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SEISMIC RETROFITTING OF MASONRY AND CONCRETE BUILDINGS

by

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ABSTRACT

Masonry and reinforced concrete buildings often get damaged to various degrees in earthquake intensities VII and more on MSK scale. Most of such damages can be minised if they are strengthened before hand to withstand future shocks safely. This paper presents the causes of damage, and principles of retrofitting masonry and concrete buildings. Various methods of strengthening of masonry and concrete buildings are described. Examples of strengthening done in some earthquake areas of the world including India are presented. Results of a study carried out to retrofit an existing concrete buildings are also highlighted.

1. INTRODUCTION

Buildings of various types such as those of clay, stone or brick in general and of reinforced concrete to a lesser extent, receive distress to various degrees in earthquake Intensity VII and more on MM or MSK scales. The level of distress may vary from minor cracking to partial or complete destruction. A very large stock of such damageable buildings exists in seismic zones III, IV of V of India. For their survival during future probable maximum earthquakes, appropriate seismic retrofitting methods need to be volved and implemented in the field. The method of strenthening naturally depends very largely on the structural scheme and materials used for the construction of the building in the first instance and the technology that is feasible and economical.

The understanding of mode of failure, structural behaviour and weak and strong aspects of design as derived from the post-earthquake damage surveys has a strong influence on retrofitting methods of buildings. There are often variations in these methods because of different types of materials, planar configuration and construction types encountered at different places.

The paper presents the need and principles of effective seismic strengthening of masonry and concrete buildings and illustrates the same with examples of strengthening masonry buildings as adopted in some earthquake countries of the world. Results of a study carried out to retrofit an existing multistoreyed concrete framed building are also presented.

Key-note address presented, at the National Seminar on **Earthquake Resistant Structures** New Delhi, February, 22-23, 1990.

2. CAUSES OF FAILURE OF MASONRY BUILDINGS

The following are the main causes of damage of masonry buildings in earthquakes:

a. The masonry buildings possess heavy mass along with large in-plane rigidity. These characteristic make the time period of the buildings 'short' (less than 0.4s) and result into large lateral seismic forces.

b. Most of the masonry buildings tend to fall apart and collapse because of lack of structural integrity. The lack of structural integrity could be due to lack of 'through' stones in stone masonry, absence of bonding between perpendicular walls, absence of diaphragm action of roofs, and lack of box-like action. The falling elements generate impact loading also that causes progressive destruction of the entire building.

c. The tensile and shearing strength is very small, almost zero for masonry in mud, thus incapable of resisting such imposed stresses during earthquakes.

d. Usually there is lack of good design and quality of construction of masonry buildings hence reduced earthquake resistance.

e. The earthquake forces higher than those expected or used in design may actually occur.

3. CAUSES OF FAILURE OF REINFORCED CONCRETE BUILDINGS

The main causes of damage of reinforced concrete buildings in earthquakes may be summarised as follows:

a. Lack of necessary strength in adopted design of beams. columns, frame action and foundation.

b. Poor quality of construction.

c. Inadequate detailing of reinforcement in various components, particularly at joints, and in columns and beams for ductility.

d. Inadequate diaphragm action of roofs/floors.

e. Inadequate treatment of infill masonry walls.

f. Earthquake forces higher than the design forces may actually occur. This may some times be indicated by an upgraded seismic zone in the national standards/codes.

4. SEISMIC RETROFITTING

The term 'Seismic retrofitting' means upgrading the structural strength of a structure to make it capable of resisting future probable earthquake shocks without serious damage. This will usually involve adding new elements or modifying existing elements of the building structure.

The seismic strengthening of masonry buildings involves several measures such as the following:

- Modification of roofs to achieve their integrity and connection to the supporting structure;
- Planar modification of floors and walls to achieve diaphragm action, and near-symmetry in the buildings, etc;
- Injection of strong mortar in wall hollows;
- Preventive measures against delamination of stone walls; and
- Introduction of horizontal and vertical reinforcing elements to upgrade the lateral seismic resistance.

In reinforced concrete framed buildings, the following are the main devices to achieve the desired strengthening:

- Injection of epoxy in cracked elements if any :
- Introduction of in-fill type panel shear walls or diagonal braces to increase the lateral resistance of the building as a whole;
- Modifications to improve symmetry; and
- Strengthening of beams and columns by jacketing, casing, etc.

These techniques are applicable for post earthquake seismic restoration and strengthening of damaged buildings as well as for retrofitting existing undamaged buildings which lie in severe seismic zones but not originally designed to be seismically strong.

<u>General principles of strengthening:</u>

The underlying concepts and principles of strengthening of buildings are enumerated below:

1) Before adopting any strengthening scheme, the structural inadequacies of original structure and weakness of critical sections should be worked out by observation and analysis. The degradation of material properties and deterioration of strength of structure with time should be assessed by testing.

2) Any planar modification to maintain symmetry or otherwise should take into consideration the social and functional need of the people.

3) All elements of the building should be suitably tied together to obtain integral action of the building.

4) Adequate structural members, strong and ductile connections between the walls, roof elements and foundations should be ensured. During strengthening, the effort should be made to increase both strength and ductility.

5) Strengthening of weaker sections by steel, timber or reinforced concrete should be given special attention.

6) High quality of construction and insertion of special binding elements is a key to any strengthening method.

7) Addition of new elements like shear walls, infill walls, wing walls and columns should ensure adequate connection between old and new construction. The connection between old and new masonry and old and new concrete must be made with epoxy adhesives, or shear keys and suitably designed dowels.

8) Besides strengthening and increasing ductility, reduction of dead load may have to be recommended in some cases to improve seismic performance, as for example, reduction in number of storeys in the case of low-strength masonry houses.

9) The strengthening of foundations becomes necessary in some cases to carry increased loads. The construction works of foundation are generally expensive.

5. RETROFITTING METHODS FOR MASONRY BUILDINGS

As stated earlier, the masonry buildings in weak mortars and having flat roofs always have certain inherent undesirable properties and weaknesses, like high rigidity, heavy mass and negligible tensile and shear strengths. It is neither structurally possible nor economically feasible to alter and improve these characteristics. But inspite of these shortcomings, it is fairly possible at a reasonable cost to remove many of the constructional defects and introduce enough strength to meet the future earthquake resistance requirements. The measures usually adopted are described below:

(a) Grouting

If the existing masonry building shows cracking in walls, they could be treated by cement grouting. For fine cracks, the grout should be neat cement and water in the ratio about 1:1. For wide cracks, it may consist of cement and fine sand in the ratio of 1:1 or 1:2 depending upon the crack width, the water is to be added to obtain desired flowing consistency. For grouting operation, a low pressure mobile grouting pump run on diesel will be suitable. But it could be carried out by using a container kept about 1.5 to 2m higher than the cracked area and grout allowed to flow freely through a plastic pipe into the cracks. The cracks to be grouted will be sealed with mortar first along their length leaving a few ports open to receive the nozzle of the grout pipe. The grouting is to be done starting with the lowest part and proceeding upwards after the lower part of the crack gets filled up, see Fig. 1. It may be mentioned that it will be too expensive to fill the normal joints in dry masonry walls by this procedure, and should not be attempted.

(b) Stitching of Stone wythes:

This is required for stone walls of random rubble or half-dressed type. For new constructions, the 'through' stones or 'bonding' elements are recommended to be provided at the rate of one per meter square area of the wall. For retrofitting work, however,, it is considered adequate that stitching elements may be provided at one level in each storey at about mid-height between the floor and the reinforced concrete lintel level band, that is, about 1.2m above the floor and at horizontal distance of not more than about 2m. For installing the bonding element, a hole will be made through the wall by removing one external stone and one opposite internal stone. After cleaning the hole, it is to be filled with concrete while embedding an 8mm dia bar hooked at both ends in it transverse to the wall length. The length of this bar will be kept 5cm less than the wall thickness (see Fig.2). These may be omitted where cross walls exist at right angles to the external walls.

(c) Treating Bulged Walls:

The grouting of the hollow should be done after installation of bonding elements whose number could be increased locally if the bulge area is large. The grouting mortar could in this case be cement fine-sand in the ratio of 1:3. Alternatively the bulged wythe may be dismantled and reconstructed using 1:6 cement sand mortar and installing 'through' stones or bonding elements, as the reconstruction proceeds. See Fig. 3.

(d) Installing of horizontal and vertical reinforcing

This is the most important operation for seismic strengthening of existing unreinforced masonry buildings whether damaged or undamaged, to meet the requirements of design seismic intensity VII and higher. Since it will not be feasible to insert the band inside the walls, they will have to be added on the surface of masonry walls and bonded to them. Figure 4 shows a scheme of reinforcing called 'Splint and Bandage' that was used successfully in Skopje, Yugoslavia after the earthquake of 1963. In this scheme the 'bandage' is for horizontal bands and 'splints' for vertical steel. Here 'welded mesh' type steel, equivalent to the required steel areas has to be provided at the critical sections, properly nailed to the masonry after removing the plaster and raking the joints and covering the steel with micro-concrete to bond it with the walls. Such bands and splints should theoretically be provided on both faces of external as well as internal walls. As a minimum provision, however, these must be provided on all external or internal walls alongwith cross-tie bars, going across the building in both directions, and embedded in the external wall bands. The cross-bars are absolutely necessary in both directions to ensure integral action of the bearing walls like a 'crate' without separation at vertical corners.

ILLUSTRATIVE EXAMPLES

5.1 Seismic strengthening method employed in North Yemen:

Figure 5 shows the reinforcing scheme framed for seismic strengthening of a 2-storeyed stone building that was slightly damaged in North Yemen after Dec. 1982 earthquake. It consisted of surface bands on both faces of all external walls and cross-ties in both directions. The vertical splints were not proposed in view of infrequent seismic activity with intensity limited to MM VIII. The following steps were involved (see Fig. 6).

(i) Making through hole in the walls, one stone in size, just below the roof or floor, one each at the ends of spans at a spacing not more than 5m, through which the cross-ties were installed. Additional holes were made at centre of these spans for providing additional shear-connection between outer and inner bands.

(ii) Installation of cross ties through the holes and filling all holes in internal walls with concrete 1:2:4. The cross ties were placed parallel to cross walls and where they were far apart additionally at two points in each direction dividing the length or width of the spans in two or more parts, each less than about 5m in length. The ties consisted of two high-strength-deformed bars 10 or 12mm dia.

5.2 Seismic strengthening method used in Dharmsala, India:

The following main items were adopted for seismic strengthening of damaged brick buildings at Dharmsala after April 1986 earthquake:

1) Installation of reinforced concrete band just below the wooden roof trusses which should also serve as filling under the roof slopes.

2) Conversion of hipped roofs with wood rafters to roofs with trusses by adding horizontal ties and verticals.

3) Installation of steel meshes at corners and junctions of walls, both outside and insides, and covering with strong plaster.

4) Providing gable band on outside face and connecting it to the eave level band.

5.3 Seismic retrofitting method employed in China:

China has embarked upon an extensive plan of retrofitting the masonry buildings of upto 4 storeys so as to upgrade their seismic resistance to design intensity VIII or IX depending on the location. The major components in the reinforcing scheme are the following:

1) Adding reinforced - concrte pillasters on the external face of outside walls, raised from foundation level, bonded to walls with reinforced concrete shear keys, and going right to the top of the building, whatever the number of storeys. These piers are most essential element of the scheme. (See Fig.7).

2) Adding reinforced concrete horizontal beams running on the external perimeter of the building, monolithic with the new pillasters and bonded with the walls with R.C. Shear keys. Such beams are not essential elements and are provided as and where required. Where both vertical and horizontal elements are used, the building gives the appearance of a framed building.

3) Cross-ties connecting the external pillasters through the building, frequently provided with turn-buckle arrangement to produce some initial tension.

4) Adding reinforced-concrete plates onto masonry walls inside the buildings, as required, in transverse or longitudinal directions, so as to increase their strength as shear walls.

5) Using cement mortar coatings or reinforced cement mortar coatings attached to single or both the surfaces of brick wall to increase its strengths.

6) Using additional reinforced concrete or reinforced cement mortar coating ring beams, steel tie rods, and/or reinforced cement mortar tie coatings for increasing integrity of floor and the whole building.

5.4 Seismic retrofitting method used in Newzealand:

The most common method of strengthening used in Newzealand is through the application of a reinforced, sprayed concrete layer onto interior face of walls. A thickness of upto 150 mm is applied and the reinforcement in the form of rods or mesh lapped with dowels into foundation wall and concrete ring beams (Fig.

8). A variety of cementitious coatings are possible for the inplane strengthening of unreinforced brick masonry walls against seismic loading. These fibre reinforced coatings, even when application is by hand plastering are economically very competitive with the more common reinforced sprayed concrete solution.

5.5 Shotcrete retrofit of unreinforced masonry in California,USA:

Many unreinforced brick masonry walls, both load bearing and architectural, have been strengthened to provide earthquake resistance by applying a 75 mm or thicker layer of shotcrete to either the outside or inside surface of the wall. The technique has been used for retrofit of school buildings in California. It was considered that the brick-shotcrete bond provided by a wet, saturated brick surface is sufficient to hold the brick masonry intact during an earthquake. Some engineers believe that a bonding agent like epoxy is required to be painted or sprayed on the brick so that adequate brick - shotconcrete bond is developed. There is no consensus on brick - to-shotcrete bonding and the need for dowels anchorage. Application of a layer of reinforced shotcrete to unreinforced brick masonry panels is considered to be an effective method for greatly increasing the inplane diagonal strength plus providing reversed cycle and inelastic deflection capacity.

6. RETROFITTING METHODS OF REINFORCED CONCRETE BUILDINGS

Damage investigations after earthquakes have clearly indicated that a certain percentage of reinforced concrete buildings suffer damage requiring repair and strengthening. Even an existing building may require some retrofitting in order to increase its seismic resistance level. The retrofitting or strengthening of existing buildings may become a necessity under following situations.

(i) Upgrading of a seismic zone
(ii) Upgrading of design code
(iii) Deterioration of structural strength due to various reasons.

The building codes emphasize the importance of ductility of a structure. 'Ductility' implies that a structure deforms well into an inelastic range. Hence some repair work will be required if the structure performs as designed according to code during a strong earthquake motion.

The retrofitting of a structural system can be affected by the following procedures:

a. Strengthening of individual members and connections including restoration of lost strength.

b. Addition of new structural systems such as shear walls, wing walls and diagonal bracing system to an existing structure.

Many times a combination of these two approaches will render the best solution.

6.1 Retrofitting by strengthening of individual members:

The main merit of this method is that the original structural system is maintained and architectural scheme is not altered. In order to improve the moment capacity of deficient members, the following restoring and retrofitting techniques are employed:

Restoring: This is achieved by epoxy injection in cracks of elements, such as in buildings in Alaska (1964), Kayna dam in Koyna (1967), and structures in SanFernando (1971) earthquakes. Vacuum imprgnation is very effective for injecting epoxy in damaged concrete. Epoxy sand mortar can be adequately used for replacing damaged concrete (Fig.9).

Casing: The section is cased from all the four sides with new concrete and reinforcement in order to increase its moment of resistance and ductility (Fig. 12).

Jacketing: The beam is enclosed from three sides with new concrete and reinforcement (Fig. 13). The method is suitable for retrofitting under reinforced beams.

Building-up: In this method the end sections of structurally deficient beams and columns of rigid frames are reinforced by removing the existing cover and welding extra reinforcement and then grouting the section. The extra reinforcement is provided for a distance of one fifth of span from either ends. Building-up can also be achieved by gluing steel strips or shapes to concrete elements by means of epoxy adhesises (Fig.9).

Case study of Retrofitting a multistoreyed building

In the present case study of a multistoreyed building shown in Fig. 10 and 11, the following combinations of retrofitting techniques are tried:

Case I Casing of beams as well as columns (Figure 12)

Case II Jacketing of beams and building up columns from two sides (Figure 13)

Case III Building-up of beams and columns from two sides (Figure 14)

Case IV Building-up of beams and columns from one side (Figure 15)

Case V Strengthening of end portions of beams and columns (Figure 16)

All methods were found feasible, the most economical being case V.

Expansion Joint: The details of existing expansion joint is shown in Figure 17. The dynamic analysis indicates that at the joint the net displacement between tower block and side frame exceeds the existing gap of 15 mm. Thus hammering can occur at the joint during a severe earthquake. In order to avoid hammering the expansion joint detail needs to be modified to accommodate expected displacement. The end portion of the slabs meeting at expansion joint should be cut by 19 mm. The recommended modification of expansion joint detail is shown in Fig. 18.

6.2 Retrofitting by adding new system to existing structures:

There are various ways in which the lateral resistance and ductility of a building can be increased. For example, H. Ohishi, M. Tarahashi and Y. Yamazaki made analytical studies with two types of strengthening techniques. In the first one, insitu concrete walls were tried which would block the large glass windows partly. In the other, diagonal steel braces were infilled in the openings. It was found that both the methods could provide sufficient seismic capacity. However, steel braces were selected as the strengthening method in view of construction time, environmental conditions for living and lighting etc, inspite of higher cost-to-performance ratio.

7. CONCLUSIONS

Retrofitting of existing masonry and concrete buildings is a practical possibility with the methods briefly described here above. The success of every scheme will much depend on a detailed engineering survey and analysis of the buildings to be treated and should be carefully carried out before an appropriate scheme for seismic retrofitting of existing buildings is taken up for execution.

ACKNOWLEDGEMENT

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* 9WCEE stands for Ninth World Conference on Earthquake Engineering proceedings volumes.

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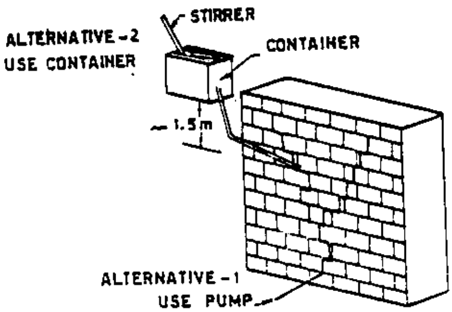
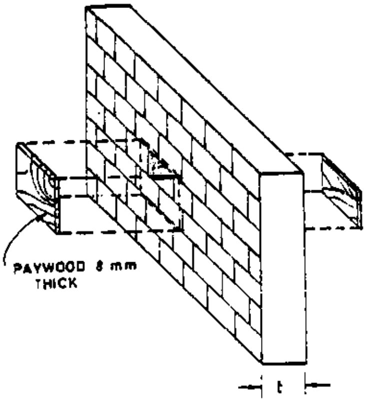
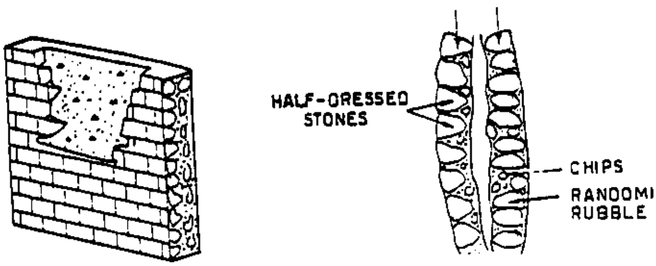


FIG. 1 _ GROUTING OF CRACKS

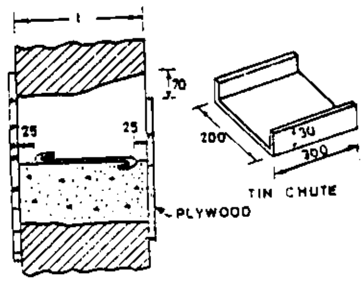


(a) MAKING HOLE, FIXING SHUTTERS



(a) WYTHE FALLEN (b) WALL BULGED

FIG. 3 _ DELAMINATED WALLS



(b) CONCRETE FILLING

FIG.2 _ PROVIDING BONDING ELEMENT

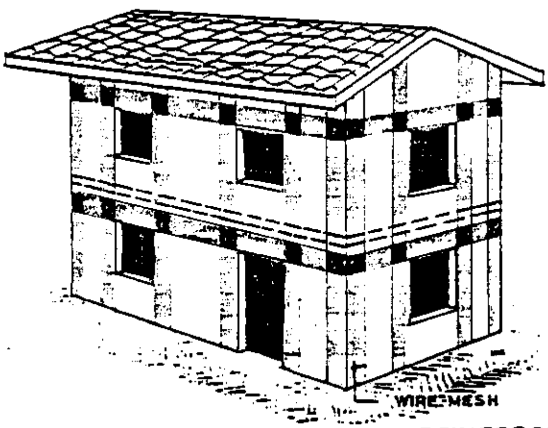


FIG. 4 _ SPLINT AND BANDAGE REINFORCING

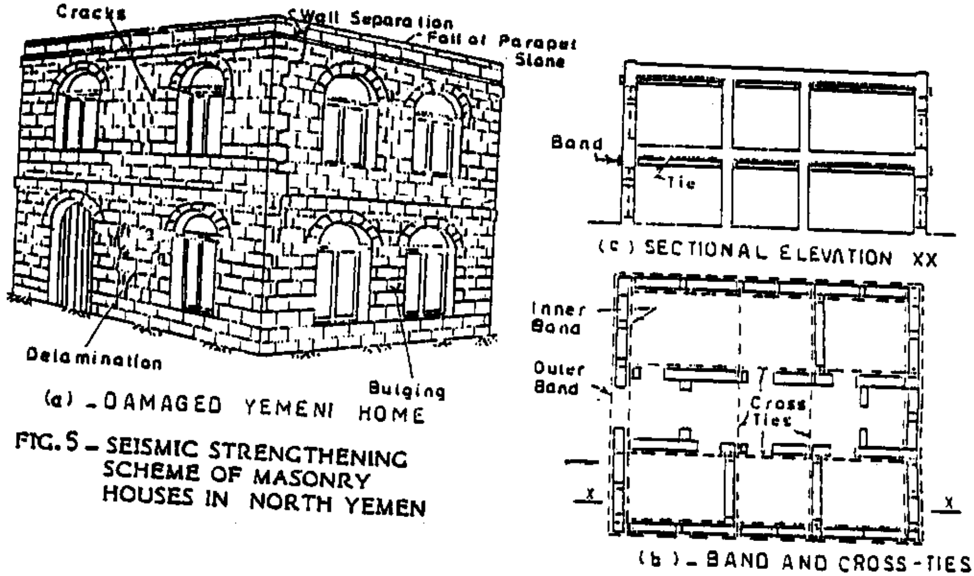


FIG. 5 - SEISMIC STRENGTHENING SCHEME OF MASONRY HOUSES IN NORTH YEMEN

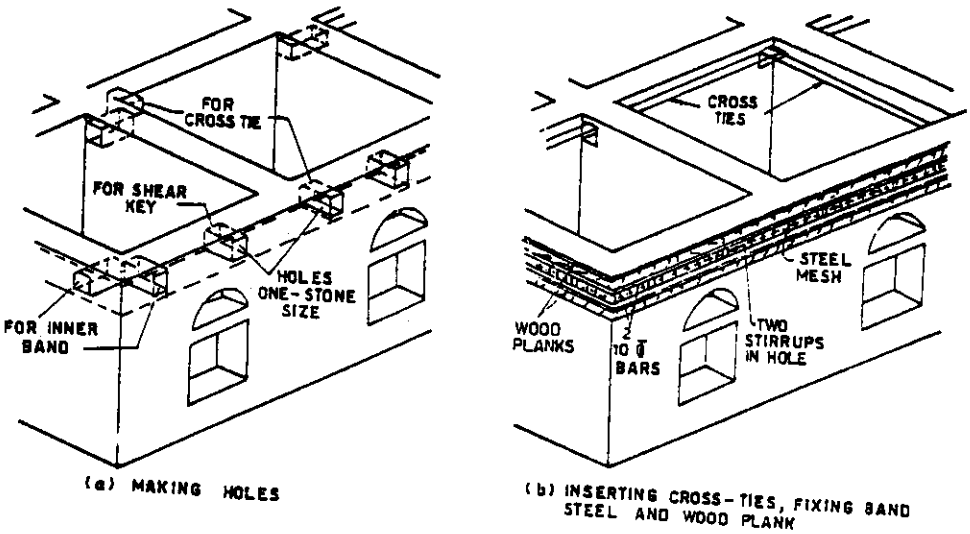


FIG. 6 - INSTALLING BANDS AND CROSS-TIES

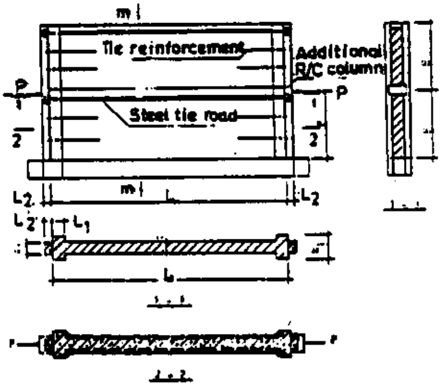


FIG. 7 _ STRENGTHENING BY ADDITIONAL R.C. COLUMN AND TIE ROD

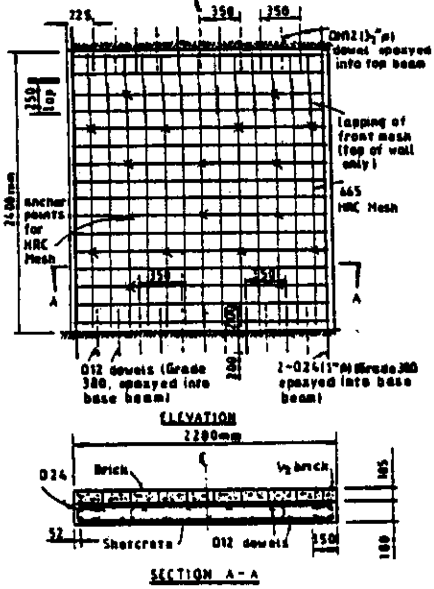


FIG. 8 _ STRENGTHENING BY SPRAYED CONCRETE

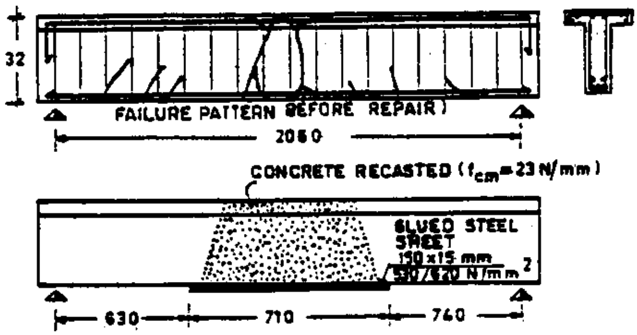


FIG. 9 _ REPAIR OF BEAMS

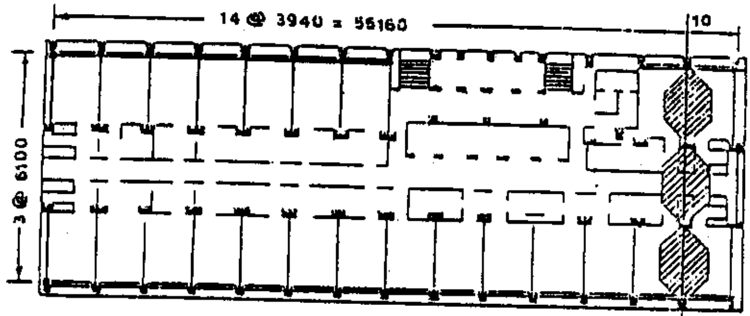


FIG.10 _ FLOOR PLAN OF TOWER BLOCK

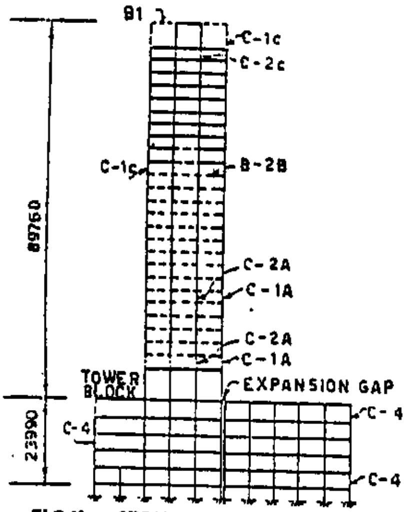


FIG.11 _ STRUCTURALLY DEFICIENT MEMBERS IN DOTTED ALONG GRID 10

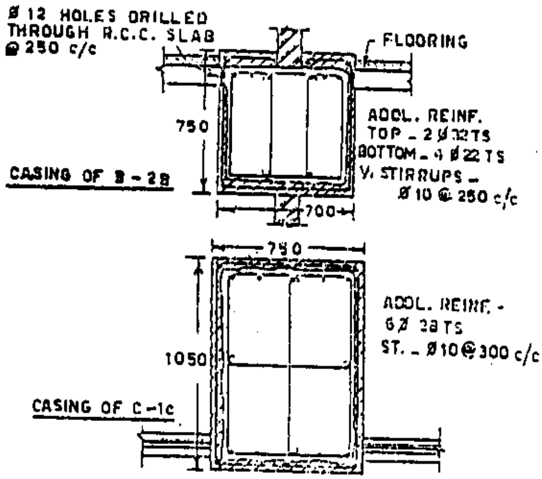


FIG.12 _ CASING OF BEAM/COLUMN CASE I

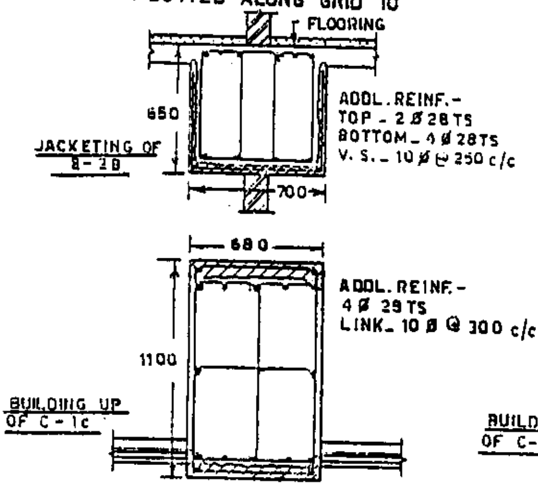


FIG.13 _ JACKETING OF BEAM AND BUILDING UP OF COLUMN _ CASE II

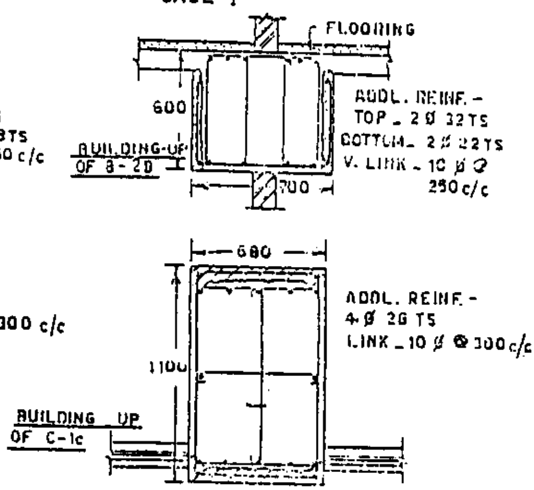
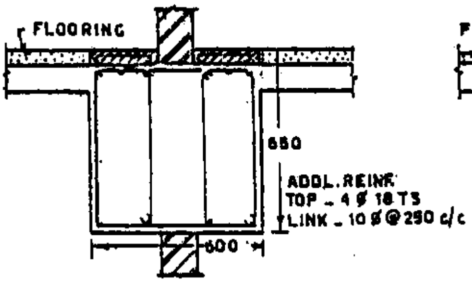
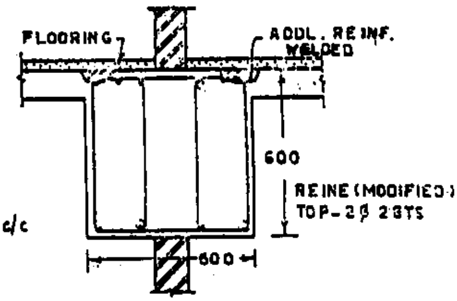


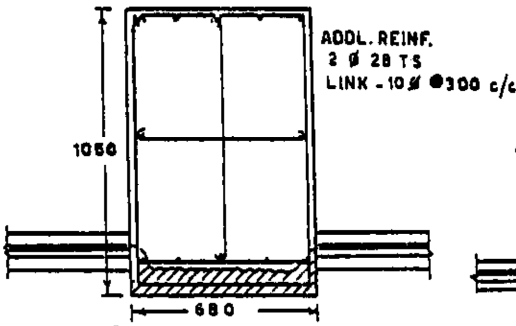
FIG.14 _ BUILDING UP BEAMS/COLUMNS FROM TWO SIDES - CASE III



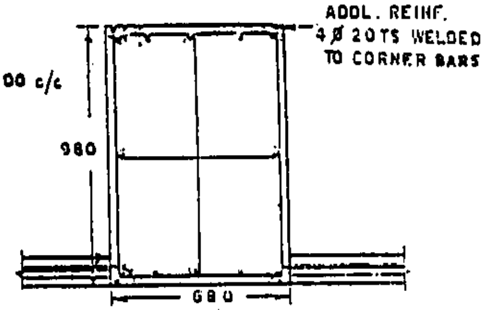
BUILDING UP OF B-2B



BEAM B-2B



BUILDING UP OF C-1c



COLUMN C - 1c

FIG.15_ BUILDING UP OF BEAM / COLUMN FROM ONE SIDE-CASE IV

FIG.16 _STRENGTHENING END PORTION OF BEAM / COLUMNS - CASE V

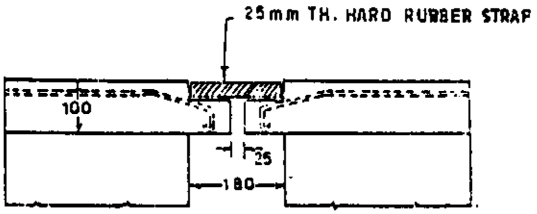


FIG.17 .EXISTING EXPANSION JOINT

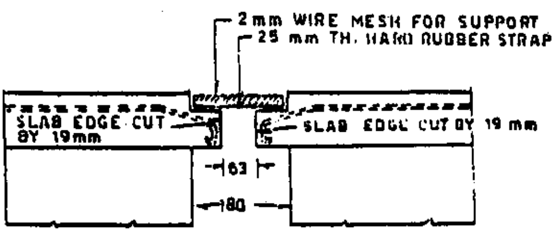


FIG. 18 _MODIFICATION OF EXPANSION JOINT