جامعة عين شمس
كلية الهندسة

طرق تدعيم العناصر الخرسانية المسلحة

بحث تطبيقي مقدم من

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للحصول على ماجيستير الهندسة في الهندسة المدنية

المشرف على البحث

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الملخص

ترميم وتدعيم المنشآت الخرسانية المتهالكة عملية في غاية الاهمية لضمان أمان السكان او المستخدمين للمنشأ . القواعد والاعمدة و الكمرات والبلاطات هي عناصر انشائية مهمة لمقاومة الاحمال الواقعة على المنشأ ، لذلك ايجاد الطرق المناسبة لتدعيمها ضرورة لأمان المنشأ . الهدف من هذا البحث هو استعراض الطرق و الاساليب الاكثر شيوعا في تدعيم المباني التقليدية وذلك لمساعدة المهندسين الانشائيين في اختيار الاسلوب المناسب في التدعيم بناء على دراسات حالة لمشاريع تم تنفيذها فعليا .

هذا البحث يبدأ في الفصل الاول كمقدمة يستعرض من خلالها الهدف من البحث و متى ولماذا و كيف يتم التدعيم . الفصل الثاني يتناول المواد المستخدمة في التدعيم مثل الخرسانة المصبوبة في الموقع ، و الخرسانة المقذوفة ، و المواد البوليمرية ، و الواح الصلب ، والمواد المركبة الحديثة . الفصل الثالث يناقش تدعيم القواعد الخرسانية المسلحة باستخدام القميص الخرساني . الفصل الرابع يتناول تدعيم الاعمدة الخرسانية باستخدام القمصان الخرسانية ، و القمصان الحديدية ، و تدعيم العمدان باستخدام المواد المركبة الحديثة . الفصل الخامس يناقش تدعيم الكمرات الخرسانية باستخدام القمصان الخرسانية ، والواح الصلب ، و الواح المواد المركبة الحديثة . الفصل السادس يتناول تدعيم البلاطات الخرسانية عن طريق تكبير المقطع الخرساني ، و الواح الصلب ، و التدعيم باضافة كمرات حديدية ، و التدعيم باستخدام ألواح المواد المركبة الحديثة ، والتدعيم باستخدام الشد اللاحق بالاضافة الى تدعيم البلاطات في حالة عمل فتحات باستخدام ألواح الصلب ، و ألواح المواد المركبة الحديثة . وفي النهاية يتم مناقشة ثلاث دراسات حالة لمشاريع تم تنفيذها فعليا باستخدام معظم طرق التدعيم للعناصر الخرسانية ، هذه المشاريع هي مصنع كريستال عصفور(3) ، ومعرض اتصالات مصر فرع الحجاز ، و البنك المصري العربي فرع محمد فريد .

لكل طريقة من طرق التدعيم مجموعة من المزايا و مجموعة من العيوب ايضا ، فعلى سبيل المثال القمصان الخرسانية تعمل على زيادة الحمل الدائم بينما التدعيم باستخدام ألواح الصلب او الشد اللاحق يعيبها امكانية حدوث مشاكل بسبب الصدأ .

كل أساليب و طرق التدعيم مفيدة جدا في زيادة مقاومة المنشأ ورفع اداءه ، لكن اختيار الاسلوب الامثل للاستخدام يتوقف على عدة عوامل مثل المقدار المطلوب للزيادة في المقاومة ، المتطلبات المعمارية ، السرعة المطلوبة لانهاء اعمال التدعيم ، والتكلفة الكلية .

ABSTRACT

Repair and strengthening of damaged or vulnerable reinforced concrete structures is important in order to guarantee the safety of residents or users. footings, columns, beams and slabs are important structural elements for withstanding loads, so finding the efficient strengthening methods are necessary in terms of maintaining the safety of the structures. The objective of this research is to review the most commonly used strengthening techniques in traditional RC buildings and, in order to help structural engineers to choose the most appropriate solutions based on real case studies.

This research start by Chapter 1 as an introduction to discuss the objective of this research, when, why and how to strengthen a structure. Chapter 2 discusses Strengthening Materials like cast- in –situ concrete, concrete, resins, steel plates and composite materials. Chapter 3 discusses isolated footings strengthening by concrete jacketing .Chapter 4 is about columns strengthening techniques such as concrete jacketing, steel jacketing and FRP wrapping. Chapter 5 describes beams strengthening by concrete jacketing, using steel plates and by using of FRP. Chapter 6 presents strengthening of slabs by section enlargement, external steel plate bonding, strengthening by adding steel beams, by using of FRP and strengthening by post tension, Chapter 6 also discuss strengthening techniques of RC slabs with cut-outs openings by using of steel plates around the opening or by using of FRP sheets around it. After the six chapters there are three case studies utilising the most commonly used strengthening techniques for reinforced concrete elements, The three case studies are projects which had been completed , these projects are Crystal Asfour Factory3 , Etisalat Misr Center and Egyptian Arabian Bank .

Each of these methods comes with a series of advantages and disadvantages. Some, like section enlargement, add considerable permanent load to the structure and may need more strengthening done to the other structural members. The external plate bonding technique and external post tensioning are susceptible to corrosion damage which may lead to failure of the strengthening system.

All of the strengthening techniques are very effective in increasing the element’s carrying capacity or at least restoring the structural performance of the concrete members before deterioration. The selection of the most appropriate method to use will depend on several factors, such as the amount of strengthening required, the location where strengthening is required, architectural requirements, simplicity and speed of application, and total cost.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Structural strengthening represents an important aspect of the construction industry and its significance is increasing. Several methods are available, each with different advantages and handicaps. However, little information is available and insufficient code guidelines are accessible. In fact, most repair and strengthening designs are based on the assessment of engineers only and, often, empirical knowledge and current practice have an important role in the decisions to be made.

1.2 Objective

The objective of this research is to review the most commonly used strengthening techniques in traditional RC buildings and, in order to help structural engineers to choose the most appropriate solutions based on real case studies.

1.3 When, why and how to strengthen a Structure.

1.3.1 WHEN

The need to strength a structure may arise at any time from the beginning of the construction phase until the end of the service life. During the

construction phase, it may occur because of

- design errors.
- deficient concrete production.
- bad execution processes.

During the service life, it may arise on account of:

- an earthquake.
- an accident, such as collisions, fire, explosions.
- situations involving changes in the structure functionality.
- the development of more demanding code requirements.

1.3 .2 WHY

The decision to rehabilitate must be made only after the inspection of the structure, its structural evaluation and a cost/benefit study of the different solutions. So we can use strengthening techniques as it's may be more economic according cost/benefit study.

1.3.3 HOW

The choice of the repair and/or strengthening method depends on the structural behavior objectives. the goals of the strengthening strategies may be divided into increasing the resistance, improving the ductility, and an association of both. Basically, the strengthening techniques for reinforced concrete structures can be divided into:

- Addition of new structural elements.
- Strengthening of the existing structural elements.

1.4 Scope

This research presents the most commonly used strengthening techniques in traditional RC buildings .Chapter 2 discuss Strengthening Materials. Chapter 3 discusses isolated footings strengthening by concrete jacketing Chapter 4 is about columns strengthening techniques such as concrete jacketing, steel jacketing and FRP wrapping. Chapter 5 describes beams strengthening by concrete jacketing, using steel plates and by using of FRP. Chapter 6 presents strengthening of slabs by section enlargement, external steel plate bonding, strengthening by adding steel beams, by using of FRP and strengthening by post tension , Chapter 6 also discuss strengthening techniques of RC slabs with cut-outs openings by using of steel plates around the opening or by using of FRP sheets around it. After the six chapters there are three case studies utilising the most commonly used strengthening techniques for reinforced concrete elements, The three case studies are projects which had been completed , these projects are Crystal Asfour Factory3 , Etisalat Misr Center and Egyptian Arabian Bank .

CHAPTER 2

Strengthening Materials

2. 1 Introduction

Repairing and/ or strengthening of RC 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 sometimes a special concrete may be needed .

2.2 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

2.3 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 form- work tests performed on cantilever slabs and beams repaired by shotcrete showed that this technique is useful and efficient however more tests on different cases are still needed

2.4 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.In general before doing a repair job, engineer should be aware of all kind 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.

2.5 Steel plates

The in situ rehabilitation or upgrading of RC beams using bonded steel plates has been proven in the field to control flexural deformations and crack widths, and to increase the load-carrying capacity of the member under service load for ultimate conditions. It is recognised to be an effective, convenient and economic method of improving structural performance.

However, although the technique has been shown to be successful in practice, it also has disadvantages. Since the plates are not protected by the concrete in the same way as the internal reinforcement, the possibility of corrosion exists which could adversely affect the bond strength, leading to failure of the strengthening system. Uncertainty remains regarding the durability and the effects of corrosion. To minimize the possibility of corrosion, all chloride-contaminated concrete should be removed prior to bonding and the plates must be subjected to careful surface preparation, storage and the application of resistant priming systems. After installation, the integrity of the primer must be periodically checked, introducing a further maintenance task to the structure. The plates are generally prepared by grit blasting which, unless a minimum thickness of typically 6mm is imposed, can cause distortion. Steel plates are difficult to shape in order to fit complex profiles. In addition, the weight of the plates makes them difficult to transport and Review of materials and techniques for plate bonding handle on site, particularly in areas of limited access, and can cause the dead weight of the structure to be increased significantly after installation. The weight of the plates and this flatness requirement generally restricts the maximum plate length to between 6–8 m. Since the spans requiring strengthening are often greater than this length, joints are required. Welding cannot be used in these cases since this would destroy the adhesive bond. Consequently, lapped butt joints have to be formed, adding further complications to the design of the system.The process involved in strengthening with steel plates can therefore be considered as relatively time consuming and labor intensive.

2.6 Composite materials

To overcome some of the shortcomings that are associated with steel plate bonding, it was proposed in the mid-1980s that fiber reinforced polymer (FRP) plates could prove advantageous over steel plates in strengthening applications. Unlike steel, FRPs are unaffected by electrochemical deterioration and can resist the corrosive effects of acids, alkalis, salts and similar aggressive materials under a wide range of temperatures .Consequently, corrosion-resistant systems are not required, making preparation prior to bonding and maintenance after installation less arduous than for steel. The reinforcing fibers can be introduced in a certain position, volume fraction and direction in the matrix to obtain maximum efficiency, allowing the composites to be tailor made to suit the required shape and specification. The resulting materials are non-magnetic, non-conductive and have high specific strength and stiffness in the fiber direction at a fraction of the weight of steel. They are consequently easier to transport and handle, can be used in areas of limited access and do not add significant loads to the structure after installation. The drawbacks are the intolerance to uneven bonding surfaces which may cause peeling of the plate, the possibility of brittle failure modes and the material cost. Glass, aramid and carbon fiber composites may be considered for strengthening applications. With particular regard to plate bonding, a comparison of the important characteristics of FRP produced from these fiber types is shown in Table 2.1, in which the fiber volume fraction is typically around 65% and the fibers are unidirectional aligned.

In common usage, glass is the most popular reinforcing fiber since it is economical to produce and widely available. However, concern exists regarding the durability of composites composed of glass fibers, especially for structural uses involving concrete, Carbon fibers exhibit better resistance to moisture, solvents, bases and weak acids, and can withstand direct contact with concrete . Composite materials produced from them are light in weight, with strengths higher than steel and stiffness higher than either glass or aramid composites. For example, laminates fabricated from glass fiber must be three times thicker than CFRP laminates to achieve the same tensile stiffness for the same fiber volume fraction. CFRP has excellent fatigue properties and a very low (or even negative) linear thermal coefficient of thermal expansion in the fiber direction. Quality assurance can be performed by nondestructive testing, for example infrared inspection in the field, if CFRP laminates are used; this is not possible with steel plates. This technique allows fast and accurate judgment on the quality of the strengthening work. Despite the higher cost, carbon composites appear to provide the best characteristics for structural strengthening.

Characteristics	Carbon	Aramid	E-glass
Tensile strength	Very good	Very good	Very good
Compressive strength	Very good	Inadequate	Good
Stiffness	Very good	Good	Adequate
Long term behaviour	Very good	Good	Adequate
Fatigue behaviour	Excellent	Good	Adequate
Bulk density	Good	Excellent	Adequate
Alkaline resistance	Very good	Good	Inadequate
Cost	Adequate	Adequate	Very good

Table 2.1 - Comparison of the characteristics of FRP sheets produced from different type of fibers.

CHAPTER 3

Reinforced Concrete Foundations Strengthening Technique

3. 1 Introduction

Strengthening implies any changes in the structure or dimensions of existing foundations for the purpose of adapting them for service under alter conditions. Strengthening is associated with restoration or replacement of their obsolescent or physically broken-down construction elements as well as with increase in load on foundations. Sometimes seismic strengthening of foundations is required due to earthquake loads which may directly cause some problems for foundation or in addition to the other loads uplifts may be founded.

Foundations are subject to physical wear with passage of time. It is not unusual to come across instances of foundations breaking down, much earlier than their designated period of service. For instance, when a foundation is exposed to the action of corrosive groundwater, its protective concrete layer is destroyed and its reinforcement thereby exposed to corrosion. Under such conditions, a foundation may lose its load-bearing capacity to such an extent that strengthening it becomes an inevitable necessity.

3. 2 RC Foundations Strengthening by Concrete Jacketing.

Columns foundations need strengthening in the case of applying additional loads. Widening and strengthening of existing foundations may be carried out by constructing a concrete jacket to the existing footings. The new jacket should be properly anchored to the existing footing and column neck in order o guarantee proper transfer of loads. The size of the "jacket" shall be selected such that the average maximum foundation pressure does not exceed the recommended allowable value. Attention shall be given during construction in order that the excavations for the new "jackets" do not affect the existing adjacent foundations.

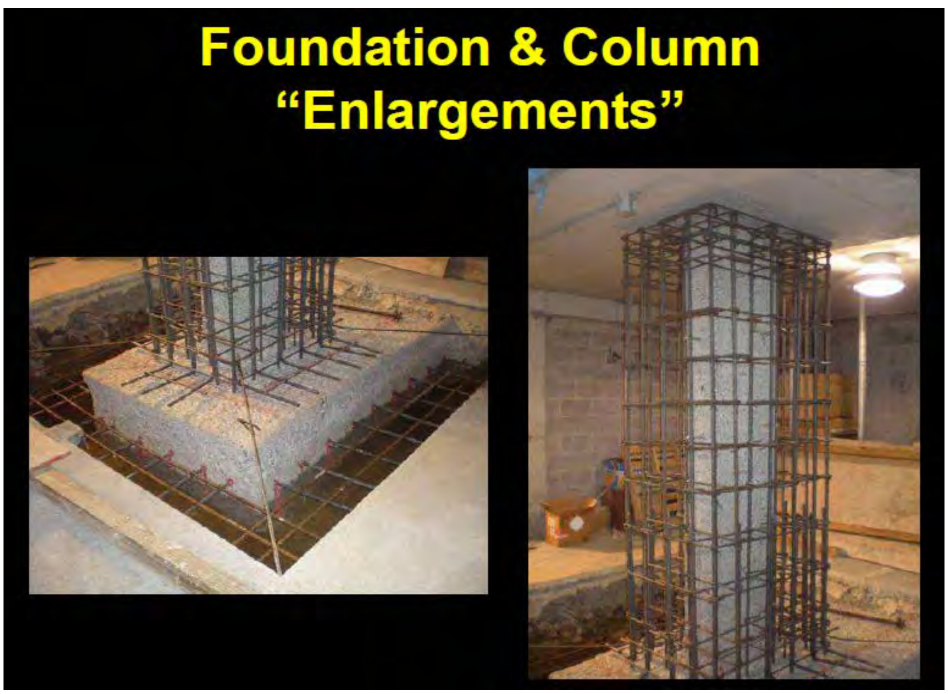


Figure 3.1 Foundation and column strengthening by RC jacketing.

3.3 Concrete Jacketing Steps

An isolated footing is strengthened by increasing the size of the footing and the reinforcement steel bars as follows:

1. Excavating around the footing

2. Cleaning and roughening the concrete surface.

3. Installing dowels at 25-30cm spacing in both directions using an appropriate epoxy material.

4. Fastening the new steel bars with the dowels using steel wires. The diameter and number of steel bars should be according to the design.

5. Coating the footing surface with a bonding agent in order to achieve the equired bond between old and new concrete.

6. Pouring the new concrete before the bonding agent dries. The new oncrete should contain a non-shrinkage material.

The previous steps are illustrated in Figure 3.2

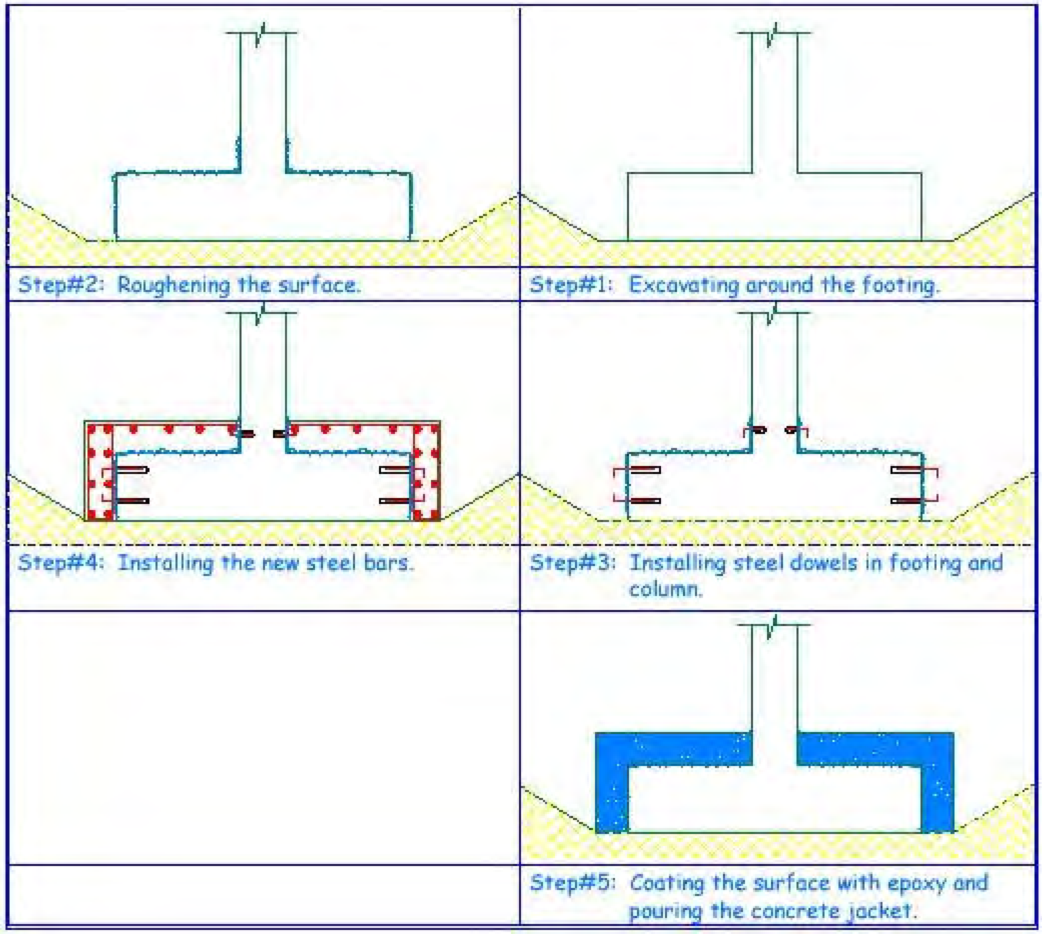


Figure 3.2 Steps for strengthening foundations.

The following figures (3.3-3.6) illustrate the practical way of jacketing a footing by reinforced concrete.

Figure 3.3 Excavation around the footing.

Figure 3.4 Harding the surface and installing the dowels

Figure 3.5 Installing the main steel.

Figure 3.6 Completing the jacket.

CHAPTER 4

Columns Strengthening Techniques

4. 1 Introduction

Over the years, engineers have used different methods and techniques to retrofit existing structures by providing external confining stresses. For the past few years, the concept of jacketing has been investigated to provide such forces. Externally applied jackets have been used as a reinforcement to contain concrete for different reasons. Engineers have used traditional materials such as wood, steel, and concrete to confine and improve the structural behavior of concrete members .

4. 2 Concrete Jacketing

Section enlargement is one of the methods used in retrofitting concrete members. Enlargement is the placement of reinforced concrete jacket around the existing structural member to achieve the desired section properties and performance. The main disadvantages of such system are the increase in the column size obtained after the jacket is constructed and the need to construct a new formwork as shown in figure 4. 1.

Figure 4. 1. Increasing the cross-sectional area of column by RC jacketing.

4. 2.1 When we need the strengthening of reinforced concrete columns?

We need the strengthening of reinforced concrete columns when

1. The load carried by the column is increased due to either increasing the number of floors or due to mistakes in the design.

2. The compressive strength of the concrete or the percent and type of reinforcement are not according to the codes' requirements.

3. The inclination of the column is more than the allowable.
4. The settlement in the foundation is more than the allowable.

4. 2.2 Concrete Jacketing Steps

In some cases, before this technique is carried out, we need to reduce or even eliminate temporarily the loads applied to the column; this is done by the following steps:

- Putting mechanical jacks between floors.
- Putting additional props between floors.

Moreover, in some cases, where corrosion in the reinforcement steel bars was found, the following steps should be carried out:

- Remove the concrete cover.
- Clean the steel bars using a wire brush or sand compressor.

- Coat the steel bars with an epoxy material that would prevent corrosion.
- If there was no need for the previous steps, the jacketing process could start by the following steps:

1. Adding steel connectors into the existing column in order to fasten the new stirrups of the jacket in both the vertical and horizontal directions at spaces not more than 50cm.Those connectors are added into the column by making holes 3-4mm larger than the diameter of the used steel connectors and 10-15cm depth.
2. Filling the holes with an appropriate epoxy material then inserting the connectors into the holes.
3. Adding vertical steel connectors to fasten the vertical steel bars of the jacket following the same procedure in step 1 and 2.
4. Installing the new vertical steel bars and stirrups of the jacket according to the designed dimensions and diameters.
5. Coating the existing column with an appropriate epoxy material that would guarantee the bond between the old and new concrete.
6. Pouring the concrete of the jacket before the epoxy material dries. The concrete used should be of low shrinkage and consists of small aggregates, sand cement and additional materials to prevent shrinkage.

The previous steps are illustrated in Figure 4. 2.

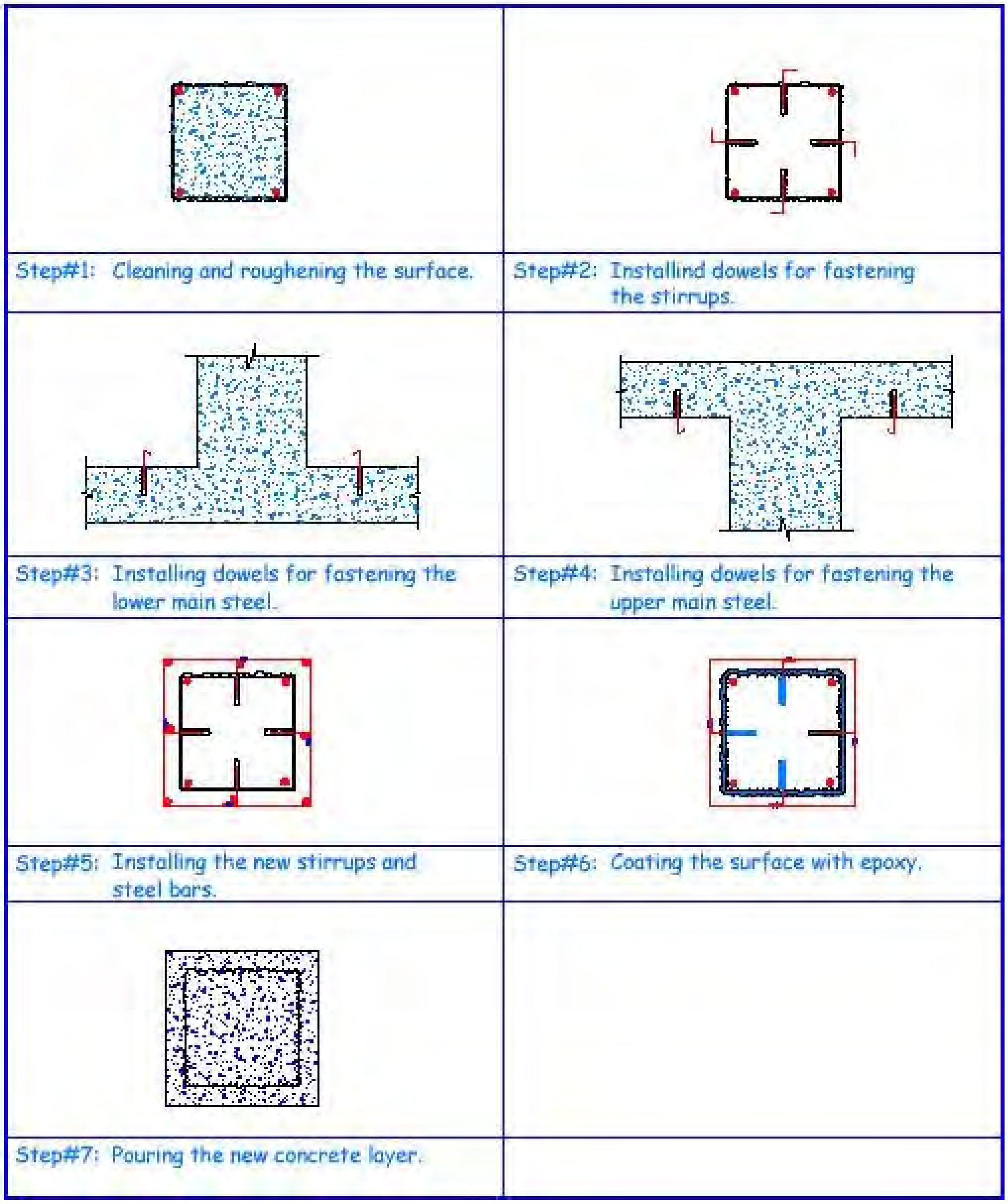


Figure 4. 2. Concrete jacketing steps.

4. 2.3 Points Should Considered When Using Column Concrete Jacketing .

- Involves addition of a thick layer of Reinforced Concrete (RC) in the form of a jacket, using longitudinal reinforcement and transverse ties.
- Additional concrete and reinforcement contribute to strength increase.
- Minimum allowable thickness of jacket = 100 mm.
- The sizes of the sections are increased and the free available usable space becomes less.
- Huge dead mass is added.
- The stiffness of the system is highly increased.
- Requires adequate dowelling to the existing column.
- Longitudinal bars need to be anchored to the foundation and should be continuous through the slab.
- Requires drilling of holes in existing column, slab, beams and footings.
- Increase in size, weight and stiffness of the column.
- Placement of ties in beam column joints is not practically feasible.
- The speed of implementation is slow.

The previous points are illustrated in figure 4. 3

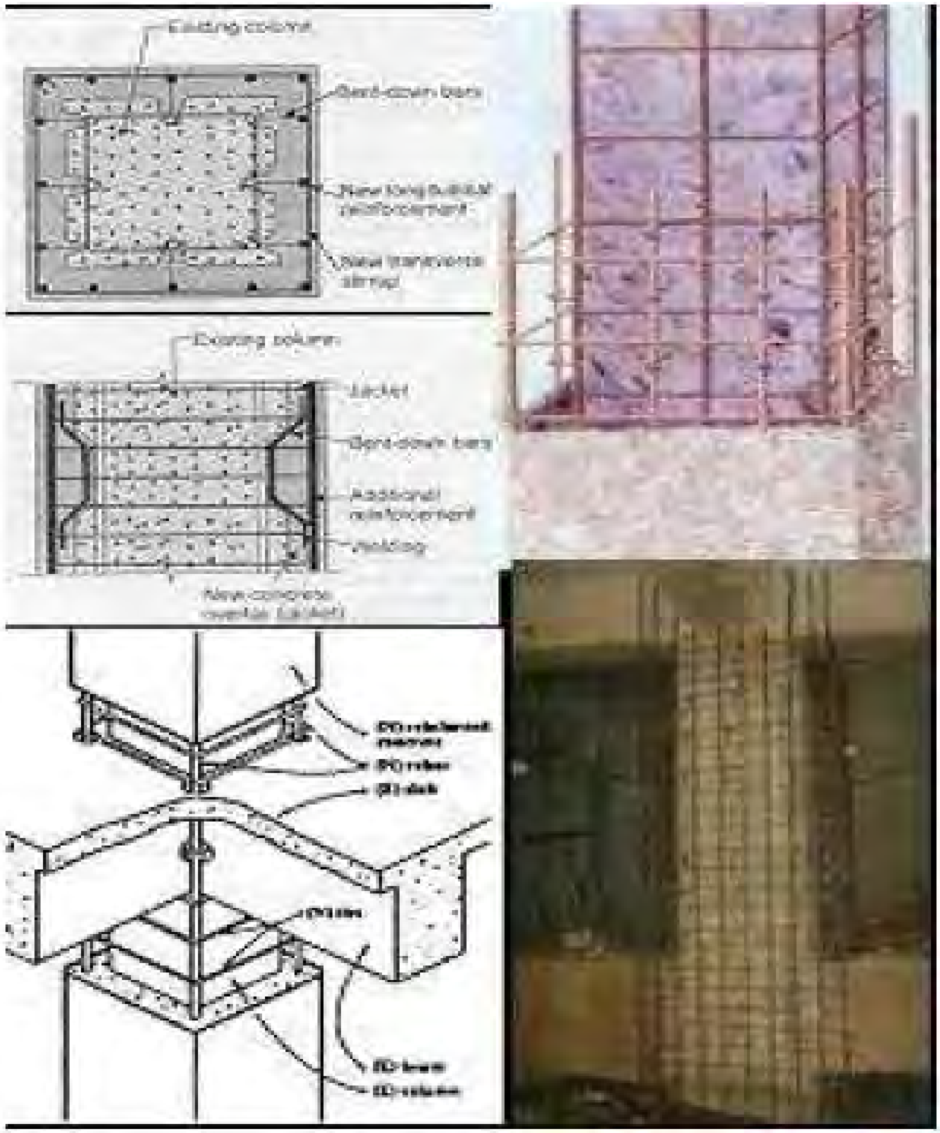


Figure 4.3. Points should considered when using column concrete jacketing

Reinforced concrete jacketing can be employed as a repair or strengthening scheme. Damaged regions of the existing members should be repaired prior to their jacketing. There are two main purposes of jacketing of columns:

(i) Increase in the shear capacity of columns in order to accomplish a strong column-weak beam design

And

(ii) To improve the column's flexural strength by the longitudinal steel of the jacket made continuous through the slab system are anchored with the foundation. It is achieved by passing the new longitudinal reinforcement through holes drilled in the slab and by placing new concrete in the beam column joints as illustrated in Figure 4.4. Rehabilitated sections are designed in this way so that the flexural strength of columns should be greater than that of the beams. Transverse steel above and below the joint has been provided with details, which consists of two L-shaped ties that overlap diagonally in opposite corners. The longitudinal reinforcement usually is concentrated in the column corners because of the existence of the beams where bar bundles have been used as shown in figure 1. It is recommended that not more than 3 bars be bundled together. Windows are usually bored through the slab to allow the steel to go through as well as to enable the concrete casting process.

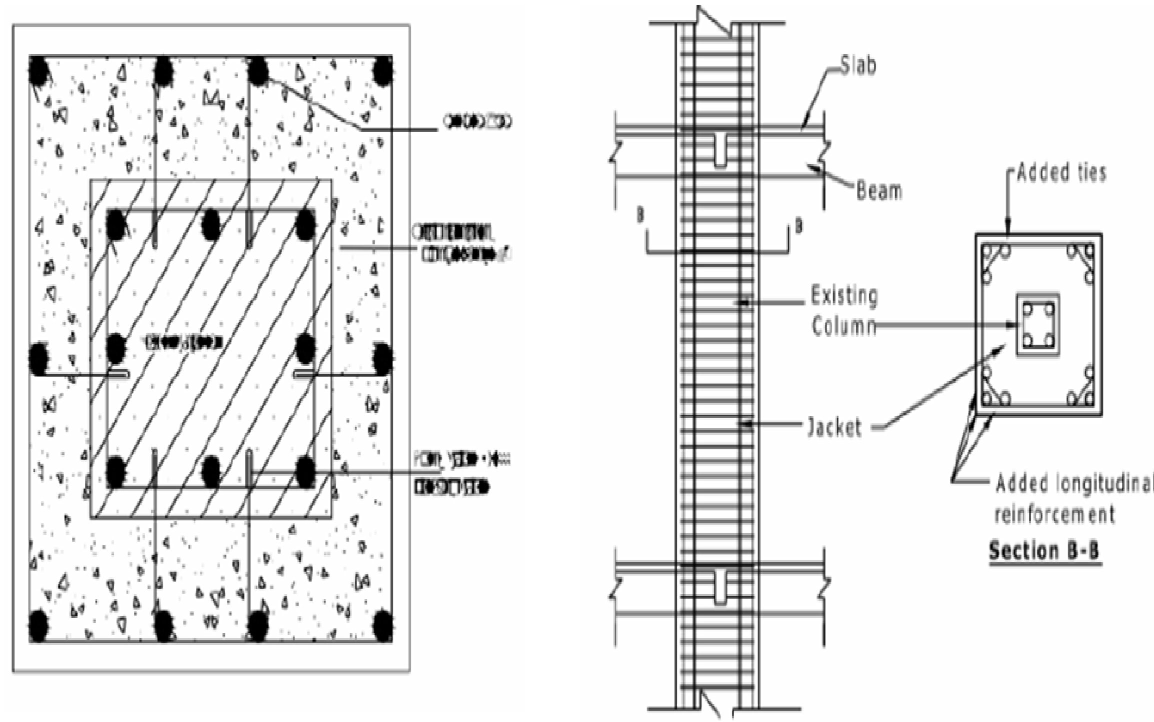


Figure 4.4. Placing new concrete in the beam column joints

4. 2.4 Anchoring to the footing.

One advantage of RC jacketing strengthening is the fact that the increased stiffness of the structure is uniformly distributed, in contrast to the addition of shear walls or steel bracing. In fact, for these procedures, it is usually necessary to execute new foundations or, at least, to strengthen the existing ones. Generally, in the case of RC jacketing, the steel longitudinal reinforcing bars of the added jacket can be anchored to the original footings. Although there are several commercial products, very effective to bond the added steel bars to the RC footing, attention must be taken when executing this operation. Actually, the quality of the bonding can only be ensured if some details are considered. Ju´ lio performed tests on RC columns strengthened by jacketing. The steel bars of the added longitudinal reinforcement were anchored to the footing of the original column by a commercially available two-component epoxy resin. The models were submitted to monotonic tests, consisting of a constant axial force combined with an increasing bending moment and shear force. Initially, failure of all steel bars of the longitudinal reinforcement of the original column and slipping of all the corresponding steel bars of the added jacketing were observed . Pull-out tests were performed to analyse the problem and it was concluded, without any doubt, that the bars slipped because the holes drilled on the footings had not been adequately cleaned. The use of a vacuum cleaner was enough to guarantee the change from slipping failure to tension rupture of the added steel bars.

4. 3 Steel Jacketing

Confining reinforced concrete column in steel jackets is one of the effective methods to improve the earthquake resistant capacity. As compared with conventional hoops or spirals, steel jacket has two more remarkable advantages; 1) to easily provide a large amount of transverse steel, hence strong confinement to the compressed concrete, and 2) to prevent spalling off of the shell concrete. Spalling of the shell concrete may be considered as the main reason for deterioration of bond and buckling of longitudinal bars of columns and is hardly prevented by conventional hoops. Because of these advantages of the steel jacket, confining method utilizing steel jacket has been increasingly used to retrofit or strengthen the existing reinforced concrete columns without adequate detailing. This method is referred to as the steel jacket retrofit hereafter.

Figure 4. 5. Steel jacketing

Steel jacketing has been proven to be an effective technique to enhance the seismic performance of old bridge columns as shown in figure 4.6. The steel jacket is manufactured in two shell pieces and welded in the field around the column. However, this method requires difficult welding work and, in a long term, the potential problem of corrosion remains considered.

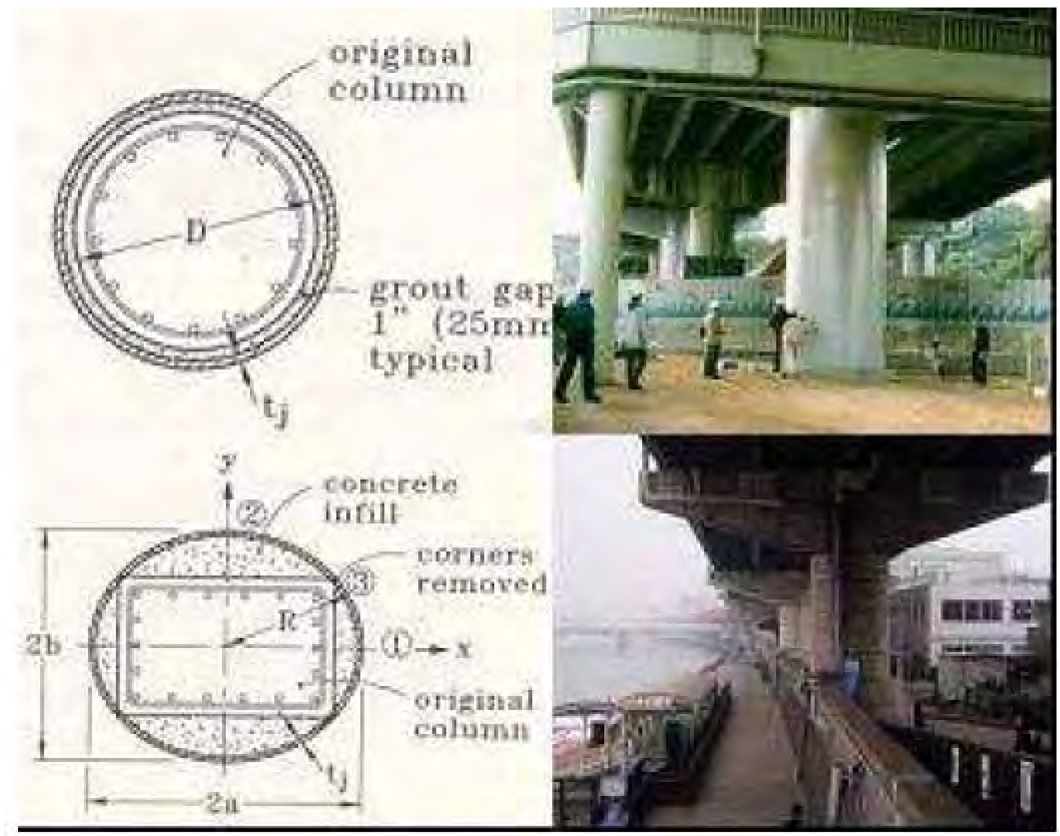


Figure 4. 6. Steel jacketing at old bridge columns .

4. 3.1 When we prefer column Steel Jacketing?

This technique is chosen when the loads applied to the column will be increased, and at the same time, increasing the cross sectional area of the column is not permitted.

4. 3.2 Steel Jacketing Steps

This technique is implemented by the following steps as shown in figure 4.7

1. Removing the concrete cover.

2. Cleaning the reinforcement steel bars using a wire brush or a sand compressor.

3. Coating the steel bars with an epoxy material that would prevent corrosion.

4. Installing the steel jacket with the required size and thickness, according to the design, and making openings to pour through them the epoxy material that would guarantee the needed bond between the concrete column and the steel jacket.

5. Filling the space between the concrete column and the steel jacket with an appropriate epoxy material.

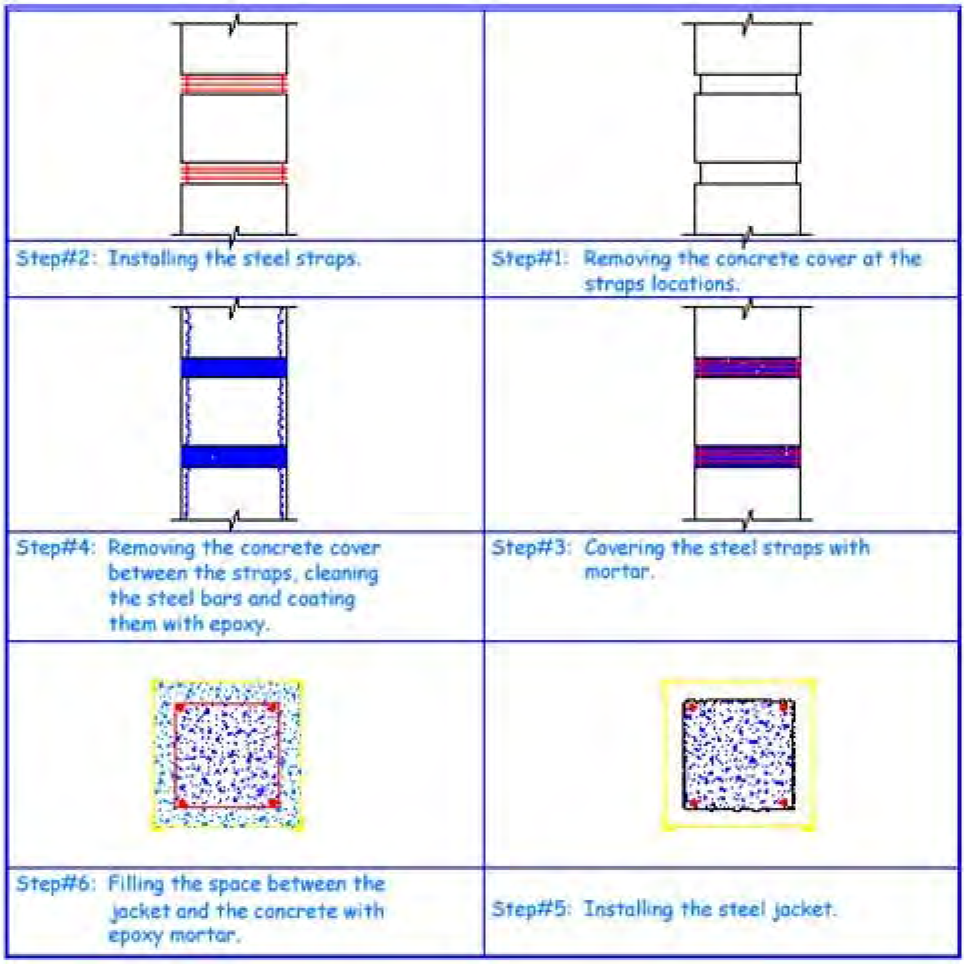


Figure 4.7. Steel jacketing steps .

Figure 4.8. shows a column which was strengthened with steel angles

4. 3.3 Points Should Considered When Using Column Steel Jacketing .

- Encasing the column with steel plates and filling the gap with a non-shrink grout.
- Provides passive confinement to core concrete.
- Its resistance in axial and hoop direction can neither be uncoupled nor optimized.
- Its high young's modulus causes the steel to take a large portion of the axial load resulting sometimes in premature buckling of the steel.
- General thickness of grout = 25 mm.
- Rectangular steel jackets on rectangular columns are not generally recommended and a use of an elliptical jacket is solicited.
- Since steel jacket is vulnerable to corrosion and impact with floating materials, it is not used for columns in river, lake and seas.

4. 4 Strengthening of RC Columns by FRP Composites.

Interesting in the use of flexible fiber reinforced plastic (FRP) sheets for the external wrapping of concrete compressed members is today a very popular theme, especially as regards estimating the effectiveness of this reinforcing technique in increasing the strength and ductility of members in seismic areas.

Several advantages are observed in using FRP wraps compared to the most common other techniques based on the use of steel reinforcements such as the high-mechanical properties of the material (tensile strength and elasticity modulus) compared with its lightness; its insensitivity to corrosion; the ease of applying the reinforcing material .

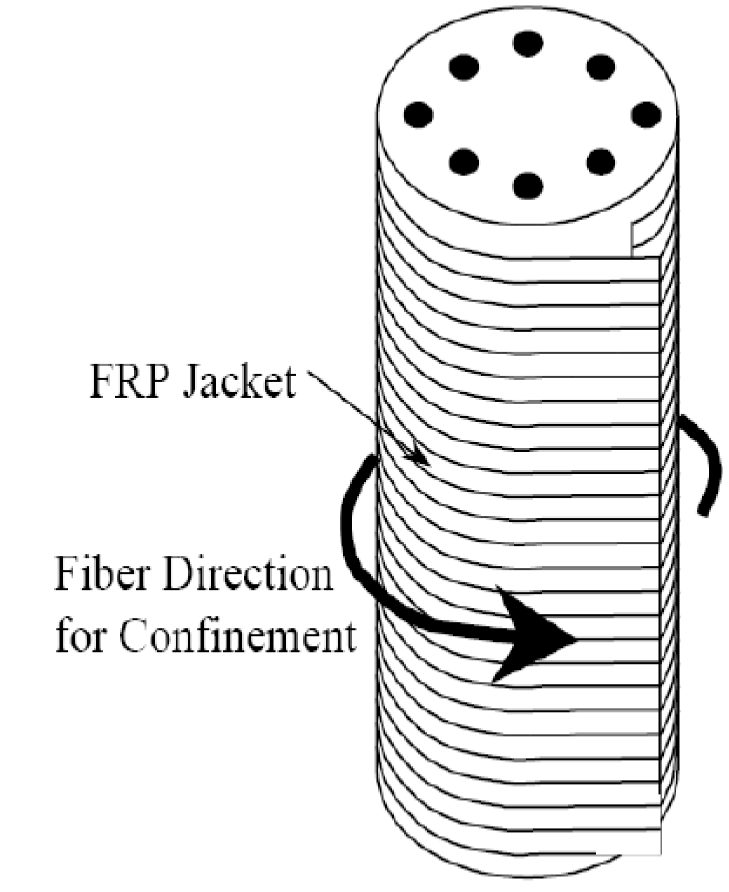


Figure 4. 9. Strengthening of RC columns by FRP composites

4. 4.1 FRP Wrapping Steps.

A proper application procedure involves following steps:

1. Surface preparation: This includes

a. Grinding to the column surface to remove dust and cement loose layer.

b. Repair of hairline cracks, if any.

c. Rounding off of column corners to specified rounding radius

d. Application of Primer

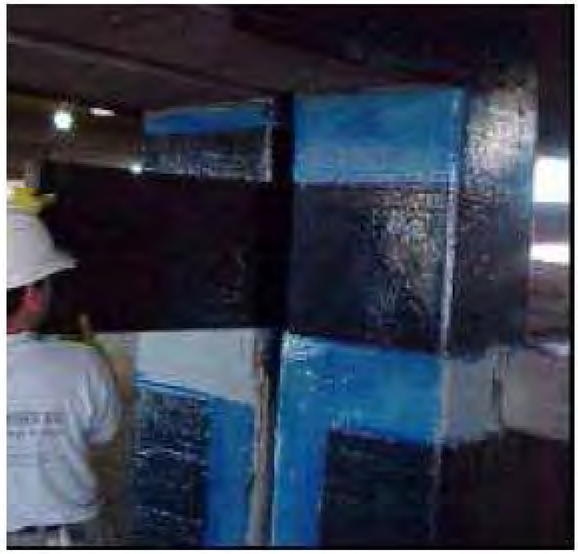
2. Once the surface is prepared and primer dried, the next step is application of saturant.

Application of Saturant

Figure 4.10

3. The fiber wrap is then wetted with saturant.

4. Fiber is then wrapped on the column skillfully so that there are no undulations in the wrap.



Wrapping with Carbon Fiber

Figure 4.11

Wrapping with Glass Fiber

Figure 4.12

5. After wrapping, the fiber is again wetted with one more layer of saturant to make sure that the fiber is soaked fully with saturant.

Application of Saturant on FRP Wrapping

Figure 4.13

RC Columns after Completion of FRP Wrapping

Figure 4.14

4. 4.2 Advantages of FRP for strengthening RC columns .

- It provides a highly effective confinement to columns.
- The original size, shape and weight of the members is unaltered (unlike any other jacketing), thus not attracting higher seismic forces.
- Due to the fact that the original shape and size of the members is practically unaltered, this method is particularly useful for strengthening historic and artistic masonry structures.
- Due to the orthotropy built in by fiber orientation, the wraps essentially provide only confinement without interfering with the axial load which is taken completely by concrete column as against steel jacketing, where the jacket takes most of the axial load and becomes susceptible to buckling.
- No drilling of holes is required as against concrete and steel jacketing.
- The FRPs have extremely good corrosion resistance, which makes them highly suitable for marine and coastal environments.
- FRP wraps prevent further deterioration of concrete and inside reinforcement.
- As the wraps are available in long rolls, construction joints can be easily avoided.
- Ease of installation, which is similar to putting up wall papers, makes the use of FRP sheets a very cost-effective and efficient alternative in the strengthening of existing buildings.

- Provides minimal disturbance to existing structure and generally the strengthening work can be performed with normal functioning of structure.

- To increase the effectiveness of wrap, the sharp edges of the rectangular sections must be rounded.

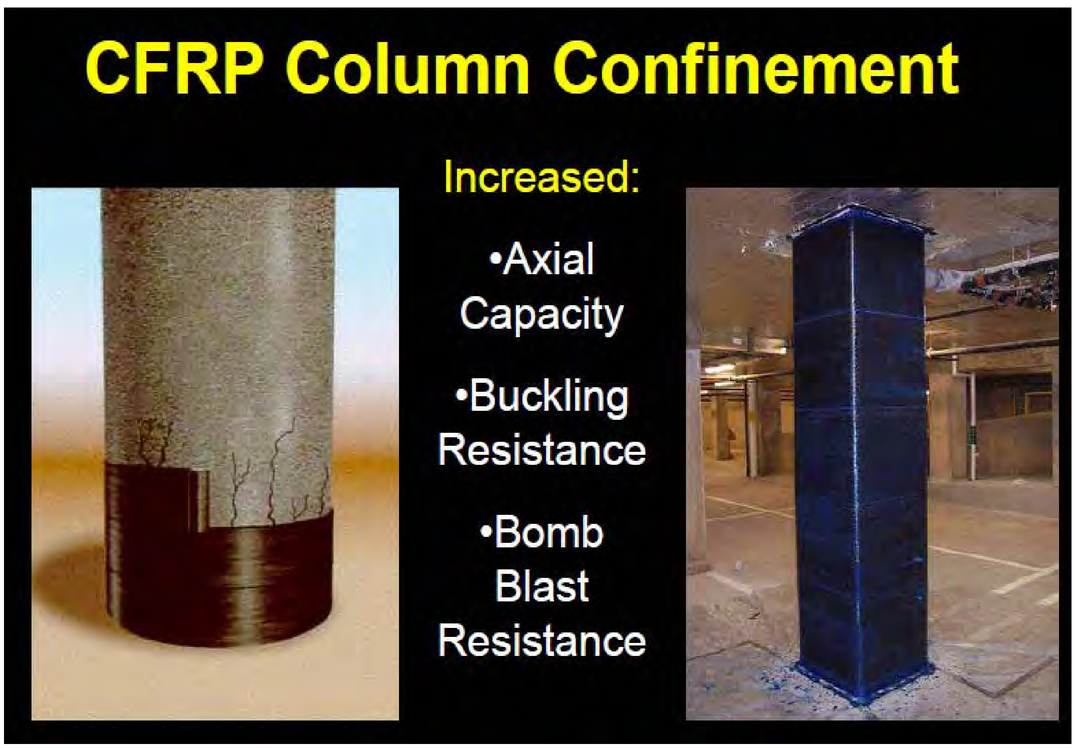


Figure 4.15 Effect of FRP for strengthening RC columns at resistance .

4. 4.3Corrosion protection by FRP.

- Corrosion in reinforced concrete structures causes deterioration of infrastructure.
- Structures in or near marine environments are especially vulnerable.
- A widely promoted method for protecting structures in corrosive environments is the application of FRP composite wraps over the surface of the concrete elements.
- Corrosion due to chloride ingress is purportedly arrested by the prevention of further chloride contamination and penetration by the oxygen and water needed to continue a corrosion process that has begun or has caused damage.

Figure 4.16 .Corrosion protection by FRP

4. 4.4 Points Should Considered When Using FRP for strengthening RC columns.

- Involves wrapping of RC columns by high strength-low weight fiber wraps to provide passive confinement, which increases both strength and ductility.
- FRP sheets are wrapped around the columns, with fibers oriented perpendicular to the longitudinal axis of column, and are fixed to the column using epoxy resin.
- The wrap not only provides passive confinement and increases the concrete strength, but also provides significant strength against shear.

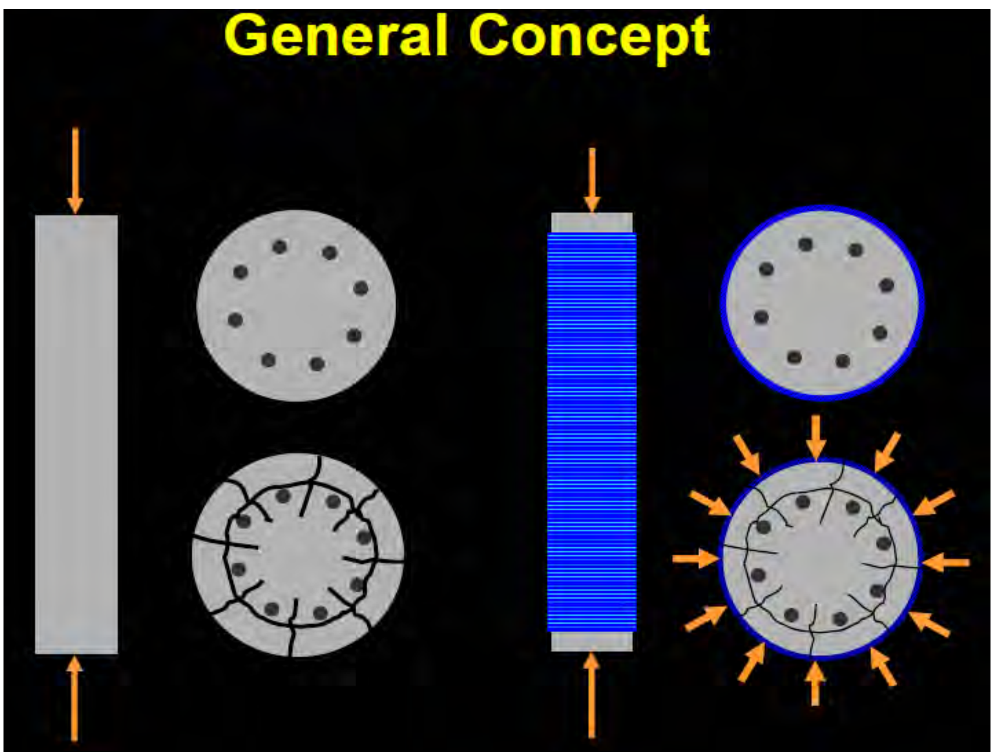


Figure 4.17 General Concept of FRP column wrapping .

4. 5 Comparison of FRP system with concrete jacketing & steel jacketing .

Description	Concrete Jacketing	Steel Jacketing	FRP Wrapping	Remarks
Mode of strengthening	Increase in concrete and steel area	Confinement	Confinement	
Preparation of column for strengthening	Significant dismantling of cover concrete. At least 40 mm cover concrete to be removed. Epoxy primer to be applied on exposed surface.	Not major dismantling work involved. Mainly plaster to be removed and epoxy primer to be applied on exposed surface.	Only plaster to be removed and epoxy primer to be applied on exposed surface. For rectangular columns, corners to be rounded off.	FRP involves minimum surface preparation.
Drilling of holes	Large amount of drilling is required	Large amount of drilling is required	No drilling required	FRP involves minimum work since no drilling is required.
Additional weight	Extremely high (In example shown, the weight becomes 225% for just 50% increase in strength.	Very high (In example shown, the weight becomes 169% for 50% increase in strength.	Negligible. No increase in weight at all.	FRP does not increase the dead weight of the structure.
Size Increase	Very high (In example shown, the diameter of column increases from 400mm to 600mm for 50% increase in strength.	High (In example shown, the diameter of column increases from 400mm to 450mm for 50% increase in strength.	Negligible. The total increase in diameter is less than 5 mm.	The size remains unaltered thus retaining the free area.

Table 4.1 Comparison of FRP system with concrete jacketing & steel jacketing

CHAPTER 5

Beams Strengthening Techniques

5. 1 Concrete Jacketing

Placing additional layer of concrete surrounding an existing beam is called section enlargement. Concrete jacket is to add reinforced concrete jacket on the existing beam. Jacketing by reinforced concrete could improve resistance against applied loads and enhances the durability at same time. Furthermore, section enlargement and concrete jacketing maybe easier and cheaper compared to other approaches such as steel plate jacketing.

Concrete jacketing can be easy, effective and inexpensive technique to rehabilitate and strengthen concrete structures. Concrete jacket is achieved by adding the reinforced concrete jacket to the existing structure components such as beams and columns .

Jacketing by reinforced concrete and section enlargement may be the relatively easy and economic strengthening method compared to attachment of an external steel, external post-tensioning or externally bonded composite system. It effectively increases the load carrying capacity or stiffness. However, the addition of concrete and steel to repair beams increases the weight of beams. So, the lightweight concrete may be considered as better applied when strengthening the beams. Strengthening with concrete and steel rebar might lead to corrosion in beams. Hence, section enlargement and concrete jacketing are limited to use in harsh environment and the protecting corrosion is important work.

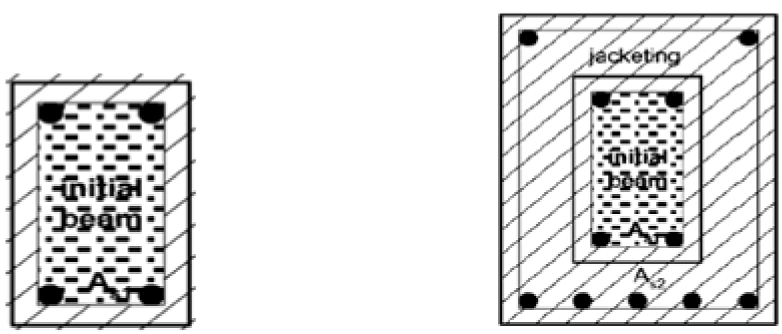


Figure 5.1 Cross-section of beam before and after concrete jacketing .

5. 1.1 When we need the strengthening of reinforced concrete beams?

Reinforced concrete beams need strengthening when the existing steel bars in the beam are unsafe or insufficient, or when the loads applied to the beam are increased.

5. 1.2 Concrete Jacketing Steps

In such cases, there are different solutions that could be followed:

I-Adding reinforcement bars to the main steel without increasing the beam cross section area .

This solution is carried out when the reinforcing steel bars are not capable to carry the stresses applied to the beam. The following steps should be followed:

1. The concrete cover is removed for both the upper and lower steel bars.

2. The steel bars are well cleaned and coated with an appropriate material that would prevent corrosion.

3. Holes are made, in the whole span of the beam under the slab, as shown in Figure 5.2, 15-25cm apart, a diameter of 1.3cm and extend to the total width of the beam.

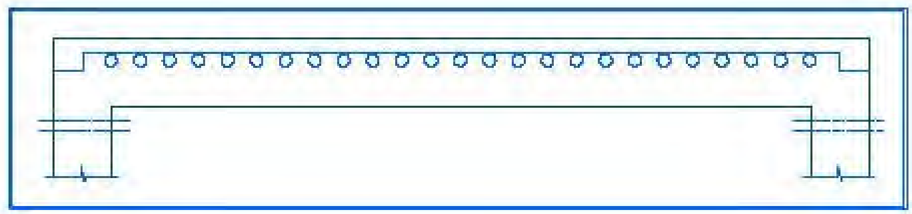


Figure 5.2 Holes in the span of a beam

4. The holes are filled with an epoxy material with low viscosity and installing steel connectors for fastening the new stirrups.

5. Steel connectors are installed into the columns in order to fasten the steel bars added to the beam.

6. The added stirrups are closed using steel wires and the new steel is installed into these stirrups.

7. The surface is then coated with a bonding epoxy material.

8. The concrete cover is poured over the new steel and the new stirrups.

The previous steps are illustrated Figure 5.3.

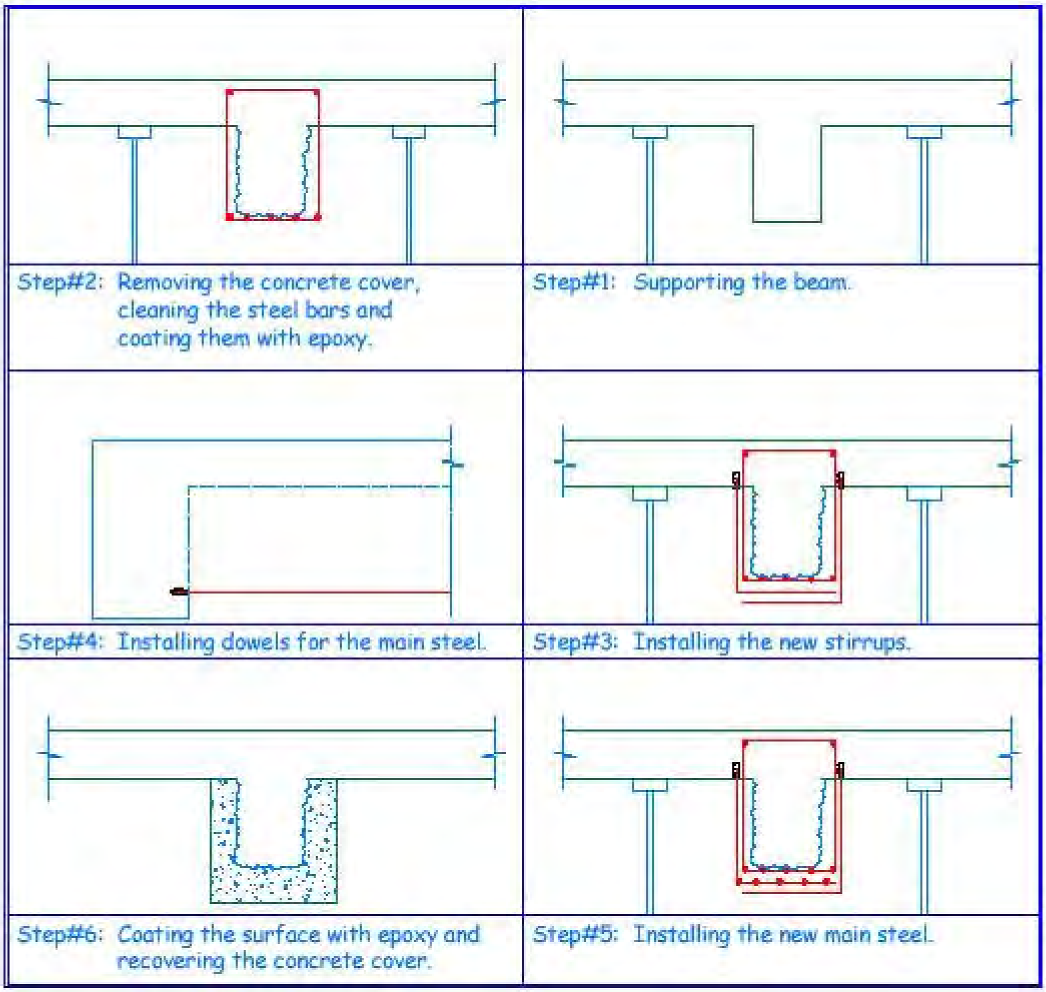


Figure 5.3 Strengthening a beam without increasing cross sectional area.

II-Increasing both the reinforcement still bars and the cross section area of the concrete .

This solution is chosen when both the steel and concrete are not able to carry the additional loads applied to the beam. In such cases the following steps should be followed as in Figure 5.4.

1. Removing the concrete cover, roughing the beams surface, cleaning the reinforcement steel bars and coating them with an appropriate material that would prevent corrosion.

2. Making holes in the whole span and width of the beam under the slab at 15-25cm.

3. Filling the holes with cement mortar with low viscosity and installing steel connectors for fastening the new stirrups.

4. Installing the steel connectors into the columns in order to fasten the steel bars added to the beam.

5. Closing the added stirrups using steel wires and the new steel is installed into these stirrups.

6. Coating the concrete surface with an appropriate epoxy material that would guarantee the bond between the old and new concrete, exactly before pouring the concrete.

7. Pouring the concrete jacket using low shrinkage concrete.

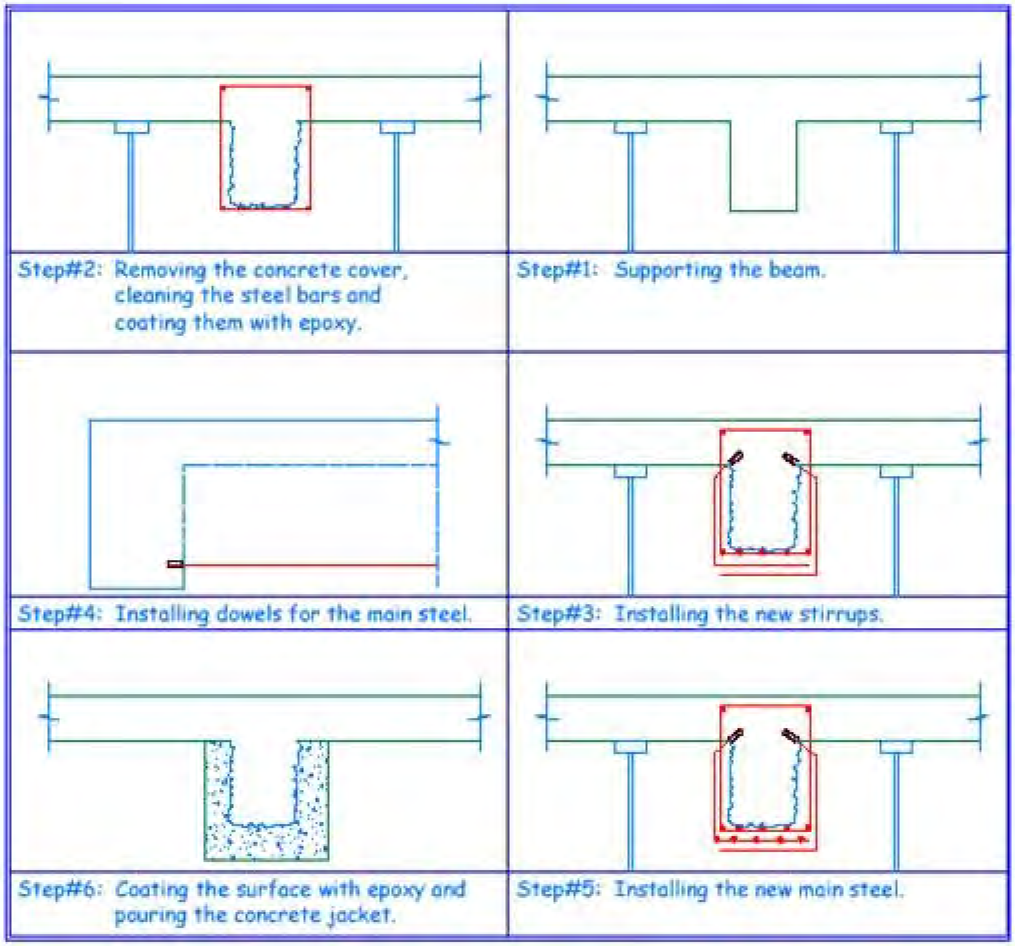


Figure 5.4 Strengthening of beam by increasing the cross-sectional area and bars

5. 2 Beams Strengthening by the using of steel plates.

Attaching steel plates to certain external surface of the beams is another popular strengthening technique. Anchoring or bonding steel plates to reinforced concrete beams can increase flexural and shear capacity. Furthermore, it can control deflections and cracking of beams. The efficiency of steel plates is influenced by some factors such as the dimension of the steel plate, the arrangement of bolts, and bonding method. This chapter discusses how to optimally repair and strengthen the beams by considering these factors.

Attaching external steel plates in different areas of reinforced concrete beams can certainly improve flexure and shear capacity of RC beams. Bolting or bonding plate to the certain external surface of the beams could effectively strengthen beams. The researchers focus on the different specific factors like bolt arrangement, thickness and depth of the steel plate, attachment method; which can influence the performance of steel plate. The obvious advantage of using this strengthening method is that it needs relatively short installation time and the steel plates do not disrupt operations compared to concrete jacketing. The disadvantages include deboning, expensive, temporary weakening, and corrosions.

It was found that failure of the beams occurred at one end by horizontal shear in the concrete adjacent to the steel plate, commencing at the plate end and resulting in sudden separation of the plate with the concrete still attached, up to about mid-span. The external plate was found to have a much more significant effect in terms of crack control and stiffness. The loads required to cause a crack width of 0.1 mm were increased by 95%, whilst the deflections under this load were substantially reduced. The postcracking stiffness was found to be increased by between 35–105% depending upon the type of adhesive used and the plate dimensions.

The ultimate behaviour of steel plated RC beams appears to be closely related to the geometry of the plated cross-section. For thin plates, failure usually occurs in flexure. However, if the plate aspect ratio falls below a certain value, separation of the plate from the beam can occur, initiating from the plate end and resulting in the concrete cover being ripped off. These observations are consistent with the fact that simple elastic longitudinal shear stresses are inversely proportional to the plate width. Consequently, as the steel plate width decreases, the longitudinal shear stresses increase. In addition, the bending stiffness of the plate increases, thereby increasing the peeling stresses normal to the beam.

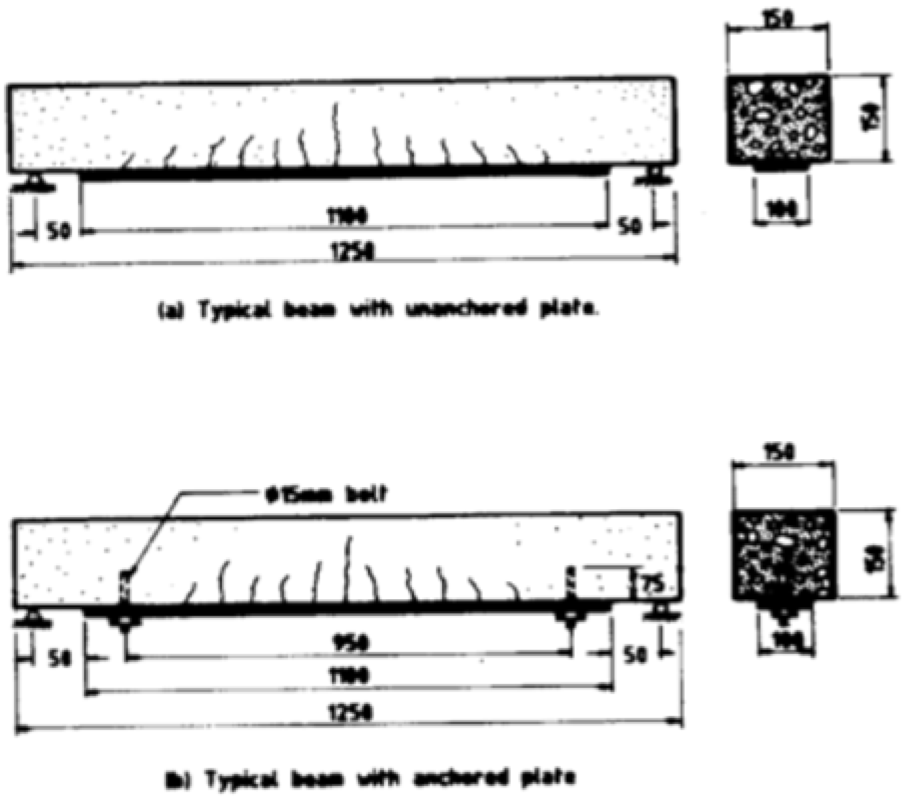


Figure 5.5 Strengthening details of two typical beams, one with an anchored plate and another with unanchored plate.

5.2.1 Disadvantages of external strengthening using steel plates

The *in situ* rehabilitation or upgrading of RC beams using bonded steel plates has been proven in the field to control flexural deformations and crack widths, and to increase the load-carrying capacity of the member under service load for ultimate conditions. It is recognised to be an effective, convenient and economic method of improving structural performance. However, although the technique has been shown to be successful in practice, it also has disadvantages. Since the plates are not protected by the concrete in the same way as the internal reinforcement, the possibility of corrosion exists which could adversely affect the bond strength, leading to failure of the strengthening system. Uncertainty remains regarding the durability and the effects of corrosion. To minimise the possibility of corrosion, all chloride-contaminated concrete should be removed prior to bonding and the plates must be subjected to careful surface preparation, storage and the application of resistant priming systems. After installation, the integrity of the primer must be periodically checked, introducing a further maintenance task to the structure. The plates are generally prepared by grit blasting which, unless a minimum thickness of typically 6mm is imposed, can cause distortion.

Steel plates are difficult to shape in order to fit complex profiles. In addition, the weight of the plates makes them difficult to transport and Review of materials and techniques for plate bonding handle on site, particularly in areas of limited access, and can cause the dead weight of the structure to be increased significantly after installation. Elaborate and expensive falsework is required to maintain the steelwork in position during bonding. The plates are required to be delivered to site within flatness tolerances to prevent stresses being introduced normal to the bondline during cure. The weight of the plates and this flatness requirement generally restricts the maximum plate length to between 6–8 m. Since the spans requiring strengthening are often greater than this length, joints are required. Welding cannot be used in these cases since this would destroy the adhesive bond. Consequently, lapped butt joints have to be formed, adding further complications to the design of the system.

Studs are required to assist in supporting the steel plates during installation and under service loading conditions. This is especially true towards the ends of the plates where anchorages are required due to the high bending stiffness of the plate. The position of these studs must therefore be established prior to bonding. This process can involve a considerable amount of site work. Finally, if the plates are loaded in compression, buckling may occur, causing the plates to become detached. The process involved in strengthening with steel plates can therefore be considered as relatively time consuming and labour intensive.

5. 3 Beams Strengthening by FRP.

To overcome some of the shortcomings that are associated with steel plate bonding, it was proposed in the mid-1980s that fiber reinforced polymer (FRP) plates could prove advantageous over steel plates in strengthening applications. Unlike steel, FRPs are unaffected by electrochemical deterioration and can resist the corrosive effects of acids, alkalis, salts and similar aggressive materials under a wide range of temperatures. Consequently, corrosion-resistant systems are not required, making preparation prior to bonding and maintenance after installation less arduous than for steel.

The use of fiber-reinforced polymer (FRP) composites for the rehabilitation of beams and slabs started about 25 years ago with the pioneering research performed at the Swiss Federal Laboratories for Materials Testing and Research or EMPA (Meier, 1987). FRP composites, used in the repair of beams and slabs as external tensile reinforcement, increase the strength (ultimate limit state) and the stiffness (serviceability limit state) of the structure. Repair with FRP is thus motivated by requirements for earthquake strengthening, higher service loads, smaller deflections, or simply to substitute for deteriorated steel reinforcement.

External plate bonding is a method of strengthening which involves adhering additional reinforcement to the external faces of a structural member. The success of this technique relies heavily on the physical properties of the material used and on the quality of the adhesive, generally an epoxy resin, which is used to transfer the stresses between the flexural element and the attached reinforcement. The first reported case strengthened by this technique was in 1964. Epoxy-bonded mild steel plates were applied to load bearing beams in the basement of an apartment building, in Durban in South Africa (McKenna and Erki, 1993).In the 1980s, Swiss researchers at the Swiss Federal Laboratories for Materials Testing and Research called EMPA pioneered studies on the uses of Fibre Reinforced Plastic Materials (FRP) as a replacement for steel in strengthening applications. These materials -unlike steel do not suffer from corrosion and their other mechanical and physical properties can be better than steel.

Glass, aramid and carbon fibre composites may be considered for strengthening applications. With particular regard to plate bonding In common usage, glass is the most popular reinforcing fibre since it is economical to produce and widely available. However, concern exists regarding the durability of composites composed of glass fibres, especially for structural uses involving concrete . Carbon fibres exhibit better resistance to moisture, solvents, bases and weak acids .

Figure 5.6. Beam U wrap.

5. 3.1 Beams Strengthening by FRP Steps.

A proper application procedure involves following steps:

1. Surface preparation: This includes

a. Grinding to the surface to remove dust and cement loose layer.

Figure 5.7. Grinding to the surface.

b. Repair of hairline cracks, if any.

c. Application of Primer

Figure 5.8 Application of primer .

2. Once the surface is prepared and primer dried, the next step is application of saturant.

Figure 5.9 Application of saturant.

3. The fiber wrap is then wetted with saturant.

Figure 5.10 CFRP saturator.

4. Fiber is then lay up on the beam skilfully so that there are no undulations in the wrap.

Figure 5.11 Fiber lay up.

5. After wrapping, the fiber is again wetted with one more layer of saturant to make sure that the fiber is soaked fully with saturant.

Figure 5.12 Fiber take another coat.

Figure 5.13 CFRP installation completed .

Figure 5.14 Topcoat installation .

Figure 5.15 Finished beam .

CHAPTER 6

Slabs Strengthening Techniques

6.1 Introduction

Different strengthening techniques have been developed so far for the reinforced concrete slabs with or without cut-outs. The development of these methods was a necessity due to different causes, such as inadequate maintenance, overloading of the reinforced concrete member, corrosion of the steel reinforcement and other different situations that appeared in time. Each of the techniques that are presented is better suited for a given situation and come with their advantages and disadvantages. These techniques are considered to be traditional due to their long usage in time and that they involve only traditional construction materials such as concrete and steel . The selection of one of these methods is imposed by a sum of technological and economical factors.

6.2 Necessity of Strengthening Reinforced Concrete Slabs.

For taking in consideration the necessity of strengthening RC elements we must analyse the situations that arise in practice where existing concrete structures or some of their components may, for a variety of reasons, be found to be inadequate and in need of repair and/or strengthening. The situations in which the reinforced concrete slabs require the Intervention for repairs or strengthening are the following

a) Repairing damaged/deteriorated concrete slabs to restore their strength and stiffness.

b) Corrosion of the reinforcement.

c) Limiting crack width under increased (design/service) loads or sustained loads.

d) Retrofitting concrete members to enhance the flexural strength and strain to failure of concrete elements requested by increased loading conditions such as earthquakes or traffic loads.

e) Rectifying design and construction errors such as undersized reinforcement.

f) Enhancing the service life of the RC slabs.

g) Shear strengthening around columns for increasing the perimeter of the critical section for punching shear.

h) Changes in the structural system such as cut-outs in the existing RC slabs.

i) Changes of the design parameters.

j) Optimization of structure regarding the reduction of deformations and of the stresses in the reinforcing bars.

The reduction of alkalinity of the concrete leads to the oxidation of the reinforcing steel. As a direct consequence due to the corrosion of the reinforcement premature cracking occurs which leads to reduced strength, stiffness, and service life as well as concrete failure, which in turn can lead to structural failure. The corrosion of steel reinforcing bars weakens concrete structures as a result of tension caused by the expansion of corroded steel. The concrete members which are affected by the corrosion of the reinforcement need rehabilitation to restore their strength and stiffness. The rehabilitation may occur only after controlling the corrosion rates through different conventional means such as cathodic protection.

6. 3 Section Enlargement

Section enlargement is one of the methods used in retrofitting concrete members. Enlargement consists of the placement of reinforced concrete jacket around the existing structural member to achieve the desired section properties and performance. The main disadvantages of such system are the increase in the concrete member size obtained after the jacket is constructed and the need to construct a new formwork. With section enlargement slabs can be enlarged to increase their load-carrying capacity or stiffness. A typical enlargement is approximately 5…8 cm for slabs. The strengthening by section enlargement can be performed in two ways

a) Strengthening by adding the new reinforcement and new concrete layer to the bottom of the structural element.

b) Strengthening by adding the new reinforcement and new concrete layer to the top face of the RC member.

In this technique the most important problem is to ensure an appropriate bonding between "old" concrete in the existing structure and "new" concrete applied for strengthening the structure. In particular it must be considered the shrinkage of these two concretes.

From the two methods it is considered that strengthening by adding new reinforced concrete layer is much easier to be realized when the works are performed on the top face of the member. From practice it is observed that in many cases it is necessary to add the new reinforced concrete in the bottom face of the member, especially in their positive bending moments zones. Concreting of the bottom face requires the use of special formwork or can be done by shotcrete.

6. 3.1 Section Enlargement Steps

In some cases, and due to increasing the applied loads on slabs or their unsafe design, or corrosion of the reinforcing steel bars, or cracks in the slabs, one of the following solutions should be made:

1. If the slab is unable to carry the negative moment and the lower steel is sufficient, upper steel mesh should be added with a new concrete layer.

2. If the slab is unable to carry the positive moment or when the dead load (that will be added to the slab)is much less than the live load carried by the slab , a new concrete layer on the bottom of the slab should be added.

In order to implement the previous solutions, the following steps should be made as shown in Figure 6.1 and Figure 6.2

1. Removing the concrete cover.

2. Cleaning the reinforcing steel bars using a wire brush or a sand compressor.

3. Coating the steel bars with an epoxy material that would prevent corrosion.

4.If a high percent of corrosion was found in the steel bars, a new steel mesh, designed according to the codes' requirements, must be added.

5.The new reinforcing steel mesh is then installed and fastened vertically to the slab of the roof and horizontally to the surrounding beams ,using steel dowels.

6. Coating the concrete surface with an appropriate epoxy material that would guarantee the bond between the old and new concrete.

7.Before the epoxy dries, the concrete is poured with the required thickness .Additional materials that would lower the shrinkage should be added to the concrete.

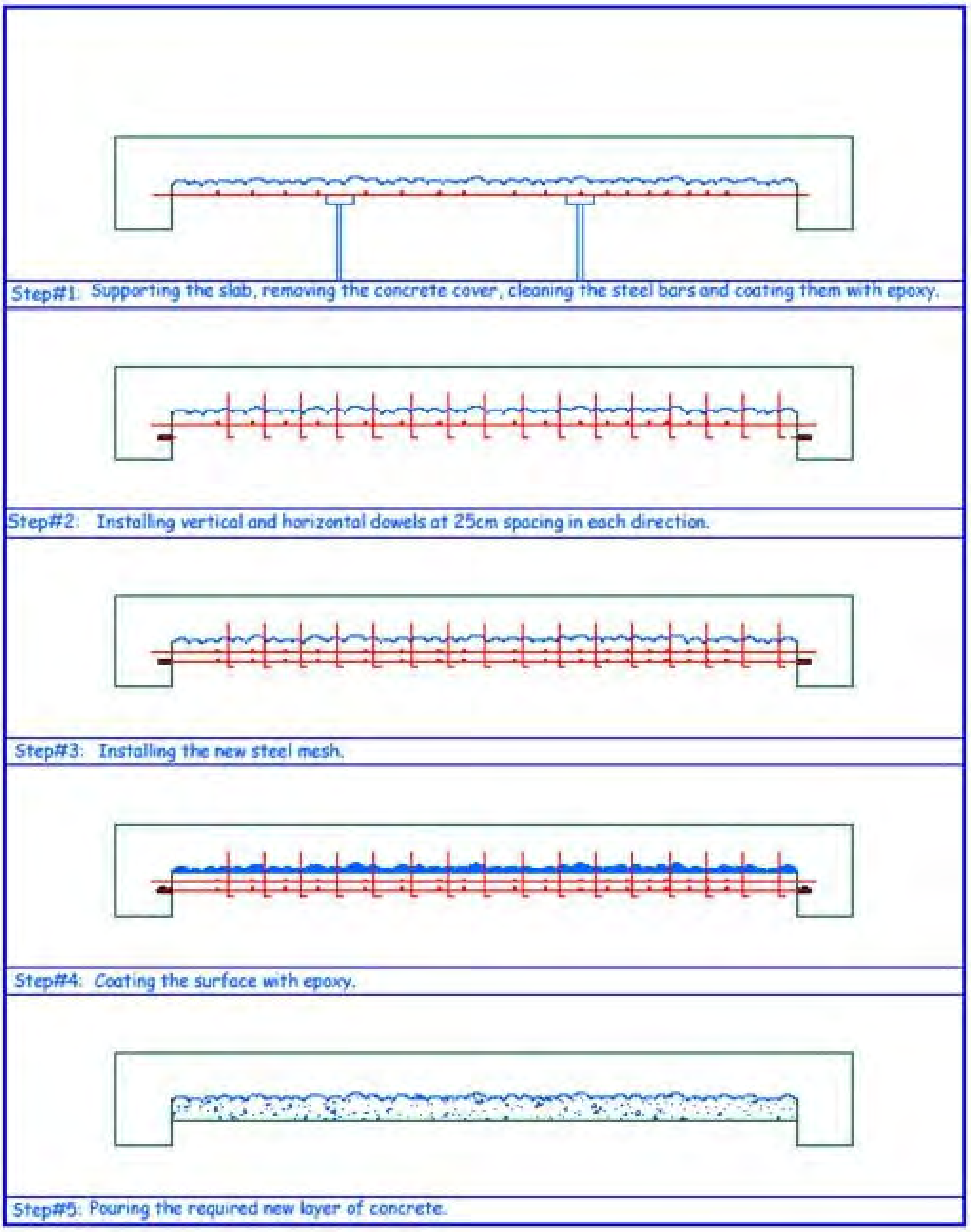


Figure 6.1 Strengthening a slab by increasing its depth from bottom

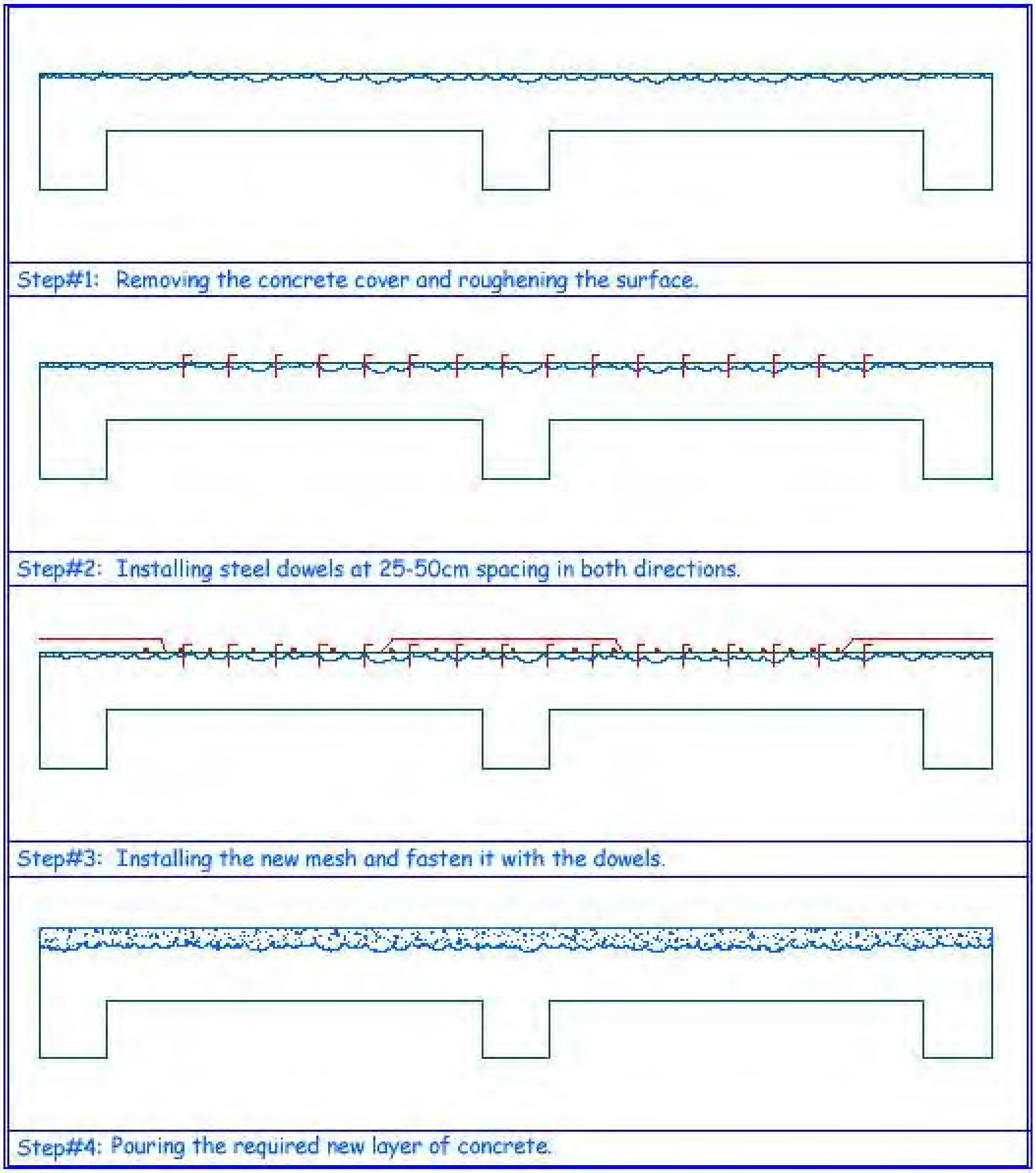


Figure 6.2 Strengthening a slab by increasing its depth from top.

6.4 External Steel Plate Bonding.

This method was first used more than 30 years ago in France, in the mid 1960s and it is considered by some publications to be a "classic" method. It consists in bonding steel plates or steel flat bars to the structural elements and it is widely is strengthening of bridge structures.

The bonding of the steel plates or steel flat bars to the concrete members is ensured by the use of epoxy adhesives and in some cases, additional fastening is provided by means of dowels or bolts glued to the holes drilled in the concrete members .

In the case of RC slabs strengthening this method is used to augment the member's bending resistance. Therefore, the steel plates or steel flat bars can be applied to the bottom or upper faces of the reinforced concrete slab to ensure the bending resistance (positive or negative bending moments zones). One of the disadvantages of this method is that it can be applied only to the relatively sound structures. In case of severe concrete deterioration and major cracks of the RC member other methods should be considered.

The decisive factor for the effectiveness of strengthening in this method is given by the quality of the contact layer between the concrete surface and the steel plates or flat bars. The quality of the resin adhesives represents a fundamental problem.

Design procedure is based on general principle concerning the concrete design of glued joints or glue–bolt and glue–dowel joints. The basic assumption is that the integrity of the plate-adhesive and adhesive–concrete interface is maintained and that structural integrity prevails up to the expected pick load .

Figure 6.3 Strengthening a RC slab by external steel plate bonding.

6.5 Strengthening of RC Slabs by Adding steel beams.

The main idea of this method is to decrease the RC slab span or to change the load distribution from one way slab to two way slab, which both mean decreasing in the flexural moment.

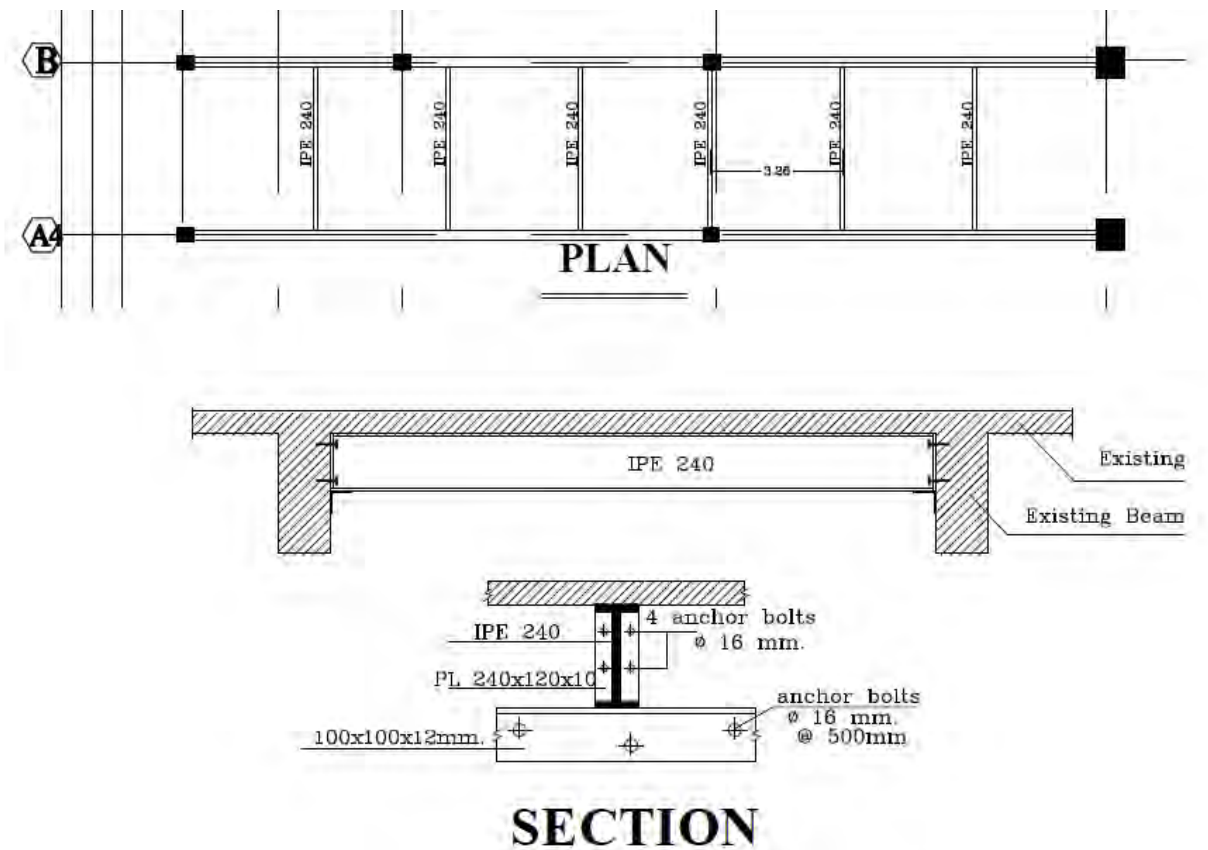


Figure 6.4 Strengthening a RC slab by adding steel beams.

Figure 6.5 Steel beams installing.

6. 6 Strengthening of RC Slabs By Using FRP.

Generally speaking, the two-way RC slabs are elements subjected to flexure with irrelevant shear effect. That is why they are susceptible rather to flexural than shear failure. This particularity makes the use of composite materials in two-way RC slabs strengthening to be considered as an optimal solution. In addition to the important increase in serviceability and flexural capacity, using of FRP strengthening methods is justified by its unlaborious appliance. The reserve in using of FRP materials in strengthening of flexural structural members is the brittleness of such materials that can cause a decrease in the element's stiffness. The retrofitting method, same as one-way RC slabs, presumes the laying up of the lamellas or sheets bonded on the tensioned side by using resins, the FRPs being, off course, mounted parallel to both length and width of the slabs. This method increases the capacity in both directions of the element.

Figure 6.6 Strengthening of RC slab by using FRP.

Figure 6.7 Strengthening of one way RC slab By using FRP.

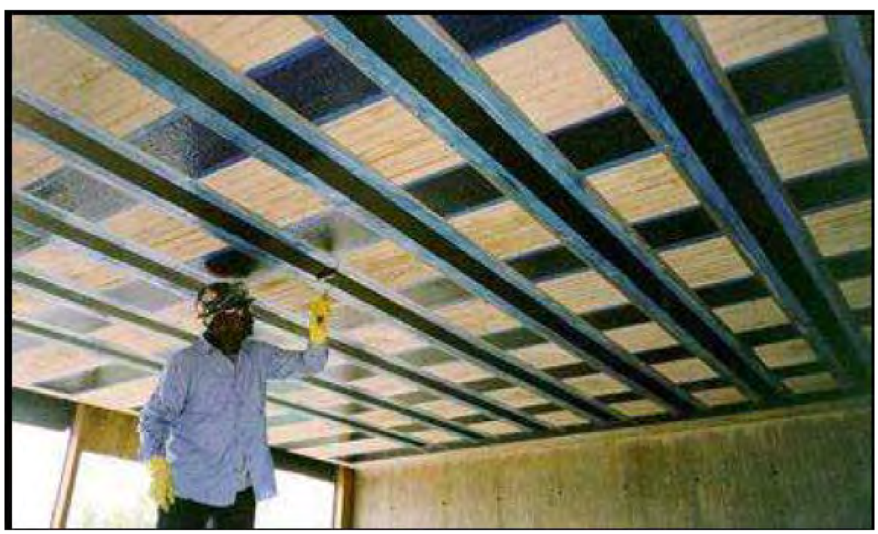


Figure 6.8 Strengthening of two way RC slab by using FRP.

6. 7 Strengthening of RC Slabs by External Post Tension.

This strengthening method is considered to be a classic method that has been used since the 1950s. It is very effective in increasing the flexural and shear capacity of concrete members. The technique is applied to RC slabs to correct the excessive deflections and cracking. The repair system supplements minimal additional load to the structure thus being an effective economical strengthening technique. The post-tensioning forces are delivered by means of standard prestressing tendons or high-strength steel rods, usually located outside the original section. The tendons are connected to the structure at anchor points, typically located at the ends of the member. End-anchors can be made of steel fixtures bolted to the structural member, or reinforced concrete blocks that are cast *in situ*. The desired uplift force is provided by deviation blocks, fastened at the high or low points of the structural element. Before the strengthening technique can be applied necessary repairs to the structural members must be performed. The existing cracks must be repaired by means of epoxy injecting or other known methods. If there are existing spalls patching must be done, because this repairs must ensure that the prestressing forces are distributed uniformly across the section of the member. This method has been effectively applied in bridge rehabilitation, and in all the cases it has chosen because of its advantages, being economical and requiring less time to complete. The system provides active forces and therefore was more compatible with existing construction

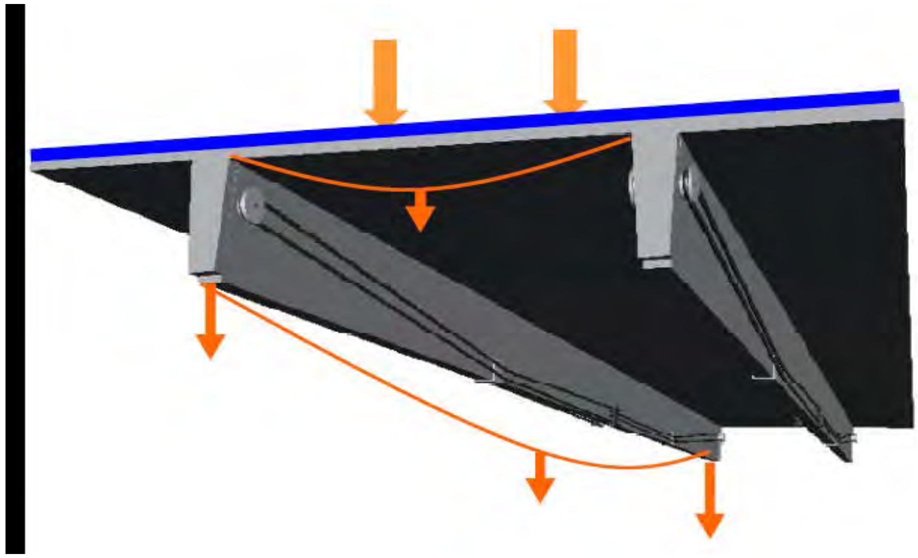


Figure 6.9 External actions due to additional load .

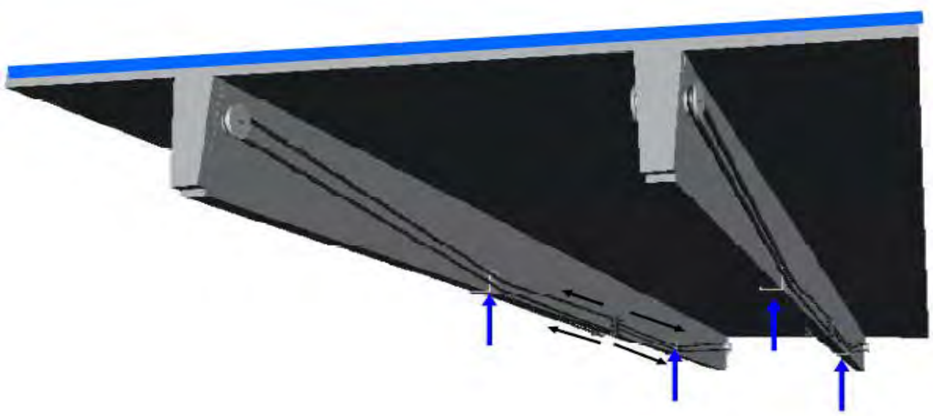


Figure 6.10 Internal forces in cable due to post tensioning.

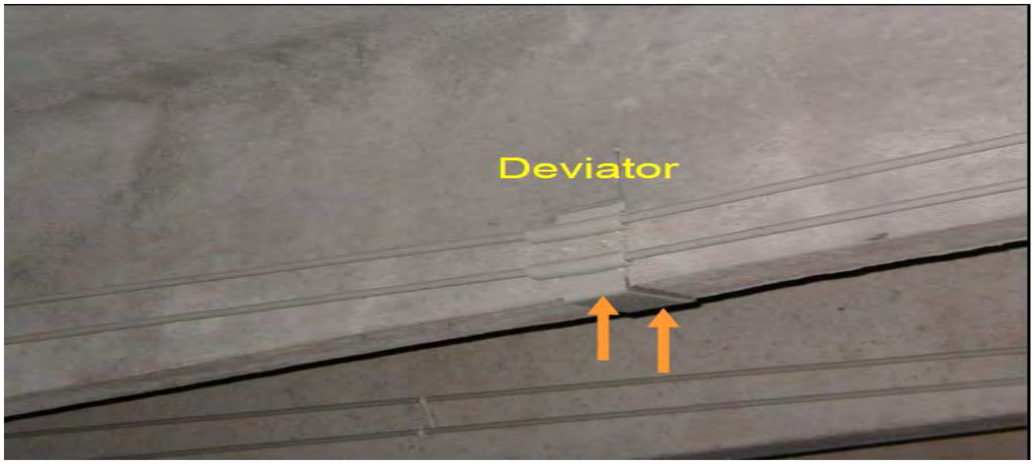


Figure 6.10 Cable deviator added to make a profile similar to the bending moment .

Figure 6.11 Cable end.

Figure 6.12 Cable jacking from life end.

6.8 Strengthening Techniques for RC Slabs with Cut-Outs openings.

If we consider designing openings for new structures we must consider the proper detailing of additional reinforcing steel in the slab or beams, or thickening of portions of the slab around openings. In the case of existing structures the method of approach changes. First it must be determined if the structure can accommodate new openings without strengthening. If strengthening is requested the situation becomes more complex and strengthening techniques must be considered.

6.8.1 Adding Steel Plates around the openings.

The most used method for increasing the moment capacity is to add steel plates to the surface of a slab, connected with the help of bolts or post installed anchors. Although the installation of the steel plates is rather easy it has to be considered that it must not interfere with the flooring system. When using bolts for connecting the plates, they interfere with the flooring system.

Normally the plates are installed on the bottom of the slab with post-installed anchors. A disadvantage of this method is that overlapping difficult, thus it works best when strengthening is required in only one direction.

Figure 6.13 Adding steel plates around the openings.

6.8.2 Installing a CFRP Plates around the openings.

Another very simple technique is used , that installing a CFRP plates around the required opening before cut out the slab . this technique is the easiest and the fastest technique although it's highly relative cost .

Figure 6.14 Installing a CFRP plates around the openings.

Conclusions

Each of these methods comes with a series of advantages and disadvantages. Some, like section enlargement, add considerable permanent load to the structure and may need more strengthening done to the other structural members. The external plate bonding technique and external post tensioning are susceptible to corrosion damage which may lead to failure of the strengthening system.

All of the repair techniques are very effective in increasing the element's carrying capacity or at least restoring the structural performance of the concrete members before deterioration. The selection of the most appropriate method to use will depend on several factors, such as the amount of strengthening required, the location where strengthening is required, architectural requirements, simplicity and speed of application, and total cost

REFERENCES

[1] Shri. Pravin B. Waghmare.2011. "MATERIALS AND JACKETING TECHNIQUE FOR RETROFITTING OF STRUCTURES. "International Journal of Advanced Engineering Research and Studies Vol. I/ Issue I/October-December, 2011/15-19.

[2] CIPRIAN COZMANCIUC, RUXANDRA OLTEAN and VLAD MUNTEANU.2009. "STRENGTHENING TECHNIQUES OF RC COLUMNS USING.

[3] FIBRE REINFORCED POLYMERIC MATERIALS." BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI Publicat de Universitatea Tehnică.

[4] Kenji SAKINO And Yuping SUN." STEEL JACKETING FOR IMPROVEMENT OF COLUMN STRENGTH AND DUCTILITY"Graduate School of Human Environment Studies, Kyushu University, Fukuoka, Japan.

[5] Website http://theconstructor.org/

[6] Dr. Gopal L. Rai "Different Strengthening Techniques for RC Columns." R&M International Pvt. Ltd.

[7] E S Ju´ lio, F Branco and V D Silva .2003 "Structural rehabilitation of columns with reinforced concrete jacketing" REPAIR AND REHABILITATION Published online 26 February 2003.

[8] Nasreddin S. El-Mezaini. "REPAIR AND STRENGTHENING OF REINFORCED CONCRETE STRUCTURES. "faculty of engineering , Gaza University.

[9] Dat Duthinh and Monica Starnes. 2011 "Strengthening of Reinforced Concrete Beams with Carbon FRP" National institute of standards and technology.

[10] Yunlan Zhang. 2012. "Repair and Strengthening of Reinforced Concrete Beams" HONORS THESIS The Ohio State University.

[11] DRAGOŞ BANU and N. ŢĂRANU.2010." TRADITIONAL SOLUTIONS FOR STRENGTHENING REINFORCED CONCRETE SLABS" BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI Publicat de Universitatea Tehnică .

[12] SORIN-CODRUŢ FLORUŢ, VALERIU STOIAN, TAMÁS NAGY-GYÖRGY, DANIEL DAN and DAN DIACONU "Retrofitting of two-way RC slabs with and without cut-out openings by using FRP composite materials" Department of Civil Engineering University of Timisoara.

[13] Nima Tafazzoli and Behrouz Shafei "Methods of Strengthening of the Shallow Foundations" 7th International Congress on Civil Engineering.

[14] Case studies projects from CPAS "Center of Planning and Archtecural Studies", Cairo, Egypt.

[15] L .C HOLLAWAY AND M .B LEEMING "Review of materials and techniques for plate bonding" .

[16] Structural Preservation Company "Strengthening and Repair of Reinforced Concrete Structures".

Case Studies

Case (A) Crystal Asfour Factory 3, Bahteem, Egypt

A.1 Description

Crystal Asfour company decided to buy and reuse an old Textile spinning factory consist of five reinforced concrete workshops, An elevated reinforced concrete tank and a fence as shown in figure A.1

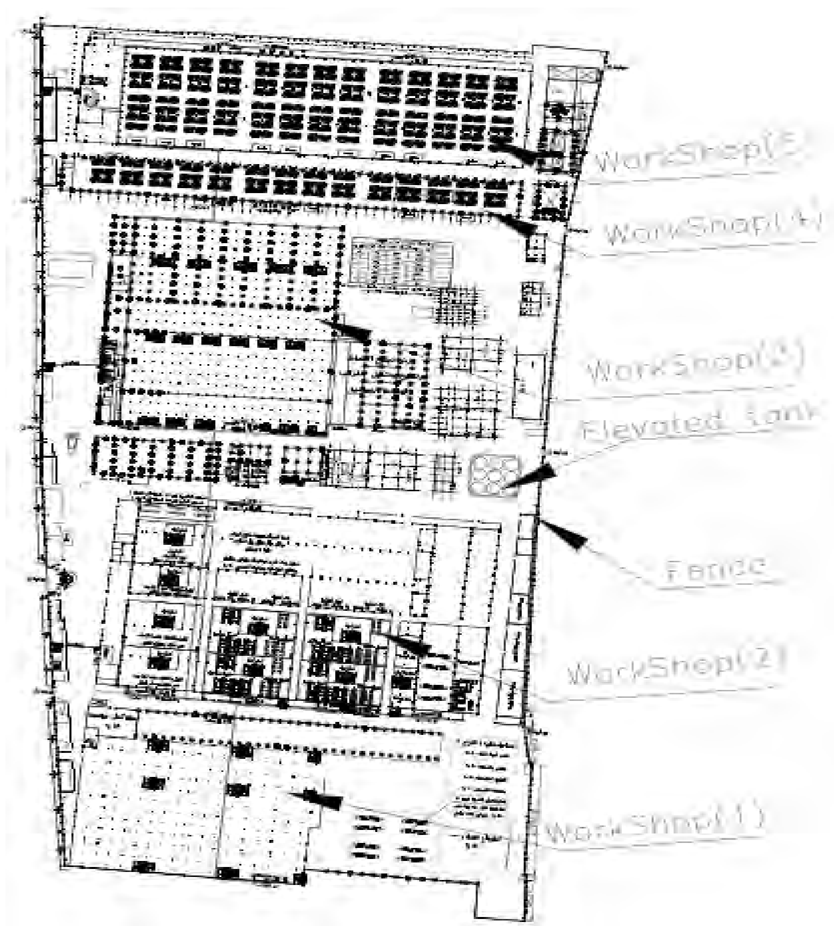


Figure A. 1 Layout of Crystal Asfour Factory 3.

A.2.1 Workshop (1)

a) The problems

Workshop (1) has a traditional columns and beams statical system except the last span which has a Saw Tooth system as shown in figure A.2 .

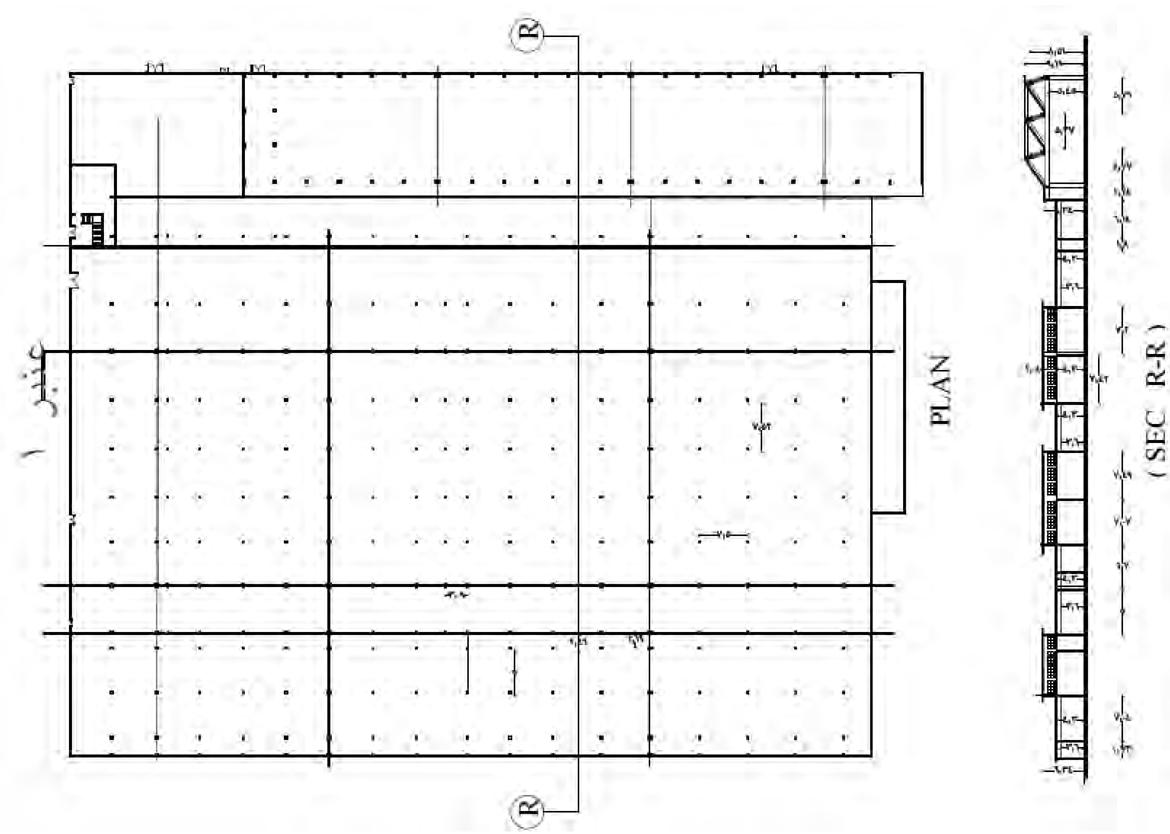


Figure A. 2 Workshop (1) statical system.

By visual inspection it’s clear that the columns hatched in figure A.3   are with dimensions of 35 X35 or less and a clear height of more than 6.30m and its concrete was damaged which mean it wouldn’t be safe to use under these conditions as shown in figures (A.4, A.5 , A.6) .

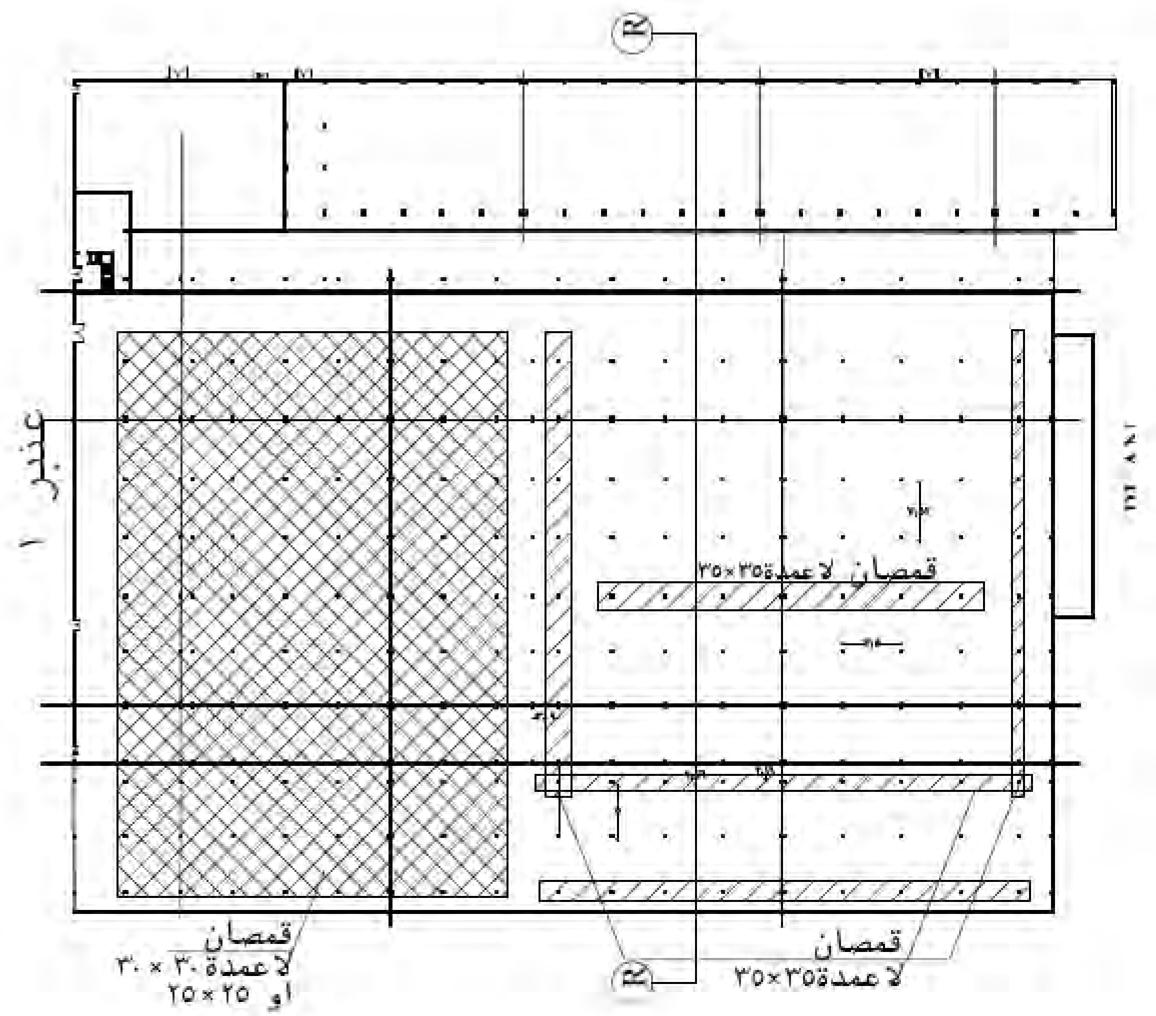


Figure A. 3   Columns need strengthening in workshop (1).

Figure A. 4 Columns concrete damaged.

Figure A. 5 Column with longitudinal cracks.

Figure A.6 Columns with clear height of more than 6.3m

and a concrete dimensions of 35X35 or less.

b) The solutions

The columns and the isolated footings were strengthened by means of reinforced concrete jacketing as shown in figures (from A.7 to A.15)

Figure A.7 Excavation around the footing.

Figure A.8 Installing the main steel of the footing jacket.

Figure A.9 Completing the main steel of the footing jacket.

Figure A.10 Interaction between the column jacket steel and the footing jacket steel.

Figure A.11 Completing casting the footing jacket

and installing reinforcement steel jacket of the columns.

Figure A.12 Installing reinforcement steel jacket of the columns.

Figure A.13 Rebar's splice between column's jacket main steel and steel dowels planted in the footing jacket.

Figure A.14 Steel dowels between the old concrete and the jacket.

Figure A.15 Preparing casting of the concrete jacket.

A.2.2 Workshops (2 & 3)

a) The problems

Workshops (2&3) have a Saw Tooth system as shown in figure

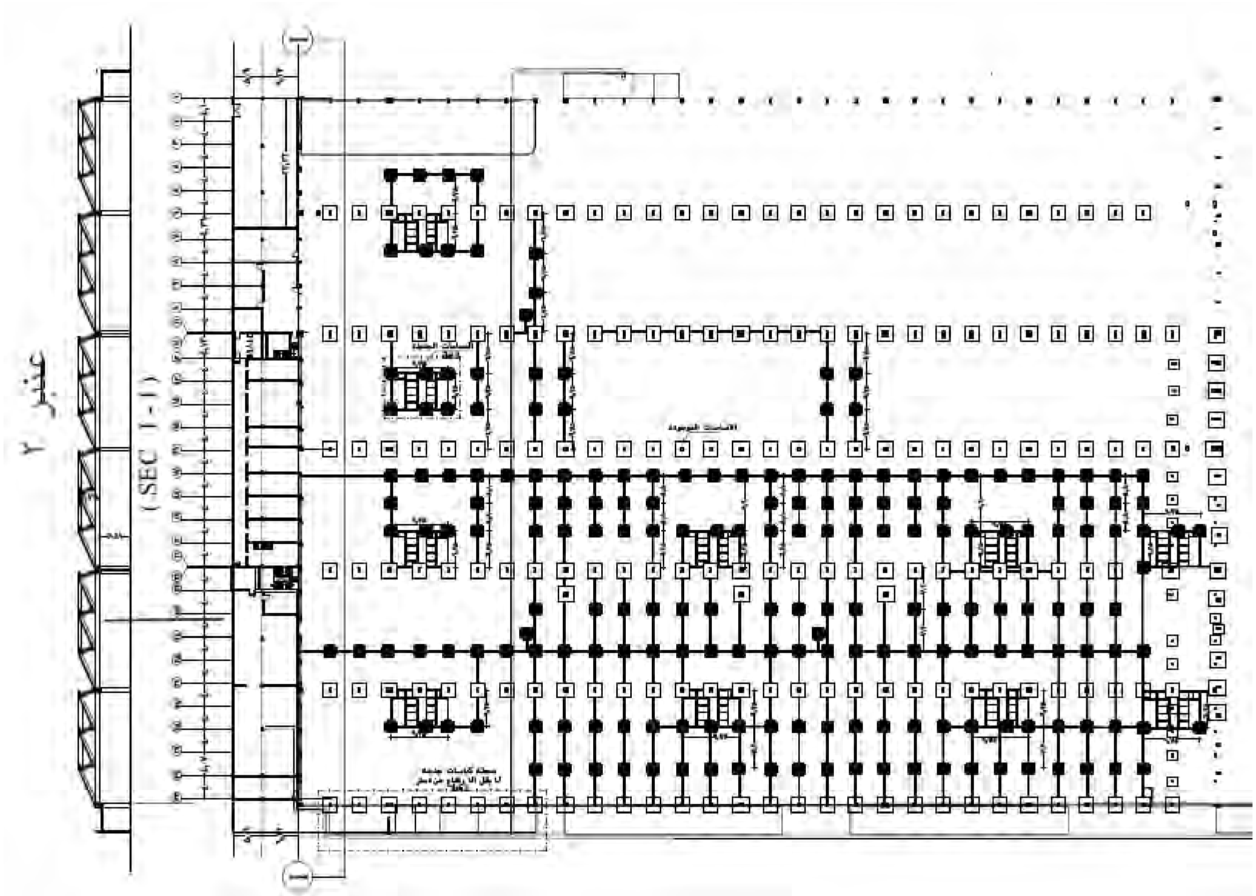


Figure A.16 Workshop (2) statical system.

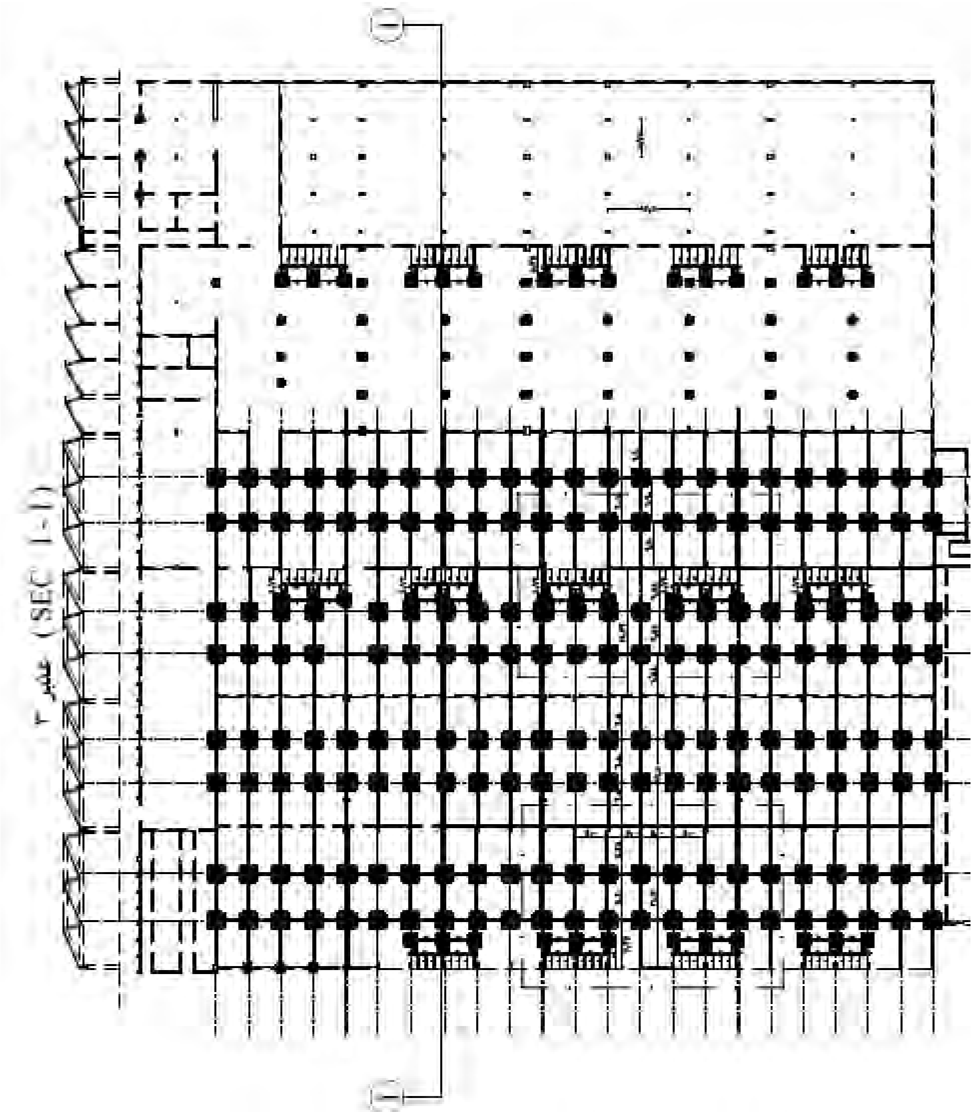


Figure A.17 Workshop (3) statical system.

By visual inspection it was clear that

I) At workshop (2)

1-Parts of the saw tooth slabs concrete were damaged and steel rebar corrosion was found which mean it wouldn’t be safe to use under these conditions as shown in figure 7.18.

2-It decided that some of the saw tooth upper girders carry additional loads due to air condition units and it was found that it wouldn’t be safe to use under its condition of damaged concrete as shown in figures (A.19, A.20)

II) At workshop (3)

1- Some of the saw tooth lower girders were found wouldn’t be safe to use under its condition of damaged concrete as shown in figures

Figure A.18 Damaged slabs in workshop (2).

Figure A.19 Damaged girder.

Figure A.20 Damaged slab and girder in workshop (2).

b) The solutions

I) Workshop (2)

1-The damaged slabs replaced by corrugated sheets carried on secondary steel beams as shown in figure A.21.

2- The upper girders were strengthened by means of steel angels and plates

As shown in figures (A.22, A.23).

II) Workshop (3)

1-The lower girders were strengthened by means of steel angels and plates

as shown in figures (from A.24 to A.27).

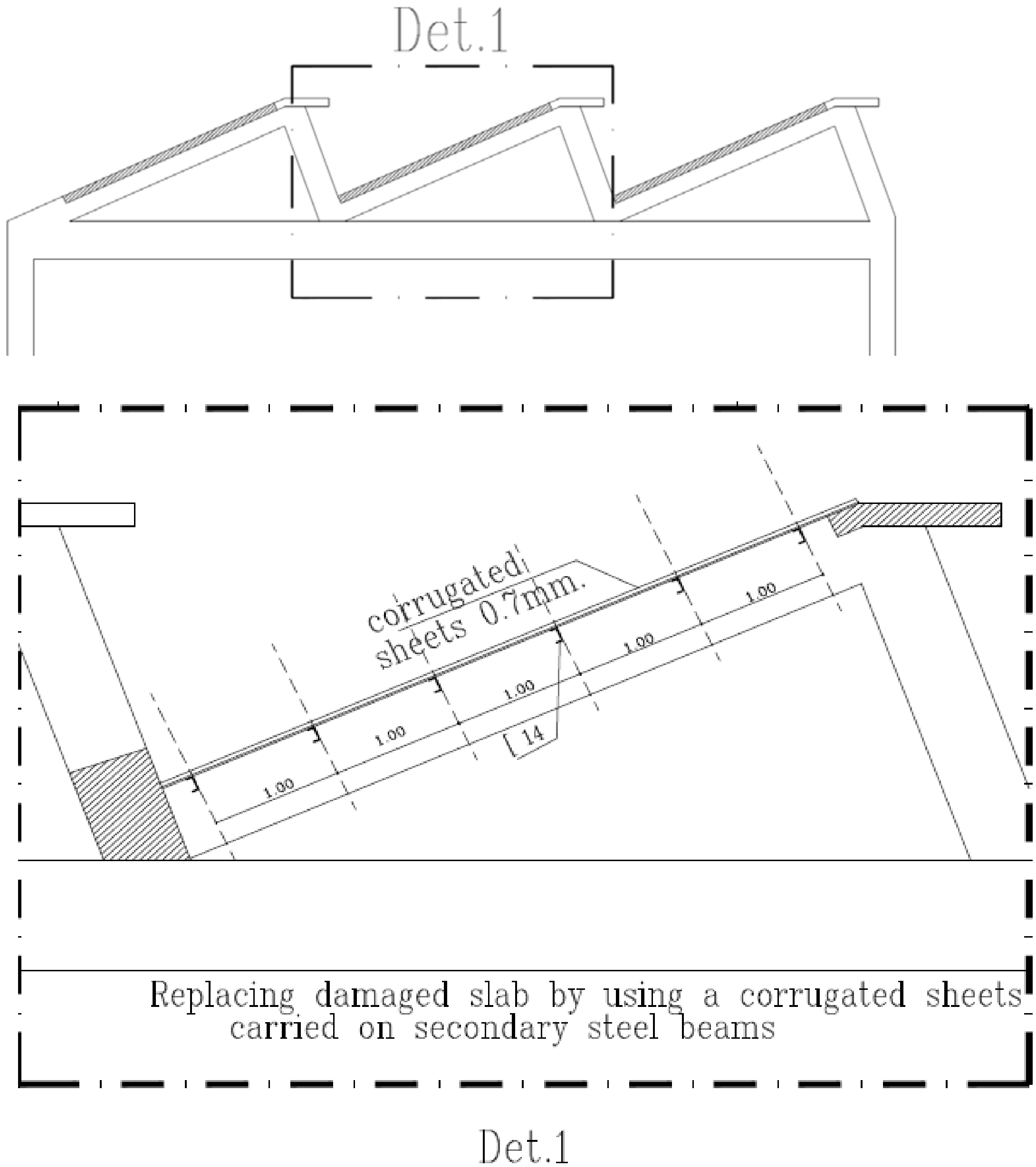


Figure A.21 Replacing damaged slab by corrugated sheets

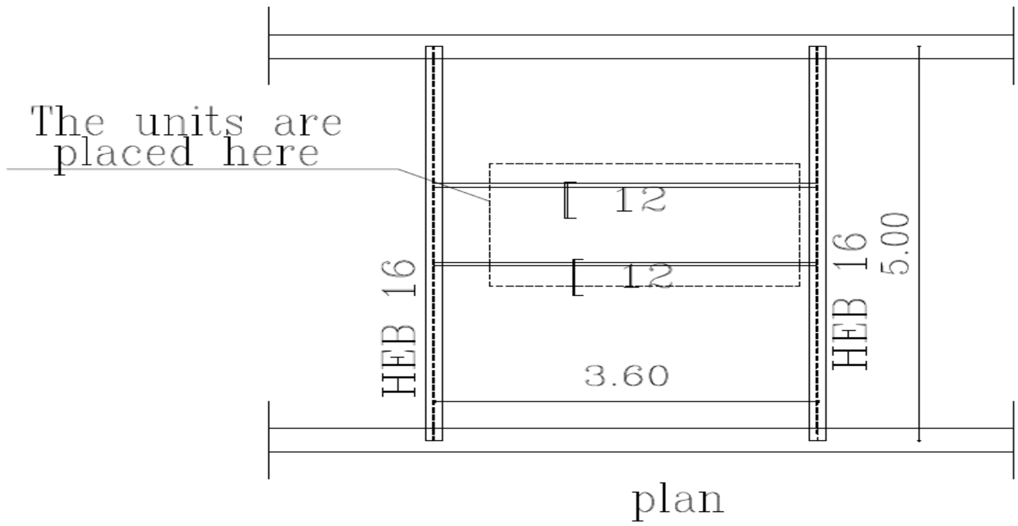


Figure A.22 Plan show air condition units carried on secondary steel beams loaded on the girders in workshop(2)

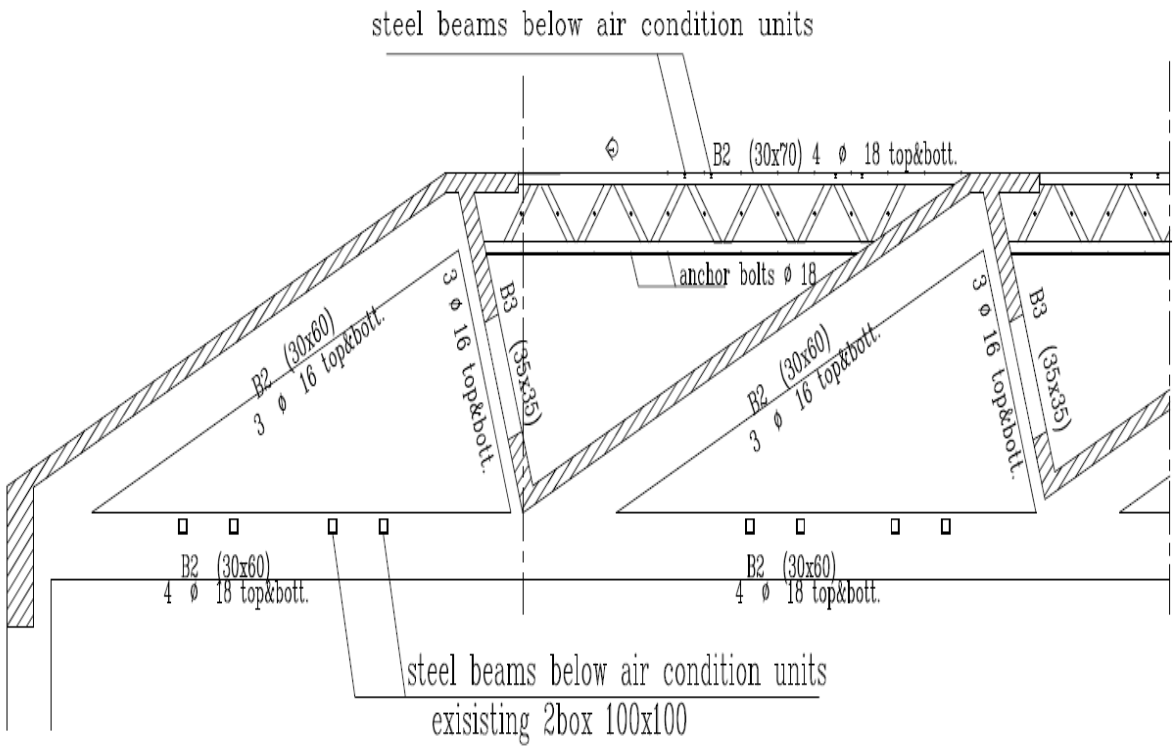


Figure A.23 Upper girders strengthened in workshop (2)

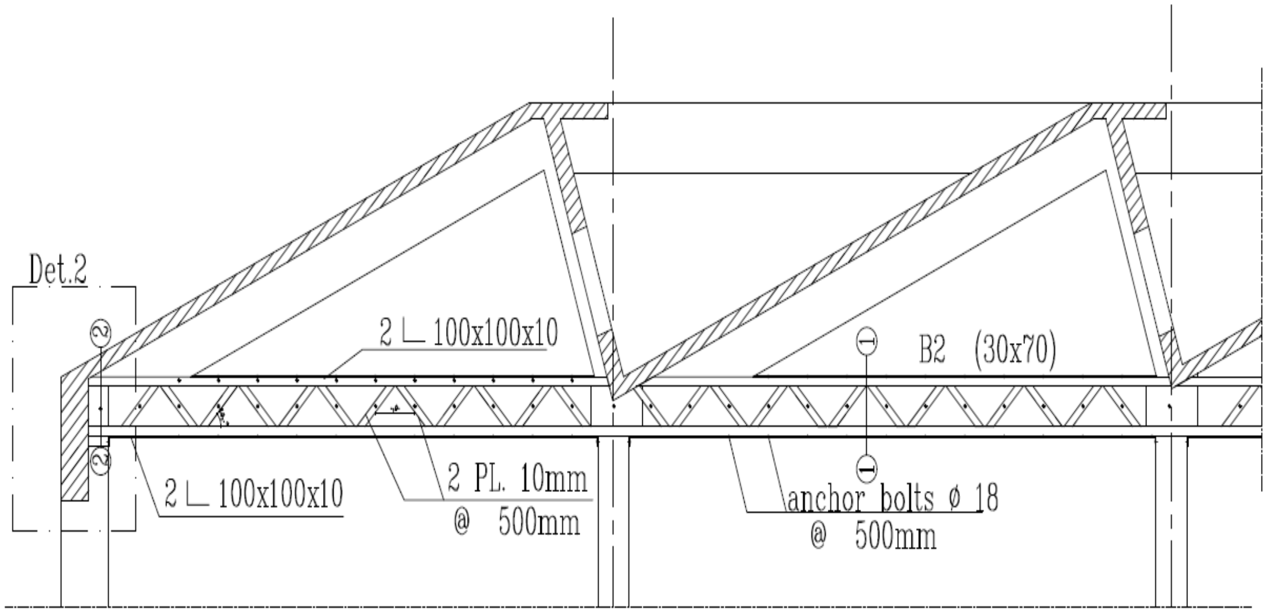


Figure A.24 Lower girders strengthened in workshop (3).

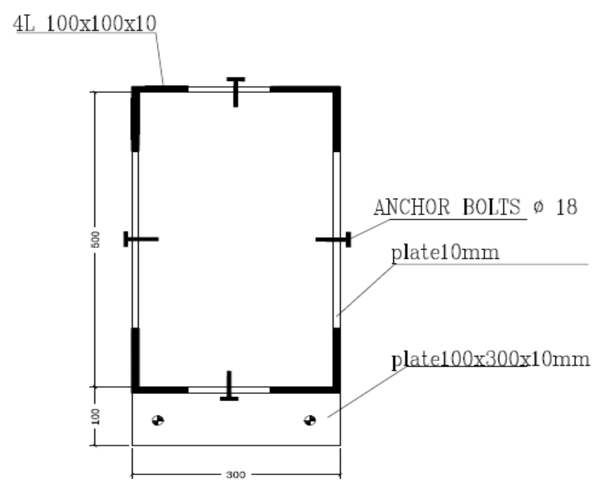


Figure A.25 Section in the mid span .

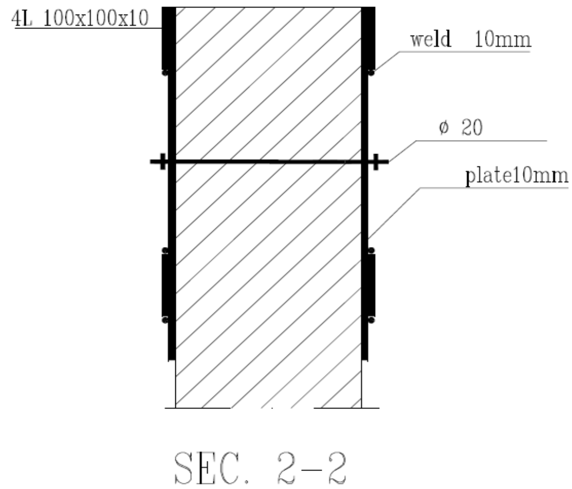


Figure A.26 Section near the support.

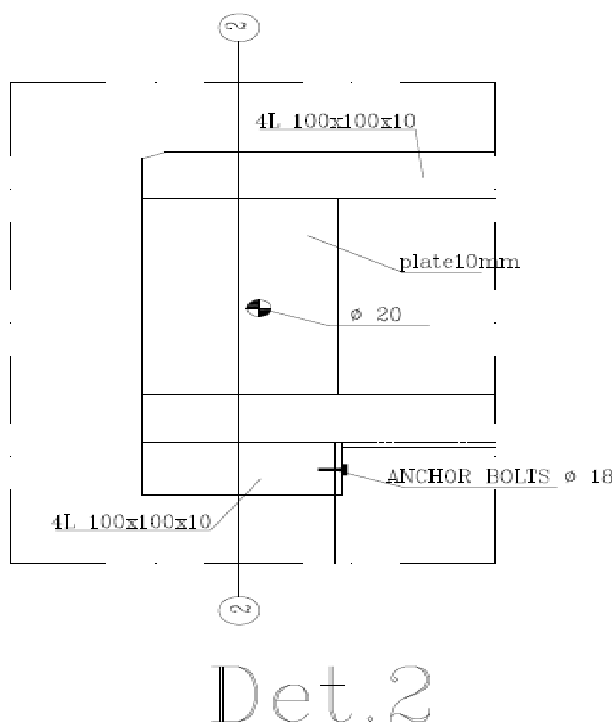


Figure A.27 Connection Detail at end support.

Figure A.28 Completing girders strengthening.

A.2.3Workshop (4)

a) The problems

Workshop(4) has an arch girder system and by visual inspection it's clear that concrete members were in a good condition except some surface cracks , and by making of nondestructive tests and calculations it was found that concrete members acceptable to reuse without strengthening , just surface cracks should be treated .

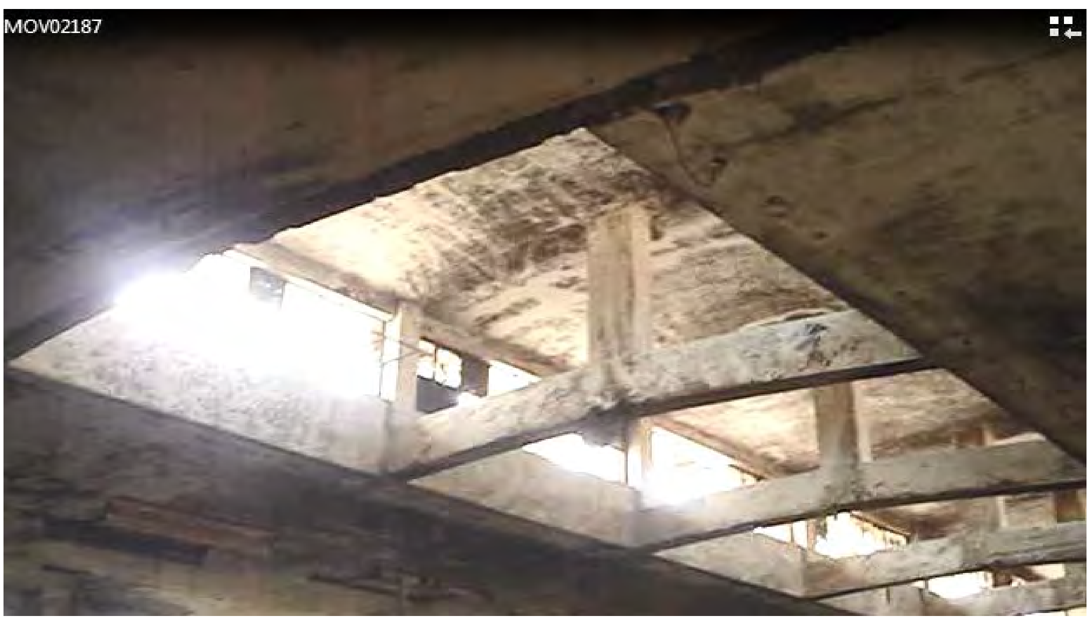


Figure A.29 Workshop (4) members with good condition.

b) The solutions

Surface cracks treated by mean of injection.

Figure A.30 Workshop (4) after repairing and coating.

A.2.4Workshop (5)

a) The problems

Machines needed to be added on a specified zone of the slab which was not designed at this additional load.

b) The solutions

The slab was strengthened by means of steel beams as shown in figure A.31.

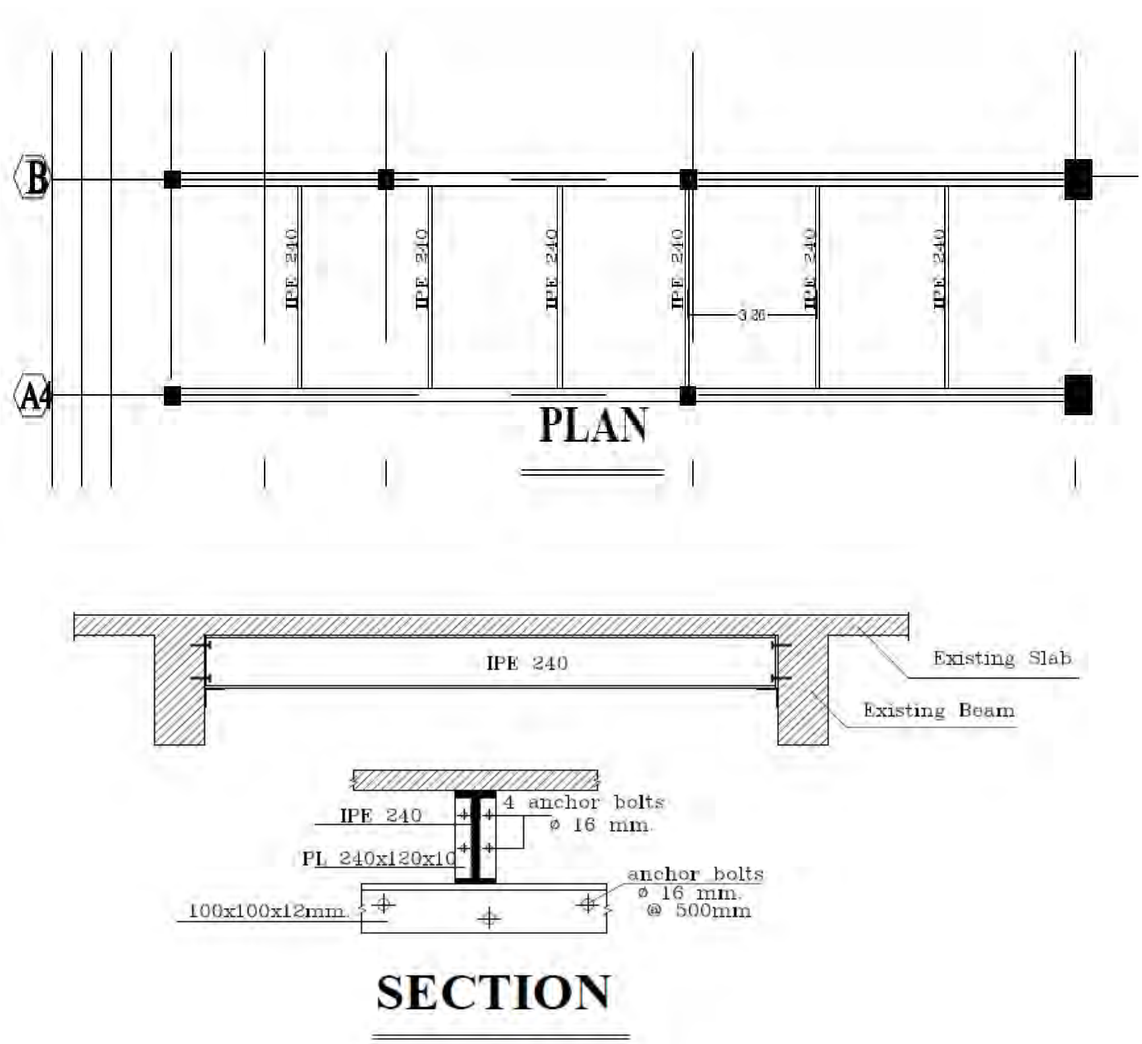


Figure A.31 Slab strengthened by means of steel beam.

A.2.5 Elevated tank

The elevated reinforced concrete tank consist of

1- RC columns tied with RC beams at different levels and RC slab in the first level as shown in figure A.32.
2- Tank body (RC walls, RC floor and RC slab).

Figure A.32 Elevated tank.

a) The Problems

By visual inspection it’s clear that

1-RC columns and beams are damaged in the first level and it wouldn’t be safe to use under its condition as shown in figures (from A.33 to A.35).

2- Tank body (RC walls, RC floor and RC slab) concrete was completely unsuitable to reuse and it wasn’t any isolation due to water as shown in figure A.36.

Figure A.33 Damaged column in the first level.

Figure A.34 Damaged Beam in the first level.

Figure A.35 Damaged Beam and column in the first level.

Figure A.36 Tank body water effect due to not isolation.

b) The solutions

1-The columns, beams were strengthened by means of reinforced concrete jacketing as shown in figures(from A.37 to A.40) . The isolated footings were found safe.

2-Tank body decided to repaired by installing a new reinforcement mesh and cast a new concrete layer as shown in figures (from A.41 to A.43).

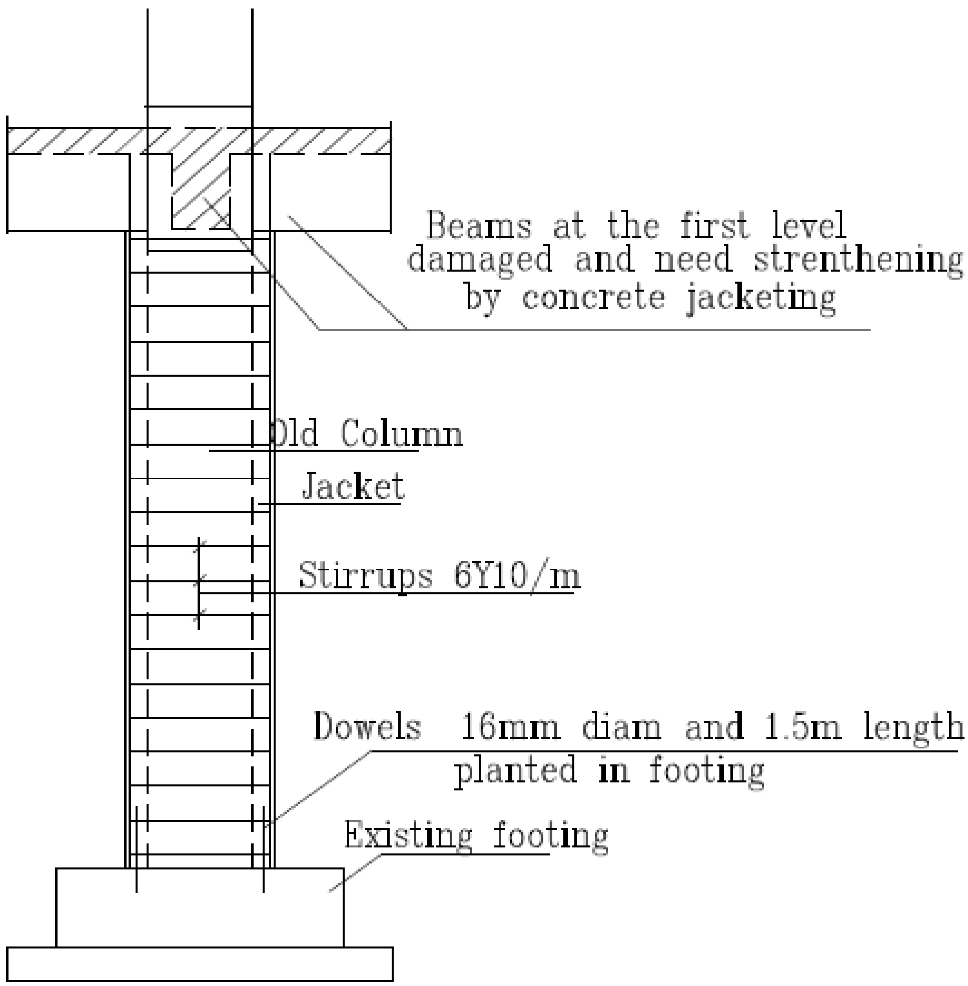


Figure A.37 Columns and beams concrete jacketing.

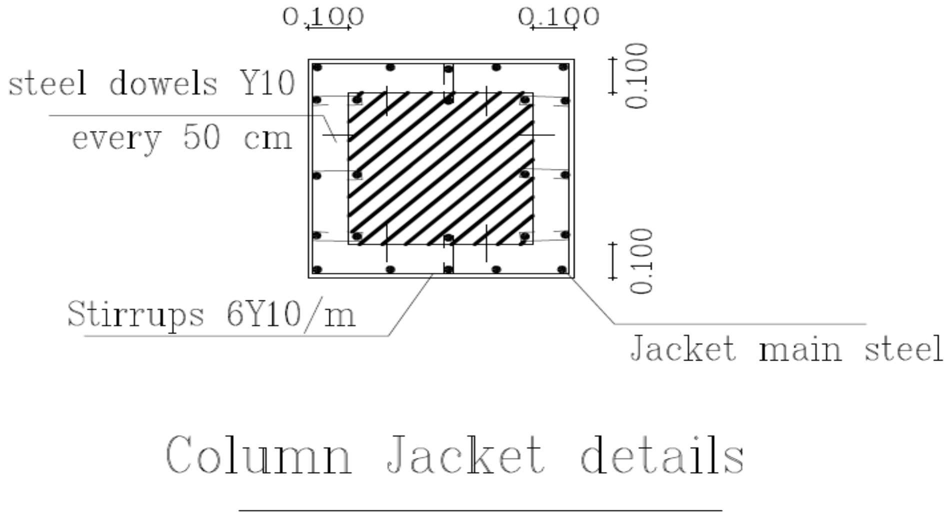


Figure A.38 Column jacket details.

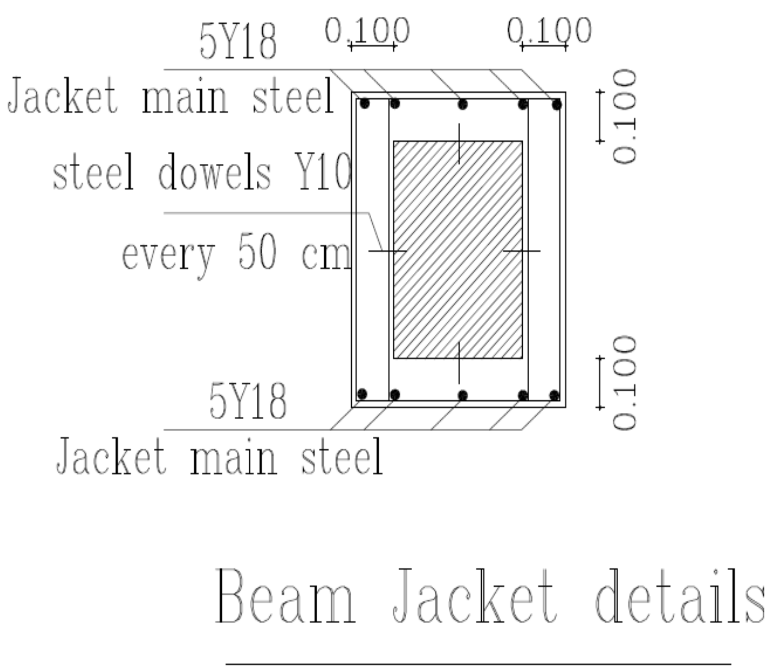


Figure A.39 Beam jacket details.

Figure A.40 Completing of columns and beams concrete jacketing.

Figure A.41 Installing a new reinforcement mesh.

Figure A.42 Dowels between tank floor and the new layer.

Figure A.43 Dowels between tank wall and the new layer.

A.2.6Fence

a) The problems

The fence was around the four side of the factory, two side of the fence were damaged as shown in figures (A.44 and A.45) .

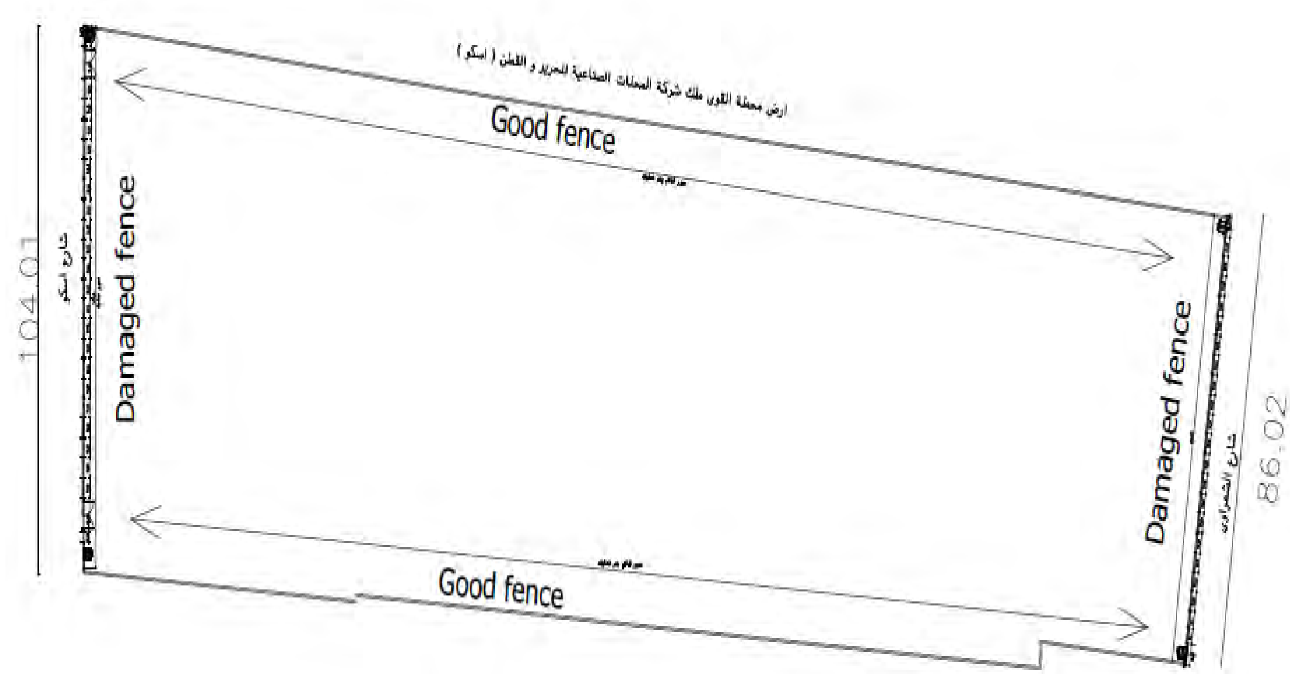


Figure A.44 Fence layout.

Figure A.45 Damaged fence.

b) Solutions

It was two alternatives solutions, first alternative was to replace the damaged fence the second alternative solution was to repair and strengthening of the damaged fences by the traditional strengthening techniques.

After a feasibility study it decided to choose the first alternative as it was more economic because of the long length of the two sides (104m, 86m) as shown in figure which means a large number of elements to be strengthened.

Figure A.46 New fence.

Case (B) Etisalat Misr center El Hegaz branch , Cairo , Egypt .

B.1 Description and the problems

In 2012 Etisalat Misr company decided to renew El-Hegaz branch decoration which is a ground floor in an old building consist of five stories and locate in El-Hegaz street ,Cairo. The first floor was empty which mean that the live load was zero on the Center slab. After they had removed the false ceiling , the RC slab and beams appeared and the problems was a very bad statical system that consist of solid slabs and beams , there were a long span beams with unsuitable depth and width relative to its spans and loaded with another beams , large sudden variation in beams concrete dimensions and RC column removed by a steel column . to make calculations they removed the cover to discover the amount of reinforcement steel as shown in figures (B.51 and B.52) , after making calculations with consider that the first floor became not empty and the live load became not zero it was found that some beams were be unsafe . problems shown in figures (from B.46 to B.50).

Figure B.1 Etisalat Misr center El Hegaz branch, Cairo, Egypt.

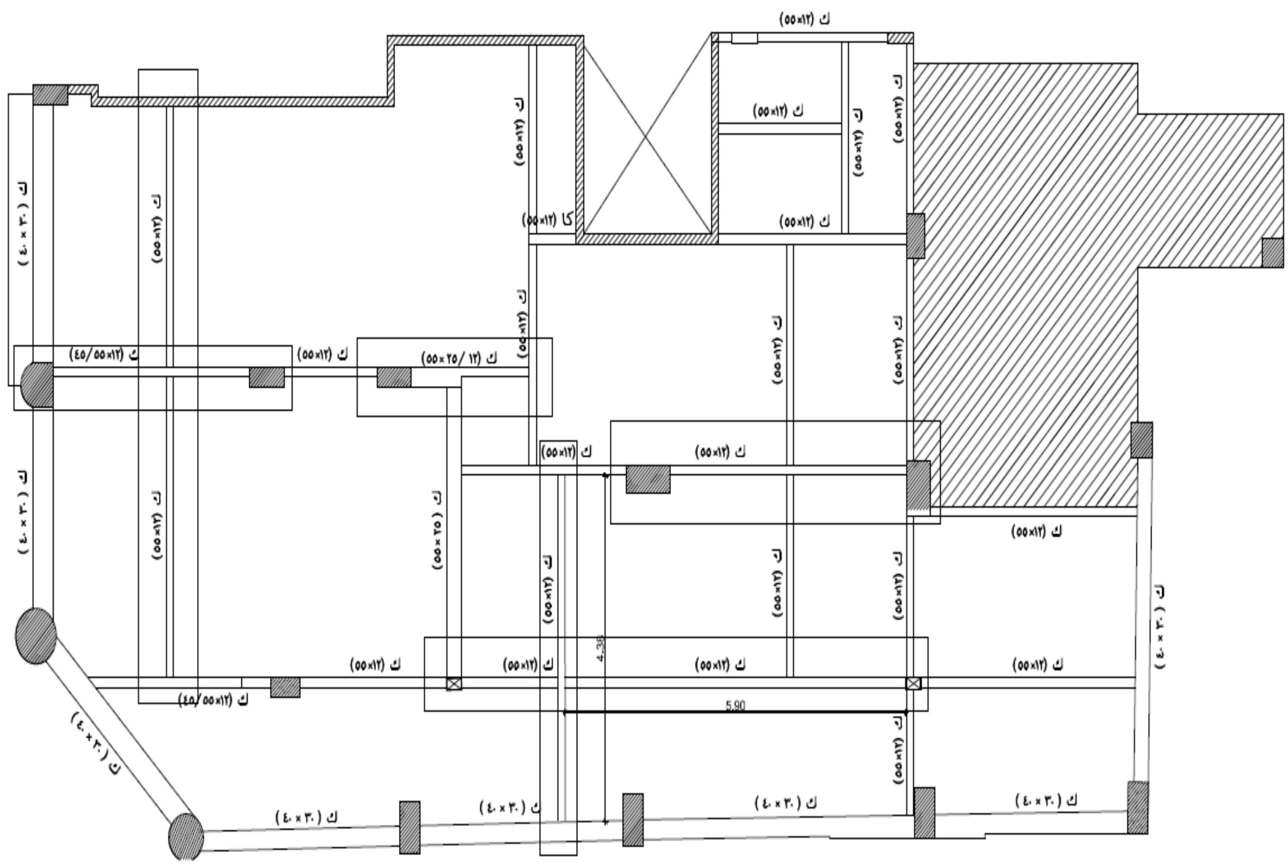


Figure B.2 Plan show beams need strengthening.

Figure B.3 Very bad beams system.

Figure B.4 long span beam with a 55 cm depth only loaded by tow beams.

Figure B.5 Beam with a sudden variation in the depth.

Figure B.6 RC Column removed by a steel column.

Figure B.7 Cover removing

Figure B.8 Jacking process during cover removing.

B.2 The solutions

It was three alternatives solutions; first alternative was to use a concrete jacketing for the beams strengthening. The second alternative solution was strengthening beams by using of steel plates, the last alternative solution was Strengthening of beams using carbon fiber plate.

After a feasibility study it decided to choose the third alternative as shown in figures (from B.53 to B.55) because it was not allowed any variation in the clear height and the time duration must be short as much as possible .

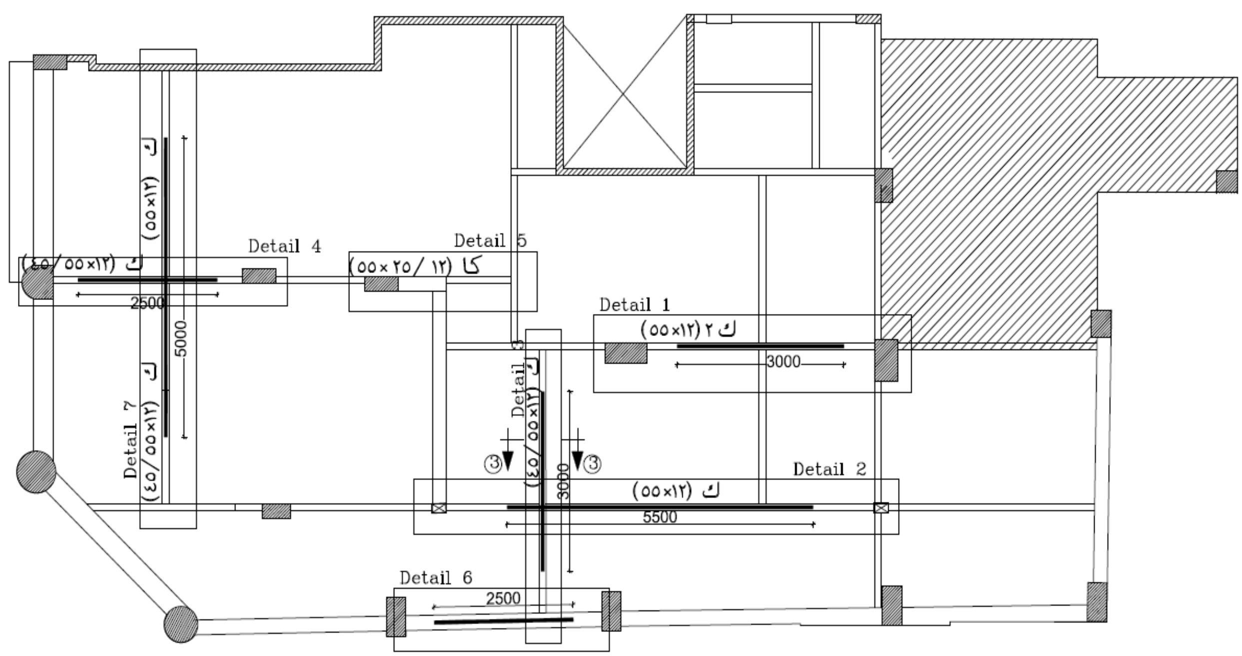


Figure B.9 Plan show beams which strengthened by CFRP.

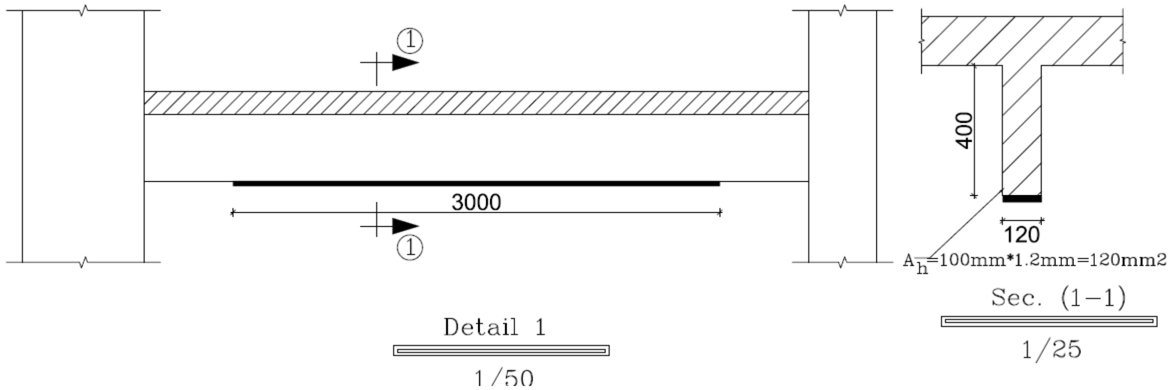


Figure B.10 Beam strengthened by CFRP at mid span.

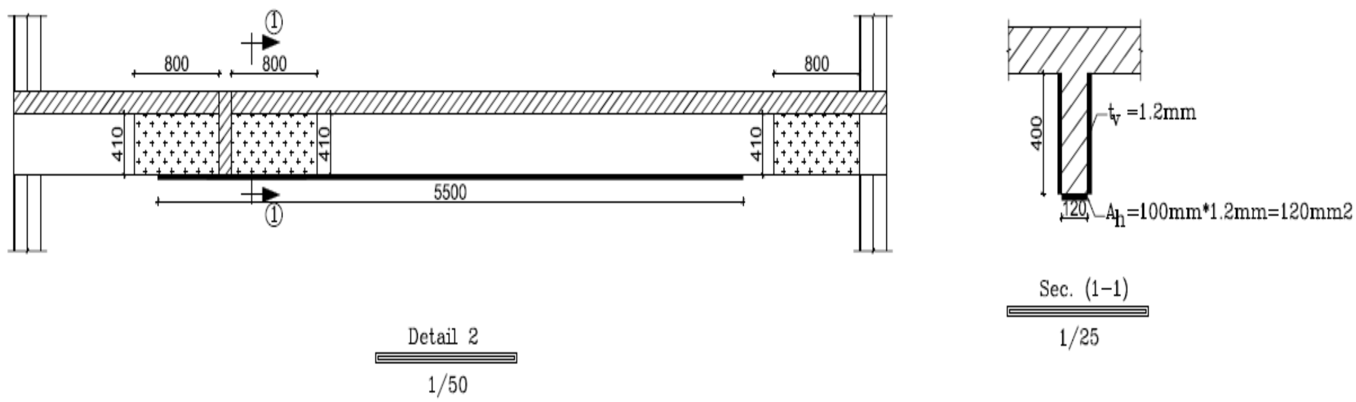


Figure B.11 beam strengthened by CFRP at

mid span and near supports.

Case(C)   Egyptian Arabian Bank (Mohamed Fareed branch), Cairo, Egypt.

C.1 Description

Egyptian Arabian Bank (Mohamed Fareed branch) is an old building consists of three floor (basement , ground and first) locate in Mohamed Fareed street , cairo , Egypt.

Figure C.1 Egyptian Arabian Bank (Mohamed Fareed branch).

C.2 The problems

Because of the long age of the building, after the visual inspection and calculations it's clear that many of the slabs and beams , stone and RC wall bearing and the two RC columns are needed to be strengthened as shown in figures (from 7.56 to 7.62).

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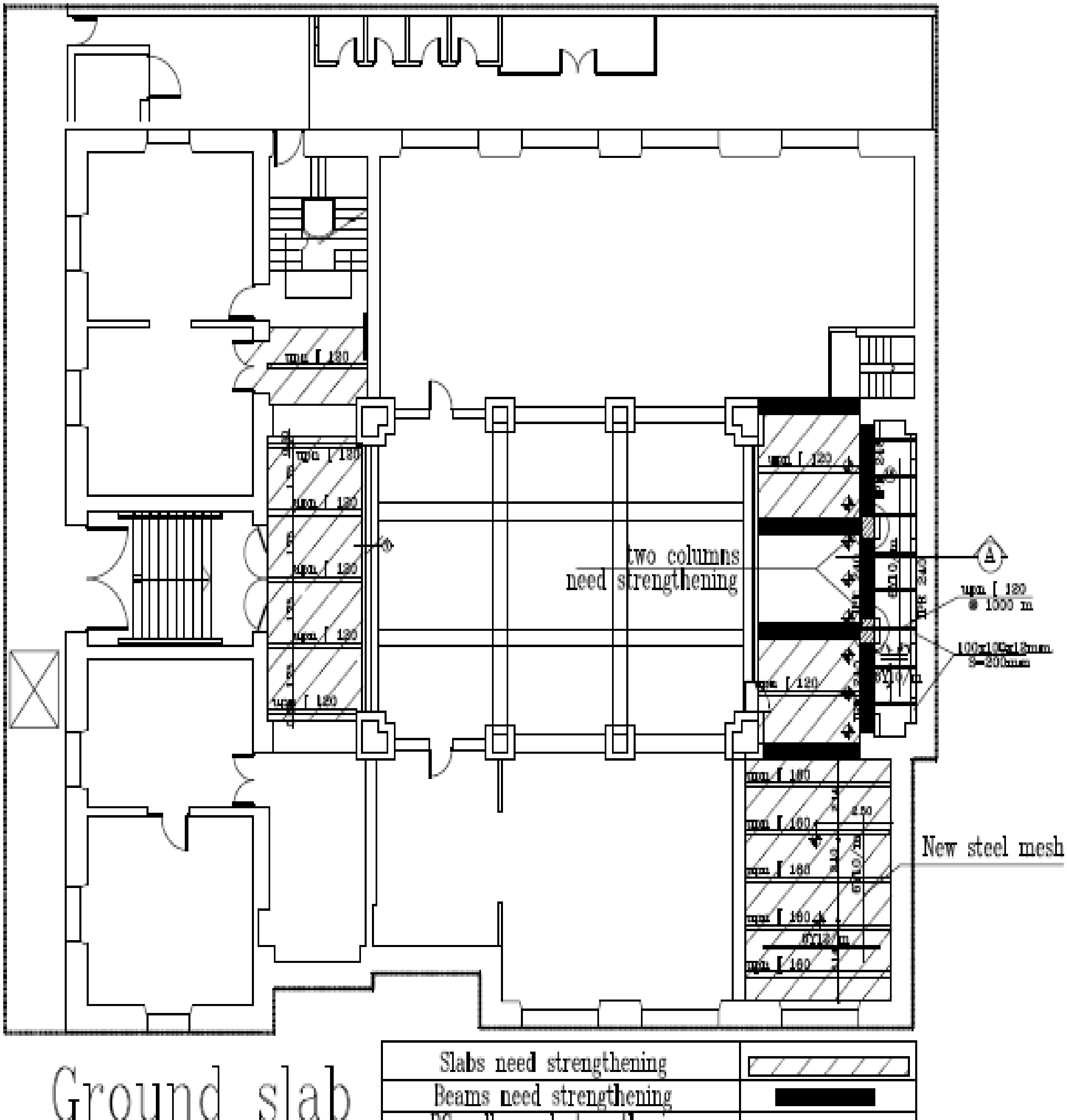
Figure C.2 Slab steel corrosion.

Figure C.3 Damaged stairs slab.

Figure C.4 Damaged beam.

Figure C.5 Damaged beam and slab.

Figure C.6 Two RC columns need strengthening.



Slabs need strengthening	
Beams need strengthening	
RC walls need strengthening	
Jacks needed during repair	✦
Stone walls need strengthening	

Figure C.7 Ground slab plan show members need strengthening.

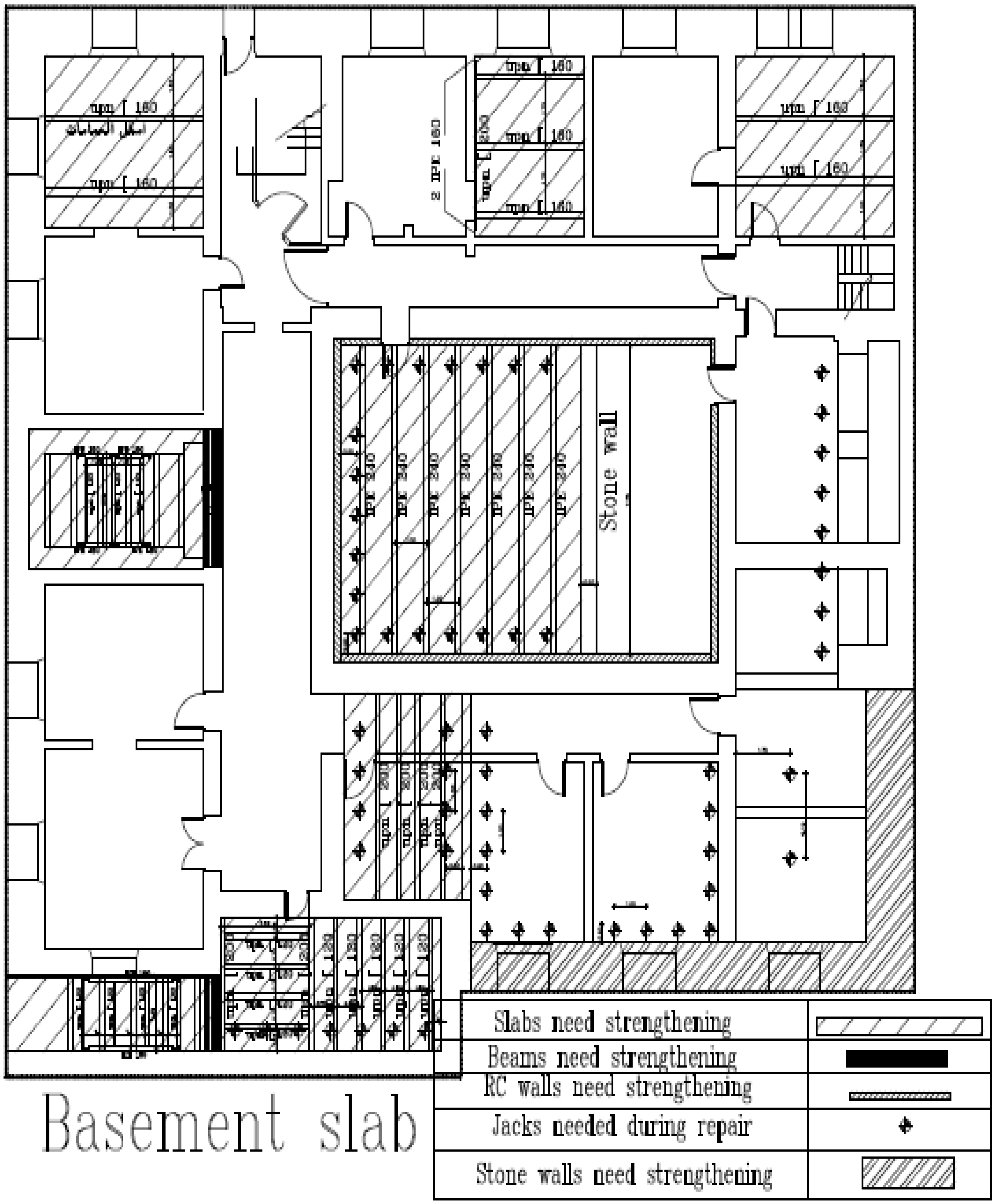


Figure C.8 Basement slab plan show members need strengthening.

C.3 The solutions

1-Repairing the damaged slabs then strengthening it by secondary steel beams as shown in figures

2- The beams were strengthened by means of steel and concrete jacketing as shown in figures

3-The two columns were strengthened by means of steel jacketing as shown in figures

FigureC.9 Damaged slab strengthened by steel beams.

Figure C.10 Stair slab strengthened by steel beams.

Figure C.11 Beam steel jacketing.

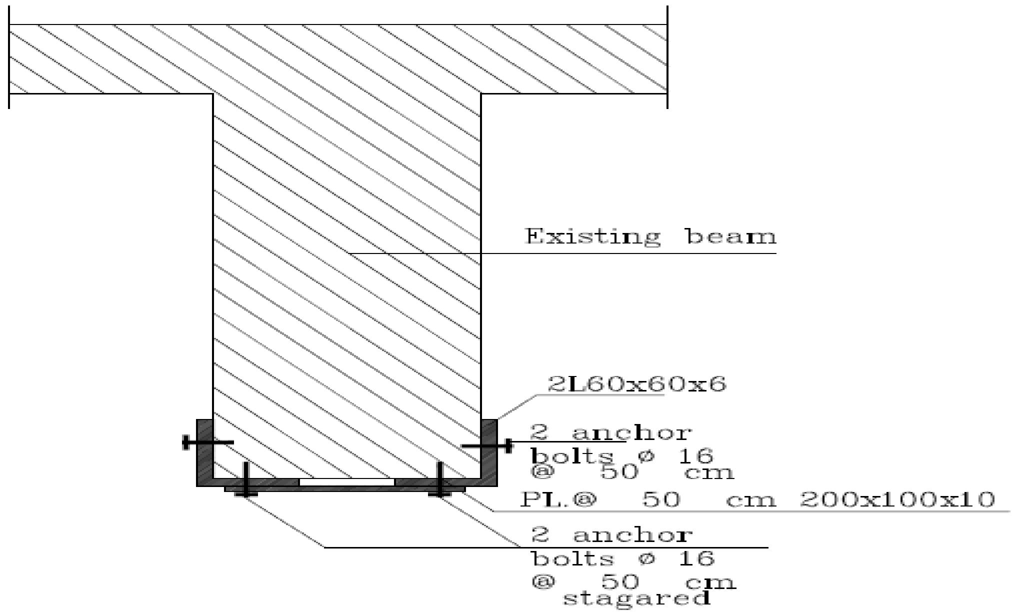


Figure C.12 Beam strengthened by steel plate and angels with lower anchors.

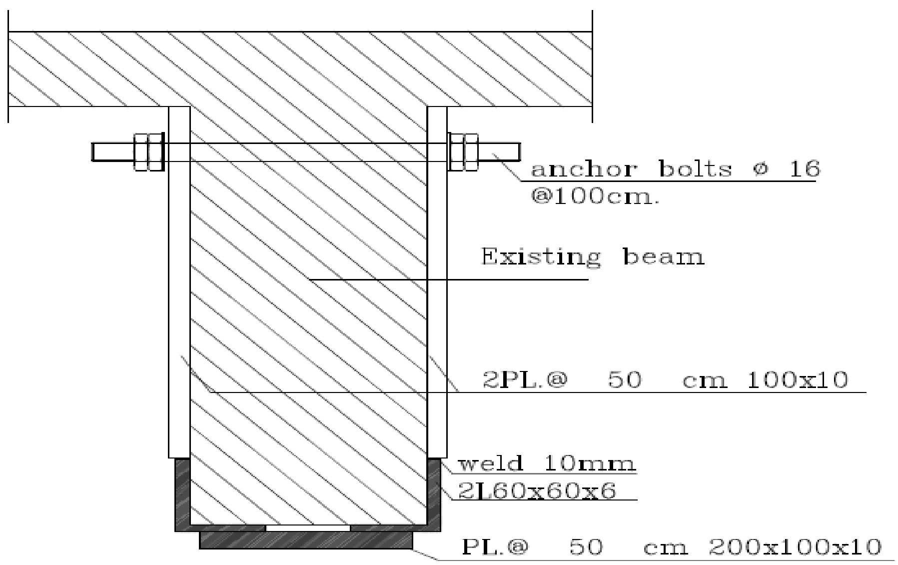


Figure C.13 completely damaged Beam strengthened by steel jacketing (Without lower anchors).

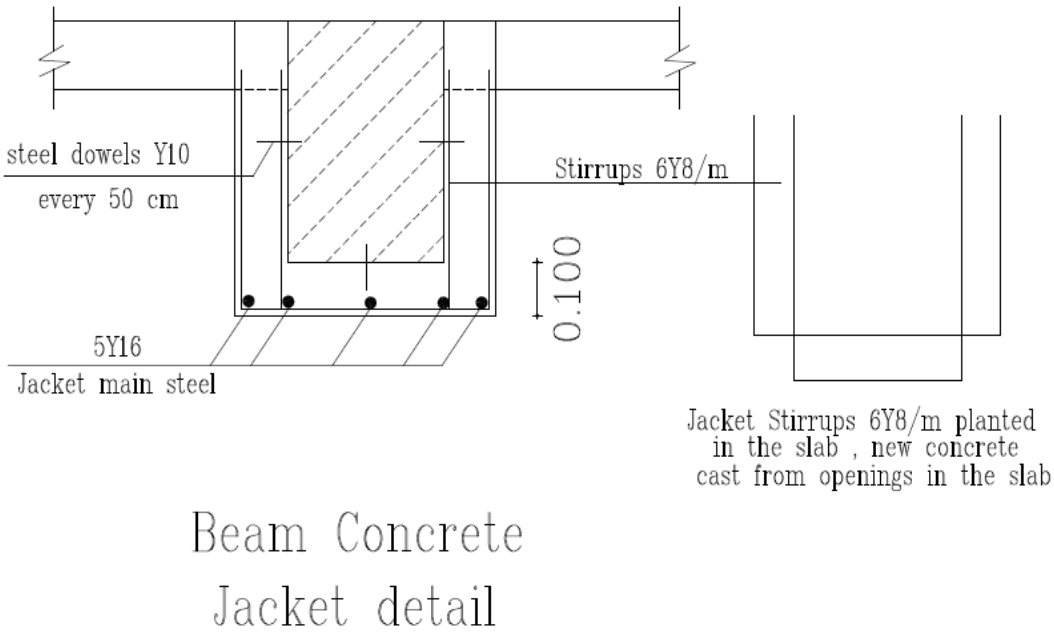


Figure C.14 Beam concrete jacket detail.

Figure C.15 Column steel jacketing.

Figure C.16 Jacking process during column strengthening.

Figure C.17 Completing column steel jacketing.

Figure C.18 Steel jacket connection with slab.

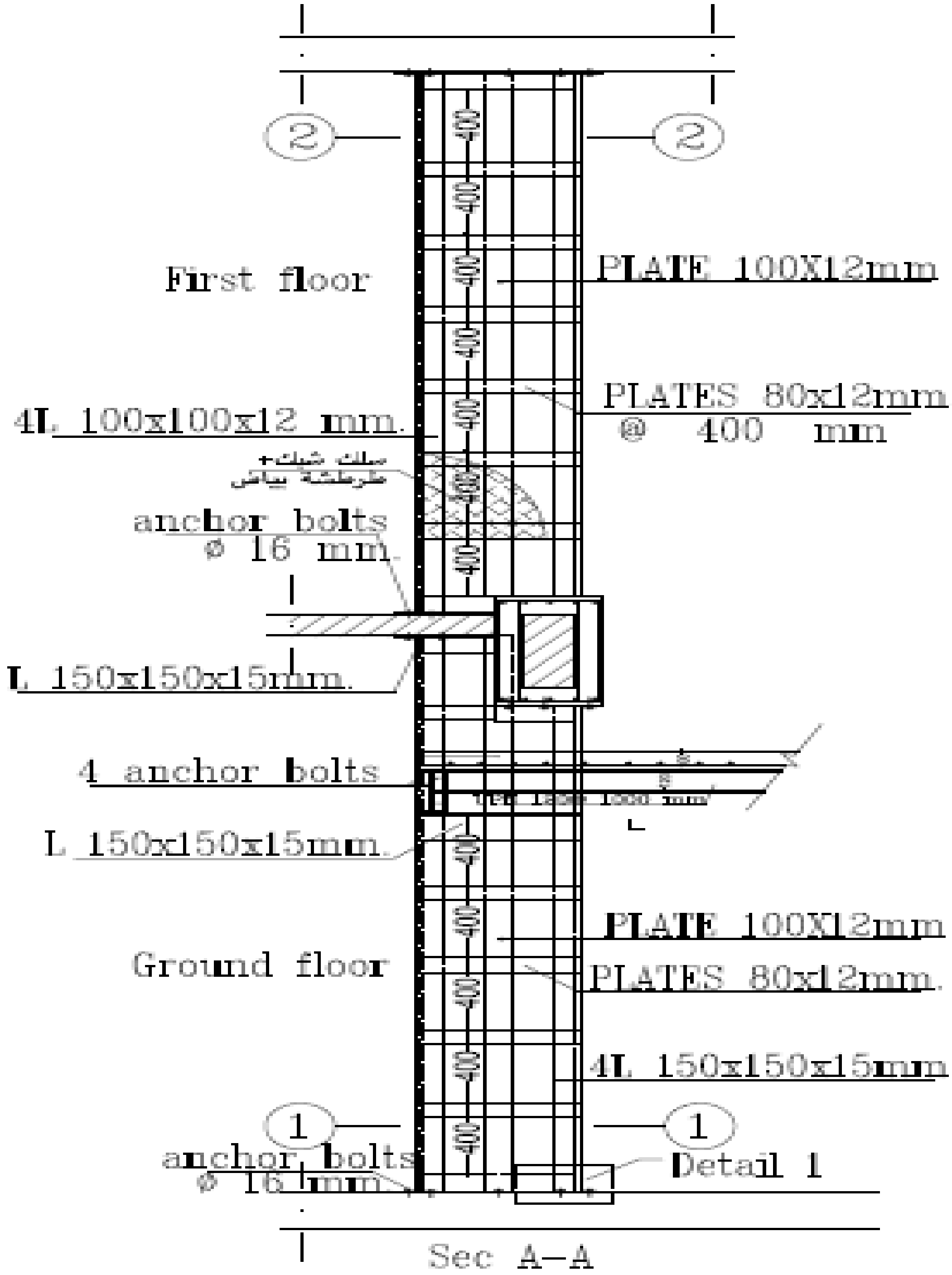


Figure C.19 Column steel jacketing details.

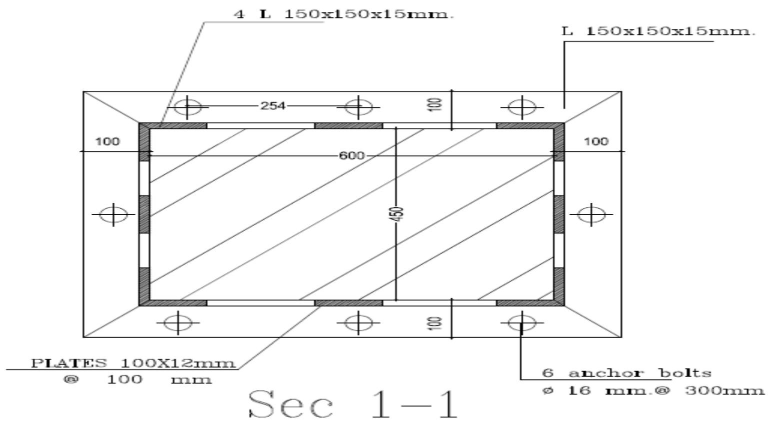


Figure C.20 Section 1-1

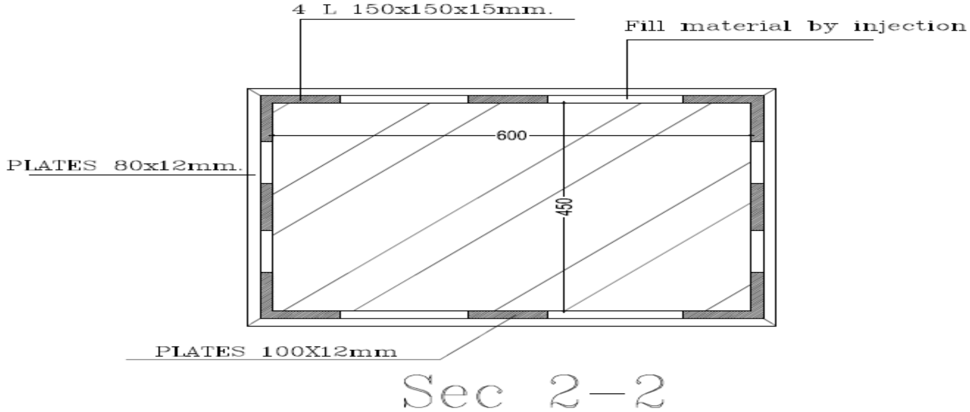


Figure C.21 Section 2-2

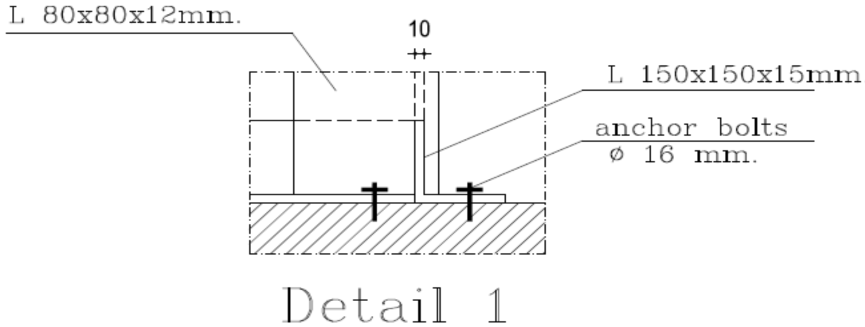


Figure C.22 Detail 1.