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DAMAGE REPORT OF THE LATUR - OSMANABAD EARTHQUAKE OF SEPTEMBER 30, 1993

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ABSTRACT

Widespread devastation and loss of life were witnessed in the epicentral region of the September 30, 1993 earthquake in the 2 districts of Latur and Osmanabad in south eastern Maharashtra. Traditional construction in the region was non - engineered and had no resistance against horizontal earthquake forces. In most houses walls were made of random rubble stone masonry and such structures suffered extensive damage. Survey of various earthquake affected villages, engineered and non - engineered buildings, hospitals, forts and monuments, places of worship, schools, building materials used, construction practice prevalent in the region, their performance, causes of high casualty figures and strange phenomena associated with the earthquake are presented in this paper.

INTRODUCTION

The ten day long Ganesh festival concluded with the immersion of idols in a finale that lasted well into the night of September 29, 1993. Tired after the prolonged festivities the villagers of Killari slept, unaware of the impending doom. The entire Marathwada region was shaken up violently by an earthquake of magnitude 6.4, at 3.56 a.m. IST, (- 5.5 hours for GMT), on 30th September , 1993, on the Maharashtra-Karnataka border. Milder tremors followed in quick succession at 4.41 a.m., 6.24 a.m. 6.34 a.m. and 7.46 a.m.

Sholapur is the biggest town nearest to the devastated region. People were jolted out of their sleep in the states of Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Gujarat and Madhya Pradesh. The earthquake was felt with ferocity in the towns of Gulbarga, Bijapur, Bidar and Raichur. A mild tremor was also felt in Dharwad, Bellary and Belgaum districts. Most of the worst affected villages in Karnataka lie along the Bhima river which runs through the four northern districts of Karnataka.

More than 50 villages within an area of 100 square km on both sides of Terna River were severely affected. This river forms a natural divide between Latur and Osmanabad districts in the region ravaged by the quake. Killari, a densely populated and prosperous village 45 km south of Latur in Ausa taluka, was one of the worst affected villages and also the epicentre, 76° 35'E, 18° 03'N. A 15 km segment stretching between Makni dam and Killari bore the brunt of the devastation. Not a single stone structure in these villages was left intact and not a single family was left unscathed. The worst affected villages were Ekondi, Ganjankheda, Gubal, Huli, Kawtha, Killari, Killariwadi, Lamjana, Limbada, Mangrul, Peth Sangvi, Rajegaon, Sastur, Tausigarh, Talni, etc., shown in fig 1.

Visiting damaged and quake affected areas for study purposes is not simple and creates tremendous hardships. The stench of rotting flesh still buried under the debris was mixed with the nauseating smell and sight of numerous cremations. The silent and morbid atmosphere was pierced occessionally by hysterical wailing of villagers. As wood was in short supply broken door frames and wooden rafters were used for on the spot cremations. This, coupled with unseasonal rain made the survey work difficult and could be completed only becausse of great determination, courage and steadfastness on the part of authors. The rescue and relief work carried out by several agencies working in the area was hampered by movement of VIPs, idle onlookers and rain. This led the Army to seal off the area.

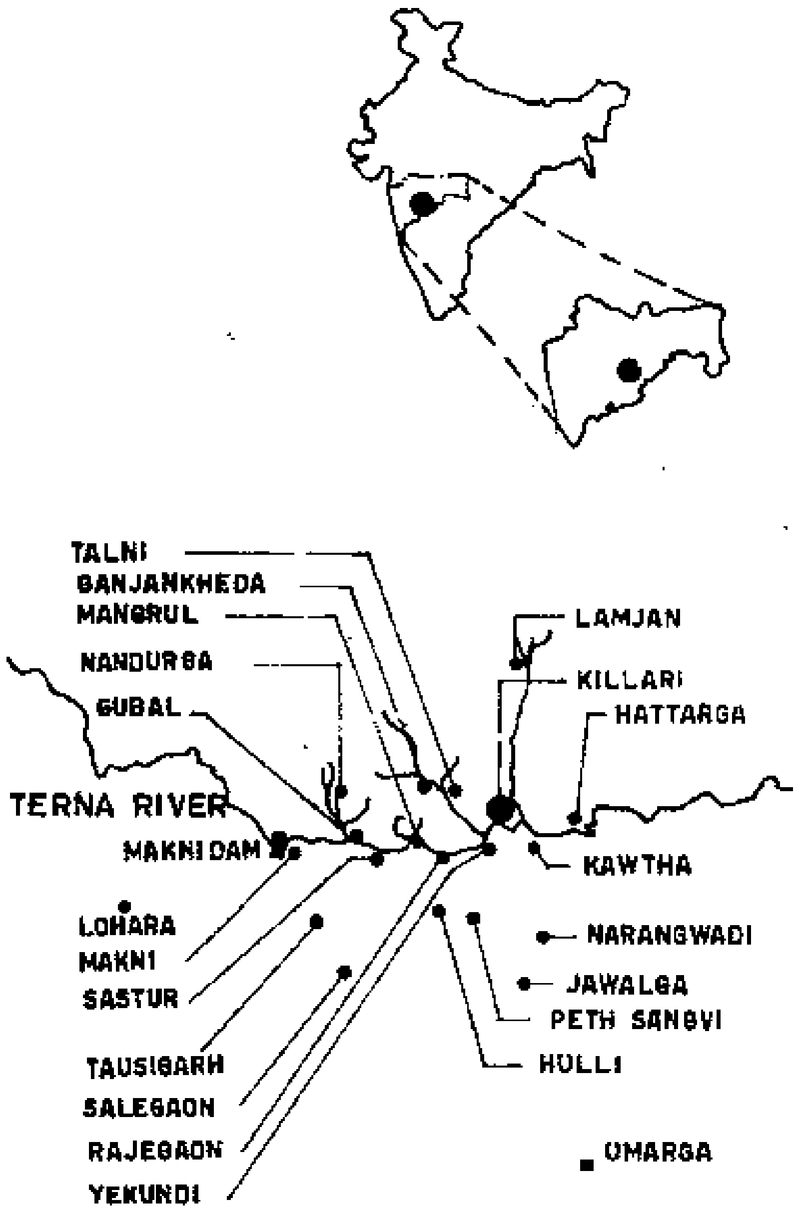

Fig 1 *Location of some of the worst affected villages devastated by the Latúr - Osmanabad earthquake of September 30, 1993. (Modified after Survey of India Toposheet 56 B). Inset shows epicentre of the earthquake on map of India.*

SEISMIC HISTORY OF THE REGION

Major portions of Maharashtra and Karnataka fall in Seismic Zone I of the Seismic Zoning Map of India, as per Indian Code IS: 1893 - 1984. The quake affected region lies in that part of the country which was considered seismically stable prior to this earthquake. When the authors of this paper toured the affected areas immediately after the disaster the survivors at Killari and neighbouring villages were still in a state of shock and fear as mild tremors continued to spread panic in the area. The villagers claimed they have been living with these shocks for the past 30 years.

Killari, where the impact of the earthquake was the severest, had experienced tremors in 1962, 1967, 1983, 1984 and 1992. 125 tremors were felt in 1992 between August and October. An earthquake of magnitude 4.5 that rocked the village on the night of October 18 - 19, 1992, and had sent villagers scurrying into the open, was the strongest felt before the killer quake of September 30, 1993. The next morning it was found that most houses in the southern tip of the village had developed cracks.

The villagers firmly believe that since the filling of the reservoir of the Lower Terna Dam two years ago, the frequency of tremors increased in this area. Between October 1992 and June 93, most villagers in and around Killari were sleeping outdoors, to avoid being trapped in an earthquake. They started sleeping inside their houses to shelter themselves from rain, till the earthquake took its toll on 30th September 1993.

GEOLOGY OF THE REGION

The region is a typical Deccan trap terrain consisting of hard weathered basaltic rock covered by black cotton soil. The undulating topography gives rise to a soil depth which varies between 50 cm and 20 meters. Most villages are located on soil where depth varies between 50 cm and 3 m.

OCCUPATION

The quake affected area is fertile and most people in the area are poor, uneducated and are occupied with the cultivation of sugar cane, sunflower, kardi, grapes, wheat, jowar, gram and bajra. Grapes from Killari have a good export market. The richer segments of the population live in brick houses. The poor live in huts made of grass and reeds, and these structures survived the earthquake. Most people live in houses which have walls made of big stones laid in mud mortar. It is these houses which collapsed and trapped the inmates in rubble. Many villagers survived because they were either tending cattle in fields or were operating agricultural pump sets. Some had just slept in the open as villagers are used to doing.

CONSTRUCTION PRACTICE

The survey of various damaged and undamaged structures, materials used and construction practices prevalent in the quake affected region is presented in this paper. All stone houses were razed to the ground, only heaps of rubble, dislodged pieces of timber and mud was witnessed in several villages, figs 2 and 3. Well built structures made of high strength masonry survived with repairable cracks, like several Government buildings. In RCC framed buildings partition walls were separated. A huge overhead water tank at Kawtha collapsed.

All construction in the surveyed area can be classified into two broad categories :

a. Non engineered construction
b. Engineered construction

NON ENGINEERED CONSTRUCTION

Non engineered buildings are those which are traditionally constructed either by local artisans and masons or by villagers for their own use, without any design considerations whatsoever. Houses are made according to local conditions such as availability of building materials, climate and socio - economic conditions. Houses in rural Marathwada are constructed with heavy materials - perhaps the main cause of

Fig 2 View of the devastated Killari village.

Fig 3 This heap of stone rubble, timber and mud was street of stone houses at Killari before the earthquake.

high casualty figures. As stone is available in abundance, it was a very popular building material till the earthquake occurred. Other building materials used in the area are mud, timber, tin sheets, brick, blocks made either of stone or concrete, bamboo and grass.

STONE HOUSES

Most village houses are individually enclosed within a very high boundary wall made of stones. A high beautiful doorway leads into the courtyard, locally known as 'bara'. These houses have one to three rooms and are usually surrounded by a common verandah.

The foundation of these houses, as per the information divulged by the villagers, goes down to a depth which ranges from 60 cm to 2.5 m and rests on firm rock or dense soil.

The walls are made of random rubble stone masonry laid in mud mortar with very few and small openings for doors and windows. The walls are usually 70 cm to 1.8 m thick, with 1 m being the norm. Such thick walls are popular as they provide thermal comfort and security. Everywhere typical wythe failure or delamination associated with stone walls is visible due to absence of bond stones, fig 4. The quake has demolished all such houses in the entire meizoseismal area.

The roof has heavy timber rafters running in two perpendicular directions over which wooden planks and a thick layer of mud are spread. The lowest tier consists of a frame made of heavy wooden joists, placed approximately 1 - 1.5 m apart, centre to centre. Lighter joists are placed on these, perpendicular to the lower ones, about 30 cm apart, centre to centre. On top of this a layer of wooden planks is laid. This is coated with a layer of compacted mud, about 30 - 80 cm thick, mixed with local bushes and grass, fig 5. The roof unit has no interlocking connection with the walls, it just rests on thick stone walls, it has no bracing in plan which could have given a rigid diaphragm action.

Such houses, made of random rubble stone masonry laid in mud mortar and ill designed to withstand any shaking and with no earthquake resistant measures proved to be deadly when the roofs collapsed on 30th September 1993.

Mixed Construction

In bigger villages such as at Killari, extensions are sometimes made in existing stone structures either in the front court yard, or when there is a shortage of open space another storey is added on to an existing stone house. The new storey is made of brick or stone blocks which are laid in cement mortar. Mixed construction of this type had very typical failure, fig 6.

Timber Framed Structures

In many old and traditional stone houses the roof rests on a timber frame, instead of on a stone wall. The use of such vertical reinforcement in a house increases its capacity to resist earthquakes. The frame work of many such houses survived the earthquake, fig 7, the roof did not collapse on the sleeping inmates and the stone walls collapsed outwards. Casualty figures in such houses are much less compared to those houses where the roof rests on stone walls directly.

In some houses the earlier construction had a timber frame, later rooms were added which had no framed structure but stone walls only. It is very significant that it was the latter which collapsed and caused casualties and the former which survived and saved the inmates.

Timber frames are made by carpenters locally known as Suthars. Vertical posts of wood are provided at a distance of about 1 to 1.5 m, centre to centre, with an excellent quality of joints. The stone wall is made around this frame. The timber framed construction has been discontinued, perhaps due to scarcity and high cost of timber.

Fig 4 Failure of stone wall. The outer wythe bulged out and collapsed completely, Sastur.

Fig 5 Details of roof on stone building at Killari.

Fig 6 *Failure in a construction of mixed type at Killari. Brick was laid in cement-sand mortar to make walls above a stone house. The brick wall slided and came down en masse as there was no connection between old and new type of construction.*

Fig 7 *An old stone house with wooden frame has an intact roof at Killari. No casualties occurred in this portion of the house. Newer construction in this and adjoining houses without wood frames collapsed completely and killed the inmates.*

Roof of Corrugated Galvanized Iron (CGI) Sheets

In most stone houses the roof in the verandah is made of CGI sheets. The shaking caused by the earthquake separated the walls at corners, the walls moved outwards and the roof collapsed. School buildings in the meizoseismal area were usually made of brick with CGI roof. Damage to such a school building is shown in fig 8.

RCC Roof

In some buildings the roof is made of an RCC slab which is supported on stone walls where the stone is laid in mud mortar. The earthquake caused failure of stone walls in such buildings, which caused the concrete slab to come down like a sheet, and this proved to be an unmitigated earthquake disaster on September 30, 1993, as shown in fig 9.

Brick Masonry

As the local soil is not conducive for manufacture of good quality bricks therefore it is not a common building material. Where bricks were used they were mostly laid in cement - sand mortar and only sometimes in mud mortar. The latter have very thick walls. The police station, the post office, the society building and the Bank of Maharashtra, all at Killari, showed horizontal, vertical and diagonal cracks in walls. Several shops made in this way at Sastur showed partial damage. Damage to the Panchayat Office at Sastur is shown in fig 10.

Block Masonry

Rectangular blocks made of crushed stone or concrete are also popular as a building material. These are laid in cement - sand mortar. These houses performed rather well in the earthquake. Buildings which are made either of brick or stone block and are laid in good quality cement mortar usually had an RCC roof. Such buildings performed well during the earthquake, as shown in fig 11.

Adobe Building

Adobe houses were rare in the area and their collapse is similar to that of stone buildings, fig 12.

Thatched Huts

At the periphery of most villages houses are made of bamboo frames with thatched walls or reed coated with mud and a thatched or tin roof. These flimsy structures have survived the earthquake, figs 13 and 14, and no casualties were reported from these.

Dry Pack Masonry

In Karnataka villages near Gulbarga have houses commonly made of dry pack masonry. These usually use either big uneven stones, fig 15, or flat stones. The roof is made of big heavy flat tiles supported on wooden joists. Since this area was far from the region of intense shaking these structures survived the shock, though some roofs have started leaking in post earthquake rains. The performance of such structures will be disastrous in the event of a similar near field earthquake.

ENGINEERED CONSTRUCTION

High strength masonry buildings which have been given design and construction considerations by qualified engineers, architects and builders are classified as engineered structures. Most government buildings are engineered and are made of burnt bricks or stone blocks, laid in cement mortar with thick plaster on walls. The roof is made of reinforced concrete or reinforced brick. A few private buildings are also made in this way. Such buildings developed large and deep cracks in walls, or partial wall collapse, but total collapse was not witnessed in the meizoseismal area. No casualties were reported from such structures.

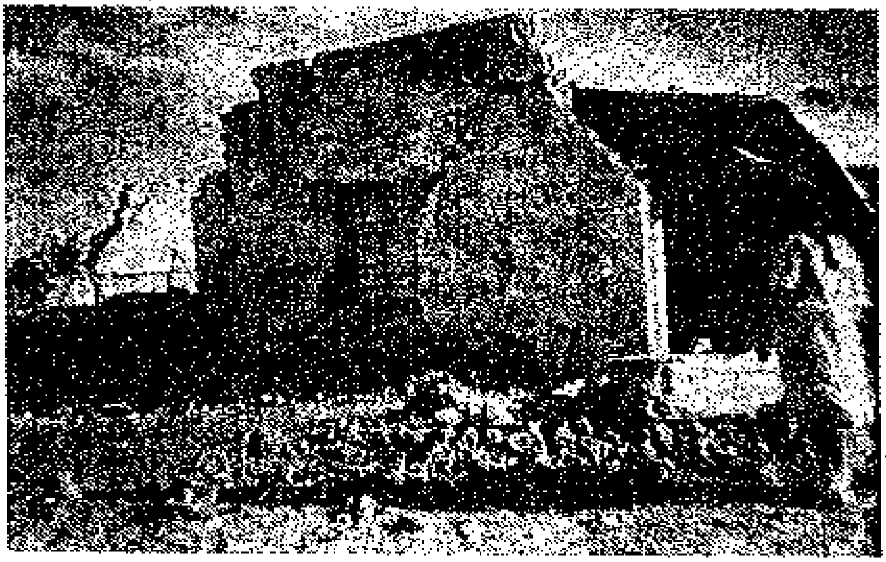

Fig 8 Collapsed CGI roof of Government School at Mangrul.

Fig 9 A jeep trapped under the collapsed RCC roof of District Cooperative Bank at Killari. The RCC roof rested on stone walls before the earthquake.

Fig 10 *Brick building of Panchayat office at Sastur showed extensive damage to the first floor. This was because the tin roof rested on iron rafters and did not have a roof band.*

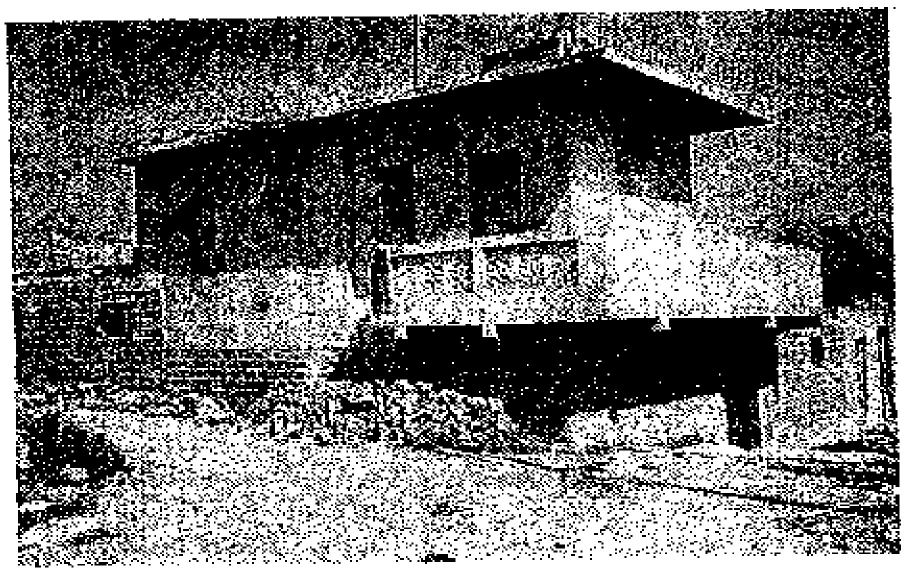

Fig 11 *Well constructed stone block masonry house survived the quake at Kawtha.*

Fig 12 Collapsed adobe house at Killari.

Fig 13 Huts survived but heavy stone houses collapsed.

Fig 14 Reed coated with mud, Killari.

Fig 15 Dry pack masonry with big sized stones, in rural houses of Karnataka.

All engineered structures such as aqueducts, bridges, canal embankments, dams, overhead water tanks, power houses etc., performed very well during the earthquake with minor non structural failure. Only one over head water tank collapsed, at Kawtha.

Reinforced Concrete Buildings

Reinforced concrete framed buildings in the area were either single or double storeyed. These and the ones which were under construction resisted the earthquake fairly well, figs 16 and 17. At Killari efficacy of earthquake resistant measures is proved very well, fig 18, brick masonry houses with cement sand mortar which used a lintel band, or vertical steel have withstood the earthquake. Mr. Kale, a primary school teacher built a brick house with lintel band at Killari on the advice of his brother who works for the building industry in Bombay. The house survived the earthquake with minor cracks. Ms Pushpa Rani's house was made with vertical RCC columns at joints and corners. It developed minor cracks only and is erect at Killari.

Roads and Power Supply

No damage was observed in metalled roads in the epicentral region. However, narrow streets within villages were choked with stones which fell from walls, fig 19, thus making rescue and relief work very difficult. Rain made the kutcha roads slushy and unmotorable.

Power failure occurred in the meizoseismal area immediately after the earthquake. This plunged the villages into an eerie darkness and added to the prevailing confusion and chaos.

Sugar Mill at Killari

A well engineered structure, the sugar mill at Killari has very heavy machinery installed inside. Damage to this large mill was minimal, fall of plaster was observed at one place only. A portion of the infilled stone masonry fell off, fig 20. Slight damage to the huge chimney was observed at the top in the form of vertical cracks. This suger mill served as a local centre for collection of relief material in post earthquake operations.

Canal and Aqueduct at Ganjankheda

At Ganjankheda a long fissure developed in the left embankment of the canal due to slope failure of loose material, figs 21 and 22. The surface opening was more than 2 cm wide at places, the slope settled about 10 cm. A diagonal fissure in the canal covered 3/4th of the width of the right embankment, in north south direction. It was 4 - 5 cm wide and 12.5 - 25 cm deep at places. A newly constructed aqueduct showed non-structural minor cracking in the railing of the bridge at several places.

Lower Terna Dam and Rest House

At Makni a 15.4 meter high earth dam consists of a reinforced concrete spillway in the middle and earthembankments on both sides. A 400 m long fissure was observed in the left embankment which was one meter deep as confirmed by pit opening, fig 23. The embankment partially settled down which was clear from the side of the spillway bridge, fig 24. However, the fissure developed 130 m away from the bridge where anchoring effects of the spillway were lost. A similar failure but of lesser extent occurred on the right embankment also. This type of failure confirms dominance of vertical motion. This kind of typical damage indicates that since an earth dam dampens the vibrations therefore it offers an inherent resistance against earthquakes, the damping being proportional to the deformation. As reported by the dam engineers all gates of the dam leaked after the earthquake and healed on their own 24 hours later.

Damage to the rest house for this dam is shown in fig 25. The doors were jammed at the time of the earthquake and inmates had problems in escaping.

Over Head Water Tanks

The only failure of an engineered structure in the entire meizoseismal area was found at Kawtha.

Fig 16 *The well engineered brick masonry building of Electricity Board survived with cracks, at Sastur.*

Fig 17 *Framed building under construction near the sugar mill at Killari, undamaged after the earthquake.*

Fig 18 *An undamaged building with RCC bands at Killari, surrounded by collapsed stone houses.*

Fig 19 *Blocked street, Lamjana.*

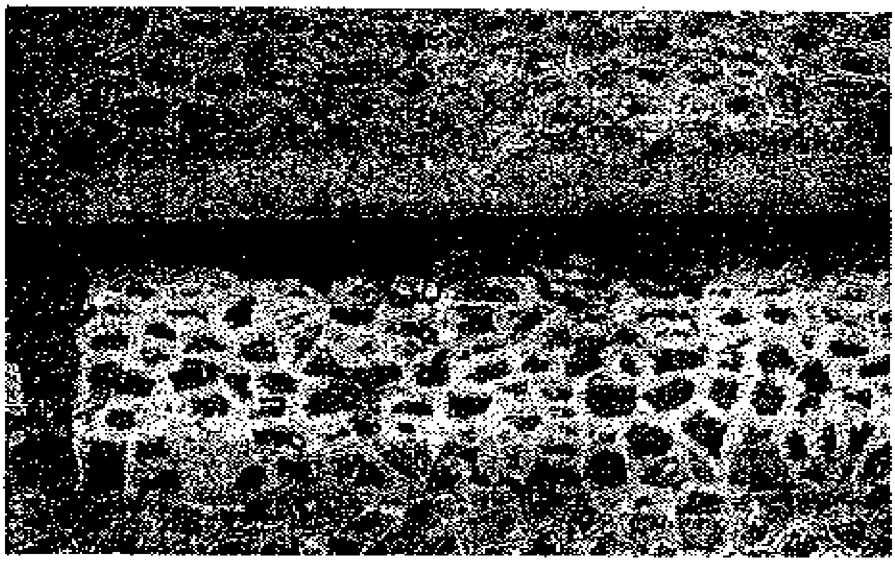

Fig 20 Damaged stone masonry infilled panel in sugar mill at Killari.

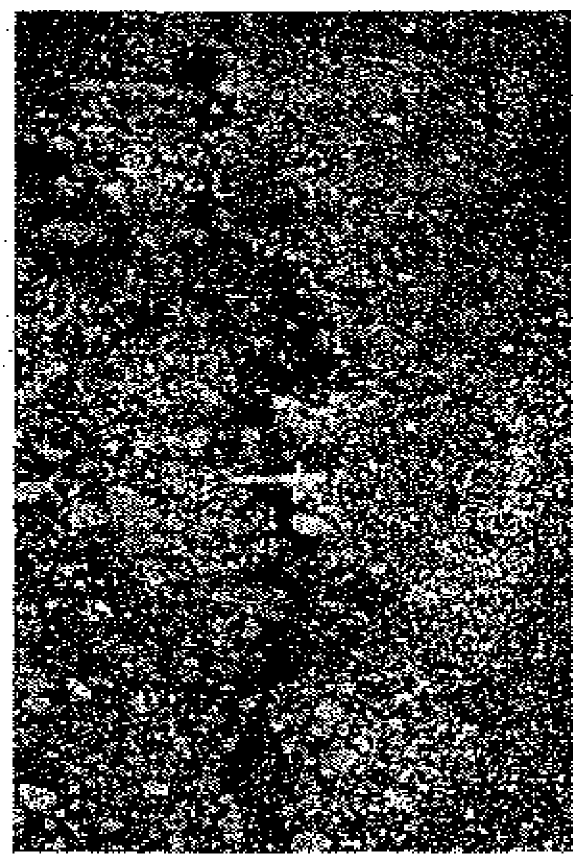

Fig 21 Fissure in left embankment of canal near Ganjankheda.

Fig 22 Slope failure of canal embankment at Ganjankheda.

Fig 23 One meter deep fissure in left embankment of lower Terna dam, as confirmed by pit opening.

Fig 24 Settlement on left embankment in spillway bridge, Terna Dam.

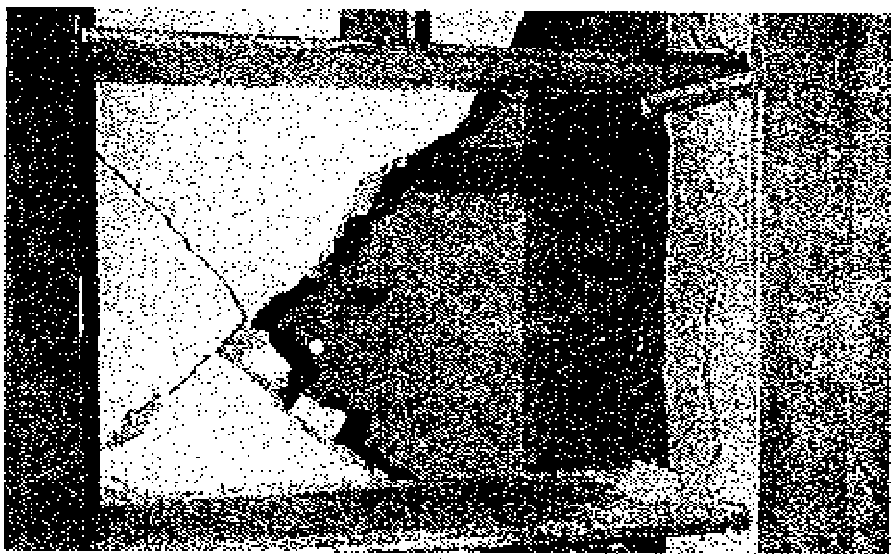

Fig 25 In the brick masonry building of rest house of Lower Terna Dam Project at Makni, walls cracked, plaster fell off from walls and part of a half brick thick wall collapsed. Fig shows a portion of the collapsed partition wall between bedroom and washroom.

An overhead water tank, fig 26, of 100 kilo liter capacity, full at the time of the earthquake, collapsed completely. The possible reasons of failure could be a combination of one or more of the following factors

1. Torsional component of ground motion
2. The stair case tower was connected with the tank, which increased torsion in the eccentric structure, fig 27.
3. Presence of water at the time of the earthquake generated heavy inertia forces.
4. Inadequate transverse reinforcement was used near joints in columns, fig 28.
5. P - effect, i.e. vertical load vs horizontal displacement effect.

Other water tanks in the epicentral area which were empty at the time of the earthquake were intact except for spalling of cover concrete in columns near joints such as at Limbada and at Killari, fig 29.

HOSPITALS

Hospitals surveyed in the quake affected area were : the Rural Hospital and Dr. Vilas Bhujbal's Clinic at Killari, figs 30 and 31, the leprosy centre at Mangrul, fig 32, and a hospital at Nandurg.

The Rural Hospital at Killari is made of brick masonry in cement - sand mortar. The earthquake caused wide, deep, diagonal and horizontal cracks in walls, fig 33, and some portions of the wall fell off. The doctors showed the authors portions of the walls where cracks had developed due to a previous tremor which occurred on October 18, 1992. These were subsequently repaired, fig 34. Extensive damage was observed to non structural elements like tiles, wash basins, electric fittings etc, fig 35. Several doors of the hospital were jammed. Seven resident patients (2 for tubectomy, 4 for gastro enteritis and one for delivery) escaped after the earthquake. Several houses on the hospital campus developed cracks and roof of the garage and boundary wall of the post mortem room collapsed. An hour after the earthquake the dead and the injured were brought into the hospital premises.

SCHOOLS

Schools made of random rubble stone masonry collapsed in the quake affected area, such as the Maharashtra Vidyalaya, fig 36, and Shishu Vihar at Killari. However, since the Dayanand Vidyalaya at Kawtha was made of dressed stone it sustained the shock. The Zila Parishad Basic School at Limbada is made of brick masonry with a tin roof inclined at a very low angle. Damage to this school was in the form of huge gaps in wall. A small building of a government school at Mangrul, made with one and a half thick brick wall with cement mortar and a tin roof showed huge diagonal cracks. The roof of one room collapsed because of outward movement of wall. Fig 37 shows the damaged school at Sastur which had a tin roof and very thick brick walls laid in poor quality mortar.

SOME TYPICAL BUILDING COMPLEXES

Apart from the different types of aforementioned structures, several other kinds of building complexes such as places of worship, caves, forts and monuments also suffered very typical damage.

Places of Worship

A temple and a masjid are generally located in each large village. The temples are ancient whereas the masjids are relatively new and are made of dressed stone. The former have suffered extensive damage while the latter have survived with repairable damage.

The ancient Shri Neel Kantheshwar Temple at Killari has been built in three stages. These are the sanctum sanctorum of the original old temple which consists of a dome, a place for offering worship which has a roof of reinforced concrete on dressed stone masonry arches, and an assembly place which is an RCC framed structure and is relatively new in construction. A massive Nandi bull is situated between the RCC frame and the arched structure. The statue of Nandi bull slided on its base by about 1.5 cm. The

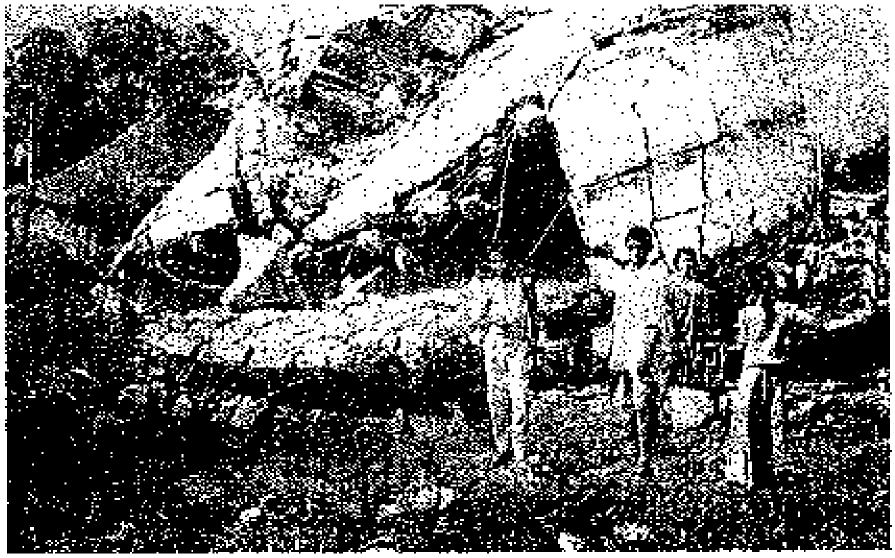

Fig 26 *Failed overhead water tank with domical base at Kawtha.*

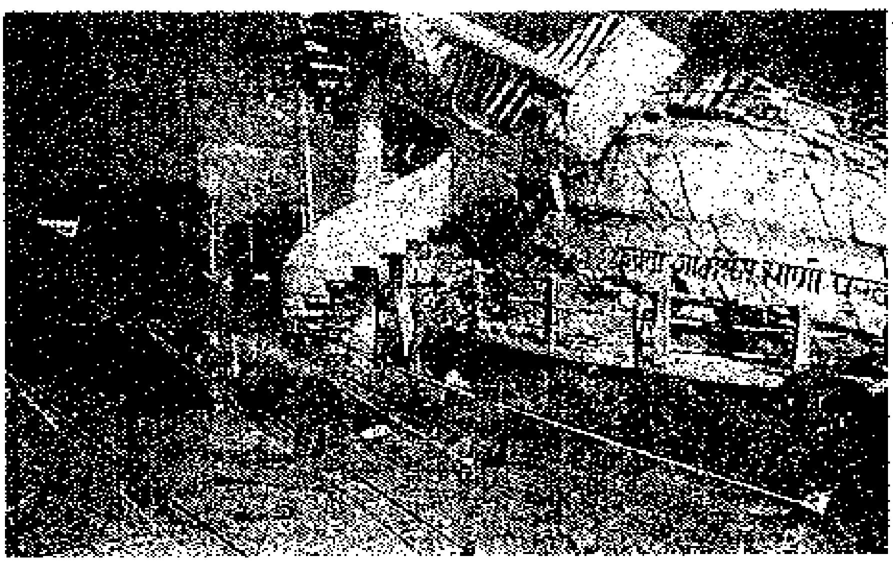

Fig 27 *Failed staircase unit of overhead water tank, Kawtha.*

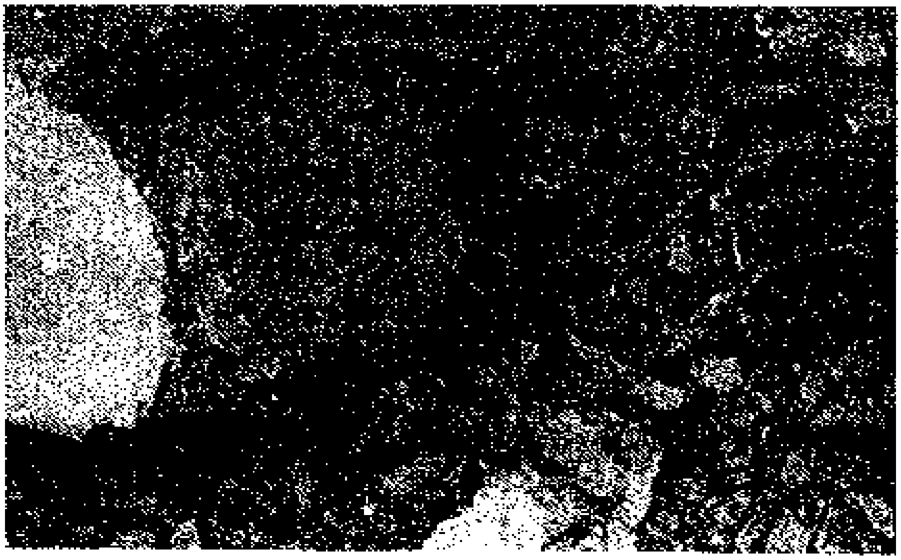

Fig 28 *Broken column with inadequate transverse reinforcement, water tank at Kawtha.*

Fig 29 *Undamaged water tank at Killari.*

Fig 30 *Dr. Bhujbal's clinic at Killari made of stone block masonry.*

Fig 31 *Thick plaster bulged out at Dr. Bhujbal's clinic, Killari.*

Fig 32 *Brick masonry building of leprosy centre at Mangrul developed large and deep cracks.*

Fig 33 *Portions of wall fell off in the gynecological ward, Rural hospital, Killari.*

Fig 34 *Doctors showing portion of a wall which developed cracks one year earlier, in the tremor of October 18, 1992. These were plastered subsequently, Rural Hospital at Killari.*

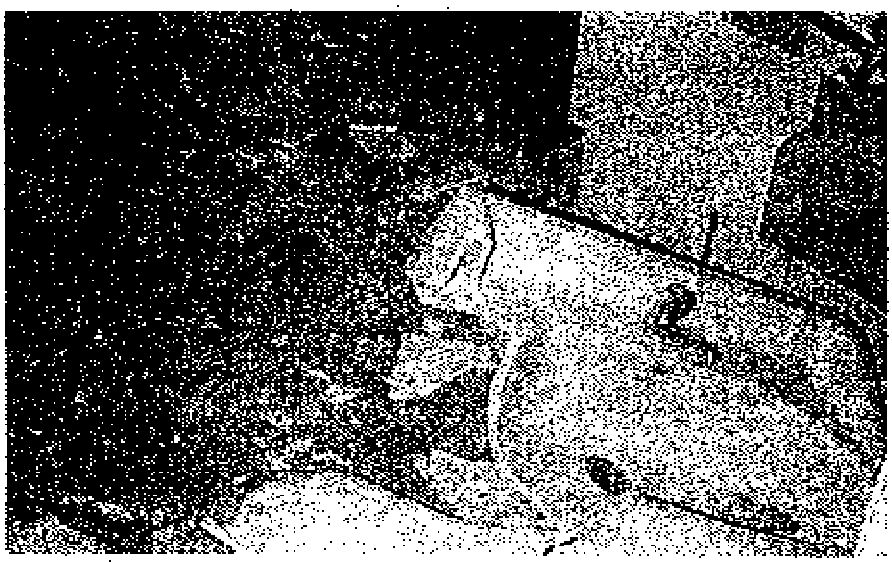

Fig 35 *Dislodged electric fittings and wash basin inside the operation theatre at Rural hospital. Killari.*

Fig 36 Collapsed building of Maharashtra Vidyalaya at Killari.

Fig 37 Collapsed school at Sastur.

famous Shiva Linga and heavy stones in the wall were dislodged in the same direction. Damage to this temple is shown in figs 38 - 41.

The Jama Masjid at Killari is made of well dressed stones and shows very little damage. At Tuljapur plaster fell off from the highest spire of the famous Bhawani temple, from just below the Kalash. A stone from the parapet fell off from one of the buildings in the temple complex. The Ganesh temple at Sastur once again shows the efficacy of timber framed structures during an earthquake. The walls are built outside this frame and collapsed but the roof is intact, fig 42 and 43. A 1200 year old temple at Ambajogai, made of stone masonry remained intact.

Kharosa Hillock and Caves

At Kharosa the flat hill top supports three building structures, a very old temple of Renuka Devi, a mosque and mazar complex, made at a later date, and a newly constructed wireless station of the Irrigation Department, fig 44. At one end of the hillock old caves are carved out of stone, in 3 tiers. These have sculpted in-situ rock carved figures of Shiva and the legendary Pandavas. Some cracks occurred in pillars and walls of these caves. The damage pattern of all these structures clearly brings out the performance of different kinds of structures during an earthquake and safety of engineered construction.

The central column of the Prakash Stambh outside the Renuka Devi temple and the sanctum sanctorum of this ancient temple collapsed completely, fig 45. A new idol has since been installed in the place of the old one. A heavy Kalash, (brass pot) almost 75 kg in weight, fig 46, fell off at a horizontal distance of about 8.25 m from a height of 10 m. The mosque and mazar complex is of a later date and 2 minarets partially collapsed due to the earthquake, fig 47. Plaster fell off the dome and vertical hair line cracks appeared in the mazar of Peer Pasha. The wireless station is a well engineered structure, fig 48 and remained intact in wake of the earthquake.

Forts and Monuments

A very large fort with heavy walls survived the earthquake without any damage at Naldurg. Some walls collapsed inside the fort at Udgir. Three domes near Sastur, believed to be of Mughal times, show different patterns of damage, one was partially damaged, fig 49, and the one which is about 300 m from Sastur was the least damaged. The famous circular dome at Bijapur rests on a square base, fig 50. Hairline cracks were observed in the portion where the square base changes into a circular form. This type of crack can appear at this place due to vertical acceleration. A previously repaired crack in wall showed widening, fig 51. A 12 m high Hutatma tower at Killari had a tilted flame of torch at top.

DIRECTION OF MOTION

Description of motion felt at the time of earthquake and presented in this paper is based on interviews held with local residents. Vertical and torsional motion was observed and reported at several places like Killari, Kawtha, Limbada and Makni.

At Killari the motion was a complex combination of swinging, jumping and vertical type, and the ground shook like a sieve. Three masonry columns made of dressed stone show a dominantly rotational component, fig 52, whereas stone pillars in the Maharashtra Vidyalaya show a vertical component of motion of the earthquake, fig 53.

At Sastur the swinging motion came from Killari. A man sleeping on the floor was awakened and could not stand up despite his best efforts. He remembers being swung on the floor twice, and was displaced by as much as 60 cm from his place of rest.

At Limbada torsional motion in north east direction is evident from the rotated statue of Lord Shiva, fig 54. This is also confirmed by deflection of four piers around the temple, the two piers in the east are tilted towards the north while those in the west are tilted towards the south. In Umarga the motion came from north west.

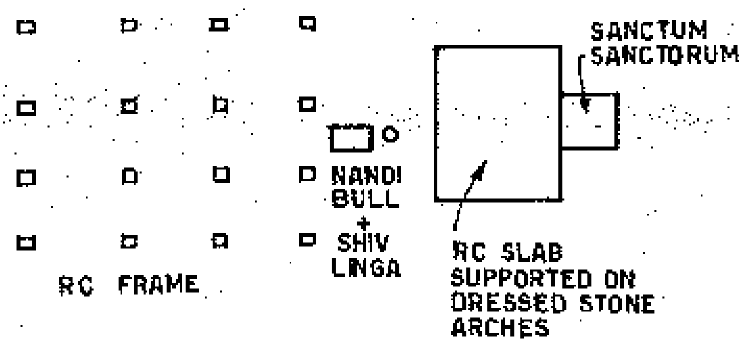

Fig 38 Plan of Neel Kantheshwar temple.

Fig 39 Collapsed dome of Neel Kantheshwar temple at Killari.

Fig 40 *Worship place with arches and RCC roof at Neel Kantheshwar temple, Killari. This portion of the temple survived with minor cracks in arches.*

Fig 41 *Undamaged RCC frame at Neelkantheshwar temple, Killari. Tiles fixed on RCC column fell off.*

Fig 42 Ganesh temple at Sastur. Walls around the timber frame collapsed outwards while the roof is intact.

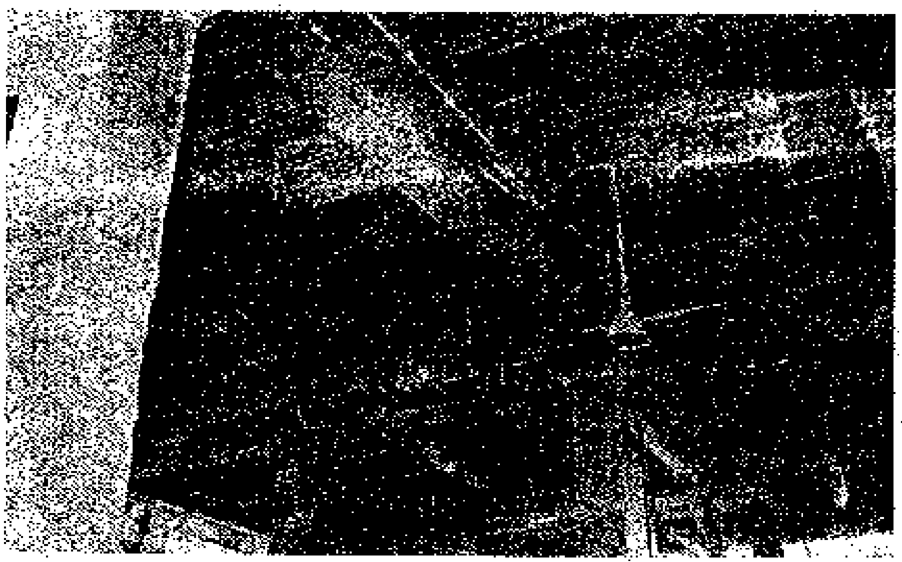

Fig 43 Inside view of roof of Ganesh temple at Sastur. The timber frame has excellent wooden joints.

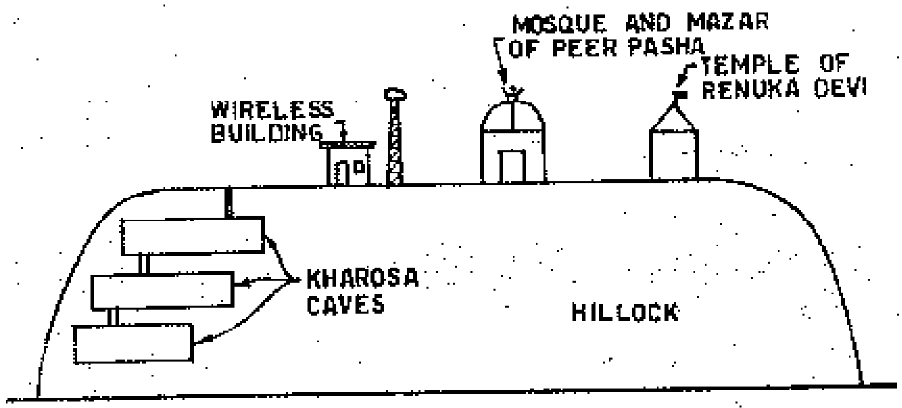

Fig 44 *Plan of Kharosa hillock with several caves and three buildings on top of it. Not drawn to scale.*

Fig 45 *Completely collapsed sanctum sanctorum of Renuka Devi Temple at Kharosa.*

Fig 46 *Heavy kalash which fell off the spire of Renuka Devi temple.*

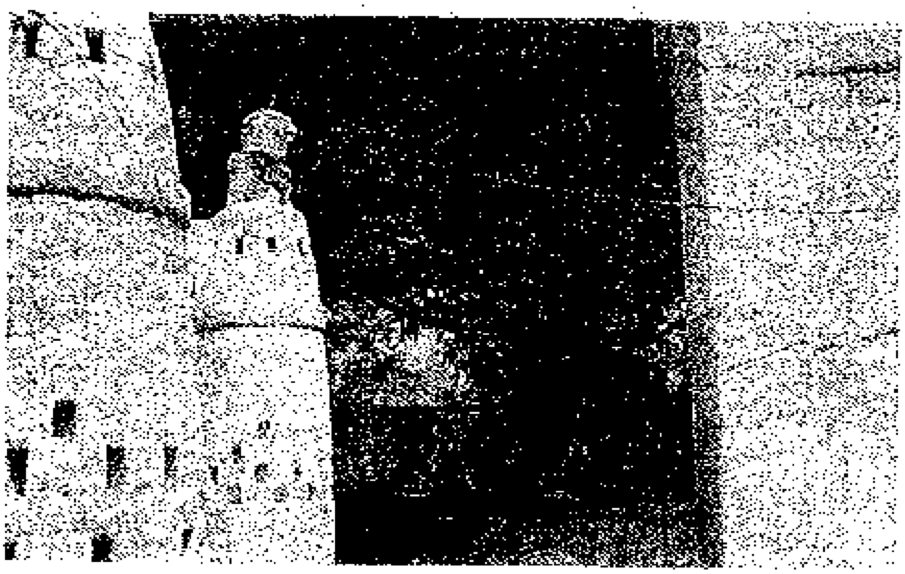

Fig 47 *Damaged minaret of mosque at Kharosa.*

Fig 48 Intact wireless building on hillock at Kharosa.

Fig 49 Collapsed Mugal dome near Sastur.

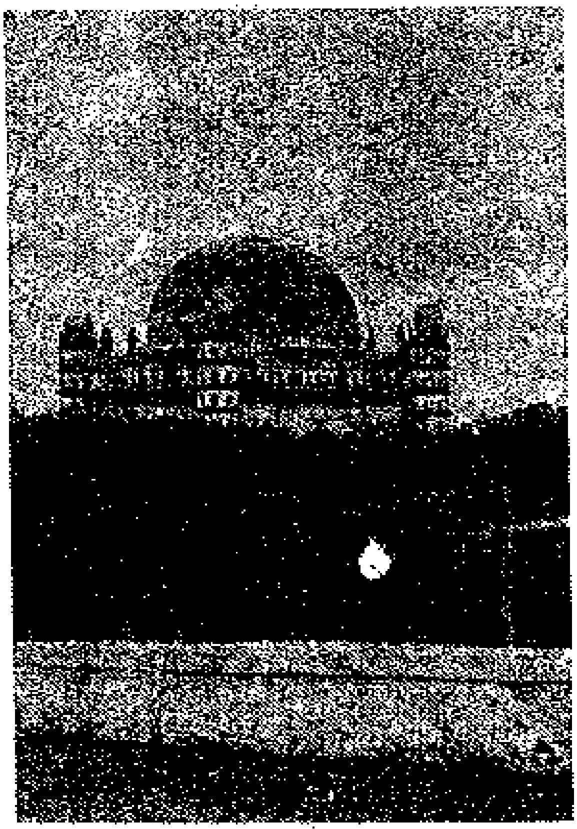

Fig 50 *The famous dome at Bijapur.*

Fig 51 *Cracks inside the Bijapur dome.*

Fig 52 *A shop building at Killari with damaged masonry columns. Three masonry columns support the traditional verandah roof which is properly connected with the main structure. Torsional effects are evident.*

Fig 53 *At Maharashtra Vidyalaya in Killari stones were displaced in pillars towards the north by about 4 - 6 cm. The circular pillar was made of 5 layers of hewn stones. One stone was displaced by a lift of 8 cm in 12 cm showing presence of vertical motion.*

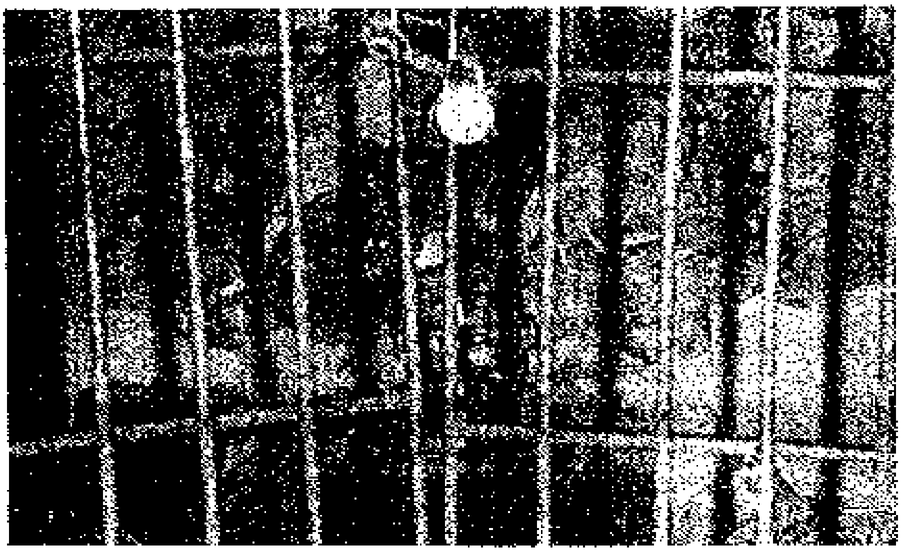

Fig 54 Twisted statue of Lord Shiva at Limbada.

Rotation of two fridges in the Rest House at Makni are indicative of a complex earthquake motion. At Makni the sound and vibrations came from the east, as if from Killari. The vibrations felt were dominantly horizontal.

At Kawtha a field near the water tank which was prepared and ploughed the previous evening for sowing sunflower was flattened after the event and the furrows had disappeared. It seemed that the field had undergone shaking comparable to that of a sieve and the fine particles had settled on top. The new seedlings which were planted before the earthquake were not showing any signs of growth, probably the tender rootlets had broken off. Post earthquake rain introduced virus in the vineyards. The farmers take these signs as an ill omen. The farm labour was too disturbed to return for work on the fields. A large number of after shocks were felt in the village and the direction of motion, as observed by the villagers, was vertical and came from the direction of Killari which is north of Kawtha.

The Sarpanch of Kawtha village, Sri Shivaji Rao Patil, informed the authors that several wall clocks stopped at 3.58 a.m. The motion was first vertical then rotational and then there were very pronounced horizontal movements, which seemed to come from Killari.

At district headquarters of Osmanabad vertical motion was reported. A free standing boundary wall of a school at Mangrul fell towards the west. At Gubal the motion came from the north and the ground shook violently. At Gulbarga the motion was swinging and horizontal at the time of the earthquake. At Halikasd the shock came from the south. At Kamal Nagar the motion was horizontal and came from the west.

PHENOMENA ASSOCIATED WITH THE EARTHQUAKE

Description of sounds, smells and other strange phenomena observed prior, during and after the earthquake and presented in this paper is largely based on interviews with local inhabitants. The earthquake was accompanied by a pungent smell of sulphur in the rupture zone. Frightening sounds accompanying the earthquake were described by interviewees as those associated with a fast train running by, a bomb explosion, [illegible], thunder, helicopter, thrashing machine for sun flower seeds, etc.

Sounds

At Killari the earthquake was accompanied by a commotion which seemed to come from the south. It was described as a combination of a train running under the feet of the inhabitants, a very heavy object rolling inside the ground, whirring of helicopter rotor blades, followed by a screeching sound, as if a fast train had suddenly applied brakes. The sound was similar to what was heard at the time of the previous earthquake i.e. of October 18, 1992. The falling debris gave rise to dust clouds as high as the houses, i.e. 3m high approximately.

At Limbada the shock was accompanied by a noise like a bomb explosion, then like crackling of a fire. At Makni the noise was like that made by a motor cycle. At Osmanabad creaking sound was made by doors and windows. Picture frames were displaced. Terrifying sounds of a running train and fire crackers were heard at Ausa. At Bijapur people reported a sound like that produced by lightening during a thunder storm. At Gubal a peculiar and dreadful sound of 'gud gud' accompanied by a stormy noise was heard. The shocks were accompanied by sounds which resembled dynamite explosions. At Gulbarga the awful sound was as if a road roller had hit the house. At Halikasd all were awakened by a rumbling noise of a running train. At Kamal Nagar the sleeping people were awakened by a noise of a train running past somewhere nearby. Heavy furniture like beds and swings moved. The sound was like that of a big bomb blast accompanied with a frightening sound like 'dhum- suen'. At Mangrul a loud cracking sound was heard, as if several road rollers were moving simultaneously. At Umarga the earthquake was accompanied by a noise akin to a distant bomb blast.

Smells

The earthquake was accompanied by a strange smell of burning sulphur akin to that felt after firing Diwali crackers. It lasted for about 10 - 45 minutes and was reported from Gubal, Killari, Limbada and

Osmanabad . The smell was absent at Kamal Nagar and Umarga.

Animal Behaviour

Strange animal behaviour was observed with the main event, foreshocks and after shocks even in regions with lesser MM intensity. The Chief Executive Officer of the Zila Panchayat, Gulbarga, Sri Subhas Chandra, I.A.S., informed the authors that large ants came out of their colonies in droves the night before the earthquake. At Kawtha dogs wailed and peacocks screeched before and after the event. This pattern of strange animal behaviour continued for each after shock. At Mangrul dogs wailed the entire night and continued to do so prior to every shock. At Sastur the chorus of wailing dogs was witnessed by the authors, a mild shock occurred immediately after that.

Ground Water

Since the quake of October 18, 1992, ground water conditions in the meizoseismal area have been highly disturbed. Two tube wells in Dr. Poddar's field, about 100 m deep, ran dry after the quake of 18 October 1992. The Doctor had his pump sets taken out for fear of damage in the numerous small quakes which followed. After a subsequent shock of 28 October 1992, sound of gushing water was clearly heard even 3 meters away from the well. The pump set was immediately re-installed, and a very thick discharge of water was obtained. The pumps are dry after the earthquake. Others in the village have reported turbid and foul smelling water from wells. On 18.10.92 for one day the water was like a very dilute solution of plaster of paris in some wells.

Dr. Poddar narrated a very interesting incidence about his friend Basavraj Virajdar. The latter uses a drip irrigation system for watering his vineyard. Sometime between March and April 1993, he found that small stones in the field seemed to be unusually oily after being watered, as if kerosene had been sprinkled on them. To his surprise he found that when these stones were immersed in a bucket of water a thin film of oil came on top.

At Kawtha the Sarpanch, Sri Shivaji Rao Patil informed the authors that 1.5 km west of the failed water tank, the bore wells showed an increase of output, whereas 1/2 a km east of the same water tank the situation was reverse.

In Takari village of Paranda taluka, Osmanabad district, bubbles were reported and white smoke emanated from wells and continued for 3 - 4 hours after the earthquake.

Lights and Smoke

Strange atmospheric phenomena were reported to have been observed before the earthquake, like smoke emanating from ground and lights in the sky. The Sarpanch of Gubal, Sri Alauddin Abdul Patel, accompanied by many villagers, informed the authors that about a month before the earthquake very strange phenomena were observed in the village. About 1 km west of Gubal on both sides of a nullah, in a 10 - 12 acre field, 3 - 4 metre high white and black smoke was observed between 9.00 am and 1.30 pm, from far off places. On that day, or a day before or after the smoke appeared, a very strange bright light was seen in the sky after 7 o'clock in the evening, i.e. after it was dark, which persisted for about 20 minutes. It left the villagers stunned. Foul smelling warm water came out from the pump sets thereafter. Also, a lot of diseases like jaundice and gastro enteritis started after that. Since then water in the region has been 'khara' i.e. brackish.

In Rubrawadi and Khajuri villages of Gulbarga district in a 60 cm wide by 50 m long area 30 cm high smoke was seen by the villagers the day after the earthquake, in the evening around 5 - 5.30 pm. These are not isolated instances but were repeated in several villages.

ISOSEISMAL MAP

On the basis of an extensive damage survey and information collected from local people, a preliminary isoseismal map has been drawn for the earthquake of September 30, 1993. The MMI scale given in IS 1893 - 1984 was used in preparing the isoseismal map. The maximum Modified Mercalli Intensity (MMI) was VIII+, observed at Killari, Talni, Sastur and adjoining villages. Isoseismals VIII to V are given in figure 55.

Intensity VIII+ was assigned to those places where all rural and poorly built structures such as stone houses were razed to the ground, ordinary brick buildings with cement - sand mortar developed large and deep cracks in walls, gaps occurred in walls, some heavy furniture overturned, people were frightened and panicked, some monuments twisted and moved, cracks occurred in soft embankments upto widths of several centimeters, dry wells refilled and existing wells dried up.

Intensity VII was assigned to those areas where most people were frightened and ran outdoors, many found it difficult to stand, heavy damage occurred in stone buildings, and fine cracks developed in plaster and small pieces of plaster fell off in well built buildings.

Intensity VI was assigned to areas where the earthquake was felt by most, a few persons lost their balance, a loud rattling of windows and doors was heard, many people were frightened and ran outdoors, objects fell off from racks and shelves, fine cracks appeared in plaster, small pieces of plaster fell off in some ordinary brick masonry buildings and small cracks appeared in many stone buildings.

Intensity V was assigned to areas where many sleeping people were awakened, a few ran outdoors, animals became uneasy, buildings trembled, picture frames knocked against walls and unstable objects fell indoors, the sensation was similar to that of vibration due to heavy object falling inside buildings and slight damage occurred in stone houses.

CAUSES OF EXTENSIVE DAMAGE

Disastrous effects of the earthquake are concentrated within an ellipse of about 100 square kilometer area. Stone houses collapsed because they had heavy roofs and thick walls. These features shattered the wythes, separated the walls at joints and corners and led to collapse of walls and roof. If bond stones had been used in walls and the walls and roof had been properly tied together by earthquake bands fewer casualties would have occurred. The traditional timber framed stone houses performed much better compared to those stone houses which had no frames.

Several causes have been identified which led to high casualty figures. These are

1. The timing of the quake. The earth shook violently in the early hours of the morning when most people were still in bed and were caught unawares in their sleep.
2. The earthquake had a shallow focus.
3. Maximum shaking occurred in a very densely populated area.
4. Construction in the epicentral area was totally unsuited for shaking of the kind caused by this earthquake.
5. Most people who died were trapped in their own dwellings.
6. Quality of construction of stone houses was very poor.
7. Use of very heavy, big, rounded and undressed stones made the walls very unstable in the earthquake.
8. The use of very poor quality mud mortar has almost no cohesive strength to bind the huge stones.
9. Very thick stone walls were made without any bond stones.
10. Very heavy roof generated high inertia forces.
11. Collapsed boundary walls choked the narrow streets and killed people running outside.
12. Walls separated at joints and corners because of absence of earthquake bands.
13. Walls moved outwards where tin roof was used, resulting in roof collapse.
14. At some places mixed type of construction (brick and stone masonry) without proper connections led to damage.
15. In engineered buildings diagonal cracks occurred between two openings and between opening and corner which are mostly repairable.
16. Torsional failure occurred due to irregular shape of buildings.

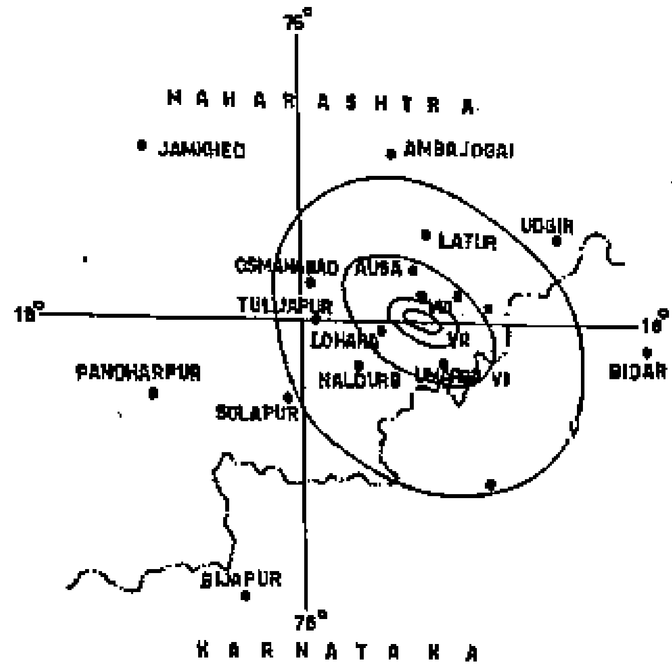

Fig 55 Preliminary isoseismal map for the Latur - Osmanabad earthquake of September 30, 1993.

17. Re - entrant corners caused damage in many buildings.
18. A sudden change in elevation of the building caused damage in upper portions.
19. Doors were jammed in well engineered buildings, specially in rooms which were at junction of two wings of a building.
20. Extensive non structural failure was observed where elements were not anchored and tied to the main structure properly, such as tiles, electric fittings and wash basins.
21. In reinforced concrete columns of water tank lateral ties were widely spaced, specially near joints, which is unfavourable to the structure during an earthquake.
22. Torsional motion was predominant at places which increased the damage.

RECOMMENDATIONS

All scientific data relevant to this earthquake should not only be widely disseminated but should also be made available to all scientists. Seismological instrumentation and interpretation techniques should be strengthened and upgraded at the national level. Strange phenomena such as animal behaviour associated with the earthquake should be thoroughly studied.

Seismic history and geotectonics had earlier indicated that earthquakes are rare in the Deccan trap region. However, this earthquake has altered the current view of an aseismic Deccan plateau and has now necessitated a thorough revision of the existing Seismic Zoning Map of India. New buildings should include all earthquake resistant measures pertaining to zone IV of the existing Seismic Zoning Map of India (ISI 1893 - 1984), as an interim measure. If proper construction practices are not implemented future earthquakes of moderate magnitudes in highly populated regions can again become unmitigated disasters.

Existing structures need to be evaluated and strengthened against earthquake forces. Traditional stone construction can be made safer with a few modifications like wall thickness should be reduced and bond stones, vertical steel and earthquake bands should be used in walls to resist lateral seismic forces as described in the Indian Standards listed in references.

There is an urgent need to create awareness about earthquake resistant measures, design, repair, restoration and strengthening among the masses. This can be achieved through workshops, seminars, video films, posters, illustrated books, exhibitions and radio broadcasts in all Indian languages. Short term specialist courses for administrators, decision makers, technical and non technical personnels also needs to be organized. Model houses which use local materials and incorporate all earthquake resistant measures should be built in each village so that local inhabitants can become aware of them.

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