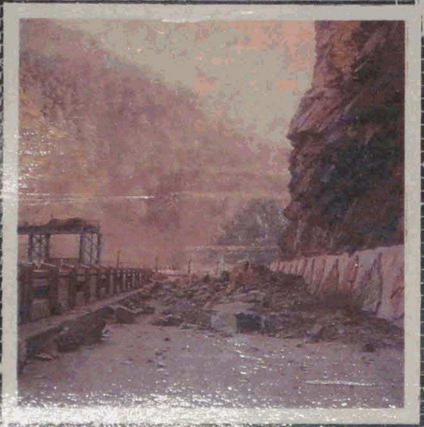
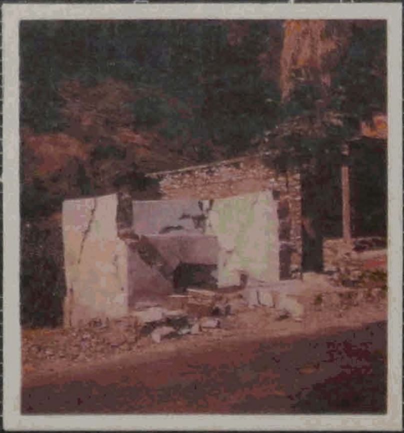
ISSN 0254-0436

UTTARKASHI EARTHQUAKE

OCTOBER, 20, 1991





GEOLOGICAL SURVEY OF INDIA
SPECIAL PUBLICATION NO. 30
1992

उत्तरकाशी भूकम्प

अक्तुवर, २०, 1991

UTTARKASHI EARTHQUAKE

OCTOBER, 20, 1991

भारतीय भूवैज्ञानिक सर्वेक्षण

बिषेश प्रकाशन ३०

GEOLOGICAL SURVEY OF INDIA
SPECIAL PUBLICATION NO. 30

भारत सरकार के आदेश से प्रकाशित

PUBLISHED BY ORDER OF THE GOVERNMENT OF INDIA

1992

Published by

Director General
Geological Survey of India
27 Jawaharlal Nehru Road
Calcutta 700 016

Processing for printing, design and layout

R. N. Datta and Samiran Banerjee
Publication & Information Division
Geological Survey of India
Calcutta 700 016

Printed by

M/s. National Graphics
12 B, Beliaghata Road
Calcutta 700 015

Price : Inland Rs. 165.00 ; Foreign £ 20.00 or $ 60.00

COVER

Photographs of the damages to structures in Uttarkashi, U. P., in the background of recorded seismograph.

FOREWORD

The Uttarkashi earthquake of the 20th October, 1991 caused considerable damage to life and property in the Garhwal Himalaya. In addition to the sufferings of the people it rekindled controversy about the imminence of a still greater and more devastating event as well as adequacy of aseismic design parameters for major civil engineering structures in the region.

Geological Survey of India being the national organisation charged with the responsibility of carrying out systematic scientific documentation of damages leading to preparation of Isoseismal maps and related studies, true to its character, mobilised its resources immediately and launched an extensive study of this event from the very next day. A group of over 25 scientists drawn from different specialist units located at Dehradun, Lucknow, Faridabad and Chandigarh were engaged in the exacting investigation coordinated by two Directors under the DDG, NR. A preliminary report of the investigation was prepared within one month of the event. DDG, Geophysics, CHQ, also sent a party to record the post-earthquake seismicity.

I had detailed interaction with other concerned Government agencies like Indian Meteorological Department, National Geophysical Research Institute, the Central Water Commission etc. wherein consensus emerged about the necessity of a consolidated volume documenting the event and its effects. A special publication incorporating data generated by all the Government Organisations is now being brought out in keeping with the GSI tradition of publishing information and results of damage surveys of major earthquakes in the country. Excellent cooperation received from the participating agencies is acknowledged with gratitude.

I do hope this volume will be of value to all concerned with Seismotectonics, Seismology and Earthquake Engineering and would stimulate research to better direct the efforts for mitigation of Natural Hazards due to earthquakes.

(C P Vohra)
Director General
Geological Survey of India

EDITORIAL COMMITTEE

CONTENTS

PART ONE

MACROSEISMIC INVESTIGATIONS OF UTTARKASHI EARTHQUAKE OF 20TH OCTOBER, 1991

Report by GSI

PART TWO

REPORT ON INTENSITY SURVEYS CARRIED OUT FOR UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

Report by NGRI

PART THREE

INSTRUMENTAL RECORD OF UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

Report by IMD

TABLES

PART FOUR

AFTERSHOCK SEQUENCE OF UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

Combined report by GSI, IMD & NGRI

TABLES

THE PUBLICATION IS AVAILABLE FOR SALE FROM

* The Director
  Publication & Information Division
  Geological Survey of India
  29, Jawaharlal Nehru Road
  Calcutta - 700 016

* The Deputy Director General
  Geological Survey of India
  Eastern Region
  12A & B, Russell Street
  Calcutta-700 071.

* The Deputy Director General
  Geological Survey of India
  Central Region
  Block-A, 1st Floor
  New Office Complex
  Seminary Hills
  Nagpur - 440 006.

* The Deputy Director General
  Geological Survey of India
  North Eastern Region
  Kumud Villa, Nongrim Hills
  Shillong - 793 003.

* The Deputy Director General
  Geological Survey of India
  Northern Region
  Plot No. 2, Sector 'E' Aligunj
  Lucknow - 226 020.

* The Deputy Director General
  Geological Survey of India
  Western Region
  A/3, Swai Jai Singh Highway
  Bani Park, Himangshu Bhavan
  Jaipur - 302 006.

* The Controller of Publications
  Govenment of India
  Civil Lines
  New Delhi - 110 054.

PART ONE

REPORT by GSI

MACROSEISMIC INVESTIGATIONS OF UTTARKASHI EARTHQUAKE OF 20TH OCT. 1991

BY

Officers of the

Geological Survey of India

Analysed, synthesised and compiled

by

P.L. Narula & S.K. Shome

MACROSEISMIC INVESTIGATIONS OF UTTARKASHI EARTHQUAKE OF 20TH OCT.1991

SYNOPSIS

The Garhwal Himalaya in the Northern India was rocked by a **6.6 magnitude** earthquake in the early hours of 20th Oct. 1991. The **official information indicates that 723 persons perished, and thousands were injured by** the earthquake and about 36000 houses were partially or completely damaged in Uttarkashi district alone. **The instrumentally located epicentre of this shock lies at latitude 30.75 N, longitude 78.86 E (IMD) and the depth of focus is 12 km.** This earthquake was followed by a number of aftershocks, the epicentres of which lie in a linear belt of 40 km by 25 kms and the fast reduction in their number with time is suggestive of a rapid stress drop.

The Geological Survey of India has carried out the damage surveys in the affected areas for evaluating the extent of damages to the constructions and the terrain changes brought about by the earthquake for drawing the isoseismals. For this purpose the **Medvedev-Sponheuer-Karnik (MSK) intensity scale** (1964) has been utilised. **The maximum intensity reached on this scale in the epicentral tract is IX which encompasses an area of about 20 sq.km.** All the isoseismals are oblong in shape with reference to the meisoseismal area. The asymmetrical attenuation patterns of the intensity isoseismals could be related to (i) Different lithocontrast materials having brought in juxtaposition by some transverse fundamental fracture. (ii) By involvement of more energy in the dip direction of the source fault and/or (iii) Intensity accentuation in the south-eastern quadrant having resulted because of fault propagation in that direction.

The damage surveys have also indicated areas of **isolated highs around Kunihar** and **Timbi** in Himachal Pradesh, **Dehradun** and **Dugadda** in Uttar Pradesh. These isolated highs of intensity VI area located within isoseist V and are located in the vicinity of MBF in a crustal block bounded by MBF in the north and the Foot Hill thrust in the south. An anomalous **intensity high** of V within Isoseist IV has also been recorded around **Delhi**. The instrumentally recorded ground accelerations in the vicinity of the isoseismal boundaries have been compared with the empirical relationship to establish correlations. The authors have opined that the attenuation relations suggested by Campbell (1981) and others are not consistent with the data generated by this earthquake.

It has also been suggested that the **source mechanism** of this shock **has both thrust and strike slip components** and this source fault is located south of the surface trace of the northerly dipping MCT, a major tectonic lineament.

1 INTRODUCTION

An earthquake of magnitude 6.6 (IMD) on open ended Richter scale struck the northern hilly parts of Uttarkashi in Garhwal Himalaya at 02.53 hrs. of 20TH October, 1991 causing heavy loss of 723 lives and numerous livestock alongwith complete damage of over 20600 houses and partial damage over 25000 houses in about 400 villages in the districts of Uttarkashi, Chamoli and Tehri. The districtwise details of damages, as furnished by the district authorities, are given in the table below:

District-wise Damages

Districts	Uttarkashi	Tehri	Chamoli	Total
Deaths	653*	64*	6	723
Injuries	1435	367	15	1817
Houses completely damaged	14644	4000 (app.)	2000 (app.)	20644 (app.)
Houses partially damaged	21221	3000	1000	25221
Note: The figures quoted appear to have been modified subsequently as Ministry of Information & Broadcasting detail 768 killed, 5066 persons injurred, 20184 houses severely damaged and 74714 partially damaged.				

*For village wise deaths see annexure II

The Garhwal Himalaya has well known and recorded seismic history where large magnitude earthquakes (+5M on Richter scale) have visited the tract between Long. 78°-81° and Lat. 29.5° to 31° for 36 times in the last one and a half century. The majority of the events have been interpreted to be of thrust type of deformation and are clustered around the surface trace of the Main Central thrust. The event under report is also located in the vicinity of this regional structural dislocation.

Consequent to the news flash on the AIR and Doordarshan regarding this earthquake, the Director General, GSI, instructed the Geological Survey of India, Northern Region office, Lucknow to take stock of the situation and organise the detailed investigations immediately. As a first step officers of Engineering Geology Division working in the Bhagirathi and Yamuna valleys were directed to take up the damage surveys on priority basis from the 21St. October, 1991 itself. In the meantime a specialist group of ten officers from different Engineering Geology Divisions and Landslides and Seismotectonic Division of Northern Region, having past experience of macroseismic investigations, was identified and necessary logistic support arranged so that the parties could leave on the 23rd October, 1991. The investigating teams were led by Shri P.L.Narula, Director, Landslides and Seismotectonics Division, G.S.I., N.R., Lucknow and Shri S.K.Shome, Director, Engineering Geology Division II, G.S.I., N.R., Lucknow in Uttar Pradesh. The investigations in Himachal Pradesh were carried out under the guidance of Dr.O.N.Bhargava, Director, H.P. Circle, G.S.I., N.R., Chandigarh. The deployment of the parties was planned in such a way that they could converge at Uttarkashi from different directions. They covered Lucknow Bareilly Pithoragarh Almora Karanprayag Gadolia Tehri Uttarkashi; Lucknow Moradabad Kotdwara Pauri Srinagar Tehri Uttarkashi; Lucknow Moradabad Nagina Hardwar Dehradun Mussouri Tehri Uttarkashi; Dehradun Rishikesh Narendarnagar Tehri Uttarkashi and Lucknow Delhi Sonepat Ambala Paonta Saharanpur Dehradun. Such a step was essential to demarcate different isoseismal boundaries and a rapid assessment of the damage patterns. In addition, to document the effect of the shock in Himachal and Punjab, a separate group was organised.

In the first phase, completed by the first week of November 1991,the parties concentrated on identifying the epicentral tract and damage surveys of the worst affected areas, as well as authentication of the epicentral location which had been reported to be around Almora at Long. 79.8 and Lat. 29.8 by IMD and flashed in the media. Another objective was examination of engineered structures like Maneri concrete gravity dam located in the epicentral tract and other ongoing hydroelectric projects in the Bhagirathi and Yamuna valleys.

The first phase of the investigation consisted of rapid assessment of the whole of the U.P. Himalayas as well as Himachal Pradesh, Haryana and Delhi. The deployment of officers for carrying out the field investigations in different sectors in this phase is tabulated on the next page.

In the second phase the investigations were continued by S/Shri S. Kumar, Prabhas Pande, Y.P. Sharda, Geologists(Sr) and B.M. Gairola, Asstt. Geologist between 13th Nov. and 5th December, 1991. During these investigations, S/Shri P.L. Narula and S.K. Shome, Directors also inspected the area between 28th Nov. 1991 and 5th December, 1991 for final review of the investigations carried out.

Sl No	Party	Area Investigated	Period
	P.L.Narula & S.K.Shome	Coordinators	23rd Oct. to 3rd Nov., 1991
1	S.Kumar & Y.P.Sharda	Dehradun to Bhatwari	23rd Oct. to 3rd Nov. 1991
2	P.C. Nawani, J.S. Rawat & R. Sanwal	Tehri as well as Uttarkashi area	21st Oct. to 6th Nov. 1991
3	R.B. Sharan & Prabhas Pande	Pauri, Tehri and Uttrkashi	23rd Oct. to 3rd Nov. 1991
4	K. Sharma, S.C. Srivastava & H.C. Khanduri	Uttarkashi area	21st Oct. to 2nd Nov. 1991
5	Sushil Kumar & V.B.Srivastava	Pithoragarh, Almora & Yamuna Valley	23rd Oct. to 3rd Nov. 1991
6	R.S. Negi, S.K. Ghildyal, S.K. Tripathi & H.C. Khanduri	Dehradun	21st Oct. to 3rd Nov. 1991
7	U.S. Rawat & A.K. Jain	Yamuna & Tons Valley	23rd Oct. to 3rd Nov. 1991
8	Gurdev Singh, S.K. Hans, Prem Kumar & N.K. Punj	Punjab & H.P.	22nd Nov.1991 to 26th Nov.1991 in Punjab and 27th Oct. 1991 to 3rd Nov.1991 in H.P.
9	P.M. Jalote & A.K. Chaudhary	Sutlej Valley	24th Oct. 1991 to 31st Oct. 1991
10	D. Srivastava & G. Dasgupta	Delhi & Haryana	27th Oct. to 3rd Nov. 1991

Sri S.N. Chaturvedi, Dy. Director General, Northern Region, Geological Survey of India, Lucknow also inspected the worst affected area between the 29th and 31St. October, 1991.

2 SEISMOTECTONIC SETTING

The region exposes sequences with long history of sedimentation, magmatism and tectonism which got involved in the Himalayan orogeny. The oldest sequences covering sizeable portion of the Himalaya are of Proterozoic age. The status of knowledge on various aspects of geology and structure have been well documented in the proceedings of Himalayan Geology Seminar held at New Delhi during September, 1976 (GSI Misc. Pub. No.41 Pts. I to V). The data generated subsequently, particularly on the palaeontological discoveries, geochronology, tectonics including neotectonics metamorphism and magmatisms; has been

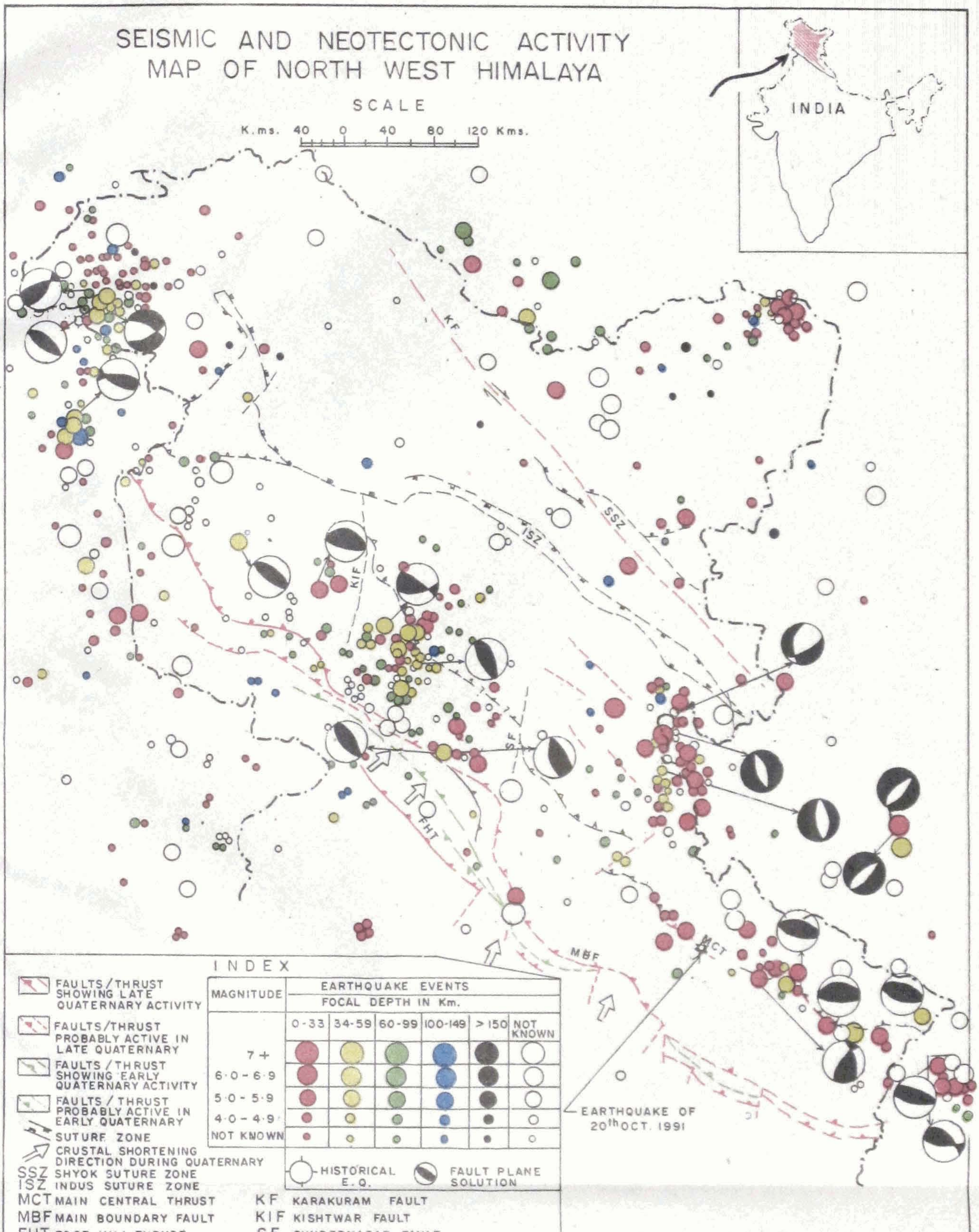


Fig. I AFTER P.L. NARULA (1991), GEOLOGICAL SURVEY OF INDIA.

Based upon Survey of India map with the permission of the Surveyor General of India.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

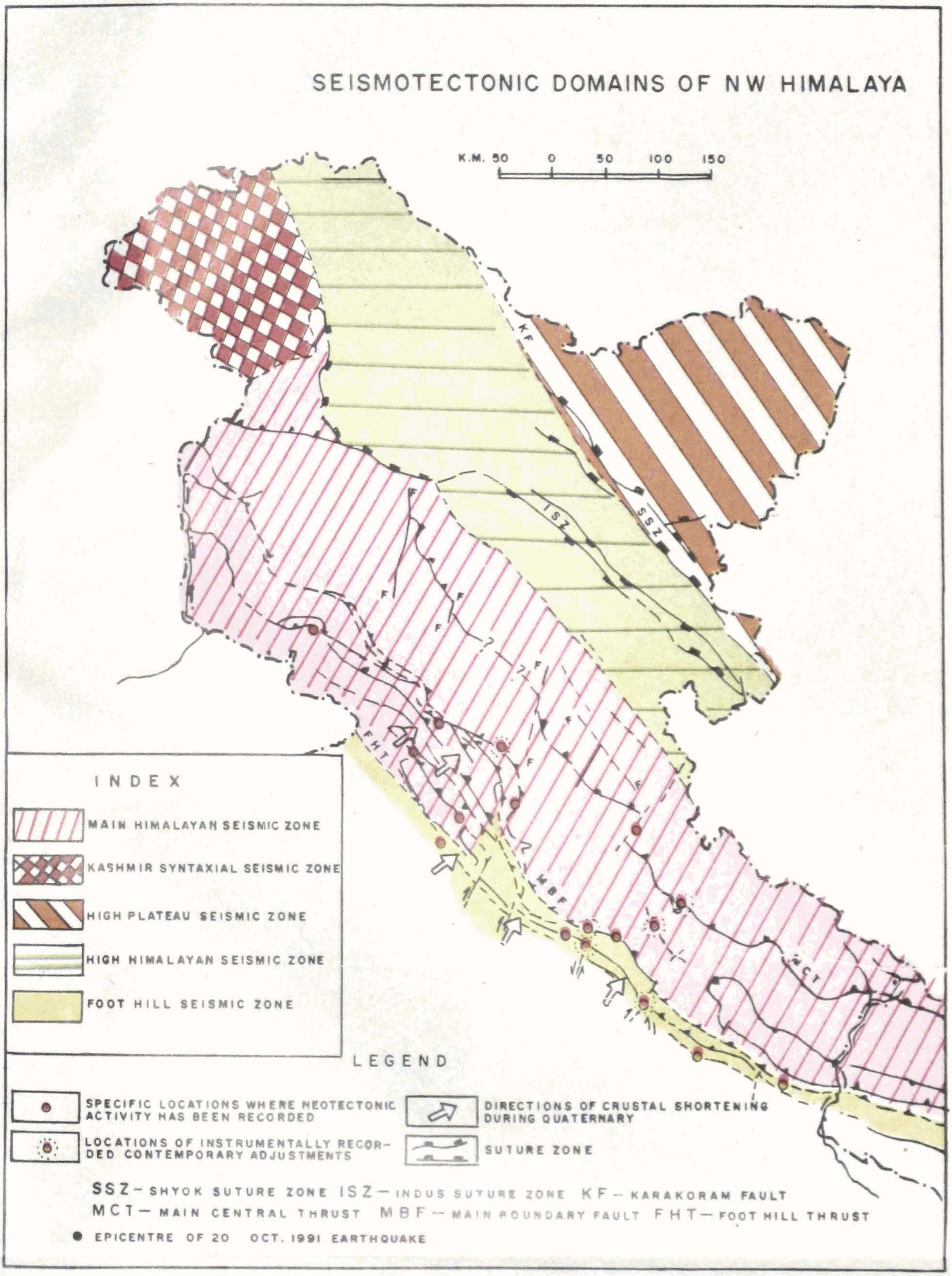


Fig. 2

AFTER P. L. NARULA (1991), GEOLOGICAL SURVEY OF INDIA

Based upon Survey of India map with the permission of the Surveyor General of India.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

discussed in detail in Geological Survey of India publication on Geology and Tectonics of the Himalaya' (Spl. Pub. 26, GSI, 1989). The geological map of the volume has been utilised as base map on which the isoseismals of this earthquake has been drawn.

The Himalayas are one of the most seismically active regions of the world where numerous large magnitude earthquakes have occurred. The earthquake records upto 1980 as obtained from the IMD have been classified and codified in relation to magnitude as well as focal depths for appreciation of the seismicity patterns of different domains of the northwest Himalaya (Narula 1991). Data obtained from the focal mechanism studies as well as the macroseismic surveys conducted by various workers has also been synthesised and incorporated with important tectonic surfaces in Fig.1. The perusal of this map indicates that the earthquake events in Garhwal and Kumaon Himalaya are mainly clustered in and around the surface trace of the Main Central Thrust. Out of 79 major events recorded from this region 25 earthquakes were of magnitude more or equal to 4 and less than 5, 26 were of magnitude more or equal to 5 and less than 6 and 10 events were those of magnitude more or equal to 6 and less than 7. When converted to total energy release, the energy release in the area demarcated by longitude 78° to 81° and latitude 29.5° to 31° has been of the order of 10^{23} ergs/decade. From the foregoing it is apparent that the domain visited by the Uttarkashi earthquake of 20th October 1991 is known for its seismic activity, in terms of both historical as well as recorded information.

The region visited by this earthquake lies in the Main Himalayan Seismic Zone demarcated by the MBF in the south and down dip influence zone of the MCT in the north, demonstrating predominantly the thrust type of fault plane mechanism (Narula 1991 in press) (Fig.2). It has been interpreted by Narula (1991) that the strain build up in different sectors of this domain is taking place at different locales and in the Uttarkashi-Kumaon sector, this is concentrated around the MCT as evidenced by clustering of seismic events in this subdomain to be around this structural dislocation. The seismic status of MCT has been a subject of interest for quite some time, though direct geological evidences of its neotectonic activity have not been recorded in the area of study. Geodetic monitoring of this tectonic surface in the vicinity of the Kumaltigad north of Maneri and some sector in Central Nepal have indicated contemporary adjustments along this feature (Omura et al 1986).

A micro earthquake network was operated by the University of Roorkee in the Uttarkashi Himalaya for monitoring of activity in connection with the Tehri Dam Project during 1979-80 and 1984-86. It defined a seismic belt extending over a distance of 140 km. from NW of Yamuna river to Alaknanda river (Khattri et.al. 1989). The focal depths determined for these micro events are predominantly of 10 to 13 km. while for some it is of the order of 23 kms. The focal mechanism studies conducted for discrete events suggest thrust fault type dislocation mechanism while some events also give strike slip mechanism.

3 DAMAGE SURVEYS

In order to prepare the isoseismal map of the area based on categorisation of damage patterns in different type of constructions and terrain changes brought about by the earthquake event, the investigating parties concentrated, in the first phase, in the maximum damage areas. The assessment of damages in these areas have been completed by carrying out surveys by concentrating in identified areas to collect the information on damage patterns. Over five hundred persons have been interviewed and the questionnaires (Annex. IV) got filled up and supplemented by preparing oriented sketches and photo-documentation by colour photographs and transparencies. For demarcating the isoseismal boundaries the Medvedev-Sponheuer-Karnik Scale (1964) (Annex. III) has been utilised which identifies categories of damages to constructions of various classes like those of poorly constructed adobe structures, the brick masonry structures and the RCC constructions, in conjunction with the terrain changes etc. (Ref. Annexure-III). The details are given below:

3.1 Terrain Changes

Consequent to the earthquake, numerous new landslides, landslips, boulder and rock dislodgements, slope failure induced ground fissures on the roads and roadside embankments as well as sharp vertical cuts in the steep river side ends of the terrace fields, failure of even very small height breaks in the hill slopes (less than 2m) like boundaries of the cultivated fields have been extensively recorded in the worst affected areas. In addition, numerous old land slides have been found to be reactivated. The road formations have been extensively damaged by wide open fissures along, and in some places across the road, with failures on the valley side retaining walls and hill side breast walls.

In certain reaches more than half of the formation as well as the painted road surface has been damaged by these fissures. Some of the major landslides have even uprooted large trees along their failure route. Changes in the discharge of water springs have also been reported at a number of places. Major landslides generated large dust clouds in their wake, often mistaken for smoke, in closed valleys. Such features occurred even after eight days of the earthquake. The Bhagirathi river water was reported to have become turbid after the earthquake but 25th October onwards there was no marked change in the turbidity of the river water. According to media reports the river Bhagirathi had been blocked upstream of Uttarkashi, but evidence of such a blockade or its having been cleared by blasting could not be ascertained. Apparently as a result of the earthquake the Power House at Tiloth, of the Maneri stage-I had tripped as provided in the designs. After tripping of the powerhouse the water flow in the tunnel automatically stopped leading to drying up of the river downstream of Uttarkashi and consequent ponding up of the water behind the Maneri dam. Because of power failure at Maneri Dam, there was nearly 12 to 14 hours time lag between the tripping and the manual operation of the spillway gates at Maneri Dam and resumption of water flow in the river downstream of Uttarkashi. This was the reason for the local populace already frightened by the earthquake, to apprehend that the river had blocked by landslides upstream of Uttarkashi.

3.1.1 Landslides

The earthquake has induced numerous landslides of rock fall type, overburden failures, slumps, debris slides, dislodgements of rock blocks in well defined wedges formed by discontinuity surfaces and boulder rolling along steep slopes. Sectorwise brief description of these landslides is as under (for locations refer Fig. 2B):

Tehri-Uttarkashi Sector

The first location of rock dislodgement between Dharasu and Dunda, primarily in the blocky to highly jointed quartzites of Nagni Thank formation, is at a distance of about 5 km from Dunda. These dislodgements continue upto Nakuri beyond which the road is practically located on the terrace material on flat slopes and dislodgements and landslips are not recorded. However, ground fissures on the river side are occasionally developed between Matli village and Uttarkashi. One such feature with concentric cracks was recorded in the overburden material, comprised of silty material, at a distance of about 1km from Matli towards Uttarkashi.

Uttarkashi-Kanauldia gad Sector

The road between Uttarkashi and Gangori is located on a flat terrace away from the hill face but river side terraces show development of cracks and slump failure. From Gangori to Bhatwari there are numerous landslides developed in the terraces composed of river borne material as well as in rock outcrops. A number of rock slides have been observed in the steep slopes with quartzite outcrops. On such slide at about a km short of Maneri is depicted in Photo 1. The intensity of these landslides progressively increases from Gangori to Maneri and then declines upto Bhatwari, the maximum number being located in the Ganeshpur-Malla sector. A few important slope induced ground failures have been documented on Fig. 3A. Around Maneri almost all the slopes have failed irrespective of the slope forming materials (Photo 2). A major rock slide has also been recorded on the left bank road of the Maneri Dam between the dam body and the tunnel intake (Photo 3). From Bhatwari to Kanauldia gad a number of rock dislodgements have been recorded while on the other bank some major slides have also developed. Some stretches between Maneri and Gangnani which are known old landslide stretches have also got activated resulting in road blockades.

In whole of this sector the formation cut of the road has been extensively damaged, the maximum damage being between km. 6 from Uttarkashi and near Pala village where slumps have taken place in the river side slopes. Wide open fissures have developed on the road which are aligned along as well as across the road and numerous retaining walls and breast walls (Photo 3A) have collapsed even on overall gentle slopes. In certain reaches more than half of the road formation as well as painted road surface has been damaged by these fissures. A remarkable feature has been observed on the left bank of River Bhagirathi near Heena where the T-3 terrace, the lowest one, has been shaved for a length of about 400m. The nearly 15m high terrace has apparently failed parallel to the river face as is evidenced by the fresh near vertical cut (Photo 4). Similar terrace shaving has also been observed near village Dedsari.

Gangori-Aghora Sector

From Gangori to Sangam Chatti, 59 dislodgements and two major landslides have been recorded in a distance of about 12 km. From Sangam Chatti to Aghora the frequency of landslides has reduced. Some of the landslides have originated from

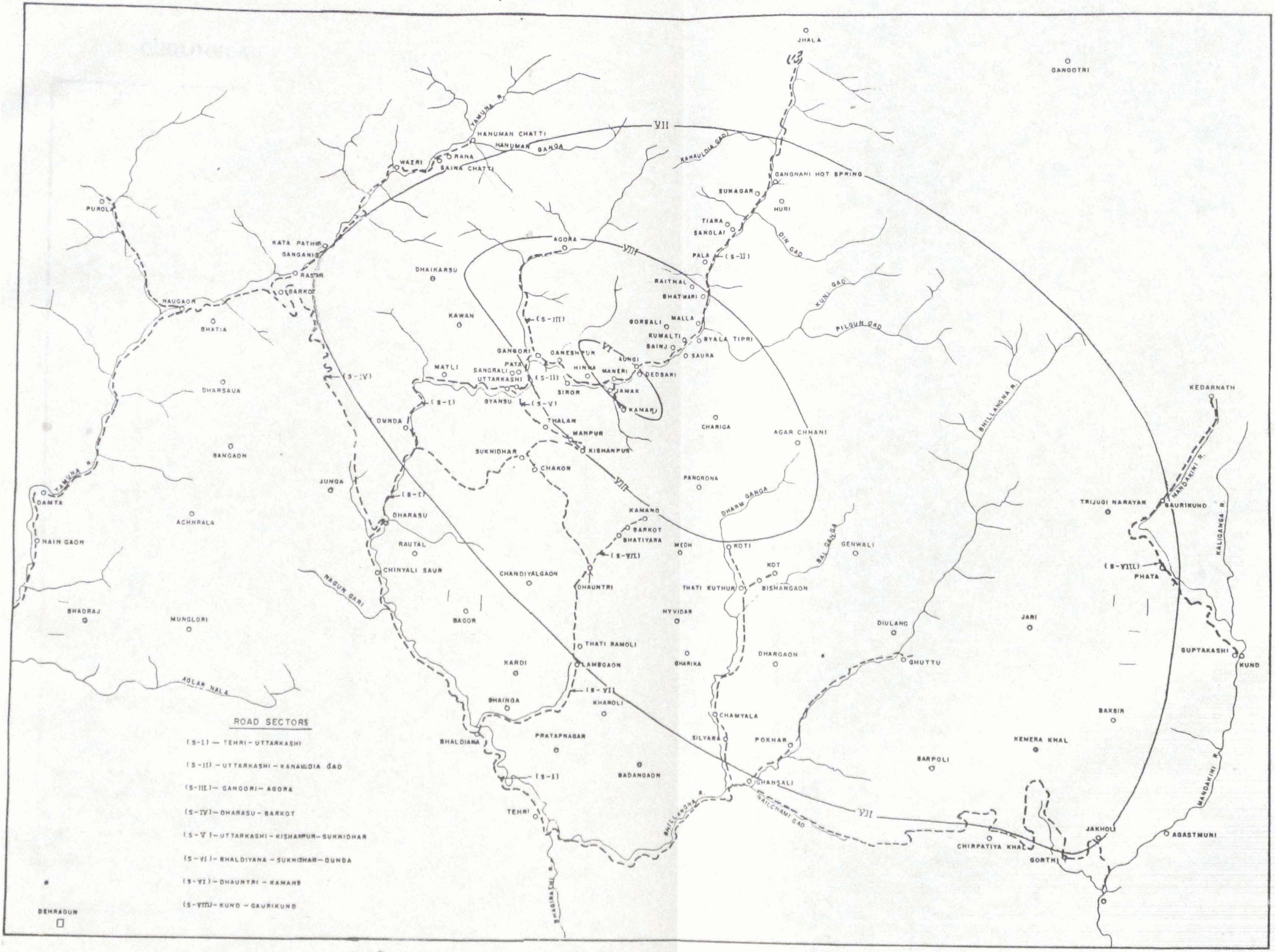


Fig.2.B LOCATION MAP OF THE WORST AFFECTED VILLAGES AND ROAD SECTORS TRAVERSED.

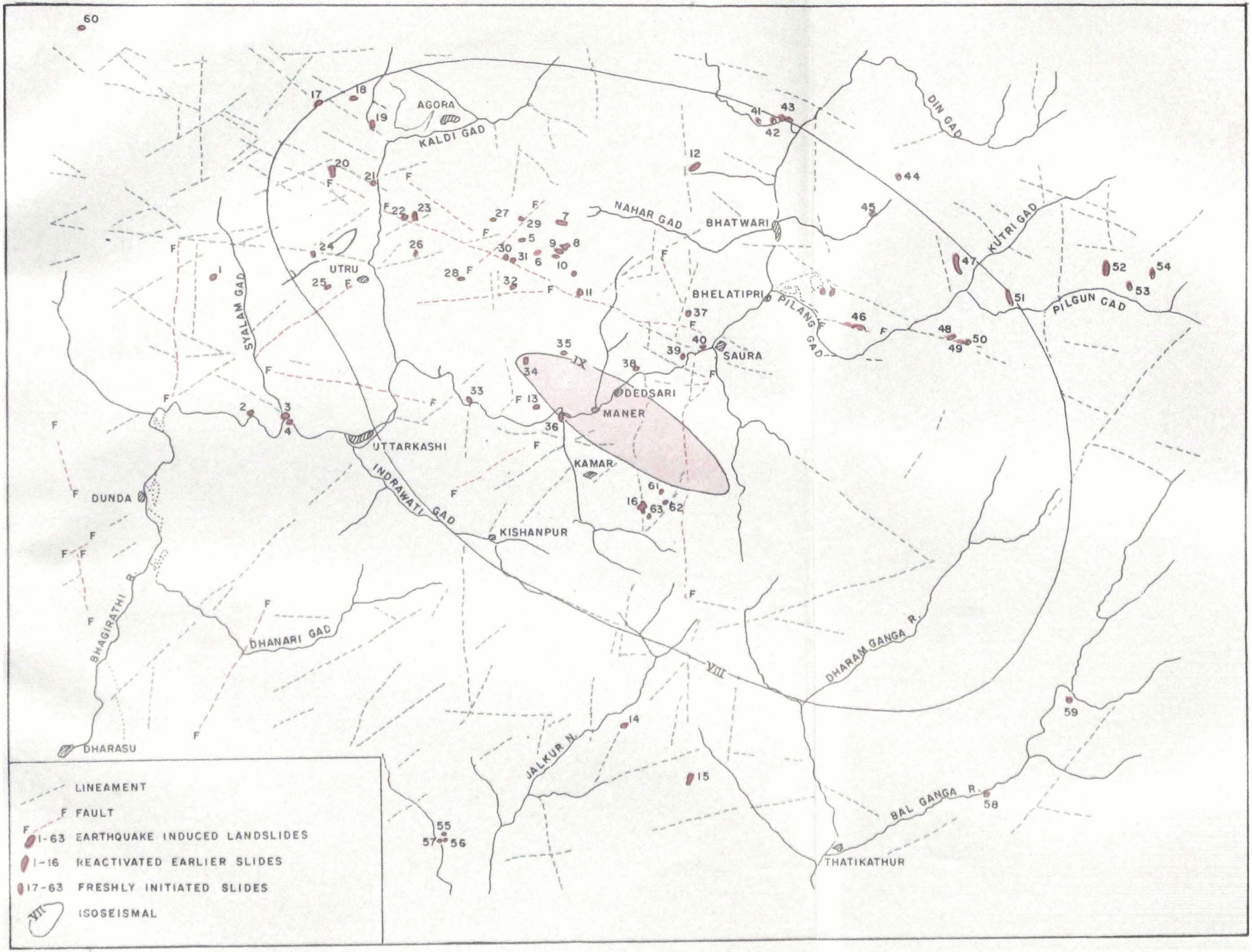


Fig. 3 : MAP SHOWING EARTHQUAKE INDUCED LANDSLIDES BASED ON AERIAL INTERPRETATION OF PRE AND POST EARTHQUAKE IRS LIST II FCC IMAGERIES — 4-10-91 AND 26-10-91.

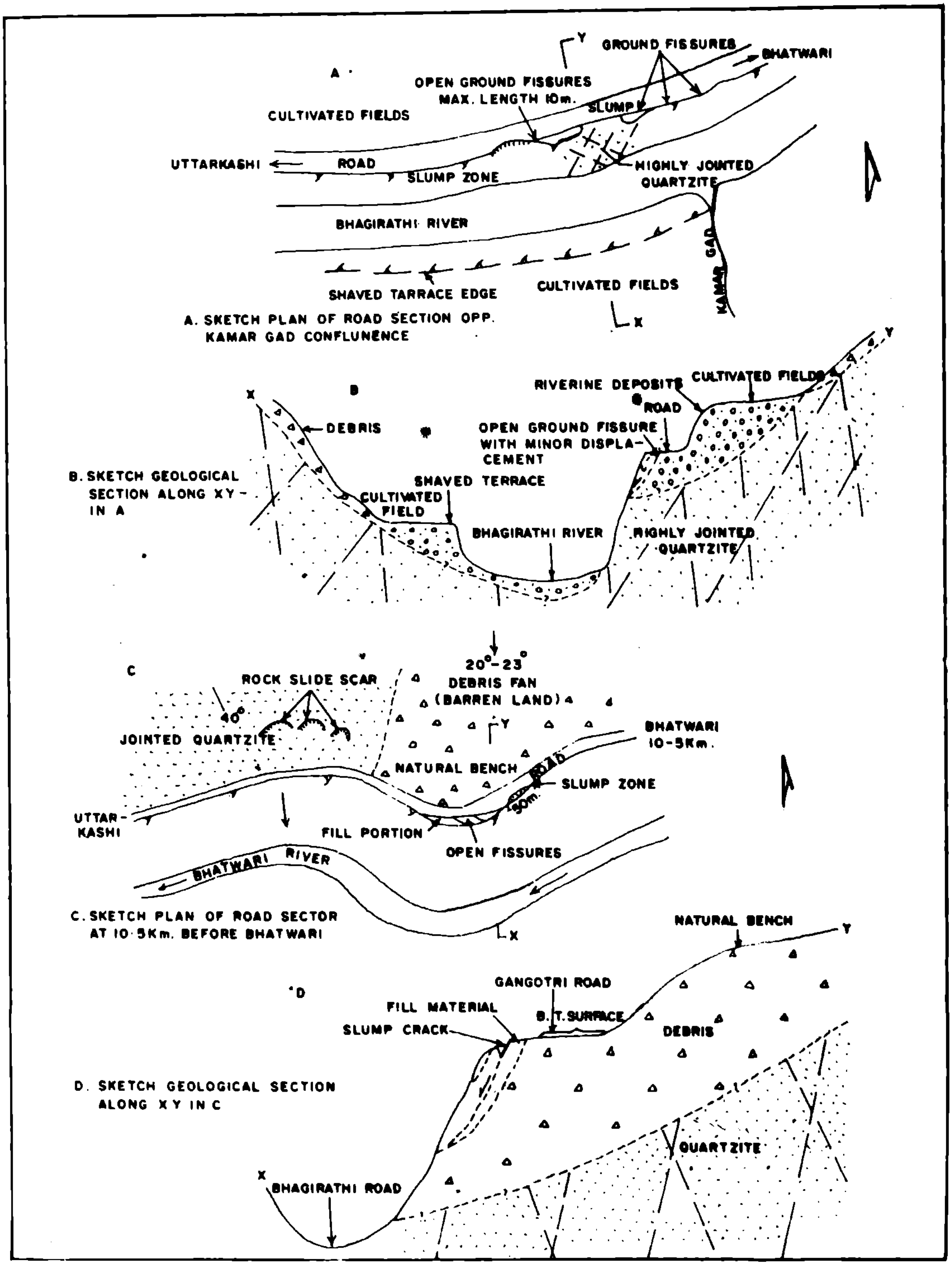


Fig. 3A: SKETCH GEOLOGICAL PLANS AND SECTIONS IN SOME SECTORS OF UTTARKASHI-GANGOTRI ROAD.

upto 100m height from the nala bed and rolling of boulders and sliding caused lot of dust clouds to rise in the horizon, often mistaken for smoke by local people, in the closed valley of Aassi Ganga (Photo 5).

Dharasu-Barkot Sector

On the Dharasu-Barkot sector there are no major damages to road nor there are many slides or dislodgements initiated by this earthquake event. However, between km. 34 and 36, some dislodgements have been observed. Similar rock dislodgements totalling 4 in number have been recorded between km stones 41 and 45.

Uttarkashi-Kishanpur Suknidhar Sector

In this road sector, 41 dislodgements have been recorded on the road between the road bend near Kutaiti colony to Thalan village in addition to 6 nos. of landslides. From Thalan to Kishanpur the frequency of landslides has increased though the back slopes have become gentler. Even very small height (less than 2m) boundaries of the cultivated terraced fields have failed, giving rise to almost uniform slopes near Kishanpur village. The river side edges of the road along with high retaining walls have collapsed (Photo 6) and the river side formation displays a number of fissures in the overburden. The approaches of the Indravati river bridge have failed over about 50m span (Photo 7). From this bridge to Suknidhar a number of dislodgements have been recorded but the intensity and frequency of these dislodgements have considerably reduced. A major retaining wall at the road crossing at Suknidhar has also failed.

Bhaldiyana-Suknidhar-Dunda Sector

In this road sector no landslides or dislodgements are recorded between Bhaldiana and Lambgaon but from Lambgaon to Dhauntri a number of rock dislodgements have been noticed. Between Lambgaon and 5km. beyond the Jalkur nala bridge, 31 dislodgements of rock blocks varying in size from $1m^3$ to $10m^3$ (Photo 8) as well as 10 rock slides have been recorded which have been caused by this event. An old landslide on the left bank of a bridge near Thati Remoli has got reactivated. All these dislodgements and slides are located in the Chamoli quartzites. Between Dhauntri and Suknidhar and the Dunda sector similar dislodgements have been recorded. Between Chakone and Suknidhar a number of retaining walls have also failed. Ground fissures trending in the NW-SE direction have been noticed along the painted surface of the road opposite Bhatiyara village.

Dhauntri-Kamand Sector

The road connecting Kamand village with Dhauntri has also displayed a number of slips mostly in the overburden material and some fissures on the river side edges of the road have been recorded. One, 8 to 10cm wide fissure, parallel to the road, has been recorded almost in the centre of the road. This fissure trends in N60°E-S60°W and is located between village Ladhu and Thati Bharkot in the Barkot Gram Sabha. It was reported by the village Pradhan of Kamand village that a number of fissures had developed on the surrounding hills. One such locality near Kobla Nami top was examined. Some ground fissures located on the overburden material at the nose of intersection of a small nala joining the Jalkur gad and related to slope failure induced by the earthquake were recorded. The longitudinal cracks at this location trend in the N45°E-S45°W directions while transverse ones are oriented in the N25°W-S25°E direction. As a result of this topographical setting and movement of the overburden material a temple built in mud masonry with RCC top has collapsed. Similar ground fissures located in overburden covered slopes have also been recorded from areas located at high altitudes.

Kund-Gaurikund Sector in Mandakani Valley

The Kund-Gaurikund road sector has also witnessed a number of dislodgements, a few small landslides and retaining wall failures. These failures have been noticed from a distance of 3 kms before Phata village, continuing upto Gaurikund. In fact, these terrain changes have been utilised to draw the boundary of isoseismals VI and VII. Over a distance of about 16km from 3 km before Phata upto Sonaprayag, eleven dislodgements, three small landslides and two retaining wall failures have been recorded. Between Sonaprayag and Gaurikund, 5 dislodgements have been recorded in a space of about 5km. The damages in the form of terrain changes are quite conspicuous on the Sonaprayag Triyuginarain road sector on which 23 dislodgements and two retaining wall failures have been recorded. Two ground fissures one 1.5km before Phata trending in N60°-S60°E direction and the other between Sonaprayag and Gaurikund trending in N60°E-60°W direction have also been recorded.

Tilwara-Chirbatia Sector

The road sector between Tilwara in Mandakani valley and Chirbatia water divide of Bhilangana catchment is marked by isolated rock dislodgements. These dislodgements, prominent between Tilwara and Mayali village, are confined to the highly jointed basic rock constituents within the gneissic and granitic rock complex. The dislodgement incidences increase considerably from Mayali towards Gorthi village and infact, in a distance of about 2km., more than 15 dislodgements have been seen in a basic rock exposure near Mayali. Incidentally the boundary of isoseismal VII passes very close to this location. Dislodgements have also been seen in the gneisses exposed in the vicinity of Gorthi village, located on a spur (Photo 9).

Evaluation of Terrain Changes from Remotely Sensed Data

In order to quantify the incidences of landslides (specially in the inaccessible higher altitude areas close to the epicentral tract) and validate the incidences of earthquake induced landslides the pre and post earthquake imageries of the area on IRS LISS II FCC of 4/10/91 and 26 & 27/10/91 have been visually interpretted in the PGRS Laboratory by S/Shri R.V. Iyer and R.S. Misra. They report the presence of 47 new landslides and reactivation of 16 old landslides (Fig.3).

On transforming this information to a base of the isoseismals and the lineaments, the following broad observations could be made:

a) Most of the new and reactivated slides are bounded by isoseist VIII.

b) A majority of these are located in a nearly 2.5km wide linear belt trending N60°W-S60°E from near Utra in the east to beyond to Saura in the west and essentially located on the southern slopes of the hills. This fault can be picked up as a megalineament along the same trend westwards into the Yamuna and Tons valleys as can be seen in the imageries.

c) Incidentally this Utra-Saura fault is located about 4km north of the epicentral tract and almost parallel to the longer axis of the isoseismals.

d) Most of the slides in the area are of rock and debris slide type.

e) The higher density of the slides are in the closed valley around Agora where the white quartzite of Nagni Thank Formations is well exposed.

This may be the reason for the dense dust billowing out of the closed valley near Agora being persistently reported in the media and by the local inhabitants as smoke. The close spaced new landslides near the course of the Pilang Gad might have been responsible for the reported partial blockade of the Gad.

On a very conservative estimate the area occupied by each landslide identified in the imageries cannot be less than $6400m^2$ and assuming again on the conservative side the thickness of the slided material to be 1m the least volume involved works out to be of the order of $+6000m^3$. Therefore, the total mass mobilised by this earthquake in 63 slides works out to be of the order of $0.4Mm^3$. Incidentally the successive imageries have a 60% overlap in the area of study. Making a stereopair the 3D view gives additional information on the aerial extent of the landslides and by this study the volume mobilised may be as much as 10 times the value computed above. This estimation may be rationalised by the Digital Image Processing that is being planned as a follow up study.

However, analysis of the remotely sensed data by Digital Image Processing of the landslide affected area coupled with parametric analysis is planned as a detailed follow up for assessment and validation of the coseismic events, if any, for the Uttarkashi earthquake.

3.1.2 Ground Fissures

One of the most important modes of terrain damages witnessed during this earthquake was the ground fissures, which were predominantly confined to the debris and riverborne material covered slopes or the road sections where the formation levels have been achieved by back filling with loose material. These features have generally been restricted within the area encompassed by isoseist VIII. Isolated incidences of formation of open fissures in the rocks, probably along pre-existing joint planes with steep side slopes, like the one near Sangrali village have also been recorded. The detailed description of these are given below.

Fissure in Bed Rock Near Sangrali Village

In Sangrali village three parallel sets of cracks over a width of about 30m have been recorded, the most prominent of which is the one which has developed at a distance of about 4.5m from the cliff face on which arenaceous phyllite of Uttarkashi Formation is exposed. This crack has been recorded in the bed rock and has been measured to a depth of 9m (Photo 10). At an isolated location the width of this opening is about 50cm. This crack is oriented in the N-S direction i.e. parallel to the cliff face. Because of the earthquake the unsupported side i.e. the cliff face has lead to the opening of rock blocks along pre-existing joint surfaces which are probably the controlling features for development of the cliff face. A sketch demonstrating the mechanism of formation of this crack is enclosed as Fig.7.

The localities, orientations, lengths and openings of ground fissures have been summarised in following Table:

SPATIAL DISPOSITION OF GROUND FISSURES

Sl. No.	Location	Isoseist	Orientation	Length (in m.)	Opening (in cm.)	Remarks
1	Khera (Doon Valley	+VI	NE-SW NW-SE	5-30	1-6	In vicinity of steep unstable slopes in overburden material (terrace).
2	Ganeshpur	+VIII	N70°E-S70°W	4-8	1-2	In debris material on moderate slopes behind the village
3	6 km NE of Uttarkashi on Uttarkashi Gangotri road	+VIII	WNW-ESE	100	20-40	Debris slope & fill material. Displacement of the order of 30 to 50 cm. (normal) (Photo 11)
4	Manpur to Kishanpur	+VIII	NW-SE	5-6	<1	A number of cracks almost parallel to Indravati river have been noticed.
5	Saura-Byala Tipri Male track on left bank of Bhagirathi	+VIII	NE-SW	10	50	A number of fissures along the debris covered slope. Maximum displacement of 0.6m noticed (Photo 12).
6	Sangrali	VIII - VII Boundary	N-S	30	20	Three cracks, maximum measured depth 9m in phyllitic rock mass above a scarp face (Photo 10).
7	Gawanagad	+VIII	N85°W-S85°E NW-SE NNW-SSE	25 7 6	55 2.5 <1	Fill material
8	Maneri Dam - Jamak Section	IX	NNW-SSE	0.1-0.15	50	A number of fissures in fill material and debris covered slopes. Maximum displacement 0.4m (normal) (Photo 12A).
9	Jamak-Kamar Section	+VIII	NW-SE & N-S	<5	1-10	A number of fissures on the foot track between Jamak & Kamar in compact debris material (Photo 12B).
10	Naid	+VIII	N20°E-S20°W	10	5	On debris covered slopes in en-echlon fashion cracks in about 30m zone.
11	Opposite Siror Suspension bridge on Uttarkashi-Gangotri road	+VIII	N70°W-S70°E	30	20	In terrace & fill material.

(Cont.)

SPATIAL DISPOSITION OF GROUND FISSURES (Cont.)

Sl. No.	Location	Isoseist	Orientation	Length (in m.)	Opening (in cm.)	Remarks
12	Opposite Bhatiyara village on Dhauntri-Chakon road	+VII	NW-SE	30	1 (Max)	Overburden material going beyond black top surface towards hill.
13	Between Lodhu & Thati Barkot villages on Dhauntri-Kamand road	+VII	N60°E-S60°W	15	8-10	In the centre of road on overburden material.
14	Robla Nami near Kamand village	+VII	N25°W-S25°E N45°E-S45°W	5 10	1	On a nose covered with overburden material, transverse and longitudinal cracks connected with slopes failure.
15	Ghorkhur, Talato Bhanian	Reported	-	-	-	In similar terrain as in 14 above.
16	Aghora	+VIII	N20°W-S20°E	-	Minor	Cracks in overburden material on steep slopes.
17	Gorthi	+VII	WNW-ESE	5	1	On rock occupied by overburden material.
18	Maneri Dam	IX	ENE-WSW	15-20	5	Fill and overburden material cutting the black top surface of the road at oblique angle (Photo 13).
19	Maneri-Bhatwari	IX, +VIII	N60°E-S60° E-W NW	10 5-20 20	5-10 5-20 20	Numerous parallel, oblique cracks and a few transverse to the road have been observed accompanied by sagging and subsidence of road.
20	Bhainga	+VI	N15°W-S15°E	10	1	Overburden material on a narrow spur.
21	Lambgaon opp. SBI building	+VII	N20°W-S20°E	50	10	On a flat ground adjecent to steep sloap measured depth 1.5m (Photo 14).
22	7km stone on Ghansali-Thayali road	+VII	N65°W-S65°E	+10	0.5-2.5	Oblique to the road in overburden material.
23	Agar, courtyard of house of Govind Singh	+VII	N30°E-S30°W	+5	0.5	Overburden/terraced fill material.
24	Slopes above Agar village	+VII	N60°E-S60°W E-W	7.25	1-30	A number of cracks in old slide debris accompanied by sagging and settlement.
25	1.5km short of Phata on Ghat-Gaurikund road	+VII	N60°W-S60°E	12	1	On road in overburden material.
26	2.5km from Sonprayag towards Gaurikand	+VII	N60°E-S60°W	10	1	Overburden material.
27	Badethi	+VII	-	-	3.5	Subsidence about 10cm, arcuate cracks on the right bank.

It is seen from this table that the preferred trends of these fissures are predominantly guided by the topography as well as the physical characteristics of the material in which they have developed. There had been a few exaggerated reports of large and long fissures. These could not be verified even by detailed ground checks.

In addition to long fissures developed mostly along the road or track alignments, at a number of localities, particularly in area of isoseist VIII, small topographic breaks have also failed in the terraced fields in Kishanpur and Manpur villages. These failures do not seem to have any genetic relationship with the source fault because most of them are located parallel to the valley slopes and a few are tensional openings in the overburden material.

3.1.3 Changes in the Discharge of Springs

It has been reported that the spring water discharges at various locations either increased considerably or reduced appreciably. The villages from where such reports have been received are as under:

i) At Gangori village the discharge in the springs has increased but at Saura village the spring discharge has considerably reduced. Both these localities are in the intensity VIII in the Bhagirathi valley.

ii) In Jalkur valley the discharge of spring at Timblichak near Bainga village increased after the shock.

iii) In Bhilangana valley discharge of spring located in Tipri village increased.

iv) In Nalichami valley, there was increase in the spring discharges at Muyalgaon and Titrana villages whereas in Gaurya and North east of Holta village appreciable decrease in the spring discharge was reported.

v) The Assistant Engineer, Irrigation Department of H.P. at Theog reported that a water spring had dried up at its usual location and had emerged about 50m down the slope. At Rakcham it was reported that one spring started emitting lukewarm water.

Hot Springs

Of the 62 thermal springs recorded in the Utter Pradesh Himalaya, 13 are located in the Bhagirathi and Yamuna valleys, the area most severely affected by the quake. These hot springs are located on either side of the MCT in the central crystallines and the Garhwal Group of rocks. Some of the hot springs like Gangnani Aungi are located very near to the epicentral tract and thus the changes in the temperatures, discharges and chemistry of these springs have been studied and brief results are given below:

In addition to the information collected by enquiry from the local people about the changes in the spring water discharges, the temperatures were measured at the known hot spring localities and compared with those measured earlier. At Gangnani the temperatures recorded on 19.11.91 was 65°C while those recorded earlier in the last 15 years, have varied between 61° and 64°. The measurements made on 4th December, 1991 and 19th Jan. 1992 indicated temperatures of 60° and 63°C, respectively. For Aungi hot spring located in the epicentral tract a temperature of 34°C has been recorded which is comparable with the ones recorded earlier. Later, on 20th January 1992, the Aungi hot spring gave a temperature of 37.0°C. It is reported that after the earthquake, the original source has completely dried down. The spring now emerges from a location about 150m upstream of the original one, along the right bank of Bhagirathi river. The reduced discharge now measures about 15 lit/min. From these observations no conclusions could be drawn though it is reported at certain locations that increase in temperature as well as discharge took place. In addition to temperature measurements water samples were collected from Gangnani and Aungi hot springs for putting these waters to chemical analysis. Results obtained from these samples as well as those of August, 1989 (nearest before the earthquake) are given in the following table. The results so obtained have been assessed mainly by Dr. Ahsan Absar of Geological Survey of India and the same are discussed below:

Common features and the differences in the water samples collected after the earthquake from Aungi and Gangnani hot springs are:

Common features:

i) Decrease in TDS, HCO_3^-, Cl^- and Na^+

ii) Increase in SO_4^{--}

Differences:

i) Decrease in SiO_2 at Gangnani and an increase at Aungi.

ii) Ca^{++} shows a marked increase at Aungi whereas Mg^{++} shows a decrease. At Gangnani Mg^{++} tends to show an increase.

	Gangnani		Aungi	
Ions (mg/l)	4/12/91 PostE.Q.	Aug.89 Pre E.Q.	4/12/91 Post E.Q.	Aug.89 Pre E.Q.
TDS	820	1040	805	980
HCO_3^-	642	817	627	771
Cl^-	64	95	133	162
SO_4^{--}	48	33	33	28
F^-	6	5.5	3	3.5
Ca^{++}	62	69	80	66
Mg^{++}	11	5	49	64
Na^+	210	280	176	220
K^+	24	27	22	26
B	4	4	5	8
SiO_2	70	0.95	42	31
Temp°C	60/65	62	34	39

The base temperatures (temperature attained by water in its deep circulating base) have been calculated utilising relationships suggested by Giggenback et al 1983, Giggenback 1986. Estimated base temperatures are given below:

	Gangnani		Aungi	
	SiO_2	K/Mg	SiO_2	K/Mg
Aug.89 (Pre-quake)	116°C	100°C	54°C	69°C
Dec.91 Post-quake	97°C	87°C	68°C	67°C

Mixing Relations at Gangnani

An overall decrease in TDS at the expense of HCO_3^-, Cl^-, Na^+ and K^+ could be the result of mixing of hot and cold waters. The representative cold ground water at Gangnani has Cl^- and SiO_2 values of 6 and 10 mg/l, respectively and with the Cl^- value of 6 the Cl– balance can be worked out as X(6) + (1–X) 96=64; x=0.348. Thus with Cl balance hot and cold water mixing ratio works out to be 65:35. For this mixing hypothesis to hold good the ratio of 65:35 worked out by balancing the mass of the conservative element Cl^- should balance other elements also. The calculated chemistry of other elements is as follows:

Chemical species used for mass balance	Calculated concentration	Measured concentration (4-12-91)	Representative cold ground water RGW (Sharma,91)	
			Cl^-	6 mg/l
SiO_2	65	70	SiO_2	10 mg/l
HCO_3^-	543	642	HCO_3^-	35 mg/l
Na^+	184	210	Na^+	6 mg/l
K^+	19	24	K^+	3 mg/l
TDS	700	820	TDS	65 mg/l

A perusal of the above table suggests that except for silica which is within 5 mg/l of the measured value all other species are far from being close to the measured values. Though composition of the Cold Regional Ground Water (RGW) varies from one area to the other depending on the country rock, depth of circulation and seasonal variations, is unlikely to influence the mass balance to such an extent. Alternatively, one may suspect the mixing ratio, calculated by using Cl^-. As mentioned earlier, Cl^- is a conservative element added to the solutions only through rock water interaction, it cannot be suspected unless an additional source of salinity i.e. salt beds or connate water has come in contact. The possibility, therefore, exists that the water diluting the Gangnani hot spring is not similar to RGW but is more concentrated (higher TDS) deeper ground water. Low Cl content of 64 mg/l suggests that the mixing water should be characterised by low Cl/HCO_3 ratio. In addition, low SiO_2 (70mg/cl) and lower

TDS values (820 mg/l) suggest that the fraction of RGW of the type given in the above table may be much smaller than assumed and following possibilities of mixing could exist.

i) Aug./89 + a higher TDS low Cl/HCO_3 ratio water.

ii) Changes in hot spring composition at deeper levels relative to Aug./89 com.+RGW.

iii) Aug./89 water + High TDS low Cl/HCO_3 water + RGW.

Having considered various possibilities of mixing, relatively high values of SO_4^{--} and Mg^{++} needs to be explained. An increase in SO_4^{--} content may be explained by assuming the presence of oxygenated water which would cause oxidation of H_2S present in the hot water. Mg^{++} could have been picked up by solutions from chloritic clays during their ascent through changed routes (after the quake), or it could have been added to the solution at deeper levels (through possibility ii or iii above).

Mixing Relations at Aungi

Through Cl^- balance, a ratio of 0.8 (Aug.89) and 0.2 (RGW) is calculated for Aungi hot spring. By taking these ratios the calculated chemistry of post earthquake sample is as follows:

Chemical Species used for mass balance	Calclated concentration mg/l	Measured concentration mg/l
SiO_2	27	42
HCO_3^-	624	627
Na^+	177	176
K^+	21	22
TDS	800	805

It is interesting to find that except for SiO_2, all other chemical species including TDS show a perfect match between calculated and measured values if it is assumed that the hot water component present at Aungi is similar to that sampled in Aug. 89 except for having a relatively high SiO_2 content of 50 mg/l instead of 31mg/l. As concentration of dissolved silica is directly proportional to temperature, an increase in silica by 19 mg/l would correspond to a rise in temperature by about 24°C at the reservoir level.

Increase in SO_4^{--} may be attributed, as in the case of Gangnani, to increased oxidation of H_2S to SO_4^{--} in the presence of oxygenated waters but increase in Ca^{++} is a bit difficult to explain. This hot spring is normally characterised by high Ca^{++} and Mg_{++} content of 66 and 64 mg/l (Aug.89) which may be related to rock water interaction in the basic rocks in the vicinity. Alteration of ferromagnesian minerals would result in leaching of Ca^{++} and Mg^{++}. It is thus possible that circulation of fluid through newly created channels (as a result of tectonic adjustments during the quake) under increased temperature conditions have resulted in variation of Ca/Mg ratio in the solution. SiO_2 and K-Mg thermometris suggest decrease in reservoir temperatures (of post equilibrium) at Gangnani and an increase at Aungi.

From the above discussions it could be concluded that:

i) The post earthquake scenario suggests that there has been mixing of the ground water with the hot springs in different proportions and the mixing of low TDS groundwaters has given lower TDS waters than those recorded in the samples collected before the earthquake.

ii) Aungi hot spring chemistry changes can be explained by mixing of regional groundwater except the percentage of SiO_2 content which instead of decreasing by mixing has increased considerably. This indicates that at the hot water source level the temperatures have increased. The mixing of thermal waters with regional ground waters has taken place at Gangnani also but the balance of the elements is not possible by simple dilution and it is likely that deeper ground water too has mixed with the thermal waters.

3.2 DAMAGES TO ENGINEERED STRUCTURES

The relative degree of safety in built in the design of engineered structures is dependant on (i) the importance and vulnerability of the structure and (ii) the capital outlay. It follows, therefore, that the capital intensive hydroelectric project structures are more rigorously analysed and have a much more conservative design as opposed to communication projects. This is amply borne out by the fact that the Maneri Dam though located in the epicentral tract escaped without any structural damage while the Gawana Gad bridge located about 6km downstream of the Dam was completely damaged. The descriptions in the following paragraphs start with the well engineered structures followed by less rigorously engineered structures like the girder and suspension bridges.

3.2.1 Maneri Dam

The 39m high concrete gravity dam across river Bhagirathi at Maneri has not suffered any damage though located very close to the epicentral tract. The appurtenances of this dam including the high wing walled approach channel to the intake portal of the head race tunnel has also escaped any damage (Photo 15). However, two buildings located on the right bank near the road and not resting on the body of the dam have been extensively damaged (Photo 16). The eastern side wall of the substation building in concrete blocks has completely collapsed while the long wall sides display major cracks. The foundation galleries of the dam have also been examined and it is noticed that the lower gallery (foundation gallery) located at RL 1269m does not show any signs of distress. The upper gallery at RL 1279m however exhibits very minute opening of the block 6-7 joint. In addition, near the left outlet on the upper gallery, hair fine horizontal cracks are seen which may be restricted to outer surface of lining. There is no apparent change in the discharge through the drainage holes but the same will have to be monitored to find whether there is any change in the water seepage quantities as compared to the corresponding periods and records already available. The wing walls of the approach channel which are at least 10m high also do not show any distress. The backfill exhibits settlement behind wing wall of the approach channel, without causing any structural damage to the wing walls. Fissures in the backfill below the approach to the Jamak village are quite conspicuous. A few rock block dislodgements and rock falls near and upstream of the left terminus have been recorded which have not caused any damage to the structure though some blocks have fallen on the dam and on to the deck of the structure. On the right bank the approach to the dam made in the fill material upstream of the dam axis show fissures. The parapet walls made in masonry have cracked and high retaining walls on the approach road to the colony have completely collapsed.

The 90MW capacity Tiloth Power House of Maneri-Bhali Project Stage-I is located on the left bank of Bhagirathi river, opposite to the Uttar Kashi town. The power house building is located on over alluvial terrace deposits with its longer axis aligned in N25°E-S25°W direction, that is roughly parallel to the course of Bhagirathi. The minor damages suffered by the power plant which resumed generation after a pause of few days, are enumerated as under.

The construction and expansion joints of the building have opened at a number of points. These appear as elongate cracks on panelling walls and ceilings, along or parallel to the joint faces. Their origin can be attributed to the differential response of the components of the building to the vibrations induced by the tremors. Peeling of plaster is also associated with some cracks. The first panel of the western face of the non load bearing partition wall has tilted outwards by about 1° The RCC pedestals of the generating units have developed 2cm to 15cm long vertical hair cracks. These features which appear to be restricted to the surface only are reportedly being monitored by the project authorities.

There is a relative displacement of the order of 10cm between the front face of the building and the outside concrete floor. This could be related to the ground settlement. The damage pattern indicates that the direction of ground oscillations would have been WNW-ESE.

3.2.2 Ichari Dam

It is a 55m high concrete gravity dam aligned in N15°E-S15°W direction with a L shaped, 120m long extension at right angles to the dam axis for the treatment of the left bank slide. The entire area of the dam exposes the Chandpur phyllites.

The operating personnel on duty at the dam during the night shift felt the movement parallel to the dam axis and observed swing of the hanging objects in the same direction. Large splash waves (variously estimated to vary between 1 to 2m) were reported to have developed in the reservoir.

The inspection and drainage galleries within the body of the dam were examined but were found to have escaped any damage. It is reported that the seepage from the drainage galleries ranged between 1.7 and 1.75 lts./sec. prior to earthquake but a rise has been reported 23 hours after the earthquake to 2.19 lts./sec. which has later on stabilised at 2.5 lts./sec.

In the non-overflow block 1A (located on the left abutment) an opening of about 1mm. has been observed along a vertical construction joint on the downstream side face. Minor seepage through this joint has deposited a thin layer of secondary carbonate over the lower part of this joint. This layer has developed a fresh, fine crack along the joint, indicating minor movement along the joint.

To monitor the stability of the left bank, 21 targets on this bank are being periodically surveyed by the project authorities from 2 stations on the dam structure. No change in the pattern of the readings could be described from the pre and post earthquake readings.

The elevator lower shaft located towards the left terminal of the dam is about 30m high of which the bottom 20m portion is partly embedded in the body of the dam and the rest projects in the air. This lower portion showed several cracks on its southern (left bank side) and western (downstream side) walls. In the lower part of the shaft attached to the dam two sets of cracks (<0.5mm), one vertical and other horizontal, developed. Vertical cracks are more common, somewhat irregular and are either terminated or deflected by the horizontal cracks. The horizontal cracks are along the joints of concrete lift joints. Cracking is more pronounced on the southern wall. The enhancement of the seepage in the drainage gallery may be attributed to opening up of the path of percolation by readjustment of the material infilling the joint openings.

There is preponderance of horizontal crack at and around the point of hinge of the elevation tower which suggests that the cracks might have been developed as a result of the interaction and interference of different modes of vibration.

Some damage has also been reported in the residential colony at Koti which is nearly 3km SW of the dam on the basis of which the area seems to have witnessed an intensity approaching VI due to the earthquake.

3.2.3 Chibbro Underground Power House

This is a 113m long, 18.5m wide and 32m high cavity housed wholly in the Dhaira argillaceous limestone/slate interbedded unit of the Mandhalis. The Power House cavity is nearly 70m laterally into the hill and 120m below the natural surface. On the downstream, N-S aligned wall of the power house cavity 1 to 2 mm wide, three vertical and two oblique cracks have been observed abut 2.5 above the turbine level in the area between 1st and the 2nd turbine. Shotcrete from about 0.6mX0.25m area along each of the oblique cracks (inclined at 40° to

Photo 1 *Rock fall cum debris slide initiated in quartzites upslope of the road about a km before Maneri. Note uprooting of a telephone pole in the toe portion of the slide.*

Photo 2 *Failure of buttressed breast wall of the approach road to Maneri colony. (Photo NGRI).*

Photo 3 *Rock fall in blocky quartzites. Note large rock blocks lying on the approach road to intake structure of the Maneri dam.*

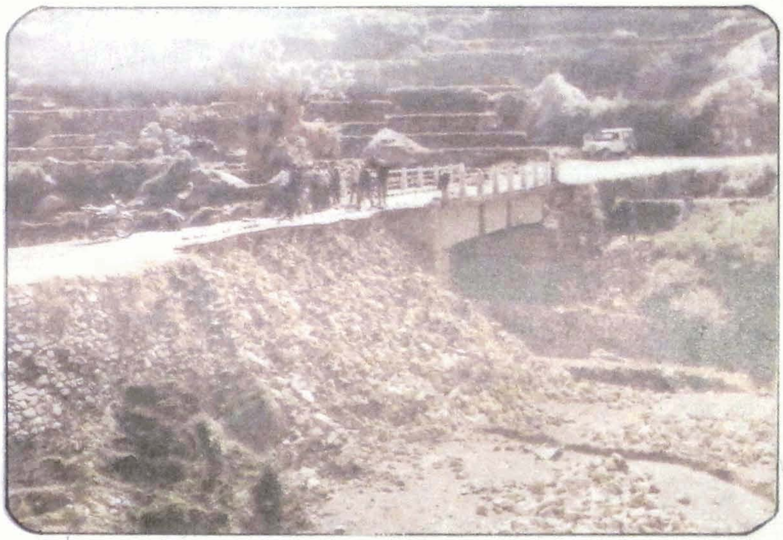
Photo 3A *Failure of breast wall leading to collapse of telegraph pole near Gawana gad bridge.*

Photo 4 *Shaving of the nearly 15 m. high river terrace on the left bank of river Bhagirathi at Kamar gad confluence.*

Photo 5 *Dust clouds bellowing out of the closed Aasi Ganga valley as a result of landslides.*

Photo 6 *Failure of the valley side portion of block top road near Mannpur.*

Photo 7 *Damaged approaches of the bridge over river Indravati near Kishenpur. See undamaged RCC bridge of about 15 m. span.*



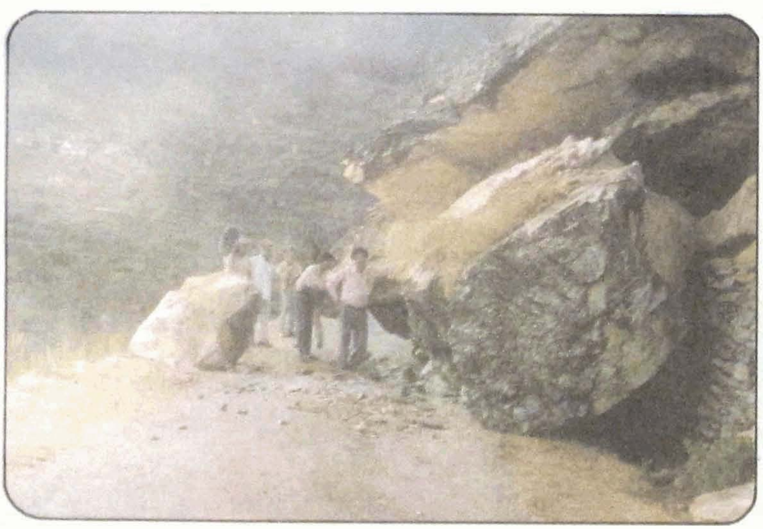


Photo 8 *Rock dislodgement on Lambagaon-Rautaldhar road section.*

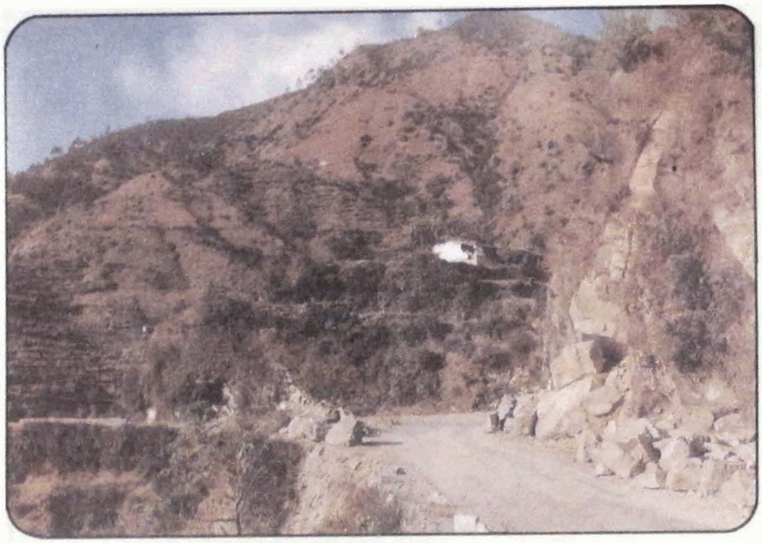


Photo 9 *Dislodgement of rock blocks near Gorthi village. Partial collapse of the short wall of a village house in the background.*

Photo 10 *60 cm. open fissure, controlled by master joints near Samgrali village (Photo–NGRI).*

Photo 11 *Open fissures in oberburden material showing 50 cm. valley side slumping, 6 km. upstream of Uttarkashi on the road to Maneri.*

Photo 12 *NE–SW trending fissure on the debris covered slope on the Saura Byala Tipri mule track.*

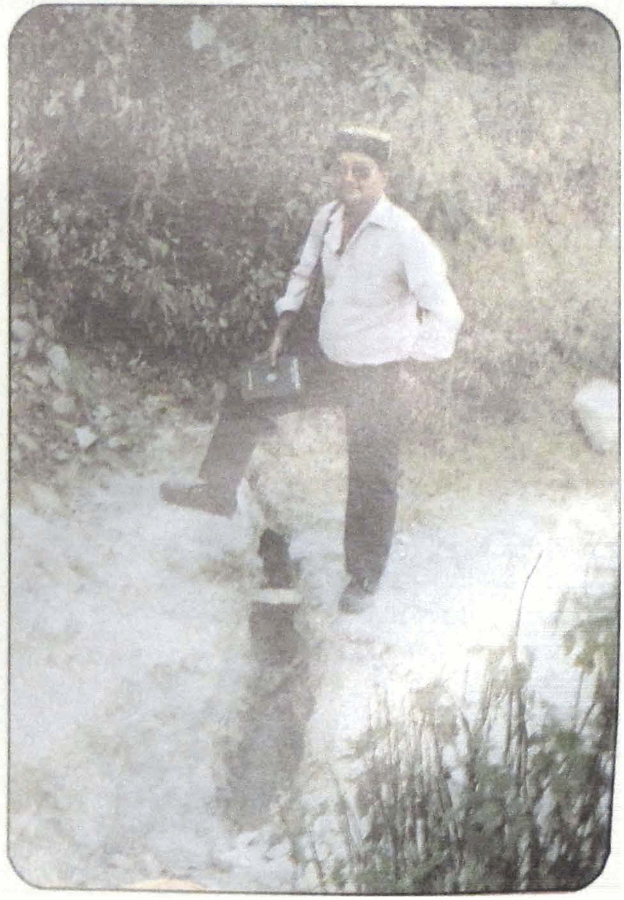
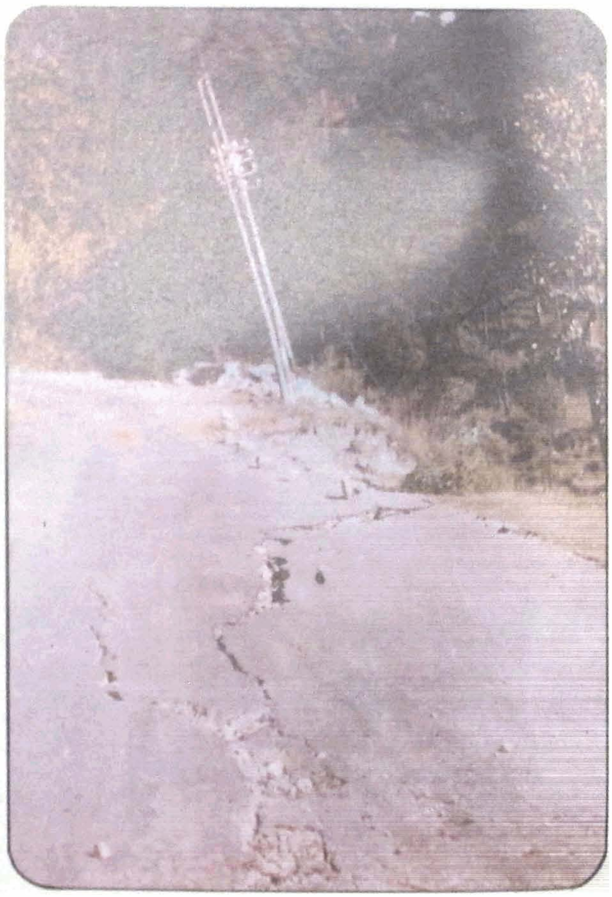


Photo 12 A *50 cm. open crack trending NNW–SSE along Manerijamak foot track.*

Photo 12 B *Nearly 5 cm long open slump fissure in the cultivated fields of Kamar village.*



hoto 13 *Arcuate ground fissures cutting the black top surface of road near Maneri.*

Photo 15 *View showing Maneri dam and the appurtenances facing downstream. Maneri colony in the background.*

Photo 16 *Wall collapses and gaping cracks in type B construction and failure of retaining wall just upstream of Maneri dam.*

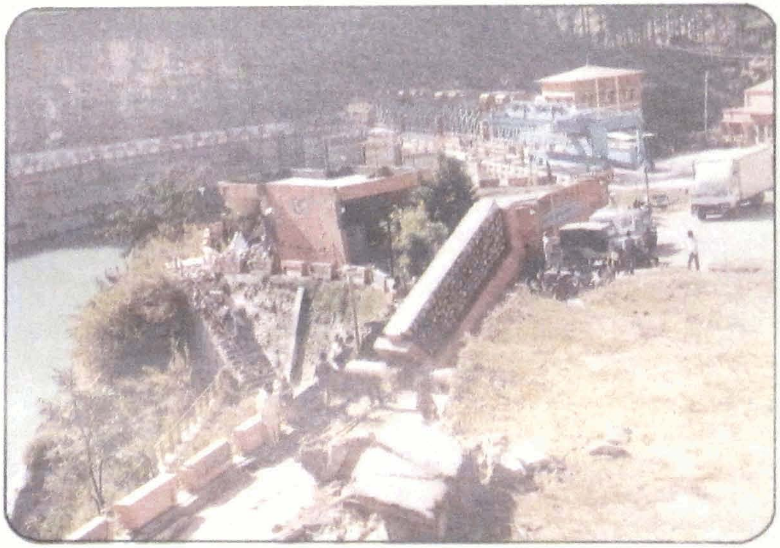


Photo 17 *Collapsed Gawana gad bridge in Uttarkashi Maneri road sector.*

Photo 18 *Intact base plate of the rocker on the Uttarkashi side of the Gawana bridge.*

Photo 19 *Upstream end intact base plate on the Maneri end of the Gawana bridge. Note rollers in place and slipped roller plate and coupling rod in the foreground.*

Photo 19 A *Clockwise rotation of the downstream end baseplate, Maneri side of Gawana bridge. Rollers and roller plate not seen as they have been thrown in the river below.*

45°) have fallen down. These cracks have developed in the shotcreted surface. In the control room area, horizontal to subhorizontal hair cracks were noted at an uniform level of about 1.4 and 2.5m above the floor in most of the pillars of the RCC frame structure. These cracks also traverse the marble slabs fixed on the pillars. A number of prestressed cable anchor heads in the draft tube operating gallery show cracks in their shotcrete cover. Cracks have been found mostly where the shotcrete over the anchor plate is thin and the exposed iron surface has considerably rusted. Cracks run mostly along the various components of the anchor head. Occasionally, however, the thick shotcrete over the heads have also developed cracks, mainly normal to the anchor. Sometimes the cracks appear fresh but in many cases their recency could not be established. Most of the corresponding anchor ends in the power house (PH) cavity were inaccessible but the ones available for examination did not show any cracks. Besides these, several cracks are present elsewhere in the PH complex but they lack freshness and other signs of recent development or are known to be preexisting. Four falling hammer type extensometers are installed on each wall (i.e. eastern and western wall) of the PH cavity. The hammer is designed to fall when the space between the knife edges exceeds some preset value which in this particular case was 6mm. In the eastern wall (which is incidentally the one closest to the free face) the hammer of one such extensometer located between the 1st and 2nd turbines has fallen while in the other the gap is of the order of 3mm. A vertical crack in the shotcrete is present close to the fallen hammer. The diagonal cracks detailed above are also within this area.

From the above following inferences can be drawn:

1) The area exhibiting the cracks and fall of the hammer were pre-existing areas of loosening (this is a common enough phenomenon in large underground excavations) which have been subjected to the earthquake shock.

2) The cracks and weaknesses were not pre-existing but have developed by the earthquake.

However, the second inference is unlikely because the cracking (1) should have been more pronounced in the approach adits or areas with much less stringent support measures and (2) would not have been restricted in only one particular segment of the PH cavity.

The strainmeters installed in the roof segment of the PH and surge shaft do not show any significant stress variation correlatable to the earthquake.

3.2.4 Khodri Power House

This is a surface power house founded on the alternating sandstone and claystone of the Lower Siwalik. Opening of the vertical construction joint within the twin columns of gantry crane was noted above the turbine floor. Openings upto about 2mm. was found in columns on both sides of the PH. Though some small cracks running across the concrete layer (about 2cm thick) present between the twin pillars appear fresh, it could not be established whether the joints were open prior to earthquake or not. There is, however, clear evidence of movement along them recently, in the form of chipping of plaster (10-15 cm long and 2-5 mm. thick pieces in some case) along some of these joints. On the valley side wall in the 4th machine area, a horizontal crack was also noted about 2m above the generator floor. The gantry column crack was traceable downwards in one case, in the upper half of the main inlet valve gallery. On the uppermost part of the RCC columns of the elevator tower, vertical and horizontal hair cracks with minor chippings are common.

Persons working in the power house during the earthquake reported initial movement (about 5 seconds) parallel to the short axis (N35°W-S35°E) of the PH, followed by mild movement (for about 10 seconds), and finally a strong movement parallel to long axis (N55°E-S55°W) for about 25 seconds. One of the engineers reported that he had observed about 15° tilt of the vertical columns during earthquake.

3.2.5 Khara Hydel Scheme

This scheme includes 13km. long water conductor system, a surface power house and tail race channel and is in an advanced stage of construction. It lies on Siwalik rocks and recent fluvial deposits. Faults with Recent activity are present in the project area.

No damage related to earthquake was found in the structures examined, and no sign of movement was observed along the faults with established neotectonic activity where they are covered by civil construction in the power house and power channel areas. In the inlet and outlet areas of the twin tunnels, which are part of the water conductor system, openings of upto about 1.5mm. is present along the construction joints between cut and cover section and the main tunnels. According to project engineers, these existed prior to the earthquake, but any change in them due to the earthquake is not determinable.

3.2.6 Gawana Gad Girder Bridge

The most conspicuous effect of the Garhwal earthquake of 20th October, 1991 has been on the Gawana Gad girder bridge, located at km 155.346 along Rishikesh-Gangotri road, adjoining Ganeshpur village. The entire superstructure has collapsed into the rivulet valley beyond redemption (Photo 17). The traffic on the route remained totally disrupted for 3 days, until an alternative temporary causeway was launched over the swifty flowing rivulet waters. The Border Road Organisation was engaged in the task of construction of an alternative, all season baily girder bridge to connect the strategically important areas of Bhagirathi valley.

The Gawana Gad girder bridge is located across Gawana rivulet, a right bank tributary of Bhagirathi river. It was a class A-A structure with a single span of 53m and bearing of N85°W-S85°E. A map of the approach roads and abutment piers has been prepared on scale 1:200 with the help of brunton and tape (Fig.4).

The approach roads on either abutment have been constructed from fill material comprising randomly dumped boulders and soil. The right abutment (Uttarkashi end) approach road has developed three sets of fissures due to the earthquake. The most prominent one trends E-W, that is parallel to the road alignment. On the southern edge, this set extends to a length of 26m with a maximum opening of 0.55m. and minor displacement. Here a 12m section of the road has slumped down towards the free southern face, thereby, leaving a prominent scar. The other two fissures trend in NW-SE and N-S directions. The former has a maximum opening of 2.5cm and length of 7m. The latter is fairly tight with a length of 5m. The joint of approach road and concrete abutment has opened up by a few mm..

The left approach road is marked by an arcuate crack of 5.5m length, roughly parallel to the northern edge. Part of the fill material in a 6.6m section on the northern edge has also slumped. The bitumen coating, covering the approach road-abutment pier joint has bulged out in a 0.65m zone.

The concrete abutments of the bridge are found intact. The two base plates affixed over concrete pedestals in the right abutment do not show any distress. The anchor bolts as well as the rockers are intact (Photo 18). The counterpart plates attached to the collapsed super structure are also found intact.

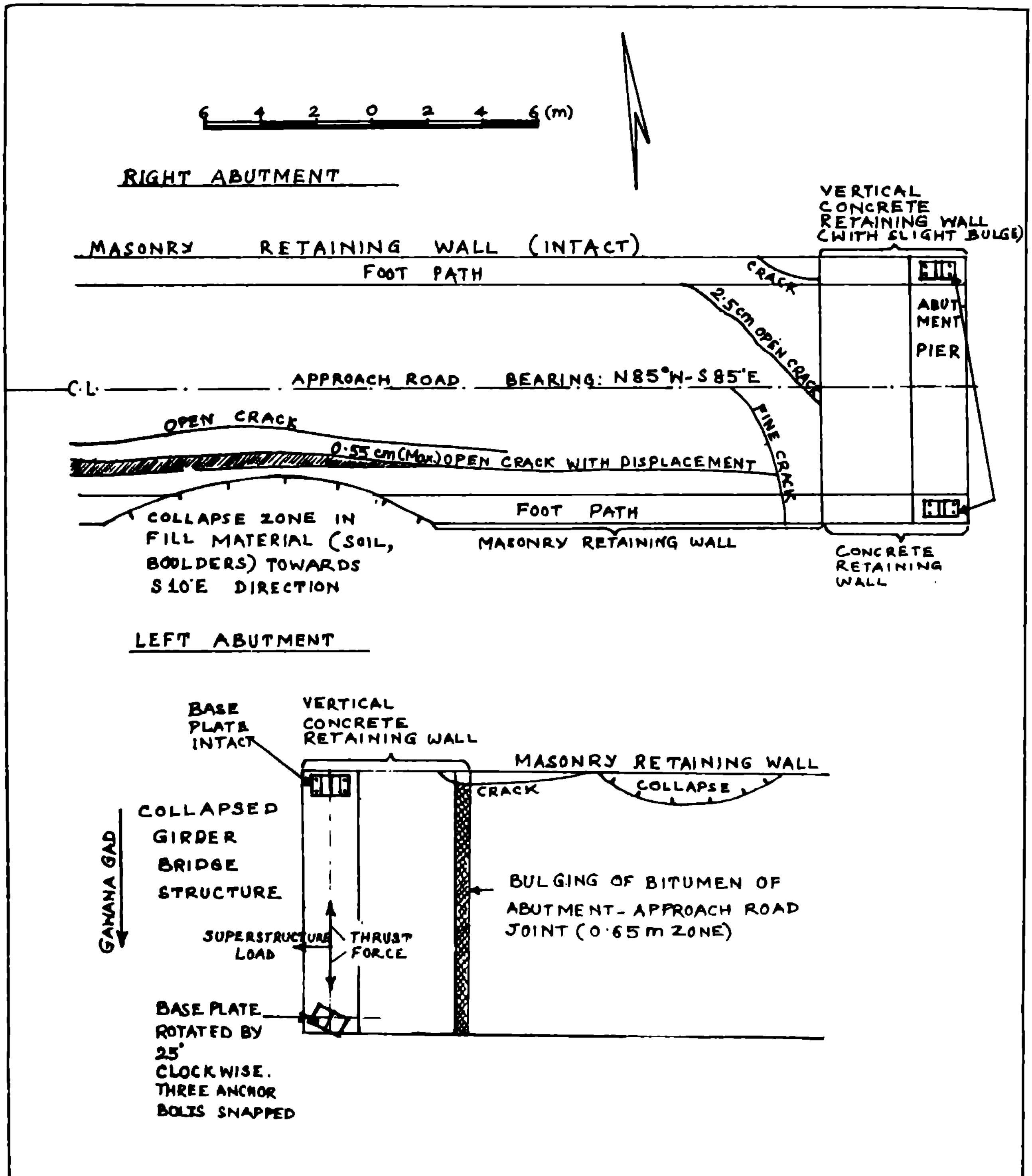


Fig. 4 : Map of approach roads, Gawana Gad bridge, Km. 155.386, Rishikesh-Gangotri road U.P.

In the left abutment, the upstream base plate with all the four anchor bolts and the two rollers are fond in place (Photo 19). Only the steel plate atop the rollers and the coupling rod have slided towards east.

The downstream base plate shows a rotation of about 25° in clockwise direction. Three of the four anchor bolts have snapped away. The rollers, the roller plate and the coupling rod have been thrown away down into the rivulet bed where the super structure lies. The edges of the two abutments have been partly sheared off by the dragging effect of the superstructure.

An attempt has been made here to analyse the causes leading to the failure of the bridge. It does not seem probable that during the earthquake the super structure vibrated to such an extent that it slipped off its bearings, because in that event the base plate would not have rotated. It is visualised that the sequence of failure would have been as below.

i) Snapping of three of the four anchor bolts of the left abutment, downstream end base plate under the influence of transverse ground oscillations related with earthquake.

ii) Rotation of base plate in clockwise direction under the action of a couple of forces with the intact anchor serving as axis.

iii) Slipping off of the rollers due to change in position of base plate.

iv) Decoupling of the super structure with its left abutment bearings, leading to its slippage.

v) Disbalancing of the entire superstructure, resulting in total collapse.

The direction of propagation of seismic waves with respect to Gawana Gad bridge appears to be E-W. The transverse ground particle oscillations created a thrust force in N-S direction.

In addition to this, the weight of the superstructure aligned in E-W direction applied a constant pulling force. Thus the anchor bolts were acted upon by a couple of forces, almost at right angles to each other. The intensity of peak ground accelerations, in association with increased pulling force on account of vibration of the superstructure would have exceeded the strength of the bolts thereby resulting in their rupturing or uprooting. As such, the base plate rotated clockwise by about 25° with the intact bolt acting as a pivot. In the rotation of the base plate, some play in bolt fixing could have facilitated the movement. Consequent to the change in the position of one of the plates, the rollers and the roller plate slipped off. The left abutment end of the super structure thus got decoupled with its bearings and moved down into the rivulet bed under its own load. The right abutment end on rocker bearings subsequently got pulled down as a reaction, resulting in total collapse of the girder structure.

3.2.7 Thalan gad Bridge

The RCC bridge of single span of about 16m, aligned in the N-S direction shows signs of distress. In the southern side masonry parapet wall the top slab has rotated by about 10° towards west and the boulder masonry has cracked and got displaced towards west. The southern side approach wall made in dry boulder fill has also bulged towards west. There is, however, no damage to the superstructure.

3.2.8 Indrawati Bridge Near Kishanpur

The approaches to the NW aligned, single span bridge across Indrawati nala near Kishanpur constructed of fill material with dry masonry retaining wall have failed in the eastern as well as western directions but the masonry abutments as well as the superstructure have, however, escaped any damage.

3.2.9 Suspension Bridges Between Uttarkashi And Bhatwari Across River Bhagirathi

There exist a total of five suspension bridges over river Bhagirathi between Uttarkashi and Bhatwari. The effect of the present earthquake event on these suspension bridges has been only marginal with the exception of the bridge at Dedsari (located in the epicentral tract) which has suffered considerable damages. The damages to the structures are described below:

Siror Suspension Bridge

The 90m long, single span Siror suspension bridge aligned over river Bhagirathi in N5°E-S5°W direction has suffered damage in the top portion of the right bank tower. The concrete slab enclosing the cables has been dislodged. The left bank tower has not suffered any apparent damage. The structure is fully serviceable.

Lata Suspension Bridge

The single span, 100m long foot suspension bridge at Lata, aligned in NW-SE direction has suffered similar damages as that at Siror but the intensity of ground motions here appears to be more. The masonry tower at the left bank has collapsed in the top portion and the concrete slabs enclosing the cables are slightly dislodged (Fig.5). All the cables are intact and the bridge is fully serviceable.

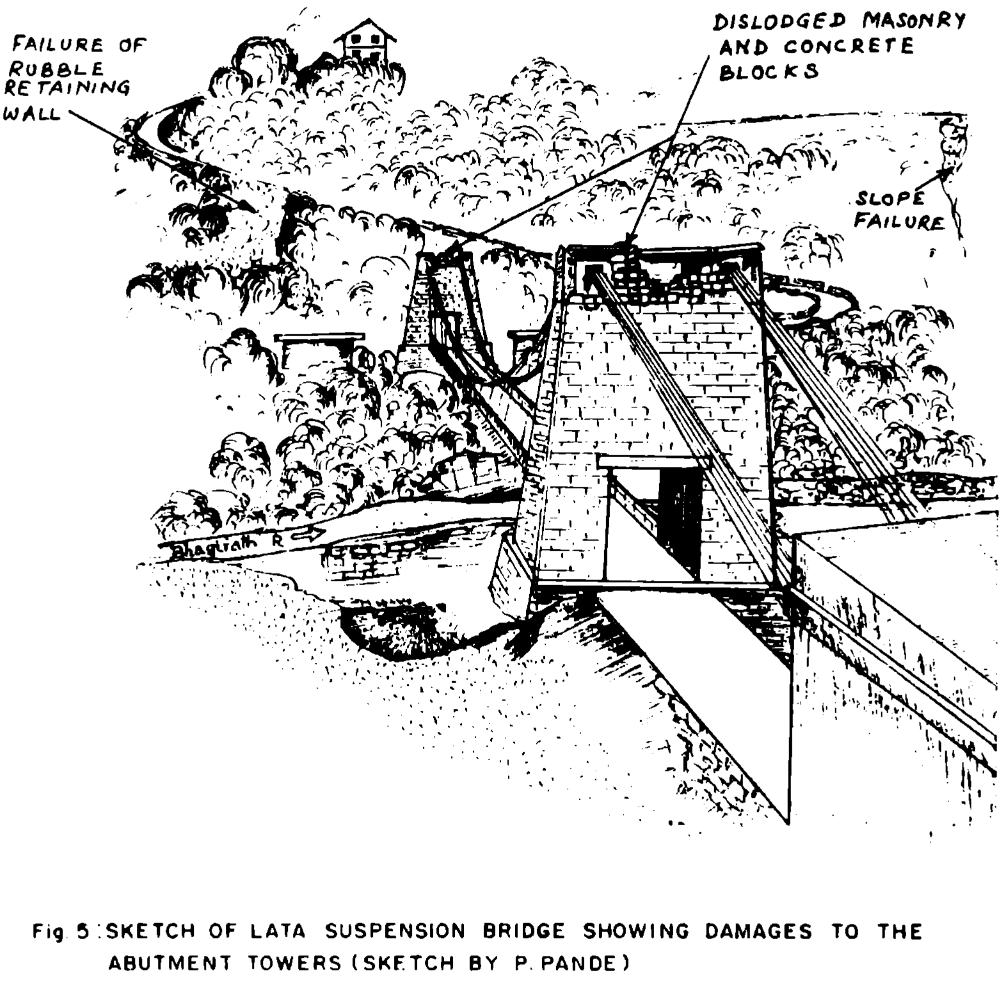


Fig. 5 : SKETCH OF LATA SUSPENSION BRIDGE SHOWING DAMAGES TO THE ABUTMENT TOWERS (SKETCH BY P. PANDE)

Dedsari Suspension Bridge

The 76.20m long Dedsari suspension bridge, constructed in the year 1979 has been analysed in detail. The foot bridge has survived the earthquake but has been damaged to some extent. The left abutment suspension tower constructed of masonry has developed prominent shear cracks on the N17°W–S17°E trending faces (Fig.6). The cracks which extend to a height of 3m from the ground have maximum opening of 11cm. A fine, vertical crack extending for about 1m is also seen at the top portion of the tower. The upstream, WNW–ESE trending face of the tower shows a displacement of the order of 10 cm and bulging.

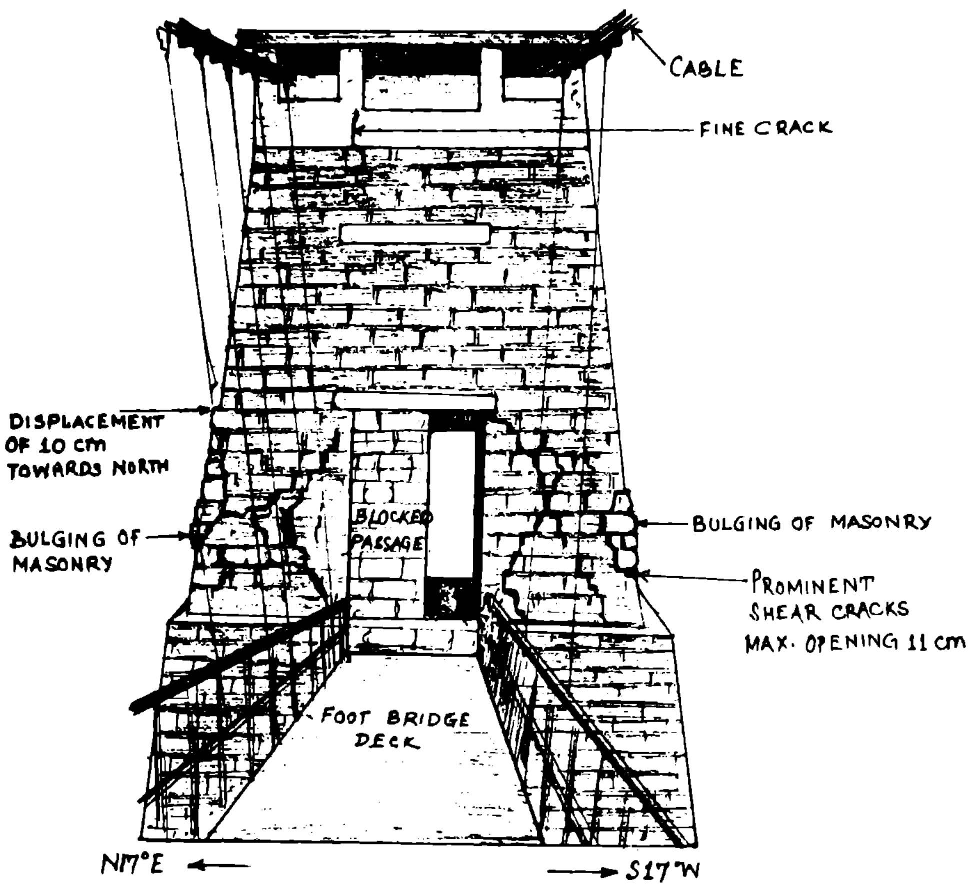


Fig. 6 : SHEAR CRACKS IN THE LEFT ABUTMENT TOWER, DEDSARI SUSPENSION BRIDGE (SKETCH BY P. PANDE)

3.3 DAMAGES TO CONSTRUCTIONS, SETTLEMENTS AND DWELLINGS

Keeping in view the objective of delineation of the epicentral tract and assessing the damages in the worst affected areas of this earthquake, detailed damage surveys have been conducted around Uttarkashi. The localities for which assessment has been made include Uttarkashi, Gangori, Ganeshpur, Heena, Jamak, Maneri, Aungi, Dedsari, Sangrali, Thalan,Manpur, Kishanpur, Gainda,Kalyani, Sainj, Godsali, Jhakol, Fold, Chakone, Bhatiyara, Thati Bharkot, Aghar (Kamlapur), Medh, Bhatwari, Malla, Sabi, Aghora, Matli, Dhani, Jakhol, Saura, Byala Tipri, Siror, Netala, Aleth and Kankrali. In addition to these comprehensive surveys sample surveys, were also conducted in order to draw the isoseismal VI and VII boundaries. The major localities covered in this survey were Silyara, Chamyali, Budha Kedar, Kalynai, Brahmkhal, Bharkot, Gangori, Kathnaur, Seana Chatti, Naogam, Bainga and Chaurangi. Sample surveys were also conducted to draw the lesser intensity isoseismals. Brief descriptions of the damage patterns in the epicentral tract and some of the localities on the basis of which the isoseismals have been constrained, are given in the subsequent paragraphs.

3.3.1 Maximum Damage Areas

Uttarkashi Town

The main portion of the town in which the district headquarters are located is on the right bank of river Bhagirathi. The town limits have now extended on the left bank, including colonies of Kotiara and Joshiara. In these 3 locations fairly wide river terraces composed of boulders and pebbles with coarse sandy material are available for the construction of the houses. Generally all the buildings in the area are founded on this overburden material. Earlier, construction in the area was restricted to single storey buildings but with the growing demands 3 to 4 storey buildings have been constructed. At places, the old buildings have also been raised to higher stories without altering the foundation and design of the single storey buildings. The new buildings which are coming up are of pillar structures. In the town more than 10% of the buildings have been badly damaged with wall collapses and wide open cracks (Photo 20) while other buildings have developed cracks on the walls in different directions. The buildings in which river boulders have been used in the wall construction, have received more damages as compared to the buildings which are constructed of flat phyllitic quartzite boulders (Photo 20A). The damage in some of the buildings is discussed in the following paragraphs.

The buildings of the Police Lines are generally single storeyed, with stone cement masonry wall and G.I sheet roofs. All the buildings have developed open cracks on the walls and, in some of the houses, wall and roof collapse has also been seen (Photo 21). The lintels provided above the door and window level have helped in retarding the complete collapse of the walls. In one of the varendahs of a house a beam supported over columns has broken due to collapse of the pillar (Photo 22).

The damage in the D.M's. residence comprises cracks in the outer walls and complete collapse of the back walls. Similarly, a portion of the wall of the Court building located at higher terrace level has also collapsed. The double storey building of the Municipal committee which is constructed of cement stone masonry walls has developed open cracks. Fall of some stones and plaster from the walls has also taken place.

The residential colony of Maneri-Bhali Project is located on a left bank terrace in Joshiara Colony. The residential quarters are constructed of cement bricks with plaster on the inner side of the walls. In all the houses cracks on the walls in different directions are reported to have been developed, such cracks are more pronounced on the upper storey (Photo 23). Fall of any wall has not been reported in this area. A hotel building on this terrace has also developed cracks on the walls, the cracks being more prominent on the inside surface.

Dr. Uniyal's Residence is a 3 storey building where damage is seen on the ground floor. The ground floor is constructed with mud stone masonry walls having cement plaster. Subsequently, the 2 floors were raised on pillars. Cracks and settlement of the floor of the ground floor is noticed. In the upper storey shear cracks on the walls have developed.

Birla Dharamsala is a double storey building with thick cemented stone masonry walls and cement plaster. The walls have been constructed of phyllitic quartzite. Cracks on all the walls with fall of plaster has been recorded, but no collapse is seen.

Garhwal Mandal Tourist Hostel is a three storey building with cement stone masonry walls and G.I. sheet roof. The long wall of the building is in E-W direction. Open shear cracks and fall of plaster have developed in the entire building. A fall above the staircase has also taken place. Horizontal cracks on the walls have developed more prominently. Leaning of one of the walls towards east is noticed.

Vishwanath Temple is one of the oldest structures in the town and is constructed of flat slab of quartzite upto its dome level. A crack in the domal arch, constructed of quartzite slabs has occurred due to tension. Another temple constructed of stone masonry by the side of the old structure has also developed cracks on its walls. In Shakti temple, which is a stone masonry structure, cracks have developed on the walls at higher level. The pillars also show tilting towards N25°W direction.

The State Bank of India building was initially a single storey structure of cement mortar-stone masonry walls which was subsequently raised by another two floors on pillars. The upper floors of the building have completely collapsed (Photo 24) but the ground floor stands, though open cracks have developed on the walls. The damage to the adjoining three storey building is in the form of shear cracks in the walls.

Gangori

Gangori village is situated at the confluence of Assiganga and Bharigathi rivers. Out of 193 houses/buildings in the village, 150 have either collapsed or suffered partial damage in the form of cracks and bulges. In most of houses with long walls aligned in N-S direction, the E-W trending walls have either collapsed or developed shear cracks (Photo 26) and bulges towards north. In Dangwal Provision Store, the light objects kept on shelves on E-W aligned walls fell down. In Amar Bhawan, located on a terrace and aligned in N-S direction, columns developed cracks and joints between pillars and beams opened up. Mud-stone masonry walls with RCC slabs had completely collapsed. The outer wall of mud-stone masonry of 40cm thickness collapsed, but the RCC slab remained intact. The house is situated on the terrace with its riverside edge to the east about 2.0m away from the cut. This edge of the terrace, held by dry masonry wall, also failed with cracks that extend beyond the western boundary of house. A hollow brick wall on the eastern side of the house also collapsed. The retaining walls aligned both in N-S and E-W directions in the area collapsed, resulting in development of slump cracks in the ground.

In the adjoining house, bulging in the western wall is observed towards the west. The windows have also tilted towards south. In case of double storey houses of the village, ground floors constructed of mud-masonry walls, have suffered heavy damage. The damages are less pronounced on the upper floors constructed of RCC pillars and slabs. Similarly, a public urinal constructed of hollow cement bricks and cement-sand plaster, has also suffered complete damage (Photo 26). Most of the kutcha buildings in the village have suffered damage. Those of mixed kutcha-pucca type developed open cracks, and a few buildings with RCC columns and beams have developed cracks in walls. The mud-masonry houses located on slopewash and terrace deposits have suffered more damage than those located near hill slope. But the buildings located close to Assiganga river on the left bank have escaped with minor cracks and peeling of plaster and occasional open cracks. The girder bridge across Assiganga has withstood the shock without suffering any damage. The water discharge of a hot spring located near Gangori village has been reported to have increased without any change in the temperature.

Sangrali

The village is located 2km north of Uttarkashi, at an altitude of 1720m on the right bank of Bhagirathi river. The village stands over a 90m high steep scarp, in phyllitic-quartzite of Uttarkashi Formation at the base of which lies Pata village. No house in Sangrali collapsed, but shear fractures have developed on E-W aligned walls. These cracks are open, and minor displacements (upto 2cm) has also been observed alongwith bulges towards west. Peeling of plaster and minor cracks were noticed in N-S trending walls. Most of the houses are of poor construction A-type structures with a few mixed A&B type according to MSK scale of intensities (see Annexure-III). The temple under construction in the village is a RCC structure with a frame of RCC columns and beams. A few columns and beams have developed cracks, or have ruptured. The cement concrete material of the columns has broken, and the exposed steel bars are found buckled towards west.

The strong ground motions have dislodged or displaced some of the rock blocks or wedges, particularly those located near the scarp face, thereby giving rise to the appearence of ground cracks (Fig.7).

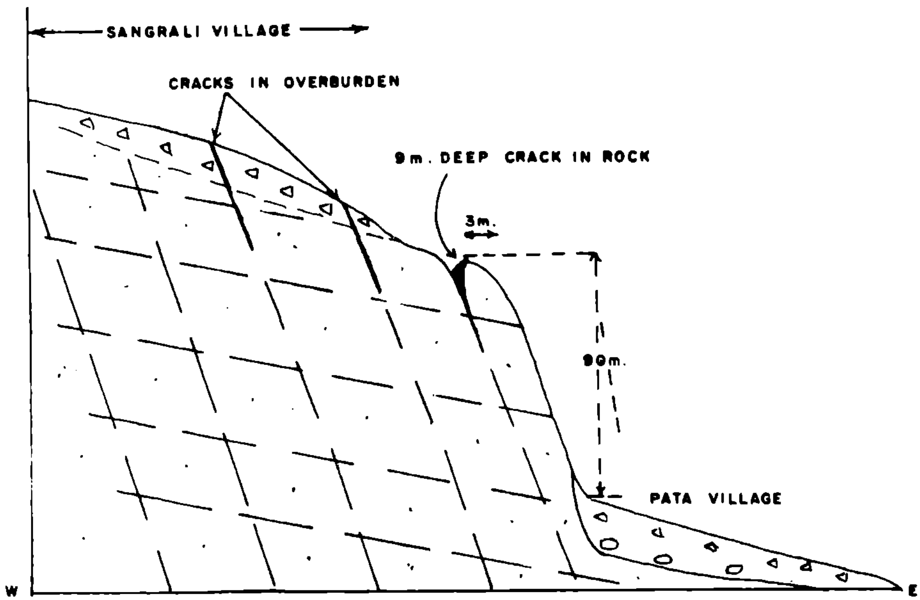


Fig. 7 : CRACKS IN SANGRALI VILLAGE.

Maneri Colony

The residential colony of Maneri project is constructed on the right bank of Bhagirathi river above Maneri dam on the upper river terraces at elevation 1350m. The houses are aligned in E-W direction. The approach to the colony has been developed by constructing a number of retaining and breast walls whereas the colony area was developed by cutting and filling the low areas especially towards the western end of the residential quarters. All the buildings are double storeyed with walls constructed of concrete blocks, covered by cement plaster on the inner surface only. Almost in all the buildings vertical as well as cross shear cracks have developed on the walls. Open cracks are more prominent in the partition walls. The extent of the damage in some of the buildings is discussed below.

The Maneri Field Hostel is a double storey building constructed of cement bricks with cement mortar and plaster on the walls. On all the walls shear cracks have developed which are open with wide gaps at places (Photo 27). Fall of the portion of a wall above the staircase has been noticed.

The Manoranjan Kendra is a single storey building with GI sheet roof. Shear cracks on the walls have developed prominently. Two pillars of the porch have shown tilting towards the south.

The project temple, constructed at the eastern end of the colony above a steep slope has been badly damaged. The structure is constructed on concrete pillars. The walls have collapsed and the pillars have developed cracks whereas the dome has remained intact. The hut of the temple priest, constructed at the edge of the slope has slided down the slope for more than 10m distance. A $1m^3$ capacity steel water tank kept on cement pillars at the side of the temple has experienced a rotation of more than 20°. One edge portion of the tank, originally in NW direction now lies in N70°W direction.

In all the houses of the residential colony, shear and vertical cracks on the walls are noticed. These become more prominent in the houses located at the western end of the colony (Photo 28) as well as in the houses located close to the steep slope on the river side. The houses on the western end show settlement as well as fall of portion of the walls. The chimney slabs of some of the houses have been rotated by about 20° anticlockwise.

The office building is a double storey structure, constructed of concrete bricks and located at a lower level at the edge of the slope. Shear cracks with opening and falling of bricks from the walls have developed in the entire building (Photo 29). In the Garage located on the edge of the slope, the pillars have come out with more than 8cm gap. Open cracks are more prominent on the southern walls, while on the E-W walls only shear cracks have developed. In the State Bank of India building, cracks in the walls have developed, some of which show openings. Falling of some of the bricks from the wall are also recorded. A portion of the top parapet with GI sheet roofing has also fallen down. In the shopping complex above the road, the retaining wall has collapsed causing a number of slump cracks in front of the shopping complex and settlement of more than 40 cms. is seen on the ground. Shear and open cracks have developed on the walls.

From the damages recorded in the colony it is seen that the buildings which are located on the western end, as well as close to the steep slopes have been damaged to a greater extent than those at other locations. The western end of the colony is reported to have been developed on fill material.

The Aungi village located just upstream of the dam and below the project colony on the lower terrace has suffered extensive damage. The constructions near the road are aligned NE-SW. Many houses with RCC slabs have completely collapsed though a few of similar type have escaped with minor damage (Photo 30). The NW-SE aligned block of the Govt. Inter College has collapsed completely while a smaller block though suffered category 4 and 5 damage but was not razed to the ground (Photo 31).

Sainj

The village is located about 75m above Uttarkashi-Gangotri road on the right side of Kasumpati nala at elevation 1400m. on a high level river terrace. There are about 70 houses in the village and all are reported to have been damaged. The houses are constructed of stone mud masonry and have developed cracks on the walls and in few houses, fall of the walls is also reported. In a house constructed of cement stone masonry with cement plaster on the walls, only cracks in the plaster have developed. The school building which is a single storey structure with mud stone masonry walls and GI sheet roof has developed cracks on the wall as well as fall of the plaster. Some of the cracks show opening. A temple constructed on pillars has completely collapsed.

Jonkhoni-Ghorsali

These villages are located at elevation 2000m on the left bank slope of Kasumpati nala where cultivated fields have been developed on the slide debris/hill wash material. In these villages the houses are constructed of mud stone masonry with mud plaster on the inner side of the walls which show development of shear cracks. Though cracks on the walls have developed no opening of cracks or fall of the walls, is seen at village Jonkhoni (Photo 32).

In Ghorsali village there are about 175 houses of which about 75 are reported to have been damaged. The houses are constructed of mud stone masonry with slate roof. Shear cracks have appeared on the walls and some very old constructions show partial collapses. The houses are generally E-W aligned and the northern walls are comparatively more damaged and show tilting towards south.

A motorable road between Ghorsali and Jonkhoni which is under construction has developed slump cracks and dislodgement of rock blocks and debris mass. At Jakhol, the school building and a house close to it located on a spur on steep slope have suffered extensive damages. The walls of the school building have collapsed (Photo 33) whereas the adjoining building, which is a cement stone masonry construction, has developed cracks on all the walls as well as partial collapses of small sections. A nearby temple which is under construction has suffered only minor cracks. Although cracks are reported to have developed on the walls in the other houses of the village wall collapse from only 2 houses is reported. Shear cracks have developed in almost all the buildings.

Agora-Kalyani

The village is located at elevation 2200m, about 100m above Assi Ganga river on its right bank. The village lies at the foot of a steep scarp, composed of gneisses of the central crystallines. Cultivated fields have been developed on the slide/hill wash material. The village dwellings are also founded on thick slide debris material. The houses are constructed of phyllitic quartzite boulders with mud plastering and slate roofing. In most of the houses including the school building, only cracks on the walls have developed. Fall of a portion of a wall above the window level is seen and leaning of wooden windows towards north is recorded (Photo 34).

The Forest Rest House building is located on a spur at the end of the village where small retaining structures on 3 sides have been constructed to develop a flat ground. The retaining structures have collapsed resulting in the development of slump cracks on the ground. The building is a stone masonry structure with GI sheet roofing. The walls of the building have collapsed resulting in the caving in of roof (Photo 35). The 3 houses constructed on the side of this building have also suffered damages, and cracks on the walls are prominent. The chimneys over the houses have broken and have fallen to the western side.

On the way to Agora in Assiganga valley, the B-type and A cum B type buildings at Kalyani have suffered damage of Grade 4&5. The damage to N-S aligned buildings include open shear cracks, tilting of western walls, and collapses and bulges on northern walls. Similarly, in the case of E-W aligned buildings, even those with pillars and cement plasters, the N-walls have collapsed (Photo 36). The Forest Rest House is badly damaged, with shear cracks in western wall and peeling off of plaster, open cracks and minor displacements in northern and southern walls. Collapses are more pronounced in NE and NW corners in case of both E-W and N-S aligned structures.

Ganeshpur

The village is located on the right bank of river Bhagirathi at an altitude of 1250m. The dwellings are clustered over an alluvial terrace which is flanked by steep hill slopes towards the north. The southern boundary of the village is marked by a shallow valley of Gawana Gad.

The earthquake had a profound effect on Ganeshpur. It took a toll of 45 human lives and left many others injured and homeless. A number of heads of cattle, constituting the main source of livelihood for the villagers also perished under the debris. One of the witnesses to the catastrophe described the event as under.

"We were fast asleep in the first floor of our house when some unseen force woke everybody up. The groud first heaved then shook violently for almost a minute resulting in falling of untensils and other loose objects and collapses of walls and roofs. Those who survived or remained untrapped ran out in utter panic and confusion.The entire village was engulfed in darkness and dust generated out of fallen debris. The roaring sound of rock ruptures and rolling blocks and boulders from neighbouring hill slopes amidst cries and wailings made things still more fearsome. It took sometime to realise what exactly had happened and the extent of devastation left behind. After recovering from the shock, the able ones began the rescue operations and helping and consoling each other. The night passed somehow and a futureless day began with much despair in store."

The damages suffered by the village have been extensive. None of the houses have remained safe for habitation, forcing the inmates to stay out. The village houses are, in general, constructed of thick mud-masonry walls with slate roofs. Some new constructions have used RCC slabs and columns and GI sheets. The earthquake has resulted in partial or total collapse of most of the thick masonry walls (Photo 37), particularly of the upper storey. Extensive, deep open cracks have surfaced in number of walls and the plaster has peeled out (Photo 38). The low, dry masonry boundary walls have invariably failed. Similarly, the terrace retaining walls have collapsed at a number of places. As per the MSK intensity scale, the type A structures have suffered grade 3 and 4 damages and type B structures suffered grade 1 and 2 damages. In a well constructed house adjoining the left abutment pier of the collapsed Gawana gad bridge, cracks in walls having a displacement of about 1 cm. towards north-west quadrant have appeared.

Netala

The village is located at km. 8 along Uttarkashi-Gangotri Motor road, on the right bank of river Bhagirathi over an alluvial terrace. Netala has a population of 900 people subsisting mainly on agriculture and animal based economy. The earthquake has caused the death of 44 persons and inflicted injuries to 120 others, affecting some 180 families. A number of heads of cattle have also perished.

Most of the thick mud masonry walls alongwith the roofs have suffered partial or total collapse. Others have developed wide, open cracks making them unsafe for habitation. As per the MSK intensity scale, type A structures have undergone grade 3 & 4 damages and type-B structures, grade 2 damages. A number of houses with mud masonry walls and RCC roofs have collapsed. The collapse of the RCC slabs has been essentially due to failure of load bearing walls and occasionally the slabs have also suffered damages due to the impact of the fall (Photo 39). The old temple of the village presents an interesting case of study. The thick masonry walls of the structure have developed open cracks and the plaster has peeled out at places. The pyramidal roof is more or less intact. However, its spire has been thrown away by about 7m in N70°E direction where it stands in the upright position (Photo 40). Both NE-SW and NW-SE trending walls of the temple have developed shear cracks. The damage pattern indicates that the direction of wave propagation was roughly from SE to NW. Fine cracks and peeling of concrete have occurred in poorly constructed RCC columns of an adjoining unfinished building.

Heena

The village is situated on the right bank of Bhagirathi river. The terraced fields, sloping gently towards the river have been carved out in debris fan deposits. The village has about 70 houses and a population of 700. The earthquake took a toll of 29 human lives and injured 28 people. The basic cause of this high magnitude of devastation was the strong ground motions acting upon poor quality constructions. Almost all the inhabitants vacated their dwellings and were staying out in make shift hutments.

The destruction of the buildings by the earthquake has been quite complete. The thick mud masonry walls have collapsed in a number of cases. The RCC slabs and beams, supported on such low strength walls have also caved in. The Primary School Building of the village aligned in the E-W direction (Photo 41) has been examined in detail. The foundation and lower portion of the building have moved by 5cm. towards north, apparently getting sheared from the upper portion of the structure. The abrupt force has made all the non-load-bearing and structural masonry walls, and part of the RCC roof, to collapse towards the south (Photo 42). This implies that the shaking was in N-S direction. As such, the long walls, including the load bearing columns bulged, tilted or collapsed towards the south. The N-S trending side wall developed prominent shear cracks (Photo 43). The direction of seismic wave propagation was, therefore, from east to west. The RCC beams have developed fine tension cracks. As per the intensity scale, type-A structures have suffered grade 4 and 5 damages and type B structures, grade 2 damages. A few type C structures show grade 1 damage.

Malla

The village is located on the right bank of river Bhagirathi over fan deposits. It consists of about 110 houses and has a population of 750 people. The earthquake has resulted in deaths of 9 persons and injuries to 44 others. Some cattles have also perished in the earthquake.

A number of houses of the village have suffered different grades of damages. Some mud masonry walls, particularly of the 1St. or 2nd floor, have totally collapsed, whereas, others have developed prominent open cracks. An old two storey housing complex of conventional construction of thick mud mortar walls has partially collapsed killing 6 persons in one room. The extensions to this house have been recently constructed with concrete slabs which have suffered considerable damage but have escaped collapse (Photo 44). Some of the walls have bulged or tilted towards south, indicating the direction of ground oscillations. Some slump cracks with minor displacement were observed in the slopes. Walls resting on such foundation have suffered much greater damage. Most of the houses have become unfit for habitation, forcing the inmates to stay out in make shift hutments.

A two storey type-A construction with its long wall oriented in N-S direction is found to have developed a slight tilt towards south. Prominent shear cracks have appeared on the long wall.

Saura

The village is located on the left bank of Bhagirathi river over alluvial terrace deposits. Saura has a population of 550 people and has about 150 houses. The earthquake took a toll of one human life and caused injury to 12 persons. A number of cattle also perished or got injured in the earthquake.

The poorly constructed mud masonry walls of the village dwellings have partially or totally collapsed in a number of cases. At places, the RCC slab or slate roof resting on such walls have also caved in (Fig.8). Almost all the standing walls have developed deep, open cracks, rendering them unsafe for habitation. In general, type A constructions have suffered grade 3 & 4 damages and type B structures grade 1 damage. The dry masonry walls used as field boundaries have failed at places.

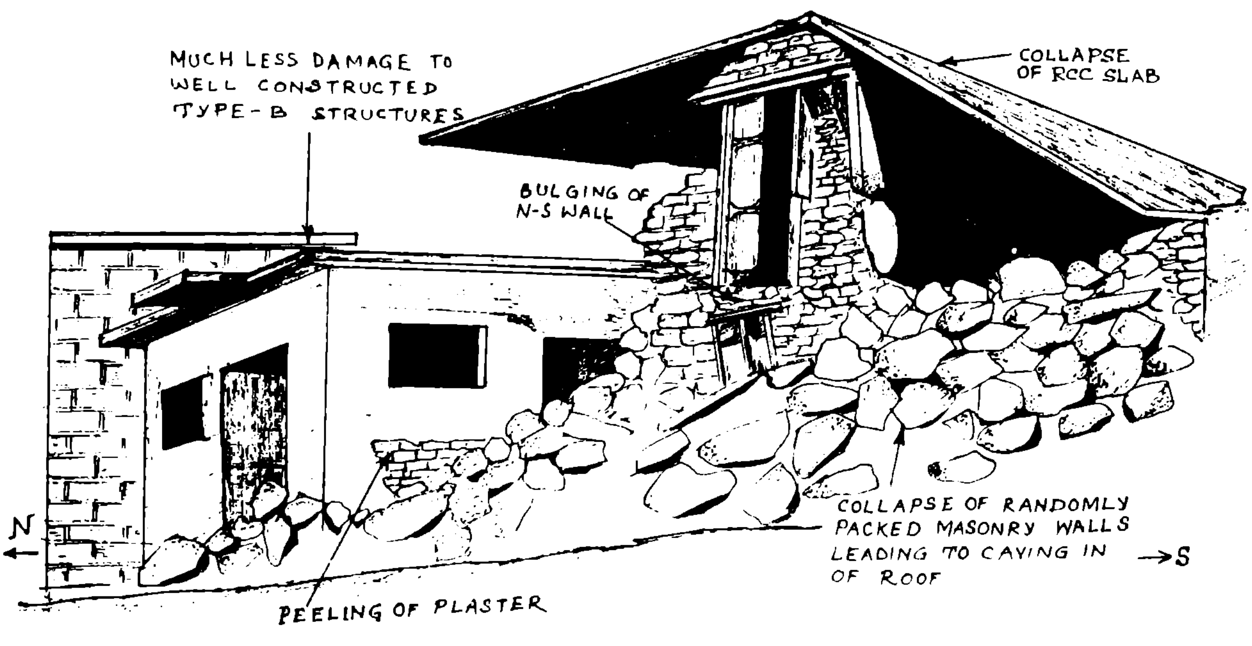


Fig. 8 : SKETCH SHOWING EXTENT OF DAMAGES TO TYPE 'A' AND TYPE 'B' CONSTRUCTIONS IN SAURA VILLAGE (SKETCH BY P. PANDE)

Photo 20 *A view of collapsed house of Shri Ram Lal, adjacent to the Nagar palika building is Uttarkashi town.*

Photo 20 A *A view of damages suffered by a conventional construction in Uttarkashi town. (Photo NGRI).*

Photo 21 *Collapsed back portion of the house of Superintendent of Police, Uttarkashi.*

Photo 22 *Collapse of pillar and beam of the varandah of a house in Police Lines, Uttarkashi.*

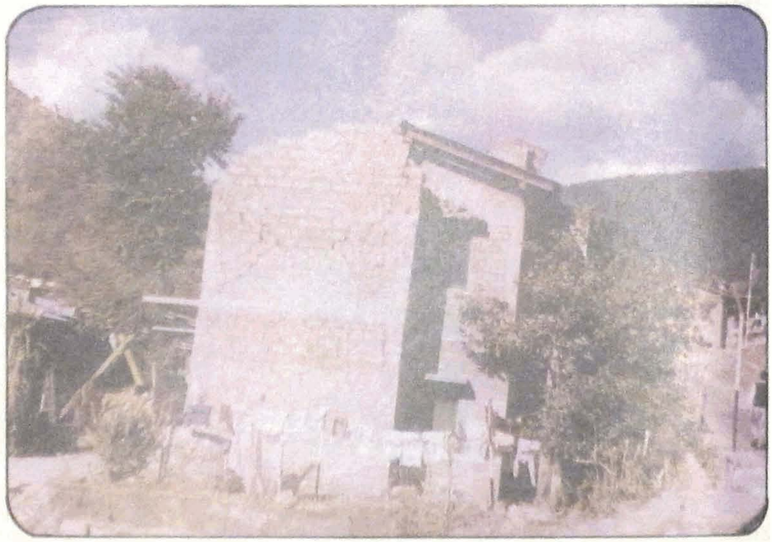


Photo 23 *Shear cracks and partial collapse of the first floor of a house in Tileth colony, Uttarkashi.*

Photo 24 *Collapse of the first floor of RCC, State Bank of India building in Uttarkashi.*

Photo 25 *Shear cracks in the E–W aligned side wall of a house in Gangeri village.*

Photo 26 *Damages in a low height structure in Gangeri village. (Photo NGRI).*

Photo 27 *Heavily damaged first floor of the Maneri Inspection house with shear cracks in both long and short walls.*

Photo 28 *Collapse of single storey office complex in Maneri dam colony.*

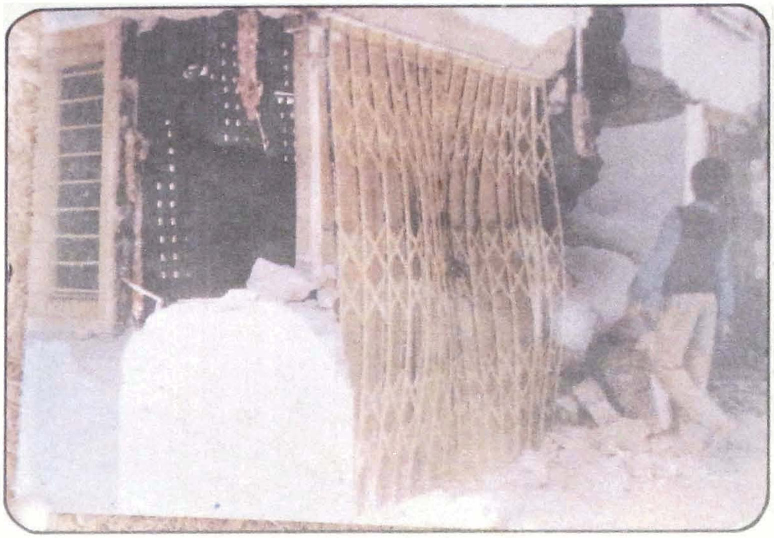
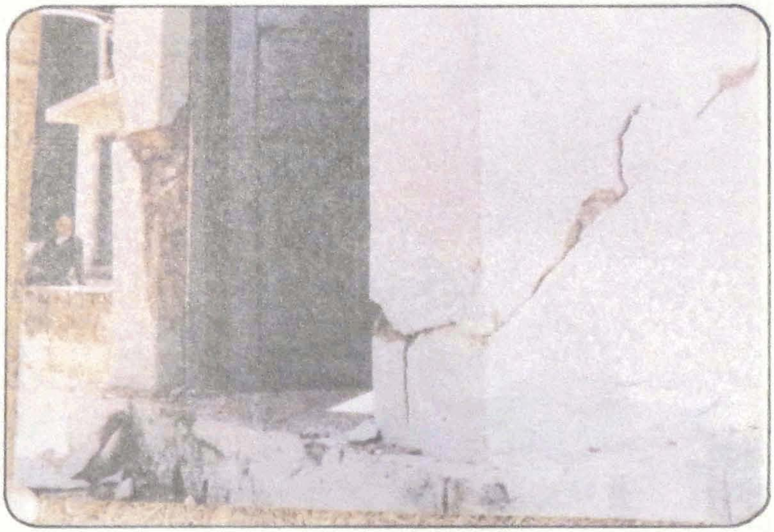


Photo 28 A *Collapsed walls and buckled shutters of the temple in Maneri project colony. (Photo NGRI).*

Photo 28 B *Shear cracks in one of the houses in Maneri colony. (Photo NGRI).*



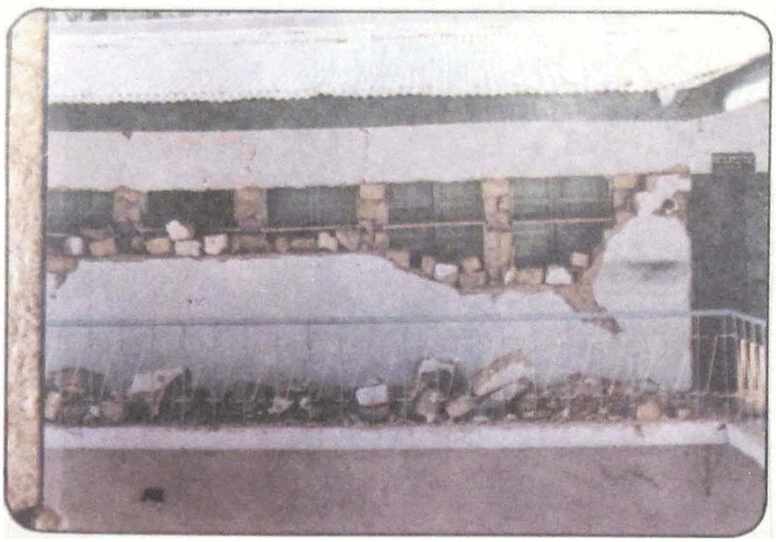


Photo 29 *Wall collapses in the first floor of the project engineer's office in Maneri colony.*

Photo 30 *Complete collapse of a house with RCC roof at Aungi village. Note relatively much less damage in a house at the top left corner.*

Photo 31 *Damaged NW–SE aligned block of Govt. Inter College at Aungi. Note complete collapse of the block oriented in the NE–SW direction behind the policemen.*

Photo 32 *Shear cracks in the ground and first floors of a house in Ghorsali village.*

Photo 33 *Complete collapse of a school building in Jakhol village.*

Photo 34 *Tilted window of a school at Aghora and partial collapse of partition walls.*

Photo 35 *Complete collapse of forest rest house at Aghora.*

Photo 36 *Collapse of the northern wall of a school building at Kalyani.*

Jamak

The village is located on a high level alluvial deposit of an abandoned channel, on the left bank of river Bhagirathi, at a distance of 0.5 km south east of Maneri dam. Jamak bore the maximum brunt of the 20th October earthquake, where 70 persons got killed and almost all the remaining were injured. The intensity of ground motions was so high that nearly 90% of the dwellings were either razed to the ground or suffered heavy damage, making them unfit and unsafe for habitation. The village thus bears a deserted look with all the inmates having moved to the neighbouring fields in make shift hutments (Photo 45).

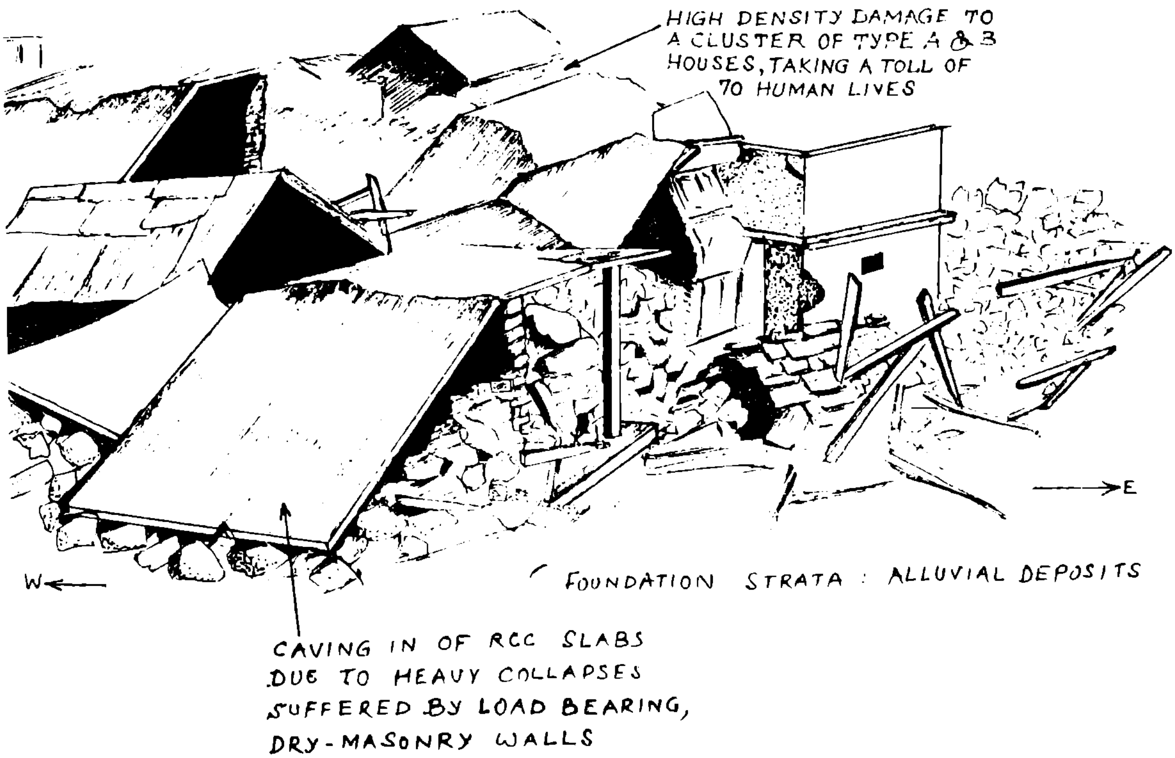


Fig. 9 : DAMAGE IN JAMAK VILLAGE (SKETCH BY P. PANDE)

The majority of the houses were constructed of thick mud masonry walls of very low strength, supporting slate or RCC slab roofs. At places, poorly cast RCC columns and beams partially replace (on one or two sides) the masonry walls. The collapse of the walls by the strong ground motions has resulted in caving in of the RCC structures, (Photo 46) as well (Fig.9). In general, the grades of damages in Type-A structures have reached upto 4 and 5 (Photo 47 and 48) and in type-B structures upto 3 and 4. Some of the RCC beams and columns have also developed cracks. The intensity of damage indicates that the village falls right in the epicentral tract.

KAMAR

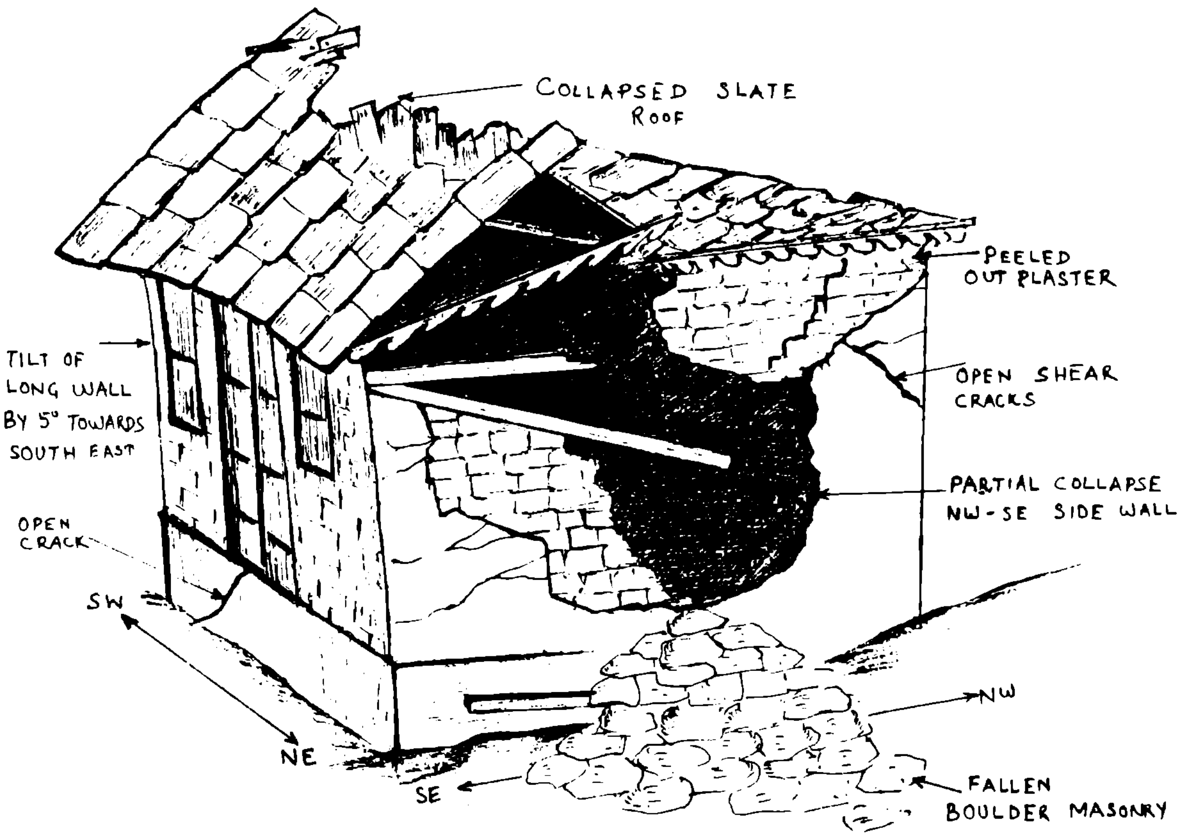
The village is located on debris slopes, 5 km. South-east of Maneri dam at an altitude of 2000 m. A low, sloping quartzite ridge is exposed in the upper periphery of the settlement. The village has about 60 houses mostly clustered at two three places at different levels, with only a few isolated ones. Here a population of about 400 persons resides. The 20th October earthquake had a profound effect in the area leaving 8 persons dead and 14 of others injured. Almost all the houses suffered different degrees of damages thereby forcing almost everybody to stay out-doors in make-shift hutments.

The houses of the village, in general, are of poor quality. The thick walls are made of random masonry, packed in mud mortar. For roofing, large stone slabs have been used in old structures. Some new constructions have utilized RCC slabs, beams and masonry columns, but without proper understanding of the structure. The orientation of houses is found to be governed by slope conditions with the frontage long wall aligned parallel to the valley.

The damages to houses are quite extensive and severe. The thick masonry walls have suffered partial to total collapses (Photo 49). In most of the cases the heavy stone or RCC roof slab, supported on masonry walls, have caved in. Open shear cracks, accompanied with displacement and peeling of plaster are very common.

The house of Pushkar Singh Chauhan, located at the edge of a sloping ridge has been analysed in detail (Fig.10). The NE-SW trending long wall of the damaged house has titled by 5° towards SE direction. The NW-SE trending side wall of mud masonry has suffered partial collapse. Part of the slate roof and the wooden beam resting over the collapsed side and partition walls have thereby caved in. Shear cracks and peeling of plaster is also evident on the side wall.

As per the intensity scale, the strong ground motions lasting for over 45 seconds caused grade 3 & 4 damages to most of type-A structures. The steeply ascending foot track between Jamak and Kamar is found to be riddled with a number of rock falls and dislodgements. The intensity has been such that many



TYPE OF CONSTRUCTION: MUD-MASONRY WALLS WITH SLATE ROOFING (TYPE-A CONSTRUCTION)

DIRECTION OF WAVE MOTION : FROM N TO S

Fig. 10 : DAMAGE PATTERNS IN THE HOUSE OF PUSHKAR SINGH, KAMAR VILLAGE, (SKETCH BY P. PANDE)

pine trees, coming in the trajectories of the shooting rock mass have snapped. A huge quartzite block within the debris zone got partially dislodged by the earthquake and now hangs precariously over the northern fringe of the village.

Dedsari

The village is located about 2 km upstream of Maneri dam on the left bank of Bhagirathi river. The dwellings are situated over a gently sloping debris fan whereas the extensive terrace deposits have been utilised for cultivation. The village has a cluster of about 55 houses with a population of about 400 persons. The devastating earthquake took a toll of 45 human lives and injured many others in the village. The magnitude of destruction can be judged from the fact that a strong stench, emanating from carcasses buried under house collapses, still pervades the atmosphere, even after a month of the tragedy (Photo 51). The entire village population has shifted in make shift hutments near the Dedsari suspension bridge. The extensive alluvial terrace deposits on the left bank of river Bhagirathi have been utilised for cultivation. The fringe of the low level terraces adjoining the river have been sliced away for a length of 100m in a highly linear fashion due to the earthquake and is similar to the shaven terrace of Heena.

The houses of Dedsari village are constructed of thick mud-masonry walls with slate roofing. Some new constructions have utilised RCC slabs or G.I. sheets and have demonstrated high grade of damage (Photo 52). A few old houses which have survived the shocks have used only timber for structural and non-structural components with slate roofing. As per the intensity scale almost 50% of type-A structures have suffered damages of grades 4 and 5 (Photo 53 & 53A). The damage in type-B structures is of grade 2 and 3 with development of open shear cracks (some with displacement), bulging and tilt.

The Kalinag Temple located on a flat ground towards the top level of the village is a type B-structure (Fig.11). The walls of the sanctum are of masonry, set in mud mortar. All around it, thick masonry columns and RCC beams support a varandah slab of RCC. The pyramidal roof of the sanctum is of RCC. The building is squarish in plan.

The N55°W-S55°E trending faces of the sanctum walls have developed prominent cross shaped shear cracks. The columns have invariably sheared near the beam contact. A displacement of the order of 2cm towards N15°E direction has been measured in one of the corner pillars. Open cracks have also appeared in the floor, particularly around pillar contacts.

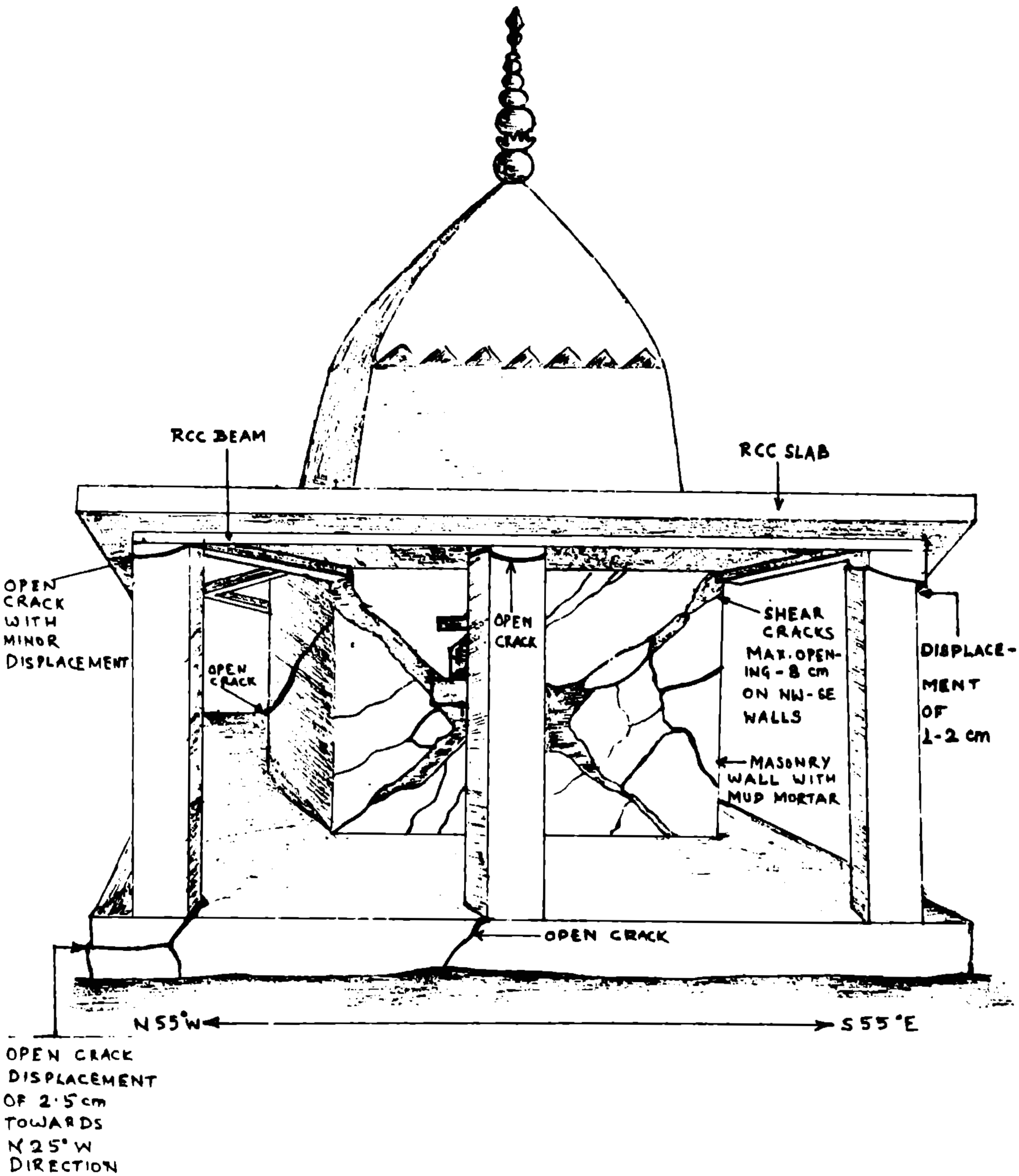


Fig. 11 : DAMAGE TO KALINAG TEMPLE, DEDSARI VILLAGE (SKETCH BY P. PANDE)

Sanglai

The village is located 8 km NNE of Bhatwari along Uttar Kashi Gangotri road on the right bank of Bhagirathi river. The dwellings lie over debris slopes with crystalline rocks exposed in the road cuts. Sanglai is a hamlet of 14 houses, clustered at 3-4 places. It has a total population of 60. The 20th October earthquake took away 17 human lives and caused injury to almost every one who survived. As the figures narrate, almost 30% of the population was wiped out by the catastrophy.

The houses have been constructed of thick mud masonry walls with stone slab, RCC slab or GI sheeet roofings. The intensity of damage to houses located at lower levels is found to be less severe than those located at higher levels. A cluster of poorly constructed type-A buildings having long wall direction as N50°E-S50°W have suffered near total collapse (Photo 54). Here the direction of fall is seen to be governed by the slope conditions. A cluster of type-A houses, located on a N60°W-S60°E trending narrow ridge have suffered total destruction (Photo 54A).

A Junior High School building has been studied in detail (Photo 55). The structure is constructed of thick mud masonry walls with masonry columns in front, supporting the varandah roof. G.I. sheets have been used for the roofing. The long wall direction is N-S and the side wall E-W. The southern end side wall has developed shear cracks and has partially failed towards south. Some of the front pillars have sheared and collapsed towards eastern side.

The tremors have caused failures of edges of the terraced fields. A few ground fissures of limited extend have also been noticed. The steep banks of Bhagirathi river north of Sanglai which are composed of alluvial terraces show slump failures at number of places that are related to earthquake. In the Sanglai-Sunagar road sector, rock slides and dislodgements are found to occur in abundance.

Judging from the extent of damage to buildings and ground slopes inflicted by the tremors, the intensity of ground motions appears to have accentuated in the Sanglai-Tiara area. This, therefore, seems to be an isolated case of VIII intensity, encircled by lower intensity level of VII at Pala and Raithal in the south and Sunagar and Gangnani in the north.

Huri Gangnani

The village is located 1 km SE of the famous Gangnani hot water springs. The place is approachable from the main road by a steep gradient foot track. The isolated village, has a total of 60 houses with a population of 600. The slopes have been converted into terraced fields for cultivation. All the houses are clustered at one place, atop a flatter ground.

The 20th October earthquake took a toll of 3 human lives and injured few others. The intensity of ground motions appears to be markedly less profound as compared to the adjoining area to the south, along the Bhagirathi valley.

The limitation of resources and skill have been responsible for poor quality construction of houses in Huri village. Thick, randomly packed masonry in mud mortar with slate roofing are the most common types of constructions. In some very old structures, timber has been freely used, both as structural and non-structural components. Few others have used timber beams as reinforcements in between the masonry walls.

The earthquake of 20th October has caused partial collapses of 1st floor masonry walls. As per the intensity scale, grade 2 and 3 damages are common in type-A structures and grade 3 and 4 in very poor quality, old type-A houses. Buildings located near the edge of slopes have suffered more damages. Some of the walls have bulged towards ESE direction.

The lighter wooden structures and those provided with wooden beam reinforcements have remained undamaged or damaged to a much lesser extent. Heavy slate roofs have also contributed to the damage, particularly of the gable portion.

The Gangnani Hot Springs have remained unaffected by the Garhwal earthquake. The temperature of spring water as measured on 27th November, 1991 was 65°C which is comparable with the earlier record. However, an earthquake related ground settlement has created an open fissure across the cemented floor of one of the two pools. This has resulted in the draining out of the accumulated water in the pool thereby making it dry. The source remains unaffected and unaltered as far as the discharge and temperatures are concerned.

Raithal-Kiar

Raithal village is located on an E-W trending spur and N-S trending slopes, covered with hill-wash material. The thickness of overburden in the slopes utilised for dwellings is less as compared to areas which have been converted into fields. The village is situated at about 2000m elevation on the right bank of Bhagirathi. The village has about 160 houses of which nearly 85% are Kutcha houses constructed of stone masonry with or without binding material. The pucca houses have been constructed with stone masonry, cement, RCC pillars and slabs. One house has been constructed with hollow bricks and RCC slabs & pillars. The houses are aligned either in N-S or E-W directions, dependidng upon their location on slope. About 90% houses in the village have suffered damages of different grades and 40% have collapsed. The collapses are confined to purely kutcha dwellings where either no binding materials have been used or mud serves the purpose of mortar (Photo 56). The collapses are restricted to western walls of E-W aligned houses and southern walls of N-S aligned houses. In case of collapses in N-S aligned houses, the walls have suffered collapses in gable portion as in the school building (Photo 57). However, here the cracks could not be noticed. Twenty five casualties have been reported in this village due to these collapses. The other 60% houses have developed cracks and peeling of plaster. The damage in form of cracks is more pronounced on western or northern walls.

A group of old temples (about 1000 years old) has also suffered damage. Out of 4 temples, one has completely collapsed and Kalas on one has moved towards S (Photo 57A). These are masonry structures constructed of dressed stones without any cementing material and are of small height (upto 2m).

Although there was report of big cracks in Raithal village, none could be observed either in the village or on the slopes above it. Some slump cracks might have developed which probably later got filled up due to rain. However, a few landslide scars have been observed there in the NW part of the village on other slope of nala. Similarly, in Kiar, most of the houses have suffered damage due to cracks. Even in buildings constructed of stone masonry with cement plaster & RCC slabs, walls have developed shear crackes. 6 Kutcha houses have suffered wall collapses (Photo 58) which are confined to western and northern sides in N-S aligned houses.

Nald

Nald village is located NW of the epicentral tract on hill slopes, at an altitude of about 1300m. It is a medium sized village with about sixty houses. Buildings are mostly double storey constructed of locally available stones, mud and timber. Some of the houses have cement plaster and RCC slabs. The village is located on thin overburden ranging in thickness from 1 to 2m. The damage pattern studies in this village reveal that most of the houses have escaped with cracks, bulging and displacement and tilt in walls and pillars. Collapses were neither reported nor observed in this village in contrast to surrounding villages like Gangori, Ganeshpur, Netala etc. The terrain has also suffered extensive damage in the form of landslides, rock slides etc. Some of the big landslides have been observed to have occurred on hill slopes located, NE, E and SE of this village resulting in generation of dust and sparks, giving an impression of fire. The cracks in the overburden in the west slope (35°) are mostly in en-echelon pattern, extnding for 10m in N20°E-S20°W direction and 5cm in width. However, no set of cracks could be traced for a length more than 30m Their formation can be attributed to slight movement of the slope forming material.

Most of the houses in the village are aligned with their long walls either in N20°-25°W-S20°-25°E direction or in N70°-75°E-S70°-75°W direction. Since no house has suffered collapses, the damage is restricted to development of shear cracks, vertical cracks etc. in walls and bulges and tilts in pillars. The crack, are open with opening going upto 5.0cm in some cases.

The house of Shri Surat Singh is a Kutcha house constructed from stone masonry with mud plaster and slate roof (Fig.12). The pillars in the varandah are also of mud stone masonry structures. The walls have timber partition. The long wall of the house is aligned in N20°W-S20°E direction. The NE-SW trending wall has developed vertical. open cracks. The pillars in the varandah have tilted towards N70°E and displacement at the top is of the order of 10cm. The cracks developed on long wall are of open nature and plaster has peeled off at number of places. Slight displacement and some bulge were noticed in this wall. No wall has collapsed but both structural elements (pillars) and non structural elements (walls) have suffered damage. However, the north eastern and south western walls have escaped with minor cracks.

Similarly, the house of Shri Ram Chandra with long walls aligned in N20°W-S20°E direction and constructed with mud-masonry and cement plaster has developed shear cracks on NW walls and bulge in north-eastern walls (Fig.13). The pillars resting on RCC slab on first floor have tilted towards N70°E. The house of Shri

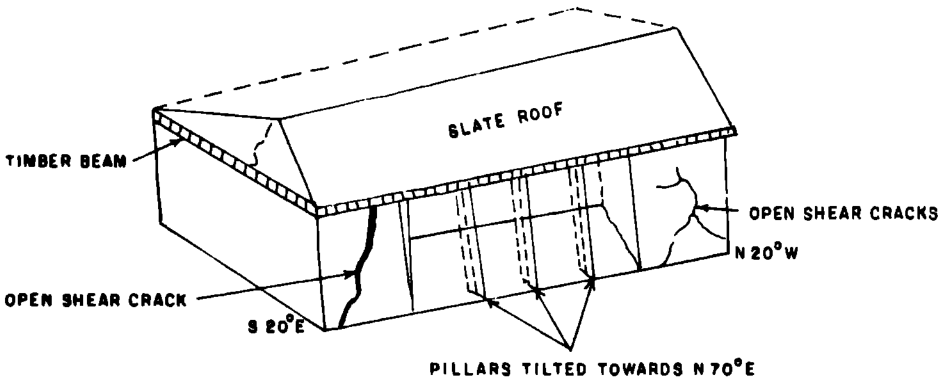


Fig. 12: DAMAGES IN THE HOUSE OF SRI SURAT SINGH VILLAGE NALD.

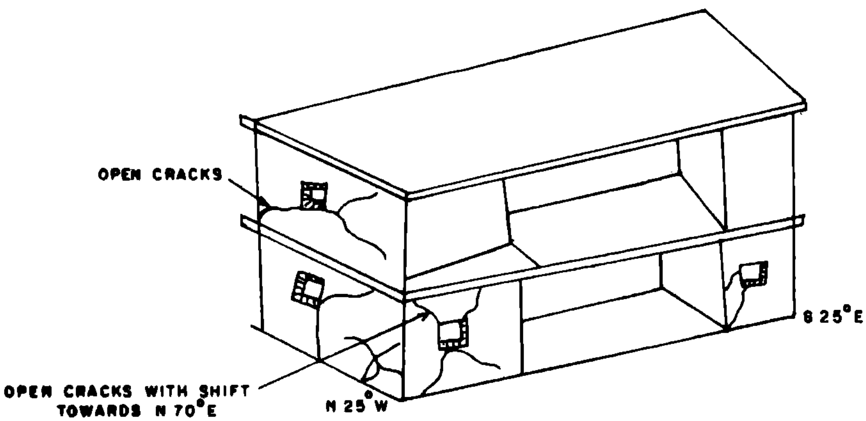


Fig. 13: HOUSE OF SRI RAM CHANDRA VILLAGE NALD.

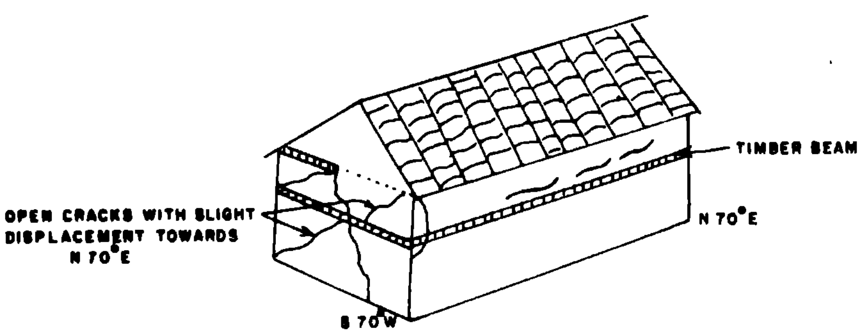


Fig. 14: HOUSE OF SRI PREM SINGH VILLAGE NALD.

Prem Singh, constructed of mud-stone masonry with slate roof and aligned in N70°E-S70°W direction has escaped with open cracks which are vertical and inclined on both N70°E-S70°W and N20°W-S20°E aligned walls (Fig.14). These cracks are open but no bulging was observed in the building except for small displacements in S wall. This displacement was also towards N70°E.

It has been observed that this village has suffered relatively less damage as compared to other neighbouring villages in the area. The terrain around the village has suffered considerable damage in form of slope failures, rock slides, etc. The village is located on gentle slopes with a thin overburden and is the reason that the foundations of most of the houses go down to bed rock. The masonry stones used in the construction are platy in nature adding to the stability of structures. These factors, coupled with the use of timber could have resulted in relatively less damage to structures in the village.

Bhatwari-Kiar

Bhatwari is a tehsil headquarter and an important town on the Uttarkashi-Gangotri Road. The village is located on both the banks of Bhagirathi river. The habitation on right bank is located on hill slopes with overburden comprising slope wash material and small fluvial terraces whereas that on the left bank is on river terraces. Kiar village is located on hill slopes and terrace of a nala flowing south, about 0.5 km north of Bhatwari. The altitude difference between the two villaages is about 100m.

In case of Bhatwari, the buildings aligned in E-W direction on both sides of Uttar Kashi-Gangotri Road have suffered less damage and escaped with minor cracks on long walls as compared to those which have been constructed on flatter slopes in relatively open areas. The Govt. Inter College, located on a fluvial terrace on left bank of the river, PWD Rest house, Residence of Executive Engineer, PWD and other houses in the village situated above the highway fall have also experienced greater intensity of damages In some houses the RCC slabs have fallen intact on the collapsed walls (Photo 59).

The PWD Rest house, with long walls aligned in NE-SW direction appears to be intact if viewed from outside (Fig.15). However, closer look reveals that the NE wall (aligned NW-SE) has been cracked badly with opening going upto 5.0cm. The cracks extend to a height of 3m on this wall. The chimney located on NE side is also badly cracked and upper slab of this has fallen down (Photo 60). The blocks supporting this slab have also been thrown out of place and are lying on GI sheet roof. Similarly, the SW wall has also suffered cracks. The partition walls have collapsed in gable portion rendering it unfit for occupation.

In case of Govt. Inter College located on a terrace on left bank of Bhagirathi, the gable portion of western and southern walls has suffered collapses (Fig.16). This N-W aligned building is a two storey complex constructed with hollow bricks and cement.

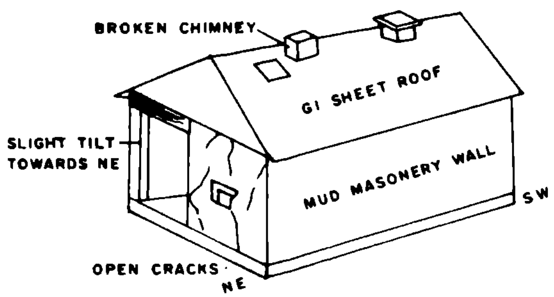


Fig. 15 : PWD REST HOUSE, BHATWARI.

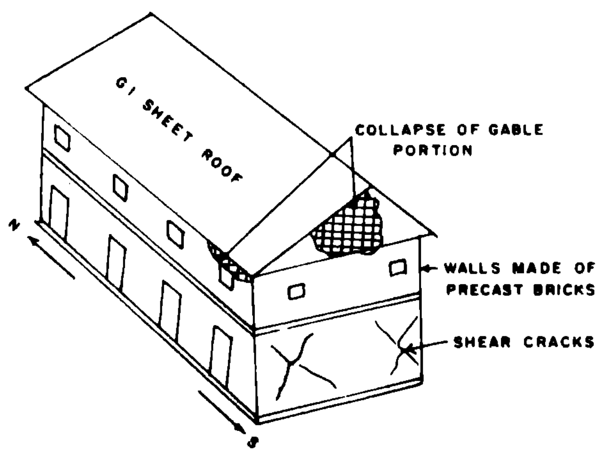


Fig. 16 : GOVERNMENT INTER COLLEGE, BHATWARI.

There are cracks in northern wall. Similarly, few houses in the village having their long walls aligned either in E-W direction or in NW-SE direction have suffered collapses in short walls and open cracks in long wall in a few cases.

Photo 37 *Collapse of a kutcha house of Ganeshpur village. The adjoining brick masonry house has suffered much less damage.*

Photo 38 *Collapse and cracks in the long walls of a house in Ganeshpur village.*

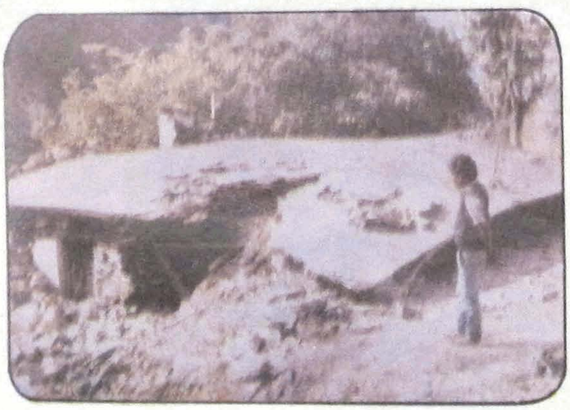


Photo 39 *Collapse of a house in Netala village Note bending of the RCC slab.*

Photo 40 *Open shear cracks in the temple in Netala village. Spire thrown down in N70^{o}E direction.*

Photo 41 *Severely damaged school building in Heena.*

Photo 42 *Complete collapse of a non-load-bearing masonry wall of Heena School.*

Photo 43 *Prominent shear cracks in the side wall of Heena school.*

Photo 44 *Collapse of a kutcha house (types A) in Malla village.*

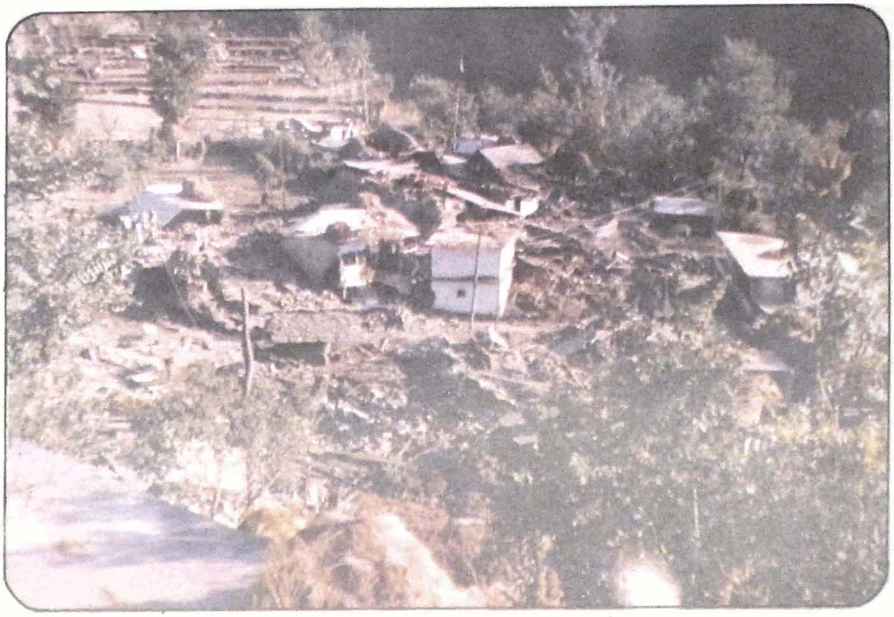


Photo 45 *Devastated Jamak village.*

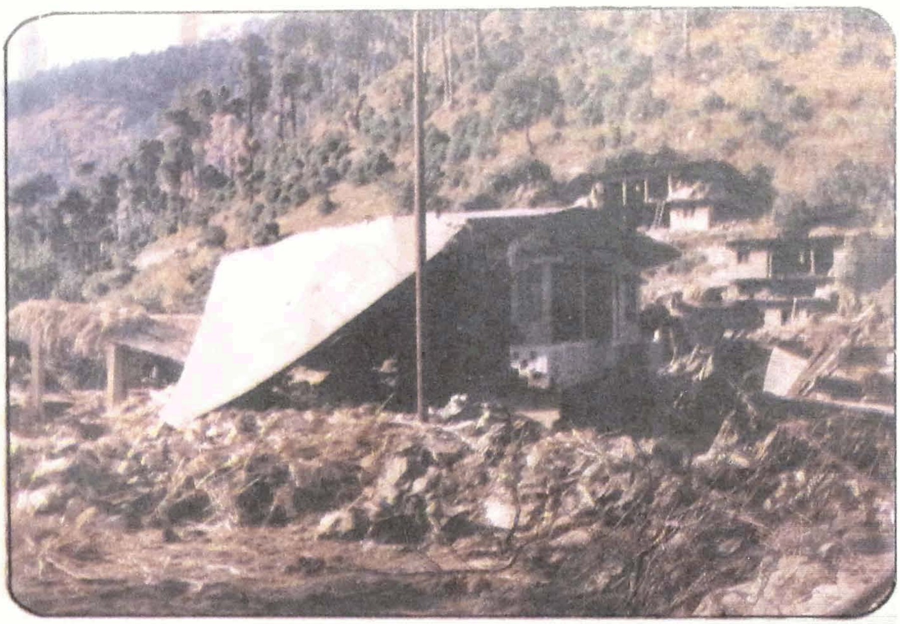


Photo 46 *Damaged houses in Jamak villages. Note severed and tilted RCC roof slab.*

Photo 47 *Villagers salvaging roofing timbers from collapsed houses in Jamak. Old man standing amongst ruins.*

Photo 48 *Collapse of a temple in Jamak village. Note intact pyramidal portion of the temple and damaged RCC roof slab.*

Photo 49 *Partial to total collapse of thick mud masonry walls in Kamar village.*

Photo 50 *Complete collapse of Kamar school building made of mud masonry with GI sheet roofings.*

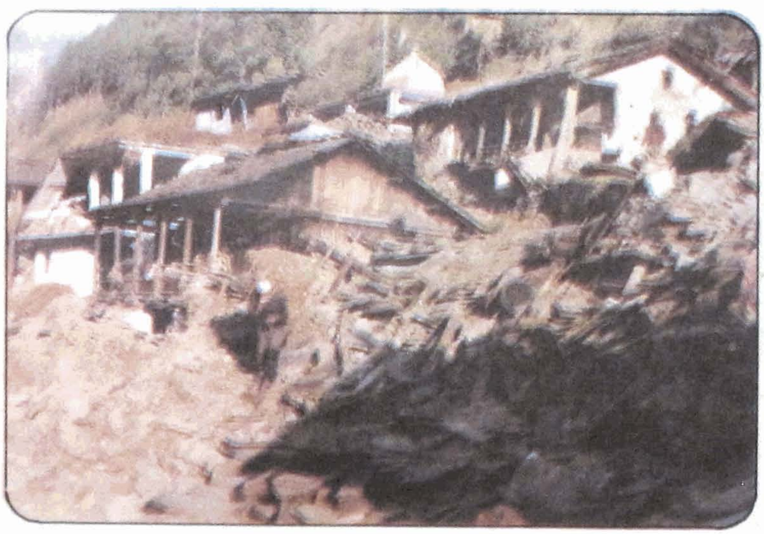


Photo 51 *Partial to complete collapse of houses in Dedsari village. Note an intact house made of timber logs and planks.*

Photo 52 *Partial collapse of the first floor of a house in Dedsari. Note damages to RCC pillars and open shear cracks.*

Photo 53 *Collapsed and precariously tilted house in Dedsari village.*

Photo 53 A *Complete collapse of type A houses in Dedsari village. RCC roof slab damaged because of wall collapses in one of the houses.*

Photo 54 *Households scattered around collapsed type–A house in Sanglai village.*

Photo 54 A *Destruction of a cluster of type–A houses located on a* N60°W—S60°E *trending narrow ridge in Sanglai village.*

Photo 55 *Collapsed school building in Sanglai village.*

Photo 56 *A distant view of damages in Raithal village.*

Photo 57 *Partial collapse of mud masonry side walls of school building in Raithal village.*

Photo 57 A *Old temple near Raithal village, displaying shifting of top cupola (kalash).*

Photo 58 *Extensive damage to conventional type–A houses. Collapse of walls and resultant breaking of concrete slab in one of the houses in Raithal village.*

In case of Kiar village, the damage is of similar nature. A few very old temples (about 1000 years old) are located in the north east portion of the village. Out of four such structures constructed from stone masonry, three have withstood the shock. One of them has collapsed and there is slight tilt towards NW in the Kalash' of one of these temples. These are structures of low height and have square base rather than elongated ones. This may be the reason why these low height old structures devoid of any cementing material have withstood the shocks without much damage.

Out of 44 houses in the village, damage in form of cracks is in all the structures. Eight of the houses have suffered collapses of walls resulting in one casualty. The houses in the village are mostly aligned in N-S to N40°E-S40°W direction. The houses aligned with long walls in above mentioned direction have suffered collapses on western and northwestern walls and open cracks on northeastern walls. The partition walls of such houses have also suffered collapses. In case of Pawar Sadan, a NE-SW aligned structure constructed of stone masonry walls and RCC slab, the NW wall has collapsed partially where as shear cracks have been observed in SW wall. Also, the joints between walls and lintel have opened upto 1.0m.

A similar pattern of damage has been observed in case of Raithal village which is situated north of Kiar.

Pala

Pala village is situated on hill slope on right bank of Bhagirathi at about 2000m altitude. There are about 30 houses in the village. These are mostly mud stone masonry structures with slate roof. There are a few houses which have RCC roofs and cement plastered walls. The damage in the village is comparable to that in Raithal resulting in seven casualities. The damages to the buildings consist of crack, both vertical and of shear type with opening and displacement and wall collapses. Some damage to the terrain has also been observed in the village in the form of small cracks with opening upto 7.5cm and extension upto 10.0m on the edges of terraced fields. These are aligned in N60°E-S60°W direction.

The houses are mostly constructed with their long walls aligned in N60°E-S60°W direction. The damage pattern indicates that south eastern walls (walls aligned NE-SW) have suffered damages in form of intense cracking and bulging towards

SE where-as collapses have been observed in the NE walls. This pattern of damage is indicated in the house of Shri Sahdev Singh & Gyan Chand and Primary School building (Photo 61).

The house of Sahdev Singh and Gyan Chand has its long wall aligned in N60°E–S60°W direction (Fig.17 and Photo 62). It is a stone masonry house with RCC slab roof. The house is double storeyed with the stair case located outside. The southeastern wall has suffered damage in the form of open cracks (upto 5 cm) which are more pronounced near the windows and extend towards the edges. Bulge towards SE was also noticed below the window in this wall. Similarly, the projections on this wall like stair case have also suffered cracks. The NE wall (aligned NW–SE) has suffered more damage in the form of partial collapse and development of open cracks. The collapse is more pronounced at upper portion of building as compared to lower. Similar damage, but of lesser intensity has been noticed in a number of houses.

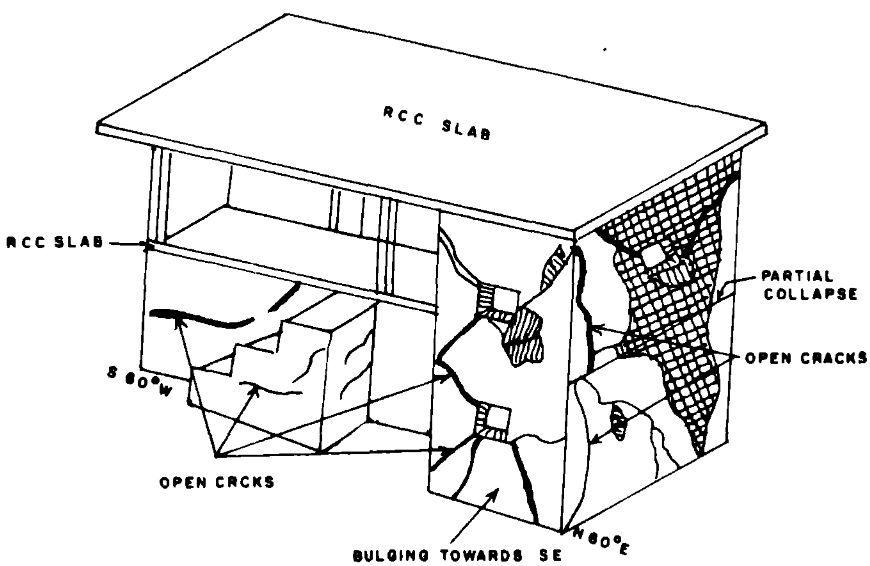


Fig. 17: HOUSE OF SAHDEV SINGH AND GYAN CHAND, PALA

The Primary School building, located on a small terrace is a single storey, mud stone masonry structure with GI sheet roof (Fig.18). It has also its long wall aligned in N60°E–S60°W direction. The failure of NW and SE corners has resulted in complete collapse of NE wall (Fig. 18). A closer examination indicates the damage of wall might have initiated in the gable portion.

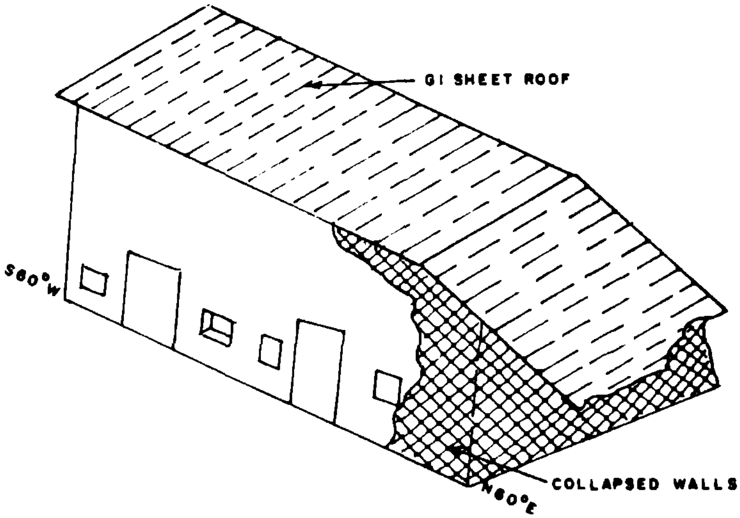


Fig. 18 : PRIMARY SCHOOL BUILDING, PALA

Two village temples situated on a NE-SW trending ridge over looking the village have been razed to the ground. These were masonry structures of low height with shikhar' about 3-4m above the ground. The collapse of these structures might have resulted because of topographical accentuation on the narrow ridge. A few buildings like Patwari Chowki aligned parallel to the Primary School have escaped any damage.

Harsil-Jhala-Gangotri

In Harsil, the construction is mostly confined on the right bank terrace. The buildings in this village have developed cracks which are either vertical or horizontal in both N-S and E-W walls. In case of one shop aligned in E-W direction, a few cracks were noticed at the floor. These could have resulted due to foundation settlement as a result of the earthquake shock.

Similarly, the PWD Rest House, which is mud stone masonry building with walls having cement plaster and GI sheet roof has been partially damaged and declared unfit for occupation. Cracks have developed on the northeastern walls and partition walls have partially collapsed. Most of the buildings in the village have suffered damage in the form of open cracks in the walls and partial collapse of Kutcha walls, near the top levels.

The wide open valley in the section beyond Jhala and meandering course through the alluvial fill in the upstream direction indicates blockade of river Bhagirathi probably by an ancient landslide downstream of Jhala.

In Jhala village, located on hill slopes on right bank of Bhagirathi just upstream of river blockade site, the damage is restricted to development of fine cracks on the southeastern walls of NE-SW aligned stone masonry buildings which are few in number and these escaped major damage. Most of the houses have used timber as construction material. The school building located about 20m above river bed, developed a few vertical cracks on SE wall and slight displacement in pillars towards SE has been noticed. This building is aligned in the N30°E-S30°W direction. The pillars have developed horizontal cracks in an isolated case, the joint with lintel has opened and the pillar has tilted towards SE.

In Gangotri, a pilgrimage centre, construction has come up on moderately steep hill slopes on both the banks of Bhagirathi river. Generally the houses donot show any damages except the Gangotri temple wherein hair fine cracks have developed on western and southern walls as a result of opening up of joints between masonry stones (Photo 63).

Suki

Suki village is located on hill slopes, on right bank of Bhagirathi river at an altitude of about 2500m, occupied by debris of a dormant land slide. The buildings in the village are either Kutcha mud stone masonry houses with slate roofs or pucca mud stone masonry walls with cement sand plaster and GI sheet or slate roofs (Figs.19,20&21). A few wall collapses and wide open cracks were observed in Kutcha houses. The bulges and open cracks are confined to northeastern short walls of N30°E-S30°W aligned houses. In the school building open cracks (upto 5.0cm) with slight bulge towards NE have been recorded (Fig. 19). The long wall of this building is aligned in N30°E-S30°W. The other walls of this building have escaped damage. In case of Kutcha houses with long wall aligned in E-W direction, a few partial collapses on northern walls were observed (Fig. 20). The northern walls of these houses have bulged towards north.

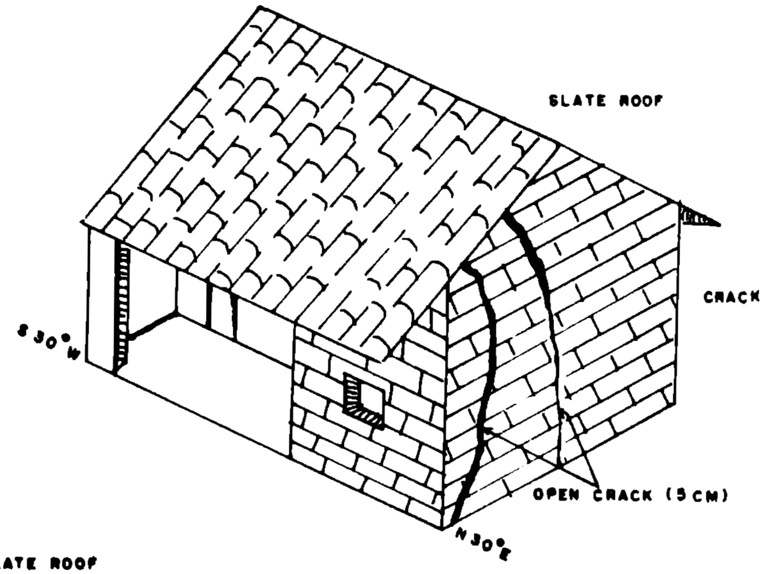


Fig. 19: SCHOOL BUILDING – SUKI

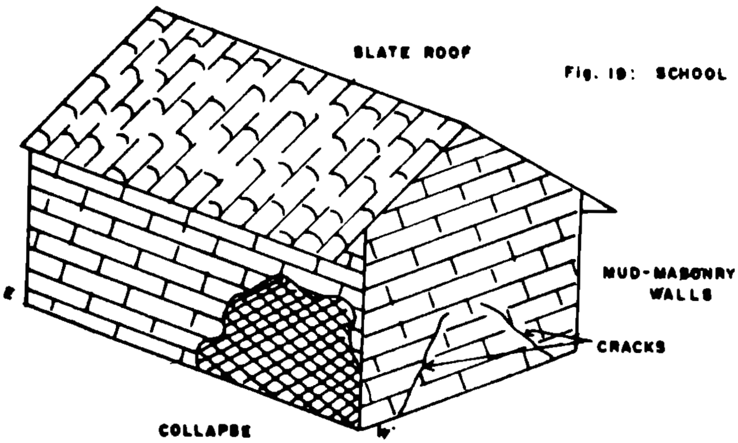


Fig. 20: KUTCHHA (MUD-MASONRY) HOUSE SUKI

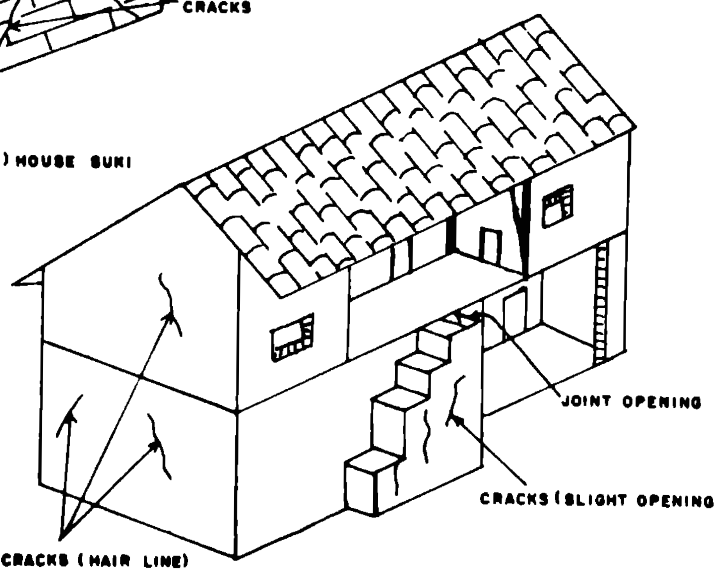


Fig. 21: PUCCA HOUSE – SUKI

In case of houses constructed using mud stone masonry walls with sand and cement plaster and GI sheet or slate roofs, damage is confined to development of hair fine cracks and peeling of plaster of southwestern walls. The projections like the stairs, have suffered more damage in form of opening up of joints and development of open cracks (Fig. 21).

Siror

The village is located on the left bank of Bhagirathi over an alluvial terrace deposit. It has a population of 600, living in congregation of 114 houses. The earthquake caused injuries to 25 persons in this village.

The houses, in general, are constructed of mud masonry walls with slate roofs. Some of the old constructions with timber columns and beams embedded in mud-mortar have been severely damaged by shear cracks but have escaped collapse because of greater flexibility (Photo 64). Tabular blocks of quartzite have been used in the masonry. This has imparted much greater shearing strength (interlocking property) to the walls which under conditions of strong ground motions have either cracked along stone interfaces or bulged but not collapsed (Photo 65). Some of the cracks show displacement of more than 5 cm. As per the intensity scale, the type B and A structures have suffered grade 2 and grade 3 damages respectively.

A newly built, well constructed RCC and RBC temple structure, located by the side of right abutment pier of Siror suspension bridge on river borne sediments, does not show even the slightest damage though the adjoining semi-Pucca constructions have been severly damaged.

Mannpur

The village is located on the right bank of Indravati river along Uttarkashi-Kishanpur road. Mannpur has a population of 800 people. The earthquake killed 19 persons and injured many more in the village. A total of 15 cattles also perished.

The damage to houses includes partial collapse of a number of mud masonry walls and open cracks in almost all types of constructions. As such, the houses have become unsafe for living forcing most of the inmates to stay out. In some instances poorly constructed RCC columns have developed fine cracks.

Though all the types of constructions have suffered damage, the most severely are the ones which are made of load bearing mud masonry walls with RCC roofs. In many of these houses the slabs have fallen intact on the collapsed walls (Photo 66). The conventional type of constructions though have been badly damaged but have escaped complete collapse (Photo 67). The walls which are aligned in WNW-ESE direction have developed shear cracks.

Ginda & Kishenpur

Ginda and Kishanpur villages are situated on the left bank of Indravati river on hill slopes on the Uttarkashi-Lamgaon Road. Ginda is located about 50m above the road level. Kishenpur village lies over debris slopes, about 200m above the road.

Ginda has 32 houses of A and A cum B types. All the houses have suffered damages of Grades 4 & 5. The damage comprises shear cracks with openings upto 10cm, bulges in walls, peeling of plaster and collapses in walls of mud and stone masonry with RCC slabs. A total of 12 two storey houses of poor type-A constructions have completely collapsed. The ground floor walls have suffered maximum collapses. In the houses aligned in N60°W-S60°E direction, the SE corners have suffered maximum damages. The northeastern end walls have collapsed and southwestern end walls have developed shear cracks and bulges.

One lined irrigation channel has suffered damages in the form of settlements and collapses. The terraced cultivable fields supported at places by retaining walls of 1m to 4m height, have suffered damage due to collapses of dry masonry walls. In a few cases, the resultant cracks developed due to slumping of slopes extend up to 50m. causing extensive loss of cultivable land.

In Kishenpur village, there are about 200 houses. These are either A-type or A+B-type constructions. A few B type houses are also there. In the B-type houses aligned in N30°W-S30°E direction, NW end walls have developed open shear cracks. The northeastern walls have collapsed resulting in cracking or buckling of RCC slabs. There is displacement in joints between beams and columns and tilting of pillars towards NE.

The damage to all types of constructions is extensive and heavy. Most of the retaining walls to support the terraced fields have collapsed and slopes of even 1.0m height have failed. Electric poles in the village have got tilted due to slope failures. The damage to buildings in these villages can be compared with those at Ganeshpur etc. but here the ground has suffered greater extent of damage.

Sada

Sada village is situated along Uttarkashi-Lamgaon road, about 1km. from Mannpur. The main habitation is located between the road and Indravati river. Both A and B type buildings in the village have suffered damages. The village temple (B or C type), Panchayat Ghar and school have been razed to the ground. These are all well constructed structures. In case of A type, two storey houses, aligned in E-W direction, upto 7.5cm open cracks with displacement and bulging are more pronounced in the western side walls. N-S aligned walls have collapsed. Bulging is more frequent towards west in N-S aligned walls. In case of one house, cracks were observed in RCC columns.

In the area near the river, ground cracks with opening upto 5.0cm and aligned parallel to slope have developed near Panchayat Ghar, school and temple buildings which have collapsed completely. In case of school building (aligned N-S), the RCC slab forming roof supported by columns has slipped by 2m towards west and columns have fallen towards north.

Thalan

The village falls on the right bank of Indravati river, a tributary of Bhagirathi river, along Uttarkashi- Kishenpur- Lambgaon motor road. The village has a cluster of 100 houses with a population of 600 people. The earthquake took a toll of 4 human lives and caused injuries to few others.

For construction of houses tabular masonry blocks, set in mud mortar have been used. Roofing of slate slabs is common and have suffered damage in the form of collapse and bulging of load bearing masonry walls resulting in cracking, sagging and collapse of RCC slabs (Photo 68). The sloping topography has accentuated damages. Most of type-A houses have suffered damages of grades 3 and 4. Development of open shear cracks and partial collapse of masonry walls, particularly of the upper floors are found in most of the buildings. As such, the houses have become unsafe for habitation, forcing the villagers to stay out in make shift settelments.

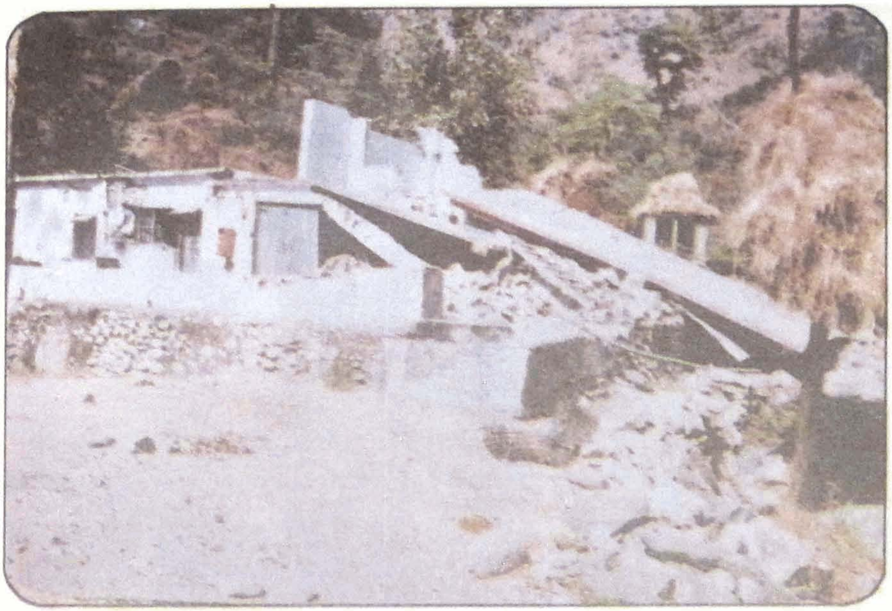


Photo 59 *Collapse of wall and slided RCC slab, Bhatwari village.*

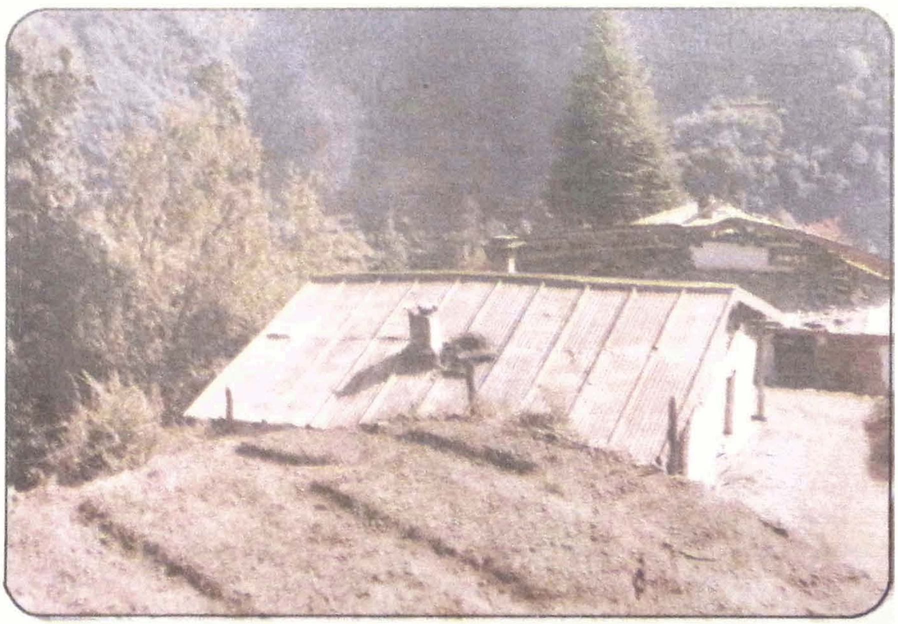


Photo 60 *Damaged PWD Rest house building, Bhatwari. Chimney slab of the out house thrown on G. I. sheet roofing.*

Photo 61 *Shear cracks in the side wall of Pala school building made in mud masonry.*

Photo 62 *Open shear cracks in NE–SW wall and partial collapse of NW–SE wall in the house of Sahdev Singh of village Pala.*

Photo 63 *Fine cracks in the outer masenry wall of Gangotri temple.*

Photo 64 *View of an old conventional house with wooden beams and columns displaying gaping shear cracks in Siror village.*

Photo 65 *Bulging and cracking of thick masonry walls of a house in Siror village.*

Photo 66 *Collapse of houses with RCC slabs in Mannpur village. Note relatively lesser damage to the conventional houses in the background.*

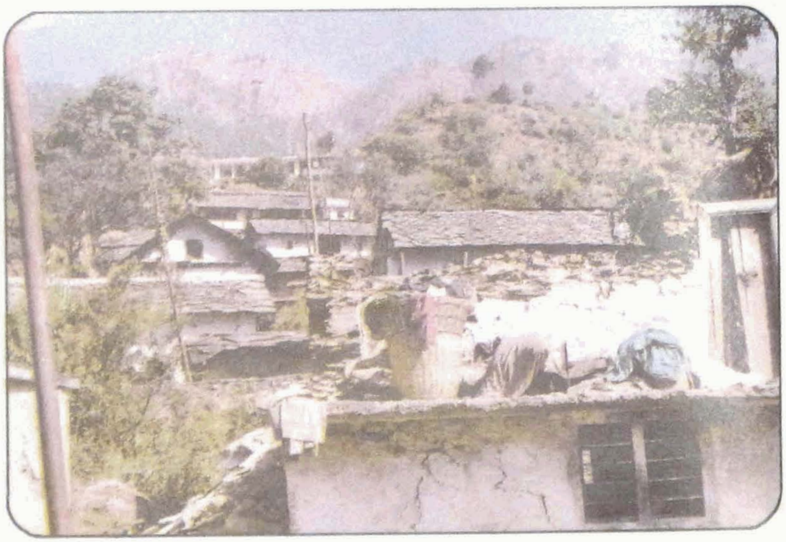


Photo 67 *General view of Mannpur village displaying damages.*

Photo 68 *Sagging and collapse of RCC slab supported on mud masonry walls in a house in Thalan village.*

Photo 69 *Partial collapse of the roof corner of the first floor of a house in Thalan village.*

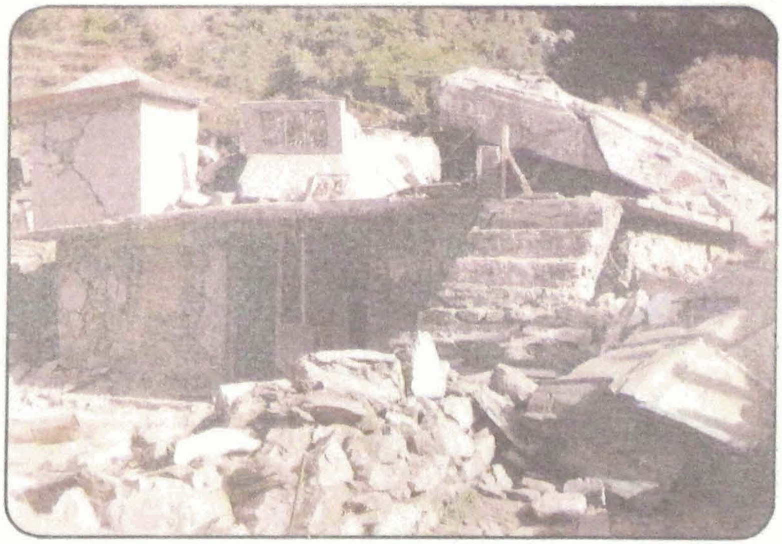


Photo 70 *Collapse of first floor of a house in Byala Tipri village with deep open cracks in the ground and first floor. (New construction).*

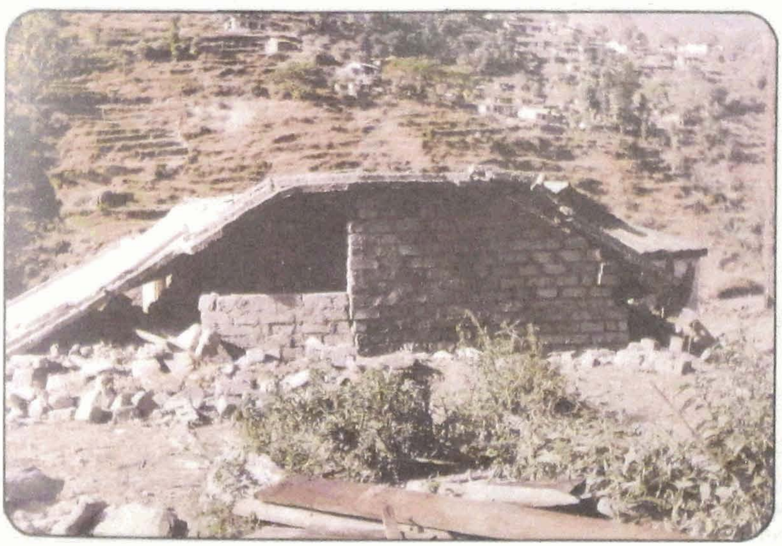


Photo 71 *Partially collapsed end walls have resulted in a hut-like shape of the RCC roof slab in Byala Tipri village.*

Photo 72 *Collapse of cluster of houses in Gyansu village.*

Photo 73 *Tilting of the first floor frontage of a double storey house because of the collapse of the ground floor wall in village Gyansu.*

Photo 74 *Failure of the stone masonry wall leading to sagging and partial collapse of a RCC roof slab in Matti village.*

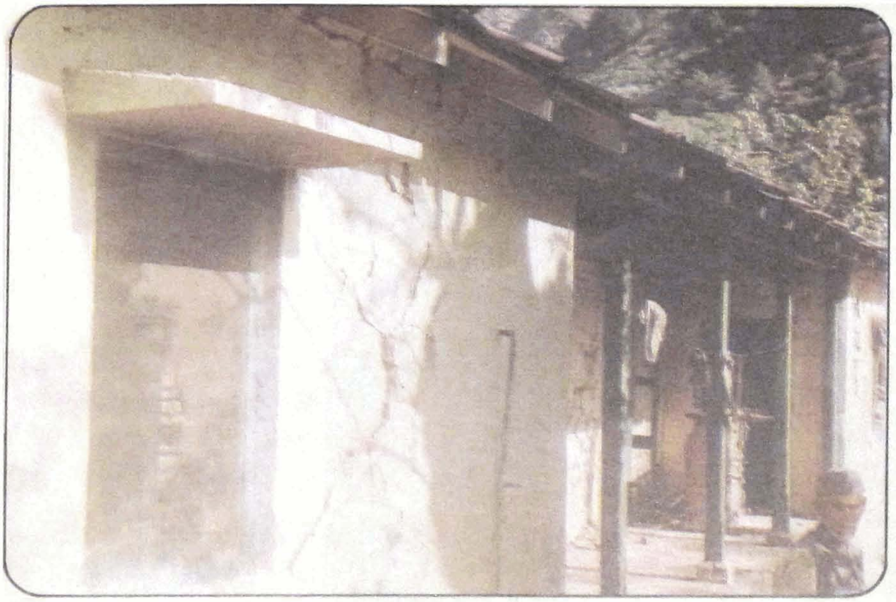


Photo 77 *Open shear cracks in the out house of PWD rest house at Lambgaon.*

Photo 78 *Damage to side walls of the PWD rest house at Lambgaon.*

Photo 79 *Collapse of shops in Lambgaon market.*

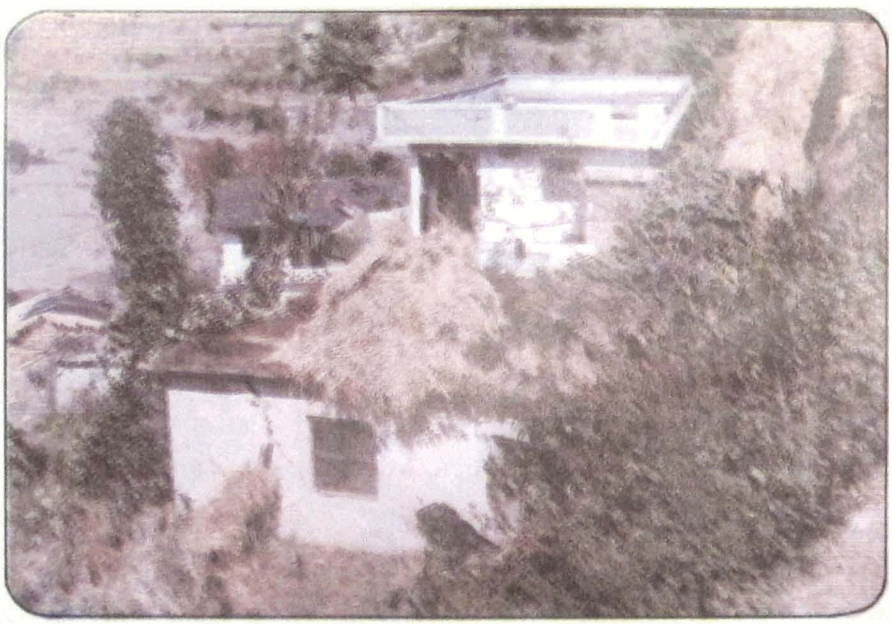


Photo 80 *Shear cracks in a house in Thati Kuthur village.*

A poorly constructed type A double storey house has its long wall oriented in E-W direction. The long wall has developed shear cracks and the upper corner of this wall has collapsed towards south (Photo 69).

Byala Tipri

The village is located on the left bank of Bhagirathi river over terrace deposits. The village has 51 houses with a population of 260. The earthquake took a toll of 2 human lives and caused injuries to fifteen persons. A number of animals also perished in the quake.

The old houses constituting almost 70% of the village dwellings are constructed of masonry walls with mud mortar and slate roofing. Such structures have suffered grade 3 and grade 4 damages in form of partial collapses, open cracks and bulging of walls (Photo 70). Some of the new constructions have replaced masonry with pre-cast concrete bricks and the slate roof with RCC slab. In such houses the failure of the side walls has led to partial collapse of the roof slabs which have acquired a tent or a hut like shape when viewed from a distance (Photo 71). The damages in first floor have been found to be more severe than the ground floor.

Gyansu

Gyansu village is located a kilometre downstream of Uttarkashi town on the right bank of Bhagirathi river at an altitude of 1100m.

The village is situated over slope wash material, composed mainly of slate, slaty quartzite and quartzite boulders in a silty matrix. The earthquake took a toll of 14 human lives in the village.

Over 50% type-A houses are essentially of poor quality, being made of undressed stone masonry set in mud mortar. One of such houses had suffered damage of Grade 4 (Photo 72). It is clearly seen from the photograph (Photo 73) of the house that the back and side walls of the ground floor have completely collapsed. The back and side walls of the back portion of first floor has almost dislodged from the main building and hanging in air, leaving a zig-zag crack with a gap of approx. 40cm. The shear crack starts from the roof level of the wall and extends down to the floor of the room dissecting the balcony. Also approx. 5cm wide open cracks running parallel to the junction of back wall with the roof slab have been noticed. The RCC roof has remained intact.

Other `A' type houses in the village have suffered less damage (Grade-2). In some houses with GI sheet roofing the walls have partially collapsed. Shear cracks, starting from the door level and continuing down to the plinth level have appeared resulting in peeling of plaster. The `B' type structures made of pre-fabricated cement bricks with cement plaster on the walls have suffered a damage of Grade-3. In one such house (long wall trending N-S), deep open crack starting from the plinth level and traversing through the mid of the wall and extending to the side wall was noticed.

Matli

The Matli village is located 10km. downstream of Uttarkashi town on the right bank of river Bhagirathi, at an altitude of about 1090m. The village is situated over river terraces which are being extensively used for cultivation.

The large village has a population of 1700 persons (approx.) living in 500 houses. As per the official records, ten persons died and 15-20 persons got injured during the 20th October earthquake.

Most of the houses in the village are of A-Type. In general, the houses have been constructed using undressed stone masonry with mud mortar, timber beams and slate roofs. Approximately 15-20 houses have completely collapsed (damage of grade 4 or even 5). In most of the houses one of the walls has either partially collapsed or major shear cracks have developed along and across the walls. In a case where the mud masonry walls were supporting on RCC slab, the slab has collapsed on the northwestern concern. The collapse has resulted in cracking of the slab (Photo 74). In some cases vertical cracks have developed along the corners of the room, leaving a gap in between the walls. A few houses made of bricks and cement (Type-B) have suffered minor damage. The damage is in form of fine surficial cracks restricted to the plaster only. Minor cracks, at the junction of RCC beam with the supporting pillars, have been noticed in such constructions.

3.3.2 LESSER DAMAGE AREAS

To study macroseismic effects in the area around Tehri Dam Project, selected traverses were taken by S/Shri P.C. Nawani, R. Sanwal & J.S. Rawat in different sections/sectors in Bhagirathi valley, Bhilangana valley, Jalkur valley, Balganga valley and Nailchami valley. A total of 400 line km. were covered by these traverses on 1:250,000/50,000 scale. The direct field observations, collected immediately following the earthquake occurrence on 20th October, 1991, have been utilized to interpret damages to relate them with MSK intensity scale. The field observations are supported by photo documentation. The traverses in the above sections/sectors were completed between 21st October 1991 and 15th November, 1991.

The summarised account of the field observations in different sectors is given below and detailed description of a few important localities, where significant damages were recorded are given in the later sections of this chapter.

TEHRI AREA

Tehri Town

Sl. No.	Type of Structure	Location	Effects/ Damages	Remarks
1	A	House of Sri A.P. Dobhal in Ahalkari Mohalla (Ward No.3)	Grade 2	Opening of construction joint upto 1.5 cm. No casuality.
2	A	House of Sri Suman Prasad Panuali, Ahalkari Mohalla (Ward No.3)	Grade 3	Bulging of walls, gaps in walls (upto 10cm). No casuality.
3	A	House of Sri T.P. Ghildiyal, Satyashwar Mohalla	Grade 2	Small cracks (vertical/ arcuate). No casuality.
4	A	House of Sri Devi Prasad, Nautiyal (Mahant) of Shri Laxmi Narayan Temple	Grade 3	60 year old house. No casuality/ one person was injured. In the Laxmi Narayan Temple (adjacent to the house of Mahant) minor cracks have developed.
5	A	House of Sri Vishnu Pd. Pandey, Raghunath Mohalla		100 year old house. Vertical cracks in walls. Contact of wall with roof is disturbed. Bulging of walls. Plaster detached. No casuality.
6	A	Shop/House of M/S Kishan Kumar & Sons (Chemist)	Grade 4	First storey of the building totaly collapsed.
7	B	House of Sri Guna Nand Uniyal, Ahalkari Mohalla	Grade 2/3	Cracks (upto 3 cm) observed in walls. Damage in first storey is upto Grade 3.

(Cont.)

(Cont.)

Sl. No.	Type of Structure	Location	Effects/ Damages	Remarks
8	B	House of Smt. Parmeshwari Devi. Ahalkari Mohalla	Grade 2	Vertical cracks on walls upto 1 cm. Construction joints opened.
9	B	House of Sri J.P. Khanduri. Ahalkari Mohalla	Grade 2	Vertical/horizontal cracks on walls.
10	B	House of Sri R.P. Kukreti. Ahalkari Mohalla	Grade 2	Vertical cracks (opening 1 to 3cm) in walls.
11	B	House of Sri Kundan Singh Aswal. Rghunath Mohalla	Grade 2*	Vertical cracks. movement along joints, direction of movement towards N40°W.
12	B	Govt. Girls Inter College. Tehri	Grade 3	New building of college has suffered more damages. Cracks horizontal to vertical. boundary wall collapsed.
13	C	House of Sri Verendra Datt Saklani. Advocate	Grade 1	Old cracks opened. fine cracks developed.
14	C	House of Sri R.D. Samelty in Samel- Tappar (Ward No.6)	Grade 1	Fine cracks developed in walls.
15	C	Hotel River View	Grade 1	Fine cracks vertical and horizontal.
16	C	State Bank of India. Purana Darbar	Grade 2	Minor cracks in walls. Parapet walls damaged, cracks in ceiling. numerous. Vertical fine crack in the supporting beam of grond floor with 4m continuity.
17	C	Post Office (Main) Tehri	Grade 1	Fine cracks developed.
18	C	Clock Tower, Tehri (built in 1887)	-	No damage seen.
19	C	Nagar Palika Office (building near clock tower)	Grade 1	Fine cracks (horizontal/ vertical) with continuity upto 1m-3m, fall of piece of plaster.

Tehri Dam Site

No Damage has been observed in the already constructed appurtenant structures (HRTs, diversion tunnels, approach adits to power house and dam foundation). No slope movement has been observed even in the existing slide mass.

Seansu-Chinyalisaur Section

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	B	Forest Rest House, Seansu	2	Cracks in walls, fall of plaster. Rotation of chimney.
2	B	Shaktipuram	2	Small cracks in walls, and fall of plaster.
3	C	Rest House at Shaktipuram	3	Large and deep see through opening of the construction joints. Numerous cracks on the wall & fall of plaster. Mumty on 3rd floor badly damaged. Damage of parapet walls.

Jalkur Valley

Bhainga Village

This village, SW of the epicentral area is located on a high level terrace of Jalkur gad on a nose formed by bend in the main river and a small tributary nala. Two levels of terraces have been observed at this location overlying phyllites of Chandpur Formation which dip at steep angles towards the river. The "Srinagar Thrust", which is a steep angle fault in this area is located just upslope of this village. The only building located at the lower terrace is that of Middle school the long wall side of which is aligned in the NW-SE direction. This building supported on pillars is about 15m. long and the side walls are about 6m. long. In the end walls of this building cracks have developed and near the SE end wall the horizontal beam has cracked under tension. The rooms on either side of the varandah of the building show shear cracks near the window openings on the walls aligned in N45°W-S45°E direction. This is comparatively a new building which was constructed in the year 1990 (Fig.22).

The village proper is located on the upper terrace and is a conglomeration of mud masonry houses and a few cement masonry houses some of which are with conventional sloping roofs with tiles and others with RCC slabs on masonry walls (Fig.23&24). All the mud masonry and old mud adobe houses have suffered the damage in form of open cracks and a few partition walls have collapsed. One housing complex belonging to four brothers Jataru Lal, Sirdaru Lal, Uttam Lal and Tara Lal aligned in the N60°E-S60°W has collapsed taking a toll of 6 lives. This house is located near the village Primary School which is aligned across the direction of long wall side of the collapsed house. The Primary School building has also suffered major damage in the form of collapse of partition walls. A fissure trending in N15°W-S15°E direction has developed in the school compound.

An interesting observation made in the B type construction of the house of Gram Pradhan at the highest level of the village was that the northwestern end wall side room displayed cracks which have broken even the quartzite slab put as rack partition in the almirah, under tension. This village has demonstrated damages which are quite near to intensity VII as some overburden covered slopes show development of cracks near steep slopes. This isolated village demonstrating damages of intensity VII is located on a nose covered by two level terraces and it is possible that local accentuation of accelerations has taken place because of topography aided by thick overburden cover.

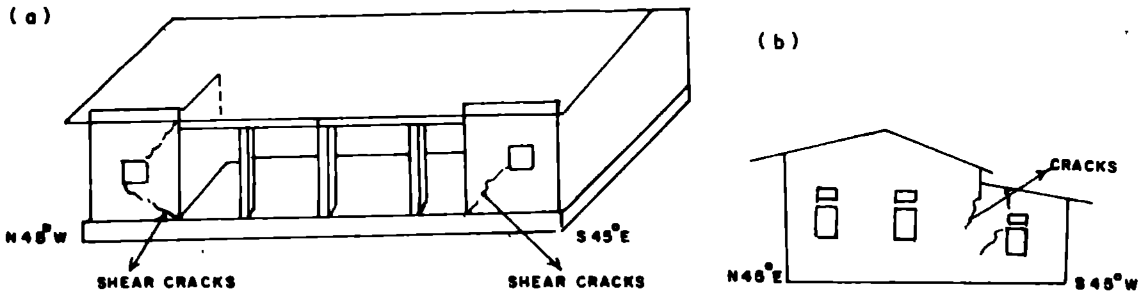


FIg.22:(a) BAINGA SCHOOL BUILDING SHOWING SHEAR CRACKS IN THE CUBICLES ON THE SIDES OF THE VARANDAH.(b) ELEVATION OF NW SIDE WALL SHOWING STEEP CRACKS IN THE SAME BUILDING.

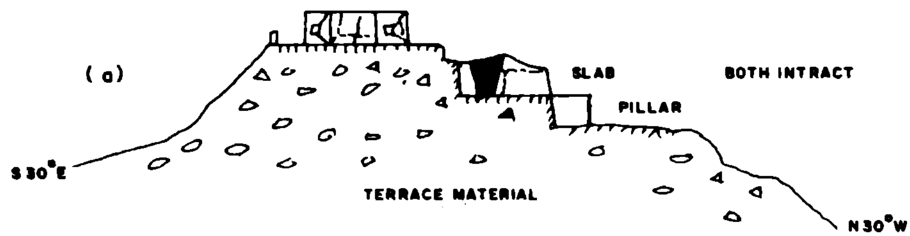


Fig.23: SKETCH SECTION OF THE NOSE ON WHICH BAINGA VILLAGE IS LOCATED.(a) COLLAPSED PORTION OF THE NE–SW ALIGNED HOUSE BUILT IN MUD MORTAR AND STONE (SHALE) PACKING, LIVES LOST IN THIS COLLAPSE.

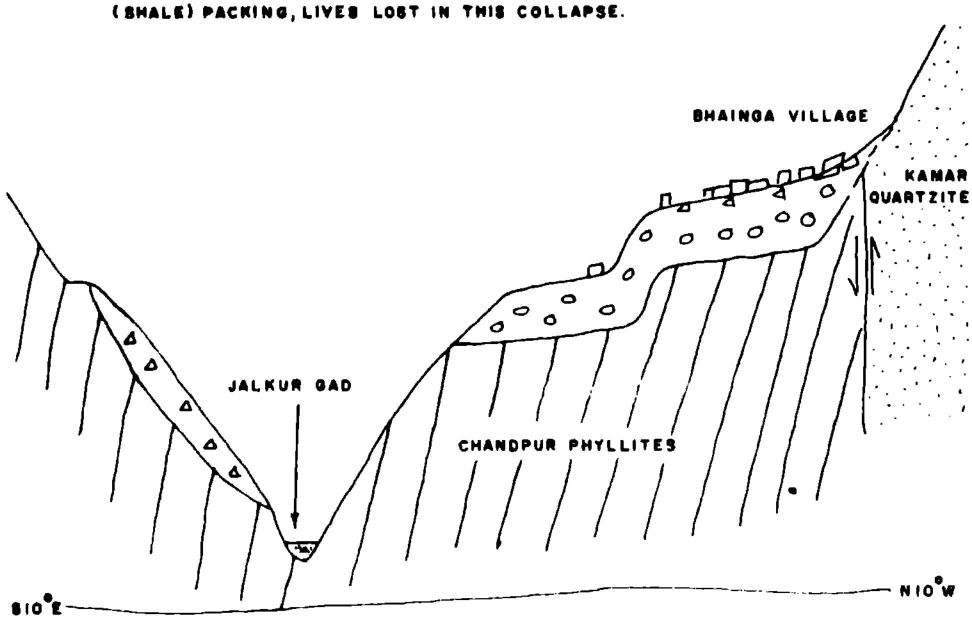


Fig.24: SKETCH GEOLOGICAL SECTION THROUGH BHAINGA VILLAGE.

Chaundhar Village

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	A	Houses of Jeeta, Chetu Mangal Das, Prem Das and Lenda Ram	4	Bulging and partial collapse of walls (Photo 76).
2	B	Primary School	3	Large deep, see through cracks (diagonal and vertical) Total collapse of roof (RCC)
3	B	Hospital	4	Large deep, see through cracks (diagonal and vertical) Total collapse of roof (RCC) (Photo 76).

i) Eight houses of A Type have partially or fully collapsed. No deaths have been reported but there are minor injuries to about a dozen persons.

ii) Cracks on the ground of primary school measuring 7-8m in length and about one cm wide, have developed.

Lambgaon - Rautaldhar Section

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	B	PWD Rest House Lambgaon (height 1160m above MSL)	4	Bulging in end walls and partial collapse, numerous deep, open vertical steep shear and horizontal cracks on the walls, two deaths reported (Photo 77 and 78).
2	A	(Govt. Inter College) G.I.C. Hostel, Lambgaon	5	Total collapse of the structure.
3	B	G.I.C. Main building	2 to 3	Bulging of walls, fall of plaster, large deep open cracks on the walls and tilting of windows.
4	C	G.I.C. Labs, Lambgaon	2	Fall of plaster, and detachment of part of masonry at the contact of wall and roof, on the 1st floor. Vertical cracks even on the ground floor.
5	B	Lambgaon market shop of Shri Jabbar Singh Rawat Thakur Mahavir Singh Attar Singh, Horticulture Office	-	Near total collapse of all the three houses/buildings (Photo 79).
6	C	S.B.I. Building, Lambgaon	2	Vertical cracks in wall and opening of construction joints.

i) Cracks have been observed on the ground in PWD rest house, G.I.C. campus (length + 15m. opening 1-2 cm) and on the road in front of SBI building (trending N20°W-S20°E, length about 50m and opening upto 10cm, measured depth 1.5m).

ii) Between PWD rest house (Lambgaon) and Rautaldhar, several land slips/slides have occurred along the road leading to road blockade.

iii) Five deaths have been reported from villages Huldyan and Malti.

iv) At Ranihar the veterinary hospital is also partly damaged.

v) Raj Rajeshwari Temple (about 80 years old) on Lambgaon - Rautaldhar section has also been damaged.

Lambgaon - Pratapnagar Section

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	B	Shop of Sri Balkrishna in Thauldhar village	2	Bulging and open joints in the walls.
2	B	Shops of Sri Khush Ram Kirti Ram, Bachan Singh Thalwal (Pradhan) Budhi Ram, in Mazav village	2	Large open joints and bulging of end walls.
3	C	House of Sri Ganga Singh in Mazev market	2	Deep cracks and opening of construction joints.
4	C	Pratapnagar Maharaja Palace complex	2	Fall of plaster at the contact of wall and roof, deep open vertical cracks in walls and considerable opening of construction joints.

Bhilanganga Valley

Tehri-Ghansali Section

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	B	Maharaja's Rang Mahal, Simlasu on the left bank of Bhilangana.	2	Large deep vertical cracks in walls, fall of plaster.
2	B	House on the road side Gadolia	2	Large deep vertical cracks in walls.
3	A	Asena village	4	Bulging and partial collapse
4	B	Asena village	2	Subvertical deep cracks on the walls and opening of construction joints.
5	C	Asena village	1	Fine cracks in the walls.

(Cont.)

(Cont.)

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
6	A	Ghansali market	4	Bulging, cracks and partial collapse of walls.
7	B	Forest building on the right bank of Bhilangana, opposite Ghansali town	4	Partial collapse of walls and deep cracks.
8	C	3 storeyed hotel in Ghansali market	1	Fine cracks in the walls.

i) As reported by people, in the area the ground motion was in N70°E-S70W° direction

ii) As reported by the villagers, the discharge of springs in Tipri village has increased appreciably, after the quake.

iii) Rolled rock blocks of quartzites, were seen at several places on the road, between Pilkhi and Ghansali village on 21st October, 1991.

iv) It was informed at Ghansali that the ground motion during the quake was strong enough to displace house hold articles.

Ghansali-Ghuttu Section

<u>Left Bank of River Bhilangana</u>

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	A	Houses in Phalenda village	4	Partial collapse of houses
2	B	Houses in Phalenda village	3	Large deep cracks and bulging of walls.
3	C	Houses in Phalenda village	2	Fall of plaster and cracks in walls.
4	A	Houses of Balbir Singh and Jagat Singh	5	Total collapse of most of the houses.
5	B	Houses of Sri Sakal Singh, Thayli village	5	Total collapse of two storeyed houses - resulting in nine deaths.
6	C	Primary School Thayli village (alignment N55°E-S55°W), 1991 - construction	2	Cracks in walls and displacement at the contact of roof and walls. Besides, some other houses have also developed subvertical and horizontal cracks.
7	A	House of Shri Devendra Datt, village Koti	4	Partial collapse in many buildings, some loose cohesion.
8	B	House of Sri Jwala Prashad	3 to 4	Large deep cracks on walls, partial collapse on end walls. NB Similar damages have also been reported from village Jakh, Dang-Khasethi, Andrath, Gawari and Bethi.

Right Bank of River Bhilangana

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
9	A	Tea shop of Sri Tara Singh Rawat, village Pokhar on the road side.	4	Partial collapse of walls.
10	B	Forest post at village Pokhar.	3to4	Bulging, numerous deep cracks and partial collapse of walls. Trend of ground motion reported as N-S
11	A	Govt. Inter College building, Dhopardhar (Dhopardhar)	5	Labs and two other buildings totally collapsed. Numerous cracks were noticed on the floor of the house.
12	B	Govt. Inter College main building, Dhopardhar.	3	Large, deep cracks and bulging in walls, fall of plaster. Cracks developed on the floor of the house. Reported ground motion in N30°E-S30°W direction
13	C	Three storeyed house of Sri Devanand Semwal (const. 1982)	2	Deep cracks on the wall opening of construction joints.
14	A	Saraswati Sishu Mandir building, Ghuttu.	3to4	Large deep, seethrough cracks, bulging and partial collapse of wall. Direction of bulging being towards due east.
15	C	Newly constructed Garhwal Mandal Tourist Lodge, Ghuttu.	2	Fine cracks on the walls and opening of construction joints.
	C	Houses of S/Sri Maheshwar Prashad, Surat Singh Kandari	2	These double storeyed houses have developed fine cracks.

i) Rock slides in quartzites, on the road section have been observed at village Phalenda, Thayli, upstream of Koti-village on the left bank and at several places between Phokhar and Ghuttu, on the right bank of river Bhilangana.

ii) At about 7km stone on Ghansali-Thayli open crack (0.5 to 2.5 cm wide and +10m length) trending N65°W-S65°E oblique to the road, has been observed.

iii) As reported by persons from Garhwal Jal Sansthan, Water tanks and pipelines have got damaged in villages Hulanakhal (Jakholi block), Thatti and Domna (Bhilanagana block).

iv) Deokhari, Kharsoli and Devlang, located upstream of Ghuttu, have suffered relatively more damages, as reported.

JAKH

Jakh village is located on left bank hill slopes of Ola Gad, a tributary of Bhilangana, at about 1400m elevation. The village is located on moderately sloping valley sides with overburden comprising slope wash material. The village is fairly large one with about 200 houses. Most of the houses in the village are Kutcha houses constructed in mud stone masonry with mud plaster and slate roofs. A few houses have been provided with cement sand plaster on walls.

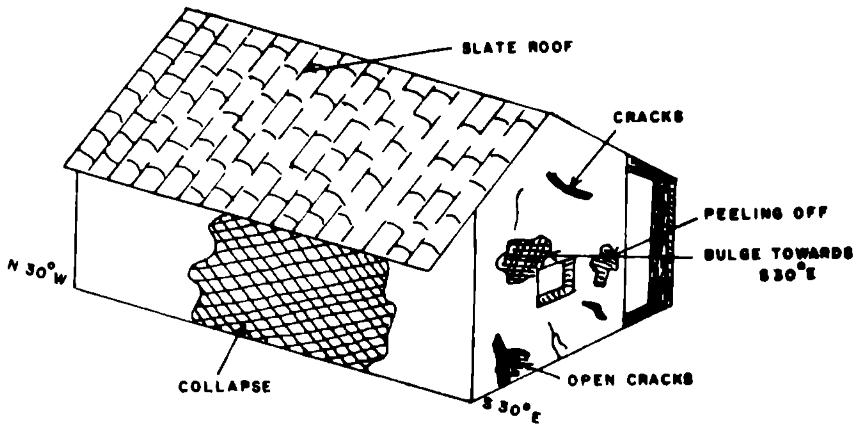


Fig. 25 : DAMAGE OF KUTCHA HOUSE, JAKH

Out of 200 houses in the village, 28 houses are reported to have suffered damage in the form of cracks in the walls and six of them have suffered wall collapses.

Open cracks with openings upto 3.0cm were observed on southwestern walls of houses with long walls aligned in NW-SE direction (Fig.25). In case of Kutcha houses aligned in the same direction, peeling off of plaster and hair fine cracks were observed on inner partition walls. But damage appeared to be relatively more on southeastern and southwestern walls compared to the northern walls. Similarly, in case of mud stone masonry houses with their long walls aligned in E-W direction, bulging was noticed on southern wall. Cracks were noticed on southern walls of about 90% houses but these were just hair fine cracks. Open cracks were observed in 60% of such houses. Walls collapses were observed in very old houses. In one case with long wall aligned in N30°W-S30°E direction, partial collapse was suffered by SW wall and open cracks with bulge towards S30°E by southeastern wall.

In this case collapses are relatively more on western and S-W walls and cracks on southern or SE walls depending on orientation of building. But damages involving collapses and open cracks are confined to Kutcha houses which are very old.

Balganga Valley

Silyara-Chamiyala-Budhakedar-Agar-Section

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	A	House in Silyara village.	4to5	Near total collapse of many houses. Others have developed deep open cracks.
2	B	House in Silyara village and market.	3	Deep cracks, opening of construction joints, bulging of end walls towards N10°E and S10°W.
3	C	House in Silyara market.	1	Fine cracks in the buildings.
4	A	House of S/Sri Sunder Lal, Jeet Singh and Bachan Singh, Chamiyala village.	5	Near total collapse of many houses, near the river. Others have developed numerous cracks with opening 5 to 10cm. In house of Sri Bachan Singh bulging of walls (5-8cm) has been recorded.
5	B	Houses in Chamiyala market.	2to3	Deep open cracks, and opening of construction joints.
6	A	Budhakedar village.	3to4	Gaps in walls, loss of cohesion and partial collapse of buildings.
7	B	Tea shop near the bridge, Budhakedar.	2to3	Large open cracks, fall of plaster.
8	C	Two storeyed shop of village Pradhan near the bridge.	2	Fine cracks in walls and minor opening at the construction joint.
9	A	House of Chandan Singh Negi, Village Agar.	4to5	Near total collapse of second floor of two storeyed building aligned in N20°W-S20°E. On the ground floor deep open cracks and tilting of door frame in S30°E direction. Deep open (upto 2cm) cracks observed along the length of ground floor.
10	B	House of S/Sri Govind Singh and Kundan Singh, Village Agar.	4	Partial collapse of end wall towards S88°E direction. bulging of end walls due to large deep cracks in the walls of ground floor. Cracks on the courtyard (length + 5m, width 5mm) have been recorded. trending in N30°E-S30°E. Two death reported from this house.
11	C	Shop near the temple, village Agar.	2	Fine vertical and horizontal cracks noticed in the temple and shop building aligned N55°E-S55°W. Opening and displacement of construction joint, both at roof level and side pillars.

i) In Silyara and Chamiyala villages, which are perched on large alluvial fans, the intensity of damage is relatively more in the vicinity of Balganga river. Deaths reported from these village is 2 and 4, respectively.

ii) Between Silyara and Budakedar, road blocked due to fall and dislodgement of rock blocks at several locations.

iii) On the slopes above Agar village, open cracks (1–30m wide, 7.25m length) trending N60°E–S60W° to E–W are recorded in old slide debris. Besides, deep local cavities and cracks have developed in the overburden mass, possibly due to settlement of matrix, attendent to the shaking effect, induced by ground motion.

iv) North of Agar village, near the hill top massive slides have been generated following the earthquake on October 20th. The blocks have even rolled down to Agar village, as a result, about hundred trees have been uprooted.

Thati Kuthur (Budha Kedar)–Kot Sector

Budha Kedar

The village of Thati Kuthur is located at the confluence of Bal Ganga and Brahma Ganga rivers which are the two major tributaries of Bhilangana river. The effect of the 20th earthquake was distinctly felt along the Bal Ganga valley. The villages, surveyed along the river course include, Thati Kuthur; Dalla, Dadori, Bishan and Kot.

The ancient temple of Budha Kedar has suffered only minor damages. The thick mud masonry walls have been provided with evenly spaced horizontal timber beams serving as reinforcements. The temple has slate roofing. The other poor constructions of the village have developed wide open shear cracks (Photo 80). There has been bulging and partial collapses of thick masonry walls towards NE direction. Some collapses have also occurred in NNW direction.

Damages of slightly higher intensity than at Budha Kedar have been obsered at Dalla and Dodori villages.

The next village on the right bank of Balganga river is Bishan. The village is located at the foot of a hill over debris slopes. It has a population of about 300 persons who reside in 64 houses. A few people were reported to be injured by the 20th October earthquake.

The houses are constructed of thick masonry walls with mud mortar, supporting slate roofing. Some new constructions with RCC slabs, beams and columns have also come up. In general, the houses are two storeyed and the quality of construction is good.

Shear cracks, some of which are open, have developed in most of the type-A houses and in some of type-B constructions. Some walls at upper storey, particularly of the gable portion, have collapsed partially towards west or south west quadrant. It is reported that the area has been experiencing mild after shocks ever since 20th October as a result of which the cracks have widened.

Kot

The village is located on the right bank of Balganga river southeast of epicentral tract. The dwellings and cultivated fields lie at two different levels. The lower level is occupied by alluvial terraces and the upper one by slope debris material. The earthquake of 20th October took a toll of 5 human lives.

The upper level of the village has about 70 houses. Here the quality of construction of type A and B structures is good and well dressed masonry blocks set in mud mortar with slate roofing have been used. Shear cracks with opening of few mm to few centimetres have appeared in most of the walls of these houses.

A cluster of 35 houses, located at the eastern end of the village at a lower elevation over a saddle have been constructed of poor quality material. Maximum damage and loss of life have occurred at this location. Partial collapses of mud-masonry walls and roofs, particularly of the upper floor is seen in most of the houses. Collapse of all the walls (Grade 4) has been recorded in three houses.

Agonda

Agonda village is located on left bank terraces of Dharamganga river at an altitude of about 1700m. It is located southeast of the epicentral tract, just east of Koti and almost north of Budha Kedar. Most of the houses in the village

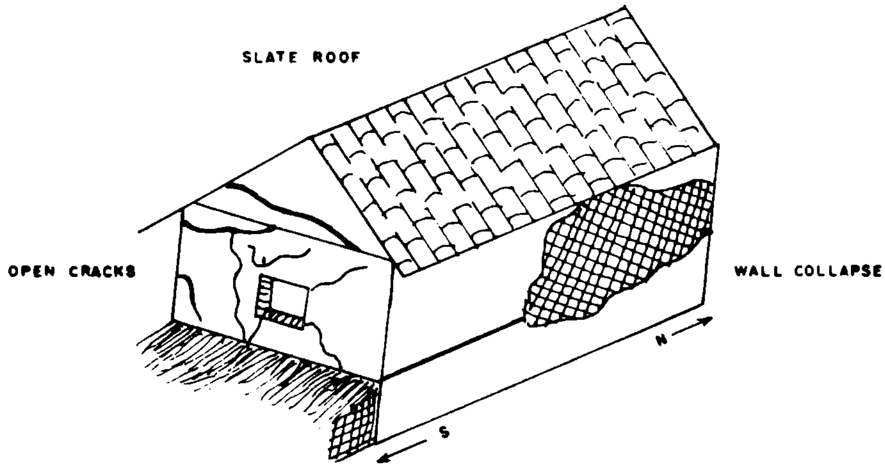


Fig.26: DAMAGE OF N-S ALIGNED KUTCHHA HOUSE—AGONDA

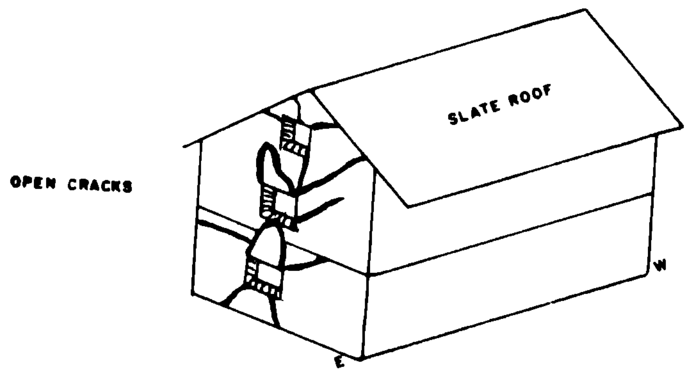


Fig.27: DAMAGE OF E-W ALIGNED KUTCHHA HOUSE—AGONDA

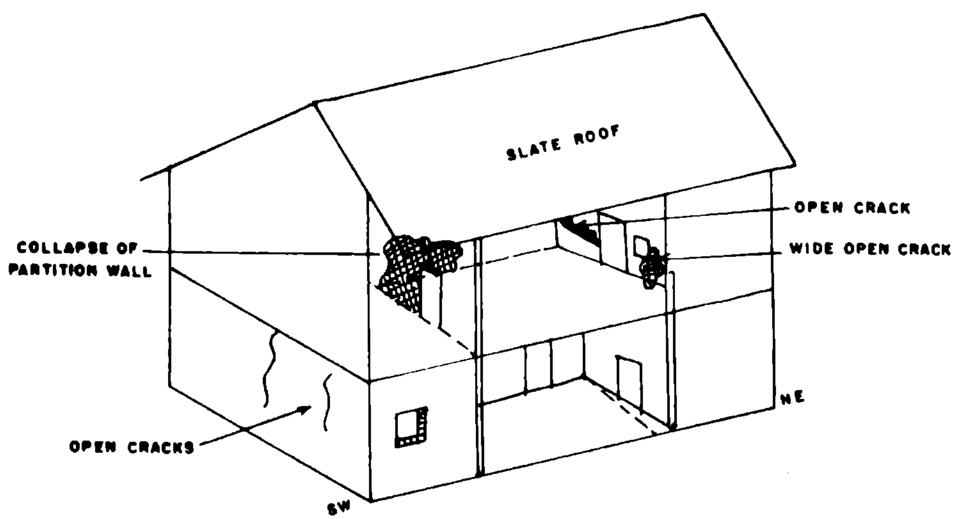


Fig.28: DAMAGE OF KUTCHHA HOUSE —AGONDA

are mud stone masonry constructions with slate roofs (Figs.26,27&28) and a few masonry houses with cement sand plaster and GI sheet roofs. About 80% of the houses have suffered damages ranging from cracks in walls to wall collapses.

In case of mud stone masonry houses with slate roofs and long walls aligned in N-S direction, open shear cracks (upto 5mm opening) have developed on the southern short walls (aligned E-W) and collapses have occurred in eastern long walls. These collapses are partial and mostly confined to upper storey and upper portions of ground floor. Partition walls have also collapsed in some cases. Houses with long walls aligned in E-W direction, have withstood the shock. However, in E-W aligned side walls, particularly the eastern ends have suffered damage in the form of cracks which extend from gable portion to the base of the building. In some cases the cracks are more intensely developed near the openings in the walls like windows etc. But long walls in such cases have escaped without any damage. The protruding portions like stairs have suffered more damage in form of cracks when located on southern side of E-W aligned houses. Cracks were also observed on northern walls of similarly aligned houses in few cases.

Similar damage is suffered by the houses with walls having cement sand plaster. In case of houses with long axis aligned in NE-SW direction, the outer walls have escaped with cracks but partition walls aligned in NW-SE direction have suffered wide open cracks and collapses.

In case of school building which is a mud stone masonry building with GI sheet roof and long wall aligned in almost N-S direction, there are open cracks on western walls and minor collapses in pillars located on western side. The cracks are open upto 2.0cm. The southern wall (aligned E-W) also shows slight bulging towards south. The partition walls aligned in E-W direction failed at upper levels and collapsed.

Nailchami Valley

Ghansali-Chirbatia Section

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
1	A	Houses in village Sakhniyali on either bank of Nailchami gad.	3	Large deep cracks, partial collapse of walls.
2	B	Shop of Shri Ram Chandra Singh Negi, village Jakhniyali.	2	Sub vertical cracks. Minor bulging at the contact of walls.
3	C	Houses of Shri Ram Chandra Singh	2	Fine cracks in walls, fall of plaster.

(Cont.)

(Cont.)

Sl. No.	Type of Structure	Location	Effects/ damages	Remarks
4	A	House of Shri Govardhan Prasad, village Gaurya.	3to4	Near total collapse of walls. One injury reported from this house. Deep vertical and horizontal cracks reported in 70 houses in Gaurya village.
5	A	House of Shri Hukam Singh in Muyal Gaon	4	Near total collapse of house.
6	A	Houses in Oradhar village (Gram Shabha Thalla).	4	Collapse of part of 31 houses and deep open cracks noticed in about 50 houses. 4 deaths reported.
7	C	Junior High School building, village Tilrana.	3	Deep open diagonal cracks in walls and opening of construction joints at the contact of walls and roof.
8	C	Ganga Yamuna Gramien Bank, Thalla.	2	Vertical and horizontal cracks on walls.
9	A	Houses in Holta village.	4to5	As reported by Sri Jagat Singh Rawat, about 25 houses got collapsed and vertical and horizontal cracks developed in about 150 houses.
10	A	Houses in Budna village.	3	About 70 houses have developed deep open cracks. One death reported.
11	A	Houses in Gorthi village.	4to5	About 60 houses have partially collapsed and in many other houses vertical and diagonal cracks recorded. 3 deaths and 2 injuries reported.
12	B	Govt. Rest House in village Gorthi.	2	Open cracks and fall of plaster.
13	A	Houses in Thatti village.	4to5	In about 45 houses partial to total collapse, open cracks developed in about 200 houses. Three deaths and one injury reported.
14	B	Primary School building in Thatti village.	4to5	Near total collapse of the building.
15	A	House of Shri Shanker Singh in Badiyar gaon. (near the road side)	3	Deep open cracks, bulging and partial collapse of wall.
16	B	House of Shri Roop Singh, Badiyar gaon (near the road side).	3	Diagonal cracks and damage to the floor of this three storeyed house.
17	A	Houses on either side of the highway in Chirbatiya.	3to4	Partial collapse in 22 houses and deep open cracks in walls of 27 houses.
18	B	Shops on the main road, Chirbatiya.	2to3	Large deep cracks and minor bulging.
19	C	House of Shri Kunwar Kalntura and Prem Singh Mehra, in Chirbatiya.	3	Deep open diagonal cracks dipping 40°/S70W° on inner and outer walls. Opening of construction joint tilting of roof.

i) General feeling of the people in Ghansali-Chirbatia area is that the ground motion was in E-W direction.

ii) Increase in the discharge of water springs has been reported in Muyal gaon and Titrana villages, where as in Gaurya and NE of Holta village appreciable decrease in Spring discharge is reported.

iii) Cracks on the main road measuring +5m in length and 5-10cm width, have been recorded near Gorthi village. Open crack (width 2cm) extending for about half km. has been reported in Chirbitiya village, on the overburden mass.

iv) Minor damages to water pipelines, noticed in Chirbatia and Muyalgaon, mainly because of rock falls.

v) Fresh land slips and rock falls are reported from areas near Gorthi, Muyalgaon and Holta.

Gorthi

The village falls in Jakholi Block of Tehri district. It is located along Tehri-Tilwara road over a ridge. Here granite gneiss is exposed in road cuttings. The dwellings and cultivated fields lie over debris mass. The village has about 120 houses with a population of 600. The 20th October earthquake took a toll of 3 human lives and caused injuries to 2 persons. Over 54 houses suffered different degrees of damage where as 7-8 houses collapsed (Photo 81 and 82).

The usual type of construction in the village is of thick mud-masonry walls with slate, RCC or GI sheet roofing. The quality of construction material is generally poor. As per the intensity scale, damages of grades 2 and 3 are evident in most of the type-A constructions with cracking and partial collapses of walls and caving of roof in a few.

Two buildings of the village have been analysed in detail. The first building has its side walls aligned in E-W direction and the long walls in N-S direction (Fig.29). The southern part of the house has RCC slab as roofing where as the northern portion has the conventional slate roofing. The side wall has developed very prominent shear cracks some of which have wide openings (Photo 83). The masonry at the slab junction has collapsed at places. The long wall has suffered partial collapse towards the western side. The south western corner of the building shows partial collapse of the outside face of the masonry wall under tensional force.

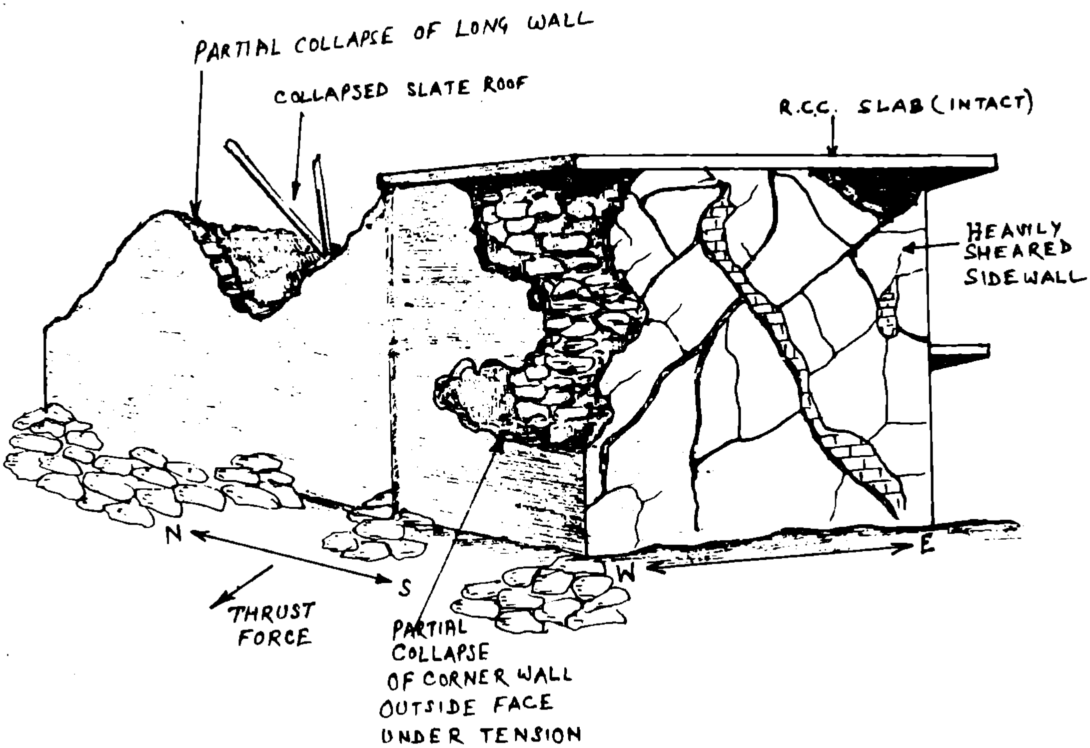


Fig. 29 : PATTERNS OF DAMAGE TO A HOUSE IN GORTHI VILLAGE TEHRI DISTRICT, (SKETCH BY P. PANDE).

The Basic Pathshala Building has also suffered considerable damage. The poorly constructed masonry walls have partially collapsed. The bottom portion of two of the masonry pillars supporting the varandah have been shifted by about 1 to 2cm towards N20°E direction.

Jakholi

Jakholi village is located on the southwestern and eastern slopes of a ridge trending N30°W-S30°E at an altitude of about 1500m. The Government buildings like Block offices and residences of Block officials have suffered considerable damages where as houses and buildings located on southwestern slopes of this ridge have escaped with minor damages like hair line cracks and peeling off of plaster in upper portions.

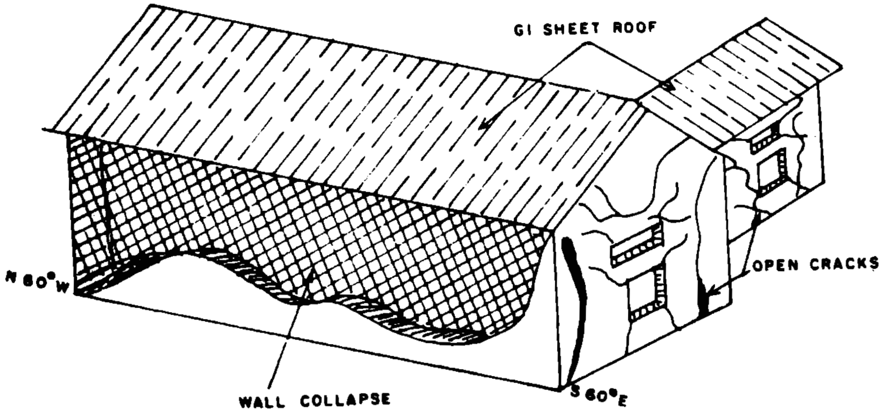


Fig.30: VETERINARY HOSPITAL - JAKHOLI

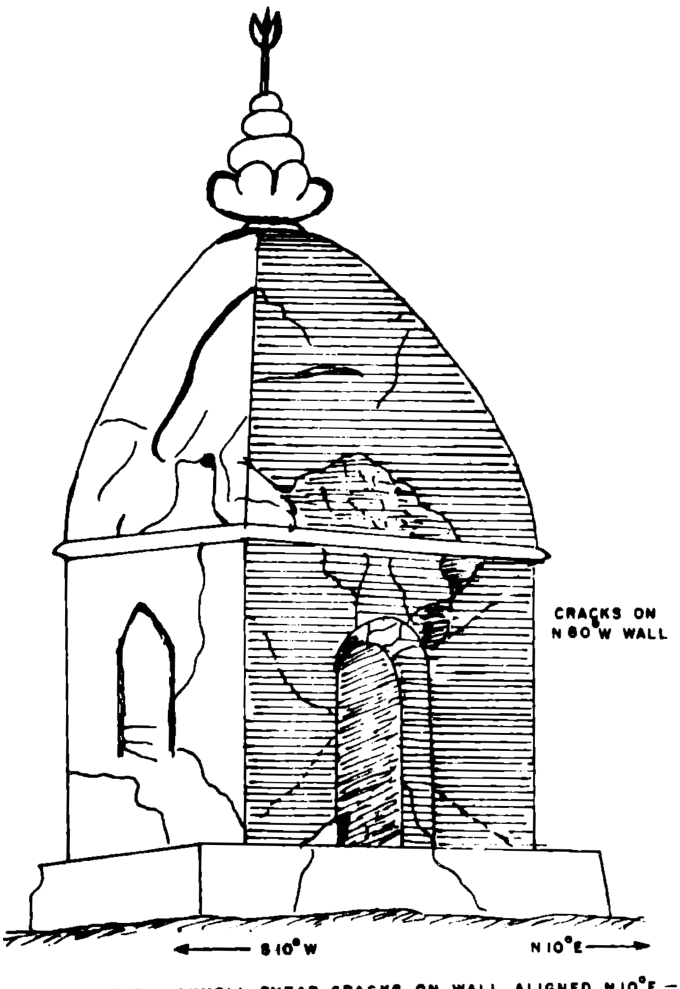


Fig. 31: SHIV TEMPLE, JAKHOLI. SHEAR CRACKS ON WALL ALIGNED N 10°E - S 10°W.
KALASHA SHIFTED TOWARDS N 30°E BY 2 CM.

The office buildings like Veterinary Hospital, residence of Veterinary Doctor, residence of BDO and a few other residential Quarters located on ridge line show heavy damages, including shear cracks and collapses of walls (Fig.30) (Photo 84, 85).

The Veterinary Hospital, a mud stone masonry building with GI sheet roof aligned in N60°W-S60°E direction; the S-Western end wall including the partition walls have completely collapsed (Photo 86). The southeastern end of this building has developed open cracks in wall corners which run almost from top to bottom. The opening at top is of the order of 5.0cm and narrows down towards bottom. Shear cracks were also observed to have developed on this wall. The cracks were concentrated more towards the openings like windows and ventilators. This wall also indicated slight bulge towards SE in the gable portion. An anteroom, projecting out of the main building also indicated similar damage on SE wall. The residence of BDO has been razed to ground and Chimney of one house has been thrown towards NE direction.

A temple located NW of block offices on top of the same ridge has withstood the shock without collapse but prominent shear cracks have developed on SE wall and Shikhar portion (Fig.3). The cracks are wide open and extend down to the base. The kalash' of the temple is shifted by 2cm. towards NE (Fig.31).

In Government Inter College, a two storey building, aligned in N30°W-S30°E direction, the damage comprises appearence of fine cracks and peeling off of plaster on SE wall and in the gable portion of first floor. The examination of damage of buildings on top of the ridge indicates damages as compared with those lower down in the same village.

YAMUNA VALLEY

The Yamuna valley, extending for a length of over 240km between Hanuman Chatti in the north east and Badshahi Bag in the South west was surveyed in detail for assessing the effect of 20th October Uttarkashi earthquake. Traverses were undertaken in Haripur-Chakrata and Naogaon road sectors and more than 60 localities visited besides to interviewing a number of persons. The description of different sectors is given in the following paragraphs.

Hanuman Chatti–Kharadi Sector

The villages covered in this sector include Hanuman Chatti, Rana, Saina Chatti, Wazri. Kuthnor and Kharadi which are located on the banks of Yamuna river, having a NE–SW course. Hanuman Chatti is the northern most village located at an altitude of 2400m. It is the motor road terminus for Yamunotri glacier and has only limited number of buildings. In the early hours of 20th October, the inmates felt three distinct shocks. Almost everybody ran out in utter panic as the tremors lingered for over 45 seconds with a rumbling sound. The direction of wave propagation was reported as E–W. The houses, constructed, in general, of masonry walls with mud mortar have developed minor cracks. The Chauhan Tourist Hotel, with its long wall aligned in N60°W–S60°E direction is a B Type structure. The walls of the building are constructed of brick and cement mortar. The ceiling is supported over columns and RCC beams. The damage to the building includes appearance of fine shear cracks on the side walls trending N30°E–S30°W and rupture of one of the columns near the beam junction. In the Anand Bhawan Hotel, the plaster at places has peeled out and the construction joints have opened up. People have reported rock falls from the slopes of Durbil village, located on the right bank of Yamuna.

In other villages of the sector, the damages to civil structures include appearance of cracks, bulges, peeling of plaster and collapse, tilt of walls and columns (Photo 87). Wazri, located on the right bank of Yamuna seems to be the most affected place with nearly 20% type A constructions showing partial collapse of masonry walls. Low intensity but perceptible after shocks have been reported to be occurring in the area frequently.

Gangani Sector

The effect of Uttarkashi earthquake in the Yamuna valley has been most conspicuous in this sector. In the Gangani village, located 8km. NE of Barkot along the road to Hanuman Chatti at an altitude of 1300m, most of the houses belong to type A category of thick mud masonry walls and cement plaster. The sloping ground comprises debris and fluvial terraces. Almost 20% of the houses have been damaged to a great extent. Partial collapses of roofs and walls and development of shear cracks of varying dimensions are common. Maximum damage has been observed in buildings founded on unconsolidated sediments at the edges of steep slopes. Landslides have either been initiated or reactivated around Gangani in fluvial terraces and loose deposits. The extent of damages indicates that the intensity of ground motions would have been VII on MSK scale.

A few of the type B structures are located by the side of the road. The space for construction of these houses has been won by constructing retaining walls. Many of these houses have collapsed due to failure of retaining walls. (Photo 88). A two storey house constructed of mud-masonry walls with wood beams and columns shows complete collapse of first floor side wall trending E-W (Photo 89 and 90). An old construction aligned in N-S direction displays conspicuous tilt of about 15° towards east of the eastern end long wall. The collapse of the partition walls of this house has caused injuries to few persons (Photo 91). A few conventional houses constructed at the lower terrace in this village also show partial collapse of the walls and caving in of the roof (Photo 92). In Nandgaon and Mashalgaon, comprising some 300 type-A structures, a total of 12 houses show major collapses of thick mud masonry walls.

An analysis of damage pattern in a house of Gangani village has been made. The type-A structure with long wall trending N35°E-S35°W has suffered partial collapses and bulging. Open shear cracks and peeling of plaster are seen in the long wall. It appears that the ground oscillations were in NE-SW direction and the wave propagation was from SE to NW.

Raster-Sarigad Sector

In this sector, a total of 10 villages have been surveyed. Barkot is located on the left bank of Yamuna at an altitude of 1250m. Here the ground comprises alluvial terraces and debris slopes. The village felt 3-4 tremors and ran out of doors for safety. The extent of damage spreads to almost all the buildings in some form or the other.

The single storey PWD Rest House building at Barkot is aligned in N60°E-S60°W. It has masonry walls with RCC roof. Fine shear cracks have appeared in the eastern side long wall. A few multistorey buildings of RCC frames showed deep cracks. These structures are located on fairly steep slopes in overburden material with pre-existing valley ward dipping fissures. The damage to these buildings, therefore, appears to be due to foundation failure.

In other villages of this sector, development of shear cracks is common on most of the masonry walls. In some cases bulging or partial collapses of walls and roofs is evident.

A girder bridge, constructed in June, 1990 across Pathar gad is located about 7 km from Barkot. The right abutment approach road junction is marked by the development of a fine N35°W-S35°E trending ground fissure. The right abutment retaining wall is also found damaged.

In Chami village, a house trending in N20°W-S20°E direction has partially collapsed. The house is a double storey structure with thick mud masonry walls and slate roofing. The northern portion has suffered the damage whereas the southern part remains unaffected (Photo 93).

Sarigad - Badshahi Bag Sector

In this sector, extending from Sarigad in the north east to Badshahibag in the south west, a total of 28 villages were surveyed. Majority of the houses observed were of type-B. From Sarigad to Barwala, the buildings mostly stood on sloping ground on loose or compact soil. Downstream of Sarigad damage was found to be of minor nature. The type of damage was in the form of thin cracks open upto 2mm. Mostly the pre-existing fine cracks, specially along the construction joints were found to have opened. At times it became difficult to establish the relationship of cracks with the earthquake.

The movement direction was found to be N40°W-S40°E to N65°W-S65°E, N10°E-S10°W to N30°E0S30°W and N60°E-S60°W to N80°E-S80°W. At Juddo area movement was reported to be felt in two directions by two different persons on ground and at first floor, viz. N20°E-S20°W and N65°W-S65°E.

The movement was reported to be accompanied by sounds resembling storm, blowing wind, starting of engine, heavy rains, running crowd, galloping horses, etc.

Naogaon-Purola Sector

This sector, including a total of 5 villages of Naogaon, Kansola, Hudoli, Chandeli and Purola extends along SSE flowing Kamola rivulet, a right bank tributary of Yamuna river. The northern most Purola town is located 20km from Barkot in a wide valley at an altitude of 1400m. The village dwellings are a cluster of pucca and semi pucca houses where the long axes are aligned mostly in NW-SE direction with some having NW-SE trend. It is observed that seven of the houses have suffered partial collapses (Photo 94). A type-B construction has developed prominent shear cracks on E-W trending side wall. The double storey office building of Executive Engineer, PWD has developed cracks. As per the intensity scale, grades 2, 3 and even 4 damages have occurred in the type-A constructions. It is note-worthy that some of the old houses constructed of masonry with wooden beam reinforcements have remained unaffected. The granaries, constructed of timber have also not suffered any damage. In Purola, the direction of movement of hanging objects was reported as N16°W–S16°E. During the earthquake, sounds resembling that of speeding automobiles, thundering, storm, etc. were described by the residents.

Haripur–Chakrata Sector

The villages surveyed in this sector include Haripur, Byas Bhud, Kalsi, Sahiya and Chakrata which are aligned in N–S direction. Along this traverse, well built, cement brick/stone and masonry houses have been noticed. Most of the houses have been founded on compact soil except a few on rocky foundations. Slight damage in form of cracks in plasters was noted in stronger houses while weakly built houses suffered cracks in walls. Partial collapses were noted in a few cases of weak (dry stone masonry or very poor & old mud masonry) houses. Some buildings escaped any damages and the movement as reported by few persons was mainly in N60°W–S60°E direction. At Chakrata, an additional movement in N30°E–S30°W direction was also reported preceding the above movement. The unusual sound during the shock were reported to be like those of moving train and strong hissing sound coming from nearby forest/hills. In Sahiya area, two mild after shocks were felt by some persons at about 6 A.M. on 20/10/91 and at about 11 A.M. on 21/10/91.

The ground surveys indicate that a narrow belt encompassing Gangani has higher earthquake intensity of VII. The surveyed area to the north of Gangani comes in intensity VI. Similarly, the area to the south of Gangani upto Damta can be included in intensity VI.

DOON VALLEY

The Uttarkashi earthquake of 20th October, 1991 had a conspicuous effect in the Doon valley which becomes evident from the damage pattern survey and interview of number of persons. A summary of locality wise observations is given in the following paragraphs.

Rajpur–Khera–Kulhan Sector

The villages covered in this sector are located in the northern fringe of the valley. They include Rajpur, Khera, Kuthalgate, Sanola, Nagal, Kulhan, Gujrara and Jakhan. The Khera–Gopiwala hamlet consisting of 14 houses show considerable damages to almost 50% of the structures. Gaping cracks with opening of 0.1cm to 4cm, partial collapse of masonry walls and peeling of plaster are common in type A structures. However, no perceivable damage was noticed to well constructed houses.

The Khera village is located on a spur of a wide alluvial terrace where active erosion by two nalas has given rise to the development of steep escarpments. Such slopes have shown evidences of failure in the past. The strong ground motions related with the present earthquake appear to have accentuated the falling tendency of the critical slopes. As such a number of cracks with opening of 1cm to 6cm and length of 5m to 30m have appeared in the cultivated fields. The trend of these cracks is NE-SW and NW-SE.

An assessment of the damage pattern indicates that the shear cracks have, in general, appeared in N-S trending walls. Falling of objects like table fan, water drum, etc. and swinging of hanging pieces have been reported by most of the residents.

Raipur-Thano-Bhogpur Sector

This sector with Barkot in the east and Raipur in the west extends for about 20km length. The villages surveyed included Raipur, Thano,Bhogpur and Ranipokhari. The settlements are located over Quaternary fill deposits. In the Raipur Industrial area, well constructed multistorey buildings have developed extensive cracks in the walls and along construction joints. Bulging and buckling of face stones have been observed in one of the buildings.

In Thano, Bhogpur and Ranipokhari. areas, some of the poorly constructed houses have suffered partial collapse. The direction of propagation of waves is estimated to be E-W or NW-SE. Reactivation of old slides has taken place in the area.

Dobhri-Sorna-Langha Sector

The sector lies in the western part of Doon valley and spreads all along the foot of the Outer Himalayas. The area consists of alluvial fan deposits and Recent fills. Partial collapses of few houses and development of shear cracks and bulging of masonry walls have been witnessed in a number of cases.

Doiwala-Joligrant-Sherpur Sector

The sector is located in the central part of Doon valley with the ground comprising unconsolidated gravels, boulders and silt of Quaternary age (Doon Gravels). The damages to structures include appearence of fine cracks in walls and peeling of plaster. However, no collapse has occurred anywhere in this sector which is indicative of a lesser intensity of ground accelerations as compared with that of Raipur and Rajpur sectors.

Clementown-Subhash Nagar-Dat Sector

The area lies in the southern part of the valley along Saharanpur road. The damages to type A and B buildings includes cracks ranging from 0.1 to 3cm in thickness. The foundation material comprises Doon Gravels with fairly thick layers of silt and clay.

Arkadia Tea Estate-Prem Nagar-Sahaspur

This sector, comprising the western part of Doon valley shows varied earthquake intensity patterns. In the Arkadia Tea Estate the buildings have developed hair line to open cracks (maximum opening 6cm). In the adjoining Prem Nagar locality no distinct damage is in evidence. Here, even poorly constructed type A structures do not show any appreciable damage.

IIP Complex-Jogiwala-Harrawala Sector

The sector is located in the central part of Doon valley. Here the damages to civil structures includes fine cracks in walls. At Indian Institute of Petrolium (IIP), Mohakampur, an E-W trending Kuchha wall has tilted towards south. This, to some extent gives the direction of wave propagation as E-W.

Dehradun Town

Forest Research Institute Building is a double storey structure with its longer axis trending E-W (Photo 95). The major crack in this building has developed along E-W direction all along the junction of the porches with that of the main building. The width of the crack varies between 1.5 and 2.0 cms. Similarly on the upper storey, the floor of the E-W running varandah has got separated by a few mm from the walls, and the brick made arches of the varandah have developed prominent cracks trending E-W (Photo 96). It has been noticed that the arches towards the western half of the varandah have suffered more damage as is also evident from the dislodgement of bricks from the lower portions of these arches (Photo 97). Similar damages are also seen in the brick made arches of N-S trending varandahs. Several hair fine and surficial cracks are seen on the ceiling of the convocation Hall, except for a N-S trending major vertical crack right from the top (roof margin of the building) to the bottom of its northern outer wall.

The fall of the thick plasters from the ceiling and dislodgement of a few bricks has also been noticed from the areas of construction joints between the porches and the main building.

Hilton Hotel is located on Haridwar Road, near Araghar. The N25°E-S25°W outer wall has developed cross-cracks, one of which trends N60°W-S60°E with a dip of 50° towards N30°E; whereas the other one dips towards S30°W at an angle of 55°. The continuity of these cracks through the wall could not be ascertained for want of approach to the other side.

Hair fine cracks were noticed in a wall trending N75°E-S75°W at the very entrance to the Reception Hall (Photo 98). A 0.5cm wide crack along construction joint of the above wall with that of the ceiling (a part of the porch) is noticed. Another wall just opposite the reception counter has developed a crack trending N80°E-S80°W (same as the trend of the wall) with a width of 0.2 cm to 1.0cm. The upper block with reference to this crack has shifted or displaced towards south, relative to the lower block, by about 3-4mm. Several small sympathetic fractures (very similar to feather cracks) were also observed which are dipping towards N80°E, joining the main fracture along which the displacement has taken place. The width of this main crack is increasing upto 1cm towards N80°E and is minimum towards the opposite end (S80°W). A wall which trends N15°W-S15°E and joins the above mentioned wall has developed cris-cross cracks, one of which dips towards N18°W and the other towards S18°E with same trend i.e. N72°E-S72°W and dips at 45°. The staircase in the basement chamber has developed a crack trending N-S and dipping towards E. In the kitchen hall of this basement, southern block of the floor has subsided by 1.0cm along N65°W-S65°E trending glass-lining of the mosaic floor.

National Institute for Visually Handicapped (NIVH) building is situated on the Rajpur Road some 4.5 km. NNE of the Clock-Tower. Cracks have appeared in the building in the upper floor rooms.

A crack in the Director's Room and Seminar Hall, trending N15°W-15°E (same trend as that of wall) has developed along the construction joint of wall and ceiling. The width of this crack is between 5-10mm. Further, the southern half of the N-S trending beam has tilted downwards, and the southern wall of the room has developed an E-W trending hair fine crack. Two construction joint cracks trending E-W and N-S have developed between the wall and ceiling of the seminar Hall also. A N15°W-S15°E trending crack along the joint of ceiling of Establishment Section and western wall of E-W extending Hall was noticed. Almost all the vertical pillars have developed hair fine cracks. North-South extending beams of the northern half (of the E-W trending Hall) have developed cracks trending N80°E-S80°W and dipping 70° towards S10°E. However, these cracks are strictly confined to the beams only and are not traversing through the intervening portions of the ceiling between two beams. According to the staff members, a wall-clock hanging along a N-S trending wall was seen having been shifted towards South by about 15° from its main position.

The Account Section Hall is trending in E-W direction. Two sets of cracks, trending in N-S and E-W directions, with a width of 1mm are noticed in the ceiling. Almost all the beams of the entire Hall have developed hair fine to 1mm wide small cracks which are dipping towards North in the Southern half portion of the ceiling and towards south in the northern half portion of the ceiling, at an angle of 60-65°. Besides, several vertical pillars of the Hall, have developed randomly oriented hair fine cracks.

The East-West trending old boundary walls of Dayanand Brijendra Swaroop (DBS) Postgraduate College and Dayanand Anglo Vedic DAV (PG) College have collapsed due to tremors. The debris was seen having fallen towards North.

Das Motors Building on Railway Station Road near Laxmi Cinema Hall is a double storey structure with its roof and pillars built up of RCC. Vertical cracks trending N15°E-S15°W were seen in northern wall of the hall on the ground floor. The other two sets of the cross-cracks, in the same wall, are dipping at 45°-60° towards N65°W and S65°E with a strike direction of N25°E-S25°W.

The cracks on the first floor, along the construction joint of the RCC ceiling and non-RCC wall are trending N80°W-S80°E (same as the trend of the wall).

The glass panes of the windows on the ground floor as well as on the first floor have been broken due to the vibration. Breakage of glass panes, however, has not been frequent in the other buildings surveyed.

Hotel Drona, a multistorey building is located very near the Roadways Bus Stand. At the Western end of the hotel a vertical crack, (most probably along some construction joint) of 1 to 3mm width continuing from ground floor to top floor was observed, however the width of this construction-joint crack is found increasing towards the top where it has become 1.0cm wide. Similarly, the spacing along the joint of floors of the E-W running Varandah and the southern wall has increased by 1.0 to 2.00 mm. Also, a few random cracks were noticed on the staircase towards the western end of the hotel. The fall and chipping out of the plasters from the walls and construction joint areas is also reported from the same end.

A minor hair fine crack of zig-zag nature roughly of N35°E-S35°W trend has also been noticed in the conference room at the second floor of the hotel.

The St. Francis Church is located near the main Branch of SBI on Convent Road. Two sets of cracks, trending NW-SE and NE-SW were noticed in the false ceiling of the Prayer Hall. A vertical crack trending NW-SE was recorded in a wall (trending N35°E-S35°W) in which is set an idol of Christ. This crack is penetrating across the whole thickness of the wall. In the same wall is set a small almirah/wardrobe, which was seen as having been partially detached towards NW due to the tremors. A horizontal crack along the construction joint of the ceiling and N35°E-S35°W trending wall has also been observed.

Aketa Hotel/LIC Office is located on Rajpur Road, approximately 3.0 km. NNE of Clock Tower. No major cracks were noticed on the ground floor, however, a crack in the vicinity of the reception counter had been repaired as per the version of the hotel-workers. Another crack which has developed in a rectangular decorative stone piece (set in a wall) is seen dipping towards N25°E-S25°W. Similarly a minor crack of approximately 1.0mm width was seen striking E-W, and dipping towards North at an angle of 65°, in a wall of the ground floor.

Further, several rooms on the first and second floor have developed cracks of various attitudes.

In the first floor of Accounts Section, following two sets of cracks were seen in this room:

a) North-South trending wall has developed a horizontal crack of same trend as that of the wall.

b) Another crack in the wall is trending N-S, with 30° dip towards East.

The floor (of the second storey) has developed a minor vertical crack, which is trending N55°E-S55°W. Lift of the hotel was found out of order and a wardrobe toppled and fell down on the floor following the earthquake - as reported by the workers of the hotel.

The time of the earthquake in Dehra Dun as reported by majority of the people was same as that broadcast by All India Radio and Doordarshan the next morning i.e. between 2.50 AM to 3.00 A.M. The quake of this intensity caused severe panic/fear amongst the people. Almost all were awakened and many of them remained outside their houses till the break of the dawn and a considerable number of persons even could not have a sound sleep in the subsequent days mainly due to fear psychosis regarding the possible recurrence of the earthquake. The most commonly recorded duration of the tremors was between 20 to 50 secs.

The response of persons to the direction of the movement was very unambiguous and prompt. It was E-W and N-S with only one person reporting it to be NW-SE. This N-S vibration/movement is supported by the fall of small, wooden and lighter objects of showcases either towards North or south of their original position. However, the swinging of fans and displacement of cots etc. suggest an E-W movement. Spilling over of milk, water, falling of kerosene lamp and small wardrobe, severe rattling of doors, windows, with occasional cases of breaking of window-glass panes and twisting of door-latches, falling of small torch, medicine-bottles, candle stand etc. were very commonly reported.

According to the versions of the persons residing on the second floor of houses the angular movement of the building with respect to the vertical axis of opposite buildings was of the order of at least 10-15°. The ringing of small to medium size bells of some temples was heard by pujaris/priests but the huge/giant bells of church top reportedly did not ring.

The sound of the approaching earthquake was described differently by various persons. According to some, it was a mild drumming/thumping of the ground accompanied by approaching storm and rain like sounds, typical of its own, which was never heard before. Others described the sound as that of a starting of a jeep or car, gradually rising in loudness as the quake approached.

As regards the unusual/abnormal behaviour of certain animals and birds prior to such calamities, and also which is a topic for intensive research in foreign countries with a view to using them for earthquake prediction, two typical/strange phenomena have been explained to the party. At about 12.30 A.M. (2 hours and 20 minute before the occurrence of the quake) the crows dwelling on a tree just opposite a house, suddenly started crowing and continued the activity till the observers/residents of the house slipped into sound sleep. Similarly, a few persons reported the unusual barking or wail of dogs just a few minutes or in certain cases few seconds before the havoc. However, the dogs, launched furious and continuous barking immediately after the quake was over and kept on barking for quite some time.

Another strange and enigmatic phenomenon which came to the notice of the party through the persons interviewed, was the occurrence of flash of light or sudden lightening kind of event (but without the accompaniment of the thundering sound) just before or during the quake. Some persons described this light/flash like the one at break of the dawn i.e. light-yellowish-reddish colour with dusty/hazy appearance of the sky, though nobody was able to give the specific direction of the redness of the sky. They say it was an overall redness of the sky up above.

As regards the number of shocks, by majority it was one continuous vibration starting gently and having assumed the proportions just short of spelling disaster. Only one or two persons are of the view that first it was a mild and tolerable vibration followed by a pause of 3-4 secs and then the heavy shaking stage of about 15-20 seconds or even less. Based on the above account and nature of damage, the value of isoseismal enclosing the Doon valley comes to VI on the MSK scale.

HIMACHAL PRADESH

The macroseismic investigations of this earthquake in Himachal Pradesh, Punjab and the Union Territory of Chandigarh were conducted by the officers of Punjab and Himachal Pradesh circle, Chandigarh as well as two officers from the Engineering Geology Divn.II, GSI, NR, Lucknow. The areas covered by different parties is as follows:

Party	Area Examined
Gurdev Singh	Punjab and Union Territory of Chandigarh
Gurdev Singh S.K. Hans	Eastern Himachal Pradesh bordering UP covering Sirmaur, Shimla and Kinnaur disttricts
P.M. Jalote A.K. Chowdhary	Satluj catchment
Prem Kumar N.K. Punj	Central Himachal Pradesh covering Mandi, Bilaspur and Solan districts.

The data generated by all these parties have been synthesised and utilised for extension of the isoseismals of the shock in Himachal Pradesh and Punjab.

In Himachal Pradesh the earthquake was felt by almost all the people and resulted in death of one person at Badsari in Sangla valley, Kinnaur district. About 20 houses collapsed in the districts of Sirmaur, Kinnaur, Solan and Hamirpur and a large number of residential and office buildings developed cracks but major engineering structures like Andhra dam, Bhaba project and Bhakra dam, escaped without any damage.

In Central Himachal Pradesh encompassing Mandi, Sundernagar, Bilaspur, Arki, Solan and Parwanoo area, 2 to 3 shocks were reported. At Arki and Naindurl it was reported that the initial shock was mild one while the second and third ones were much stronger. The duration of the earthquake was consistently reported to be 45 seconds. At Parwanoo people reported that the sound accompanying the shock was as if electric short circuiting had taken place. At Arki the sound was compared with that of a truck hitting the building while at other places it was reported to be similar to that of strong stormy wind. In Bilaspur district the people felt the shock more severely and stray incidences of people not able to stand were also reported. The direction of the vibrations was consistently reported from northeast to southwest with the exception of Mandi where it was felt from east to west.

Damages in the form of development of cracks in some Kutcha houses and isolated incidences of opening up of joints in brick houses with cement mortar have been reported. In Kunihar village located on Quaternary sediments the damages in the form of partial collapse of adobe type constructions, suggesting intensity VI, have been observed. Brief description of damages sustained in Kunihar village are as under:

The earthquake has caused severe damage to about 20 adobe constructions out of which 5-6 houses have demonstrated partial collapse of walls. In one, two storey house, built in 1920, both long and short walls have collapsed and gaping cracks have developed all along the length of the walls (Photo 99). The gap in the cracks varies from about 12 cm at the top to 1mm towards the base. In another house the southern short wall has been damaged and a gaping crack with an opening of 5-6cm at the top and pinching out near the bottom has developed near the corner (Photo 100). At the police post construction joints opened up due to the tremor.

The description of cracks observed in different localities are tabulated below:

Place	Cracks	Opening	Type of House
Parwanoo	Wide cracks trending NW-SE in the ceiling	2mm to 4mm	Four storey cement houses. Cracks on the 3rd floor in the ceiling towards the end of the building.
Arki	Vertical joints. Opening of joints between two walls	2mm to 4mm	Type A Kutcha house.
Satoti	Vertical cracks	5mm to 10mm	Kutcha houses of Type A as well as in cement, cemented stones and bricks.
Darlaghat	Irregular cracks inclined, vertical	Towards the base	Cemented stone Type B
Bilaspur	Vertical cracks in N-S direction 30 to 65cm from top towards the base	2-3cm wide gap	Kutcha houses Type A
Mandi	Opening of the joints	1cm	Cemented pucca single storey house (Type B)
Barmana	Cracks both in ground floor & Upper storey	Inclined en echelon type	Concrete building
Swarghat	Old cracks	Opened up	Stone cemented Pucca single storey

In the eastern Himachal Pradesh, adjoining Uttar Pradesh in the plains of Shambuwala and Paonta Sahib and in the lower Lesser Himalaya including the localities Shillai, Kamrao, Timbi, Ronhat, Tiani and Rohru, the shocks reported varied from one to three in number and the maximum duration was reported to be about 1 minute. In the upper parts of the Lesser Himalaya including Jubbal, Kotkhai, Shimla, Narkanda, Rampur, Bhabanagar, Tapri, Poo, Kalpa and Tabo people mostly felt one continuous shock lasting for 30 to 45 seconds though a few reported upto 3 shocks at short intervals. In the lower reaches including Nahan, Kwanu, Shillai and Khadrala people felt sound of strong wind blowing, in

Shimla the sound resembled that of moving of vehicles while in Kinnaur district rumbling and thundering sound accompanied by resonance was felt accompanied by rattling of doors and windows. Cases of falling of loose objects on tables and shelves were reported at Shambuwala, Daula Kuan, Minal Bag, Kwanu, Tapri Kotkhai, Theog and Kalpa. There was no change in the discharge of springs except at Theog where the Assistant Engineer; Irrigation Department reported that a water spring had dried up at its usual location and had emerged out about 50m down slope. At Rakcham it was reported that one spring started emitting lukewarm water. The predominant direction of wave propagation was reported to be NE-SW but a few NW-SE, N-S and E-W directions were also reported.

The general damage to the constructions was restricted to development of cracks in A type houses and a few of brick masonry at Tapri,Atal, Kotkhai, Skandon-Korga, Morang all falling in isoseismal V or near to the boundary of isoseismal VI. In Chitkul much more damages have been caused as it lies in the isoseist VI. It has also been noticed that damages in and around Timbi village have been of higher category and collapses of some adobe houses has been recorded in this village. The villages which have suffered considerable damage are described below:

CHITKUL (DISTRICT KINNAUR)

This village is located on gentle slopes occupied by glacial fan deposits on the right bank of river Baspa. The houses in this village are generally made of interlocked wooden beams with dressed stone layers and slate roofs. Most of the houses are two storey 5 to 6m high adobe structures and no damage has been reported to these conventional dwellings. Many recent Government constructions which are about 20 years old including PWD Rest House, Ayurvedic Dispensary building, Primary School building and PWD stores building made of load bearing masonry walls with tin roofs have suffered considerable damage, the worst effected being the Dispensary building.

The double storey Dispensary building built in stone masonry with cement taping from outside and mud plaster on the inner surface of the walls show damages in the form of collapse of roof of the store room, broken top portion of walls and cracks in the east west long walls. The N85°E-S85°W wall has collapsed in the gable portion while the wooden frames and the ceiling are standing intact. The chimney projection above the roof has also suffered considerable damage (Photo

101). Near vertical cracks which taper near the roof as well as the first floor have been recorded in the N-S wall. These are inclined at 70° and 85° towards south and north respectively and extend for a length of about 1 to 1.5m.

The Primary School single storey building has demonstrated damage in the form of collapse of gable portions in the N-S direction damaging wooden furniture in the class rooms. Big chunks of mud plaster has also fallen.

The side walls of the PWD Rest House aligned in the N-S direction show bulging, one in the easterly direction at mid level (Photo 102) and the other bulges towards west. The back long wall aligned in the E-W direction has developed horizontal crack as well as few subvertical cracks near the top of the wall. The slab of the chimney of the PWD stone building has rotated.

A single storey Chakki owned by Sri Nand Negi built in stone masonry in mud mortar suffered heavy damage in the form of gaping cracks in the walls and partial collapse of walls. Northern wall of this small structure developed 1.5X1m size hole. Shri Mahabir Negi of Indo-Tibetan Border Police (ITBP) who happened to be in house in Chitkul reported that the mule track between Chitkul and Rani Kanda had been damaged at a distance of 12 km from Chitkul because of rolling of boulders. Incidence of rolling boulders from the northern slopes of Chitkul village have also been reported.

BADSARI VILLAGE

This village is located about 5 km from Rakcham towards Chitkul on the right bank of Baspa river. The Rakcham granites constitute the high hills of the right bank slope while the village proper is located on gently sloping area occupied by overburden material. A dry gully with steep slopes formed of rolling boulders occurs at the head of this village. Due to the earthquake four rock blocks of approximate $3m^3$ size got detached from the parent rock mass at higher elevations and rolled down along this steep gully slope. Three of these boulders were entrapped in the bouldery zone while the fourth one rolled down to the habitated area killing one person, injuring five others and killing 10 animals.

SANGLA

Everybody in this village was awakened, panicked and ran out of the houses. The GI sheet roofs rattled but the loose objects did not fall. In the town no damage was reported in the house, generally made up of interlocked wooden beams with intervening dressed stone masonry layers. The Rukti Power house and the appurtenances located on overburden material were examined and no apparent damage was seen in these structures. However, in the residential buildings, three storey apartments made in dressed stone masonry with cement mortar and horizontal wooden beams displayed minor cracks in the walls. The Himachal Pradesh State Electricity Board (HPSEB) rest house built in 1989 with dressed stone masonry and cement mortar has developed hair fine cracks specially in the back varandah at the junction of beams with pillars.

RAKCHAM

The PWD rest house made up of stone masonry with mud mortar and cement taping has not been damaged but the kitchen and chaukidar's residence by its side has developed cracks from the roof level to the window base and big chunks of mud plaster have fallen in the kitchen. One of the side walls aligned in the N60°E-S60°W has bulged in the S30°E direction. In the Ayurvedic Dispensary Building aligned in the N30°W direction cracks along the mortar are seen below the windows on both the walls, plaster has fallen. This building is made in cut stone masonry with cement mortar and mud plaster. Another building of the same type (Junior Engineer's residence), displays crack from top to the ground level in a side wall aligned in the N30°W-S30°E direction. The Gram Sewak's hut also show vertical cracks in the side walls and some of the preexisting cracks have widened.

SHIMLA-THEOG-NARKANDA

SHIMLA

In the Sanjoli area people felt the shock strongly and everybody awakened and many came out of the houses. Mr. Verma, SDO of Nathpa-Jakhari Project Corporation (NJPC) staying in second floor of a RCC frame building reported that the shock came from eastern side and further felt that the vibrations were in east-west direction and the swing was about 5 to 7cm in 3m high structure in second floor. No damage has been reported in his building. He further reported that near Jhaku temple on fourth floor of the RCC frame structure building hair cracks have developed in partition walls.

The Post and Telegraph building, a three storey structure, made up of red bricks with lime mortar displayed no damage.

The Grand Hotel buildings are in general about 100 year old and no damage has been reported in the main buildings. In block No.II quarter No.IV, minor crack has been observed in the wall (the building is slightly poorer in construction than the main building).

Theog

The shock was felt strongly and people came out of houses. No damage has been reported. It is reported that in near by villages old houses of poor construction has developed minor cracks.

Narkanda

The shock was felt strongly but no damage has been reported.

NOGLY-RAMPUR-JHAKRI-JEORI-POOH-KHAB

In the Nogly power house building situated on overburden, no damage has been observed. In the 33 KW control room which is an extension of the main building and constructed after 1975 Kinnaur earthquake about 2m long vertical cracks in the wall have developed at the junction of RCC pillar and masonry wall at two places. The height of the wall is 4 to 5 meter and crack has developed in top 2m. only. No damage has been observed in the anchor blocks of the penstocks.

People in Rampur felt the shock strongly and came out of houses in ground floor also. The 80 year old Satya Narayan temple made up of lime mortar and stone stands erect. The side courtyard building made up of wooden beam and stone which is tilted earlier has not been damaged.

The Jhakri colony is situated on about 40 to 80m thick fluvio-glacial deposit. Most of the houses are two to three storey RCC framed structure with partition walls while a few houses are single storey buildings with load bearing walls. Due to earthquake people came out of houses, but no damage to building has been reported. Nothing fell down from shelf etc. The type VI quarter (single storey with load bearing walls) which are situated in the slow creep zone and had developed cracks due to creep movement earlier and were later filled up by cement mortar, no damage has been reported due to this earthquake.

In the NJPC colony at Jeori (previously HPSEB colony) in four storey RCC framed structure building, the partition wall has developed cracks below the window in second floor. The newly constructed club building shows hair line cracks along the floor.

Tapri is situated on the Satluj river terrace deposit. Here people felt the shock strongly. In Ram Charan Dass hotel minor cracks in wall on first floor portion in partition wall has been observed (Poor construction). In the out house of the rest house aligned in N30°W-S30°E widening of preexisting cracks in the side walls and irregular diagonal cracks extending for length of about 1.25m have been noticed in the long wall at ground floor. The upper storey is not damaged.

A Kirana shop owner At Agpa while sleeping on wooden cot on ground floor felt the shock strongly, he did not come out of the shop. Nothing fell down in his shop. The weighing balance hanging from the roof started swinging.

The Morang village is situated on the left bank slope of the Satluj river (about 200m above the river bed level) and slope wash material forms the slope. Shri Jasbir Singh, School Teacher felt the shock strongly on ground floor. No utensil has fallen from the racks. His house is govt. quarter made up of stone masonry with mud mortar and cement taping. In his house vertical cracks on back side has developed due to 19th January, 1975 Kinnaur earthquake. These cracks have slightly opened up due to this earthquake also.

The residence of Shri Chaube another school teacher, a double storey stone masonry old building aligned in the N80°E-S80°W has developed cracks in the long walls as well as the side walls. Loosely stacked stones in the gable portion fell and a man sleeping below this with a child had a providential escape. The double storey building police station building shows cracks only on the first floor and the gable portion of the N-S aligned side wall has bulged in the westerly direction. A stone has also fallen from the loosely packed gable portion. In the Govt. Ayurvedic dispensary building aligned in N30°E-S30°W preexisting cracks have opened out; a few new cracks have developed and back wall is severely damaged and needs to be dismantled. A long wall has bulged in the N60°W direction. It is apparent from the reports that many buildings in Morang had been severely shaken and damages in the form of cracks were caused (intensity VI) during the Kinnaur earthquake of 1975. The constructions were only patched to make them habitable. As a result their strengh was reduced and thus suffered considerable damage during this event.

People at Pooh felt the shock strongly. The PWD rest house made up of dressed stone masonry with cement taping built on slope wash material consisting of clay and shingles has not been affected by the earthquake. In village the houses are made up of stone masonry with mud mortar and mud plaster. A few have developed cracks in plaster about 0.5m long.

The Dubling Police quarters were examined. These are built on rock and are made up of stone masonry with mud mortar and mud plaster. No damage has been reported and nothing has fallen from shelf.

Khab

In the army camp people were watching TV at the time of earthquake. The table on which the TV was kept started shaking. It was so severe that one of the man caught hold of TV so that it did not fall. In the village no damage has been reported. The houses are made up of stone masonry with mud mortar and mud plaster.

In addition to the above described damage patterns incidences of rolling down of boulders and stones were reported from many parts of the Kinnaur district mainly from Chitkul area (Badsari village described earlier), Sangla, Rakcham, Karcham, Morang and Shiyasu Khad and many of the old landslides got reactivated. SDO Morang reported that a big landslide had occurred which could be seen from Morang in the N30°W direction and had caused rising of dust clouds which could be seen upto the noon of the 20th October, 1991, the day the earthquake had occurred. These incidences of landslides have been utilised for constraining the isoseismal VI though in certain localities the damages to the construction have been of lesser degree.

In the lower Lesser Himalaya in eastern Himachal Pradesh the general damages are akin to those expected in isoseismal V but in localised area around the village Timbi higher grade damages have been recorded, the details of which are given below:

TIMBI AREA

Timbi area reportedly experienced three shocks in a span of 30-50 seconds, the first shock being severest and of longest duration. All the people were awakened, frightened and rushed out of houses. The village Pradhan reported that as he tried to come out he fell in the N20°W direction. Rattling of windows and doors was reported by all, untensils fell from the shelfs and two directions of wave propagation, one in N70°E-S70°W and the other in N30°W-S30°E, were reported. Three Kutcha houses collapsed. Long wall of a house, constructed of stacked cement stone and plastered with mud, collapsed in N20°W direction (Photo 104). The western side wall of another house, under construction, also collapsed in S70°W direction.

At Baldwa located near Kamrao a double storey B-type house has developed shear cracks in the side walls oriented in the N20°E-S20°W and even the partition walls parallel to the side walls have developed similar cracks. The long walls of this house do not show any significant cracks (Photo 105). It was reported that the first shock was felt from N60°E-S60°W direction while the second was in the N60°W-S60°E and the side walls oriented oblique to the first wave propagation have failed under shear.

At Kamrao, preexisting cracks in the wall below the beam in the Sub-Tehsil office building is widened due to this earthquake. This building is built in brick masonry. The cracks extend in the WNW-ESE direction which is parallel to the long wall of the building. Cracks at the floor of the building, oriented a little oblique to the long wall direction have also widened. At Kamrao Sub-Tehsil one collapse was reported and a few buildings developed cracks but these reported damages could not be confirmed. Further north in the villages of Atal and Tiuni the damages have significantly reduced.

CENTRAL AND NORTH-WEST UTTAR PRADESH

Lucknow-Bareilly Sector

The area between Lucknow and Bareilly is a part of the Indo-Gangetic plain. At Lucknow, a few people staying on the upper storey of the buildings and fortuitously awake felt a minor jerk for a fraction of a second. Enquiries show that this shock was not uniformly felt at places between Lucknow and Malihabad. The chaukidar on duty at petrol pump in Malihabad could not feel it. The people awoke by chance at that time could feel minor jerk but could correlate this with the earthquake only after reading the newspaper the next day.

The cabinman at Sandila Railway Station, on duty sitting on the first floor of the east cabin felt a momentary jerk, while people in the township could not feel it.

In the level crossing No.96 on the track to Sandila, the shock was not felt and same was the case at Kachona thana.

The enquiries made in the market and at the petrol pumps in Hardoi and at Shahabad revealed that the shock was not felt even by persons who were awake.

The Shahjahanpur town remained unaware of the shock. The enquiries made at Nariman Petrol Pump and Balli timber merchants shop revealed that nobody felt the shock, except at the Dhaba at railway crossing where minor vibrations were felt. At Tilhar township the minor shock could be felt by few persons incidentally awake and residing on the first floor.

In the urban settlement at Faridpur, about 15km. short of Bareilly town on Shahjahanpur-Bareilly road, many people were awake after returning from Ramleela and thus could narrate their experiences of the shock. Accroding to Shri Satya Prakash at Jai Ambe filling station a strong shock was felt while lying on the E-W oriented cot on 1st floor of the Pucca house. The shock was felt from N to S for about 20 sec. He reported the swing of a hanging dholak' and rattling of latch of wooden box. It appears the intensity IV starts from this place as the shock was felt by many who were awake in this township.

In Bareilly town many persons who were awake felt a strong shock. Dr. M.P. Saxena, Sr.D.M.O. and his family members felt the shock which lasted for about 30 to 40 seconds. The hanging bulbs swung for more than 5 minutes. They felt the shock from north to south while lying in E-W direction on the cot. The Pujari of Sankatmochan temple, Baba Rajgiri in front of Railway Station described it as a strong shock. His bed was aligned in E-W direction and was shaken in N-S direction. He felt 3 shocks of which the second was stronger than the other two. He informed that it was felt by many staying around the temple. A Railway Assistant Engineer Mr. Som Bir Singh had felt three shocks and was awakened by the shock. He saw hanging objects like bulb swinging. His pet dog started whining. He was sleeping in E-W lying bed and felt the shocks from north to south . Strong shocks were felt by Mr. Tiwari and Mrs. Pande in residential building of Telephone Exchange. These people were on the 2nd floor. The ceiling fans and hanging bulbs started swinging though they could not mark the direction of the swing. Shri Abdul Quadir of Hazi brick field at Mundie Ahmed Nagar about 10km. from Bareilly on Pilibhit road felt the shock at 2.30 A.M. for a few seconds. He was lying on the bed on ground floor of a pucca house. He observed that photograph hanging on the wall started swinging. The earthquake shock was felt at Akupur village near Nababganj, 32km. from Bareilly on Pilibhit road as informed by Mr. Daler Singh a resident of the village.

Enquiries made at Pilibhit town reveal that most of the people fast asleep could not feel the shock but few sensitive ones woke up by this shock. Mr. Ravindra Singh, Rohilkhand Service Station describes it as a minor jerk. He felt the shock at about 3.00 A.M. Sri Jasveer Singh of Doordarshan Kendra who was sleeping on the ground floor verandah of a single storey building woke up. He felt three shocks and saw plants shaking and heard rattling of doors and windows. The shock in this locality was felt from N to S. He also showed a thin crack in plaster above the lintel level on the long wall oriented in E-W direction.

KUMAON HIMALAYA

In Khatima township located NE of Pilibhit on Bareilly-Tanakpur Road, people got awakened by the quake and felt a strong jerk. Shri Ved Prakash Mishra staying in Sri Hanuman Mandir felt one shock, though few persons are reported to have felt three shocks also. The shock was felt accompanied by rattling sound of utensils and creaking sound of thatched roofs.

In Tanakpur town located at the foot of the hill in the Bhabar zone, majority of the people remained asleep but a few residing on first floors woke up.

The earthquake shock was felt at about 3.00 A.M. at Brijnagar village located on Siwalik formation. Shri Brij Mohan, owner of the Achar Udyog, residing in pucca double storey building could not feel the shock as he was in motion when he was returning to home from Ramleela but his family members reported that they got up and tried to rush out in panic. They felt three shocks from N to S and the pendulum wall clock stopped. A thin crack trending E-W was shown on the top floor. However, the Ramleela viewers, returning back to their houses on foot could not feel the shock but the same was felt by most of the persons at rest.

The village Chalthi is situated on the left bank slopes of Ladhiya river. At the Primary Heath Centre, it was reported that the shock was felt by everybody all in the village. Shaking of beds and rattling of windows and untensils were also reported.

In Champawat town spread in a wide valley at an altitude of about 1600m, two shocks were felt which awoke most of the people. The owner of hotel Basant Vihar reported the fall of utensils from the rack.

Shri Chintamani working in the DGBR gang described that he and others of village Nayal woke up due to the tremor which was felt at about 3 A.M. Three shocks, middle one being the severest, were reported.

The residents of Lohaghat area woke up due to the quake. Shri Prakash Punetha of Parwati filling station felt the shock at 2.55 A.M. with gradual increase in the vibrationn which passed from west to east. Hissing sound like the one at the time of a storm was heard. Shri Punetha felt another shock in the day at about 1.00 P.M.

The forest check post at Ghat bridge, on left bank of Saryu River a small pucca building, with tin roofing and wooden false ceiling was shaken due to shock and Shri Mohan Chand sleeping inside woke up and felt three shocks within a span of about one minute.

In the Pithoragarh town, shock was felt by many who were asleep. Shrimati Bhawana staying in PWD bungalow had felt three shocks in a span of about 30 seconds accompanied by sound as if boulders were rolling in the river. The watchman of PWD rest house, Shri Nand Kishore felt three shocks at 2.55 A.M. the second shock being stronger than the other two.

The shock was felt at 2.52 A.M. for 20 seconds. Rattling sound of tinshed roofs, windows and doors was heard. All the persons woke up and the fall of wooden box was reported by a person in the market.

Shri Bhupendra Singh, PWD, Didihat was awakened by the shock and rushed out of the house in panic. All the people of the PWD colony were awakened. Crack in the wall was reported in one of the houses of PWD colony but could not be examined.

In Berinag town situated at a height of 1800m, the quake was felt mildly as reported by Shri Nandan Prasad. He felt the ground motions from W to E.

Almora District

In Kamari Devi, Siroli villages and Bageshwar town, the shock awakened many people and the ground motion was felt from W to E.

Kausani township located south of Garur Valley, suffered minor damages. Hotel Sagar, a newly constructed pucca building consisting of two separate blocks aligned in E-W and N-S directions displayed damages to the E-W block while the N-S block escaped damage. The room No. 102 of E-W block has developed cracks both along the long and short walls. The cracks are at the ceiling level and along the junction of the walls. Shear cracks at 45° towards south on N-S trending walls have also been observed. The plaster on the pillars outside the room has cracked The E-W trending wall bulged out at the lintel level of window of the room on first floor of a tea shop in the market. The plaster of the E-W trending wall of the temple at Kausani cracked and the clock kept on the table fell down. An E-W motion was reported.

The forest rest house at Kausani is located at a slightly higher elevation than the market and temple. The chaukidar's house is a double storey N-S trending katcha (masonry with cement plaster) building. The western side N-S wall of the kitchen room has collapsed partially between the door and ceiling. The crockery was broken due to fall of material from the wall as well as the fall of the crockery on the floor. Cracks on the E-W wall (western side) of the house have also been observed. The main rest house is aligned N-S. The eastern side wall of the rooms developed shear cracks through the wall with inclination of about 45° to 50° towards south.

The quake was felt less severely at Someshwar village than at Kausani. Mr. Khem Singh felt three shocks with middle shock being more powerful. Rattling sound was heard and people woke up. The Pujari of Ram Mandir at Brambha Sarovar, Gaughat near Kosi describes a minor shock between 2.30 and 3.00 A.M. He woke up due to shock. The people in nearby villages also felt the shock and heard rattling sound of the utensils. Mr. Ayaz Husain of Niyaz Ganj in Almora township was sleeping on bed on the 2nd floor of a RCC pucca building woke up due to the shock. The toys fell from the cupboard. Shri A.N. Joshi of Almora town Mall road market felt shock which gradually became stronger and lasted for 50 to 60 seconds. He was sleeping in N-S direction while he could feel shock travelling E-W. Few people came out of their houses. Mr. N.C. Joshi describes the development of cracks in his house by the side of Prem Ara Mill at Jakhandevi place.

The market at Gasur is situated at the bank of Gasur Ganga. The shock was felt by all in general and people woke up. The stock of cloth fell down from the almirah in one of the shops. Cracks widened in the wall of upper storey of the house of Shri Ganga Dutta Pandey. Fall of articles have also been reported by Madan Singh of Jinoli village, one km south of Gasur.

The Kumaon Pharmacy at Gasur market, a pucca building, suffered crack of plaster and walls. The RCC beam to support projected shed developed crack. Shri G.S. Pandey the owner of the shop felt three shocks lasting for 30 to 40 seconds. He felt shock from west to east. The building is aligned N-S. The wall trending N-S (easterly) developed more cracks than the E-W aligned wall.

The town Baijnath is situated in the open wide valley at the confluence of Gomati and Gasur Ganga at a height of 1190m. The quake was felt by all. People woke up from sleep and report two shocks from west to east accompanied by rattling of tinshed.

GARHWAL HIMALAYA

Chamoli District

In the market area of Gwaldam (1896m) people reported three shocks felt within 45 seconds, of these the middle shock was the strongest. The bus conductors and drivers sleeping inside the bus woke up and came out. Fall of pickle containers in the shop was reported by Mr. Balwant Singh. In general, the shock was felt from north to south. The north-south trending wall (eastern side) of first floor of the four storeyed hotel Man Sarovar, suffered cracks on the outer face of the wall. 1m long patch of plaster of the same wall inside the room had fallen and shear cracks have developed.

Talwari village is situated at a height of 1886m and is 10km away from Gwaldam on Karnaprayag Road. The quake was felt by all and few ran out. The shock was felt from N-S direction. Mr. Narain Singh reported the fall of utensils in his house and shaking of the trees in front of his house.

In the remaining areas of the district, the damage suffered by the structures is comparatively more in NW sector in Mandakini valley than those located on eastern and southern sides in Alaknanda valley.

The famous Badrinath Temple and the township are located in Alaknanda valley at an altitude of 3200m, on glacial and fluvio glacial deposits. The temple is situated on the right bank of the river whereas the supporting structures like dharamshalas, hotels, guest houses etc. have come up on both the banks. The main temple is a stone masonry structure whereas other buildings are constructed of various types of materials like mud masonry, cement maşonry and RCC. The kutcha buildings of mud masonry have suffered damages comprising open cracks with a few instances of wall collapses. In case of buildings like Subodh Dharamshala and Kurmanchal Dharamshala with their long walls aligned in N-S direction, partial collapses have been observed in southern walls and cracks and peeling off of plaster in eastern or western walls. In case of house of Shri Dewan Singh, open cracks with slight bulge were observed on southern wall. The intensity of damage in case of other Kutcha structures is quite low. In case of pucca buildings, the damage comprises open cracks on walls of first and second floors and development of hair line cracks on walls of ground floor as in the case of office of temple committee. In general, the damage is of low intensity and confined to a few buildings.

In addition to the damages discussed above, no instances of terrain changes were observed in the area except for rolling of one boulder of 3m size from hill slope to road near Hanuman Chatti. Damage comprising development of hair line cracks and a few instances of open cracks in upper floors were also observed in Gopeshwar (Hospital Building), Joshimath (PWD Rest House) Chamoli, Karanprayag (Dispensary) and Rudraprayag. The intensity of damage was observed to be slightly more in case of Rudraprayag where the frequency of development of cracks in walls of RCC buildings is slightly more.

The intensity of damage increases progressively in Mandakini valley towards north and NW direction. Development of shear cracks was noticed on SW end walls of NE-SW aligned houses located on the outskirts of Rudraprayag, Tilwara, Augustmuni, etc. But no cases of collapses have been reported in these localities. However, the emission of air and water have been reported from Bawai and Nera Busta villages, located near Rudraprayag and Augustmuni.

Further north in the Mandakini valley, almost all the Kutcha (mud masonry) houses have suffered damages comprising hair line craciks to open cracks in walls. In a few cases the development of shear cracks was observed in south eastern walls of NW-SE aligned houses. A few instances of cracks in pucca houses (stone masonry with cement sand plaster) and partial collapse of partition walls was also observed. However, these collapses are confined to gable portions only. The building of Primary Health Centre falls in this category. The structure with its long wall aligned in NW-SE direction has developed, open shear cracks in short walls (Photo 106). In buildings aligned in NE-SW direction, open cracks with slight bulge and tilt were observed in short walls (Photo 107). The partition walls have collapsed partially with the damage confined to the gable portions only. The damage, in general, is of same intensity in the villages around Okhimath.

The village Pathali is located about 100m above Aakash Kamini river, a tributary of Mandakini, on a ENE-WSW trending narrow ridge. In this village, many houses have been damaged but no collapse was reported. The houses with their long walls aligned in N70°E-S70°W have suffered more damage compared to those with long walls aligned in N20°W-S20°E direction. It is also reported that one old landslide located on right bank of Akashkamini on southern edge of the village was reactivated on 15th October, 1991 causing blockage in the course of river. One of the possible cause for reactivation of this slide could be fore shocks of this main shock.

Similar pattern of damage was observed in villages Usara, and Duggal Bita, located east of Okhimath where cracks with slight bulge were noticed in Kutcha houses and PWD Rest House. In all these cases, cracks with slight bulge were prominent on SE walls of NW-SE aligned buildings.

Further, north of Okhimath, similar pattern of damage continues in Guptkashi upto Phata beyond which the intensity and frequency of cracks in houses increased. The development of cracks trending N20°W-S20°E was also observed in road near Phata. These were observed off and on upto Sonprayag. The damages progressively increased further north upto Sonprayag (about 5 km south of Gaurikund) where first instances of house collapses were observed.

TRIJUGI NARAYAN

The village is located 13 km. north of Sonprayag at an altitude of 2600m. and is approachable by a metalled road. The place is famous for Trijugi Narayan temple.

The influence of the 20th October earthquake was quite severe in the area. Almost 80% of the poorly constructed type-A structures, that is houses of thick mud masonry walls with slate roofing developed open cracks and nearly 20% suffered partial collapses, particularly of the gable portion (Photos 108 and 109).

The Trijugi Narayan temple has suffered minor damages. The symmetrical structure is constructed of tabular granite gneiss blocks (1mX0.5mX0.1m) which have not been much weathered during centuries of exposure. The influence of the 20th October earthquake on the temple can be seen at two points that is at the `Shikhar' and the amblak' (Fig.32). The raised stones of the NE-SW trending face of the Shikhar have bulged or opened out by about 2 to 5cm towards south. The large granite-gneiss block chiselled in lotus shape (amblak) and placed atop the `Shikhar' has been reported to have moved by about 5 to 10cm towards NE quadrant. The rest of the structure is intact. The large shear friction provided by the horizontally placed tabular granite-gneiss blocks have been responsible in preventing any loosening or movement under the influence of the strong ground motions. The bulging of a portion of the `Shikhar' could have been the product of compressive stresses generated as a result of interaction of vertical component of ground accelerations and load of the structure.

Photo 81 *Complete collapse of houses in Gorthi village.*

Photo 82 *General view of damages in Gorthi village.*

Photo 83 *Heavily sheared side walls of a house in Gorthi village.*

Photo 84 *Damaged residence of doctor in Jakheli village.*

Photo 85 *Collapse of a type–B house in Jakholi village located on a spur.*

Photo 86 *Collapsed veterinary hospital in Jakholi village.*

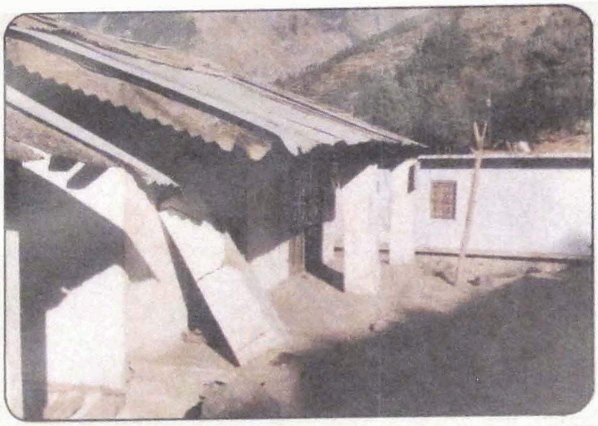


Photo 87 *Tilting and collapse of pillars of a house in Rana village.*

Photo 88 *Damage to cluster of houses in Gangani village.*

Photo 89 *Collapse of first floor of a conventional house in Gangani village.*

Photo 91 *Tilting of the eastern long wall of a conventional house in Gangani village.*

Photo 92 *Caving in of the roof of a conventional construction because of partial collapse of supporting walls, Gangani village.*

Photo 92 A *Damaged lowrise roadside temple, a few km before Barkot along Kalsi-Barkot road.*

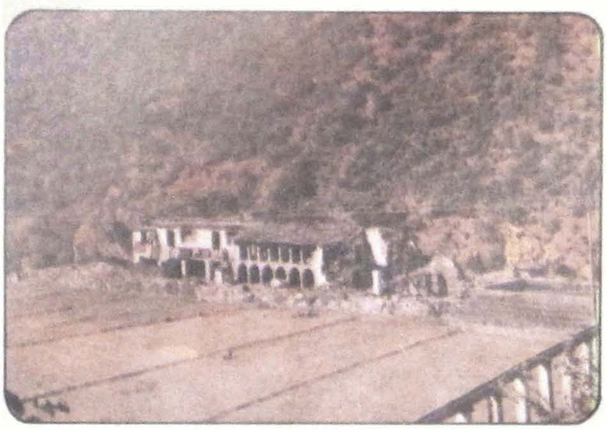


Photo 93 *Partial collapse of an old house located on Yamuna terrace. Small water channel supported on high pillars has escaped damage.*

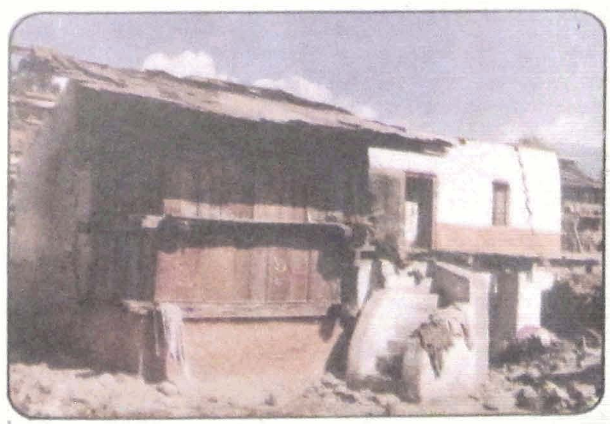


Photo 94 *Bulging and cracking of walls of a house in Purola village.*

Photo 95 *A general view of FRI building, Dehradun.*

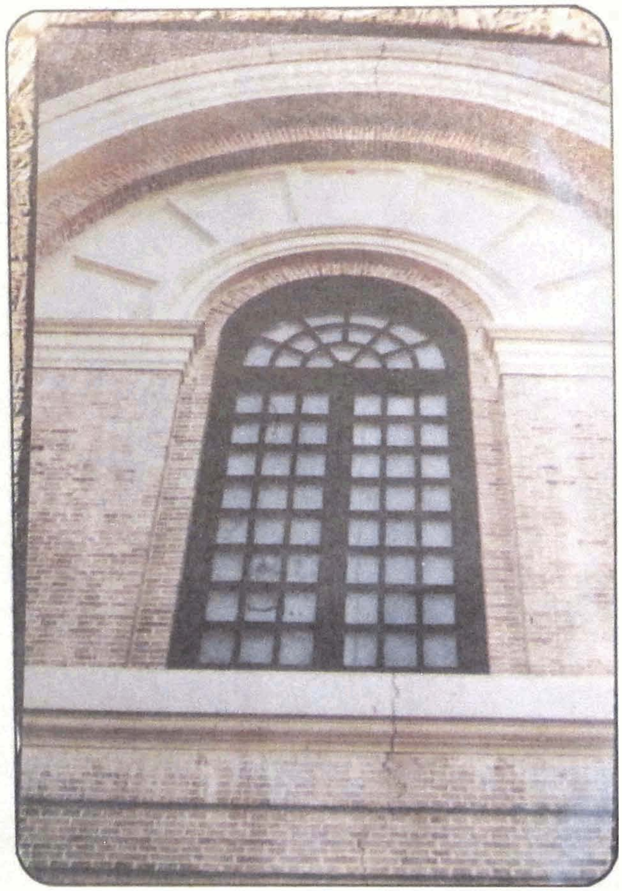


Photo 96 *Cracks in the arch and sill portion, in the rear wall of FRI building.*

Photo 97 *Dislodged brick from the centre of the arch portion of the first floor corridor–FRI building Dehradun.*

Photo 98 *Fall of plaster and development of cracks in the panel wall adjacent to the porch–Hilton Hotel, Dehradun.*

Photo 99 *Partial collapse of an old house in Kunihar village.*

Photo 100 *Vertical crack with 5–6 cm. opening in a kutcha house in Kunihar.*

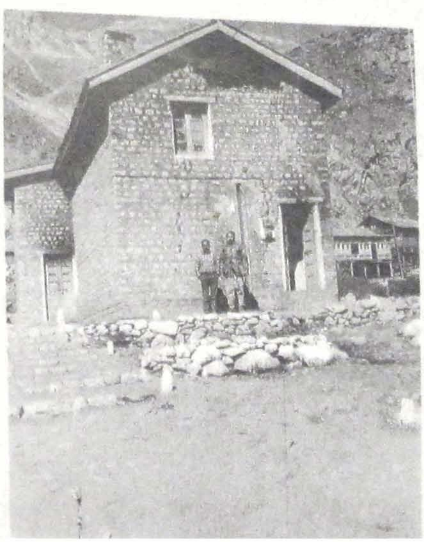


Photo 101 *Partial collapse of gable portion of a type–B construction (dispensary building) at Chitkul.*

Photo 102 *Bulging of the west wall of double storey Rest house at Chitkul.*

Photo 104 *Collapsed house in Timbi village.*

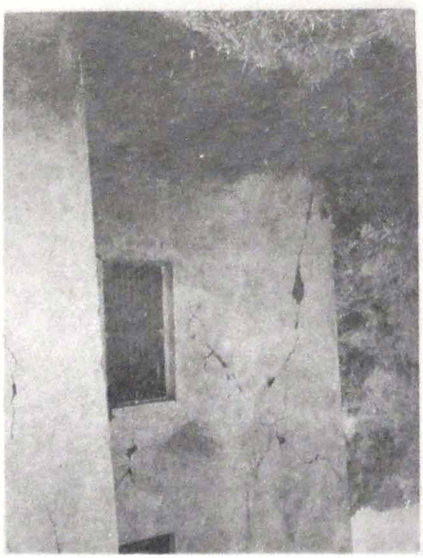


Photo 105 *Shear cracks in a type–B, double storey house in Baldwa village.*

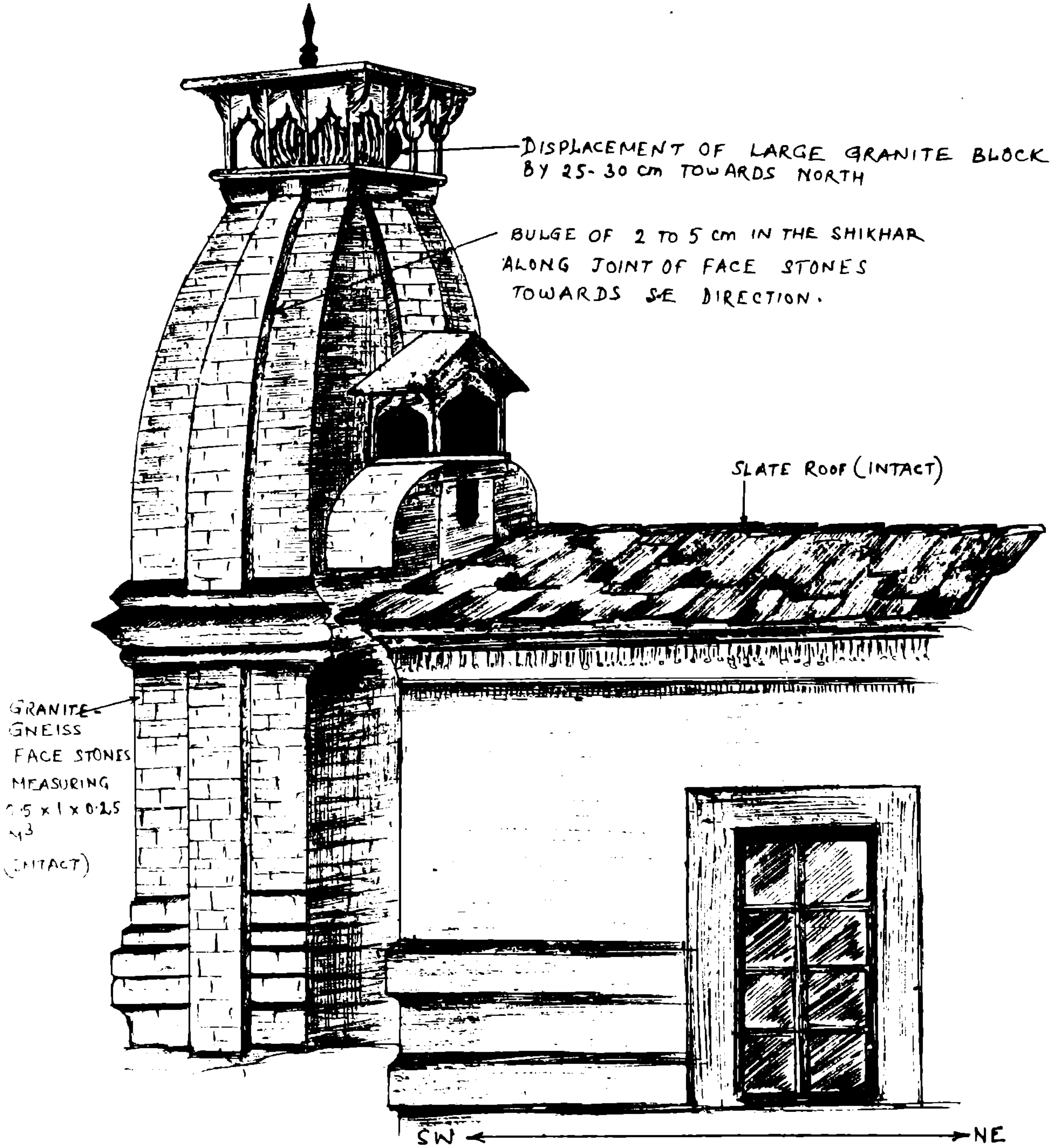


Fig 32 : SKETCH SHOWING BULGE IN THE SHIKHAR AND DISPLACEMENT OF AMBLAKH OF TRIYUGI NARAYAN TEMPLE, CHAMOLI DISTRICT (SKETCH BY P. PANDE)

GAURIKUND-KEDAR NATH

Gaurikund is located almost in the east of epicentral tract on right bank of Mandakini at an altitude of about 1900m. Gaurikund village is situated on right bank hill slopes, about 100m above the river bed. Gaurikund attaches lot of significance as it has the famous hot springs and is the road terminus point for the holy pilgrim centre of Kedar Nath.

In case of buildings and houses, the damage includes cracks in buildings. These cracks are open in some cases. The crack openings are more pronounced on southwestern walls of NE-SW aligned structures like Rest House of Garhwal Mandal Vikas Nigam. The cracks on SW wall of the NE-SW aligned buildings are open upto 5.0cm near the top portion. The openings gradually decrease towards bottom. Few SW and NE walls of Kutcha houses have collapsed partially (Phto 110 and 111).

The main building of Police Post (mud stone masonry with cement plastered walls), aligned in N60°E-S60°W direction, small cracks have developed on SW and SE walls and plaster has peeled off from SE corner of the building (Fig.33). The crack on SW wall rises from plinth level to window height and extends towards window on SE wall. The cracks have also developed on SE end walls. But in case of annexe building which has been constructed adjacent to the main building with long walls aligned in N30°W-S30°E direction, the intensity of damage is much severe. In this case open cracks have developed on SW short wall (aligned N60°E-S60°W). These cracks show opening upto 1.0cm near the middle portion. Diagonal cracks, starting from top and extending to plinth level have developed on NE-SW trending long walls. These cracks are open. The projected parts have also cracked but not collapsed.

The PWD Rest House is an old building constructed in 1928 of mud stone masonry walls with cement plaster and GI sheet roof (Fig.34). It has its long walls aligned in N45°E-S45°W. The long walls of this building from inside (i.e. NE-SW aligned walls in rooms) have developed shear cracks which originate from plinth level. The damage to long walls is more pronounced on SW side of the building. The NE side wall which is aligned in NW-SE direction has collapsed in the gable portion damaging the false ceiling, furniture etc. in the room. From outside, this wall has developed cracks which are wide open and a very prominent bulge towards NE. The window has tilted by about 20° as a result of this bulge (Photo 112).

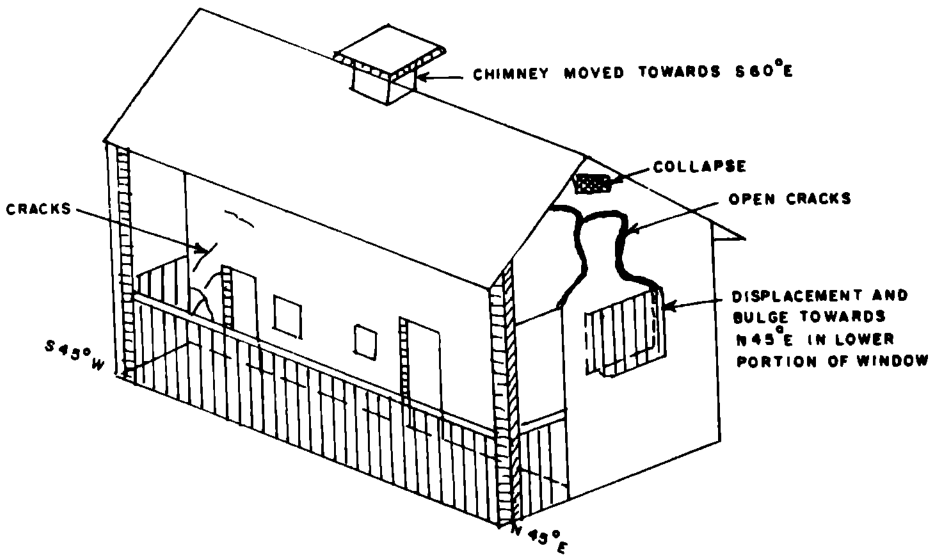


Fig. 34 : PWD REST HOUSE — GAURIKUND

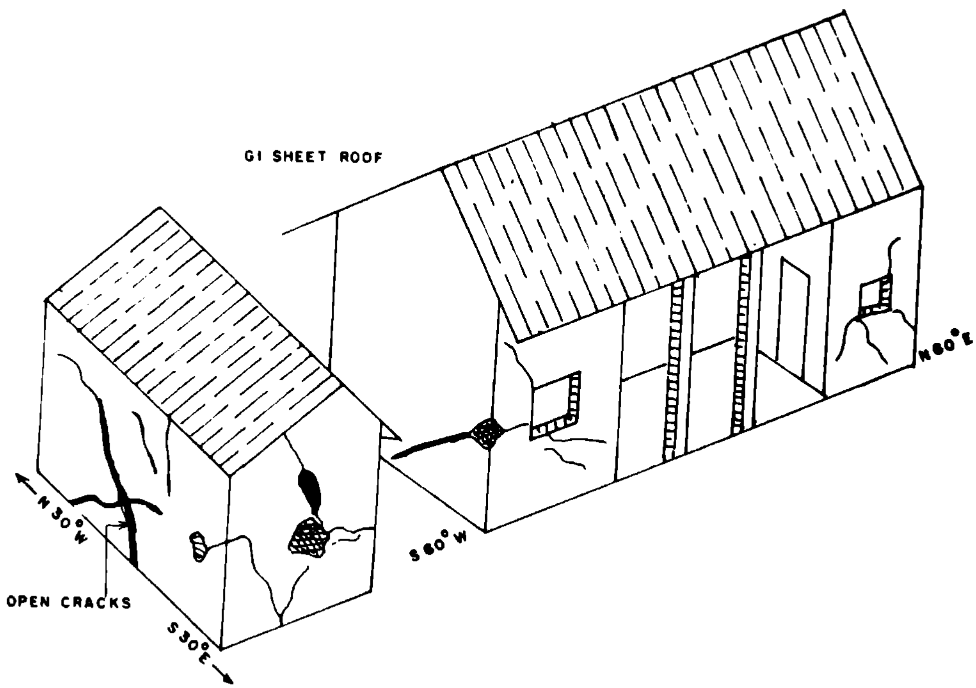


Fig. 33 : POLICE POST — GAURIKUND

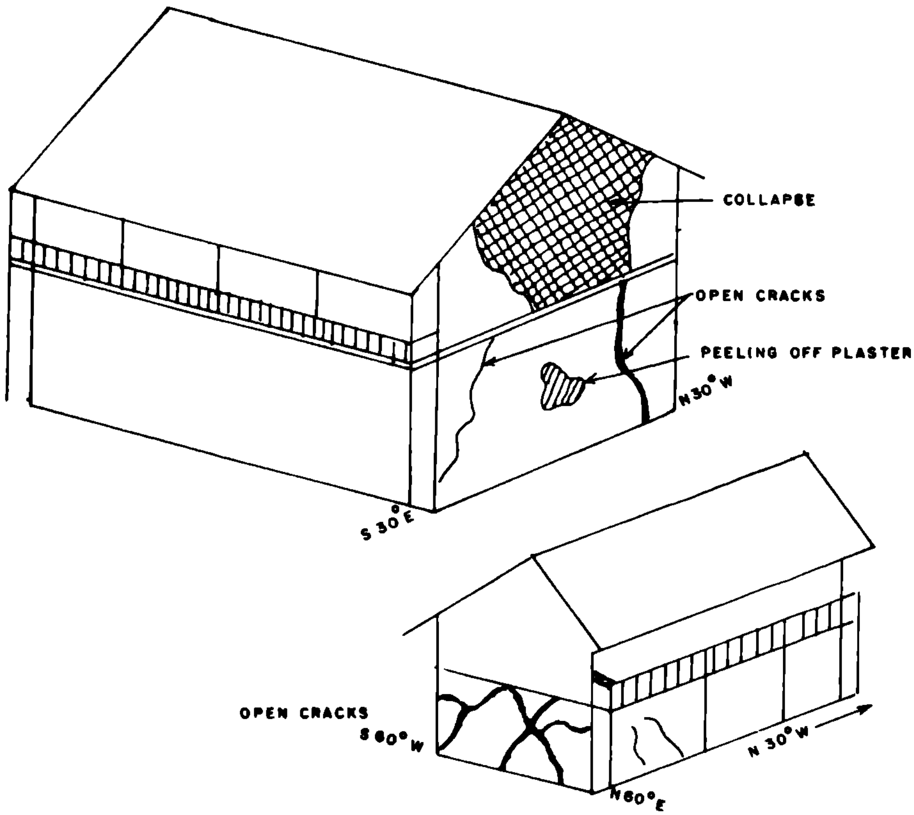


Fig. 35 : HOUSE IN GAURIKUND VILLAGE

The chimney erected on top of roof, i.e. projection outside the main building has rotated towards S60°E and has developed open vertical cracks (Photo 113). If all these damages are taken into account, it can be concluded that the building is badly damaged.

Similar pattern of damage was observed in Gaurikund village which is located about 50m above the PWD Rest House (Fig.35). Most of the houses are aligned either in NE–SW direction or N60°E–S60°W direction. The open cracks, bulges and peeling of plaster were observed on NE side walls i.e. short walls aligned NW–SE and cracks on long walls. Partial collapses of some houses have also taken place.

Similarly, in the houses with long walls aligned in N30°W–S30°E direction, the side walls have developed open cracks at lower levels (shear cracks) and fine

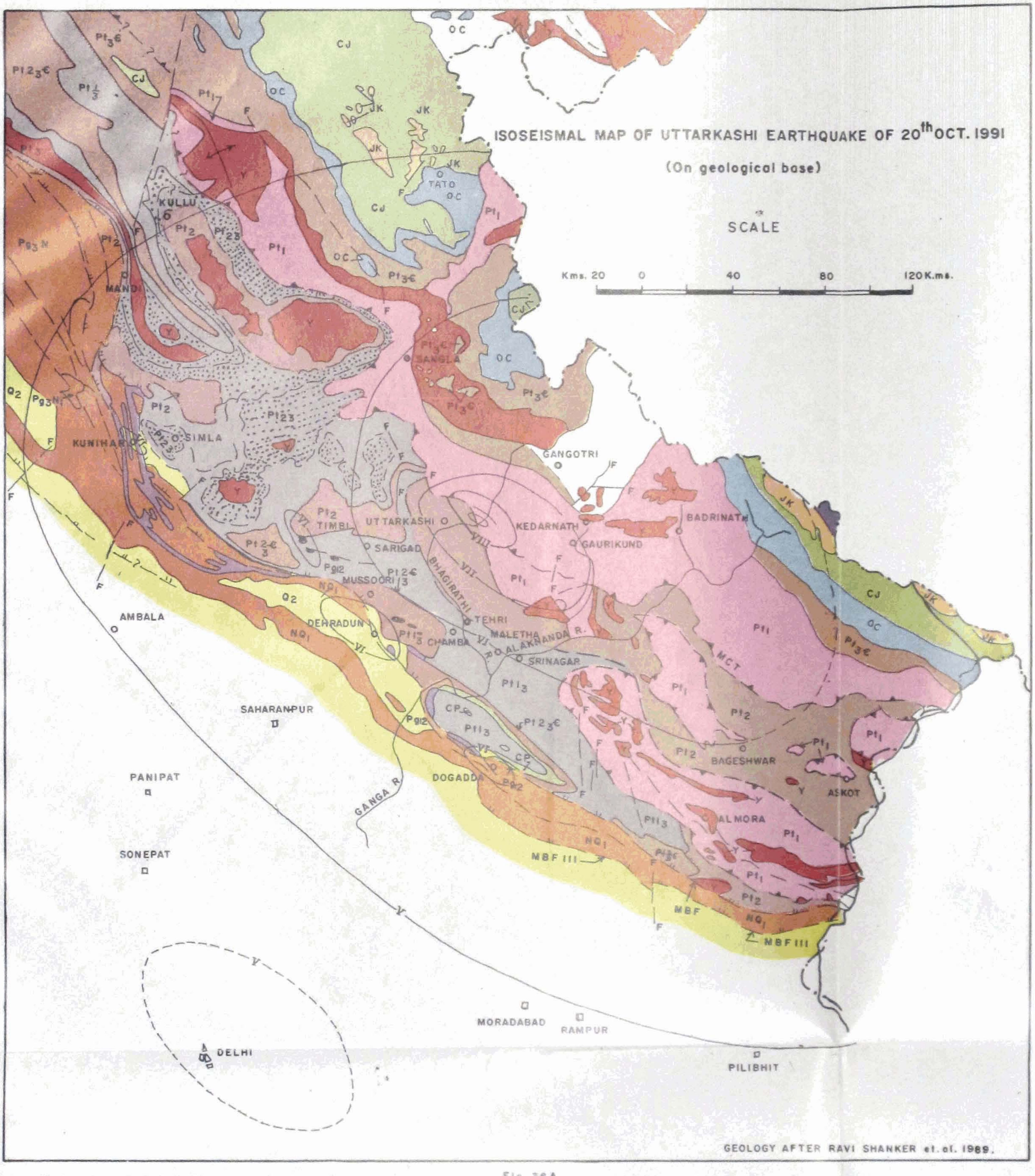


Fig. 36A

Based upon Survey of India map with the permission of the Surveyor General of India.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

GEOLOGICAL SURVEY OF INDIA

GEOLOGICAL TIME SCALE			GENERAL LITHOLOGY	SEDIMENTARY CYCLE
QUATERNARY	HOLOCENE	Q_2	Unconsolidated pebble, boulder, sand, clay.	XI
QUATERNARY (1·8 my.)	PLEISTOCENE	? N_2Q_1	Silt, clay, pebble. (lacustrine deposits) / Gravel beds	X
NEOGENE	PLIOCENE	NQ_1	Boulder conglomerate, sandstone, shale, clay, soft sandstone, reddish sandstone, and shale.	IX
NEOGENE (23 my.)	MIOCENE	Pg_3Q_1	Red shale and sandstone.	IX
PALAEOGENE	OLIGOCENE	Pg_{23}, Pg_3N		
PALAEOGENE	EOCENE	Pg_{12}	Limestone & shale (marine facies) grey to purple shale, carbonaceous shale + coal beds (continental facies)	VIII
PALAEOGENE (65 my.)	PALAEOCENE	KPg_{12}		VIII
MESOZOIC	CRETACEOUS	K	Predominantly basic volcanics / Calcareous sandstone	VIII
MESOZOIC	JURASSIC	JK (K, J)	Sandstone, shale, limestone, ferruginous oolite	VII
MESOZOIC (243 my.)	TRIASSIC	CJ (J, T)	Limestone, dolomite, shale, sandstone, dark grey shale	VI
PALAEOZOIC (270 my.)	PERMIAN	P	Predominantly volcanics with shale & siltstone, plant-bearing beds	VI
PALAEOZOIC	CARBONIFEROUS	C	Quartzite, conglomerate / diamictite, slate	VI
PALAEOZOIC	DEVONIAN, SILURIAN, ORDOVICIAN	OC	Limestone (with marine fauna) siltstone, shale (with plant fossils), variegated-siltstone / quartzite, matured quartzite, silty & calcareous shale, limestone, quartzite with marine fossils	V
PALAEOZOIC (570 my.)	CAMBRIAN	Є, $PT_3^2Є$, $Pt_3Є$	Greenish grey sandstone, quartzite, grey & dark grey shale siltstone ± bands of limestone ± chert ± phosphorite	IV
PROTEROZOIC (670 my.)	VENDIAN	Pt_3^2	Limestone, dolomite with stromatolite, dark grey shale / slate with minor quartzite, diamictite, shale ± limestone	IV
PROTEROZOIC (900 my.)	III	Pt_3^1, Pt_{23}	Slate, phyllite, quartzite, grey shale, siltstone ± limestone ± gypsum; Metamorphosed in proximity of granite / Grey & purple quartzite, siltstone, dark grey shale/ slate, phyllite ± limestone	III
PROTEROZOIC (1600 my.)	II	Pt_2, Pt_{12} (?)	Ortho-quartzite ± basic volcanics & limestone / dolomite with stromatolite ± phosphorite ± syngenetic sulphide mineralisation	II
PROTEROZOIC (2500 my.)	I	Pt_1	Regionally metamorphosed katazonal metasediments of green schist and amphibolite facies	I
ARCHAEAN			NOT YET RECOGNISED (ABSENT) →	
			GRANITE & GRANITOID COMPLEX	

GOVERNMENT OF INDIA, 1992

Fig. 36 B

hair line cracks have come up on long walls. But no collapse has been reported in the buildings. Cracks have also developed in one or two cement plastered structures.

The damage to structures is more on hill slopes than on the banks of Mandakini. Also, the structures aligned in NE-SW direction have suffered relatively less damage as compared to those aligned in NW-SE direction.

Kedar Nath is an important pilgrim centre, located about 15km. north of Gaurikund, at an altitude of 3500m. The temple and other buildings like rest houses, shops, dharamshalas and residences of supporting staff are located on glacial moraine deposits. At the time of the visit, the winters had set in and the pilgrimage was closed, bearing an absolutely deserted look. But traverses in the area indicated that the Main Kedarnath Temple, a tall masonry structure with high rise shikhar, constructed on the pattern of medieval temples of South India, has not been affected to any appreciable extent by the shock except for opening up of joint between two masonry stones. A few wall collapses in other buildings of mud stone masonry have been reported. Since these have been repaired, only two such evidences were observed. The examination indicated that NE end of NE-SW aligned walls of two buildings showed partial collapses. A couple of deaths have been reported because of house collapse of a portion of Bilaspur Bhawan.

4 DELINEATION OF ISOSEISMALS

The MSK scale has been used for assigning the intensities to the damage patterns and delineation of isoseismals (Fig.36). An attempt has been made to delineate the epicentral tract and the boundaries of the higher intensity isoseismals on the basis of complete damage surveys while the lesser intensity isoseismals have been constrained by rapid reconnaissance and sample sruveys.

The epicentral tract has been determined by the following characteristic damage patterns: (a) Complete destruction of mud mortar and adobe constructions, collapse of stone masonry houses with thick walls and cement slabs damage to RCC column structures in the form of cracks in the pillars, minor rotations and heavy damage as well as collapse of partition walls, (b) Development of wide open fissures in the valley side slopes development of fissures in the formation cuts of the roads, collapse of the retaining as well as breast walls in large numbers, development of fissures controlled by the topographic setting in the hill side slopes occupied by overburden material, and (C) Initiation of innumerable landslides in the rock as well as terraced slopes with berms of less than 2m height. The area which displays all the above features have been included in the tract corresponding to the intensity VIII+. Within isoseist VIII a linear tract could be delineated around Maneri, Jamak and Dedsari which shows the maximum damage. The Maneri dam is located in this tract covering an area of about 20 Sq km. This has been designated as the meizoseismal area corresponding to intensity IX. In this area the damages include complete collapse of majority of poorly constructed houses, development of wide open fissures even in flat ground, and shaving of terraces. Also many constructions of type A suffered damage in the form of collapses or open cracks. Reinforced structures occasionally show collapse of pillars and conspicuous cracking.

The delineation of the isoseismal boundary of intensity VII and VIII has been done primarily on the basis of terrain changes as the damages to the constructions in the higher side of the intensity VII and start of the isoseismal VIII are almost identical. While considering the terrain changes the frequency and intensity of landslides, dimensions of ground fissures, and rock dislodgements have been comparatively assessed. In the intensity VII frequent rock dislodgements have taken place but failure of small height terrace slopes has not taken place. This has been taken as a criterian for separation of intensity VII from that of VIII.

Utilising the above criteria the isoseismal VIII has been drawn. This has been well constrained on the northwestern side but on the south-eastern end particularly for the inaccessible areas north and northwest of Budha Kedar, the information used for drawing the isoseismal VIII was scanty. The tract bounded by the isoseismal VIII is oblong in shape, the long axis of which is aligned in the N50°W-S60°E direction. The length of this tract is about 35km, and the width is about 18 km in the central portion. The isoseist VIII covers an area of about 441 sq.km. The boundary of isoseismal VIII passes from near the villages Gangori, Mannpur, Kishenpur, Kamand, Medh, Bhatwari, Raithal and Agora (Fig. 3A). The damage in this tract progressively increases from Gangori to Maneri and then progressively decreases towards Bhatwari.

4.1 Isoseismal VI & VII

The isoseismal VII has been drawn utilising the following observations. (a) General fright and panic and movement of furniture. (b) The Kucha mud mortar buildings suffering heavy damage in the form of wide open gaping cracks and collapse of walls as well as partition walls and the houses with thick stone masonry in mud mortar and RCC roof slabs collapsing in many cases. (c) The brick and stone masonry houses developing open cracks and shear cracks in the side walls particularly in those houses which are oriented in the east-west direction. (d) Initiation of rock dislodgements, failure of higher retaining walls and occasional development of fissures. The operative parameter utilised in differentiating the intensity VII and VI has been the initiation of rock dislodgements, because the other damages in the higher side of intensity VI are almost similar to those of beginning of isoseist VII. Moreover, well constructed reinforced structures are not available in all the localities and thus the operative minor damages, characteristic of isoseist VII are not available at all the locations for delineating the boundary of isoseismal VI and VII. For example, the village Bhainga in Pratapnagar Tehsil of Tehri district located on two high level terraces on a nose near the confluence of a north-south flowing nala and Jalkur gad has demonstrated local collapse of Kucha houses, shear cracks in the partition walls as well as end walls of a school building built on RCC pillars (which show minor cracks), and cracks in stone masonry houses. These damages are very close to that of isoseismal VII but other ground changes commensurate with isoseismal VII have not been recorded and hence this locality has been included in isoseismal VI. In the Bhaldiyana Suknidhar sector of the road, the isoseismal VII has been assigned on the basis of appearance of rock dislodgements, although the damages to the constructions in and around Lambgaon is almost similar to those of the higher side of VI.

The isoseismal VII passes north of Gangnani hot springs in Bhagirathi valley; near villages Rana and Gangani in Yamuna valley; 5km from Dunda towards Chinyali Saur on Tehri-Uttarkashi road; Lambgaon in Jalkur valley; near villages Silyara and Ghansali in Balganga and Bhilangana valley respectively; Gorthi and Jakholi villages and near villages Phata and Gauri Kund in Mandakini valley (Fig. 3A and 36).

4.2 Isoseismal V & VI

The boundary of isoseismal V and VI has been drawn primarily on the basis of damages of the form of fine cracks in the brick and stone masonry structures, gaping cracks in poorly constructed earthen houses and adobe constructions and occasional settlement of wet and unconsolidated ground resulting in cracks in a few well constructed buildings. In the isoseist VI such areas which show damages in the form of collapse to *kutcha* houses, damage of wide open gaping cracks in brick masonry constructions have been included though all these damages are located in the upper boundary of this isoseist. Many localities like those of Kalyani and Brahmkhal on Dharasu-Barkot road, Barkot and Purola townships in Yamuna valley, Bainga village in Jalkhur gad, Gansali village in Bhilangana valley show damages which are akin to those in the isoseist VII, but in the absence of terrain changes these localities have been kept in the isoseist VI. On the contrary small areas wherein the damage to constructions are of a lower isoseismal but due to reactivation of old landslides, as around Morang in Sutlej valley, have been included in isoseist VI.

The boundary of isoseismals V & VI passes near Sangla village in Baspa valley Himachal Pradesh (HP) and in the anticlockwise direction it passes through Saigad in Yamuna valley, cuts the Mussoorie-Dhanaulti road near Buras Khanda, near Chamakhal on Rishikesh Tehri road, near Maletha on Kirtinagar-Tehri road and near Bageshwar in Kumaon hills.

4.3 Isolated Highs of Isoseismal VI

During the course of the macroseismic surveys four isolated isoseists of intensity VI have been observed. One around Dehradun, one near Dugadda, north of Kotdwar in UP Himalaya, one around Timbi and one around Kunihar in Himachal. These areas are located within the isoseist V. These isolated isoseists are aligned in the NW-SE direction, and have their long axes in the same quadrant.

4.3.1 Dehradun Isoseist of VI

Dehradun town and its vicinity experienced a higher intensity than in the area around this town, like Rishikesh and Haridwar in the south-east, Mussoorie on the north and Harbertpur in the west all of which fall within the isoseist V. In Dehradun almost all the people were frightened and ran out doors. Many buildings, some of which are good constructions, developed cracks. Some Kutcha houses located in the surrounding villages developed gaping cracks, and a few walls also collapsed. Some of the important structures which have demonstrated these damages are the Main Block of the Forest Research Institute building, the Hilton Hotel in Dehradun, and the Mini cement plant near Rajpur.

4.3.2 Dugadda Isoseist of VI

The Dugadda area, like that of Dehradun, has experienced higher intensity of ground accelrations than its surroundings. These are reflected in the appearance of fine to open cracks, and bulging and partial collapses of masonry walls. The

Photo 106 *Cracks in walls of the staff quarters of Okhimath Public Health Centre.*

Photo 107 *Northward bulging in short wall of Okhimath Public Health Centre.*

Photo 108 *Partial collapse of first floor long wall of a house in Trijugi Narayan.*

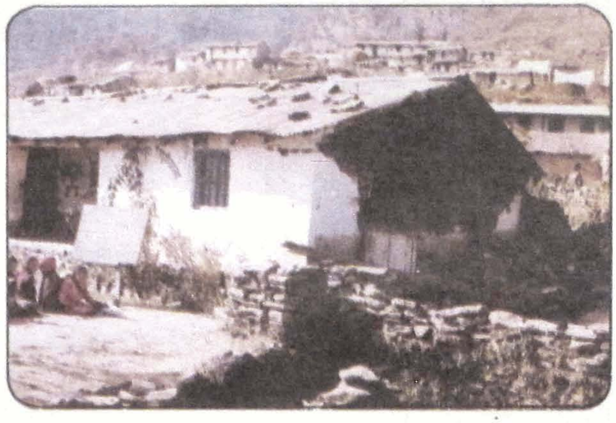


Photo 109 *Collapse of short wall of the School building, Trijugi Narayan.*

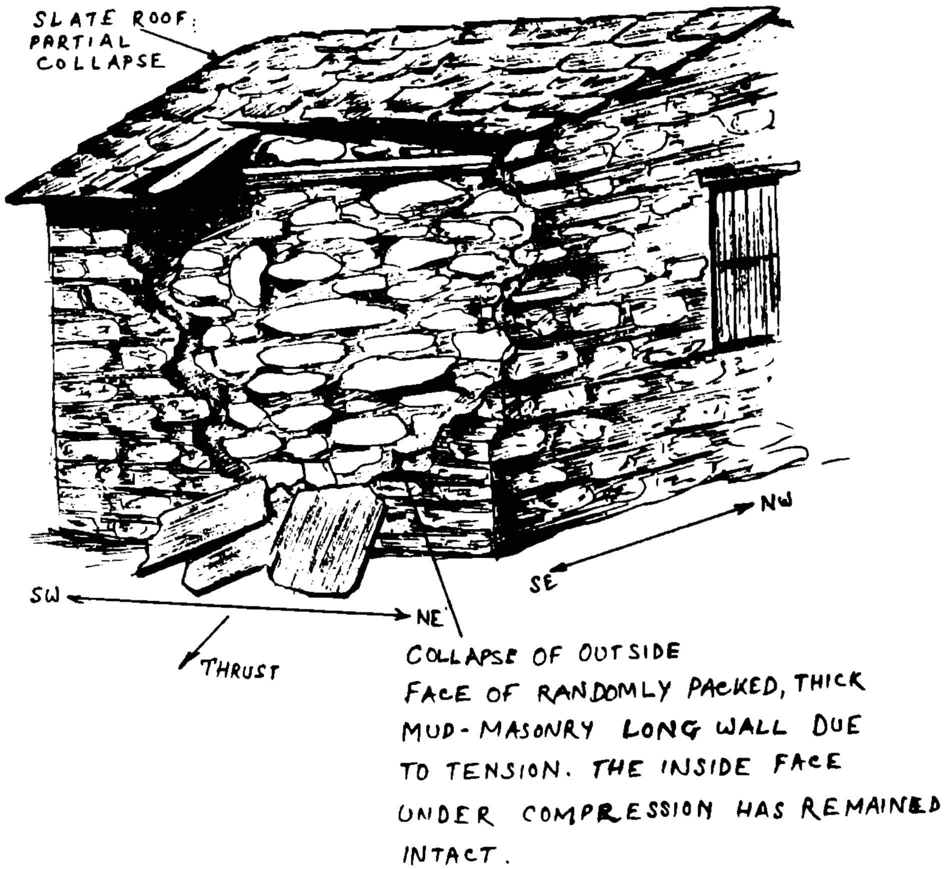
Photo 110 *Plaster fall of the house in foreground and partial short wall collapse of the house in the background at Gaurikund.*

Photo 111 *Total collapse of the first floor type–A house at Gaurikund.*

Photo 112 *Bulging and cracking around the ventilator and partial collapse of the gable portion of the PWD Rest house, Gaurikund.*

Photo 113 *Separation and cracking of chimney in the out house of PWD Rest House, Gaurikund.*

Photo 114 *Horizontally cracked minaret of a mosque, Dugadda.*



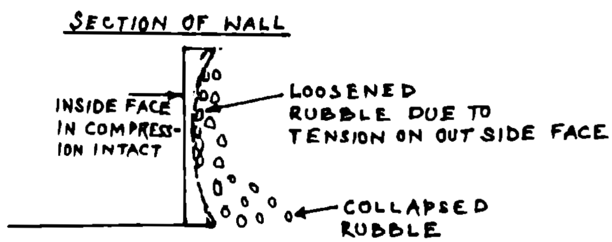


Fig. 37 : PARTIAL COLLAPSE OF MUD MASONRY WALL UNDER TENSION, GAURI GRAM, DUGADDA (SKETCH BY P. PANDE)

residents of Dugadda reported a series of strong shocks in a span of few seconds which resulted in the falling of utensils and furniture thereby creating a sense of general panic. One of the road side minarets of the village mosque, approximately 10m in height, although not thrown off, has severed in the middle along a horizontal plane (Photo 114). The adjoining village of Gram Gauri, located over a terrace deposit, shows the maximum damage in the area. Here, in one poorly constructed house, the outside face of the long mud-masonry wall, trending NE-SW, has partially collapsed (Fig.37). Few other such walls have bulged out. Another well constructed type-B house shows development of prominent, open shear cracks. The damage patterns to civil structures correspond to an intensity of VI.

4.3.3 Timbi Isoseist of VI

The macroseismic surveys in the eastern parts of Himachal Pradesh have indicated that in a localised area around village Timbi in Kamrau tehsil damage patterns in the constructions indicate an intensity VI, though in the surrounding areas only intensity V could be assigned. The boundary of this isolated high has been drawn by utilising the data of the damages in the Tons valley, particularly Ichari dam and Chhibro Power House areas, wherein damages higher than the intensity V levels have been recorded. Three Kutcha houses collapsed in Timbi and a B type of construction in Baldwa had developed shear cracks in the sidewalls.

4.3.4 Kunihar Isoseist VI

Similar to the localised high of Timbi, damages in village Kunihar, west of Shimla and south of Arki, have been assigned intensity VI within the isoseist V. As this is a very small area encompassing only one village the envelop of this isoseist has been drawn guided by the general trends obtained for other isolated highs in Timbi as well as Dehradun area. In Kunihar area 20 houses of adobe type have suffered severe damage with partial collapse of walls in 6 houses and gaping cracks in many others.

4.4 Isoseismal IV & V

The questionnaires about the effects of this earthquake in different parts of the North-western India have been analysed and the boundary of isoseismal IV-V has been drawn on the basis of this analysis (Fig. 36). This boundary passes near Kullu and Mandi in Himachal Pradesh, Ambala in Haryana and Muzaffarnagar, Kanth and Pilibhit in U.P. and then enters the Napelese territory.

It has, however, been noticed that the Delhi-Sonepat sector has experienced shock which could be attributed the intensity V though the surrounding areas fall in intensity IV. The intensity V has been assigned to the Delhi area on the basis of general awakening, fall of objects, swinging of hanging objects and isolated cases of reported cracks in plaster of some buildings as well as stoppage of a pendulum clock.

5 INTENSITY DECAY PATTERNS

The macro-seismic studies for this earthquake have indicated that the general trend of the Meizoseismal area is N50°W-S50°E and the shape of the epicentral tract, which has touched intensity IX on the MSK scale is elliptical with a length of about 9.5km and a width of about 3.25km. The highest damage in this isoseist is located between Ghorsali and Jamak villages. The decay and/ or accentuation patterns in isoseismals of lower intensities have been related with the geographical location and disposition of the epicentral tract long axis.

The isoseismal VIII has its long axis almost parallel to the epicentral tract and extends for a distance of 35km. With reference to the centre of the epicentral tract, the extension of this isoseismal in the NW direction is 15km, while in the south-eastern side it is about 20km. The attentuation of intensity with distance is much higher as shown by the ratio of the length of the short axis south-west of the epicentral tract to that on the northeastern side.

The asymmetrical behaviour of the isoseismal VII and VI is much more pronounced and the attentuation in the northwestern direction is much faster than that in the southeastern side. The attenuation in the southwestern quadrant is also very much pronounced. The dimensions and other parameters of these isoseismals are tabulated below:

Isoseist	Area in Sq.km.	Long Axis - a Length in km.	Short Axis- b Length in km.	Distances (in km) From the mid point of Epicentral tract			
				NW	SE	NE	SW
IX	20	9.5	3.25	-	-	-	-
VIII	441	37	18	17	20	11	7
VII	2415	85	47	27.5	57.5	27	20
VI	23,930	240	150	70	170	100	50

It is apparent that the intensity decay is much quicker in the NW quadrant along the long axis while the same is true for the short axis on the south western side. Apparently, there is no lithological control to effect such a pattern because there are no lithological contrasts which could explain this behaviour. Other possible reasons for such patterns are as under:

The sharp attenuation of the isoseismal VII on the Yamuna river side could have been due to damping caused by a transverse feature which is of a fundamental nature. It is very difficult to correlate this feature with some of the transverse features (faults) geologically mapped, though a number of them namely the ones passing south of Gorsali and Saura villages, the Hinna fault, the Gangori fault along Aasi ganga, the Kawan-Bason fault and the Panjala fault have been mapped by Agarwal and Kumar (1973) between Bhagirathi and the Yamuna valleys. The existance of a number of such features suggests that there is a system of north-south to NNW-SSE extending faults in the area and there is a possibility of presence of a major tectonic break of fundamental nature which might have effected the attenuation. Based on the study of the seismicity of the region Narula (1991) has interpretted a transverse tectonic flux fault in this vicinity and thus there is a possibility of existance of a fault which has brought different velocity contrast materials in juxtaposition and thus could have caused such an abrupt decay in the intensity.

The above reasoning, though explains the abrupt/sharp attenuation along the long axis of the isoseismals but the anamolous behaviour particularly extension of the short axis in the north-eastern quadrant needs alternative explanation.

It is possible that this assymetrical behaviour of the isoseismals is because of the dip of the seismic source involving more energy in the dip direction than that on the sector which is against the dip as in the northeastern quadrant deeper portion of the source fault could have got activated resulting in more area to have experienced the influence in the down dip direction. By similar analogy it could be possible that the accentuation of intensity in the SE quadrant for main axis of the isoseismals has resulted because of fault propagation in that direction.

6 INTENSITY ACCENTUATION

The field surveys have indicated that the intensity of damage has got accentuated in certain localities resulting in isolated higher intensity contours within the lesser level isoseists. It is well known that these accentuations could take place in isolated localities because of a particular geological condition like thick deposits of unconsolidated sediments over the bedrock on which constructions have been made, topographic conditions of isolated spurs or mounds the time period of vibration of which could be different from the general ground conditions. In fact, these ground conditions coupled with the type and orientation of construction, accentuate the damages and in certain cases these damages go beyond the limits of a particular isoseist and thus it becomes imperative to demarcate higher intensity contour. Some of the accentuations could also be related to the source machanism characteristics.

The intensity accentuation at Bhainga village of its having attained level of VII intensity within VI isoseist could be due to topographic as well as lithological conditions on a nose which is aligned almost in the direction of wave propogation (direction of wave approach) as established from its location vis-a-vis the epicentral tract location. Similarly intensity VIII has been reached at a locality Thati Bharkote on Dhauntari - Kamand sector. In this accentuation has been probably due to the topographic reasons as the maximum damage is confined in the NW-SE aligned nose, the long axis of which is many times more than its width.

Anomalous Intensity Accentuations

It has been discussed in the earlier chapters that within the isoseist V there are localised intensity highs around Dehradun and Dugadda in U.P Himalaya and around Kunihar and Timbi in Himachal Pradesh. All these VI intensity isoseismals follow NW-SE trend and are located almost along a line. These intensity highs cannot be explained either by the lithological conditions or by particular topographical conditions except the Dehradun area which has history of giving localised intensity high.

The intensity high around Dehradun is located south of the Main Boundary Fault (MBF) and the northern boundary of intensity VI passes very close to its surface trace and damages are also more near this boundary, particularly in Rajpur, Khera, Kulhan block, Rajpur-Thano-Bhogpur block and Dobhri-Sarna-Langha block. All these villages are located in the vicinity of the MBF. During the 1905 Kangra earthquake, a local high of intensity VIII on Rossi Forel Scale was assigned to this area while the surrounding areas were of lower intensities. This local intensity high could be attributed to accentuations because of the Doon valley fill deposits overlying the Siwalik rocks.

In the Kotdwar-Dugadda sector, similar intensity accentuation has taken place. This anomalous intensity high of VI is also located between the MBF and the Foot Hill Thrust and has a limited linear extent.

A localised intensity high has been observed in the Himachal Pradesh around village Timbi and the extent of damages caused to the engineered structures in the vicinity of Koti dam, Chhibro Power house and Khodri Power House. The boundary of this accentuated intensity is based on these damage patterns. Similar intensity high, a localised one has been recorded around village Kunihar.

These high areas are located north of the MBF and cannot be explained either with respect to geological environment or by topographic accentuation. These could be related to localised release of stresses from the asperity surfaces where strain build up is takeing place. The Delhi isoseismal high of intensity V within IV may possibily be explained by lithological accentuation caused by the deep flood plain fill of Yamuna. This fill has been designated by Sinha (1986) as the Shahdara surface covered within the Faridabad surface.

7 EPICENTRAL LOCATION

The Meteorological Department of India, in its first report on the epicentral location indicated that the epicentre of this shock was located at Lat. 29.8 degree and Long. 79.8 degree east which falls in the Almora district (Kamble 1991). The magnitude of this earthquake which occured at 02 hrs. and 53 min. IST was reported to be 6.1 on Richter scale. The details of the instrumental record of this shock are included in a separate paper in this volume.

The damage surveys conducted by Geological Survey of India, however, have indicated that the epicentral tract of this earthquake lies between distances 10 km. NE of Uttarkashi to 15 km. East of Uttarkashi. The ends of this epicentral tract are marked by points at Lat. 30.72 degree : Long. 78.59 degree and Lat. 30.78 degree : Long. 78.50 degree.

The department of Earthquake Engineering, University of Roorkee have determined the epicentre at Lat. 30.8°N : Long. 78.6°E on the basis of strong motion records from the stations in the vicinity. This location is reasonably close to the one demonstrated by the field surveys conducted.

The preliminary epicentral location determined by NGRI and the Geoscope Project is Lat. 30.756 : Long. 78.56 and that by USGS is Lat. 30.73 : Long. 78.79.

The IMD have revised the earthquake parameters after the first determinations and the final parameters given by them are (Joul. Geo. Sur. Ind. 1991):

Epicentre : Lat. 30.75°N : Long. 78.86°E
Depth : 12 km.
M : 6.6 (Wt. 10 stns)
O : 21h 23m 16.4 sec. GMT (Wt 9 stns)

It is observed that the epicentral location of this earthquake as determined by various agencies has a good fit with the meizoseismic area except for the ones suggested by the IMD and the USGS. The field surveys also corroborate that the locations suggested by Dept. of Earthquake Engineering, NGRI and GEOSCOPE fall within the epicentral tract (GSI) of the earthquake (Fig.40).

It is observed by certain workers that the epicentral location may not always coincide with the maximum damage areas explaining the same either by focusing or by fault propagation which could result in maximum damage areas away from the epicentre. It was reported in the media that even if the epicentre was as reported by IMD in the first report the damages could take place as far away as Uttarkashi.

8 INTER-RELATIONSHIPS OF EARTHQUAKE PARAMETERS

The consensus magnitude of this event has been computed as 6.6 on the Richter scale as indicated by India Meterological Department and the depth of focus as 12km. The macroseismic studies conducted by the Geological Survey of India have indicated that in localised area, an intensity of IX has been reached in a linear tract. The depth of focus can also be computed by using empirical relationships suggested by a number of researchers for shallow focus earthquakes. According to Gzovsky (1962) (i) the focal depth could be calculated by the relationship:

$$I_0 = 1.5M - \frac{h}{15} \qquad \text{- (i)}$$

and the same for this earthquake works out to be of the order of 13.5 kms. According to N. Shebalin's empirical relationship (ii)

$$I_0 = 1.5M - 3.5\log h + 3 \qquad \text{- (ii)}$$

where I_0 is the epicentral intensity, M is the magnitude and h is the focal depth, the focal depth works out to be of the order of 13.01 km.

By utilising the differential areas occupied by successive isoseists and the radii of these isoseists the focal depth could be calculated by the relationship

$$\frac{1}{3}h = \frac{AI_n - AI_{(n-1)}}{r_n^2 - r_{(n-1)}^2}$$

Where AI_n is the area of a particular isoseist while AI_{n+1} is the area occupied by the next higher isoseist. r^2_n and r^2_{n+1} are the mean radii of the successive isoseists. Using isoseismals VIII and IX the depth of the fous works out to be 7.7 km, for intensity VII and VIII it works out to be 7.8 km. while for intensity VII and VIII it works out to be of the order of 9.1 km. This simple relationship is free from the maximum intensity reached from a particular event and thus would be relatively free from personal bias of assigning the maximum intensity. It is seen that the depth of focus from the instrumental data as well as that determined from macroseismic epicentral intensity felt areas in progressive intensity scale, are comparable.

A number of empirical relationships have been suggested by researchers to correlate the intensities with the maximum ground accelerations and two such relationships suggested by Gutenberg and Richter (1942) and Neumann (1955) have been represented in Fig.38. The maximum ground accelerations obtained from these relationship are as follows:

Intensity	Gutenberg (1942) Max. Ground Acc in cm/Sec²	Neumann (1955) Max. Ground Acc in cm/Sec²
VI	35	75
VII	75	140
VIII	140	260
IX	300	560

The isoseismals drawn by the authors of this report have been compared with the ground accelerations obtained from the strong motion records (Chandrasekhran & Das 1991). From these correlations following inferences have been drawn.

Two stations namely Tehri and Srinagar are located very near the isoseismal VI. The ground accelerations (Max.) at these locations are also comparable i.e. 0.073 and 0.065, respectively. Similarly the localities Barkot in Yamuna valley and Ghansali in Bhilangana valley which are located very near to the isoseismal VII show comparable max. ground accelerations of 0.104g and 0.138g respectively. Out of these localities Ghansali is located nearer to the isoseismal line VII, than that of Barkot and thus little higher values are explained. Uttarkashi and Bhatwari lie very close to the isoseismal line VIII one on the southern side and the other of the northern side of the epicentral tract. These locations give accelerations of the order of 0.303g and 0.273g. respectively. The above comparions indicate that the isoseismals drawn on the basis of damage pattern studies can be compared well with the instrumental accelerations.

The maximum ground accelerations obtained near the isoseismals VI, VII and VIII have been plotted in Fig.38 on which the two empirical relationships suggested by Gutenberg & Richter (1942) and Neumann (1954) have been plotted. It is seen that the instrumental data compare well with the relationship suggested by Neumann (1954).

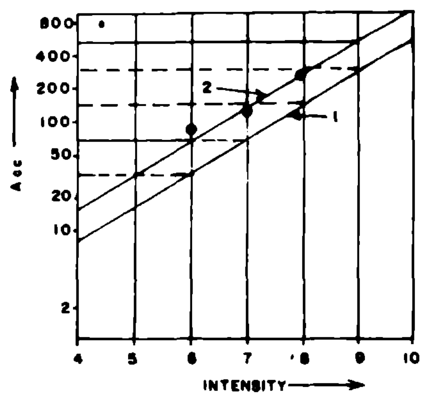


Fig.38: EMPIRICAL RELATIONSHIPS BETWEEN THE INTENSITY AND MAX. GROUND ACCELERATION. 1-ACCORDING TO GUTENBERG AND RICHTER (1942) 2-ACCORDING TO NEWMANN (1954)

Some of the empirical formulae reported in the literature for attenuation of the accelerations at particular distances from the hypocentre with given magnitude of earthquake have been used to calculate the accelerations at stations where different intensity contours are passing. In all these relationships certain amount of attentuation has been related with the hypocentral distance. In view of the asymmetric pattern of the isoseismals, and the elliptical shape of the same it is clear that none of these relationships could be reasonably correlated with the isoseismals. For example, the isoseismal line of intensity VI passes from very close to Tehri as well as Srinagar but these stations are located at a distance of about 44km and 63km from the epicentre of this earthquake. According to the attenuation relationship suggested by Campbell (1981) the expected accelerations at Tehri and Srinagar work out to be of the order of 67.26 cm/sec^2 and 47.39 cm/sec^2 which are not consistent either with the isoseismals nor with the instrumentally recorded values which are almost same at both these stations. The isoseismal VIII passes close to Uttarkashi and Bhatwari which are located at distances of about 16km and 5km from the epicentre with hypocentral distances of about 18km and 11km. These stations would also give different accelerations based on any of the empirical relationships. It has also been pointed out in the chapter on intensity decay patterns that the attenuation in the northwestern quadrant is much more than that in the southeastern quadrant. Thus these empirical relationships do not explain these characteristics. As the isoseismals compare well with the instrumental data of almost similar values of peak ground accelerations along the isoseismal lines, it could be said that well constrained macroseismic studies have their own merit for estimating the ground accelerations and cannot be replaced by any empirical relationship and widespread strong motion instrumentation networks may be the only answer. Incidentaly the area which has been struck by this earthquake has been covered by a very good network of strong motion instruments.

9 PATTERN AND DISTRIBUTION OF AFTER-SHOCKS

This earthquake was followed by a number of after shocks the frequency of which has shown a rapid fall from more than 150 on the 21st October, 1991 to less than ten by the end of November. The stations located far away from the epicentral tract have recorded lesser number of shocks. The after-shock decay pattern at these stations is depicted in Fig.39. It is seen from this plot that the stress drop is very rapid, and near the epicentral tract the number of after shocks have fallen from more than 150 on the first day after the main event, to 70 on the 4th of November, and 40 on the 9th Nov. Within a period of about 3 to 5 weeks the after-shock number has fallen to about 15 shocks per day. At stations which are located at quite a distance the after shock number has fallen down to 4 to 5 shocks per day.

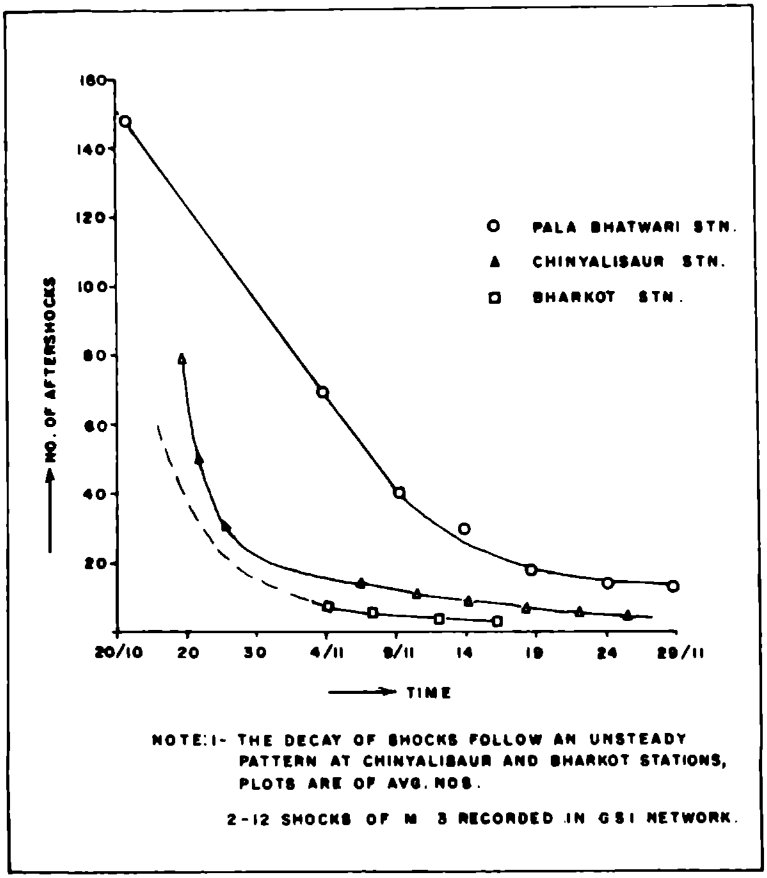


Fig.39: AFTER SHOCK DECAY PATTERN.

Only limited data is available on the epicentral location of the after shocks. These epicentral locations fall on the south-eastern and the northeastern side of the epicentral tract as well as the instrumental epicentral location of the main shock. The epicentral locations (various determinations) of the main shock and those of the aftershocks are depicted in Fig. 40. For a detailed evaluation of the aftershocks refer Kayal et al in this volume.

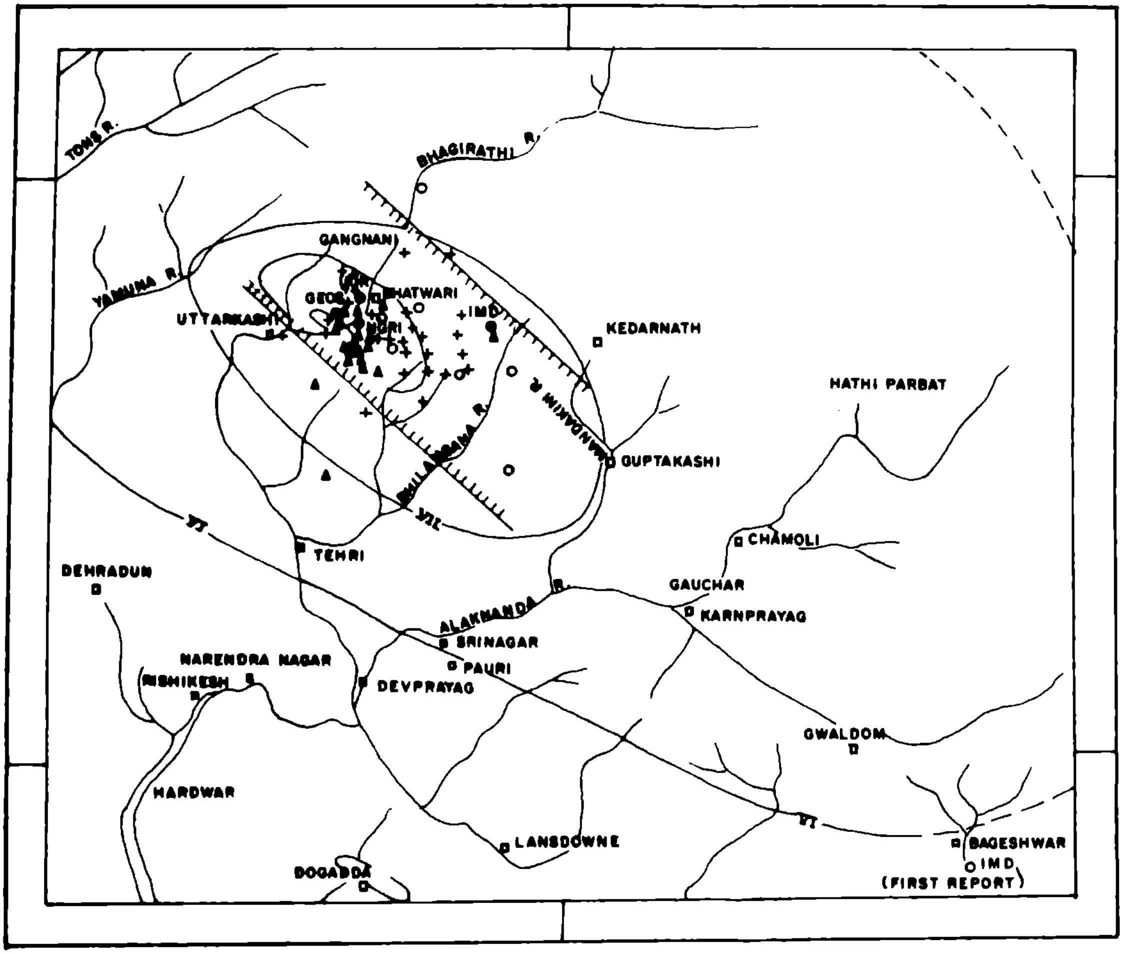


Fig.40 EPICENTRAL LOCATIONS OF THE MAIN AND AFTER SHOCKS. MAIN SHOCK LOCATIONS IN SOLID CIRCLES AS PER VARIOUS AGENCIES. OPEN CIRCLES-AFTER SHOCKS OF FIRST DAY. CROSSES-AFTER SHOCKS AS PER JOUL. GEO. SOC. IND. VOL. 39, 1992. SOLID TRIANGLES -AFTER SHOCKS AS PER G.S.I. DATA. HATCHURED AREA ENVELOPS THE AFTER SHOCKS.

10 SOURCE DIMENSIONS

A number of general empirical relationships between magnitude of shallow focus earthquakes and the volume of deformed region and the length and amount of displacement on activated surface faults have been known for more than two decades. The relationship of logarithm of fault length to magnitude is the most widely used relationship particularly for those areas for which maximum probable earthquake estimates have to be made for engineering purposes. The Fig.41

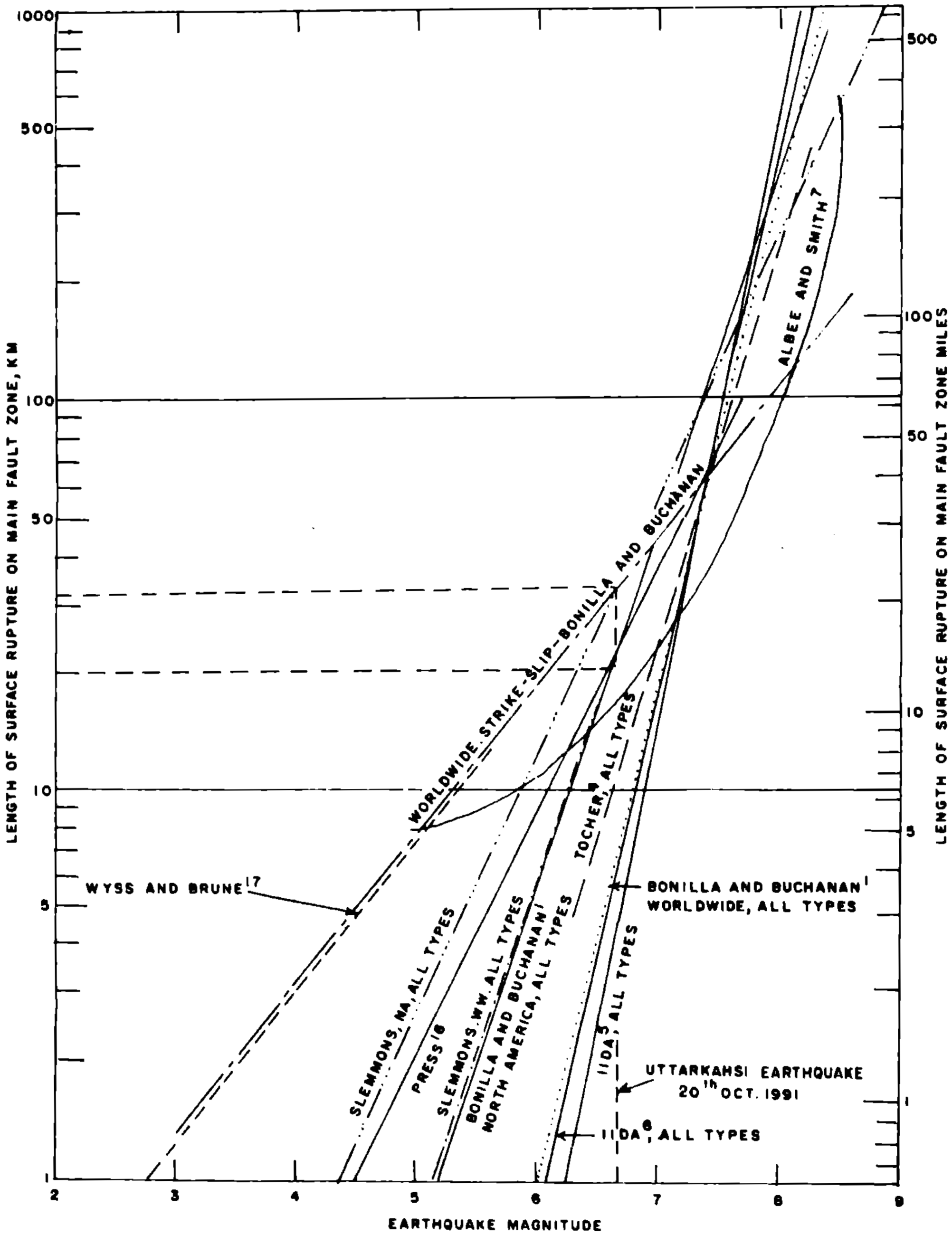


Fig. 41 : RELATION OF EARTHQUAKE MAGNITUDE TO LENGTH OF FAULT.

summarises the straight line correlations published by various workers. In these studies the type of the deformation responsible for sets of events have also been classified and different empirical relationships have been suggested. It is interesting to note that, these average straight line relationships (considering all types of deformations) give different values of fault lengths involved for generating a given magnitude earthquake. For example, for a magnitude 6.6 earthquake (the case under study) the fault length which could have generated this earthquake turns out to be about 4km. (Iida all types), 10km (Tocher all types), 20km (Slemmons, W.W. all types as well as Bonilla and Buchanan) and 32km (by Wyss and Brune as well as world wide strike slip of Bonilla and Buchanan). If the relationships for the reverse slip and reverse oblique slip deformations are considered the fault length which could have been involved for a magnitude 6.6 earthquake would be less than 10 kms.

The field surveys conducted by the authors did not reveal any manifestation of surfacing of the source fault. It is, therefore, very difficult to prefer any of the relationships suggested above.

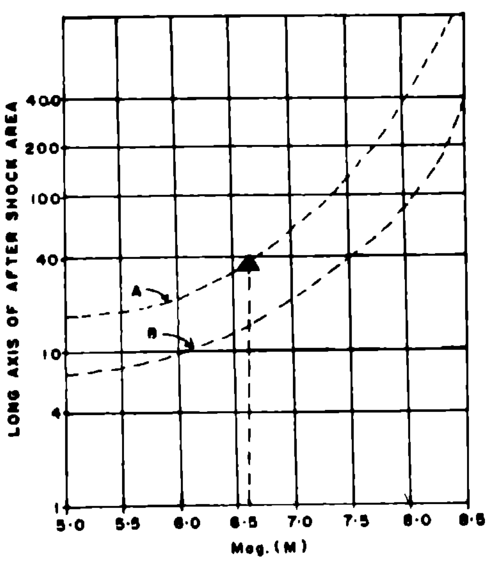


Fig.42: RELATION OF EARTHQUAKE MAGNITUDE TO LONG AXIS OF AFTER SHOCK AREA. CURVE 'A' IS APPROX. LIMITING CURVE AND CURVE 'B' IS CURVE OF BEST FIT. SOLID TRIANGE IS PLOT OF PRESENT EARTHQUAKE VIS-A-VIS LONG AXIS OF AFTER SHOCK AREA.

Albee and Smith have tried to compare the fault length versus the magnitude with those of the long axis of the after shock area and have suggested that the shallow focus earthquakes without surface faulting fall on the same curve as those which show surface faulting (Fig.42).

From the epicentral locations of the aftershocks based it could be interpretted that the aftershocks are located within a 25km. wide band the long axis of which is almost parallel to the epicentral tract and extends to a distance of about 40km. If this length of the long axis of after-shcok area is plotted in the curve suggested by Albee and Smith the plot of this event with 6.6 magnitude lies very close to the limiting A curve. From this it could be surmised that the maximum fault length which could have been activated by a source for this event may not have been more than 40 km. The other relations discussed earlier give fault lengths much less than this figure.

11 GEOTECTONIC SETTING AND SOURCE MECHANISM

The maximum damage area of this earthquake is located in the Garhwal Group of rocks comprised of Nagni Thank formation, Shyalna formation and Uttarkashi formation (Agarwal and Kumar 1973). The epicentral tract is predominently located in the Gamri quartzites of Nagni Thank formation while the area occupied by intensity VIII encompasses all the formations of the Garhwal Group. The northeastern and eastern parts of this isoseist are located in the central crystallines comprised of migmatites and amphibolites. The Garhwal Group of rocks have been brought in juxtaposition with the Dudatoli Group of rocks along a major tectonic surface, the Srinagar thrust (North Almora Thrust of Agarwal and Kumar 1973) which is a steep angle (dip varying between 45°-80°) fault dipping in the northeast direction in Bhilangana valley and in the southwest direction as encountered in the head race tunnel of Maneri-Bhali (stage-II) project. The Garhwal Group of rocks are juxtaposed with the older Central Crystallines along a well known regional tectonic surface, viz., the Main Central Thrust.The epicentral tract of the present earthquake is located about seven km. south of the surface trace of this tectonic lineament. In addition to these two regional tectonic lineaments, the Garhwal Group of rocks have been traversed by a number of faults trending in the N-S direction like Hinna fault, Kaldigad fault, Kawan fault and Panjala fault exposed north of the Bhagirathi valley (Fig.42b). Another conspicuous set of faults trends in the ENE-WSW direction and most of the N-S trending faults merge with this set of faults.

Near the epicentral tract one ENE trending fault passes below Jamak village and another is very conspicous in the vicinity of Aghora village cutting across Aasiganga (Utron-Saura fault).

The record of earthquakes from Garhwal Himalaya indicate that these are mainly clustered along the surface trace of the MCT. This domain has not been frequented by earthquakes of magnitude >4<5 but the earthquakes of magnitude >5<6 and >6<7 are much more frequent than other sectors of the Himalayan belt and thus as far as total energy release is concerned this domain is comparable to the high concentration areas like that of Kangra, Kinnaur and Kashmir Syntaxis.

The tectonic flux map prepared on the basis of total energy release in 1°/2X1°/2 grid pattern by Narula (1991) has indicated that there are three prominent tectonic flux faults, one west of Uttarkashi, other along the Alakananda valley and the third in the vicinity of the Indo-Nepal border in Garhwal and Kumaun Himalaya. These faults trending in the NE to NNE direction have been interpretted as fundamental fractures. It has also been contended by Narula (1991) that, the Main Himalayan Seismotectonic Belt displaying the thrust type of deformation styles could be divided into sub-domains because of the presence of transverse features across which contrasting geophysical attributes are interpretted to have brought crustal blocks of different properties in juxtaposition. It has also been argued that the domains of strain build up in different sectors is at different locales with respect to the surface trace of the tectonic features. It has been claimed that in Garhwal and Kumaon Himalaya the strain build up is taking place in the vicinity of the MCT while in the adjacent Himachal Himalaya the same is taking place in the vicinity of the MBF. As far as the tectonic model (steady state) suggested by Seeber et al (1981) and supported by Ni and Barazangi (1984), the MCT, MBF and other thrusts located further south are concerned, they are all imbrications along a decollement and merge in depth with a low angle northerly dipping detachment surface. Thus any of these surfaces could be the domains of strain buildup and stress release in contemporary times. In certain sectors strain buildup seems to be taking place along MCT and in others it is in the vicinity of the MBF. According to the subdomains suggested by Narula (1991) the Garhwal earthquake of October, 1991 falls in the Garhwal block constrained by Alkananda tectonic flux fault in the east and the Kinnaur fault on the west. This domain contains another tectonic flux fault which is located west of the locale of the present earthquake. It has been discussed earlier that there is abrupt attenuation of intensity in the Yamuna valley as demonstrated by the instensity VII. It is possible that the interpreted tectonic flux fault mentioned above could have been responsible for

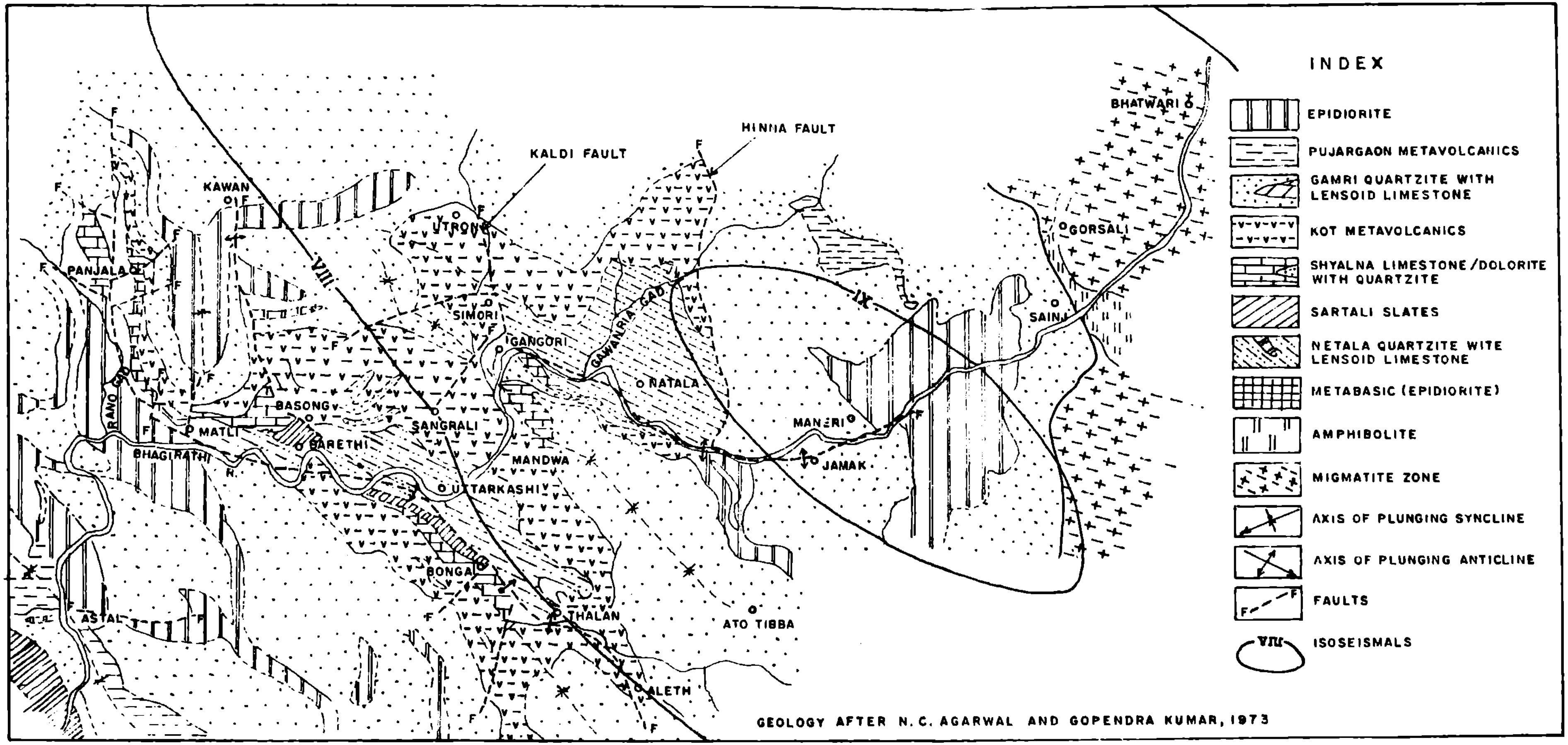


Fig. 42 A : DETAILED GEOLOGICAL MAP OF UTTARKASHI AREA SHOWING IMPORTANT TECTONIC LINEAMENTS.

the abrupt damping as a media having higher attenuation characteristics might have come in juxtaposition. It has also been contended by Narula (1991) that the locales of strain build up are in the vicinity of intersection of the underthrusting detachment surface and the transverse block boundaries. It is possible that the source region for this earthquake is in the vicinity of this intersection and the rupture propagation might have taken place in the south easterly direction. It has been discussed earlier that the epicentral locations of the after shocks are located in a 25km wide band which has a general trend of N60°W--S60°E. All these earthquakes, particularly those which have immediately followed the main shock are located in the south eastern direction of that of the main shock, located near Maneri and thus it is likely that the rupture propagation might have taken place in the south easterly direction. Accentuation of the isoseismals in the southeasterly direction could also be explained by such a reasoning.

From the disposition of the epicentral tract, the isoseismal patterns and the aftershock locations it could be interpretted that the source feature is somehow aligned in the N60°W-S60°E direction. The only regional feature in the vicinity of the epicentral tract, having the above disposition is the Main Central thrust, though this has been modified near the surface by transverse features. It is understood that the MCT is dipping in the northerly direction. If we take the fault plane to have been on the MCT, the epicentral tract should have been located about 15km further north of the location inferred from the macroseismic surveys. Thus, a simple correlation of this event with the MCT itself is not possible. While discussing the seismicity patterns in the Garhwal and Kumaon Himalaya it has been mentioned by Narula (1991) as well as Khattri et al (1989) that the epicentres of the past earthquake events are clustered around the MCT. Even the clusters of microseismic events obtained by studies conducted by Department of Earthquake Engineering during periods June (1974 to May 1977) and later by Khattri et al (1989) between 1979-80 and again between 1984-86, lie predominantly south of the surface trace of MCT. If northerly dip of MCT is considered, none of these events could be explained by MCT and the picture demonstrated by the present event is no different. It is, therefore, possible that the basement thrust front is located south of the surface trace of MCT in the Garhwal block (Fig. 43).

It is opined that the lower levels of the basement thrust regime is dissected by a strike slip fault with minor thrust component, overlain by low angle detachment surface. It is possible that the source mechanism of this earthquake has both thrust and strike slip components. It may, however, be pointed out that the source mechanism would become clearer when the focal mechanism studies for this earthquake are conducted. Howerver, a preliminary fault plane solution (USGS) suggesting thrust type of mechanism with strike slip component has been included in the IMD report (this volume).

The macroseismic surveys, detailed earlier, have indicated four isolated highs of intensity VI within isoseist V aligned almost parallel to the trend of the regional thrust surfaces. As already discussed these cannot be attributed to local accentuations like topography or geological environment except probably for the Dehradun area. Therefore, a genetic relationship with the source mechanism could be attributed.

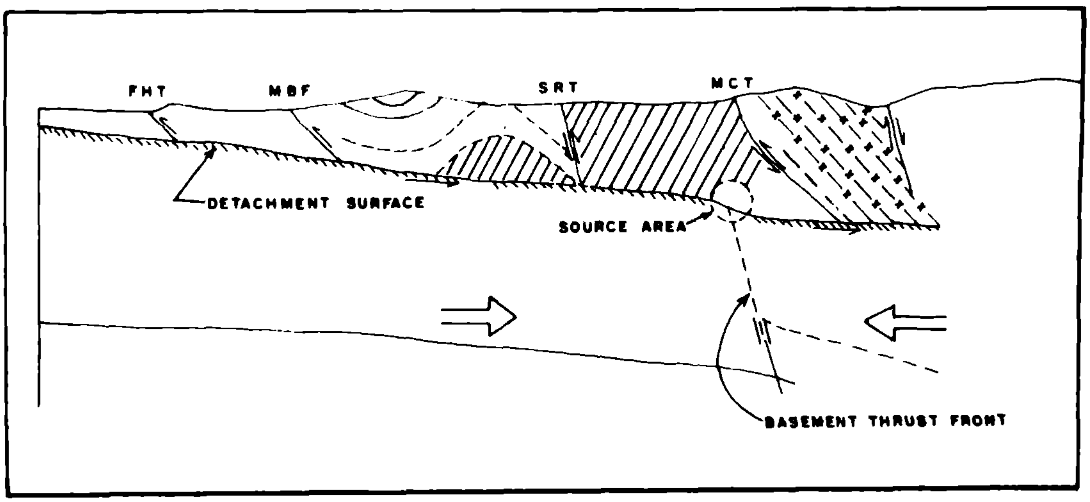


Fig. 43: SCHEMATIC DEPICTION OF THE MECHANISM OF THE UTTARKASHI EARTHQUAKE.

12 GENERAL OBSERVATION

This earthquake has caused unusually high degree of terrain changes in the form of a number of dislodgements, initiation of landslides, reactivation of old slides, generation of ground fissures (mostly in the areas occupied by overburden material). Such terrain changes are not unusual in the intensity VIII and IX but the number of dislodgements even in the intensity VII and some in the intensity VI are also very high though they are controlled by the lithological conditions being most pronounced in the highly jointed quartzites and basic intrusive bodies. Even in the lower levels of intensity VI, the loose terrace material on low height slopes have been thrown out on the roads as evidenced in the Srinagar area where small pebbles were scattered on the road for considerable stretches. These unusually high incidences of dislodgements could be related to the long duration of the shock which lasted for more than 45 sec. The long duration shock would loosen the rock blocks or loosely packed terrace material in the initial wave propagation and with the continued movement dislodgements have taken place.

Accentuations are expected to be higher at higher elevations in similar lithological conditions and the constructions at higher elevations should show greater damages. Contrary to this, the damages to the constructions, in certain localities as in Uttarkashi town, is much more in the open lower level terraces than those hugging the hill slope at comparatively higher elevations, even in the houses of same category and of similar orientations. Such an anomalous behaviour could be explained by the difference in the time periods of vibrations. The constructions in the open spaces have vibrated with their independant periods while those hugging the hills had their periods dampened by the nearby hillmass.

The damages to the constructions have got accentuated in the areas located on narrow spurs aligned in the direction of wave propagation as evidenced at Jakholi, Gorthi and Bhainga. The extent of damages in similar spurs oriented across the direction of wave propagation is comparatively lesser.

Damages to the constructions in the isoseists VI and VII is much more in the buildings, with the long walls oriented along the direction of wave propagation. In cases where the shortwalls are parallel to the wave propagation the damages to the buildings are comparatively lesser. The square type of buildings have suffered much lesser damage except the slender one's like small dimensioned temples in which one set of walls have failed under shear. In fact what follows is that if length (L) is greater than the width (W) the damages are more but as L reduces and approaches to W i.e. the building becomes square the damages get reduced. However, in smaller L=W type temples where height (H is greater than L or W, it vibrates like a pillar and is again prone to greater damage.

The conventional constructions, made in mud mortar masonry with wooden braces at the roof levels, small openings in walls, wooden bracings, wooden roof rafter and relatively lighter roof coverings by slates or G.I. sheets have suffered lesser damage in the form of collapses than those built in mud masonry thick walls with RCC roof slab. This has been observed in most of the cases though some of the old conventional types of houses have also collapsed but these have happened only for very old constructions wherein the wooden members as well as the walls have lost their strength. Contrasting situations have been observed in the Bhagirathi and Mandakini valleys. In Bhagirathi valley in isoseists VI and VII many houses have been built in mud masonry walls with RCC roof slab while in Mandakini valley the conventional type of constructions predominate. In Mandakini valley the cases of collapses are much less than those of Bhagirathi valley and though open shear cracks have developed in the walls the lighter roofs have not collapsed.

Another interesting observation is that whereever the long axis of the houses are transverse to the wave propagation the long walls have escaped damage and only near the junction of the walls near vertical cracks have opened up from the roof down to the floor. Possible explanation for this rather unusual behaviour is that the larger bearing area of the longwall has minimised the damaging capability but in the shorter walls because of the thrust the contact area in the corner has been under concentrated thrust and vertical cracks have opened up. However, this is only true for the area lying towards the lower side of VII but in higher isoseismals both walls display shear type of failure.

13 ACKNOWLEDGEMENTS

The authors take this opportunity to express their sincere thanks to Shri C.P. Vohra, Director General, Geological Survey of India for his keen interest and motivation to launch this work and bring it to fruition. They are also thankful to Shri S.N. Chaturvedi, Dy.Director General, Northern Region, Geological Survey of India, for his personal involvement, field guidance and for providing all the logistic support for the timely initiation and completion of the work. They also express their thanks to S/Shri O.N. Bhargava, B.K. Aalok, Directors, GSI, NR, for diverting their officers for this work. In addition, they wish to acknowledge the cooperation and benefit of discussions with S/Shri D. Gupta Sharma, Director, S.C. Bhatia, B.K. Rastogi, R.K. Chadha of NGRI, Profs. P.N. Agarwal and A.R. Chandrasekharan of University of Roorkee, Dr. C.D. Thatte and M. Gopalkrishnan of Central Water Commission. S/Shri Ravi Shanker, B.L. Jangi and Ahsan Absar helped in the proper assessment of the chemistry of the thermal springs. S/Shri S.D. Shukla, R.S. Misra and R.V. Iyer provided the necessary facilities for the preliminary assessment of the pre and post earthquake imageries. Fruitful discussions were held with S/Shri K.N. Srivastava and D.R. Nandy which is gratefully acknowledged. The authors are thankful to Smt. Jaya Singh for the sincere and meticulous handling and correction of the manuscript and plates during the various stages of processing for publication. Shri Dharmendra Singh, Steno, Engg. Geology Divn.I, NR, GSI, deserves special appreciation for undertaking the advance task of computer processinng the manuscript as well as S/Shri Shiv Nath Prasad for preparing and finalising the plates and figures.

14 REFERENCES

Agarwal, N.C. and Kumar Gopendra (1973): Geology of the Upper Bhagirathi and Yamuna Valleys, Uttarkashi district, Kumaun Himalaya. Jour. Himalayan Geology, Vol.3 pp, 1-23, 1973.

Albee, A.L. and Smith J.L. (1966): In State of the art for assessing earthquake hazards in the United States, Report 6: Faults and earthquake magnitude by David B. Slemmons, May 1977, U.S. Deptt. of Commerce,National Tech. Int. Science, AD/A040 870.

Anon (1992): Uttarkashi Earthquake - Oct. 20, 1991, Jour. Geol. Soc. Ind. Vol. 39, No.1, pp 83-88.

Bonilla, M.G. and Buchanan J.M. (1970): In State of the art for assessing earthquake hazards in the United States, Report 6: Faults and earthquake magnitude by David B. Slemmons, May 1977, U.S. Deptt. of Commerce,National Tech. Int. Science, AD/A040 870.

Burbank, D.W. (1983): The Chronology of Intermontane basin development in the northwestern Himalaya and the evolution of the northwest syntaxis. Earth and Planet. Sc. letters 64(1983) pp 77-92.

Campbell, Kenneth W. (1981): Near source alternation of peak horizontal acceleration. Bull. Seis. Soc. Am. Vol. 71. No.6, pp. 2039-2070, Dec. 1981.

Chandrasekharan, A.R. and Das. J. (1991): Analysis of Strong Motion Accelrographs of Uttarkasi Earthquake of 20th Oct. 1991. Deptt. of Earthquake Engg. Roorkee University. Rep. No. EQ-91-10, Dec. 1991.

Giggenbach, W.F., Gonfiantini, R., Jangi, B.L. and Truesdell, A.H. (1983) - Isotope and chemical composition of Parbati valley geothermal discharges, NW Himalaya, India. Geothermics Vol. 12, No 23, pp. 192-222.

Giggenbach, W.F. (1986) - Graphical Techniques for the evaluation of water/rock equilibrium conditions by use of Na, K, Mg, Ca contents of discharge waters. Proc. 8th New Zealand Geothermal Workshop, pp. 37-44.

Gzovsky, M.V. (1962): Tectonophysics and earthquake Forecasting Bull. Sci. Soc. Ann. Vol. 52 pp, 485-86.

Iida, K. (1959 & 1965): In State of the art for assessing earthquake hazards in the United States, Report 6: Faults and earthquake magnitude by David B. Slemmons, May 1977, U.S. Deptt. of Commerce,National Tech. Int. Science, AD/A040 870.

Kamble, V.P. (1991): Seismically Velnerable region hit again. Curr. Sc. Vol. 61 No.8.

Kayal, J.R.; Sinha, T.K.: Sagina Ram, Singh R.P., Pahwa, A.K., Biman Ghosh, Chakraborty P. and De. Reena. (1992): Preliminary Report on Aftershock study of the Uttarkashi Earthquake of Oct. 20, 1991. Unpublished GSI report.

Khattri, K.N., Ramesh Chandra, V.K. Gaur, Sarkar I. and Sushil Kumar (1989): New Seismological results on the tectonics of the Garhwal Himalaya. Proc. Ind. Acad. Sci. (Earth Planet. Sci.) 1989, Vol. 98, No 1, pp. 91-109.

Narula, P.L. (1991): Seismotectonic evaluation of Northwest Himalaya. Unpublished GSI report. Abstract in Press being published in GSI Record Vol.

Neumann. F. (1954): In Design of Earthquake Resistant Structures by S.V. Polyakov. Mir. Publishers, Moscow, 1985, Vol. 125, pt. 8.

Ni. J. and Barazomgi, M. (1984): Seismotectonics of the Himalayan Collision zone Geometry of the underthrusting Indian plate beneath the Himalaya. Jour. Geophys. Res. 89(B-2) pp. 1147-1163.

Omura, M, Yokoyama, K & Kubo, S. (1986): Geodetic monitoring of crustal movements in the Himalayas, at the MCT and MBT, Central Nepal. Proc. Intl. Symp. on Neotectonics in South Asia, Debradun, India - Feb. 18-21, 1986.

Ravi Shankar, G. Kumar and Saxena, S.P. (1989): Stratigraphy and sedimentation in Himalaya: A reappraisal structure and tectonics of Himalaya. Pub. 26 Geol. Sur. Ind., pp. 1-60.

Seeber, L. and Armbruster, J.G. (1981): Great detachment earthquakes along the Himalayan Are and long term forecasting: Earthquake Prediction and International review. Am. Geophysical Union Morris Ewing Series Vol. 4 pp. 259-277.

Shebalin, N.V. (1974): Seismology - The study of Earthquakes, Moscow, 1974.

Sinha, R.K. (1986): Morphotectonic evolution of the Quaternary land systems of the middle reaches of Yamuna basin. Proc. Intl. Sym. Neotectonics in South Asia, Dehradun pp. 289-300.

Slemmons, D.B. (1969 & 1972): In State of the art for assessing earthquake hazards in the United States, Report 6: Faults and earthquake magnitude by David B. Slemmons, May 1977, U.S. Deptt. of Commerce,National Tech. Int. Science, AD/A040 870.

Tocher, D. (1958): In State of the art for assessing earthquake hazards in the United States, Report 6: Faults and earthquake magnitude by David B. Slemmons, May 1977, U.S. Deptt. of Commerce,National Tech. Int. Science, AD/A040 870.

Wyss, M. and Brune, J.N. (1968): In State of the art for assessing earthquake hazards in the United States, Report 6: Faults and earthquake magnitude by David B. Slemmons, May 1977, U.S. Deptt. of Commerce,National Tech. Int. Science, AD/A040 870.

ANNEXURE I

LOCALITY INDEX
(Uttar Pradesh)

S.No	Locality	Latitude	Longitude
1	Agora	30°50'45"	78°29'00"
2	Aleth	30°41'20"	78°29'05"
3	Almora	29°36'00"	79°40'00"
4	Ambari	30°29'47"	77°48'50"
5	Augustmuni	30°23'25"	79°01'22"
6	Aungi	30°45'01"	78°33'06"
7	Babugarh	30°27'43"	77°45'50"
8	Badrinath	30°46'00"	79°29'45"
9	Badshaibagh	30°19'30"	77°38'58"
10	Bageshwar	29°50'20"	79°46'16"
11	Bagi	30°30'20"	78°27'10"
12	Baijnath	29°54'17"	79°36'57"
13	Bandrani	30°48'35"	78°36'40"
14	Barkot	30°37'57"	78°32'47"
15	Barkot	30°48'43"	78°12'48"
16	Barnigad	30°43'50"	78°05'00"
17	Barwala	30°30'04"	77°50'20"
18	Baun	30°45'55"	78°12'31'
19	Berinag	29°46'44"	80°03'21"
20	Bhainga	30°29'00"	78°26'03"
21	Bhatgaon	30°32'40'"	78°36'55"
22	Bhatiyara	30°36'39"	78°30'39"
23	Bhatwari	30°48'30"	78°37'15"
24	Bhatwari Dhanari	30°39'12"	78°25'30"
25	Bhisangaon	30°35'15"	78°40'30"
26	Bhudna	30°23'30"	78°51'55"
27	Bhukki	30°51'50"	78°39'30"
28	Brijnagar (Sukiidang)	29°09'40"	80°05'56"
29	Byala Tipri	30°46'55"	78°37'05"
30	Byas Bhud	30°32'05"	77°50'37"
31	Chagera	30°30'45"	78°35'27"
32	Chakon	30°40'10"	78°26'30"
33	Chakrata	30°42'15"	77°51'48"

34	Chalthi	29°11'41"	80°04'38"
35	Chami	30°42'20"	78°04'30"
36	Chamoli	30°24'10"	79°20'00"
37	Champawat	29°20'04"	80°05'31"
38	Chamyala	30°28'45"	78°37'50"
39	Chandeli	30°51'06"	78°05'30"
40	Charma Bridge	29°45'10"	80°16'10"
41	Chatanga	30°48'55"	78°14'30"
42	Chaukari	29°50'25"	80°02'09"
43	Chinyalisaur	30°35'00"	78°18'50"
44	Chirpatiya Khal	30°23'20"	78°50'15"
45	Damta	30°38'53"	78°01'15"
46	Darrpit (Timli)	30°20'40"	77°42'40"
47	Dedsari	30°44'50"	78°33'15"
48	Dharmawala	30°25'00"	77°43'45"
49	Dhauntri	30°36'12"	78°31'03"
50	Dibogi	30°30'18"	77°59'00"
51	Didihat	29°48'06"	80°15'16"
52	Digadi	30°48'20"	78°13'30"
53	Dikhad	30°39'28"	78°26'07"
54	Dogalbitta	30°29'15"	79°10'32"
55	Dumet	30°30'18"	77°50'50"
56	Dunda	30°42'20"	78°21'00"
57	Fathehpur	30°25'54"	77°44'10"
58	Gadali	30°51'26"	78°12'03"
59	Gangani	30°49'50"	78°15'17"
60	Ganeshpur	30°45'20"	78°28'15"
61	Gangnani Hot Spring	30°54'15"	78°40'50"
62	Gangori	30°45'25"	78°27'10"
63	Gangotri	30°59'35"	78°56'40"
64	Garur	29°53'43"	79°36'49"
65	Gaurikund	30°39'15"	79°01'25"
66	Ghat Bridge	29°30'00"	80°07'42"
67	Ghansali	30°25'45"	78°39'40"
68	Ghuttu	30°31'50"	78°47'30"
69	Ginda	30°41'42"	78°29'35"
70	Galari	30°51'30"	78°12'21"
71	Gopeshwar	30°24'50"	79°19'20"
72	Gorsali	30°47'05"	78°35'30"
73	Gorthi	30°24'15"	78°51'55"

74	Gana	30°50'15"	78°12'55"
75	Guptakashi	30°31'35"	79°05'00"
76	Gyansu	30°43'42"	78°26'30"
77	Hanman Chatti	30°55'51"	78°24'17"
78	Hanuman Chatti (Badrinath)	30°41'50"	79°30'52"
79	Hanuman Chatti (Yamnotri)	30°55'50"	78°24'15"
80	Harburtpur	30°26'20"	77°44'30"
81	Haripur	30°31'05"	77°50'20"
82	Harsil	31°22'30"	78°45'00"
83	Heena	30°44'35"	78°30'30"
84	Hudoli	30°50'01"	78°05'30"
85	Huri	30°54'05"	78°41'00"
86	Irak	30°50'44"	78°12'31"
87	Jakh	30°22'37"	78°45'55"
88	Jakholi	30°25'30"	78°53'45"
89	Jamak	30°44'10"	78°31'45"
90	Jaunkani	30°46'47"	78°35'46"
91	Jhala	31°01'25"	78°92'40"
92	Jinoli	29°53'26"	79°35'53"
93	Jiwangart	30°29'30"	77°48'31"
94	Jokani	30°44'00"	78°25'16"
95	Joshimath	30°33'30"	79°33'30"
96	Juddo	30°31'18"	77°55'01"
97	Judaldi	30°46'06"	78°22'02"
98	Kabi	30°32'30"	78°50'43"
99	Kalsi	30°32'22"	77°50'50"
100	Kalyani Kaldya	30°49'13"	78°27'00"
101	Kamand	30°38'00"	78°34'00"
102	Kamar	30°43'10"	78°32'30"
103	Kameridevi	29°50'50"	79°57'55"
104	Kanda	30°22'59"	78°45'28"
105	Kansala	30°48'30"	78°07'30"
106	Kansen	30°43'45"	78°25'45"
107	Karnprayag	30°15'50"	79°13'00"
108	Kata Pathar	30°30'44"	77°52'00"
109	Kausani	29°50'53"	79°35'36"
110	Kawan	30°47'16"	78°23'30"
111	Kedarnath	30°44'15"	79°04'50"

112	Khalyan	30°27'30"	78°44'45"
113	Kharadi	30°50'40"	78°16'31"
114	Khasonkyari	30°33'13"	77°59'15"
115	Kishenpur	30°42'50"	78°28'15"
116	Kisna	30°47'54"	78°10'35"
117	Kot	30°35'15"	78°40'45"
118	Koti	30°36'16"	78°38'30"
119	Kumalti	30°46'08"	78°35'45"
120	Kurura	30°53'16"	78°04'31"
121	Kuthnaur	30°52'13"	78°18'20"
122	Kuwa	30°44'00"	78°05'05"
123	Lakhwar Dam Site	30°30'36"	77°56''45"
124	Lakhwar Village	30°32'07"	77°55'30"
125	Lakshman Pur	30°28'25"	77°47'00"
126	Lambgaon	30°30'50"	78°29'50"
127	Lodara	30°37'03"	78°30'30"
128	Lohaghat	29°23'50"	80°05'39"
129	Maletha	30°14'20"	78°43'25"
130	Malla	30°47'10"	78°37'37"
131	Maneri	30°49'40"	78°32'25"
132	Mannpur	30°41'55"	78°29'10"
133	Marora	30°35'28"	78°00'53"
134	Mathi	30°44'30"	78°23'00"
135	Mathiyasi Site	30°31'15"	78°53'28"
136	Mayali	30°23'03"	78°53'53"
137	Medh	30°36'30"	78°35'48"
138	Mussouri Bend	30°30'38"	78°00'00"
139	Muyal Gaon	30°25'45"	78°43'15"
140	Nainbag	30°35'26"	78°00'45"
141	Naingaon	30°36'31"	78°00'55"
142	Nakuri	30°44'30"	78°20'25"
143	Naid	30°46'10"	78°27'55"
144	Naugaon	30°47'14"	78°08'31"
145	Naumana	29°25'50"	80°03'30"
146	Nayal	30°48'35"	78°12'01"
147	Netala	30°45'05"	78°29'40"
148	Niwalgaon	30°35'35"	78°37'07"
149	Okhimath	30°31'00"	79°05'45"
150	Paini Bhawan	30°39'25"	78°22'45"
151	Pala	30°50'22"	78°37'06"

152	Panb	30°45'12"	78°20'15"
153	Panjala	30°46'25"	78°22'10"
154	Panyala	30°30'48"	78°28'35"
155	Pata	30°44'50"	78°26'32"
156	Paunthi	30°25'50"	78°54'15"
157	Phalenda	30°25'55"	78°41'20"
158	Phiphiyari	30°42'20"	78°04'52"
159	Phata	30°34'55"	79°02'30"
160	Pillang	30°46'15"	78°40'00"
161	Pipal Khanda	30°37'18"	78°21'20"
162	Pithoragarh	29°35'03"	80°10'40"
163	Pokhar	30°27'45"	78°42'10"
164	Purola	30°52'30"	78°04'40"
165	Raithal	30°49'05"	78°36'20"
166	Rajgarhi	30°50'30"	78°14'38"
167	Rana	30°55'14"	78°23'00"
168	Rastar	30°49'10"	78°14'45"
169	Rudra Prayag	30°14'37"	78°59'00"
170	Saina Chatti	30°54'11"	78°21'43"
171	Sainj	30°46'00"	78°35'10"
172	Sahiya	30°32'30"	77°50'43"
173	Sanglai	30°51'43"	78°39'07"
174	Sarigad	30°39'20"	78°05'00"
175	Sarendi	30°37'00"	78°29'20"
176	Saura	30°45'50"	78°35'50"
177	Sendul	30°26'25"	78°38'20"
178	Silla	30°46'14"	78°38'05"
179	Silyara	30°27'25"	78°38'25"
180	Sirkot	30°53'34"	78°05'22"
181	Siroli	29°49'54"	79°50'35"
182	Siror	30°44'22"	78°29'25"
183	Son Prayag	30°38'10"	79°00'00"
184	Srinagar	30°12'00"	78°47'00"
185	Sukki	32°00'10"	78°42'10"
186	Suknidhar	30°40'54"	78°27'18"
187	Sunagar	30°53'30"	78°4010"
188	Talwari	30°02'15"	79°31'22"
189	Tanakpur	29°04'19"	80°06'54"
190	Tehri	30°23'00"	78°29'00"
191	Thal	29°49'30"	80°08'28"

192	Thalan	30°42'16"	78°28'10"
193	Tharali	30°04'22"	79°30'16"
194	Thati Kathur	30°39'45"	78°39'00"
195	Thayeli	30°26'40"	78°41'25"
196	Tilwara	30°20'25"	78°58'30"
197	Timli	30°22'19"	77°43'20"
198	Trijuginarayan	30°38'35"	78°58'50"
199	Tunalka	30°47'37"	78°09'35"
200	Ushara	30°30'00"	79°05'45"
201	Uttarkashi	30°43'45"	78°26'30"
202	V. Bamanpur	30°28'44"	77°47'30"
203	Vikashnagar	30°28'10"	77°48'30"
204	Wardnol Bansipur	30°27'00"	77°45'25"
205	Wazri	30°54'22"	78°20'10"

(cont.)

LOCALITY INDEX
(Himachal Pradesh)

S.No	Locality	Latitude	Longitude
206	Akpa	31°35'00"	78°23'45"
207	Arki	31°09'00"	76°58'20"
208	Atal	30°49'30"	77°46'00"
209	Badsari	31°23'00"	78°21'30"
210	Bhabu Nagar	31°33'35"	77°58'54"
211	Bilaspur	31°19'30"	76°46'00"
212	Chitkul	31°21'10"	78°26'15"
213	Dabling	31°45'00"	78°38'10"
214	Darlanghat206	76°54'00"	31°08'00"
215	Dhaula Kuan	30°30'00"	77°30'00"
216	Jhakri	31°29'30"	77°42'30"
217	Jubbal	31°06'30"	77°40'00"
218	Jyori	31°31'00"	77°46'30"
219	Kalka	30°50'00"	76°55'00"
220	Kalpa	31°32'00"	78°15'00"
221	Kamru	31°26'00"	78°15'35"
222	Khab	31°48'00"	78°38'00"
223	Khadrala	31°53'30"	77°39'30"
224	Khotkhai	31°07'00"	77°33'00"
225	Kinnu	31°28'00"	77°49'00"
226	Korga	30°35'30"	77°35'30"
227	Kulu	31°57'30"	77°07'00:
228	Kunihar	76°57'00"	31°04'00"
229	Mandi	31°42'30"	76°56'00"
230	Morang	31°35'45"	78°27'00"
231	Nahan	30°33'00"	77°17'00"
232	Narkanda	31°15'20"	77°27'30"
233	Nisang	31°38'30"	78°31'00"
234	Nogli	31°24'00"	77°38'00"
235	Paonta Sahib	30°26'00"	77°38'00"
236	Peo	31°32'50"	78°16'30"
237	Poo	31°45'45"	78°35'00"
238	Rakcham	31°23'30"	78°21'20"
239	Rampur	31°26'30"	77°38'00"
240	Rarang	31°36'00"	78°21'30"

241	Ribba	31°35'20"	78°22'00"
242	Rispa	31°34'30"	78°25'30"
243	Rohru	31°12'00"	77°45'00"
244	Ranhat	30°46'45"	77°45'00"
245	Sangla	31°25'00"	78°15'31"
246	Shalai	30°40'30"	77°43'00"
247	Shambuwala	30°31'30"	77°17'00"
248	Simla	31°06'30"	77°10'30"
249	Slapper	31°25'00"	76°51'00"
250	Solan	30°55'00"	77°06'00"
251	Sunder Nagar	31°32'00"	76°54'30"
252	Swarghat	31°14'00"	76°42'30"
253	Tabo	32°05'	78°22'00"
254	Tapri	31°31'30"	78°05'30"
255	Thangi	31°33'00"	78°28'30"
256	Theog	31°07'30"	77°22'30"
257	Timbi	30°39'20"	77°39'00"
258	Tiuni	30°56'30"	77°51'00"

ANNEXURE II

CASUALITIES IN DIFFERENT VILLAGES

Sl. No.	Village	Tehsil	District	Deaths	Injurries
1	Sukki	Bhatwari	Uttarkashi	3	-
2	Pala	-do-	-do-	7	15
3	Sunagar	-do-	-do-	5	-
4	Bhatwari	-do-	-do-	6	58
5	Bandrani	-do-	-do-	2	4
6	Jonkani	-do-	-do-	1	10
7	Nateen	-do-	-do-	1	-
8	Kyark	-do-	-do-	1	39
9	Bayala Tipri	-do-	-do-	2	15
10	Kumalti	-do-	-do-	1	20
11	Malla	-do-	-do-	9	44
12	Piljang	-do-	-do-	4	22
13	Huri	-do-	-do-	3	5
14	Salang	-do-	-do-	6	24
15	Silla	-do-	-do-	16	52
16	Bhukki	-do-	-do-	11	22
17	Tihar	-do-	-do-	29	43
18	Raithal	-do-	-do-	25	136
19	Sagava	-do-	-do-	9	18
20	Saura	-do-	-do-	1	12
21	Dedsari	-do-	-do-	45	58
22	Maneri	-do-	-do-	34	30
23	Jamak	-do-	-do-	70	35
24	Sainj	-do-	-do-	6	14

25	Kamar	-do-	-do-	8	14
26	Biana	-do-	-do-	8	5
27	Aungi	-do-	-do-	2	2
28	Dausda	-do-	-do-	3	3
29	Jakhole	-do-	-do-	8	135
30	Nald (Godhar)	-do-	-do-	3	5
31	Heena	-do-	-do-	29	28
32	Netala	-do-	-do-	44	120
33	Gavana (Ganeshpur)	-do-	-do-	45	29
34	Nismaur	-do-	-do-	7	8
35	Gaynsu	-do-	-do-	14	3
36	Barahat (Uttarkashi)	-do-	-do-	-	2
37	Bonga	-do-	-do-	18	33
38	Gangori (Sera)	-do-	-do-	10	2
39	Sadaung	-do-	-do-	4	8
40	Uttaro	-do-	-do-	4	-
41	Naugaon	-do-	-do-	2	-
42	Gajoli	-do-	-do-	1	-
43	Sainku	-do-	-do-	1	-
44	Basoonga	-do-		2	5
45	Bogadi	-do-		1	-
46	Kishenpur	-do-	-do-	19	37
47	Mannpur	-do-	-do-	19	29
48	Kansen	-do-	-do-	2	4
49	Thalan	-do-	-do-	4	46
50	Ladhari	-do-	-do-	1	9
Total in Bhatwari Tehsil				562	

51	Panchar	Dunda	-do-	8	25
52	Dikthol	-do-	-do-	7	6
53	Bhatwari Dhanari	-do-	-do-	3	9
54	Paini Bhawan	-do-	-do-	3	-
55	Pajaf	-do-	-do-	3	4
56	Jugairi	-do-	-do-	3	15
57	Chinakholi	-do-	-do-	1	3
58	Panjyala	-do-	-do-	2	3
59	Baun	-do-	-do-	1	16
60	Nakuri- Barsali	-do-	-do-	1	13
61	Matli	-do-	-do-	10	-
62	Kawan	-do-	-do-	4	7
63	Surkot	-do-	-do-	4	13
64	Huldiyana	-do-	-do-	3	9
65	Kharawa	-do-	-do-	4	7
66	Par	-do-	-do-	1	10
67	Saund	-do-	-do-	1	-
68	Bhurkot Gajna	-do-	-do-	12	-
69	Pipalkhanda	-do-	-do-	1	7
70	Khalsi Didili	-do-	-do-	1	9
71	Matligajna	-do-	-do-	1	-
72	Lodara	-do-	-do-	5	6
73	Bhatyara	-do-	-do-	7	6
74	Sirigaon	-do-	-do-	3	8
75	Chakon	-do-	-do-	1	-
Total in Dunda Tehsil				90	
76	Gadoli	Bharkot	-do-	1	8
77	Lambgaon	Pratapnagar	Tehri	1	-

78	Paniyala	-do-	-do-	1	-
79	Bhagi	-do-	-do-	3	-
80	Bhainga	-do-	-do-	6	-
81	Sondi	-do-	-do-	1	-
82	Chamgora	Bhilangana	-do-	6	-
83	Sendul	-do-	-do-	2	-
84	Agar	-do-	-do-	3	-
85	Silyara	-do-	-do-	1	-
86	Kot	-do-	-do-	7	-
87	Niwalgaon	-do-	-do-	4	-
88	Bhatgaon	-do-	-do-	1	-
89	Medh	-do-	-do-	1	-
90	Ghuttu	-do-	-do-	2	-
91	Chamayala	-do-	-do-	2	-
92	Kanda	-do-	-do-	1	-
93	Narora	Dhauldhar	-do-	1	-
94	Thati	Jhakholi	-do-	3	-
95	Thala	-do-	-do-	1	-
96	Thayali	-do-	-do-	8	-
97	Bhudna	-do-	-do-	1	-
98	Gorthi	-do-	-do-	3	-
99	Uroli	-do-	-do-	2	-
100	Chaura	-do-	-do-	1	-
101	Jakh	-do-	-do-	1	-
102	Koti	-do-	-do-	1	-
Total deaths in Tehri District				64	
Total deaths in Chamoli District				6	
Total deaths reported				727	

ANNEXURE III

INTENSITY SCALES

A. The Rossi–Forel Intensity Scale (1983)

I Microseismic shock – Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II Extremely Feeble shock – Recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III Very feeble shock – Felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV Feeble shock – Felt by persons in motion; disturbance of movable objects, doors, windows cracking of ceilings.

V Shock of moderate intensity – Felt generally by everyone; disturbance of furniture, beds, etc., ringing of some bells.

VI Fairly strong shock – General awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible agitation of trees and shrubs; some startled persons leaving their dwellings.

VII Strong shock – Overthrow of movable objects; fall of plaster; ringing of church bells; general panic without damage to buildings.

VIII Very strong shock – Fall of chimneys; cracks in the walls of buildings.

IX Extremely strong shock – Partial or total destruction of some buildings.

X Shock of extreme intensity – Great disaster; ruins, disturbance of the strata, fissures in the ground, rock falls from mountains.

(Ref.: From Elementrary Seismology' by Charles F. Richter)

B. The Modified Mercalli Intensity Scale (1956), with Cancani's Equivalent Acceleration.
(Note: These are not peak accelerations as instrumentally recorded)

Degree	Description	Acceleration mm/sec²
I	Not felt - only detected by seismographs.	Less than 2.5
II	Feeble - Felt by persons at rest, on upper floors, or favourable places.	2.5 to 5.0
III	Slightly felt indoors - Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognised as earthquake.	5.0 to 10
IV	Moderate - Hanging objects swing. Vibration like passing of heavy trucks, or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rocks. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.	10 to 25
V	Rather strong - Felt outdoors, direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset, doors swing, close, open. Shutters and pictures move. Pendulam clocks stop, start, change rate.	25 to 50
VI	Strong - Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Ornaments, books, etc., fall of shelves. Pictures fall off walls, Furniture moved or overturned. Weak plaster and masonry cracked. Small bells ring (Church, school), Trees, bushes shaken visibly or heard, to rustle.	50 to 100
VII	Very strong - Difficult to stand. Noticed 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, also unbraced	100 to 250

	parapets and architectural ornaments. Some cracks in masonry C. Waves on ponds, water turbid with mud. Smallslides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.	
VIII	Destructive - Steering of motor cars affected. Damage to masonry C, partial collapse. Some damage to masonry B, none to masonry A. Fall of stuco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down, loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.	250 to 500
IX	Ruinous - General panic. Masonry D destroyed, masonry C heavily damaged, some times with complete collapse, masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames cracked, serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountations, sand craters.	500 to 1000
X	Disastrous - Most masonry and frame structures destroyed with their foundations. Some well built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.	1000 to 2500
XI	Very disastrous - Rails bent greatly. Underground pipelines completely out of service.	2500 to 5000
XII	Catastrophic - Damage nearly total. Large rock masses displaced. Lines of sligh and level distorted. Objects thrown into the air.	Over 5000

Note:

Masonry A-	Good workmanship, mortar, and design; reinforced laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
Masonry B-	Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
Masonry C-	Ordinary workmanship and mortar; to extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
Masonry D-	Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

(Ref: `Elementary Seismology' by Charles F. Richter)

.....

C. Medvedev-Sponheaer-Karnik (MSK) Intensity Scale (1964)

The description of this scale opens with definitions of terminology and then proceeds to define the scale steps as follows:

Types of Structures:

Structure A:	Buildings in field-stone, rural structures, adobe houses, clay houses.
Structure B:	Ordinary brick buildings, buildings of the large block and prefabricated type, half timbered structures, buildings in natural hewn stone.
Structure C:	Reinforced buildings, well built wooden structures.

Definition of Quantity:

Single, few	- about 5%
Many	- about 50%
Most	- about 75%

Classification of Damage to Building:

Grade 1 Slight damage - Fine cracks in plaster; fall of small pieces of plaster.

Grade 2 Moderate damage - Small cracks in walls; fall of fairly large pieces of plaster; pantiles slip off; cracks in chimneys; parts of chimneys fall down.

Grade 3 Heavy damage - Large and deep cracks in walls, fall of chimneys.

Grade 4 Destruction - Gaps in walls; parts of buildings may collapse; separate parts of the building lose their cohesion; inner walls and filled-in walls of the frame collapse.

Grade 5 Total Damage - Total collapse of buildings.

Arrangement of the Scale:

Introductory letters are used in paragraphs throughout the scale as follows:

a) Persons and surroundings;

b) Structures of all kinds;

c) Nature

Intensity:

I. Not noticeable

a) The intensity of the observation is below the limit of sensibility; the tremor is detected and recorded by seismographs only.

II. Scarcely noticeable

a) Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.

III. Weak, partially observed only

a) The earthquake is felt indoors by a few people, outdoors only in favourable circumstances. The vibratioh is like that due to the passing of a light truck. Attentive observers notice a slight swinging of hanging objects, somewhat more heavily on upper floors.

IV. Widely observed

a) The earthquake is felt indoors by many people, outdoors by a few. Here and there people awake, but no one is frightened. The vibration is like that due to the passing of a heavily loaded truck. Windows, doors and dishes rattle. Floors and walls creak. Furniture begins to shake. Hanging objects swing slightly. Liquids in open vessels are slightly disturbed. In standing motor cars the shock is noticeable.

V. Awakening

a) The earthquake is felt indoors by all, outdoors by many. Many sleeping people awake. A few run outdoor. Animals become uneasy. Buildings tremble throughout. Hanging objects swing considerably. Pictures knock against walls or swing out of place. Occasionally pendlum clocks stop. A few unstable objects may be overturned or shifted. Open doors and windows are thrust open and slam back again. Liquids spill in small amounts from welfilled open containers. The sensation of vibration is like that due to a heavy object falling inside the buildings.

b) Slight damage of Grade 1 in buldings of Aype A is possible.

c) Sometimes change in flow of springs.

VI. Frightening

a) Felt by most people indoors and outdoors. Many people frightened and run outdoors. A few persons lose their balance. Domestic animals run out of their stalls. In a few instances, dishes and glassware may break, books fall down. Heavy furniture may possible move and small steeple bells may ring.

b) Damage of grade 1 is sustained in single buildings of Type B, and in many of Type A. Damage in a few buildings of Type A is of Grade 2.

c) In a few cases cracks up to widths of 1 cm possible in wet ground; in mountains occasional landslips; change in flow of springs and in level of well water is observed.

VII. Damage to building

a) Most people are frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motor cars. Large bells ring.

b) In many buildings of Type C damage of Grade 1 is caused; in many buildings of Type B damage is of Grade 2. Many buildings of Type A suffer damage of Grade 3,a few of Grade 4. In single instances landslips of roadway on steep slopes, cracks in roads, seams of pipeline damaged, cracks in stone walls.

c) Waves are formed on water, and water is made turbid by mud stirred up. Water levels in wells change, and the flow of springs change.In a few cases dry springs have their flow restored and existing springs stop flowing. In isolated instances parts of sandy or gravelling banks slip off.

VIII. Destruction of building

a) Fright and panic, also persons driving motor cars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hanging lamps are in part damaged.

b) Many buildings of Type C suffer damage of Grade 2, a few of Grade 3. Many buildings of Type B suffer damage of Grade 3, and many buildings of Type A suffer damage of Grade 4. Occasional breakage of pipe seams. Memorials and monuments move and twist. Tombstones overturn. Stone walls collapse.

c) Small landslips in hollows and on banked roads on steep slopes; cracks in ground up to widths of several centimetres. Water in lakes becomes turbid. New reservoirs come into existence. Dry wells refill and existing wells become dry. In many cases change in flow and level of water.

IX. General damage to buildings

a) General panic; considerable damage to furniture. Animals run to and fro in confusion and cry.

b) Many buildings of Type C suffer damage of Grade 3, a few of Grade 4. Many buildings of Type B show damage of Grade 4, a few of Grade 5. Many buildings of Type A suffer damage of Grade 5. Monuments and columns fall. Considerable damage to reservoirs; underground pipes partly broken. In individual cases railway lines are bent and roadways damaged.

c) On flat land overflow of water, sand and mud is often observed. Ground cracks to widths of up to 10 cm., on slopes and river banks more than 10cm.; furthermore a large number of slight cracks in ground; fall of rock, many landslides and earth flows; large waves on water. Dry wells renew their flow and existing wells dry up.

X. General destruction of buildings

b) Many buildings of Type C suffer damage of Grade 4, a few of Grade 5. Many buildings of Type B show damage of Grade 5; most of Type A have destruction category 5; critical damage to dams and dikes, and severe damage to bridges. Railway lines are bent slightly. Underground pipes are broken or bent. Road paving and asphalt show waves.

c) In ground, cracks upto widths of several tens of centimetres, sometimes upto 1 metre. Broad fissures occur parallel to water courses. Loose ground slides from steep slopes. From river banks and steep coasts considerable landslides are possible.In coastal areas displacement of sand and mud; change of water level in wells; water from canals, lakes, rivers etc. thrown on land. New lakes occur.

XI. Catastrophe

b) Severe damage even to well built buildings, bridges, waterdams and railway lines; highways become useless; underground pipes destroyed.

c) Ground considerably distroted by broad cracks and fissures as well as by movement in horizontal and vertical directions; numerous landslips and falls of rock. The intensity of earthquake requires to be investigated specially.

XII. Landscape change

b) Practically all structures above and below ground are greatly damaged or destroyed.

c) The surface of the ground is radically changed, considerable ground cracks with extensive vertical and horizontal movements are observed. Falls of rock and slumping of river banks over wide areas; lakes are dammed; waterfalls appear, and rivers are deflected. The intensity of the earthquake requires to be investigated specially.

Ref.: Sponheuer W and Karnik V 1964 New Seismiche Skala (New Seismic Scale) pp 69-76 in W Sponheuer, Ed, European Seismological Commission, 7th Symp. held at Jena, Sept. 24-30th Sept, 1962, Veroff. Inst. f. bodendyn. K. Erdbeber forsch Jenaddeutchen Aentchen Akad. d. Wiss No.77.

ANNEXURE IV

EARTHQUAKE REPORT
(Proforma)

Place of Observation:

i. Town or village

ii. Tehsil, taluka

iii. District or State

iv. Nearest Railway Station

1. Date of earthquake

2. Time of occurrence

3. Number of separate shocks with time and their duration.

4. Situation of observer, whether in upper storey or out of doors asleep or awake, sitting or standing etc.

5. Type of building of observer's house, i.e. Kutcha, Kutcha-pucca pucca, one or more storeys. When built.

6. Were any unusual sounds heard either before, during or after the shock and what did they resemble?

7. What was the nature of the movement and did it appear to come from any particular direction as ascertained from line of swing of hanging lamps, movement of liquids in cups, tubs or tanks.

8. Was the intensity of the shock strong enough to have the following effects:

a) To be felt by persons sitting or lying?

b) To be felt by persons in motion?

c) To make doors, windows, etc., or loose objects rattle?

d) To make hanging, objects swing?

e) To shake trees or shrubs?

f) To shake the observer's seat or bed?

g) To throw down loose objects on tables and shelves such as clock, bottles, utensils?

h) To crack the walls of building?

i) To cause greater damage? (to be specified)

j) To cause other phenoma such as ground fissures, sand and water spats, slipping of the banks of tank or rivers?

9. General remarks. (How the shock was felt in the locality, indicating damage, if any).

Dated: Signature

Place: Name of Observer:

PART TWO

REPORT by NGRI

REPORT ON INTENSITY SURVEYS CARRIED OUT FOR UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

BY

B.K. Rastogi & R.K. Chadha
National Geophysical Research Institute,
Hyderabad-500007

REPORT ON INTENSITY SURVEYS CARRIED OUT FOR UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

BY

B.K. Rastogi & R.K. Chadha
National Geophysical Research Institute,
Hyderabad-500007

SUMMARY

The earthquake of body-wave magnitude 6.6 (IMD) and surface wave magnitude 7.1 (USGS) that rocked the Garhwal region of Uttar Pradesh for 45 seconds at 2.53 AM (IST) on October 20, 1991 has left behind a trail of 769 deaths about 5000 injured persons and about 1 lakh damaged houses in Uttarkashi, Tehri and Chamoli districts. Damage to buildings was also reported from Himachal Pradesh, Chandigarh and Delhi. The earthquake was felt as far as in Jammu, Amritsar, western Nepal and all parts of Uttar Pradesh including Pithoragarh, Shahjahanpur, Pilibhit, Lucknow and Kanpur upto distances of about 900 km.

Numerous landslides occurred in Uttarkashi and adjoining districts. Landslides,cracks and slumping of road were noticed all along the route between Gangori and Gangnani in Bhatwari block. Landslides had broken telephone and electric poles disrupting communication and electric supply.

Gawana bridge, located about 8 km from Uttarkashi on the road to Gangotri collapsed, cutting off hundreds of villages. Because of this, rescue and relief teams could not reach the worst affected areas for several days. Approaches to another bridge on Uttarkashi-Lambgaon road were also damaged.

Cracks were observed in the mountain slopes in the vicinity of Agora, Sangrali, Jamak, Didsari etc. in Uttarkashi district and at Phata in Chamoli district. These cracks in the hill slopes increased the chances of major landslides and made some villages situated at the foot of such slopes unsafe. Wide cracks which developed in the fields made tilling difficult. Landslides accompanied by dust clouds were occurring even after 2 weeks of the earthquake, making road journey a hazardous task.

Because of shortage of firewood, people directly consigned the dead bodies in the Bhagirathi river. These bodies were seen floating in the river for several days.

Direction of strong shaking and sound was reported by most people to be from north to south in Uttarkashi district. The objects have also fallen towards south.

After the earthquake people could not open the doors and windows and thus got trapped inside the dwellings. After the earthquake, people were scared due to recurring aftershocks and a misleading declaration by some people that a great earthquake is imminent. People had to sleep in the open even in the biting cold and rain.

The unusual observations reported include fire balls, glowing of the mountains, electric shock and smoke.

Damage survey in the three affected districts of Uttarkashi, Tehri and Chamoli were carried out. Based on our observations and interviews of people, isoseismals have been drawn using MSK scale. Isoseismals drawn had a fairly good fit with those drawn by Geological Survey of India and hence are not reproduced. Similarly the photographs taken by NGRI party are not shown separately and some of these are included in the GSI report. Trend of long axes of the isoseismals is NW-SE. The isoseismals widen towards SE. We assign a maximum intensity of IX in an area of about 10km X 7.5km from Gawana to Didsari along Uttarkashi - Gangotri road. The isoseist VIII is in an area extending 40km X 25km between Uttarkashi and Pala on the same road. Isoseismal VII passes through Dunda, Ghansali Jakholi, between Guptkashi and Phata and north of Gangnani hot spring encompassing elliptical area having a long axis and short axis of about 90km and 50km, respectively. Isoseismal VI passes from north of Mussoorie and isoseismal V through Chandigarh and north of Muzaffarnagar, Moradabad and Pilibhit. Isolated pockets of intensity VI at Dehradun and V from Delhi to Sonepat have also been identified.

Intensity IX has been assigned on the basis of total destruction of houses, ground cracks with opening of more than 10cm., shaving of river banks and broken water pipeline.

Medvedev-Sponhearer-Karnik (MSK) scale is broadly similar to the Modified Mercalli (MM) scale. Advantage of the MSK scale is that in this the description of damages are quantified in a better way. Hence, this has been adopted. The distinguishing features are described on next page:

DISTINGUISHING FEATURES OF INTENSITY SCALES
Modified Mercalli Scale

VI Weak plaster and masonry cracked.

VII Damage (partial collapse) to poor constructions including cracks.

VIII Partial collapse of better houses constructed with bricks.

IX Poor constructions destroyed, sometimes better houses made with bricks also completely collapsed.

Medvedev-Sponheaer-Karnik

VI (a) Cracks in poor constructions.

(b) A few cracks upto widths of 1 cm. in wet grounds. IN mountains occasional landslips.

VII (a) Partial collapse in a few poor constructions

(b) In single (about 5%) instances landslips of roadway on steep slopes, cracks in roads.

VIII (a) Many (about 50%) poor constructions suffer partial collapse.

(b) Small landslips on hollows. Landslips of roads on steep slopes. Cracks on ground upto widths of several centimetres.

IX (a) Many poor constructions suffer total collapse. Underground pipes partly broken. In individual cases railway lines are bent.

(b) Ground cracks upto width of 10cm., on slopes and river banks more than 10cm., many landslides.

Detailed description of scales is given in the GSI report. In assigning the intensities both the factors concerning damage to houses and the ground effects have been considered. For example, in intensity VIII area, besides partial collapse of many poor constructions there have to be many landslides and ground cracks upto widths of several centimetres. Similarly in intensity VII, besides partial collapse of a few poor constructions there have to be single instances of landslides and cracks in the ground. Due to this reason, though partial collapse of houses and some deaths have occurred, the areas encompassing Sukhi and villages south of Ghansali and Jakholi have been assigned intensity VI because of absence of terrain changes.

1 INTRODUCTION

The earthquake of magnitude 6.6 (IMD) on Richter-scale, body-wave magnitude 6.5 (USGS) and surface-wave magnitude of 7.1 (USGS) that rocked the Garhwal region of Uttar Pradesh for 45 seconds at 2.53 IST in the morning of October 20, 1991 has left hundreds of people dead and several thousand injured in Uttarkashi, Tehri and Chamoli districts. The worst affected was Uttarkashi district.

The National Geophysical Research Institute (NGRI) team carried out damage survey in the three affected districts of Uttarkashi Tehri and Chamoli by visiting the affected areas, interviewing people and scanning the newspaper reports. From the newspapers we have drawn only the factual informations like names of the affected places, location of ground cracks etc. Even then these descriptions should be considered with caution.

2 DESCRIPTION OF DAMAGES

District-wise description of damages is as follows:

2.1 UTTARKASHI DISTRICT

The Uttarkashi district is divided into seven blocks, viz. Bhatwari, Naogaon, Dunda, Chinyalisaur, Purola, Mori and Uttarkashi. The worst affected area includes Bhatwari, Dunda and Naogaon blocks approachable through three roads namely Tehri-Uttarkashi road, Uttarkashi-Lambgaon road, and Uttarkashi-Bhaldiyana road. Devastation in this whole area was wide spread.

It is reported that 97 villages of the Bhatwari block and 63 villages of the Dunda block have been devastated where 80-90 percent houses have been severely damaged. In other villages also about half of the total number of houses have been severely damaged. The remaining houses have developed wide cracks. A total of 653 deaths and 1535 injured persons are officially reported from Uttarkashi district.

2.1.1 DAMAGE DESCRIPTION IN CHINYALISAUR AND PUROLA BLOCKS

In Chinyalisaur block some villages have been damaged. There is a report of one death and over 50 injured in this block. In Chinyalisaur town, the well built houses of the Irrigation Department have suffered only minor cracks.

The affected villages in the Purola block include Kurado, Nandgaon, Sukhdala, Mairana, Dhakara, Chandeli, Kamola and Netri Garoli.

2.1.2 UTTARKASHI MUNICIPAL AREA

It is estimated that 25% of the houses have been damaged in Uttarkashi Municipal area. About 10% have been completely damaged. Important individual buildings which have been damaged are residence of District Magistrate, residence of Superintendent of Police, State Bank of India, Government Inter College and its hostel, Hospital, Court and Inspection Bungalow of Public Works Department. Some of these damages are described below:

State Bank of India: Lime masonry, two storey building. The first floor of this building completely collapsed and the ground floor was seriously damaged. The pillars of lime masonry collapsed and RCC roof of the first floor came down on the ground floor ceiling. The Bank Manager, Mr. V. Natarajan's family living in first floor miraculously survived with injuries only.

Cracks have appeared in the courtyard and main gate of ancient Viswanath Temple. Cracks have also appeared in 'Shaktima' temple situated opposite to Viswanath temple.

District Magistrate's Residence: From outside the house looks intact but inside the roof and some walls have collapsed.

Residence of Superintendent of Police, his office premises and police barracks: All these buildings have collapsed partially or fully. Master Himanshu Singh, fourteen year old son of Mr. Uma Shankar Singh, SP is reported to have died due to collapse of his residence.

Post Office: Several cracks have developed in the post office building which is a RCC construction with load bearing columns and beams. Cracks are seen at the contact of beam and a pillar. The external wall is of stones and lime mortar which developed cracks on all the sides. Irregular cracks along the contacts of the filler stones were noticed.

2.1.3 DAMAGE IN BHATWARI, NAOGAON AND DUNDA BLOCKS

During the earthquake and afterwards for more than a fortnight, rock blocks rolled down the hills and there were numerous landslides from all the mountains producing dust clouds. On the day of the earthquake, the whole area was engulfed in dust. The road from Chinyalisaur to Gangotri was blocked at numerous places, more frequently between Maneri and Bhatwari. Telephone and electric wires as well as trees snapped due to landslides. It was reported that sparks generated by rock falls gave appearance as if the mountains were on fire.

At Agora and several other places people reported fire ball moving on hill top. It is reported that 210 out of 474 drinking water schemes were damaged and 104 schemes of Irrigation Department were also damaged. Several natural water sources also dried up. Damage to water schemes created drinking water crisis.

Changes in water springs occurred at several places such as in Naogaon block, in Maneri, Gangnani and at Sunara, Khadakyar and Eedak villages. In Marapa Koti, amount of hot spring discharge has increased but temperature of water has decreased as reported in the newspapers.

Gawana bridge on Uttarkashi-Gangotri road collapsed, cutting off 75 villages from rest of the country.

In Bhatwari block of Uttarkashi district, 97 villages out of a total of 112 suffered severe damage. Population of Bhatwari block is 32,000. The worst affected villages where large number of houses collapsed were Nakuri, Matli, Nauld, Uttron, Naogaon, Gajoli, Bhankoli, Dasara, Dandalka, Shiron, Thalam, Kishanpur, Manpur, Ginda, Ganeshpur, Netala, Hinna, Maneri, Jamak, Kamar, Didsari, Lunthru, Bina, Sainj, Kumalti, Jakhol, Gorsali, Malla, Saur, Sila, Pilang, Raithal, Syana, Pala, Salang, Bhukki, Sunagar, Bhangeli, Sulki, Sukki, Kunjan, Tilam, Tihar, Mandrani, Lativa, Kamarnth, Farsu, Mahidanda, Kirthu, Sirul, Bhatwari, Vasunga, Kailsain, Jugaldi, Panjyala, Bhailudi, Bhoga, Jaula, Barethi, Pata, Panchan, Tekhla, Gyansu, Johra, Mandrany and Kamarakh.

Uttarkashi-Gangotri: Up to Tekhala bridge, 5km from Uttarkashi, there was no severe damage but between Tekhala and Gangori (6km from Uttarkashi) heavy damage is observed in the form of landslides and collapsed houses. This heavy damage continues upto Pala which is 20km from Uttarkashi.

Most of the villages between Ganeshpur and Bhatwari on Uttarkashi - Gangotri road have turned into ruins. These villages include Raiphal Pharsu, Malla, Jawada, Ganeshpur, Gawana, Jamak, Didsari, Raithal, Kamar, Bhatwari, Lunthru, Hinna, Netala and villages on the way to Dodital in Naogaon block - Sekku. Gajoli, Naogaon, Bankoli, Dandalka, Dasra and Agora. Terraced fields in these villages have developed fissures. Gawana Bridge 8km from Uttarkashi on the way to Maneri collapsed. This Bailey bridge, constructed in 1973, is made of steel girders with about 48m span. It has got concrete decking. The bridge is aligned East-West.

The 23 villages devastated in Maneri area include Kanth, Aungi, Majagaon, Silkara, Ravara, Bhatuksur etc. The villages situated on higher hills were difficult to reach and are approachable by narrow bridle paths.

The Maneri dam has not suffered damage. But the watchman room and one or two structures near the entrance of the dam suffered collapse of walls.

Maneri Dam Colony: Maneri colony has suffered severe damage. One small temple, one shop and one residential quarter near the entrance of the colony have suffered total collapse.

The office buildings, the guest house, main temple and numerous residential quarters for lower category staff have been severely damaged. The better constructed houses of RCC are less damaged. Damages to some of the individual structures are described as follows:

- Retaining wall of the approach road to maneri colony has collapsed for a length of more than 30m.
- A small temple near the entrance of the colony has totally collapsed. It was made of stone masonry in lime mortar with RCC. roof. All the walls have fallen and the RCC slab collapsed.
- One shop built of stone masonry with lime mortar and roof of corrugated iron collapse.
- One residential quarter of stone masonry with reinforced pillars and ceiling suffered a total collapsed.
- Wall of shed has collapsed.
- The ceiling and all the walls of the guest house are partially collapsed. There are diagonal, vertical as well as horizontal cracks in the walls.

- All the walls of the office of the Executive Engineer are badly sheared by diagonal, vertical as well as horizontal cracks.

- First floor room of the colony Division Office has shifted by 10cm. towards south.

- Ground floor of the adjoining block has also shifted by 10cm. towards south.

- Walls of the Administrative block are badly sheared.

- Most of the residential quarters meant for lower category staff are badly sheared by wide cracks in all the directions.

- The main temple of the Maneri colony is badly damaged and partially collapsed. The pillars situated all around the structures have failed. The steel gates have got twisted due to weight of the ceiling falling on them after the failure of the columns.

  An RCC slab used as roof of the priests's house situated near the temple and close to the hill slope was thrown out towards south by about 25m horizontally and 25m vertically. This slab had been kept loose on the walls and was kept slanting towards south or towards hill slope. Outer edge of the slab of dimensions 7mX7m was at least 1.5m away from the edge of the hill slope. Hence, movement of the slab was at least 1.5m from its edge or 5m from its centre.

Jamak village situated on a hill near the dam suffered total collapse of houses. It is the maximum damaged village and has turned into ruins where 70 people died. Rotting animal bodies trapped in the debris were giving unbearable foul smell. Many bodies were lined trapped even on the second day.

In Jamak village almost all the houses have stone and mud walls with heavy RCC roofs. Cracks on the hill slopes of Jamak village were observed to be trending between N10°W to N30°W. These cracks are parallel to hill slopes and have been induced by slope failures.

The diversion tunnel of 5m diameter from the Maneri dam passes 90m below Jamak village. The blasting for the tunnel was done during 1972-75. Residents of Jamak village blame that the greater damage to their village is because of tunnel passing below their village. However an opening of 5m diameter at a depth of 90m will not cause amplification of acceleration. It is also said that blasts done some 16-20 years back had weakened the rocks which failed. This argument is also not true as the rocks have failed at a depth of 15km. The third argument was that the relative vibrations of the tunnel lining and the ground has produced extra vibrations which have caused more damage at Jamak village. Whatever these extra little vibrations may be, they would die out in 90m. Hence, this argument is also not valid. Moreover, nearly equally damaged villages like Didsari, Netala and Heena are situated away from the tunnel. More damage in Jamak and nearby villages is due to nearness to the epicentre.

Didsari which is about 4km north of Maneri is the next most damaged village after Jamak. There also almost all the houses have collapsed. These houses are poorly constructed with stone masonry in mud mortar. The village with a population of 410 is situated on the hill slope. A total of 45 people died and 71 got injured. On the same hill slope two more villages Lunthru and Bina, located at higher elevations, have suffered less damage as compared to Didsari. Several cracks are also present on the hill slopes in this region.

In Sangrali village, 13km from Uttarkashi, a N-S trending crack of about 50cm. width is observed near the top edge of the slope. The depth of this crack is reported to be approximately 9m. This crack has developed in quartzite.

At least 40 landslides, each of about $10m^3$ size are observed between Maneri and Bhatwari.

The crack directions along and across the road between Maneri and Bhatwari ranges between N70°W and N10°E.

Landslides are frequent even north of Gangnani. For example a major landslide occurred at about 6km north of Gangnani. Majority of electric and telephone poles are broken between Bhukki and Gangnani due to landslides. South of this stretch, i.e. starting from Gawana, many electric and telephone poles have been damaged due to landslides. In a stretch, 10-15km south of Gangotri, a few poles are broken due to snapping of wires. Snapping of wires might have taken place by shaking of poles as there were no landslides.

Netala is one of the badly affected villages. This village is situated on a hill by the side of Uttarkashi-Gangotri road at a distance of about 8km from Uttarkashi. One could reach the village after jumping over the boulders and trees fallen during the earthquake. A total of 44 people died and 102 got injured. In this village, 155 families lived and the population was about 1000 until the morning of the earthquake. Damages to the drinking water pipeline has forced villagers to fetch water from river Bhagirathi. The road to Netala village was breached at several places.

In the villages north of Bhatwari all the houses did not collapse. Dr. K.D. Paul of Roorkee University observed that at Bhukki, houses situated on hill top collapsed but not in the valley. According to Dr. Aswani Kumar of Roorkee University, at Bhukki all the A type (poor quality) houses had developed cracks, while 60% had collapsed.

It is reported that in village Banas, 50 houses were buried by a landslide during an historical earthquake. This village is at the foot of a hill slope. The houses here are well reinforced by wood. Many houses are woodenframe structures. They have small windows and doors minimising weak parts of the walls. Because of these reasons these houses have suffered only minor cracks. Hot springs situated 500m away from this village showed substantial increase in discharge. A fall of about 2m in the water level of a well, located close to the main road near Uttarkashi, has also been reported by Dr. Aswani Kumar.

Local people believed the epicentre to be near Agora because of wide crack in the mountain, thick dust clouds appearing like smoke, the surrounding mountains appearing like on fire and observation of moving fire ball. Agora is surrounded by high mountains which are devoid of vegetation. Falling rocks on dry mountains produced wide spread sparks. The village is situated at about 22km north of Uttarkashi at a height of more than 2300m. Field hostel of Forest Department at Agora partially collapsed. Though this building is made up of good material and lot of timber has been used but it does not have earthquake proof features, hence it has been damaged as opined by Dr. D.K. Paul of University of Roorkee.

There were numerous cracks on the hill slopes. These were probably due to slumping of hill slopes. These cracks were 2-15cm. wide and could be seen extending for 8-10m.

At the time of the earthquake an IAS Officer from Rajasthan and his wife were staying in the Field Hostel described above. The couple told the villagers that they had seen a moving fire ball at the time of the earthquake. Basdev a native of this village also saw the fire ball. He narrated that he had come out of the room for taking water at about 2-3AM and heard a strange sound. When he saw outside, he observed a fire ball of football size moving from east to west. As soon as this fireball disappeared behind the western hill, he heard the stone falling inside the house. On enquiry, Jeet Singh, told that he was awakened by a sound and came out to see. He observed a fireball moving from Dodital side towards Uttarkashi (i.e. North to South). No body is reported to have died or seriously injured at Agora.

Dandalka and Dasra, the two villages are situated within 1km of Agora. Three children of a family (7 year old daughter, 12 and 16 year old sons) died in Dasra. The mother of these children too was seriously injured. In Dasra, Indri Devi, whose house was badly damaged, also saw the fireball. Houses in Dasra have been damaged more than those of Agora and Dandalka. People were living outside in all these villages.

Uttarkashi-Lambgaon: 12km from Uttarkashi, on Uttarkashi-Bhaldiyana road, the area of Kishanpur, Manpur and Ginda villages is the most damaged after Bhatwari block. The two sides of the road to the bridge on Indrawati river, situated opposite Ginda village have caved in causing disruption to traffic. The destruction caused in Kishanpur and Manpur villages was tremendous. Manpur is situated by the side of the main road, while Kishanpur is approachable by bridle path at a distance of about 2km.

Out of the two villages, Kishanpur is worst affected. No house was spared from destruction. In some houses, though outer walls are intact but everything has fallen inside. All the members of five families died of house collapses caused by this earthquake.

Villagers keep their cattle in the ground floor of the houses, collapse of which has buried a number of cattle.

On the Uttarkashi-Lambgaon road, after Saura village, heavy damage was seen in the villages of Thalam, Manpur, Ginda, Kishanpur, Kankari, Mustik Saur, Kroli, Aleth, Dhanpur and Baga. The approaches to the bridge near Manpur Ginda have collapsed.

2.2 TEHRI-GARHWAL DISTRICT

In Tehri-Garhwal district, the quake has affected 100 villages in Pratapnagar, Jakholi and Bhilangana blocks. The official death toll on October 26, was 64 and the number of injured 367. The figure for number of deaths was later reported to be 109.

In Mayali, several rubble masonry houses with lime mortar have collapsed and almost all the houses developed open cracks.

In Jhakoli, which is 8km from Mayali, severe damage is reported. Mr. B.S. Rawat, Assistant B.D.O. Jhakoli reported that all the 107 Primary Schools in Jhakoli block had severely cracked and were in precarious condition. Dr. Kuril, Veterinary Doctor, Jhakoli was seriously injured as his house collapsed His office building also collapsed. The office building of the Block Development Officer has developed open cracks.

In Jhakoli block, earthquake destroyed many villages in which a large number of houses collapsed and a few surviving structures have been deserted as it was feared that these houses could also collapse. Huge fissures developed in fields, making tilling difficult. As noted from the newspapers, widespread destruction is reported in Dhameli village (Dhameli could not be traced on toposheet. Daneli is given in the toposheet). In this village, most of the houses were damaged. In Kathur a large number of houses either collapsed or developed wide cracks. In Jhakoli block, about 130 villages were affected and about 7,000 persons were rendered homeless. The heavily populated Gorti village showed the evidence of destruction. In Burhana, a large number of houses developed cracks. A portion of Government Inter College, Burhana comprising four rooms was badly damaged. Tables and chairs kept in these rooms were also broken. Union Bank building was also damaged. In Mamani and Dhankurali of Lasya area, several houses cracked. In Chauran Paunthi of Silgarh area and in Khallyan and Muneghar of Varsir Banger area, cracks have developed in most of the houses and a fissure extending for about two hundred meter length developed on the hillock above the villages.

The earthquake blocked the roads between Tilwara to Saurean Khala and Tilwara to Ghansali.

In old Tehri town it is estimated that more than 200 houses were seriously damaged and more than 500 displayed cracks. Cracks have developed in almost all houses made of bricks in mud mortar. It was reported that in two houses, portions of walls had collapsed. Residents of Tehri town described that for the main earthquake, the first shaking was not very strong (P wave) then strong shaking (S wave) was noticed 4 second after the first shaking accompanied by a sound that resembled an explosion and appeared to be coming from north. An aftershock on 27.10.91 at 6.50 PM (IST) was felt by B.K. Rastogi in the same manner. This aftershock was of magnitude 4 and was felt in the entire area of Tehri and Uttarkashi districts. This observation indicates that the main shock and this aftershock are at a distance of about 35km from Tehri town. Dobata, Sinrai, Marora, Maali Dewal Uppu etc. villages had a large number of cracked houses. It is reported that in Marora village one woman Kiri Devi died due to collapse of a house. Many families were rendered homeless in Marora and Sinrai villages. In Marora village many people were living in tents erected outside their houses.

Higher reaches of Tehri district like Khaliyan, Barsil, and Banger villages have also been affected. Most of the houses have been damaged in Oradhar, Koti and Paunthi villages. Amarsar, Lasiyal and Kepars villages have suffered widespread damage. It is reported that the Post Office building of Devidhar Mamron was severely damaged.

In Chaunra and Vadiyargarh, houses were damaged and people lived outside for many days. In Chaunra area, the damaged villages were Thapli, Naut Kalkileswar, Barkot, Sankari, Mangsu etc. The devastating earthquake damaged Government Inter College building of Vadiyar area. Another college in Chhati Ghariyal was also damaged. Several houses in Kandyalgaon and Saula of Kathur area were damaged. Foul smell and crying survivors was the scenerio in Aagar and Thati Kathur areas of Bhilangana block. The Pradhan of Aagar also died in the tragedy.

There was massive damage in Siral, Dobra, Kholgarh, Mishrawan, Bhilunta, Lambgaon and Bhainga villages under Pratapnagar and Thauldhar development blocks.

In village Bhainga and Raika area of Pratapnagar block six persons of a family died.

In Lambgaon, several houses were damaged and Tehri-Lambgaon road was blocked due to landslides.

In Ghansyali area, several houses were damaged. In a small village, Changiora, situated about 125km away from Maneri,8 people died.

2.3 CHAMOLI DISTRICT

In Chamoli district damage has occurred in Gaurikund, Jangalchatti and Okhimath on way to Kedarnath. The bridle path to Kedarnath has been damaged due to subsidences at many places . In Gopeshwar area, more than 150 villages were effected .

Official death toll in Chamoli district is 6 which has been personally confirmed to us by District Administration.

In Karanprayag town, several houses have cracked. In upper Bazar, old houses have suffered more damage. In Tamata locality an inside wall of a house had fallen. In the countryside also several houses were reported to be badly damaged.

Karanprayag dispensary developed cracks on walls. This is an RCC structure.

In Joshimath PWD Guest house, cracks have developed around windows or doors.

In Badrinath, almost all the Dharamshalas and a few hotels developed cracks in the walls. Most of these cracks are diagonal in nature.

In Gopeshwar (Chamoli) Mr. P.C. Sharma, D.M. reported hairline cracks in numerous houses including government hospital building. These cracks are minor in nature.

Kedarnath : According to news paper reports, in Kedarnath a portion of the Bilaspur Bhawan collapsed and two out of six coolies who had been engaged by pilgrims from Doorg (Madhya Pradesh), died.

Several houses in Maikhanda and higher elevations are totally damaged. Sonprayag to Trijugi Narayan motorable road could be opened only after a few days.

Several houses have collapsed in villages situated in the higher reaches like Trijugi Narayan (2600 m.), Tosi and Gaurikund (2000 m.), Sonprayag, Sitapur, Rampur, Barasu, Serasi. A few houses were damaged in village Vijrakoth of Pokhari block of Chamoli district.

In Guptakashi cracks have developed in all the walls of almost every house,but collapses were not noticed. Severe damage started only after Phata village which is about 7 km from Guptakashi on way to Kedarnath.

From Uttarkashi towards the east, severe damages in the form of landslides, cracks on the hill tops and collapse of houses are noticed upto Mandakini valley. Further, east of Kedarnath, Badrinath area has suffered comparatively lesser damage in the form of cracks in the buildings. In Joshimath, Chamoli, Karanprayag, Rudraprayag, Srinagar and Devprayag similar damage has been noticed.

In Okhimath quite a number of houses made of stone masonry as well as RCC, developed cracks in all the walls. Four houses are reported to have collapsed in Kalimath, 6km north of Okhimath. Mr. Ravindra Godbole, SDM, Okhimath reported several cracks in the ground in Pathali village about 2 km. south of Okhimath. On inspection these cracks were found to be along the slope of the hill and are aligned in N70°E direction. People in the village said that these cracks were first noticed on 14th October 1991, and a part of the slip took place on 15th October when an earthquake of mild intensity for about 5 seconds was reported to be felt by several people. This coincides well with the foreshock of magnitude 4.3 which was recorded on 15th October 1991. The landslides blocked the Akashkamini river for 2 to 3 days.

Mr. P.C. Sharma, District Magistrate of Chamoli, told a Press reporter that 110 villages of the district had been effected by the earthquake, 225 houses had been completely destroyed and 1500 houses developed cracks. Maximum damage has been reported from Maikhanda to Kedarnath in Mandakini valley. Six people lost their lives in this district.

2.4 Dehradun, Rishikesh, Devprayag, Pauri, Srinagar, Rudraprayag,

Dehradun: About 25% buildings in Dehradun are reported to have developed cracks. Some of the observations are described below :

1. In Mohitnagar colony opposite Wadia Institute a number of houses have developed cracks. All the 6 houses in one lane have cracks. In house No. 197 lane No.3 Mohitnagar had vertical cracks on three walls. In a neighbouring house belonging to Mr. Sanwal, the cracks on the floor join the cracks on opposite walls.

2.Several of ONGC buildings have developed cracks. The main pillar of eight storey Geopick building has cracked. Guide frame of the lift of this building has got bent by which its alignment was disturbed and as a result the lift did not work for a few days.

3. T.V. of Mr. Sanwal living in Rajpur Road fell down.

4. In Mr. B.K. Verma's house, two dolls fell down.

5. In Wadia Institute Guest House, 15, Civil Lines, Dehradun, hairline cracks were observed in the switchboard enclosure.

6. According to "Amar Ujala" report of Oct. 21 in DAV college, Dehradun a 20 inch wide and 20 feet long wall collapsed. Three wide cracks were noticed in Tele-Communication Department building. Wide cracks developed in YMCA building on Rajpur Road. South and west facing walls developed wide cracks. Plaster also fell from the ceiling. Cracks were also seen in three buildings of Survey of India. St. Francis Church was also damaged. Plaster fell from ceiling and many walls cracked.

Cracks are observed in numerous houses in all these towns. Houses made of even rubble masonry have not collapsed.

In Srinagar Industrial Training Institute diagonal cracks were seen on the walls of RCC structures. North facing walls have prominent cracks. Two houses near the Bus stop developed diagonal cracks on walls or vertical cracks near the corners.

In Bawai village of Rudraprayag Tehsil, emission of air from some ground cracks was reported by the villagers to Mr. Ashok Kumar, SDM Rudrapryag. A case of water emission from the ground crack was reported from Nera Busta village, near Augustmuni. In Pauri, some double storey RCC buildings developed comparatively more cracks.

2.5 DESCRIPTION OF INTENSITY SURVEY CARRIED OUT IN AREAS AWAY FROM GARHWAL

Bareilly :Shock was not felt by all people. Mr. P.L. Anand, retired Railway Officer described that he was awakened as his bed shook but all the other members in the house, wife and sons did not feel it.

Mr. G.S. Gill, Manager, Oriental Bank, Bareilly, said he also felt the earthquake, but when enquired from other employees in the bank, it was a mixed reply, some felt and some did not even know about the earthquake till they heard the news next day.

Hissar: Felt strongly but no cracks have been noticed in any building as reported by Prof. S. Narwal of Agriculture University.

Ghaziabad: No damage. Felt strongly.

Meerut: No damage. Felt strongly

Muzzafarnagar: No damage. Felt strongly

Lucknow: Some people felt but some did not. Movement was felt as rocking of a boat.

Kanpur: Some people felt and some did not. The movement was described as rocking on boat.

Nainital: Felt strongly. No damage has been reported. Mr. P.K. Tripathi, an engineer from Lucknow who was staying in a guest house, felt the shaking as if monkeys were jumping on the roof. First there was mild shaking, then stronger rocking of bed. Shaking continued intermittently for 2-3 minutes. A time piece fell towards east. A boulder fell down from the China Peak and damaged a tree completely.

Manali: Naindas, Technician of Wadia Institute of Himalayan Geology, who was at Manali felt NNE-SSW movement for 4-5 sec. and reported that 11 people came out. He did not see any crack..

Delhi: Cracks in a few houses have been reported in Delhi. A few observations are described below:

1. Dr. G.D. Gupta, PSO, Department of Science and Technology informed that in his wife's dispensary in Sunlight Colony in Lajpatnagar, some cracks were noticed after the earthquake.

2. Hindustan Times of 21.10.1991 showed photograph of a damaged lift in Cannaught Place.

3. In Trans-Yamuna area of Shahdara, cracks were not reported by any resident though several were interviewed.

4. Buildings were reported to be shaken like cardboard boxes. Many said that they had never experienced such a quake in their life. High-rise apartments and buildings rattled violently adding to all round panic. Women, children and men rushed out of their houses into the open.

5. The pendulum clock in Dr. Gupta's house stopped at 2.55 AM. This is a classical description for intensity V.

6. Narendra Kumar of Delhi University, Department of Georesources described that water was seen to be vibrating in a half-filled glass bottle first continuously for 5 minutes then intermittently for half-an-hour. This observation is typical of intensity V.

7. Newspapers report quoting police sources that a house had collapse in Pushpa Vihar colony of South Delhi but our attempts to locate it failed.

8. Balcony of house no. D-389 in Kidwai Nagar collapsed injuring an old lady (Jan Satta 21.10.1991).

9. In Amar Colony of Lajpatnagar building of Sridharam Sanatan Dharma Senior Secondary School was seriously damaged. Tower of the building has fallen and walls have cracked. After hearing the sound of fallen tower, several people came for rescue,however none was injured. Watchman Vidyadhar was sleeping inside.

He told that the building was intensely shaken and several walls had cracked. Fallen plaster from ceiling showed steel rods from many places (Jan Satta, 21.10.1991).

Rishikesh: Houses have been damaged in Indira Colony.

Chakrata: As reported in newspapers a few houses collapsed, cracks developed in some other houses, trees fell and ground cracks were observed at several places.

Lakhwar: Road was blocked due to landslide.

Mussoorie: Earthquake was felt strongly. Except for minor cracks in buildings no major damage was reported.

Chandigarh: Mr. Narendra Kumar of Delhi University was told by his father-in-law that the Warehouse Corporation Building at Kurali village 30 km from Chandigarh had developed cracks. As reported in Jansatta (21.10.1991), things started falling in the rooms.

Sonepat, Haryana: Felt strongly. Doors and windows rattled (Jansatta, 21.10.1991).

Himachal Pradesh: One person, Mr. Kunjilal died due to collapse of a house in Sangla village of Kinnaur district. In Timbi, Shillai, and Kamran villages of Sirmaur district there are reports of collapse of some houses. Hundreds of houses have developed cracks in Kinnaur, Solan and Sirmaur districts.

Shahjahanpur, Pithoragarh and Pilibhit: Shock felt.

Moradabad: Three or four shocks felt for 30 seconds in the early morning. Tin sheets of the roofs of a few houses and electric poles had fallen down (Jansatta 21.10.1991). People came out of the houses for safety.

Almora: Almora city and nearby places suffered cracks in a few houses (Jansatta 21.10.1991).

Nepal: In Nepal 15-18 shocks were recorded until the afternoon of 20.10.1991. These shocks were of mag. 3.5-6.1. Some were strong and some were weak. Some shocks were reported to be felt in the bordering town of Dhangarhi in the Kailali district.

Saharanpur: At a place called "Gango" 30 km from Saharanpur towards Delhi, close to Yamuna river, cracks were reported in a house of in-laws of Mr. AD Goel, Chief Geophysicist, ONGC.

Roorkee: Felt strongly.

3 LANDSLIDES AND CRACKS ON THE GROUND AND HILLS.

Apart from the damages to the buildings, the most visible effect of this earthquake is in the form of landslides and cracks.

3.1: BHAGIRATHI VALLEY

The region where most of the landslides occurred is along the Bhagirathi valley and extent of the region affected by landslides is between Bhagirathi and Alaknanda valleys. Between Chinayalisaur and Uttarkashi, at a few places landslides were noticed. One landslide is seen close to the Srinagar thrust. Here, the rock type is quartzite, which is highly fractured and jointed. About 7 km west of Uttarkashi i.e. near Matli, huge landslides are seen at two places. These are mostly rock boulders embedded in loose sand which have slipped. On Uttarkashi-Gangotri road maximum number of landslides were seen. On this road, the first landslide encountered is after the Gangori village, and then a series of landslides were seen upto Harsil passing through the villages of Ganeshpur, Hinna, Netala, Maneri, Jamaki, Bhatwari, Pala, Gangnani and Harsil. Starting from Gawana bridge major landslides were observed at kms 155, 157, 158, 161, 162, 163, 165, 166 and 168.5 stone. These distances are from Rishikesh.

About 5 km from Uttarkashi, cracks along the road trending N70°W were observed. Along these cracks a 15cm. subsidence towards the slope was measured. Just before Gawana bridge, a crack trending E-W (the direction of the bridge) was also observed. The crack was along the contact of the road and the sloping ground. Just near this crack there was another crack trending N70°W direction.

After the Gawana bridge, near Netala village, similar road cracks in N70°W direction were noticed. Similarly between Maneri and Bhatwari several cracks were noticed either along or across the road. Mostly the direction varies between N 10°E to N70°W i.e. either N-S or E-W.

Cracks in the ground or hill slopes are also confined between the Bhagirathi and Bhilangana valley. In several villages situated on high hills north of Uttarkashi people reported occurrence of ground cracks. These cracks are mostly along the hill slopes.

Near Jamak village, after the Maneri Dam, two parallel cracks trending N10°W were noticed in the valley. While climbing towards the Dedsari village, cracks along the slope in N20°W direction were noticed.

Fractures in Sangrali, Pata and Baggialgaon: Sangrali village is situated about 2.5 km southeast of Mahidanda.(Patagaon and Baggialgaon). Rock types in the area are quartzites. The average hill slope is 42° in east direction. Two prominent sets of fractures are noticed as described in the Report of UP Dept of Geol. & MIN. More pronounced is N-S set. This crack is quite open wide and persistent. Width of the crack varies from 0.5 cm. to over 40cm. . Displacement has occurred along the dip planes. As a result of this displacement a great deal of jointing, fracturing and formation of subsurface holes and cavities have occurred making the inhabited slopes unstable. The fractured portion of hill slopes of Sangrali village, which is believed to be about 9m deep, hangs over Pata village and poses a great danger to it.

3.2: ALAKNANDA VALLEY

No land slides due to this earthquake were observed while proceeding from Rishikesh to Badrinath via Devprayag, Rudraprayag, Karanprayag, Gopeshgwar, Joshimath and Badrinath. On the Rudraprayag-Okhimath road also no landslides were observed. Thus the landslides were mostly confined between the Bhagirathi and Bhilangana valley, except near Kedarnath.

4 ISOSEISMALS:

Based on our damage survey in the three district of Uttarkashi, Tehri-Garhwal and Chamoli we have drawn the isoseismal trending NW-SE. We have assigned intensity values at different places on the basis of our observation and personal interviews.

Description of different scale is given in annexure III of report by Geological Survey of India. Until a few decades ago Rossi-Forel scale was used. Modified Mercalli Intensity Scale (1956) is being used in India and western countries. For some years Medvedev-Sponheaer-Karnik(MSK) Intensity scale (1964) is being used in USSR and eastern European countries. Both MM and MSK scales are similar, but the MSK scale is better defined and incorporates additional land deformation features. In view of this we have used MSK scale.

Intensity IX is assigned to places which experience total collapse of houses, water pipes are broken and ground cracks of width upto 10cm. on slopes and more than 10 cm. on river banks are observed. All these features have been observed in intensity IX area extending from Gawana bridge to Didsari in an area of 10km x 7.5km Moreover shaving of river banks opposite Maneri village is a feature which would give intensity IX.

Intensity VIII has been assigned within an area extending from Naogaon to north of Thati Kathur and Uttarkashi to Pala. Wherein cracks in the ground, upto width of several centimeters. Changes in ground water flow have occurred and many type A structures have suffered damage of grade 4 i.e. partial collapse of poor constructions.

We have assigned intensity VII to areas where a few houses of type A have partially collapsed (damage of grade 4) and occasional landslips on steep slopes have taken place such area include Nakuri, Gangotri, Kedarnath, Guptakashi, Jakholi, Pratapnagar etc.

In intensity VI, brick buildings (type B) get damage of grade 1 i.e. cracks in plaster or fall of plaster, and poor construction of type A get small cracks in walls.

Intensity V is assigned in areas where plaster cracks are observed.

"Some Damaging Earthquakes Of Indian Subcontinent"

Year	Region	Richter Magn.	Lives Lost	Year	Region	Richter Magn.	Lives Lost
1618	Bombay	-	2,000	1941	Andaman	8.1	Many
1720	Delhi	6.5	Some	1950	Assam	8.6	1,500
1737	Bengal	-	30,000	1952	Pondgo & Tangu NE India	7.5	Many
1803	Kumaon (U.P.)	6.5	Hundreds	1956	Bulandshahr (U.P.)	6.7	Many
1803	Mathura	6.5	Many	1956	Anjar (Gujarat)	7.0	Hundreds
1819	Kutch	8.0	Many thousand	1958	Kapkote (U.P.)	6.3	Many
1828	Kashmir	-	Few thousand	1963	Badgam (J&K)	5.3	Hundreds
1833	Bihar	7.7	Hundreds	1967	Koyna	6.5	200
1848	Mt.Abu (Raj.)	6.0	Few	1975	Kinnaur (H.P.)	6.2	42
1885	Kashmir	-	6,000	1980	Dharchula (U.P.)	6.1	
1897	Assam	8.7	1,600	1980	Jammu (J&K)	5.5	12
1905	Kangra	8.0	20,000	1986	Dharamsala (H.P.)	5.7	Few
1930	Dhubri (Meghalaya)	7.1	Many	1988	Assam	7.2	Few
1934	North Bihar	8.3	20,000	1988	North Bihar	6.7	About 1,300
1935	Quetta (Pakistan)	7.5	25,000	1991	Uttarkashi (U.P.)	6.6	769

PART THREE

REPORT by IMD

INSTRUMENTAL RECORD OF UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

BY

INDIA METEOROLOGICAL DEPARTMENT

INSTRUMENTAL RECORD OF UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

BY

INDIA METEOROLOGICAL DEPARTMENT

SYNOPSIS

Uttarkashi earthquake of Oct. 20, 1991 (M=6.6) caused extensive damage to property and killed 768 persons. The shock was widely felt all over the northern India. Hypocentral parameters of the earthquake have been determined by IMD using the data of 26 seismic stations. The main earthquake was preceeded by 2 foreshocks and followed by a series of aftershocks. In the epicentral zone, the intensity exceeded VIII on the MM scale. Accelerograph at Uttarkashi recorded maximum ground acceleration of 30 percent of `G'.

1 Introduction

1.1 An earthquake of magnitude 6.6 occurred in Garhwal Hills of Uttar Pradesh in the early hours of October 20, 1991 and caused widespread damage in the region. The shock was widely felt in the adjoining northern states of Punjab, Haryana, Himachal Pradesh, Jammu & Kashmir and the Union Territory of Delhi and caused extensive damage in the districts of Uttarkashi, Tehri and Chamoli and minor damage in the district of Nainital, Pauri-Garhwal, Dehradun and also Sirmour district of Himachal Pradesh. Only 45 seconds of severe shaking left 768 people killed, 5,066* persons injured, 20,184 houses severely damaged and 74,714 partially damaged.[1] Though the shock was in the moderate category, it affected 2093 villages and caused extensive damage to fauna and flora. The severity of the shock was so high that 3,095 cattle heads perished and affected an area of 1,47000 hectares and a population of 4.25 lakhs. The vigorous shaking also affected agricultural lands severely and caused damage to about 89,000 hectares of cultivable land.

---

1 * (source - Ministry of Information and Broadcasting)

1.2 The Government of India appointed an interministerial reconnaissance team of experts to assess damage caused by the earthquake.* [2] The central team made aerial and on ground surveys on the earthquake hit area on October 21, 1991.

1.3 The area of damage as assessed in the aerial survey is shown in fig.-1. Severe damage occurred in about 2100 sq. km area where as moderate and miner damage in an area of 7,000 and 12,000 sq. km, respectively. In the aerial survey, number of slides were observed near Gopeshwar Town, the headquarters of Chamoli district, which were caused due to heavy rains earlier in August-91.Though large number of slides were seen in the Bhagirathi, Indrawati and Bhilangana valleys, none caused blocked of the major tributaries of the Ganges. Among the engineering structures which suffered maximum damage was an Iron-span bridge at village Gawana (8 km away from Uttarkashi). damage and sinking of abutments caused due to severe agitation resulted in the failure of roller bearings and subsequent collapse of the bridge.

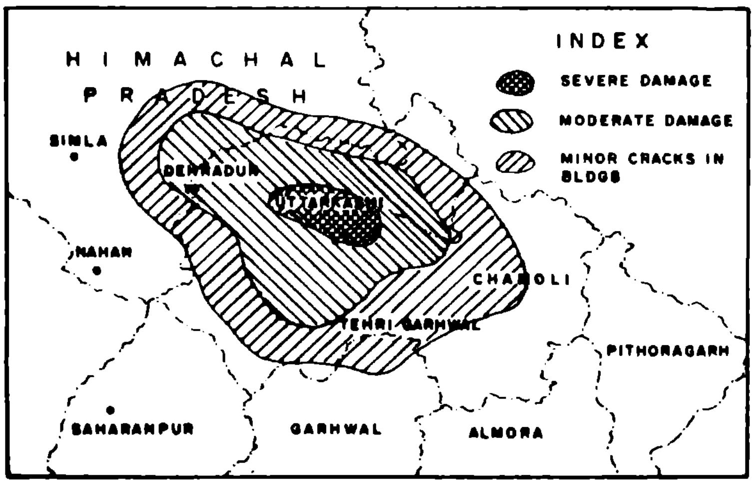


Fig. 1 : DAMAGE CATEGORIES IN THE AFFECTED AREA

2 Past seismicity of the region

2.1 Table-1 shows the parameters of past earthquakes between magnitude range of 4 and 7 for the period from 1816 to 1988. An earthquake of magnitude 7 occurred on 28 Feb 1906 in the region (Lat. 32.0 N, Long. 77.0°E) causing damage to property. Great Kangra earthquake (M = 8.0)of 1905 which killed 20,000 people and also caused extensive damage in the region. Out of the 78

2 * (Source - Ministry of Agriculture, Department of Agriculture & Co-operation)

events 46 are within magnitude range of 4–5, 25 between 5–6 and 7 between 6–7. Fig.2 shows the map of the region bounded by latitude 29.0°-32.0° and longitude 77° to 80°E in which past earthquakes have been plotted. The distribution of earthquake epicentres shows a NW-SE trend along the trace of the MCT. The earthquake activity is attributed to movement on the MCT and other thrusts active in the area.

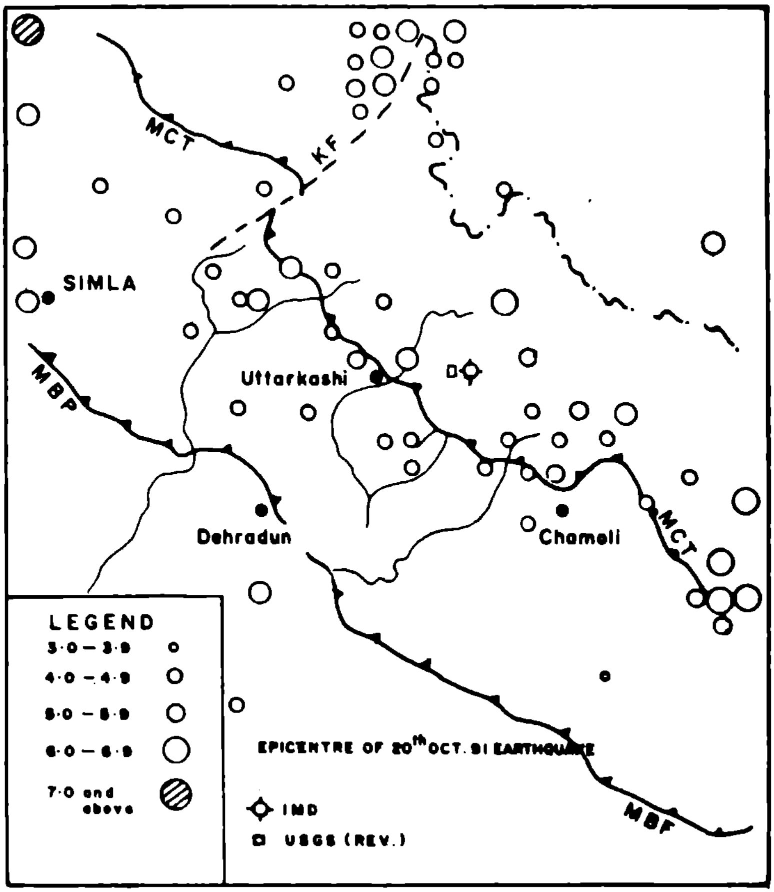


Fig.2: PAST SEISMICITY OF THE REGION BOUNDED BY LAT. 29-32°N AND LONG. 77°–80°E.

3 Determination of Hypocentral parameters

3.1 As mentioned earlier the Uttarkashi earthquake was well recorded by the national, agency and mobile networks. Phase data recorded at 26 stations were used to determine the Hypocentral parameters. Also data of seismic stations operated by the Wadia Institute of Himalayan Geology (WIHG) Dehradun and Delhi University (D.U.) were used. A list of stations and their coordinates are given in Table-2 and represented in Fig.-3.

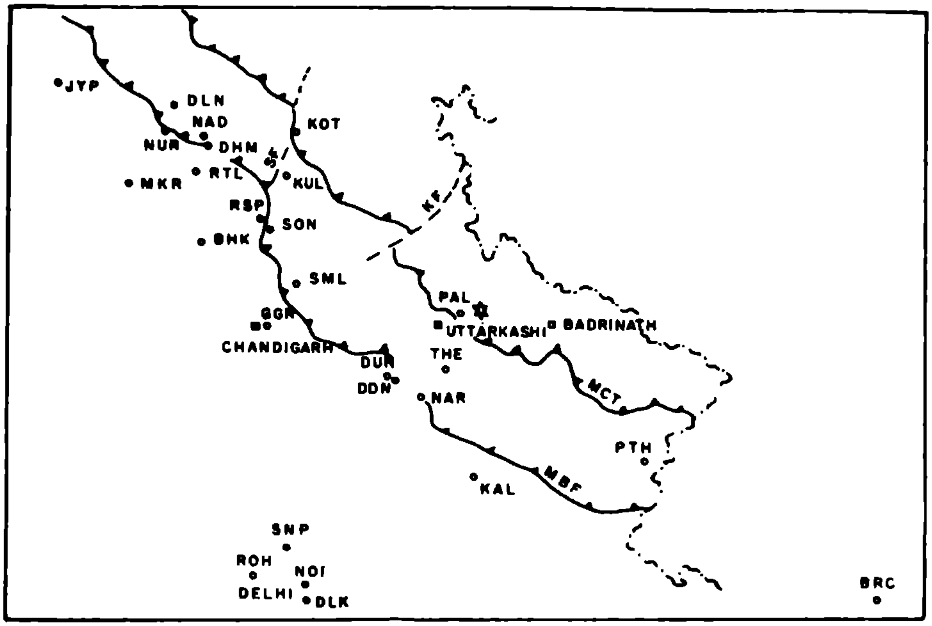


Fig. 3 : LOCATION OF 26 SEISMIC STATIONS USED IN FINDING THE PARAMETERS OF OCTOBER 20-1991 EARTHQUAKE. FOR EXPLANATION OF STATION ABBREVIATION REFER TABLE - 3.
MCT : MAIN CENTRAL THRUST.
MBF : MAIN BOUNDARY FAULT.

3.2 A velocity Model (developed in IMD) for the Himalayan region was used in the computer program for determining parameters of the main earthquake. A three layered model, described below, was tested for large data collected in the Himalayan region and is in operation IMD over two decades;

Velocity (km/sec)	Thickness of Layer (km)
5.27	surface - 24
6.61	24 to 45
8.22	above 45

3.3 Using the above model Hypocentral parameters of the main earthquake were determined and are given below:

- Origin time — 02 H 53 M 16.45 S IST On Oct. 20,1991
- Latitude — 30.75° N
- Longitude — 78.86° E
- Magnitude — Mb = 6.6
- Depth of focus — 12 km.
- Ground acceleration — 30 percentage of "g" at Uttarkashi
- maximum intensity — VIII+

The residuals (difference between actual and calculated transit times) were adjusted to the minimum. The RMS (Root Mean horizontal (ERH) and vertical (ERZ) as 5 and 3 km, respectively. The residuals at the near stations were of the order of 0.5 i.e well within the RMS value. (Table-3). The computer output is given in Table-4 giving details of computation.

3.4 It is known that estimating the focal depth is a difficult exercise. In order to assess proper depth of focus, Hypocentral parameters were also determined manually for different depths and results were compared with the computer solution. The manual solution which yielded focal depth of 12.5 km showed a good agreement with the computer solution. The United States Geological Survey (USGS) also determined Hypocentral parameters independently which showed good agreement with the final solution Fig.2 shows the map of north India where both the locations have been plotted for comparison.

4 Macro Level data

4.1 In order to assess correctness of the computer solution macro level data, collected by the field party, were used. Relying on their source of information media as well as few organisations reported epicentre at different locations. Popular among these were villages of Agora and Jhamak, Maneri Dam site, and Bhatwari town. It should be noted that macro level data though important, indicates approximate location of the epicentral zone. While making assessment on the basis of macroseismic data, the general tendency is to place the epicentre at the centre of maximum damage. While damage to buildings depends on several factors viz type of construction, nature of soil, intensity, block movement etc. the epicentre may be located hundreds of kilometer away from the area. In the hilly terrain intensity falls rapidly with distance. In view of these factors the macroseismic data were analysed carefully for locating the epicentre. Analysis showed the epicentre location towards east of the maximum area of damage. The macroseismic solution agrees well with the computer solution.

5 Fault Plane Solution

5.1 Fig-4 depicts the preliminary fault plane solution as given by the USGS. Nodal plane NPI has a strike of 332°N with a dip of 19° while the other nodal plane (NP2) has a strike of 108°N with a steep dip of 76°. The NPI solution is acceptable and indicates a predominant reverse type of faulting. The pressure axis striking 208°N shows good agreement with the direction of movement of

Indian landmass with respect to Eurasian. Several fault plane solutions worked out earlier for other earthquakes occurring in the region also indicate thrusting on a plane trending more or less in a north northwest direction.

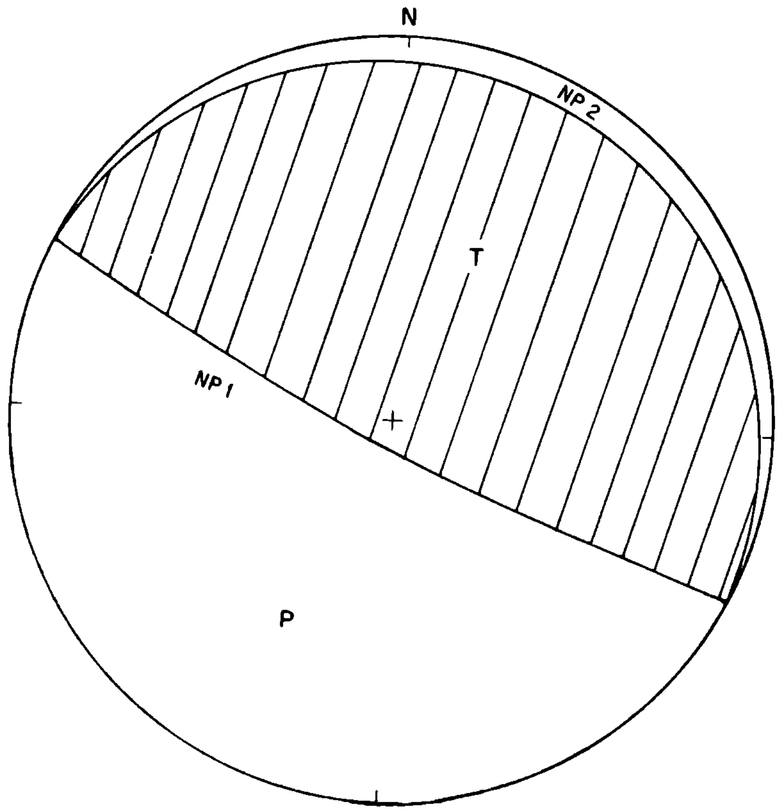


Fig. 4 : USGS FAULT-PLANE SOLUTION OF UTTARKASHI EARTH QUAKE (20.10.1991)
NP1 : Strike 116° : Dip 85° : Slip 90
NP2 : Strike 296 : Dip 5° . Slip 90

6 Foreshocks and Aftershocks

6.1 The main earthquake preceded by two foreshocks on 15th (19 H 11 M 1.67 S GMT) and 17th (08 H 01 M 54.42 S GMT) October,'91 which were recorded by the seismographs of Ridge Observatory, Delhi. The main earthquake was followed by more than 1000 aftershocks within a short period of about two months. For locating the smaller aftershocks, local temporary network was operated by different organisations. Hypocentral parameters of 134 events were determined by employing HYPO-71.using data generated by various organisations. A detailed report on aftershock sequences of Uttarkashi earthquake is given in another chapter of this volume.

7 Intensity and Acceleration due to Gravity

7.1 Although the shock falls in the moderate category,it has given rise to a maximum intensity of VIII+ on MM scale in the epicentral zone.*[3] The maximum ground acceleration recorded by Accelerograph operated by University of Roorkee at Uttarkashi is 30% of "g".**[4] A detailed report on isoseismals and Accelerograph recording of the main earthquake and subsequent aftershocks are given in other chapters of this volume.

8 Conclusions

8.1 From the foregoing discussions the following conclusions are drawn:

(a) The Hypocentral parameters of the main earthquake have been determined using 26 seismic stations operated by IMD, WHIG and Delhi University by employing HYPO-71 and are given below:

Origin time	02 H 53 M 16.45 S IST on Oct., 1992
Latitude	30.75° N
Longitude	78.86° E
Magnitude	Mb = 6.6
Depth of focus	12 km
Ground Acceleration	30% of "g"
Maximum intensity	VIII+

(b) The RMS (Root Mean Square) value of the residuals computed was 1.1 with errors in horizontal (ERH) and vertical (ERZ) as 5 and 3 km respectively.

(c) The preliminary fault plane solution given by USGS for the main earthquake shows reverse type of faulting on a nodal plane trending NNW-SSE direction and the pressure axis trending 208° N.

3 * (Source - Meeting Dt. 2.12.91 at WIHG)

4 ** (Source - DEQ , University of Roorkee)

Table -1

Past seismicity of the region bounded by latitude 29-32°N and longitude 77-80°E

DATE Y	M	D	ORIGIN TIME (G.M.T.)			LAT. DEG.N	LONG. DEG.N	DEP.	MAG.
1816	05	26	0	0	0.0	30.00	80.00	0	6.5
1842	03	05	0	0	0.0	30.00	80.00	0	5.5
1843	04	11	0	0	0.0	30.00	80.00	0	5.0
1856	04	07	0	0	0.0	31.00	77.00	0	5.0
1902	06	16	0	0	0.0	31.00	79.00	0	6.0
1906	02	28	0	0	0.0	32.00	77.00	0	7.0
1906	06	13	0	0	0.0	31.00	79.00	0	6.0
1908	12	11	0	0	0.0	31.00	79.00	0	5.0
1930	05	11	11	30	36.0	31.70	77.00	0	5.5
1937	10	20	1	23	46.0	31.10	78.10	0	5.9
1945	06	04	12	8	55.0	30.30	80.00	0	6.5
1947	08	19	20	7	6.0	31.20	79.90	0	5.9
1949	02	05	8	55	20.0	31.20	79.90	0	5.5
1958	12	28	5	34	38.0	30.01	79.94	0	6.3
1958	12	31	3	45	15.0	30.09	79.86	0	6.0
1962	07	13	5	1	6.0	30.64	79.48	0	5.5
1962	07	14	15	58	54.0	30.64	79.32	17	5.6
1963	04	12	0	41	29.0	32.00	78.79	36	5.4
1963	11	27	21	10	39.9	30.80	79.10	33	5.1
1965	03	30	22	31	13.7	31.76	78.10	0	4.5
1967	01	02	22	17	56.0	30.60	79.13	25	4.7
1968	01	05	6	42	44.4	30.41	79.25	7	5.0
1968	05	31	3	1	35.7	29.91	79.92	33	5.0

1969	03	03	6	20	21.0	30.04	79.84	18	5.0
1971	01	30	20	15	40.9	30.54	78.97	56	4.7
1972	08	17	18	14	25.3	30.75	78.42	33	5.2
1974	02	24	21	32	1.8	30.96	78.47	1	4.9
1974	07	07	20	56	55.3	30.55	78.48	96	4.7
1975	01	19	8	12	9.8	31.94	78.53	49	5.8
1975	01	19	8	18	23.3	31.98	78.51	33	4.8
1975	01	22	17	26	37.4	31.92	78.44	51	4.6
1975	01	29	15	49	25.7	31.95	78.64	33	4.8
1975	03	26	4	47	15.5	32.00	78.40	33	4.5
1975	04	01	16	18	45.1	31.90	78.39	40	4.5
1975	05	11	6	48	37.4	31.93	78.68	19	4.7
1975	07	19	6	10	53.9	31.95	78.59	0	5.1
1975	11	06	0	11	30.4	29.61	77.87	0	4.8
1976	02	05	12	4	30.5	31.24	77.03	5	5.0
1976	09	29	7	47	16.5	31.83	78.40	20	4.9
1976	10	03	15	3	43.5	31.92	78.80	16	4.7
1977	01	28	3	48	53.2	31.42	78.04	50	4.7
1977	02	19	6	15	25.0	31.80	78.43	40	5.4
1977	02	19	6	39	42.5	31.71	78.36	33	4.6
1977	04	14	18	26	50.8	31.99	78.47	33	4.4
1977	04	20	4	21	9.3	30.49	79.45	35	4.9
1978	01	07	7	23	20.0	30.51	79.40	33	4.6
1978	01	15	0	17	19.0	31.07	78.28	33	4.2
1978	01	15	2	30	30.6	31.85	78.36	60	4.5
1979	03	05	23	54	50.0	30.33	79.60	8	4.2
1979	12	28	1	59	18.3	30.82	78.57	23	5.0
1981	05	28	23	14	4.6	31.83	78.43	0	5.2
1981	06	13	0	56	56.5	31.82	78.46	33	5.0

1981	06	19	10	41	45.2	30.44	78.89	64	4.5
1981	08	10	10	58	24.4	31.10	77.82	33	4.6
1982	06	22	2	38	5.1	30.37	78.58	33	4.1
1982	07	07	22	36	24.7	30.91	78.38	0	4.4
1982	07	16	4	15	26.0	30.89	77.68	67	4.1
1982	10	16	2	22	51.5	30.42	79.25	25	4.6
1982	12	14	23	57	29.6	31.39	78.96	10	4.5
1982	12	29	0	9	17.6	30.05	79.89	21	4.7
1983	05	20	12	52	1.2	30.36	79.77	33	4.2
1984	05	03	13	18	0.6	30.54	78.56	59	4.5
1984	11	26	3	35	39.9	30.21	79.13	63	4.4
1984	12	15	10	54	14.0	31.27	77.61	63	4.5
1985	03	11	14	36	10.1	31.39	77.26	41	4.7
1985	06	14	17	19	7.0	29.70	79.40	33	3.8
1986	03	28	18	5	50.3	30.65	78.21	33	4.5
1986	06	30	13	1	42.4	31.80	78.70	33	4.5
1986	07	16	23	3	7.0	31.05	78.00	40	5.6
1987	06	06	3	14	24.9	30.52	79.22	38	4.6
1987	06	06	11	2	40.6	30.36	79.12	36	4.9
1987	07	18	16	29	17.8	31.00	77.95	49	4.7
1988	06	09	12	11	51.3	30.52	79.19	41	4.7
1988	07	14	3	53	36.1	30-.85	78.28	33	4.3
1988	07	27	7	7	44.5	31.59	78.70	46	4.3
1988	09	26	18	4	53.0	32.00	79.40	155	4.2
1988	12	26	11	11	12.4	30.58	77.92	45	4.3

TABLE-2

STATION COORDINATES

SNo.	STATION	LATITUDE (DEG.N)	LONGITUDE (DEG.E)
1.	Pala (PAL)	30-50.50	78-37.75
2.	Tehri (TEH)	30-23.00	78-29.00
3.	Narendranagar (NAR)	31-10.00	78-18.00
4.	Dehradun (DUN,WIHG)	30-19.71	78-00.78
5.	Dehradun (DDN)	30-19.00	78-03.00
6.	Kalagarh (KAL)	29-31.22	78-45.58
7.	Shimla (SML)	31-07.00	77-10.00
8.	Pithoragarh (PTH)	29-33.00	80-13.00
9.	Ghaggar (GGR)	30-47.50	76-55.00
10.	Sundernagar (SDN)	31-33.00	76-54.00
11.	Kullu (KUL)	31-57.63	77-06.25
12.	Rewalser (RSR)	31-37.00	76-50.00
13.	Kothi (KOT)	32-18.46	77-12.00
14.	New Delhi (NDI)	28-41.00	77-13.00
15.	Bhakra (BHK)	31-25.00	76-25.00
16.	Rohtak (RTK)	28-54.00	76-36.00
17.	Naddi (NAD)	32-13.50	76-21.54
18.	Ranital (RTL)	32-00.30	76-21.54
19.	Dhaulakual (DLK)	28-34.00	77-08.00
20.	Sonipath (SNP)	28-59.00	77-00.00
21.	Dharamsala (DHM)	32-13.00	76-20.00
22.	Nurpur (NUR)	32-18.00	75-52.00
23.	Dalhousie (DLH)	32-32.50	75-58.00
24.	Jyotipuram (JYP)	33-06.50	74-51.00
25.	Mukerian (MKR)	31-57.00	75-37.00
26.	Behraich (BRC)	27-34.00	81-35.00

TABLE - 3

Station Residuals for P and S waves for earthquakes on 20.10.91 in West U.P. Hills.

Station	Distance (Km.)	P-Residuals (Sec.)	S-Residuals (sec)
Pala (PAL)	23.2	-0.32	+3.77**
Tehri (TEH)	54.8	-0.94	-
Narendranagar (NAR)	84.5	-1.76	-
Dehradun (WIHG) (DUN)	93.7*	-3.25	-
Derhadun (IMD) (DDN)	91.4	+3.16	+1.63
Kalagarh (KAL)	137.8	-0.17	-
Shimla (SML)	165.9	-0.22	-
Pithoragarh (PTH)	187.8	-1.10	-
Ghaggar (GGR)	185.3	-0.50	-
Sundernagar (SDN)	205.7	-0.58	-3.39**
Kullu (KUL)	213.0	-0.86	-
Rewalsar (RSR)	214.6	+0.94	-
Kothi (KOT)	232.5*	+4.76	-
New Delhi (NDI)	279.4	+0.56	+1.31
Bhakra (BHK)	234.5	-0.58	-
Rohtak (ROH)	299.9	-0.43	-3.52**
Naddi (NAD)	287.2	+0.11	+5.16**
Ranital (RTL)	274.4	+2.67	-
New Dehli (S.C.) (DLK)	294.7	-0.30	+2.68**
Sonepat (SNP)	266.1	-2.45	-2.45(S-P) used
Dharamsala (DHL)	288.7	+0.92	+1.84
Nurpur (NUR)	331.0	+0.78	-1.12
Dalhousie (DLH)	337.5*	+2.99	-
Jyotipuram (JYP)	459.4	-0.54	-
Mukerian (MKR)	334.9	+1.30	-
Bahraich (BRC)	442.6	+0.20	-

* Station not considered in determination

** Phases not considered

TABLE - 4 COMPUTER OUTPUT OF MAIN SHOCK

CRUSTAL MODEL 1

VELOCITY	DEPTH
5.720	0.000
6.610	24.000
8.220	45.000

KS	Z	XNEAR	XFAR	POS	IQ	KMS	KFM	IPUN	IMAG	IR	IPRN	CODE	LATR	LONR
0	15.	450.	550.	1.74	3	0	0	1	1	0	000000	0 0.00	0 0.00	

DATE	ORIGIN	LAT N	LONG E	DEPTH	MAG	NO	DM	GAP	M	RMS	ERH	ERZ	Q	SQD	ADJ	IN	NR	AVR	AAR	NM	AVXM	SDXM	NF	AVFM	SDFM	I
911019	2123 16.72	30-45.63	78-51.15	12.51		25	23	187	1	1.10	5.3	3.4	D	D:D	2.49	10	36	-0.08	0.86	0	0.0	0.0	0	0.0	0.0	3

STN	DIST	AZM	AIN	PRMK	HRMN	P-SEC	TPOBS	TPCAL	DLY/H1	P-RES	P-WT	AMX	PRX	CALX	K	XMAG	RMK	FMP	FMAG	SRMK	S-SEC	TSOBS	S-RES	S-WT	DT
PAL	23.2	293	118	EP 0	2123	21.00	4.28	4.61	0.00	-0.32	1.06	0	0	0.00	0					ES 4	28.50	11.78	3.77	0.0	
TEH	54.8	220	103	EP 0	2123	25.60	8.88	9.82	0.00	-0.94	1.05	0	0	0.00	0										
NAR	84.5	219	98	EP 0	2123	29.90	13.18	14.94	0.00	-1.76	0.98	0	0	0.00	0										
DUN	93.7	239	98	EP 4	2123	30.00	13.28	16.53	0.00	-3.25	0.00	0	0	0.00	0										
DDN	91.4	237	98	EP 0	2123	36.00	19.28	16.12	0.00	3.16	0.46	0	0	0.00	0					ES 4	46.40	29.68	1.63	0.0	
KAL	137.8	184	60	EP 0	2123	40 50	23.78	23.95	0.00	-0.17	1.08	0	0	0.00	0										
SML	166 9	284	60	EP 0	2123	44.70	27.98	28.20	0.00	-0.22	1.06	0	0	0.00	0										

Cont.

Cont

PTH	187.8	136	44	EP	0	2123	48.70	29.98	31.08	0.00	-1.10	1.04	0	0	0.00	0						
GGR	185.3	271	44	EP	0	2123	47.00	30.28	30.78	0.00	-0.50	1.06	0	0	0.00	0	ES	4	80.00	63.28	9.72	0.0
SDN	205.7	295	44	EP	0	2123	49.40	32.68	33.26	0.00	-0.58	1.06	0	0	0.00	0	ES	4	71.20	54.48	-3.39	0.0
KUL	213.0	309	44	EP	0	2123	50.00	33.28	34.15	0.00	-0.88	1.05	0	0	0.00	0						
BSR	214.6	296	44	EP	0	2123	52.00	35.28	34.34	0.00	0.94	1.05	0	0	0.00	0						
KOT	232.5	318	44	EP	4	2123	58.00	41.28	36.52	0.00	4.76	0.00	0	0	0.00	0						
NDI	279.4	215	44	EP	0	2123	59.50	42.78	42.22	0.00	0.58	1.06	0	0	0.00	0	ES	0	91.50	74.78	1.31	1.0
BHK	-243.5	287	44	EP	0	2123	54.00	37.28	37.86	0.00	-0.58	1.06	0	0	0.00	0						
ROH	299.9	227	44	EP	0	2123	61.00	44.28	44.71	0.00	-0.43	1.06	0	0	0.00	0	ES	4	91.00	74.28	-3.52	0.0
NAD	287.2	304	44	EP	0	2123	60.00	43.28	43.17	0.00	ɗ.11	1.06	0	0	0.00	0	ES	4	97.00	80.28	5.18	0.0
RTL	274.4	300	44	EP	0	2123	61.00	44.28	41.62	0.00	2.67	0.72	0	0	0.00	0						
DLK	294.7	214	44	EP	0	2123	60.50	43.78	44.08	0.00	-0.30	1.06	0	0	0.00	0	ES	4	96.10	79.38	2.68	0 0
SNP	266.1	222	44	EP	9	2123	60.00	43.28	40.61	0.00	-2.45	0.82	0	0	0.00	0	ES	0	87.60	27.60	-2.45	****
DHM	288.7	304	44	EP	0	2123	61.00	44.28	43.36	0.00	0.92	1.05	0	0	0.00	0	ES	4	94.00	77.28	1.84	0.0
NUR	331.0	301	44	EP	0	2123	66.00	49.28	48.50	0.00	0.78	1.05	0	0	0.00	0	ES	0	99.99	83.27	-1.12	1.0
DLH	337.5	306	44	EP	4	2123	69.00	52.28	49.30	0.00	2.99	0.00	0	0	0.00	0						
JYP	459.4	305	44	EP	0	2123	80.30	63.58	64.12	0.00	-0.54	0.96	0	0	0.00	0						
MKR	334.9	293	44	EP	0	2123	67.00	50.28	48.98	0.00	1.30	1.03	0	0	0.00	0						
BRC	442.6	143	44	EP	0	2123	79.00	62.:28	62.08	0.00	0.20	1.06	0	0	0.00	0						

1 ***** CLASS: A B C D TOTAL *****

NUMBER: 0.0 0.0 0.0 1.0 1.0

PART FOUR

COMBINED REPORT

AFTERSHOCK SEQUENCE OF UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

By

J.R. Kayal ,V.P. Kamble and B.K. Rastogi

AFTERSHOCK SEQUENCE OF UTTARKASHI EARTHQUAKE OF OCTOBER 20, 1991

By

J.R. Kayal ,V.P. Kamble and B.K. Rastogi

ABSTRACT

Uttarkashi earthquake of magnitude 6.6 (IMD) of October 20, 1991 was followed by a series of aftershocks. More than 1000 shocks were recorded within a short period of about two months. Most of these occurred within first few days and within weeks time the number of fell to 5/6 shocks per day from about 80 shocks in the first day. Initially the shocks were recorded by the permanent seismograph stations of IMD . Later on, for locating smaller aftershocks local temporary networks were operated for about two months by different organisations. Data recorded by the permanent and temporary networks of the IMD, GSI, NGRI are used in this report. Hypocentral parameters for 134 events were determined. Most of the aftershocks are located around the MCT and majority of the events gave focal depths less than 15 kms.

1 Introduction

On October 20, 1991 a moderate earthquake of magnitude 6.6 occurred in the Uttarkashi region with disastrous effects. The parameters of the main shock determined by India Meteorologiucal Department (IMD) are given separately in this volume. This moderate earthquake developed a prominent aftershock activity.

The aftershock activity for the Uttarkashi earthquake lasted for more than two months which above average for a moderate earthquake in Himalaya. Some of the aftershocks of larger magnitude were recorded at Delhi and Bias Project Network at epicentral distances of more than 250km . On the very first day eight aftershocks jolted the area strongly which sent local population fleeing out doors. The frequency of aftershocks during the first one week was so high that it also caused panic among the local population. Some of these shocks falls damage to the structures which were badly shaken by the main shock. Aftershocks which were strong enough to be felt at epicentral distances of over 50 km, widened old cracks and caused fresh ones in houses and other buildings. The high intensity as well as frequency of aftershocks caused anxious moments, and the local authorities were worried whether the activity may lead to a more disastrous event. The strong aftershocks also caused landslides which were activated by the main shock.

2 Field Operation

Immediately after the main shock the India Meteorological Department(IMD), the Geological Survey of India (GSI) and the National Geophysical Research Institute(NGRI) sent their parties to the earthquake hit area for recording aftershocks. The NGRI operated one station at Chinyalisaur (CHL) from October 29 to 30 and then at Uttarkashi (UTK) from October 31 to Nov. 13. The GSI commissioned three stations from Nov.3, 1991 at Bhatwari (BTW), Chinyalisaur (CHL) and Barkot (BAK). After 15 days of recording the third station was shifted Ghansali (GHL). Later, one more station was operated at Ghuttu (GTU). These stations were in operation upto 4.12.91. The IMD established a network of three stations at Tehri (TEH) Uttarkashi (UTK) and Bhatwari (BTW) from November 18, 1991 to December 12, 1991. The UTK station was operated with both analog and digital seismoghraphs, the later was subsequently shifted to Maneri dam site. The digital seismograph data are not used in the analysis. The aftershocks were also recorded at permanent observatory operated by the IMD. Details of the seismograph stations are given in Table I. In addition permanent seismograph stations were operated at Tehri and Narendra Nagar by U.P. Irrigation Department and at Pala and Dehradun by Wadia Institute of Himalayan Geology (WIHG). A temporary station at Dunda was also established by WIHG from 2.11.91. These data are, however, not used in this report.

3 Determination of Hypocentral Parameters

The aftershock data collected by the above permanent and temporary networks were analysed by the GSI for the period 12.11.91 to 4.12.91 and by the IMD for the rest of the period. Hypo-71 Computer program of USGS was used for determination of Hypocentral parameters. A three layered velocity model viz. 5.72 km/s from surface to 24 km, 6.6km/s from 24 to 45 km depth and 8.22 km/s below 45 km was used for computer analysis. At least three P-arrivals and two S-arrivals were used for location. For stronger aftershocks Richter formula was used for determining the magnitude whereas magnitudes of the smaller earthquakes were determined using the following empirical formula:

$$Md = -2.44 + 2.61 \log D,$$

where **Md** is the duration magnitude and D is the signal duration. Both the scales are comparable the Hypocentral parameters determine for 134 events are listed in table II in chronological order. The RMS (Root Mean Square) values, which indicate difference between observed and calculated arrival times, are within 0.5 second for majority of the locations. The horizontal error (ERH) and vertical error (ERZ) for most events are within 5 km.

Number of located events are more during the period when closed-spaced temporary network was run in November and December. During the first fortnight the aftershocks were recorded by the permanent network operating at larger distances. Though the aftershock activity was higher during this period, the located events are comparatively less.

4 Results and Discussion

Figure 1 shows the epicentral distribution of the aftershocks, mainshock and surface trace of MBT and MCT. It is interesting to note that the mainshock occurred to the east of aftershock area. The epicentral zone of 40 x 30 km as defined by the aftershocks extends in NW direction. A cluster of epicentres is seen to the east Uttarkashi (UTK). Though depth of the main shock is 12km, those of aftershocks varies from 0 to 15km for majority of the events, while for a few of them the depth has between 15 to 30km depth range. Maximum number of events are of shallower depth (<5 km). The largest aftershocks of M=5.2 occurred at the centre of the aftershock zone, on October 20, 1991 at 5 H 32 M GMT.

Temporal variation of the aftershock sequence has been examined using the data of permanent station at Shimla (SML) for which a complete data set was available. This station records all shocks of magnitude 2 or greater from Uttarkashi area. Figure 2 shows histogram of aftershocks which were recorded at Shimla. During the first week large number of earthquakes were recorded with the highest number of 80 events on 20.10.1991. It may be mentioned that a high gain permanent seismograph station was run by the WIGH at Pala near Bhatwari which recorded about 150 aftershocks on 20.10.91. (per. comm.). On the second and third day the frequency of aftershocks recorded at Shimla, however, dropped to 38 and 20 respectively and within a weeks time it dropped to an average of 5 to 6 aftershocks per day.

Fig.3 shows distribution of aftershocks at different depth intervals. It is observed that about 60 percent shocks occurred within the top layer of 5 km depth, 40 percent within 15 km and only 6 percent below 15 km depth. Thus, the foci of the aftershocks lay mostly within 15 km below the surface.

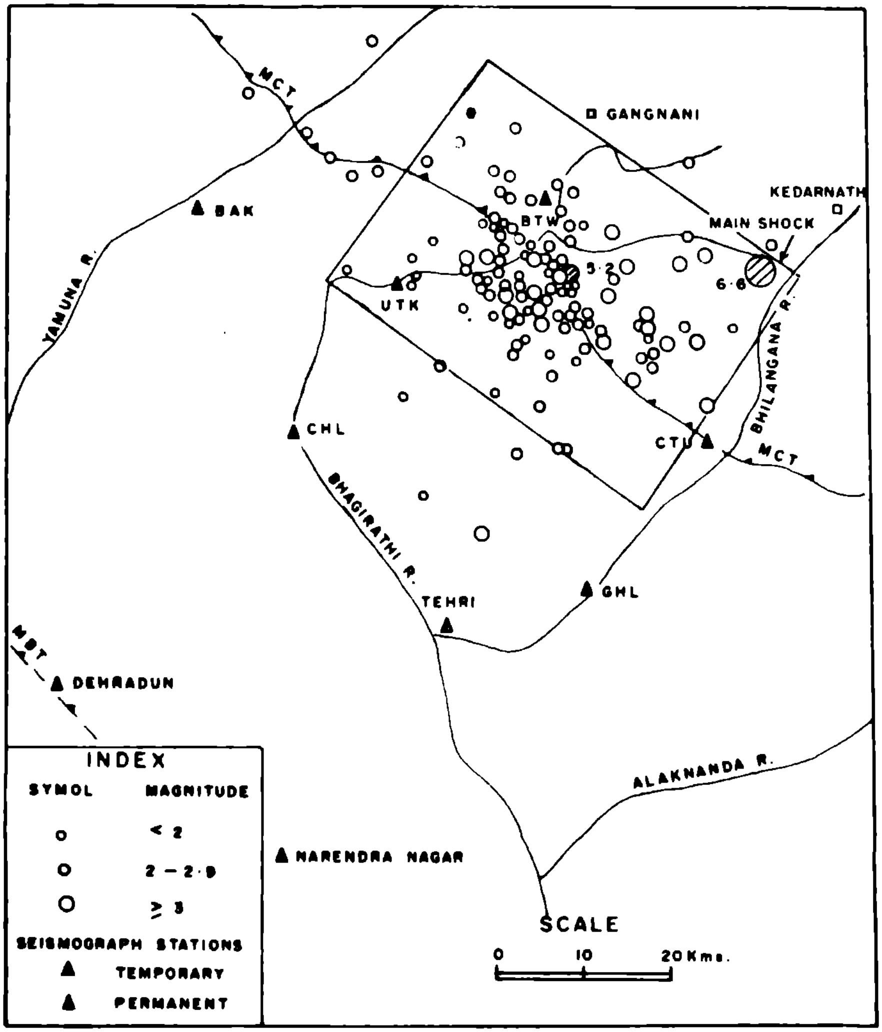


Fig. 1 : EPICENTRAL MAP OF THE AFTERSHOCKS LOCATED BY THE PERMANENT AND TEMPORARY NETWORKS. TEMPORARY SEISMOGRAPH STATIONS;CHL CHINYALI-SAUR, UTK :UTTARKASHI, BAK :BARKOT, BTW :BHATWARI, GHL, :GHANSALI, GTU : GHUTTU,MCT :MAIN BOUNDARY THRUST AND MBT : MAIN BOUNDARY-THRUST.

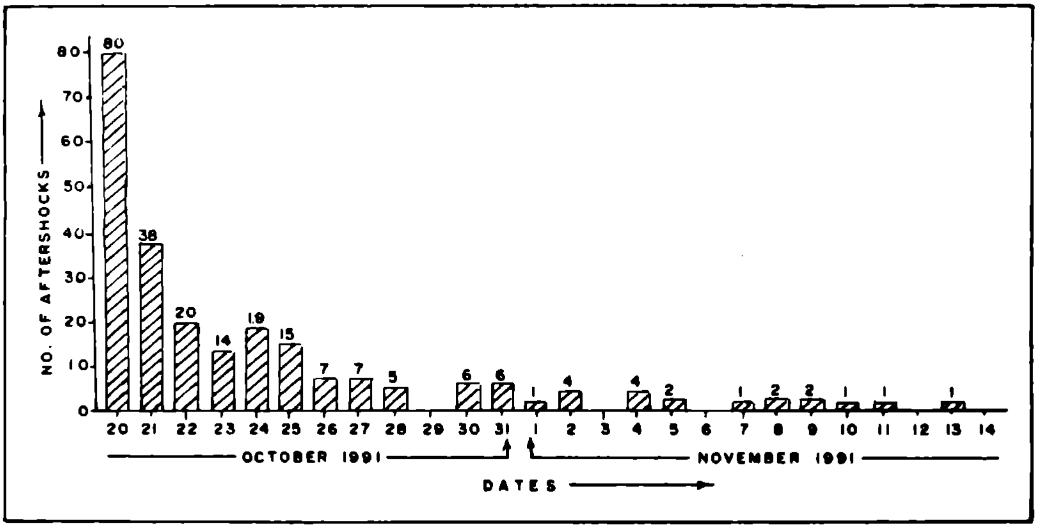


Fig. 2 : HISTOGRAM OF THE AFTERSHOCKS (MAG. >2) RECORDED AT SIMLA PERMANENT STATION (IMD OBSERVATORY)

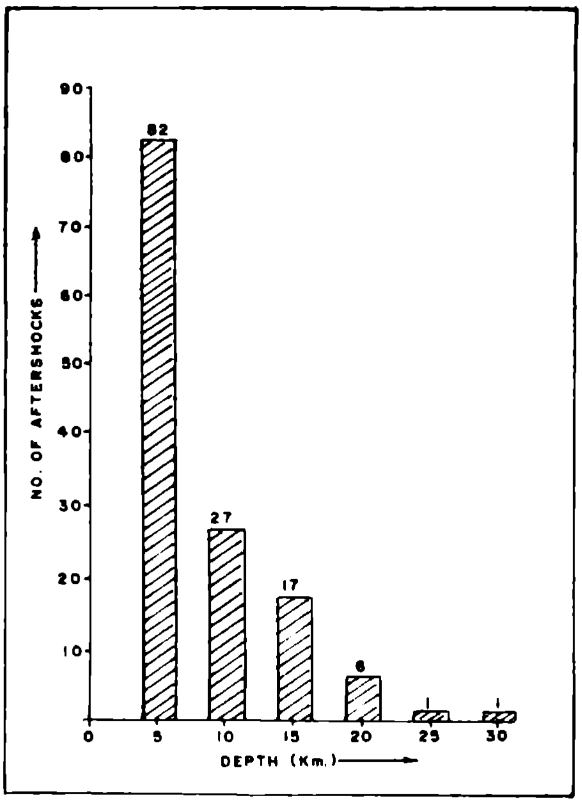


Fig. 3 : NO. OF AFTERSHOCKS VERSES DEPTH.

The frequency of aftershocks with different magnitude range is shown in figure 4. Only one aftershock was of magnitude greater than 5 and four were of magnitude between 4 to 5. It is seen that only 4 shocks of magnitude less than 1 could be recorded indicating that threshold detectibility level of the network was of the order of 1 magnitude. Except 9, all other aftershocks are in the magnitude range of 1 to 4.

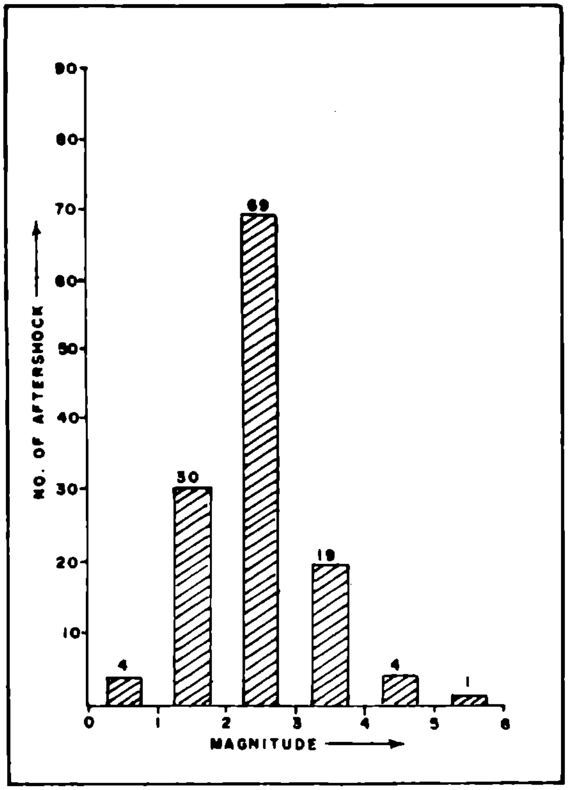


Fig. 4 : NO. OF AFTERSHOCKS VERSES MAGNITUDE.

In order to examine the energy release in the main shock the energy was calculated using the formula:

$$\log E = 5.8 + 2.4\ mb$$

By putting the value of 6.6 for mb of the main shock, energy works out to be 4.36 x 10^{21} ergs. However, for aftershocks, energy was calculated using the formula

$$\log E = 9.9 + 1.9\ M - 0.024\ M^2$$

Using this formula the energy for the largest aftershock works out to be 1.362 x 10^{19} ergs and for all the shocks in the first one week 1.654 x 10^{19} ergs. In the remaining period, the energy released is about 4 x 10^{17} ergs which is two orders less compared to the initial one week.

5 Conclusion

From the foregoing analysis the following conclusions are drawn.

(i) The aftershock activity continued for more than two months with maximum activity in the first week.

(ii) Maximum magnitude of the aftershock was 5.2.

Within the first week, 4 aftershocks of magnitude between 4 to 5 and 6 aftershocks of magnitude range 3 to 4 occurred. In the whole sequence 19 shocks of magnitude between 3 to 4 and 69 shocks of magnitude range to 3 occurred. The temporary microearthquake network recorded more than thousand aftershocks of magnitude 0.5 and above out of which 134 were located.

(iii) Most of the aftershocks were of very shallow origin i.e. within a depth range of 0 to 5 km. A good number of events were recorded within 5 to 15 km depth, whereas only a few events were recorded between 15 to 30 km. depth range (iv) The majority of the epicentres were located near MCT trending NW, in an area of about 40 km x 30 km.

(v) The energy released in the mainshock was 4.365 x 10^{21} ergs; where as in the largest aftershock which occurred 8 hours after the main shock energy released was 1.352 x 10^{19} ergs. In rest of the sequence the energy released was two orders less than the largest aftershock.

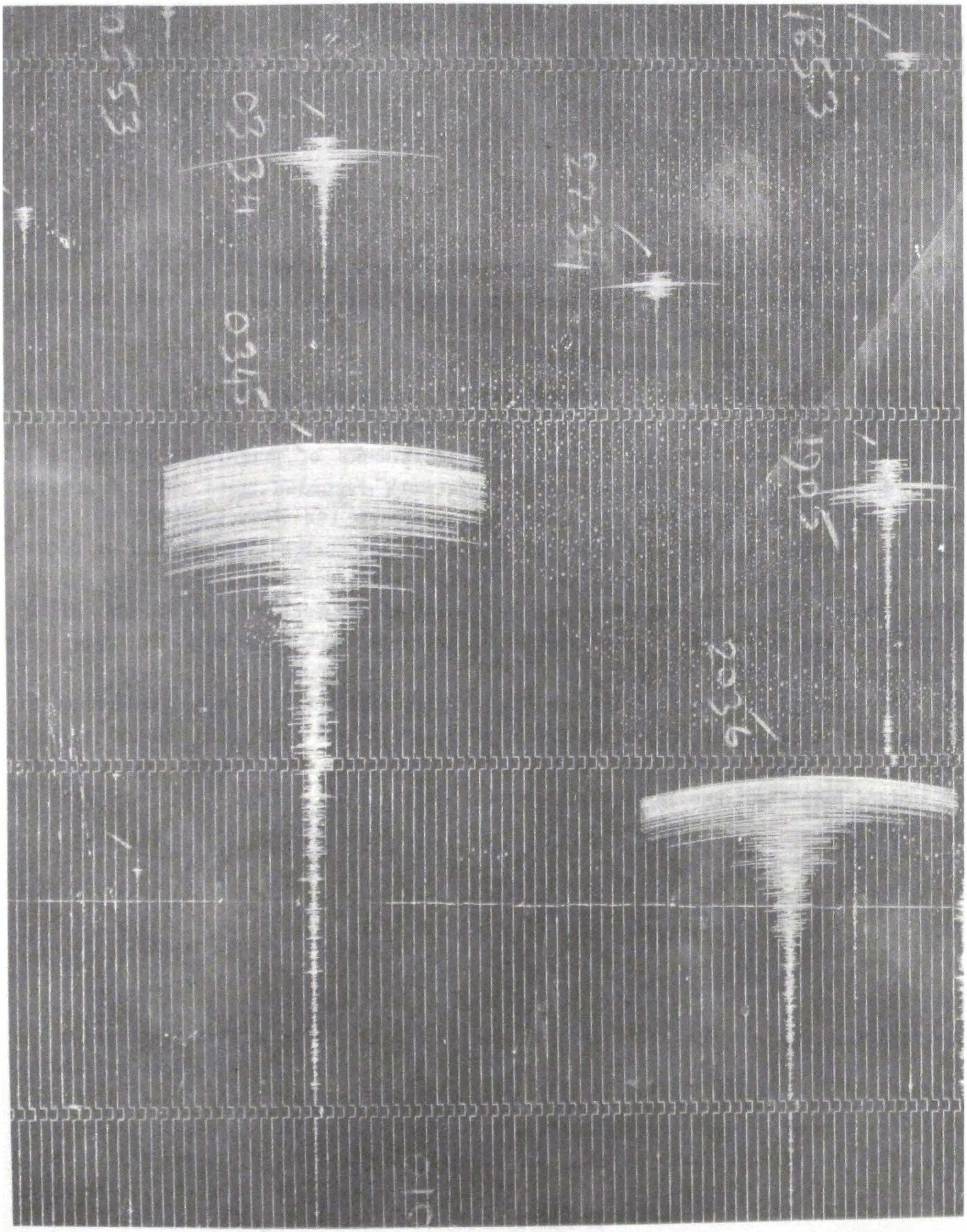


Fig - 5

PART OF SEISMOGRAM SHOWING SOME AFTERSHOCKS
RECORDED AT BHATWARI STATION ON 16 th NOV. 1991

TABLE -1

SEISMIC STATIONS USED FOR LOCATION OF AFTERSHOCKS

TEMPORARY NETWORK

SNo.	Station	Lat.(N)	Long.(E)	El.(m)	Period of Operation	Orgn.
1.	Chinyali-Saur(CHL)	30° 34.43'	78° 19.49'	1000	29.10.91 to 30.10.91 3.11.91 to 4.12.91	NGRI GSI
2.	Uttarkashi (UTK)	30° 43.62' 30° 43.68'	78° 26.81' 78° 27.00'	1109	30.10.91 to 13.11.91 21.11.91 to 10.12.91	NGRI IMD
3.	Barkot (BAK)	30° 48.41'	78° 11.89'	1200	4.11.91 to 15.11.91	GSI
4.	Bhatwari (BTW)	30° 48.60'	78° 36.6'	1600	5.11.91 to 5.12.91 21.11.91 to 12.12.91	GSI IMD
5.	Ghansali (GHL)	30° 27.24'	78° 38.76'	950	16.11.91 to 4.11.91	GSI
6.	Ghuttu (GTU)	30° 31.81'	78° 47.52'	1600	25.11.91 to 4.11.91	GSI
7.	Tehri (TEH)	30° 22.80'	78° 29.4'		17.11.91 to 9.12.91	IMD

PERMANENT NETWORK

SNo.	Station	Lat.(N)	Long.(E)	El.(m)	Period of Operation	Orgn.
9.	Dehradun (DDN)	30° 19.00'	78° 03.00'			IMD
10.	Shimla (SML)	30° 07.00'	77° 10.00'			IMD
11.	Dalhousie (DLH)	35° 32.50'	75° 58.00'			IMD
12.	Dharamsala (DHM)	32° 13.00'	76° 20.00'			IMD

TABLE -2

HYPOCENTRAL PARAMETERS OF AFTERSHOCKS

DATE Y M D	ORIGIN (G.M.T.)	LAT N	LONG E	DEPTH (Km.)	MAG (Md)	NO	RMS (SEC)	ERH (Km.)	ERZ (Km.)
911019	22 04 17.74	30-46.27	78-41.60	4.28	*3.4	16	0.68	3.6	3.3
911019	22 08 17.27	30-37.84	78-38.03	12.51	*2.4	14	0.73	3.7	3.0
911019	22 29 20.59	30-37.38	78-42.90	0.71	*4.0	23	1.76	5.1	4.8
911019	22 41 18.26	30-40.23	78-40.70	15.00	*4.7	19	1.94	8.7	7.7
911019	22 56 21.56	30-41.90	78-44.05	1.29	*4.0	11	1.04	7.1	5.0
911019	23 10 06.94	30-43.03	78-40.93	12.08	-	15	1.50	6.9	3.5
911019	23 39 30.35	30-42.26	78-41.26	12.03	*3.5	18	1.26	8.0	4.7
911020	01 04 26.77	30-41.59	78-48.25	11.79	-	15	0.88	4.6	3.9
911020	01 13 13.35	30-50.60	78-47.36	2.07	*2.4	16	1.42	6.7	4.4
911020	01 21 02.04	30-44.53	78-36.32	8.64	*2.3	21	1.60	6.5	4.5
911020	01 24 59.83	30-39.86	78-47.78	6.89	*4.2	20	1.73	6.3	4.8
911020	03 34 29.21	30-46.00	78-53.23	1.10	*2.9	22	1.68	5.7	4.5
911020	04 20 27.87	30-43.57	78-37.85	5.56	*3.0	27	1.36	4.8	3.2
911020	04 31 30.28	30-40.87	78-43.72	8.82	*3.5	15	1.25	5.4	4.8a
911020	05 32 27.58	30-43.93	78-37.85	2.01	*5.2	34	5.38	4.9	3.2
911020	05 54 42.83	30-52.21	78-45.27	3.14	-	8	0.71	6.6	4.3
911020	05 57 30.38	30-52.26	78-39.39	3.55	-	8	0.48	4.3	2.9a
911020	06 48 07.67	30-45.05	78-31.57	2.62	3.1	24	1.57	6.2	4.8
911020	07 25 49.58	30-35.82	78-36.70	15.00	2.9	15	1.65	7.7	7.0
911020	07 56 31.54	30-39.90	78-45.65	11.45	3.5	29	1.50	5.9	4.5
911020	09 01 05.95	30-32.85	78-35.07	20.95	2.7	11	1.07	6.2	7.4

911020	09	54	05.10	30-45.78	78-37.24	1.91	2.7	9	0.66	4.2	4.0a
911020	10	17	56.61	30-44.65	78-37.58	1.57	2.7	12	1.12	5.0	4.1
911020	10	39	22.07	30-44.35	78-30.90	6.74	2.6	8	1.23	12.6	7.8
911020	11	10	29.15	30-43.50	78-38.53	9.47	2.7	11	1.04	6.3	5.4
911020	21	48	47.65	30-44.20	78-42.82	1.79	2.4	9	0.87	5.5	5.6
911020	23	58	37.90	30-46.40	78-34.88	1.52	2.7	7	1.04	12.7	7.2
911021	14	02	44.32	30-45.47	78-48.21	1.82	*3.6	19	1.51	8.3	4.8
911021	14	28	12.17	30-47.84	78-33.48	3.28	2.6	10	1.58	9.8	6.7
911021	14	36	03.08	30-47.26	78-27.23	3.83	2.6	13	1.24	8.0	4.8
911021	18	44	11.54	30-47.93	78-37.98	0.25	2.5	8	0.70	6.9	4.7
911021	22	32	04.55	30-43.89	78-41.41	4.05	2.8	8	0.64	6.8	4.7
911022	06	39	26.60	30-49.23	78-34.23	0.43	2.7	15	0.99	4.0	4.0
911022	11	15	32.75	30-48.61	78-34.01	5.21	*3.4	12	0.44	2.9	1.8
911024	00	04	46.60	30-48.46	78-33.73	4.39	2.5	13	0.81	3.6	2.8
911024	08	11	21.45	30-44.11	78-37.25	0.03	*3.2	10	0.57	4.7	3.2
911024	19	21	00.00	30-43.40	78-35.50	2.92	*3.5	19	1.46	5.0	4.0
911024	20	40	04.00	30-43.73	78-26.93	11.78	2.5	8	0.93	9.9	5.5
911025	15	22	43.44	30-46.24	78-38.28	1.57	2.9	9	1.17	10.4	6.4
911025	19	09	22.53	30-50.19	78-33.29	0.12	2.7	8	1.02	13.3	6.1
911027	00	40	24.16	30-44.57	78-46.64	3.72	*4.1	13	1.25	6.0	3.9
911027	13	19	40.54	30-44.36	78-42.43	3.27	*4.0	12	1.82	14.1	8.7
911027	19	29	38.31	30-46.74	78-47.17	15.00	2.7	7	1.37	14.9	-
911111	19	43	44.71	30-51.10	78-22.64	26.48	2.38	6	.40	5.8	8.6
911111	20	43	47.83	30-43.98	78-34.30	7.48	2.11	6	.16	2.1	4.6
911111	21	01	24.62	30-43.42	78-08.01	0.86	1.85	5	.08	1.6	-

911111	21	35	13.66	30-53.21	78-21.10	1.94	2.05	6	.22	2.1	-
911112	05	03	01.71	30-44.59	78-38.01	0.88	1.89	5	.29	1.1	7.4
911112	20	28	52.69	30-38.72	78-38.56	1.60	1.97	5	.53	7.1	-
911112	23	50	12.26	30-43.03	78-37.13	0.59	2.66	6	.07	1.1	-
911113	00	31	34.27	30-41.58	78-38.32	7.82	2.76	6	.17	2.7	5.1
911113	01	06	13.81	30-42.39	78-39.86	1.10	2.55	5	.18	2.0	-
911113	12	11	13.87	30-45.10	78-32.43	1.34	2.86	5	.31	2.7	-
911113	18	35	00.76	30-42.13	78-36.15	0.31	2.73	6	.14	19	-
911114	00	04	27.94	30-36.65	78-49.21	0.60	3.16	6	.30	3.4	-
911114	07	44	38.03	30-42.25	78-35.13	6.11	1.99	6	18	2.6	6.8
911114	10	32	09.89	30-43.47	78-36.09	1.17	2.32	6	.20	1.1	-
911114	17	31	57.33	30-33.78	78-38.73	11.27	2.61	6	.09	1.6	3.2
911114	17	35	38.85	30-44.36	78-33.58	1.07	2.02	6	.10	1.1	-
911114	18	26	14.09	30-40.47	78-41.02	2.16	2.29	6	.12	2.0	-
911114	19	52	28.48	30-40.81	78-36.62	1.41	1.49	6	.19	1.8	-
911114	20	36	01.94	30.43.46	78-38.20	1.15	1.44	6	.91	9.4	-
911114	22	53	16.77	30-43.41	78-35.20	1.17	1.55	6	.08	0.9	-
911115	03	44	42.51	30-40.07	78-45.56	0.99	2.58	6	.14	2.4	-
911115	12	11	21.84	30-41.59	78-39.99	1.41	1.88	6	.37	2.0	-
911115	13	09	16.33	30-45.15	78-36.58	10.37	2.43	5	.04	0.9	1.3
911115	15	39	14.39	30-41.89	78-37.08	5.58	3.19	6	.07	1.0	2.6
911115	18	30	57.92	30-41.74	78-35.42	2.45	1.04	6	.16	0.4	2.6
911115	20	43	39.22	30-30.75	78-29.22	15.90	1.50	5	.34	9.2	-
911116	01	04	46.45	30-34.46	78-39.39	1.37	2.95	6	.10	0.9	-
911117	13	32	07.78	30-44.55	78-35.98	1.39	1.76	6	.14	1.8	-

911117	18	44	50.59	30-45.00	78-37.43	7.84	2.79	5	.12	2.8	5.4
911118	00	19	17.79	30-44.05	78-33.48	0.37	2.10	5	.08	1.4	-
911118	03	22	22.62	30-43.14	78-37.97	1.08	2.35	6	.05	0.4	6.2
911118	15	18	14.82	30-42.37	78-35.48	1.08	3.01	5	.02	0.1	1.4
911118	16	09	55.20	30-55.65	78-17.31	0.89	2.17	6	.46	8.1	-
911119	12	03	17.47	30-45.94	78-33.87	2.12	3.05	5	.34	3.7	-
911119	14	38	06.66	30-43.20	78-35.62	10.46	2.90	6	.28	3.17	-
911119	15	11	58.67	30-45.93	78-36.67	11.61	1.55	6	.12	1.6	2.2
911119	19	43	33.40	30-46.07	78-34.93	2.91	2.57	6	.20	2.7	10.0
911119	21	50	06.81	30-50.59	78-24.40	1.16	2.14	5	.23	3.5	-
911120	03	02	26.79	30-44.18	78-33.98	0.93	1.95	6	.09	0.6	-
911120	15	47	28.89	30-42.42	78-36.81	8.55	2.08	6	.11	1.2	3.3
911120	16	14	56.45	30-29.11	78-33.10	1.34	3.06	5	.20	0.9	-
911120	19	50	06.97	30-41.76	78-44.59	0.85	2.06	6	.43	4.9	-
911121	01	03	03.27	30-40.41	78-36.15	0.97	2.28	6	.12	1.0	-
911121	07	52	35.72	30-46.19	78-29.88	7.01	0.04	6	.18	2.2	5.8
911121	15	48	35.37	30-42.09	78-36.85	0.08	1.55	6	.29	1.2	-
911121	19	54	03.62	30-49.49	78-38.48	9.27	2.14	6	.09	1.6	1.2
911122	15	52	24.21	30-43.55	78-37.79	15.13	2.98	8	.24	2.1	3.3
911122	20	48	29.95	30-39.72	78-40.16	1.04	1.14	6	.06	0.4	9.7
911123	04	52	07.47	30-42.73	78-36.63	6.14	3.13	7	.25	2.1	8.7
911123	18	45	26.28	30-44.78	78-28.92	0.28	1.98	6	.13	1.4	-
911123	18	46	02.44	30-44.14	78-28.77	1.32	1.45	6	.21	2.1	-
911123	18	53	39.20	30-39.09	78-45.51	1.19	2.25	6	.29	0.9	-
911123	19	18	30.12	30-41.05	78-40.51	12.14	1.19	6	.09	1.0	2.2

911123	19	52	44.44	30-42.57	78-32.08	1.06	1.32	6	.30	1.5	-
911123	20	35	03.83	30-45.74	78-36.56	0.31	1.55	6	.26	3.7	-
911123	21	22	07.49	30-42.45	78-36.71	1.53	1.59	6	.08	0.2	2.6
911124	01	02	47.15	30-40.68	78-38.75	9.60	2.62	6	.31	3.3	9.2
911124	06	18	40.24	30-43.27	78-39.65	5.51	-	6	.16	1.9	6.2
911124	13	19	40.31	30-45.59	78-28.77	0.86	2.81	6	.05	0.3	7.4
911124	23	31	09.48	30-40.06	78-38.34	0.23	1.36	6	.28	2.7	-
911125	14	29	49.89	30-41.76	78-37.68	0.34	3.72	8	.29	1.9	-
911125	18	59	47.40	30-43.64	78-35.05	2.69	3.49	6	.35	1.7	-
911125	19	36	13.80	30-51.41	78-29.64	1.19	2.42	6	.34	1.6	-
911125	21	31	01.96	30-43.48	78-36.73	2.02	1.18	6	.49	5.0	-
911126	07	02	16.33	30-40.55	78-41.49	14.95	2.35	8	.76	6.5	-
911126	08	21	44.42	30-43.05	78-37.95	10.44	1.80	6	.06	0.7	1.5
911126	10	32	25.37	30-46.84	78-39.26	9.18	2.47	8	.19	1.9	2.4
911126	18	01	17.46	30-45.06	78-24.07	1.13	0.48	6	.37	2.8	-
911128	05	01	28.12	30-50.23	78-25.92	7.68	2.78	8	.21	2.4	3.2
911128	22	13	26.68	30-45.68	78-34.51	0.60	3.28	8	.25	2.2	-
911129	01	53	04.70	30-47.25	78-33.27	10.46	1.40	6	.28	3.8	5.6
911129	23	47	46.01	30-39.72	78-35.76	0.30	2.61	6	.14	1.2	-
911130	00	09	20.27	30-47.56	78-34.50	0.70	1.78	6	.23	3.4	-
911130	12	20	26.34	30-44.56	78-32.45	10.12	2.24	8	.03	0.2	0.4
911130	13	01	50.54	30-43.51	78-33.89	0.72	2.39	6	.10	0.8	-
911130	21	22	32.38	30-39.32	78-30.66	1.36	2.03	6	.23	0.3	8.3
911130	21	29	16.68	30-43.65	78-39.64	1.24	1.38	6	.09	1.1	-
911201	15	18	07.44	30-47.04	78-40.24	12.81	1.66	6	.10	1.5	1.6

911201	16	02	36.31	30-39.69	78-53.10	5.43	2.04	5	1.71	14.4	-
911201	16	19	11.27	30-43.46	78-37.75	1.20	1.46	6	.07	0.6	8.6
911203	01	36	27.74	30-48.43	78-36.44	7.62	2.46	8	.29	3.2	3.2
911203	03	04	51.47	30-46.50	78-35.26	6.24	2.25	6	.06	0.8	1.5
911203	06	04	32.19	30-37.01	78-27.10	8.87	2.20	6	0.63	8.5	-
911203	18	54	33.17	30-40.95	78-58.15	3.30	1.95	7	0.97	2.7	6.6
911205	00	01	06.39	30-40.60	78-43.82	9.46	1.96	6	0.18	2.13	5.7
911205	03	12	46.56	30-39.38	78-43.26	10.95	2.19	6	0.04	0.6	0.3
911206	11	31	43.29	30-48.70	78-34.07	8.54	2.42	8	0.49	4.2	2.6
911207	00	13	38.12	30-42.87	78-37.90	3.96	1.76	6	0.19	1.4	6.1
911207	01	08	04.33	30-47.07	78-33.46	6.01	1.81	6	0.25	1.1	1.7
911207	17	16	18.68	30-41.70	78-39.44	15.00	2.14	7	0.40	3.7	2.3
911208	15	46	31.79	30-42.64	78-36.70	10.25	3.17	13	0.91	5.0	2.3

RMS - Root Mean Square
ERH - Horizontal error in epicentre
ERZ - Vertical error in depth
MD - Duration Magnitude
* - Richter magnitude

Note : Duration magnitude calculated by IMD for the month of October is based on the USGS formula:

$$Md = - 0.87 + 2 \log (T) + 0035 R$$

Where T is single duration and R is the epicentral distance. Duration magnitude determined by the formula mentioned in the text is less by about .5 unit as compared to the USGS formula for magnitude upto 3.0.

ERRATA

Page No.	*Line No.*	*Instead of*	*Pl. read as*
189	7	'G'	'g'
190	5	'Where as'	'whereas'
	5	'miner'	'minor'
	10	'blocked'	'blockage'
	13	'damage'	'Damage'
192	10	'Hypocentral'	'hypocentral'
193	18	'Jhamak'	'Jamak'
	29	332° with a dip of 19°	116° with a dip of 85°
	30	108° with dip of 76°	296° with a dip of 5°
	30	NP1	NP2
	31	Predominant reverse type of faulting	pure thrust without a strike slip component
194	5		add 'was'
	11		add 'and'
195		'WHIG'	'WIHG'
203	17		add 'is'
205	1	'the'	'The'
		'Hypocentral'	'hypocentral'
		'determine'	'determined'
206	3	'40 per cent within 15 km'	'34 precent between 5 to 15 km'
209	12	range to 3	range 2 to 3