REPAIR AND STRENGTHENING OF REINFORCED CONCRETE STRUCTURES

By

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ABSTRACT

The science of repair and strengthening of buildings has attracted many researchers in the last [illegible] especially in the areas that experienced natural disasters such as damaging earthquakes. Thanks to God, we did not experience such disasters, hopefully it will not happen, but there is no guarantee!.On the other hand, we have experienced man-made disasters when many of our buildings in Gaza and West-Bank were subjected to intensive bombing by Israeli soldiers. Most of these buildings were severely damaged.

Repairing and/or strengthening of damaged buildings requires special training and skills. It is believed that most of these skills are not very familiar to many engineers in the local market.

In this paper, full description and classification of the various types of damages that may occur in reinforced concrete buildings due to an earthquake or explosion is presented. Methods of repairing and/or strengthening of each type of damage are investigated and discussed for each structural element.

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1. INTRODUCTION

Damage of structures may be due to over loading, corrosion, or due to poor material quality. In fact we can always say it is over loading, since poor material quality means less strength, also corrosion decreases strength and in both cases design load will be more than the actual load capacity, then it is over loading. If it is possible to control material quality and to prevent corrosion, in most cases, it may not be possible in many cases to control a randomly applied loads like earthquake or explosive loads. Hence, there is always a possibility for partial if not total damage. Therefore a study of what can be done to a damaged structure or to improve the resistance of undamaged structure is very important.

Before discussing the various methods and techniques of repairing and strengthening of damaged buildings, it may be useful to start with classification and definition of damage, damage evaluation, repair and strengthening:

1.1 Building damages:

Building damages are usually classified into two categories as follows:

a-Non structural Damages:

These are damages of elements which are not part of the supporting system, such as Infilled Brick walls, partitions, windows, ... etc. These damages are not usually dangerous since they do not affect the behaviour or resistance of the building. Their repair work usually require no more than replacement of the damaged element.

b-Structural damages:

These are damages of elements which are part of the supporting system of the building, such as, columns, beams, shear walls, slabs and other supporting elements. These damages are serious as they affect resistance and stability of the system, repairing and strengthening of these element is the subject of this study.

1.2 Damage evaluation

During an earthquake or explosion -dynamic loading- buildings suffer damages of deferent levels. Some buildings suffer light or no damage, while other buildings are severely damaged. It depends on many factors, such as loading magnitude, resistance of the building, site conditions, ...etc. Immediately after a damaging earthquake or explosion occur, an initial evaluation of the level of damage for each building is carried out by a professional team. As a result of this evaluation each building may be classified into one of the following categories:

a-Green: Building with light or no damage. They can be used immediately.

b-Yellow: Building with some damages that can be repaired.

c-Red : Unsafe building with sever damages. These must be immediately evacuated and removed.

1.3 Repair and strengthening:

1.3.1 Definitions:

Repair is the reestablishment of the initial strength of damaged structural members and the reestablishment of the function of damaged non-structural elements. Repaired structural elements may posses most of the original strength but its stiffness is usually reduced due to very fine cracks which cannot be restored. Damaged non-structural element are usually replaced.

Strengthening is the modification of the strength and/or stiffness of the structural members or the structural system to improve the structure's performance in future dynamic loading. Strengthening usually involves introducing new structural elements to increase the lateral resistance of the structure.

1.3.2 Selection of repairing and strengthening solution:

Each structure is a unique system and it's damage is usually different from other structures, and the required repairing and/or strengthening solution depends on many factors, such as, type and age of the structure, types and degrees of damages, available material, ...etc.

After the initial investigation and emergency protection(*) of the building under concern is performed, a thorough study of the damage must be completed by the designer, damaged elements, level of damages, cause of damages, ...etc. Based on this study the designer should develop an alternate schemes for the repair process which can be evaluated and the most appropriate solution can then be selected. The following are some important aspects to be considered in the selected solution:

- Functional requirements of the structure.
- Feasibility of construction
- Economical consideration.
- Aesthetics.

2. MATERIAL AND CONSTRUCTION TECHNIQUES

Repairing and/or strengthening of R/C elements is a special job that is for each situation there may be deferent solution which may require special material and certain construction techniques. For instance one of the problems with repairing reinforced concrete members is the difficulty of obtaining good contact between old and new concrete. This problem is mainly due to volume changes or shrinkage of the conventional cement based concrete. For this reason a special placement techniques and some times a special concrete may be needed.

Detailed discussion of material and construction techniques is out of scope of this study. However, for completion of the study, some material and construction techniques that are usually used in this kind of work will be briefly discussed:

2.1. Cast-in-situ concrete:

It is often used in repairing, but when ordinary cement is used the problem of shrinkage is usually critical. Additives like superplasticizer may be used to reduce shrinkage. Expansive cement can be used for shrinkage compensating.

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* For details about emergency protection see Ref.[2], page(5-20).

2.2 Shotcrete:

Shotcrete proved to be a good technique for concrete placement. It improves bond, reduces shrinkage and it even improves concrete strength. This is due to the good compaction, and law water-cement ratio used. Shotcrete can be sprayed on vertical, inclined and on overhead surfaces with minimum of forme-work.
Tests performed on cantilever slabs and beams repaired by shotcrete showed that this technique is useful and efficient [7]. However more tests on different cases are still needed.

2.3 Resins:

Resins are usually used for injections in repairing concrete cracks. Recently, Epoxy resins becomes very popular as it proved to be a very good repairing cement. Numerous tests on deferent kind of repair proved its efficiency [3,5].

In general before doing a repair job, engineer should be aware of all kinds of these material and techniques and their efficiency. Also there are some other precautions like having the old concrete surface roughened and cleaned to improve bond.

3. REPAIR AND STRENGTHENING OF ORIGINAL STRUCTURAL ELEMENTS

Repair and strengthening process depends mainly on the type of structural elements, it's position, function and required strength, stiffness and ductility. Some of repairing and strengthening techniques used for different structural elements will be discussed in the following sections:

3.1 Repair and strengthening of R/C columns:

Depending on the degree of damage and level of strength required, reinforced concrete columns may be repaired by injection, removal-and-replacement or jacketing as follows:

3.1.1 Injection

If damage is limited to slight cracks without damage of concrete reinforcement, injection can be used. Epoxy resin may be used for crack width (0.1-5mm). For larger cracks (2-5mm) grout injection may be used. Injection is carried out by drilling holes spaced (20-100cm), and injecting epoxy resin or cement grout from column bottom and proceeding upwards as shown in Fig.(1)

3.1.2 Removal and replacement:

If concrete is partially damaged without any damage of reinforcement, new concrete can be placed after removal of all loose concrete Fig.(2). When longitudinal and transverse reinforcement are damaged it is necessary to remove all the damaged part and have the new reinforcement welded to old one and tied together with closed ties as shown in Fig.(3).

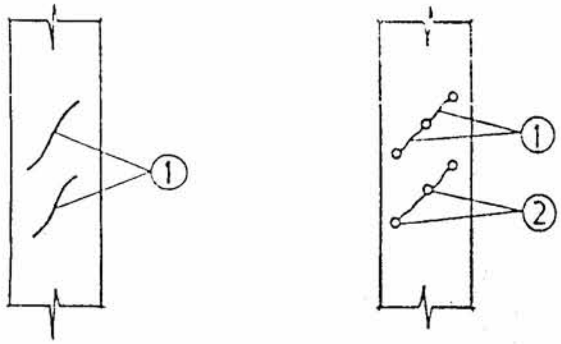
3.1.3 Column jacketing

Jacketing of R/C columns is used for repair and strengthening of damaged and undamaged columns if improvement of strength stiffness and ductility is desired. Jacketing is performed by adding reinforced concrete, steel profile skeleton or steel encasement.

a- Jacketing by adding Reinforced concrete:

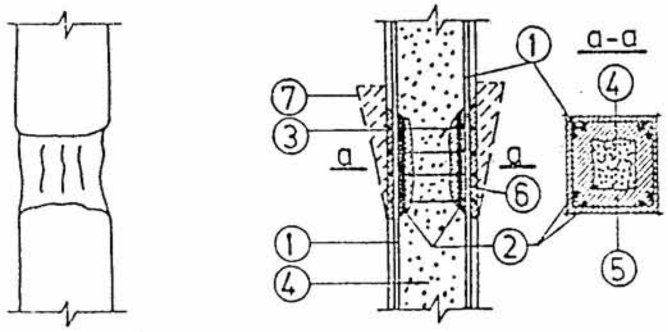
Depending on the available space, jacketing can be done for one, two, three, or four sides. However four sides jacketing is strongly recommended whenever possible. The use of adequate stirrups in four sides jacketing provides confinement which improves strength and ductility of the columns. Figs.(4,5,6,7) illustrates method of jacketing [2,7].

Jacketing of columns as mentioned above may improve local axial and shear strength. To improve flexural strength it is necessary to strengthen column-to-beam joint, which is important for moment resisting frames. This can be achieved by having the new longitudinal steel passing through holes drilled in the slab with new concrete placed in the beam-column joint region. Fig.(8) show a scheme proposed by prof. U. Ersoy [4], in which four main steel bars passes the slab through drilled holes. However, it should be pointed out that as far as lateral resistance is concern, there are more efficient ways of strengthening, such as the addition of shear walls to the building which will be discusses later.



1 - cracks; 2 - injection ports

Fig.1



1 - existing reinforcement

2 - added new reinforcement

3 - added new ties

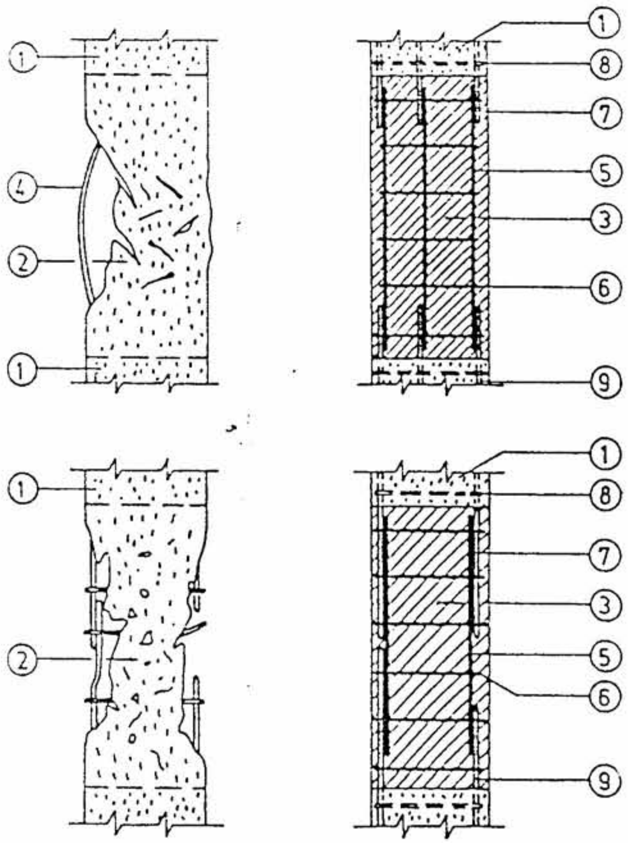
4 - existing concrete

5 - new concrete

6 - welding

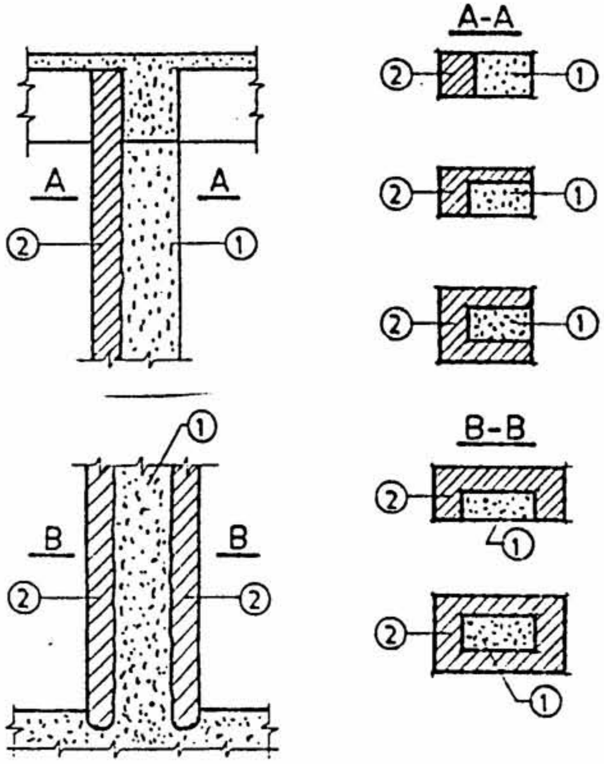
7 - temporary castform

Fig.2



1 - existing non-damaged concrete; 2 - existing damaged concrete; 3 - new concrete; 4 - buckled reinforcement; 5 - new reinforcement; 6 - new ties; 7 - welding; 8 - existing ties; 9 - existing reinforcement

Fig. 3



1 - existing column; 2 - jacketing concrete

Fig.4

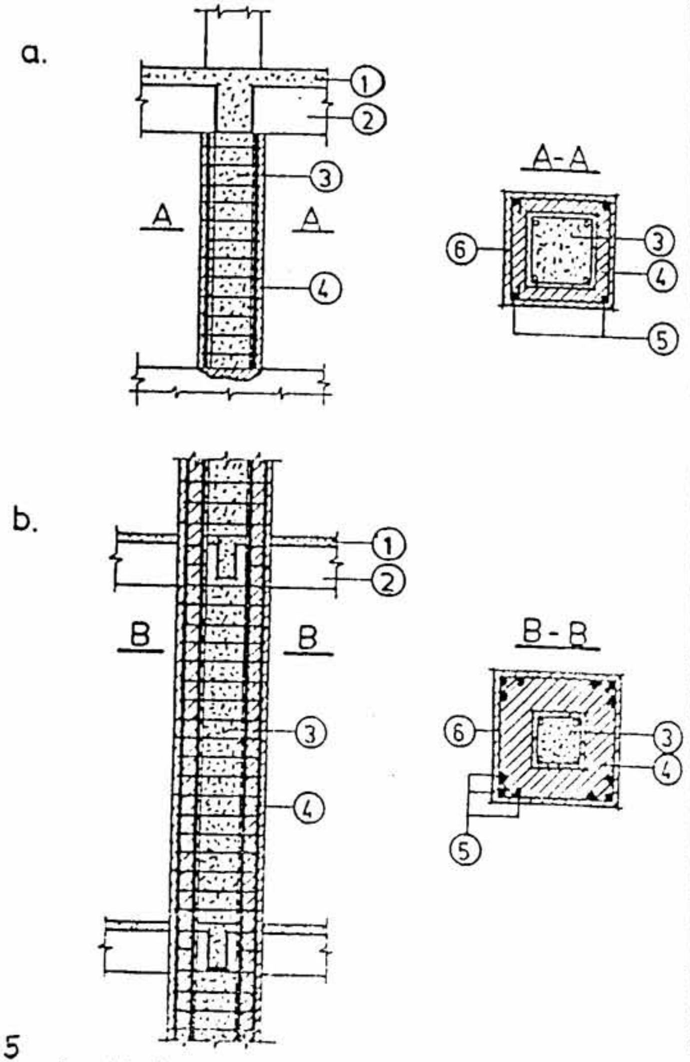
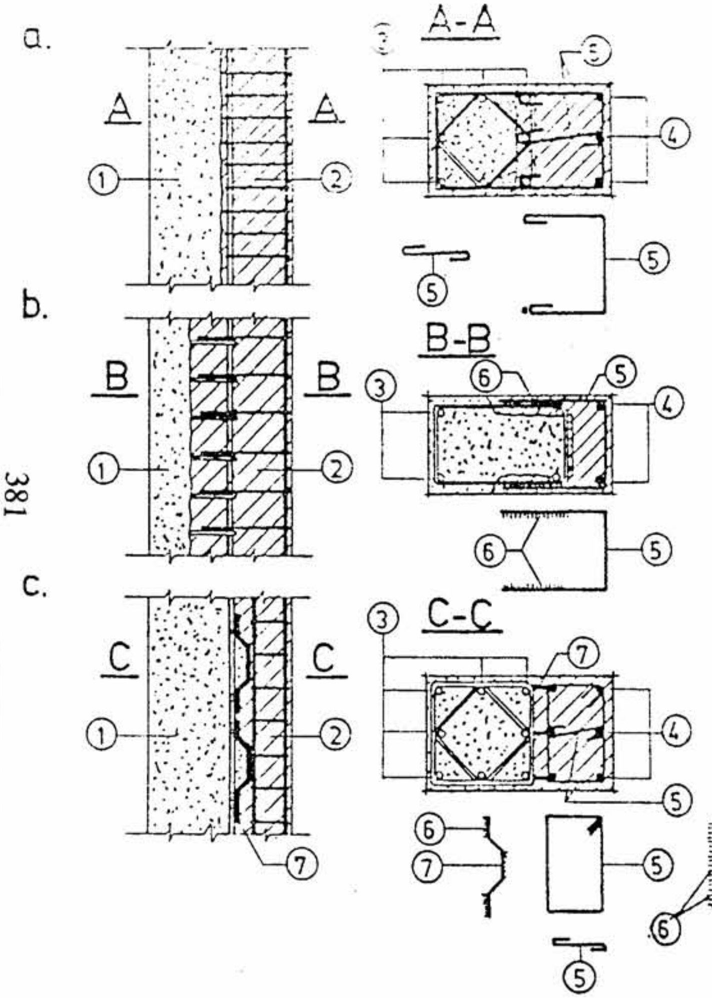


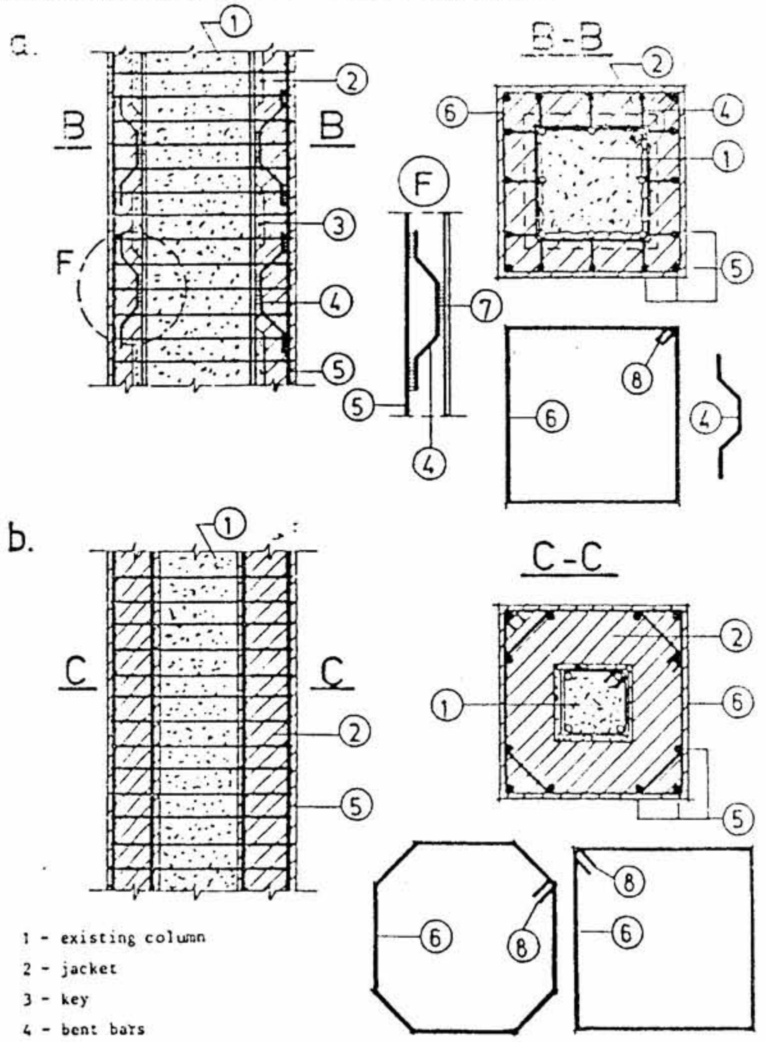
Fig.5

1 - slab; 2 - beam; 3 [illegible]
5 - added longitudinal [illegible]



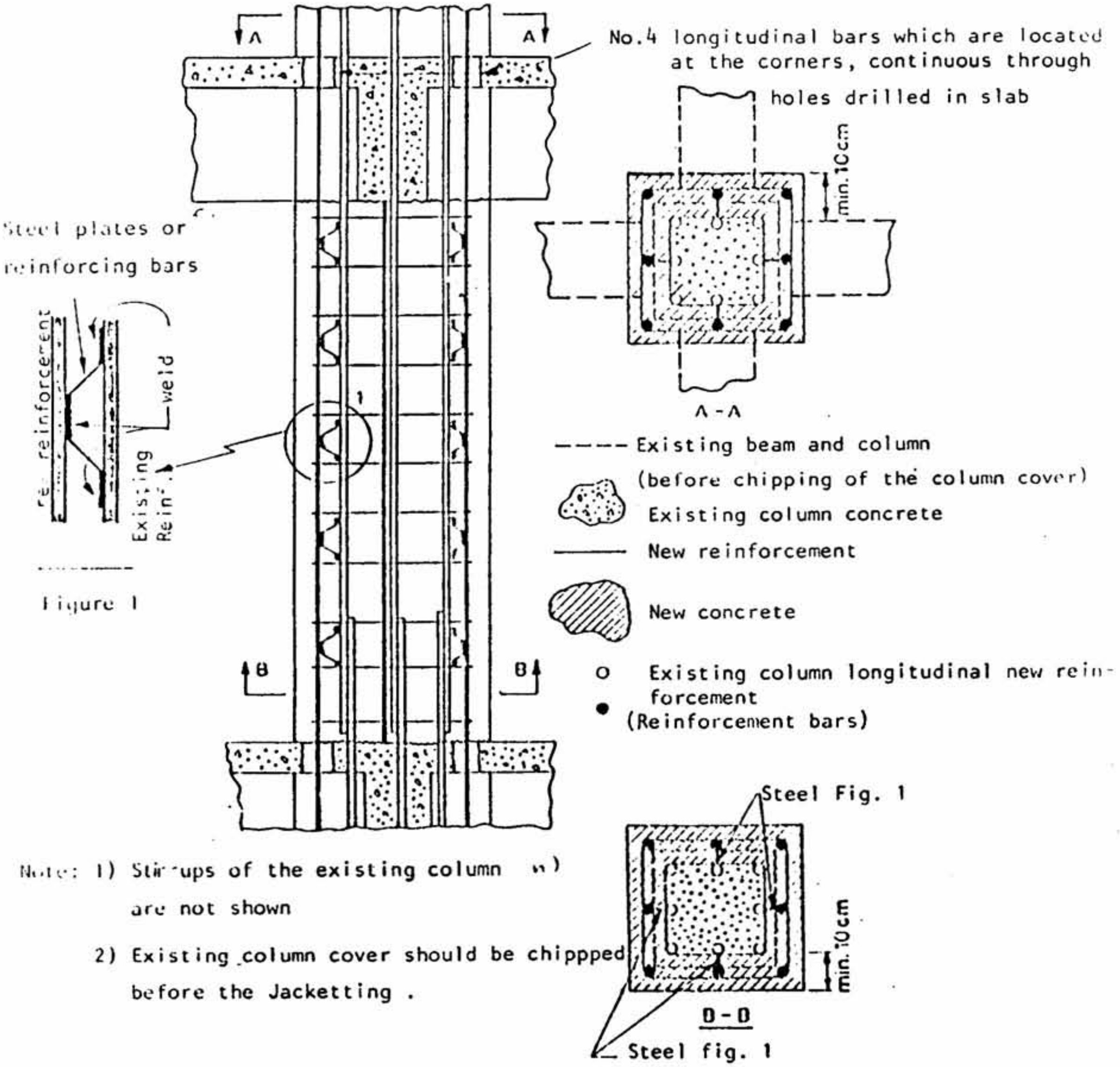
1 - existing column; 2 - jacket; 3 - existing reinforcement;
4 - added longitudinal reinforcement; 5 - added ties;
6 - welding; 7 - bent bars

Fig.6



1 - existing column
2 - jacket
3 - key
4 - bent bars
5 - added reinforcement
6 - ties
7 - welding
8 - alternative corners

Fig.7



Note: 1) Stirrups of the existing column are not shown

2) Existing column cover should be chippped before the Jacketting .

Fig. 8

b- **Jacketing by steel profile:**

In this method four steel angles are placed one at each corner of the column and connected together in a skeleton with transverse steel straps as shown in Fig.(9). This type of strengthening can be used to improve axial capacity and ductility. It can also be used as temporary support. If it is to be used to transmit moment, a special care should be given to the connecting floor girders .

c- **Steel encasement:**

In this method the existing column is completely covered with steel plate, with the left space being filled with non-shrinkage grout. It can be used for circular, square or rectangular column as shown in Fig.(10). However circular encasement is most effective as it provides good confinement hoop stresses.

3.2 Repairing of Beams:

3.2.1 Local repairs:

- If the beam is slightly damaged -hair cracks- epoxy or cement grout injections can be used.
- If concrete is damaged or crushed removal and replacement can be used as in columns.

3.2.2 Reinforced concrete jacketing:

Jacketing of beams can be performed on one, three or four sides of the beam. It is very important that the old concrete cover must be chipped away and the added steel should be welded to the old one so that to improve bond between the new and old concrete. The type of jacketing and the necessary longitudinal and transverse steel, depend on the type of strengthening required.

If only flexural strength at mid span of the beam is to be improved one side jacketing can be used as shown in Fig.(11). Four side jacketing can be used to improve shear and flexural strength. In this type of jacketing it is important that the stirrups should pass through the slab and the new longitudinal steel be welded to the old steel and it should be continuous as shown in Fig.(12).

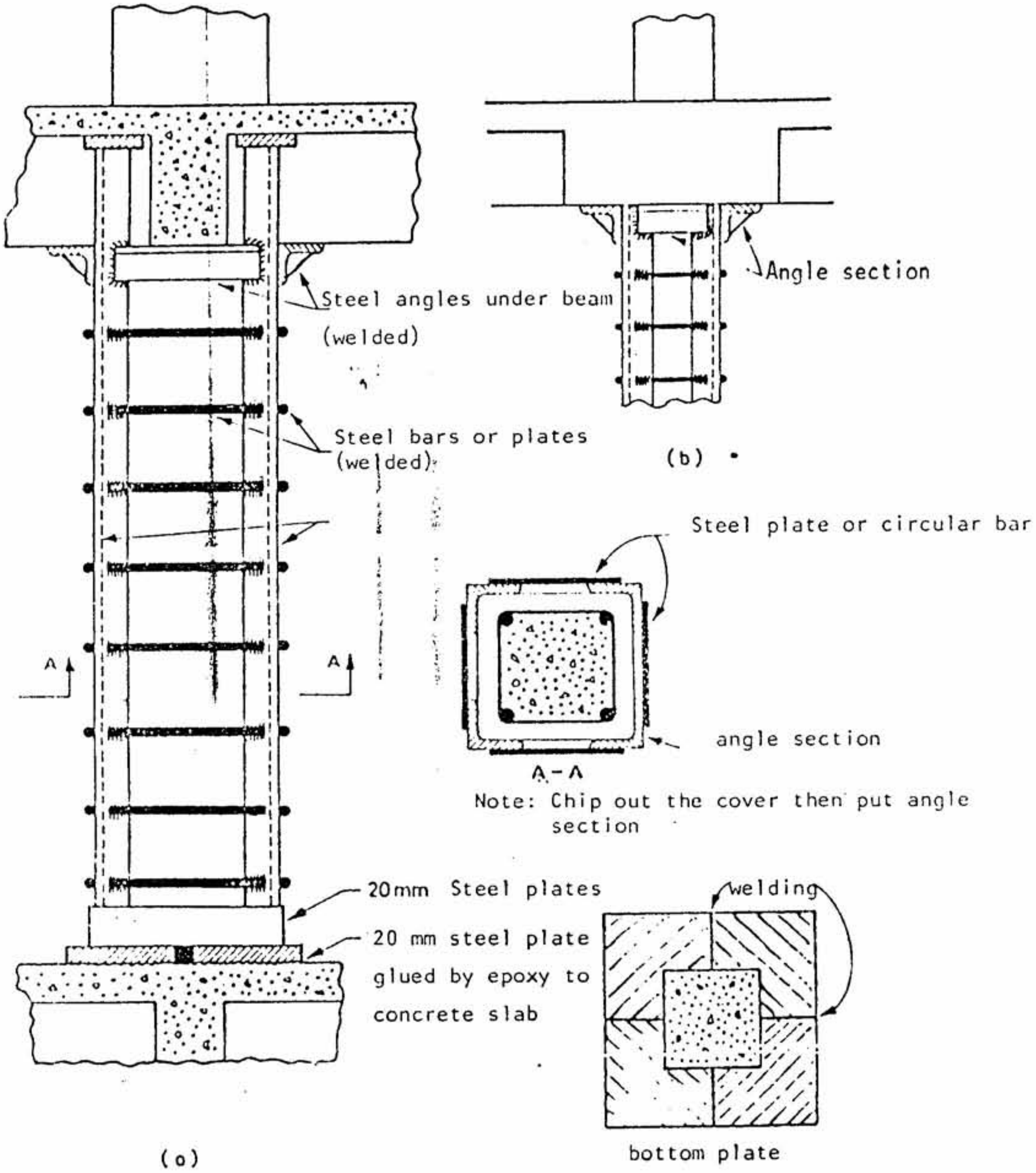
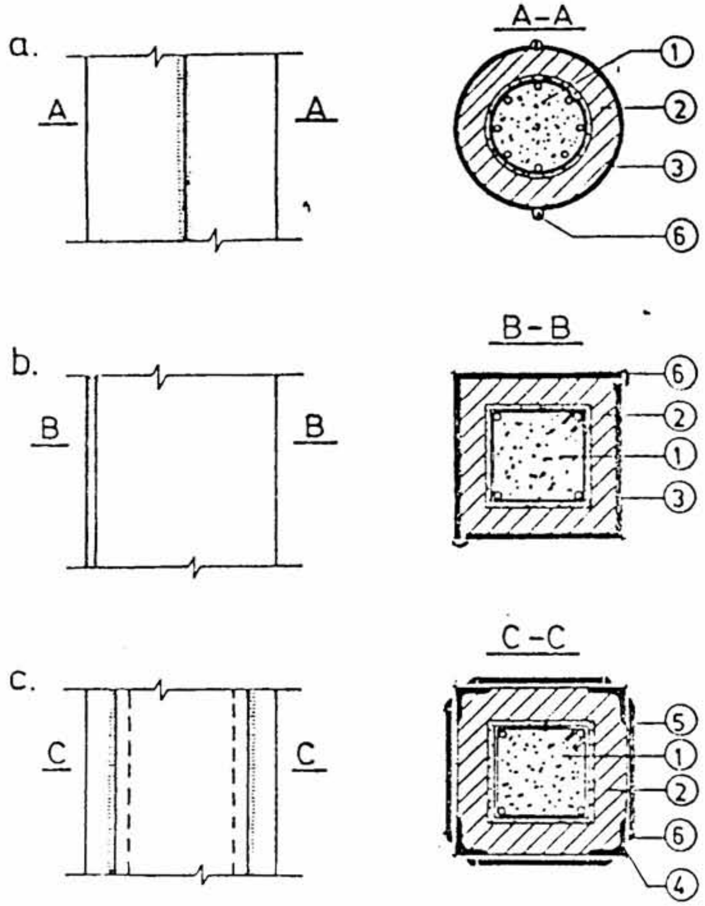
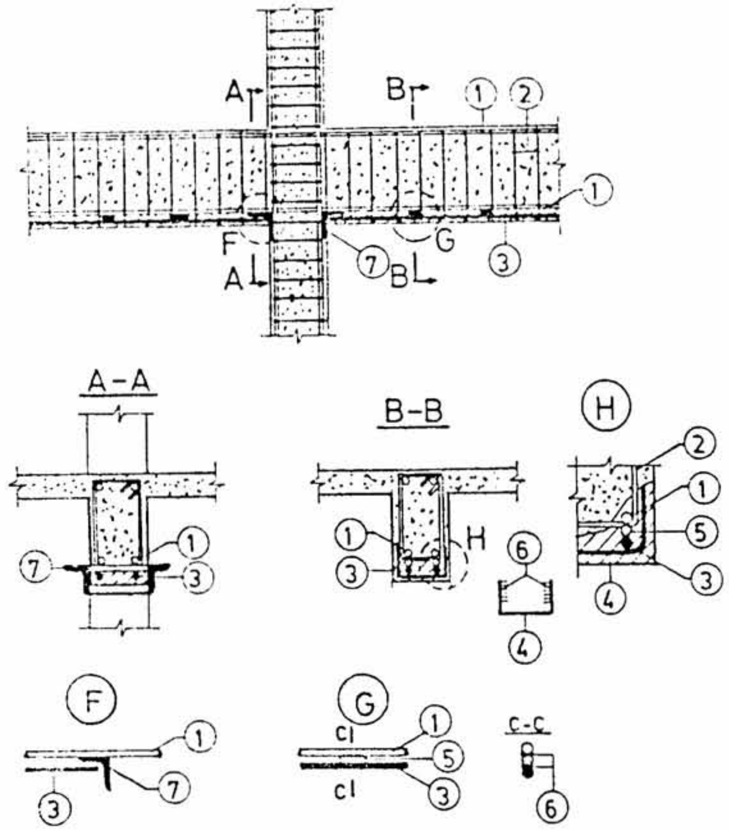

Steel angles under beam
(welded)
Steel bars or plates
(welded)
A
A
20mm Steel plates
20 mm steel plate
glued by epoxy to
concrete slab
(a)
Angle section
(b)
Steel plate or circular bar
angle section
A-A
Note: Chip out the cover then put angle section
welding
bottom plate

Fig. 9



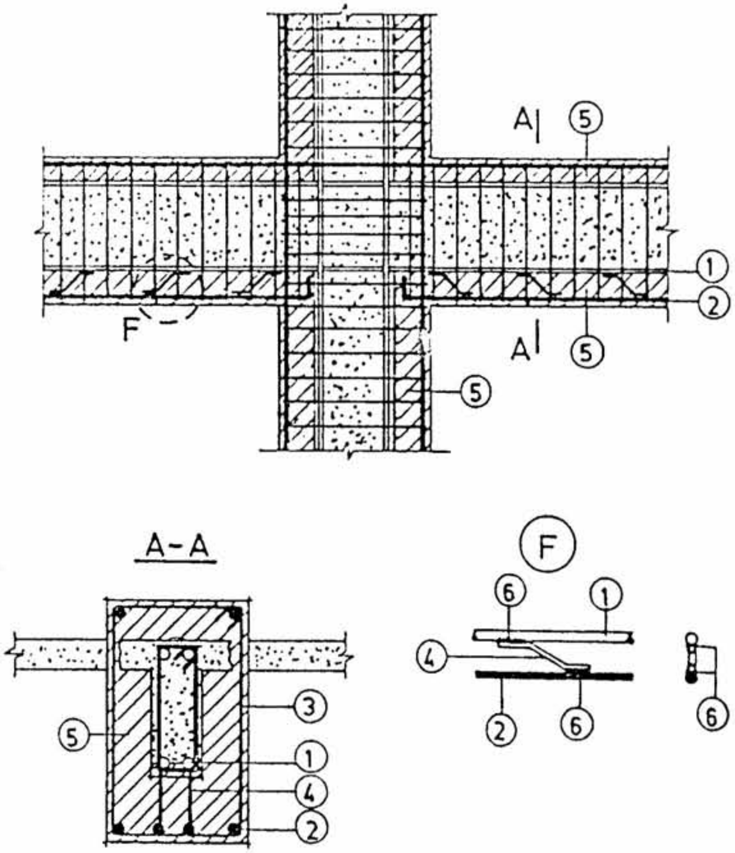
1 - existing column; 2 - new concrete or grout; 3 - steel incasement;
4 - steel angle profiles; 5 - steel plate; 6 - welding

Fig. 10



1 - existing reinforcement; 2 - existing stirrups; 3 - added longitudinal 4 - added stirrups; 5 - welded connecting bar; 6 - welding; 7 - collar of angle profiles

Fig.11



1 - existing reinforcement; 2 - added longitudinal reinforcemunt; 3 - added stirrups; 4 - welded connecting bar; 5 - concrete jacket; 6 - welding

Fig.12

3.2.3 Strengthening of shear capacity of beams:

Jacketing of beams may provide some shear strength in addition to flexural. But, if shear is critical a better shear strengthening solution can be used. For this purpose, one proposed scheme is shown in Fig.(13)[4]. In this scheme vertical external clamps are used. However, internal clamps can also be used by drilling into concrete and fixing by epoxy. Also in this scheme it is suggested that by making hunched with jacketing, shear strength will be improved as well as flexural strength.

3.3. Beam-Column joints:

May be it is the most critical region in a moment resisting frame, specially if the frame is required to resist lateral loads. All the strengthening work on columns and beams will not be effective until adequate connection at the joint is obtained. This joint should be able to transfer shear and moment between column and beam, and of most important ductility on the beam side should be considered.

3.3.1 Local repair:

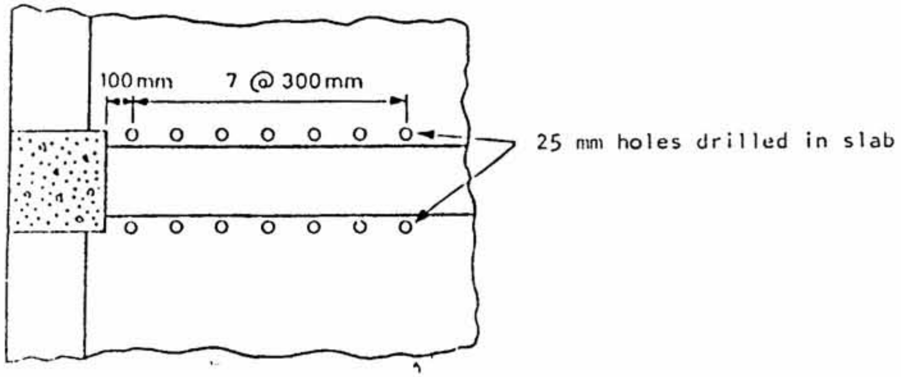
As in the cases of columns and beams for slight hair cracks, injection of epoxy can be used.

3.3.2. Jacketing:

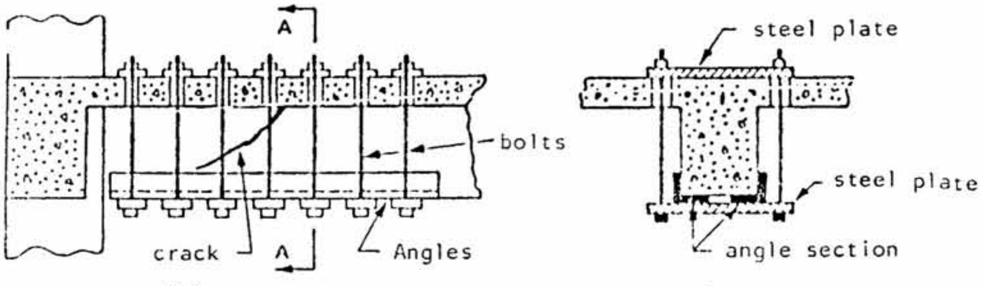
Jacketing of joint involves covering of all member connected at the joint. It is usually appropriate when columns and beams meeting at the joint are also jacketed. For heavily damaged structures jacketing of beams and columns together at the joint is desirable. Additional ties should be placed near the joint for proving adequate shear strength, Fig.(14,15). If necessary, jacketing can be located in the joint area only as shown in Fig.(16).

3.3.3. Steel plate jacketing:

In this method, steel plates shaped according to the joint configuration are glued by epoxy resin to the concrete and fixed with prestressed bolts, Fig.(17). This technique is used in some cases specially for frames in industrial buildings. It permits strengthening of joints without considerable change in size. However, it should be pointed out that this technique may not be suitable when sizable beams frame into all four sides of the joint.



(a) Plon



(b) Side View

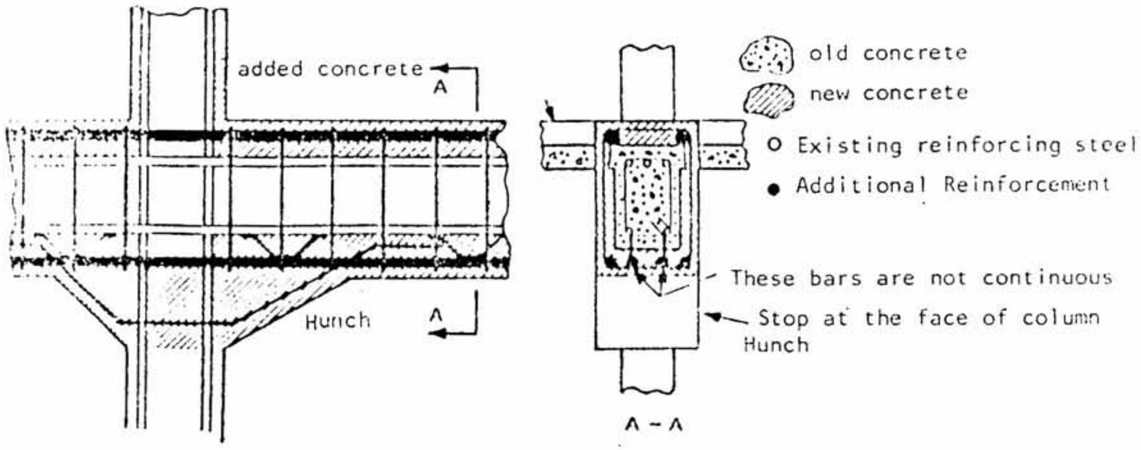
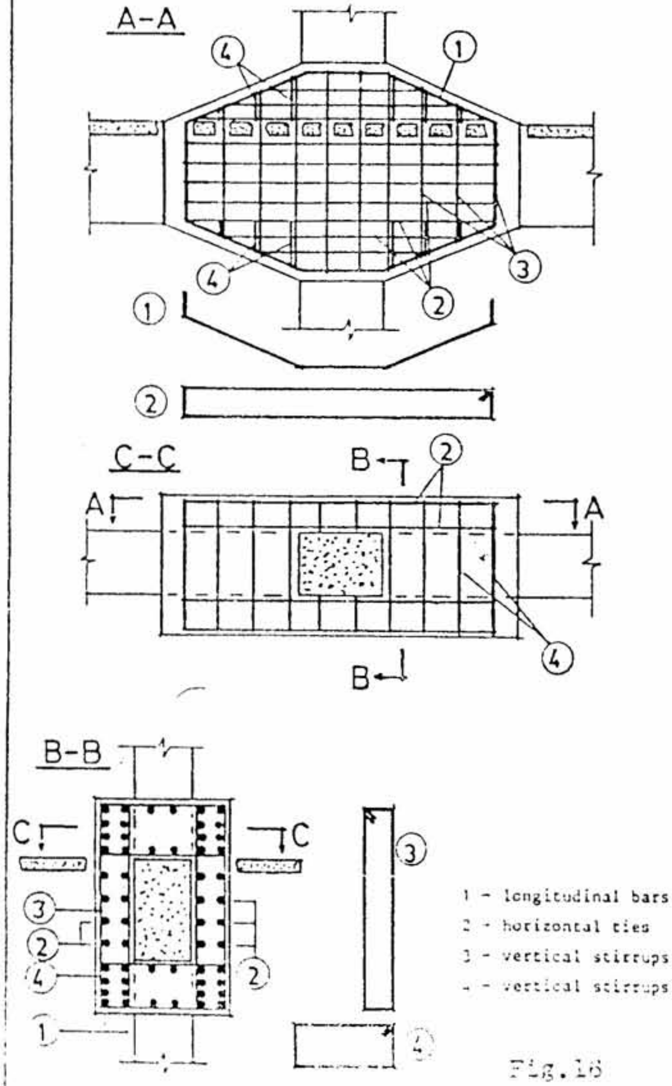
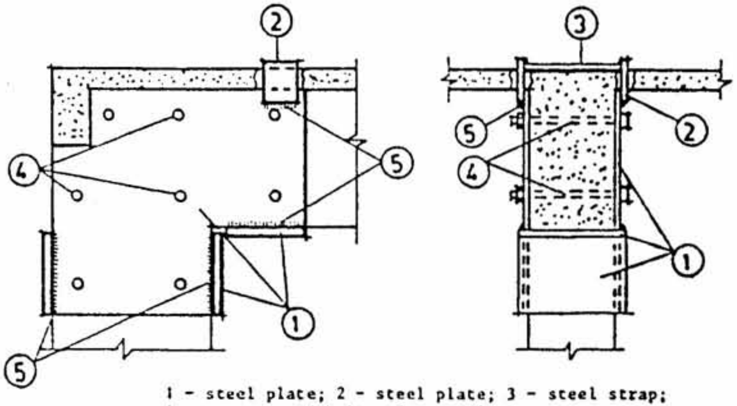


Fig. 13



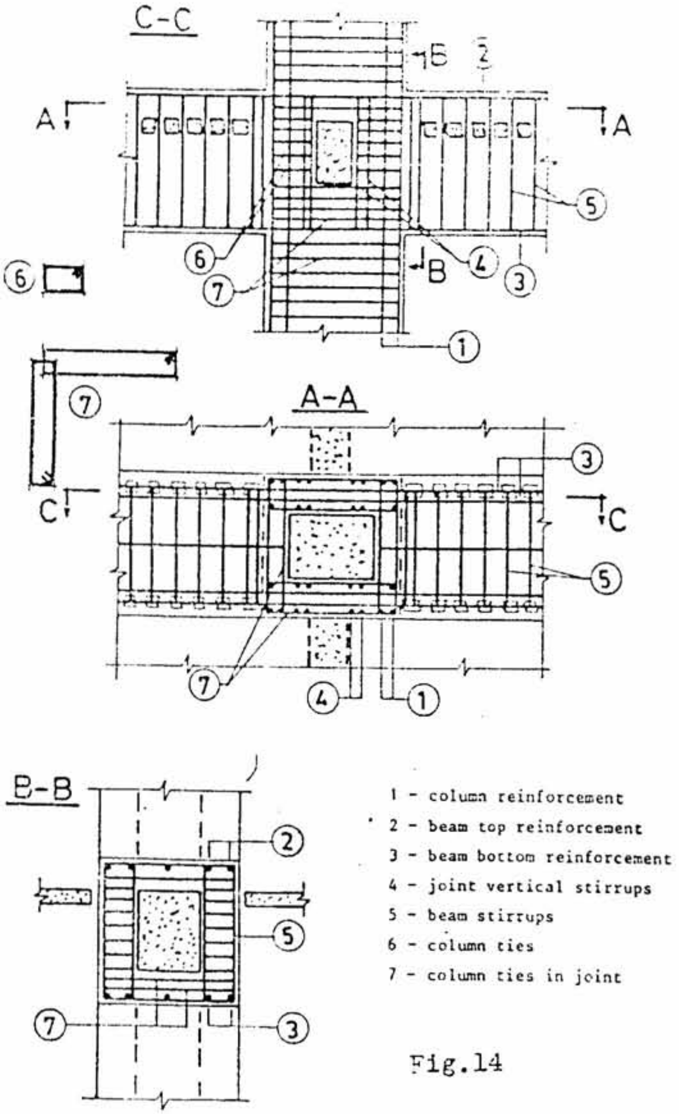
1 - longitudinal bars
2 - horizontal ties
3 - vertical stirrups
4 - vertical stirrups

Fig.16



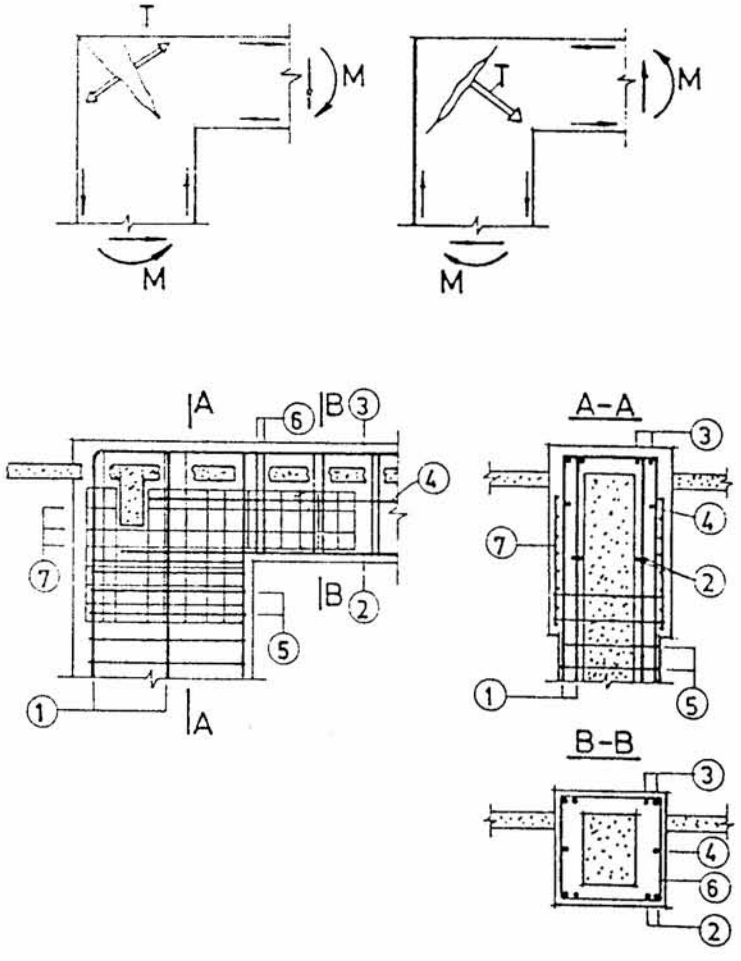
1 - steel plate; 2 - steel plate; 3 - steel strap;
4 - prestressed bolts; 5 - welding

Fig.17



1 - column reinforcement
2 - beam top reinforcement
3 - beam bottom reinforcement
4 - joint vertical stirrups
5 - beam stirrups
6 - column ties
7 - column ties in joint

Fig.14



1 - column reinforcement; 2 - beam bottom reinforcement; 3 - beam top reinforcement; 4 - beam reinforcement; 5 - column ties; 6 - beam stirrups; 7 - welded wire fabric; T - tensile resultant

Fig.15

3.4. Repair and strengthening of shear walls:

Because of their great stiffness and lateral strength, shear walls are very significant elements specially for earthquake resistance. Therefore, repairing and strengthening of shear walls attracts great attention of engineers and researchers.

3.4.1 Injection of Epoxy resin:

Several tests for repairing cracks in shear walls by injection of Epoxy resin, were performed. Most of the test results agree on the efficiency the of this method in recovering strength and ductilities. For example, in one of the test programs Higash and Endo [5], reported that shear walls which had entirely collapse with large deflection, were repaired by Epoxy risen and then tested again. As a result, strength and ductility were significantly improved. However, original stiffness usually cannot be completely recovered, as most tests agree, due to the fine cracks that Epoxy cannot reach. Figs.(18, 19).

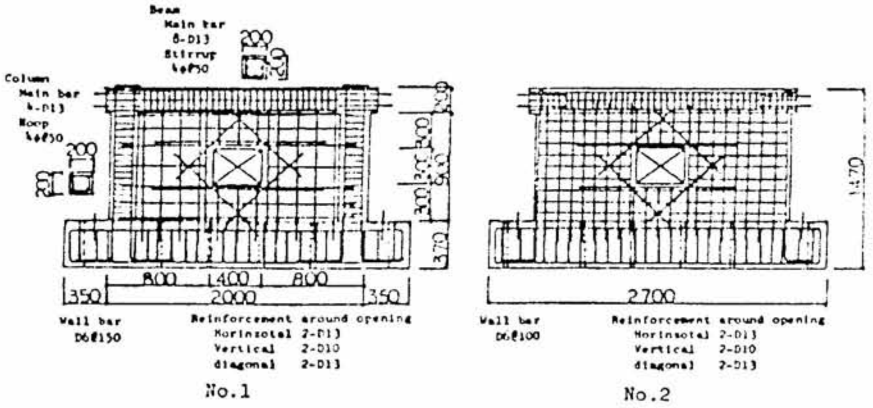
3.4.2 Removal and replacement:

If the web concrete is crushed, removal and replacement technique can be used. In a test program sponsored by PCA, 1982, Fiorato, Oesterle and corley[3], reported that this technique is useful when the boundary elements of the wall are intact. Tests showed that most of the strength and ductility of the wall can be recovered while only 50% of the original stiffness can be recovered.

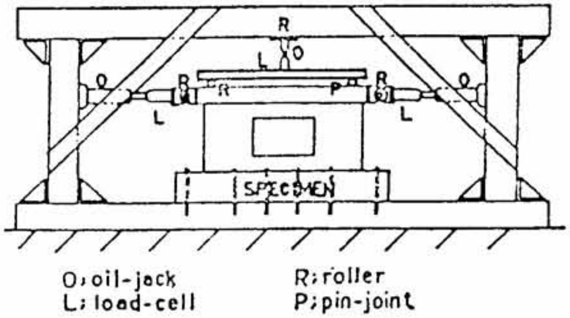
3.4.3 Increase of wall size:

In case of heavily damaged shear walls or if the strength and stiffness of undamaged walls are to be improved, increasing of wall size can be used. Increasing of the wall size can be performed by thickening of web at one side or two sides, if shear strength is to be improved. Also, increasing the size of boundary element is possible if flexural and stiffness to be improved. Figs.(20,21) show different ways for wall thickening. Wall thickening of damaged shear walls was also tested. It is found that wall thickening can improve strength of the wall as well as inelastic response. The following are some important recommendations obtained from tests results for wall thickening:

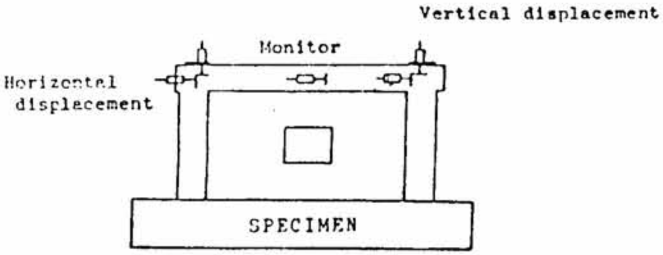
- Strength of the new material should not be less than that of the existing wall.
- The web thickness of the new material should not be less than 5cm.
- Adequate amount of steel reinforcement should be used.



1. Dimensions and Reinforcement of Specimens

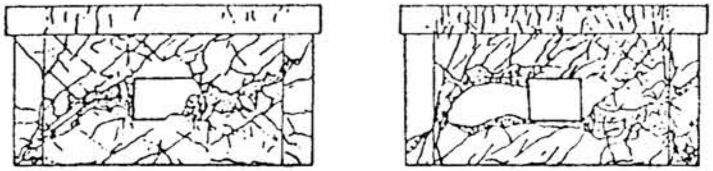


2. Loading Apparatus

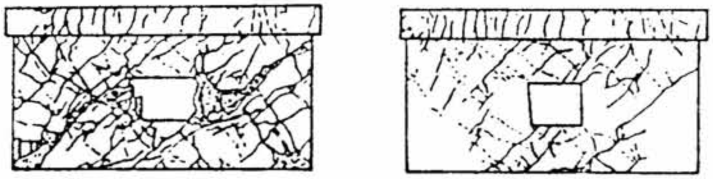


3. Posion for Measuring Displacement

Fig. 18

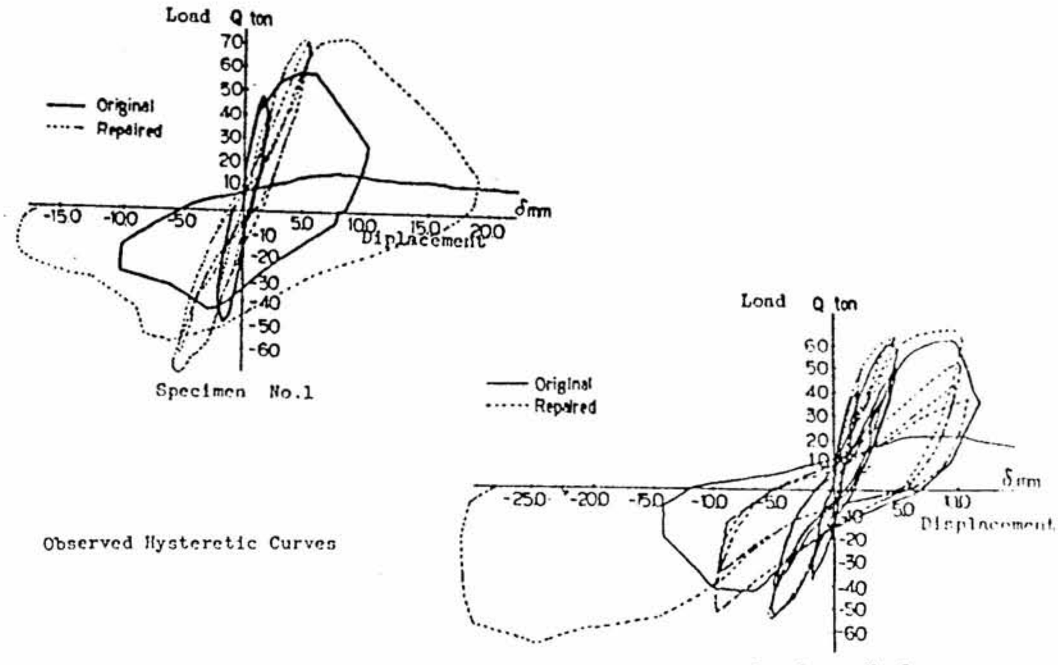


No.1 Origenal Test   No.1 After-Repair Test



No.2 Origenal Test   No.2 After-Repair Test

Final Cracking Patterns

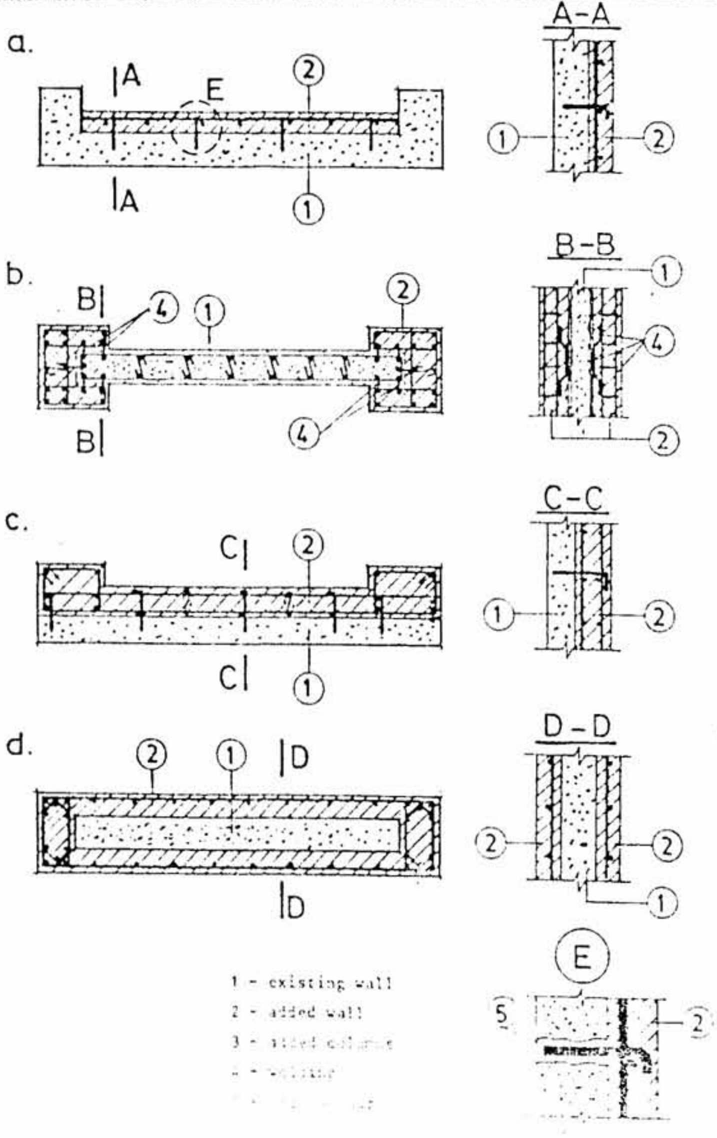


Specimen No.1

Specimen No.2

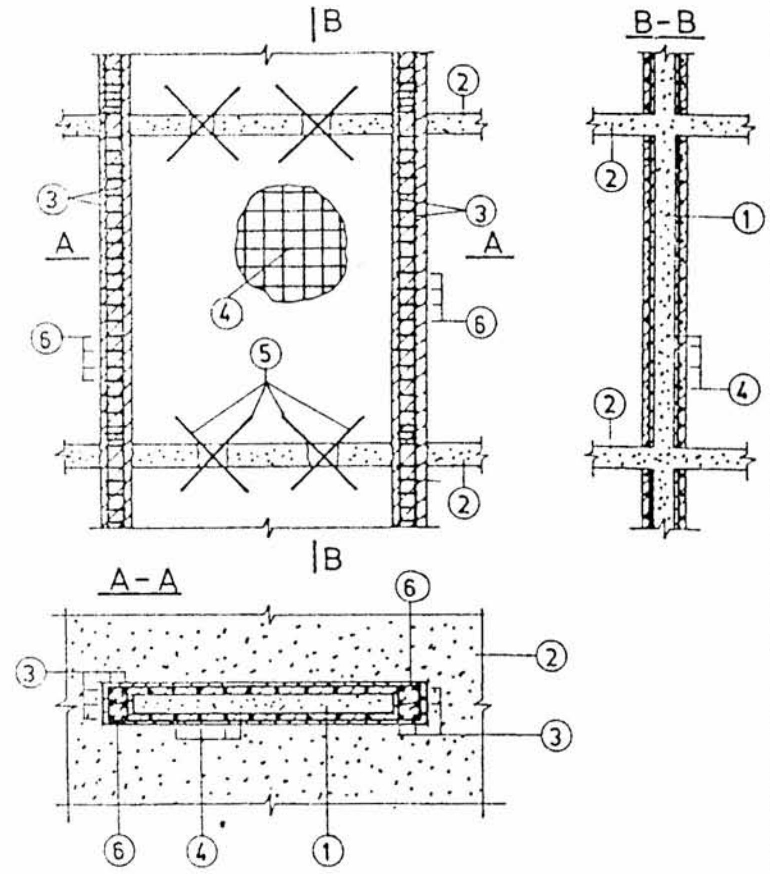
Observed Hysteretic Curves

Fig. 19



1 - existing wall
2 - added wall
3 - added columns
4 - welding
[illegible]

[illegible]



1 - existing wall; 2 - existing slab; 3 - added longitudinal reinforcement; 4 - added wire fabric; 5 - diagonal connecting bars; 6 - added ties

Fig.21

4. INTRODUCTION OF NEW STRUCTURAL ELEMENTS

In some cases, it is desired to improve the building resistance either to lateral or to vertical loads. However, resistance to lateral loads is usually more critical. This can be achieved by adding a new elements to the structural system. These added elements, usually shear walls, may share lateral forces with the original structure or it may be put to take care of all lateral forces.

Incorporation of new elements to the structural system may change the whole behaviour of the building during an earthquake, therefore, a complete analysis of the new proposed system should be analyzed and its reliability should be checked.

In introducing a new structural element the following considerations are extremely important:

- The stiffness of the structure should be uniformly distributed in plan and elevation.
- The stiffness of the new elements should be compatible with that of the old ones.
- Added shear wall should not conflict with the architectural requirement.

4.1 Strengthening by adding shear walls:

As far as earthquake resistance is concern, the resistance of many of the existing building is inadequate. Therefore strengthening by adding shear walls can be cast-in-situ (Infilled Wall), precast panels, or it can be brick or reinforced brick walls, the most popular among those is infilled wall.

4.2 Infilled Walls

Infilled walls is a shear wall consists of infilled panel acting together with beams and columns, confining boundary element. The problem with this technique is to have adequate connection between the infilled panel and the boundary elements. Also the strength of those boundary beams and column should be enough to carry the flexural and shear forces transmitted. For more details about infilled walls see ref[4].

Figs (22,23) shows some examples of added shear walls. The distributions of shear walls shown in Figs.(22-a,b) are acceptable. The ones shown in Fig.(22-c,d) are poor distributions since in Fig.(22-c) the shear walls placed at the corners are oriented along the longitudinal direction which limit the temperature and shrinkage deformations. While in that of Fig,(22-d) the large eccentricity of seismic forces create large torsional moment Figs.(23-a,b) shows how newly added wall can improve the distribution.

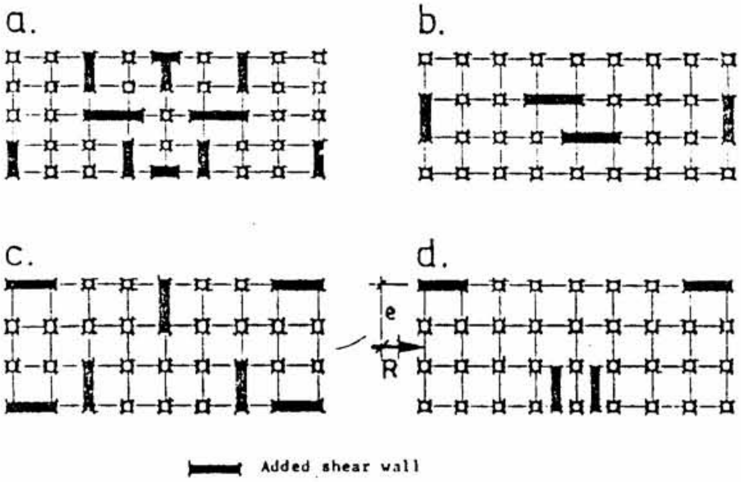

a.
b.
c.
d.
e
R
Added shear wall

Fig.22

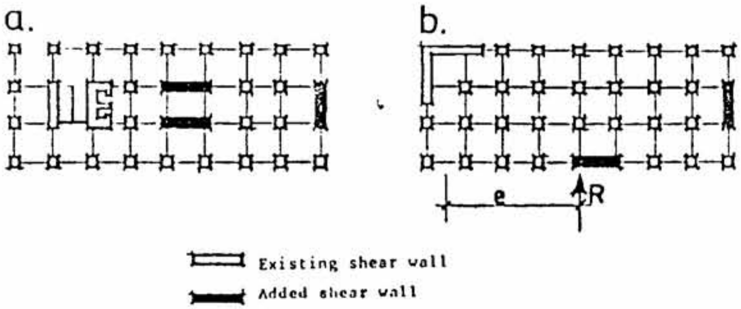

a.
b.
e
R
Existing shear wall
Added shear wall

Fig.23

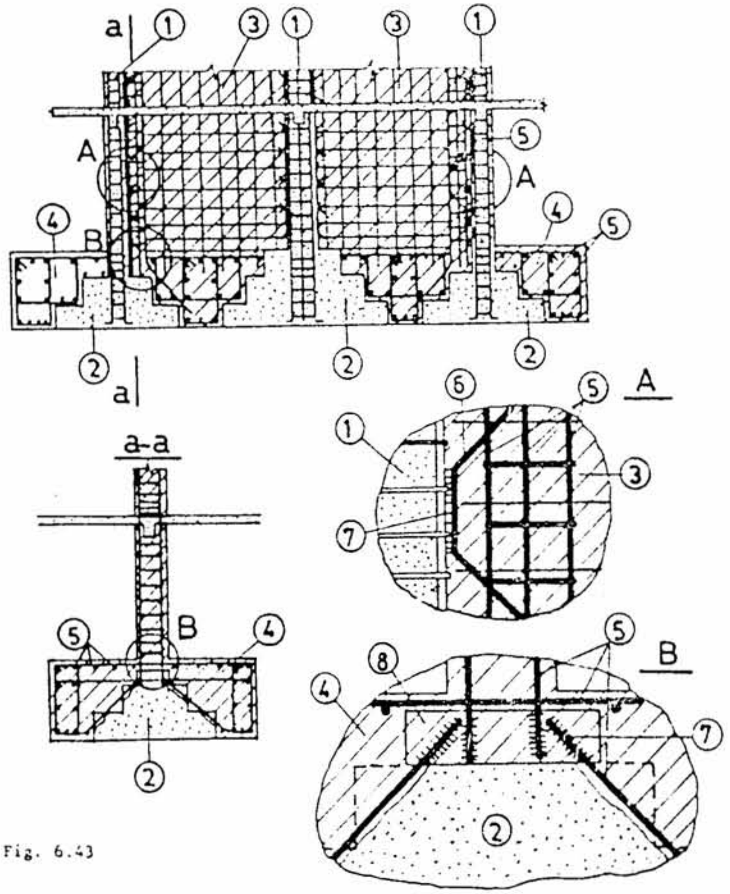
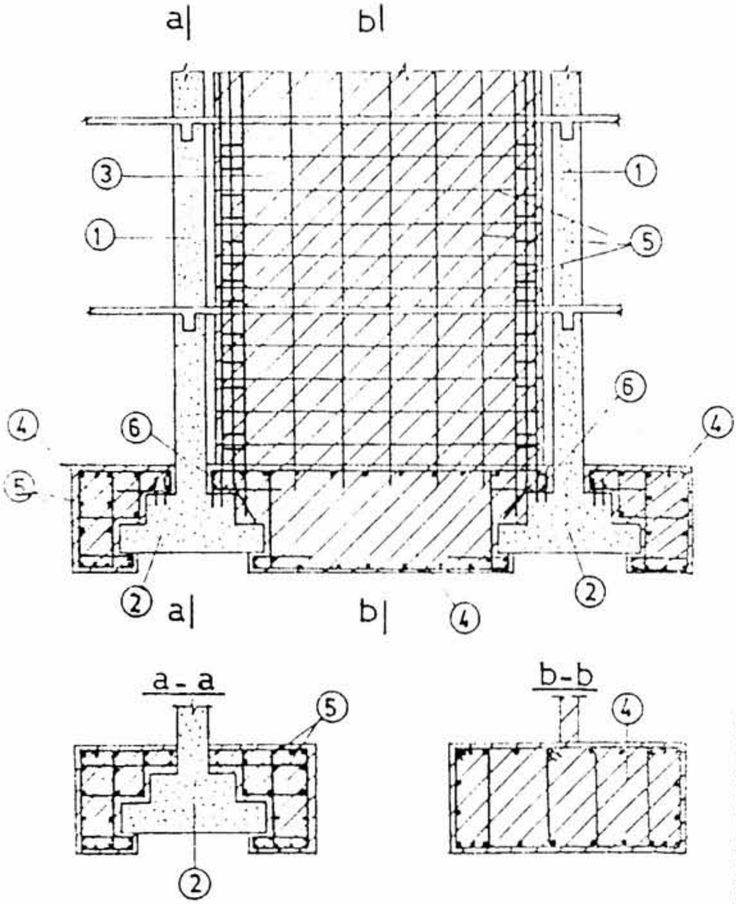


Fig. 6.43

1 - existing columns; 2 - existing foundations; 3 - added cast-in-place infilled shear wall; 4 - added concrete; 5 - added reinforcement; 6 - diagonal anchor bars; 7 - welding; 8 - steel plate

Fig. 24



1 - existing columns; 2 - existing foundation; 3 - added infilled shear wall; 4 - added reinforcement concrete; 5 - added reinforcement; 6 - welded steel plates

Fig. 25

4.3 Foundation of added walls:

Added shear walls or infilled walls should start from the foundation level, adequate connection with foundation is very important so that moments and shear forces, can be transmitted to the foundation. Figs.(24,25) shows some suggested schemes for infilled wall foundation

5. GENERAL DISCUSSION AND CONCLUSION

From the previous discussion it seems that there is a repairing solution for every case of damage that may occur. But of more importance is, How good is our new repaired element?. How it will behave in a future earthquake?.

All we have so far, are some laboratory test results, few or no data about the behaviour of these repaired elements in an earthquake or explosion, since these techniques are rather new. Shall we wait for another disaster to see what will happen to those repaired element?. Since no one can bear this responsibility, then what we can do is to increase effort for more research and tests to investigate the reliability and efficiency of these repairing and strengthening solution and may be developing another new techniques that might be more efficient

Repairing and strengthening solutions must be carefully studied. The new structural system must be completely analyzed before deciding on a repairing solution. The word improving which was used in several places in this report, does not always means increasing, since increasing stiffness in some part of the building some times affect badly the structural behaviour of the building. Therefore, repairing and strengthening is a special job needs special trained team, with enough experience.

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