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RESPONSE OF STRUCTURES IN BROACH EARTHQUAKE †

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INTRODUCTION :

Broach developed on the northern bank of the river Narmada, due to abundance of water and good fertile land, which were the principal factors for habitation in pre-historic periods. Due to proximity of sea, Broach was once a good port, the fact which contributed to the development of the town. However, with the coming up of Bombay as an international port and the technology of ship building evolving larger and larger vessels, the Broach port suffered a set back. Now the main revenue of the town and district is only on the cultivation of fields for cotton and tobbaco. The possibility of industrialisation is also rare as the town is flanked by Surat on one side and Baroda on the other, where industrial estates are fast developing ; while Ankleshwar the nearby town is coming up rapidly due to oil and gas fields. The only importance of Broach town is that it is the governmental headquarters of the district. It is fairly covered by jungles yielding good timber. Broach is, therefore, principally a town covered by the residential structures of the type prevalent before reinforced concrete structures were adopted, with a very few RCC structures built recently. The photograph, Fig. 1, gives the general idea of the residential structures in the town.

GEOLOGY AND SEISMICITY OF REGION

The river Narmada has a peculiar flow direction. Most of the rivers of India flow towards S–E and meet the Bay of Bengal while Narmada and Tapti flowing through rifts proceed to the west and meet Arabian Sea. The coastal region is completely covered by recent alluvium and barely there are any outcrops visible. Faulted structures cannot be recognised from the field observations. A network of faults beneath the alluvium has been discovered by the seismic surveys conducted by Oil and Natural Gas Commission (ONGC). As revealed by these surveys, Broach district and its surrounding regions are in a network of faults, some of which are of recent origin. Fig. 2 shows this network of faults. Other faults have also been discovered in the recent surveys by ONGC.

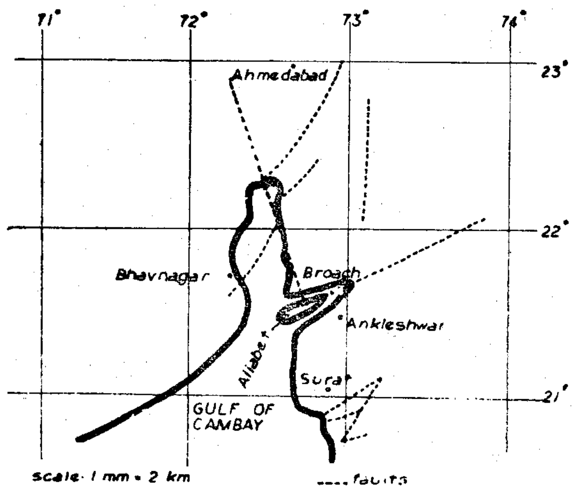

Fig. 2. Network of faults in Broach district and nearby area.

EARTHQUAKES

From the available past records, it is evident that Narmada valley had a history of earthquake experiences. They were the earthquake of : 27th March, 1847 ; 18th September, 1865 ; 2nd January, 1927 and 14th March, 1938.

To these records is added the one which took place on 23rd March, 1970 at 7.25 a.m. I.S.T., taking a toll of about 30 persons and injuring many more, with a loss of property estimated to the tune of twenty million rupees. The movement seems to have taken place

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along a hinge type fault [6] with Broach, Kantharia, Manubar, Karmad on the downthrow side and the Ankleshwar region on the upthrow side. This is evident from the damage suffered by the areas of Broach, Karmad region and comparatively negligible damage in the Ankleshwar region.

Unfortunately, even after the Anjar earthquake of August, 1956 and after finding the network of faults by seismic surveys, seismological statations were not established in Gujarat. Therefore, the estimates for magnitude and location of epicentre are to be obtained from the recording station at Delhi and Poona. The magnitude is estimated as 6.0 on Richter scale and epicentre at 21.6°N latitude and 72.6° E longitude. It is estimated that the depth of focus was very shallow. Seismograph records far away from epicentral region, giving an estimate of energy release is only a good indication of the earthquake effects, but does not give any idea about the ground motion in epicental region with which the structural engineer is usually concerned [8]. This stresses the need for strong motion recorders in the epicentral region.

The major component of earthquake acceleration is N–S. This is very clear from the diagonal cracks on N–S walls. These cracks on larger panels are running from top at north to bottom at south. indicating the seismic force from north to south (Fig. 3). This direction is also very clear from fallouts of E–W walls. The photograph (Fig. 4) shows the shift of bench seat to south from the seat rests. Cracks produced by the earthquake at the surface of the ground at Kasia and Borbhata are approximately E–W, clearly indicating the N–S direction of seismic force (Fig. 5)

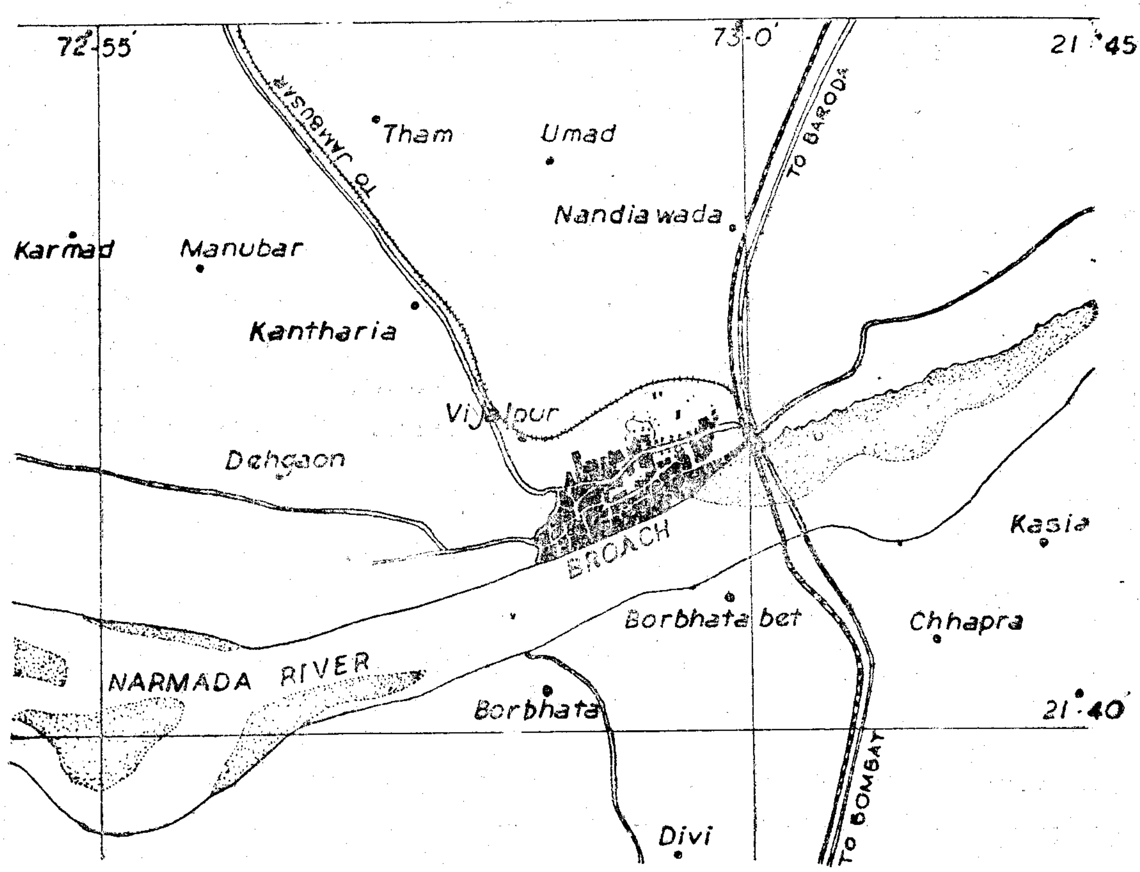

Figure 5. Map of Broach District.

RESPONSE OF STRUCTURES

In the absence of any details about ground acceleration, age, dimensions and physical properties of the materials of very old structures, the qualitative discussion is presented here about the response of structures.

General Observation

The difference of levels between the highest and the lowest area in the Broach town is about 20 metres. The damage to the structures on the areas of higher contours were more pronounced than those on lower contours and relatively plane landscape. Damages were still more severe on the areas adjacent to the river bank. Lower areas which were inundated severely several times were affected less, probably due to even consolidation of the foundation soil. while the areas on hilly portions and river bank seem to have suffered more due to probable instability of slopes under earthquake, contributing to the disturbances of uneven settlement of foundations.

Buildings in this town are of medium rise or low rise types. No building having more than 4 floors is constructed. Buildings with lighter roof stood well except the portions of the masonry gable ends. Such a gable end gave way, distorting the supporting roof and causing impact failure of floor. Portions of roof supported on trusses have remained undisturbed, indicating the failure of gable due to its inertia and facilitated by improper connections.

Effects of the inertia force on light and heavy structures are also very striking. Apart from the fact that mud-huts have suffered absolutely no damage, lighter partition walls have stood well compared with the heavier load bearing walls. Many heavier walls running E–W have suffered motion of translation to a greater extent due to higher inertia forces, while those running N–S have suffered diagonal cracks on larger panel as shown in Fig. 3. and typical X–cracks on smalles panels [6]. Higher energy absorbing capacities of thicker walls have not been exploited [7] by the builders of this old town due to poor connections with floors and other cross-walls, The photograph (Fig. 6) shows that the walls have come out at first and second floor levels, while walls at ground floor have suffered very little showing what an important role connections play in resisting seismic motions. Difference in deformations of the masonry and underneath floors due to different stiffnesses are sufficient to separate them and cause a motion of translation under interia forces. It has been observed that the lighter partition walls running E–W have not suffered such damages.

Behaviour of Walls

When the walls are not effectively anchored to the framework of either timber or RCC, then due to excessively different deformations of a wall and members of a frame, at the common surfaces, walls are practically separated and behave independently as an individual structural unit. Such a wall may be either parallel or normal to the direction of the principal component of the earthquake. It is quite obvious that the walls parallel to the principal component absorb the energy extensively and forms either X cracks or cracks inclined in one direction only, depending upon strong motion, panel size and constrained conditions.

CASE STUDIES

Out of many buildings that have suffered damages, some typical cases are presented here.

(1) Railway Station Clock – Broach

This structure about 12 metres high was constructed in the year 1881 in brick masonry with thick walls over a system of brick arches and brick pillars. This has suffered excessive cracking and the clock stopped and recorded the time of earthquake. Cracking in this structure is due to complex combination of high inertia forces on the structure supported on brick arches practically of no tensile strength and uneven settlement of pillars due to slope on the southern side. This is substantiated by the widening of cracks observed on the twelveth day after the earthquake.

Another similar structure in so called rich area is the Victoria Memorial Clock Tower, built in early nineteenth century. This is located on the highest contour of the town. The natural subsoil is retained by a heavy retaining wall on the west. The superstructure is almost a uniform mass throughout the height without any supporting arches. This tower has suffered shearing. One of the piers is out of plumb by about 2 cm. The metal stiffeners provided to act as a bracing system for the tower have also failed. Due to nearly uniform distribution of mass throughout the height the Victoria Memorial Clock Tower has suffered less damage compared to the Railway Station Clock Tower which is top-heavy construction. The heavy retaining wall on west also assisted in minimising the disturbances in subsoil.

(2) Bharucha Town Hall, Broach

This structure located near Victoria Memorial Clock Tower, was built some 50 years ago, with load bearing masonry walls and brick arches over openings, with a pitched roof on steel trusses. The ground floor houses one of the oldest and best libraries of Gujarat and the first floor is utilized as a town hall. The southern side of the building had stone pillars and brick arches over which the floor was resting. This side is almost destroyed. The photographs Fig. 7 and 8 show that part before and after the earthquake. This collapse was primarily due to high arches, with stone pillars as supporting structural elements. The floor was transferring its loads on this system by N–S timber runners. These timber runners, as can be seen from the photograph (Fig. 8) were supporting only for gravity loads and were anchored poorly even for a small amount of horizontal pull. Moreover, the rotation was allowed to arches and pillars by spherical stone hinges at the capitals and pedestals. This, with no constrains on the sides had allowed for more deformations which caused the collapse.

The northern side of the structure is absolutely different from the southern side (Fig. 9). Light construction by timber beams spanning over stone pillars is the root cause of its survival, as compared with heavy arches on stone pillars on the southern side.

(3) State Transport (S.T.) Bus Stand, Broach

This is one of the very few RCC framed structures in the town. This is located near the railway station. Infilled walls are one-brick walls in cement mortar 1 : 6. Part of the structure is exploited for a mezzanine floor. RCC columns are finished with excessively thick terrazo. The photograph Fig. 10 shows the typical crack at the junction of the beam and the column. This crack is horizontal initially at the soffit of the mezzanine beam and it extends thereafter vertically in the column. Horizontal part of the crack seems to be due to the lack of proper construction joint between the column and the mazzanine beam soffit. Vertical part of the crack is due to excessive terrazo finish to cover up the plumb discrepancies.

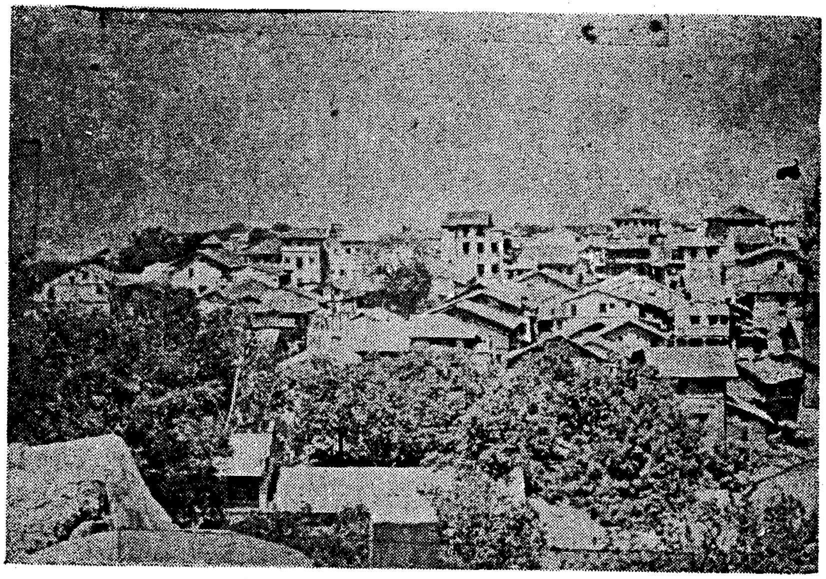

Fig. 1. Structures in Broach

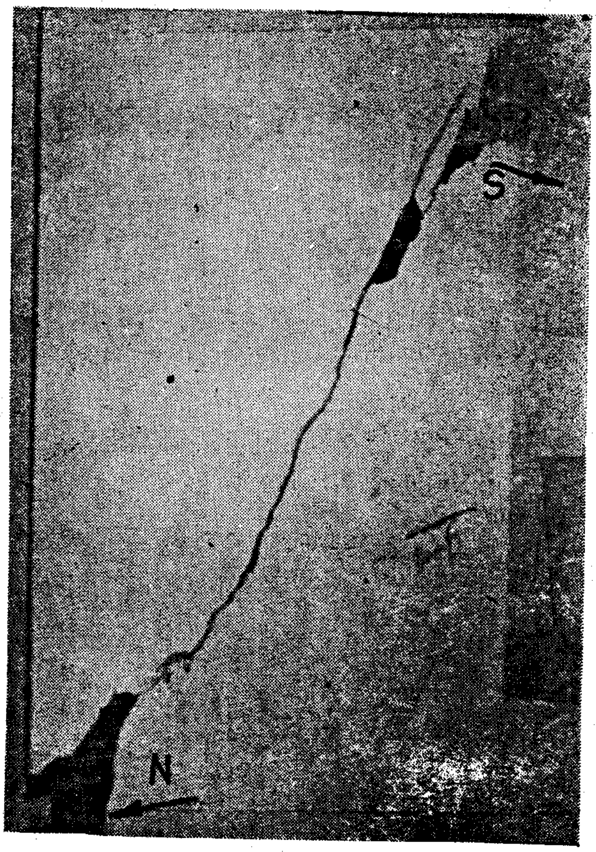

Figure 3. Diagonal Cracks bearining wall at Broach

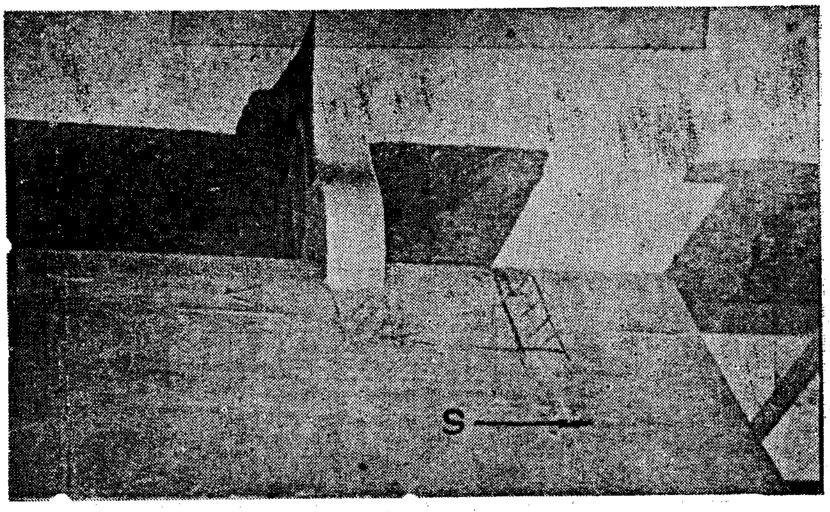

Figure 4. Shift of conerete bench seat at Broach.

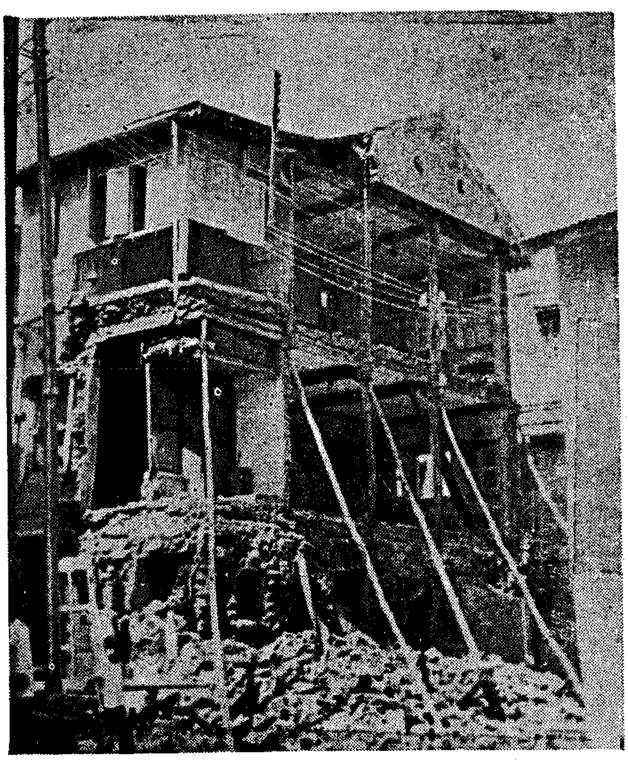

Figure 6. Failure of filler walls due to improper connections at Worwad, Broach.

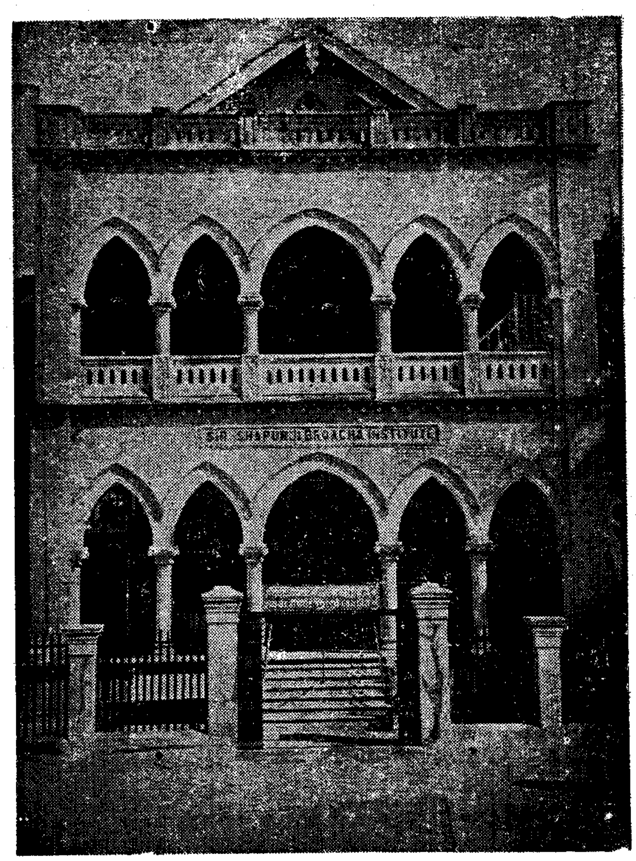

Figure 7. Bharucha Town Hall, Broach, Southern view before earthquake.

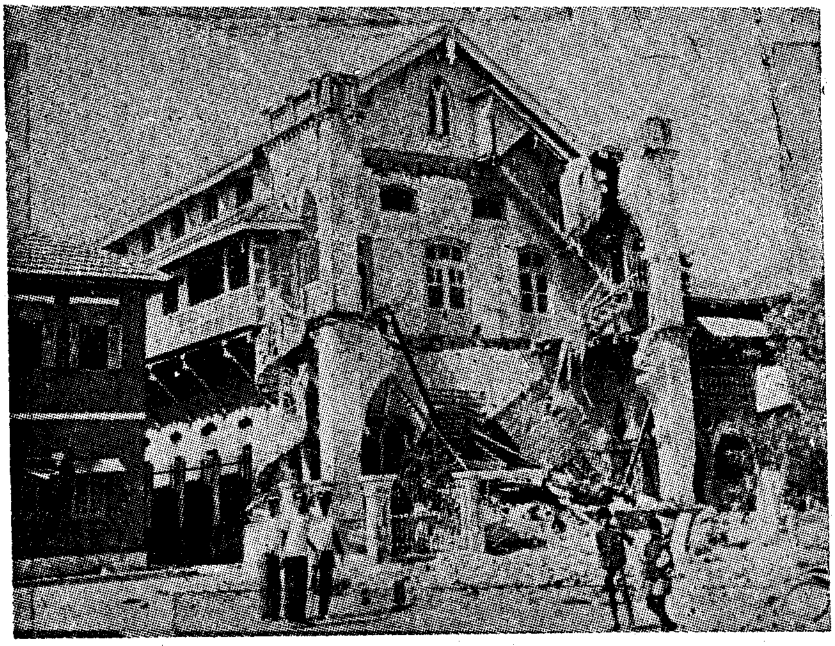

Figure 8. Bharucha Town Hall, Broach, southern view after earthquake.

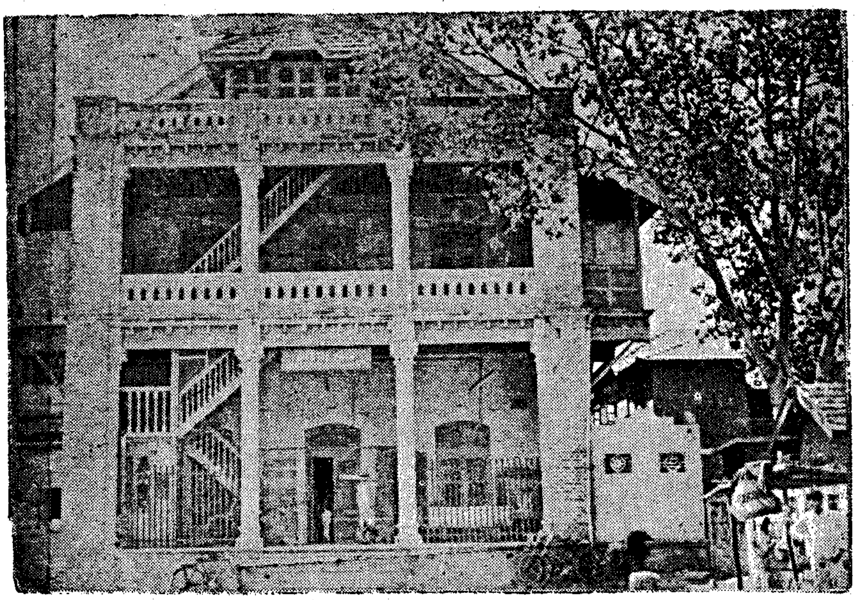

Figure 9. Bharucha Town Hall, Broach, northern view after earthquake.

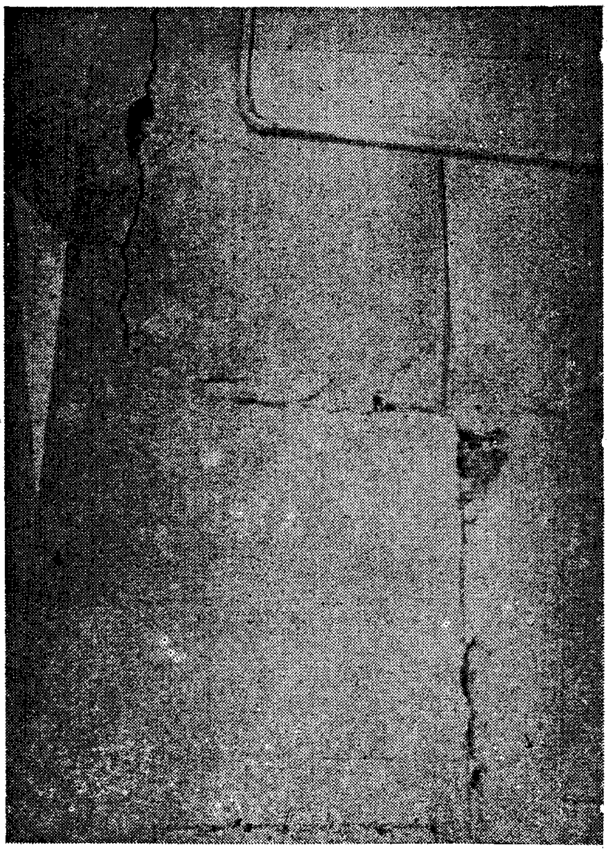

Figure 10. State Transport Bus Stand. Broach - Cracking at mezzanine level in Beam-Column joints,

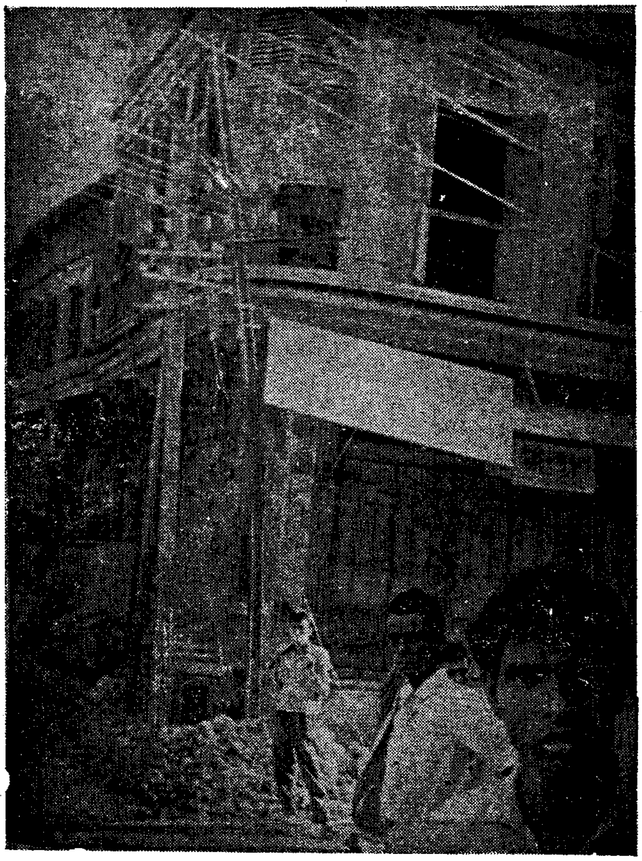

Figure 11. Bending of steel rail used as pole.

When Broach was revisited after a month, to inspect the progressive cracking in any of the structures, the diagonal cracks at quarter span in the terrace level beams were observed in this structure.

(4) Jayendrapuri Arts and Science College

This structure is a two storeyed one, built in brick masonry load bearing massive walls ($2\frac{1}{2}$ brick walls) with RCC beams and slabs forming floor and terrace floor system. This was built recently during the period of cement shortage. It is located on absolutely plane ground far away from the river bank. All the panels of N–S walls in between door and window openings have a diagonal crack in each panel similar to one shown in Fig. 3. The usual X - cracks were observed in the panels of stair well. Reinforced concrete structural units were absolutely undamaged, except at the landing joints of the stairs, where cracks were observed. Usual separation of wall and stair unit was also observed. None of the E–W walls over-toppled.

(5) New Madresa, Karmad

This building is a two storeyed structure with one and half brick bearing wall in cement mortar construction on fairly level ground. Ground floor walls have cracked very heavily with the cracking pattern of Jayendrapuri Arts and Science College building. Photograph (Fig, 3) shows one of the typical cracks in this building. Western side (one and a half) brick wall of the big prayer hall, of length 12 to 15 metres and height of about 8 metres, had cracked very badly. It has partially survived because of its N–S direction. Had it been E–W, the failure would have caused a major disaster.

(6) Response of other structures

The failures of various minarets show similar pattern. All without any exception have toppled down as they are top heavy structures supported on slender brick pillars Their failure have subsequently contributed to the secondary failure of nearby structnres like old steel water tanks on timber standards. New RCC water tower have suffered no damage due to their ductile supporting structures. Brick chimneys with steel stiffeners and steel chimneys have stood very well. Railway bridge over river Narmada spans approximately N-S. Bolts of two rocker bearings on pier no. 2 and of one rocker bearing on pier no. 3 were sheared off in N–S direction. Bolts of many other rocker bearings were loosened. There was no other damage to the bridge. Road bridge over river Narmada has suffered no damage. Transmission line poles were damaged to certain extent. In village Manubar many prestressed concrete type poles were fractured above the level of first window from ground due to fall of debris on electric wires. Near Hajikhana Masjid, in Broach, one steel rail used as a pole, was bent up excessively (Fig. 11).

CONCLUSIONS

It is advisable to go for a framed structure with in-filled walls well secured to the frames by proper connectors, to avoid the fall out of wall and to enable the structure to resist seismic forces. However, for low rise structures load bearing masonry wall can be used. Load bearing walls for high-rise structures should be avoided, as thicker walls will increase the inertia forces tremendously. In load bearing walls, vertical joints at T or L connections (in plan) in brick masonry should be suitably made and even reinforced. Reinforcing bars at every 4 or 5 courses will also help the structure to resist seismic forces. **Arya (1) and Degenkolb (2) elsewhere have discussed the construction and design aspects for** small buildings. Minarets and other top heavy structures should have a ductile supporting structure. It is imperative now that the local authorities in seismie zones should insist on approval for the design for seismic forces by well qualified structural engineers and commencement of work to follow the checking and approval of the design. As this region has close network of faults, it is necessary that number of seismological observatories using seismic recorders (4) be established in the region.

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