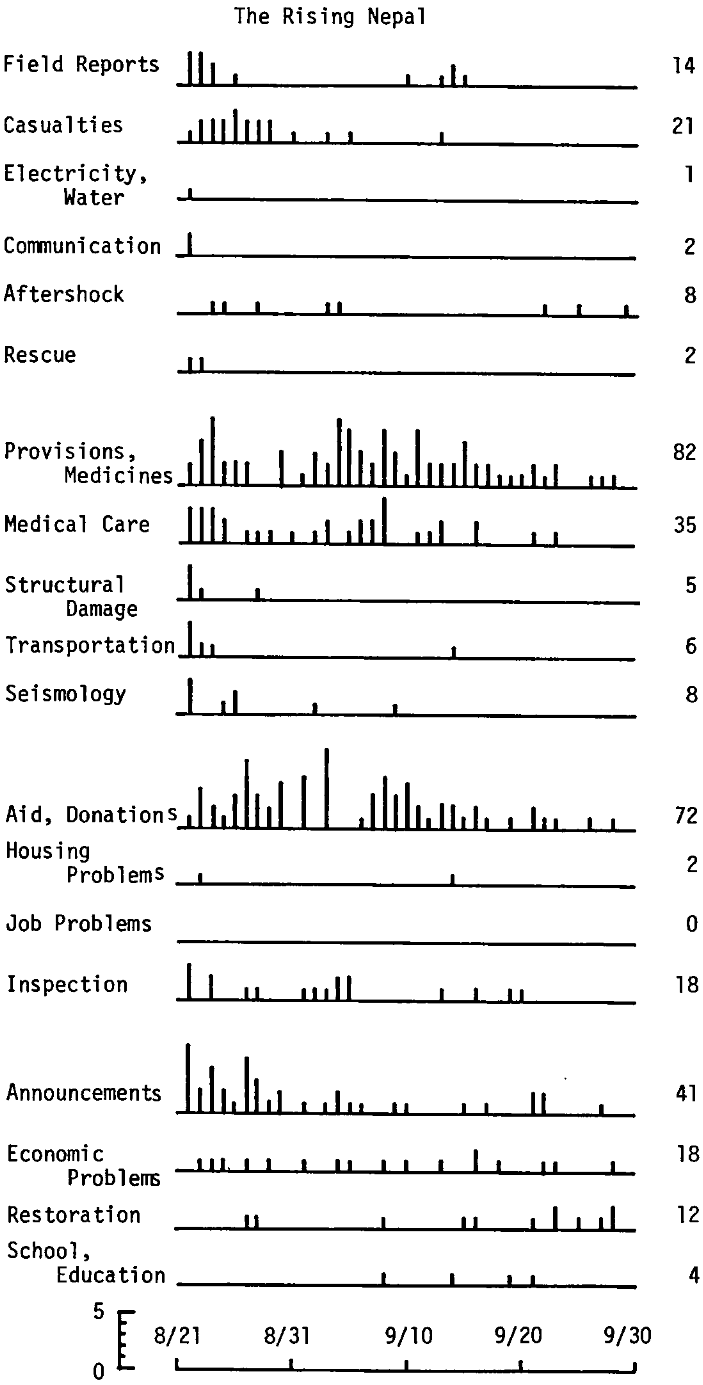


Fig. 4.16 Topics of earthquake-related articles in the newspaper Rising Nepal
22 Aug. to 30 Sep 1988

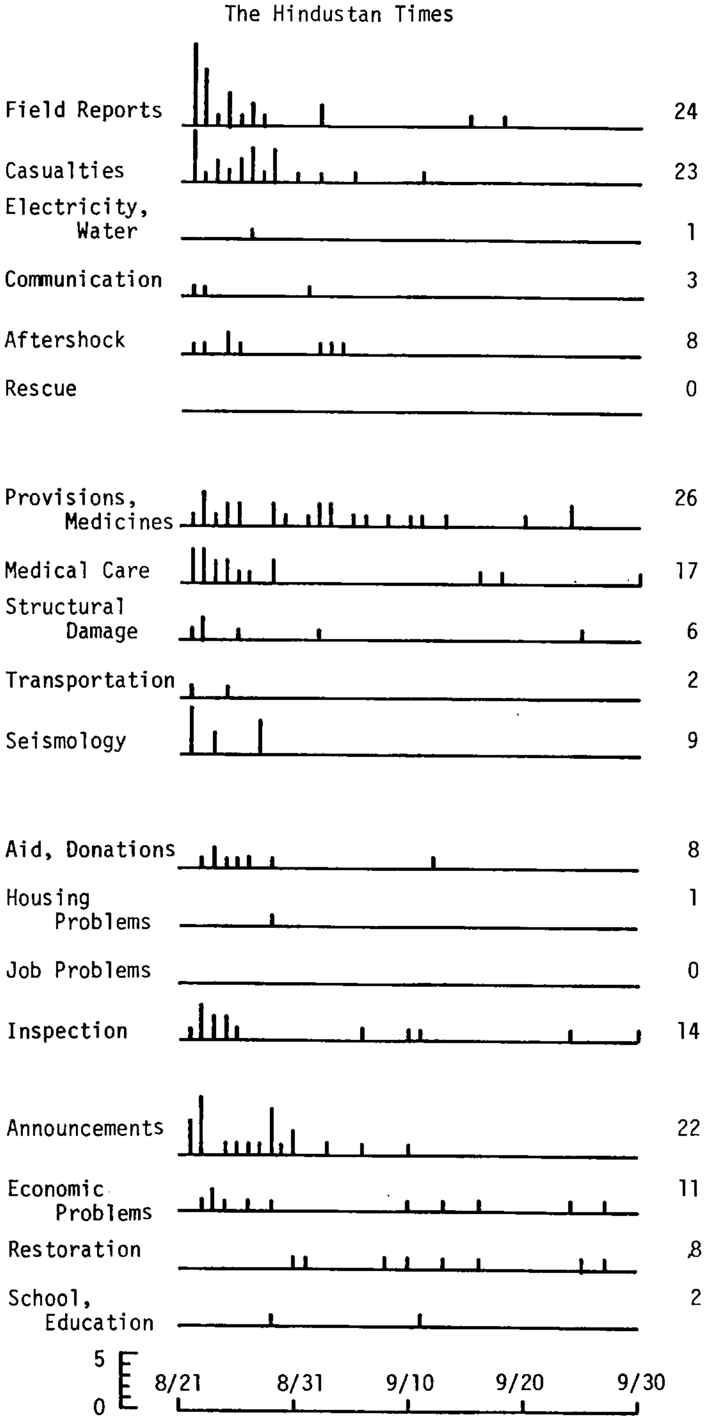


Fig. 4.17 Topics of earthquake-related articles in the newspaper Hindustan Times, Bihar State 22 Aug. to 30 Sep 1988

(hospital response, number of patients, etc.), "Aid, Donations" (from foreign governments and various domestic organizations), and "Announcements" (condolences, opinions, and political views). "Field Reports" and "Casualties" appear in the early stage; whereas, "Economic Problems" and "Restoration" appear later. The articles on specific "Structural Damage", "Housing Problems", and "Restoration" are very important, but are fewer than desirable.

The Bihar articles are classified in *Fig.* 4.17. The topics emphasized are "Field Reports" (general description of various types of damage), "Casualties" (numbers and places of the injured and dead), "Provisions and Medicines", and "Announcements". Most of those articles are concentrated in the 10 days after the earthquake, and although "Economic Problems" and "Restoration" account for only a few articles, they were published throughout the period.

4.5.2 Quantity of news

The cumulative number of earthquake-related articles per day published after the earthquake is shown in *Fig.* 4.18. On Day 1, when the earthquake took place, the Nepalese paper published 261 articles, about 2 times the 127 articles run by the Bihar paper. The average length (words) of an article was shorter in the Rising Nepal than in the Hindustan Times. This reflects the difference in the social impact of the earthquake in Nepal and in Bihar.

The day-to-day numbers of articles are shown in *Fig.* 4.19. Application of the equation formulated by T. Sato [Ref.4.12];

$$Y = A \cdot exp(B \cdot T) \qquad (4-7)$$

in which T denotes the day after earthquake, Y the number of articles, and coefficients A and B are determined by the least squares method gives

$$LN(Y) = -0.047T + 2.65 \qquad (4-8)$$

for the Rising Nepal with $R = 0.67$, and

$$LN(Y) = -0.061T + 2.13 \qquad (4-9)$$

for the Hindustan Times with $R = 0.74$.

The number of days in which the number of articles decreases to half can be shown as the duration index of special earthquake news, which is calculated by

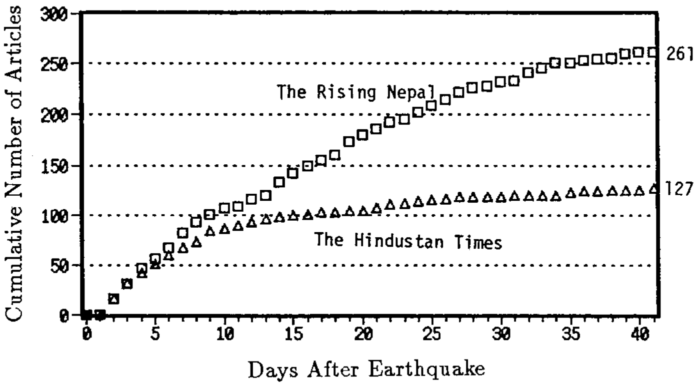


Fig. 4.18 Cumulative numbers of articles in the Rising Nepal and the Hindustan Times in the days following the earthquake of 21 Aug. 1988

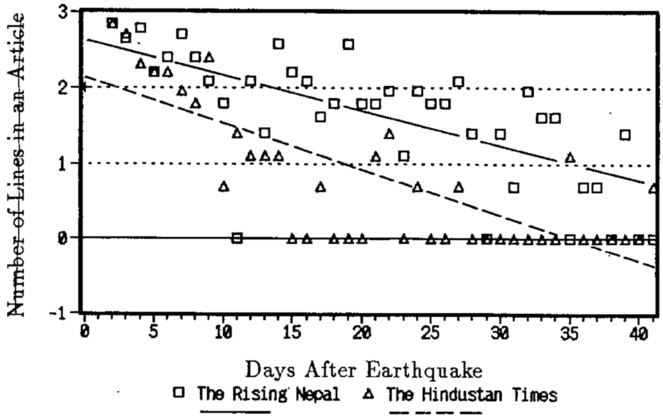


Fig. 4.19 Attenuation of the number of earthquake-related articles in the Rising Nepal and the Hindustan Times and estimated equations (4.8) and (4.9)

$$T_{0.5} = LN(0.5)/B \qquad (4-10)$$

giving 14.7 days for the Rising Nepal and 11.3 days for the Hindustan Times. These durations are shorter than those obtained from the newspapers Mexico News (24.3 days) for the 1985.9.15 Mexico Earthquake, the Akita Sakigake (36.4 days) for the 1983.5.26 Central Japan Sea Earthquake, and the Kahoku Shinpou (31.9 days) for the 1978.6.12 Off-Miyagi Prefecture Earthquake. The degree of emphasis on earthquake-related articles in a newspaper depends not only on the severity of damage and numbers and types of casualties, but on the geographical region covered and by what segment of the population subscribes.

4.6 Discussion

The extent of human casualties (injuries and deaths) has been examined from various perspectives. Casualty ratios by district and ward statistics were compared with the dwelling damage ratio and with data from previous earthquakes. The age and gender of an occupant were shown to influence the risk of fatality as found in other studies; that is, children and the elderly tend to be the victims of an earthquake. Mud-stone or brick masonry dwellings common to the damaged region of Eastern Nepal are much more vulnerable to earthquake motion than are buildings in Japan. The lethality of dwelling collapse (risk to occupants of a collapsed building of being killed), however, varied from 1%, (comparable to that for Japanese wooden dwellings) to 6%, (comparable to the value for Italian stone masonry dwellings). These results provide a basis for estimating the possible extent of human casualties in a future earthquake and for providing better disaster mitigation measures.

The emergency responses of hospitals, and earthquake-related newspaper reports were investigated in both Nepal and Bihar to determine how public and private organizations responded to the emergency caused by this earthquake. Disrupted communication and road networks were the major obstacles to a quick assessment of damage, to movement of the injured, and to transportation of relief materials. There were, however, great efforts made for the relief of the victims within the very limited resources available although there were a number of disputes about justice and equal treatment in the relief actions.

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5. CONCLUDING REMARKS

After the 1988 Nepal-India Earthquake, three other catastrophic earthquakes occurred where the Indian and Eurasian plates meet; in Yun-nan Province (China) November 1988, Spitak(Armenia, U.S.S.R) December 1988, and Tadzhik (U.S.S.R) January 1989. Although humans can not control the occurrence of earthquakes, measures can be taken throughout the world to decrease the amount and severity of damage done. Our survey was a very short one and our knowledge of India and Nepal too limited to be able to give definitive reasons for all the damage done there. But our observations and the difference in construction seen in Japan suggest some comments about the seismic problems there:

1. The intensity in the stricken areas of Udaypur, Dharan, Dhankuta and Darbhanga, derived by analysis of the aftershocks seems to have been about 6 to 7 on the MM Scale, but the intensity near Bhaktapur and Patna may have been less than 5. The estimation of the intensity in those areas, based on our questionnaire item analysis and on results of our sand liquefaction experiments, support these values.

2. The system for constructing buildings in Nepal differs markedly from that used in Japan. After the 1923 Great Kanto Earthquake (Japan), brick masonry could be used only for the construction of small scale houses because of its record of brittle failure. Nowadays, homes in Japan are built by contractors who use wood, precast-concrete or prefabricated steel. In India and Nepal, most houses are constructed of brick masonry and have been built by the people, themselves. In these countries it is imperative to give the people information about seismicity and aseismic construction methods in order for them to be able to build earthquake-resistant homes. Television and manuals may prove useful educational tools for this purpose.

3. The seismic capacities of the mud-stone and brick masonry buildings within the stricken areas were poor. The recommendations given in section 3.7 should help to improve the earthquake resistance of such buildings.

4. Nepal has no national building regulations. Buildings are designed according to various codes from other countries. Recommendations and guidelines for the aseismic design of both engineered and non-engineered structures, however, are soon to be published. A manual on earthquake-resistant, non-engineered construction has been published in India, in which methods for strengthening shear walls, slabs and connections are recommended [Ref.3.6]. It is especially important that such recommendations as having a slab rigid in plane and a collar band in the wall be implemented in both India and Nepal.

5. Some R/C buildings have been built with the idea of eventually constructing an additional floor. These show exposed connecting reinforcing bars that have been rusted by rain. The steel beams and reinforcing bars used in some severely damaged buildings also were much rusted. A water-proof construction method that prevents rusting would help reduce the damage done by earthquakes.

6. Training engineers and educating students about aseismic design and construction should prove perhaps the most important factors for decreasing future earthquake damage done to buildings. Japanese specialists and the Japanese Government are likely to provide assistance in this problem area.

7. The accumulation of data from strong earthquake records and data on soil structure would provide an information base from which effective earthquake-proof designs of structures could be made. Microzonation and aseismic planning in urban areas also are necessary in active seismic zones such as those in Nepal, Japan and the northern part of India.

APPENDIX A Questionnaire

Table A-1 Questionnaire

1988.08.21 EARTHQUAKE INTENSITY SURVEY

Hokkaido University, JAPAN

Please remember the location and the damage when the earthquake happened and answer the following questions.

1. Your address at the time of the earthquake

street ____________________

city/village ____________________

2. The place was
- 1 flat land
- 2 on a top of hill
- 3 on a slope
- 4 in a valley

3. You were
- 1 indoors
- 2 outdoors
- 3 in a vehicle

4. If you were indoors, the type of building was
- 1 house
- 2 apartment
- 3 office
- 4 shop

5. What was the building mainly made of?
- 1 brick
- 2 adobe
- 3 wood
- 4 concrete

6. How many floors did the building have? ______

7. What floor were you on? ______

8. Did the sleeping people awake?
- 1 a few people woke up
- 2 many woke up
- 3 all woke up
- 4 no one was sleeping

9. Would you say the vibration you felt was
- 1 light
- 2 moderate
- 3 strong
- 4 violent

10. How long do you think the shaking lasted?
- 1 sudden
- 2 short
- 3 long
- 4 very long

11. Were you frightened during the shaking?
- 1 not at all
- 2 a little bit
- 3 quite
- 4 almost paniced

12. What did you do during the shaking?
- 1 stayed where I was
- 2 protected myself, someone else, or some valuables
- 3 moved to another room
- 4 tried to exit building

13. Was it difficult to move?
- 1 easy to move
- 2 difficult but possible to move
- 3 couldn't move
- 4 fell down
- 5 didn't try to move

Table A-1 Questionnaire (continued)

14. How did the animals behave?
1 no animal was in sight
2 they became uneasy
3 ran out of their stalls
4 ran to and fro and cried

15. Did hanging objects like pictures and lamps swing?
1 no
2 moved slightly
3 moved a lot
4 some fell or were damaged

16. What happened to the windows, doors or dishes?
1 rattled
2 swung open or closed
3 some dishes broke
4 some windows broke

17. Did you see the liquids in open vessels move?
1 some moved a little
2 some moved a lot
3 some spilled

18. Did shelf goods move?
1 nothing moved
2 a few overturned or shifted
3 many fell off shelves
4 all fell off shelves

19. What happened to furniture?
1 furniture did not shake
2 it shook slightly
3 it moved a little
4 it moved and overturned
5 considerable damage to furniture

20. Damage to walls of the building you were in
1 none
2 fine cracks in plaster
3 pieces of plaster fell off
4 large and deep cracks
5 one or more walls collapsed

21. Was there any damage to chimneys, parapets and ornaments?
1 none
2 some cracked
3 some fell
4 most fell down

22. Was there damage to stone or brick walls, or monuments in neighborhood?
1 no damage
2 small cracks
3 big cracks
4 collapses

23. Were there ground cracks, rockfalls and landslides in your neighborhood?
1 none
2 few
3 many
4 numerous

24. Were you or your family injured due to the earthquake?
1 no
2 yes, slightly
3 treated by doctor
4 hospitalized
(what injury) ______________________________

25. You are
1 male
2 female

26. How old are you? ______

Thank you very much for your cooperation.

Table A-2 Original data from questionnaires returned

Near field: R=20-80km, 49 cases
Dharan, Dhankuta, Biratnagar, Udayapur, Darbhanga
Far field: R=160-180km, 66 cases
Kathmandu, Lalitpur, Bhaktapur, Patna

	category	NEAR FIELD		FAR FIELD	
		case	%	case	%
Q2	Place				
	1 flat land	39	79.6	20	30.3
	2 top of hill	1	2.0	1	1.5
	3 slope	8	16.3	1	1.5
	4 valley	1	2.0	44	66.7
Q3	You were				
	0	0		1	
	1 indoors	45	91.8	63	96.9
	2 outdoors	4	8.2	2	3.1
	3 vehicle	0	0.0	0	0.0
Q4	Building				
	0	2		0	
	1 house	40	85.1	64	97.0
	2 apartment	2	4.3	2	3.0
	3 office	5	10.6	0	0.0
	4 shop	0	0.0	0	0.0
Q5	Building material				
	0	0		1	
	1 brick	31	63.3	54	83.1
	2 adobe	3	6.1	0	0.0
	3 wood	9	18.4	1	1.5
	4 concrete	6	12.2	10	15.4
Q6	No. of floors				
	0	1		0	
	1	24	50.0	10	15.2
	2	18	37.5	25	37.9
	3	6	12.5	25	37.9
		0		6	9.1
Q7	Floor located				
	0	2		0	
	1	37	78.7	32	48.5
	2	10	21.3	25	37.9
	3	0	0.0	8	12.1
		0		1	1.5
Q8	People awaken				
	0	0		1	
	1 a few	9	18.4	6	9.7
	2 many	9	18.4	14	22.6
	3 all	31	63.3	42	67.7
	4 not sleeping	0		3	
Q9	Vibration				
	0	1		2	
	1 light	0	0.0	6	9.4
	2 moderate	3	6.3	16	25.0
	3 strong	24	50.0	35	54.7
	4 violent	21	43.8	7	10.9
Q10	Duration				
	1 sudden	0	0.0	1	1.5
	2 short	10	20.4	20	30.3
	3 long	32	65.3	42	63.6
	4 very long	7	14.3	3	4.5

	category	NEAR FIELD		FAR FIELD	
		case	%	case	%
Q11	Fright				
	1 not at all	0	0.0	6	9.1
	2 a little	4	8.2	29	43.9
	3 quite	25	51.0	20	30.3
	4 panic	20	40.8	11	16.7
Q12	Behavior				
	0	0		1	
	1 stayed	9	18.4	10	15.4
	2 protect	4	8.2	9	13.8
	3 move	5	10.2	7	10.8
	4 exit building	31	63.3	39	60.0
Q13	Difficult to move				
	0	1		0	
	1 easy	3	6.3	24	36.4
	2 possible	17	35.4	34	51.5
	3 couldn't	14	29.2	4	6.1
	4 fell down	12	25.0	1	1.5
	5 didn't try	2	4.2	3	4.5
Q14	Animals				
	0	3		1	
	1 no animal	26		52	
	2 uneasy	10	50.0	6	46.2
	3 ran out	1	5.0	2	15.4
	4 ran & cried	9	45.0	5	38.5
Q15	Hanging objects				
	0	3		2	
	1 not swing	2	4.3	6	9.4
	2 slightly	5	10.9	31	48.4
	3 a lot	9	19.6	22	34.4
	4 fell/damaged	30	65.2	5	7.8
Q16	Windows, dishes				
	0	2		6	
	1 rattled	14	29.8	36	60.0
	2 swung open	11	23.4	19	31.7
	3 some broke	10	21.3	3	5.0
	4 window broke	12	25.5	2	3.3
Q17	Liquids				
	0	19		21	
	1 a little	5	16.7	26	57.8
	2 a lot	6	20.0	13	28.9
	3 spilled	19	63.3	6	13.3
Q18	Shelf goods				
	0	2		4	
	1 no	0	0.0	35	56.5
	2 a few	11	23.4	21	33.9
	3 many	29	61.7	3	4.8
	4 all	7	14.9	3	4.8
Q19	Furniture				
	0	5		2	
	1 no shaking	0	0.0	12	18.8
	2 slightly	11	25.0	38	59.4
	3 moved a little	13	29.5	13	20.3
	4 overturned	14	31.8	1	1.6
	5 damage	6	13.6	0	0.0

Table A-2 Original data from questionnaires returned (continued)

	NEAR FIELD		FAR FIELD	
category	case	%	case	%
Q20 Wall damage				
0	2		1	
1 none	7	14.9	48	73.8
2 fine cracks	9	19.1	12	18.5
3 plaster fell	3	6.4	3	4.6
4 large cracks	11	23.4	2	3.1
5 collapsed	17	36.2	0	0.0
Q21 Chimneys				
0	8		2	
1 none	13	31.7	52	81.3
2 some cracked	9	22.0	9	14.1
3 some fell	8	19.5	3	4.7
4 most fell	11	26.8	0	0.0
Q22 Stone,brick walls				
0	1		3	
1 no damage	4	8.3	37	58.7
2 small cracks	11	22.9	18	28.6
3 big cracks	9	18.8	4	6.3
4 collapsed	24	50.0	4	6.3
Q23 Ground cracks				
0	1		2	
1 none	13	27.1	54	84.4
2 few	14	29.2	8	12.5
3 many	15	31.3	2	3.1
4 numerous	6	12.5	0	0.0

	NEAR FIELD		FAR FIELD	
category	case	%	case	%
Q24 Family injured				
0	0		1	
1 no	32	69.6	59	90.8
2 slightly	9	19.6	6	9.2
3 treated	2	4.3	0	0.0
4 hospitalized	3	6.5	0	0.0
	3		0	
Q25 Sex				
0	0		1	
1 male	43	87.8	51	78.5
2 female	6	12.2	14	21.5
Q26 Age				
	0		1	
1-20	1	2.0	11	16.9
21-40	26	53.1	46	70.8
41-60	19	38.8	7	10.8
61~	3	6.1	1	1.5

APPENDIX B General Statistics on Damage in Bihar State, India

Table B-1 Casualty statistics by district in Bihar

District	Date	Quick Report			Progressive Report		
		Injured	Admitted	Death	Injured	Admitted	Death
Darbhanga	8 SEP 88	8	4	1	1120	578	29
Monghyr	5 SEP 88	0	2	0	450	265	9
Madhubani	8 SEP 88	37	8	0	2063	300	4
Khagaria	8 SEP 88	1	0	0	255	76	9
Saharsa	8 SEP 88	0	0	0	331	130	3
Chapra	3 SEP 88	not reported			1	1	0
Samastipur	30 AUG 88	not reported			190	9	9
Bhagalpur	4 SEP 88	not reported			38	10	2
8 District total		46	14	1	4448	1369	65
39 District total							

District	Date	Population 1981 Cnss thousand	Blocks	Injured Ratio	Inj+Adm+Death Ratio
Darbhanga	8 SEP 88	2008	12	0.06	0.09
Monghyr	5 SEP 88	2546	26	0.02	0.03
Madhubani	8 SEP 88	2325	18	0.09	0.10
Khagaria	8 SEP 88	768	6	0.03	0.04
Saharsa	8 SEP 88	1989	16	0.02	0.02
Chapra	3 SEP 88		15		
Samastipur	30 AUG 88	2161	14	0.01	0.01
Bhagalpur	4 SEP 88	2621	21	0.00	0.00
8 District total					
39 District total		69915	590		

Information from Mr. N.K.Singh, Additional Commissioner, Health Department
Teleprinter/ Wireless Message Dated 8 September 1988
From: Shri Vishnu Kumar, Joint Secretary to Government of Bihar
Health Department, Patna
To: Dr. Banarsi Das, Control Room, Delhi
Directorate General of Health Services
Nirman Bhawan, New Delhi - 110011

Table B-2 Classification of houses damaged/collapsed by economic categories in Bihar

No	Name of District	No. of S. C.	No. of E.W.S.	No. of L.I.G.	No. of M.I.G.	No. of H.I.G.	Total
1	Darbhanga	7554	17969	13373	10050	3938	52884
2	Madhubani	4286	11740	7830	7695	6882	38433
3	Saharsa	1823	5379	4734	4251	2135	18322
4	Samastipur	456	1397	1360	1847	405	5465
5	Munger	3430	16412	7789	746	63	28440
6	Sitamarhi	251	840	450	191	67	1799
7	Khagaria	278	797	380	73	0	1528
8	Begsarai	93	183	154	121	65	616
9	Madhepura	44	119	137	95	55	450
10	Muzaffarpur	14	34	28	25	11	112
11	Nalanda	12	33	25	18	6	94
12	Bhagalpur	4	12	7	5	1	29
13	Sahebganj	0	1	0	0	0	1
14	Giridih	0	1	0	0	0	1
15	Purnea	170	384	290	218	98	1160
16	Gopalganj						
17	Jahanabad						
18	Saran						
	Total	18415	55301	36557	25335	13726	149334
		Schedled Caste	Economically Weaker Sec.	Low Income Group	Middle Income Group	High Income Group	
	Annual Income		Below 6000Rs	6000Rs	15000Rs	Over 15000Rs	

Table B-3 Damage by district and earthquake and other relief rendered by the Bihar Relief Commissioner

No	Name of District	No. of Houses Damaged			No. of Death	No. of Injured	Ex-gratia Paid Rs. in Lakh		Ex Gratia Injured Rs. Lakh	G.R. (qls.) wheat	Ready-food (qls.)	Polythene Distributed (in Tonnes)			H.B. Grant Distributed (Rs.Lakh)
		Kucha Mud Built	Pucca Brick Built	Total			By State Govt.	P.M. Relief Fund				State Govt.	Vol. Agencies	Total	
1	2	3	4	5	6	7	8	9	10	11	12	13	14		15
1	Darbhanga	25706	27178	52884	83	992	4.05	8.10	3.41	4000	4	54.50	29.50	84.00	0.00
2	Madhubani	21747	16686	38433	99	659	4.95	9.90	2.90	15736	94	30.52	50.00	80.52	0.00
3	Saharsa	18955	7367	18322	21	435	1.05	2.10	1.42	22	0	13.50	7.00	20.50	0.00
4	Samastipur	4217	1248	5465	21	158	1.05	2.10	0.46	55	0	6.00	0.00	6.00	0.00
5	Munger	18210	10230	28440	16	932	0.80	1.60	2.44	642	5	16.50	7.00	23.50	9.87
6	Sitamarhi	836	963	1799	6	75	0.30	0.60	0.15	34	0	2.00	0.00	2.00	0.00
7	Khagaria	940	588	1528	9	238	0.45	0.90	0.67	0	0	5.00	0.00	5.00	0.00
8	Begsarai	455	161	616	4	155	0.20	0.40	0.34	0	0	1.00	0.00	1.00	0.00
9	Madhepura	295	155	450	9	30	0.45	0.90	0.07	0	0	1.50	0.00	1.50	0.00
10	Muzaffarpur	112	0	112	5	19	0.25	0.50	0.03	0	0	0.00	0.00	0.00	0.00
11	Nalanda	60	34	94	1	20	0.05	0.10	0.03	0	0	0.00	0.00	0.00	0.00
12	Bhagalpur	29	0	29	3	24	0.15	0.30	0.04	0	0	0.00	0.00	0.00	0.00
13	Sahebganj	1	0	1	0	5	0.00	0.00	0.01	0	0	0.00	0.00	0.00	0.00
14	Giridih	1	0	1	1	1	0.05	0.10	0.00	0	0	0.00	0.00	0.00	0.00
15	Purnea	1152	8	1160	3	17	0.15	0.30	0.03	0	0	0.00	0.00	0.00	0.00
16	Gopalganj	0	0	0	0	3	0.00	0.00	0.01	0	0	0.00	0.00	0.00	0.00
17	Jahanabad	0	0	0	1	0	0.05	0.10	0.00	0	0	0.00	0.00	0.00	0.00
18	Saran	0	0	0	0	3	0.00	0.00	0.01	0	0	0.00	0.00	0.00	0.00
	Total	92716	64618	149334	282	3766	14.00	28.00	12.02	20489	103	130.52	93.50	224.02	9.87

No	Name of District	Damage Ratio % assumption household size=6	Casualty Ratio %	By Voluntary Agencies					
				Ready-food (pls.)	Poly-thene (Tones)	Tarpau-line (No.)	Dhoti Sari (No.)	Ready-made Garments (No.)	Blanket (No.)
1	2			6	7	8	9	10	11
1	Darbhanga	15.80	0.05	11	29.5	2000	11429	72035	2060
2	Madhubani	9.92	0.03	0	50	0	12100	11500	2050
3	Saharsa	5.53	0.02	0	7	0	0	0	0
4	Samastipur	1.52	0.01	1	0	0	210	100	0
5	Munger	6.70	0.04	0	7	700	4700	1500	500
6	Sitamarhi	0.56	0.00						
7	Khagaria	1.19	0.03						
8	Begsarai	0.25	0.01						
9	Madhepura	0.28	0.00						
10	Muzaffarpur	0.03	0.00						
11	Nalanda	0.03	0.00						
12	Bhagalpur	0.01	0.00						
13	Sahebganj	0.00	0.00						
14	Giridih	0.00	0.00						
15	Purnea	0.19	0.00						
16	Gopalganj	0.00	0.00						
17	Jahanabad	0.00	0.00						
18	Saran	0.00	0.00						
	Total			12	93.5	2700	28439	85135	4610

Bihar

(qls: 1 quintal=112 pounds)

Lakh=100,000

For floodsin Katihar, Chapra, Vaishali,
Muzaffarpur, Gopalganj and Purne 16.5
Grand total 147.02

Table B-4 Estimated restoration cost by department in Bihar

The Hindustan Times (Patna) September 10, 1988
Memo for 91-cr aid for quake-hit areas

Name of Department	Nature of damage	Amount required for restoration (Rs in Lakh)
Rural Development	Damage to bridges culverts & roads	91.450
Home (police) (DGP)	Damage to police lines and barracks	240.000
Energy Department	Damage to Generation Station & Transmission and Distribution Systems	530.670
Animal Husbandry (Dairy)	Damage to Water Tower of Dairy	620.000
Water Resources	Damage to embankment, irrigation system and buildings	469.000
Welfare	Damage to Govt. Building	22.445
Public Health Engineering	Damage to Tubewells, Pipe Lines, floors walls, Pumps Motor pumps etc.	91.000
Building Construction	Damage to Govt. Buildings	1008.000
Education	Damage to School and College Buildings	4400.000
Urban Development	Damage to Buildings Roads & Waterfacilities	1500.000
Health	Damage to Hospital & other Medical Building	500.000
Total		7987.565

Table B-5 Numbers of houses damaged in Bihar and estimated restoration costs

A (Pucca) brick house	(Rs in Crore)	Rs/House	% loss
11335 Private Pucca Collapsed	34.010	30004	100
19141 Private Pucca Major Damage	28.720	15004	50
34142 Private Pucca Minor Damage	17.070	5000	17
64618	79.800	12350	41
B(Kachcha mud house			
13758 Kachcha House Collapsed	16.510	12000	100
27258 Kachcha House Mojor Damage	8.175	2999	25
43700 Kachcha House Minor Damage	4.374	1001	8
84716	29.059	3430	29
149334 House Grand Total A+B	108.860	7290	

Lakh=100,000 Crore=100 Lakh

APPENDIX C General Statistics on Damage in Nepal

Table C-1 Casualty statistics by district in Nepal based on the census population

(Letter from S. Malla, Nepalese Government)

Zone	District	Deaths	Serious injury	Minor injury	Private Houses collapsed	damaged	total	Public buildings collapsed	damaged	total
Mechi	Taplejung	3	7	28	767	293	1060	-	12	12
	Panchthar	99	261	311	5244	6804	12048	94	2	96
	Jhapa	-	19	11	31	163	194	4	20	24
	Ilam	73	129	312	5918	5538	11456	181	88	269
Kosi	Sankhuwa Sabha	12	46	1	1944	704	2648	39	10	49
	Terhathum	67	76	62	4481	3296	7777	25	26	51
	Dhankuta	93	154	724	7277	2384	9661	47	59	106
	Bhojpur	14	88	118	2956	3114	6070	21	-	21
	Morang	32	941	233	637	852	1489	38	38	76
	Sunsari	138	327	1790	2494	4466	6960	11	22	33
Sagarmatha	Okhaldhunga	8	28	108	2162	3137	5299	7	12	19
	Udayapur	82	70	453	5457	3933	9390	27	20	47
	Saptari	13	45	80	1263	1138	2401	24	28	52
	Siraha	8	41	-	76	1279	1355	10	58	68
	Khotang	26	140	275	7919	7143	15062	10	11	21
	Solukhumbu	-	4	-	297	341	638	2	1	3
Janakpur	Dhanusha	2	3	25	375	306	681	-	55	55
	Mahottari	1	2	18	26	4	30	-	38	38
	Sindhuli	32	33	209	1670	1177	2847	11	25	36
	Dolakha	2	5	14	268	933	1201	21	19	40
	Ramechhap	2	1	32	589	1800	2389	10	31	41
Narayani	Bara	-	-	-	-	-	-	-	-	-
Bagmati	Kathmandu	-	-	3	-	200	200	-	19	19
	Lalitpur	1	3	22	376	137	513	-	3	3
	Bhaktapur	7	23	20	274	1477	1751	-	11	11
	Kavre	-	-	-	-	5	5	-	1	1
	Sindhupalchok	2	4	30	711	478	1189	22	38	60
Total		721	2450	4879	53212	51102	104314	604	647	1251

Table C-2 Statement on houses destroyed by the earthquake needing reconstruction [Ref.1.2]

District	Number of Houses	District	Number of Houses	District	Number of Houses
EASTERN REGION					
Mechi Zone		Koshi Zone		Sagarmatha Zone	
Taplejung	767	Sangkhuwa - Sabha	1,983	Solukhumbu	299
Panchthar	5,338	Bojhpur	2,977	Okhaldhunga	2,169
Illam	6,099	Tehrathum	4,506	Khotang	7,929
Jhapa	35	Dhankuta	7,324	Udaipur	5,484
		Sunsari	2,505	Siraha	86
		Morang	675	Saptari	1,287
	12,239		19,970		17,254
CENTRAL REGION					
Janakpur Zone		Bagmati Zone		Narayani Zone	
Sindhuli	2,955	Sindhupalchowk	1,073	Parsa	1
Ramechhap	2,389	Kavrepalan chowe	1,920	Makwanpur	1
Dolakha	1,261	Lalitpur	513	Routahat	45
Dhanusha	775	Dhadid	16		
Sarlahi	9	Kathmandu	200		
Mahottari	15	Rasuwa	5		
		Bhaktapur	1,826		
	7,404		5,553		47

Total No. of Houses 62,467

Table C-3 Statement of damage to buildings and the estimated cost [Ref.1.2]

District	Houses Destroyed		Cracked/Useless		Cracked/Repairable		Simple Cracks		Estimated Cost
	Govt	PVT	Govt	PVT	Govt	PVT	Govt	PVT	
Taplejung	-	29	-	738	4	234	8	59	6,177,000
Panchthar	6	2046	88	3198	2	1295	-	5509	21,419,057
Illam	62	1756	119	4162	88	5538	-	-	65,956,121
Jhapa	-	11	4	20	13	31	7	132	400,050
Sankhuwasabna	26	521	13	1423	10	295	-	409	12,375,500
Bhojpur	6	586	15	2370	-	3114	-	-	66,850,000
Tehrathum	2	1176	23	3305	26	3296	-	-	56,217,500
Dhankuta	47	2343	-	4934	59	2384	-	-	100,000,000
Sunsari	-	447	11	2047	14	1008	8	3458	211,352,592
Morang	18	373	20	264	38	852	-	-	47,224,400
Solukhumbu	2	98	-	199	1	201	-	140	60,981,480
Okhaldhunga	2	620	5	1542	9	1921	3	1216	27,539,120
Khotang	-	2312	10	5607	8	2956	3	4187	96,827,000
Udaipur	4	2577	23	2880	15	-	5	3933	9,368,000
Siraha	1	57	9	19	58	1279	-	-	1,657,200
Saptari	24	12	-	1251	14	92	14	1046	42,874,530
Grand Total	200	14964	340	33959	359	24496	48	20089	827,219,550

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