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TRADITIONAL SOLUTIONS FOR STRENGTHENING REINFORCED CONCRETE SLABS

BY

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Abstract. 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 in this paper is better suited for a given situation and come with their advantages and disadvantages. These techniques are considered to be traditional do to their long usage in time and that they involve only traditional construction materials such as concrete and steel. The five techniques from this paper have been and are the most effectively used, in the past and present days, worldwide and a short presentation of the methods and the way they are applied is presented in this paper. The selection of one of these methods is imposed by a sum of technological and economical factors.

Key words: reinforced concrete slab; strengthening system; ferrocement; section enlargement.

1. Introduction

Strengthening of reinforced concrete (RC) structures is frequently required due to inadequate maintenance, excessive loading, change in use or in code of practice, and/or exposure to adverse environmental conditions. A common feature of a number of different causes of deterioration is that there is a reduction of the alkalinity of the concrete which allows oxidation of the reinforcing steel to take place. This oxidation process leads to cracking of the concrete and possible spalling of the cover to the reinforcement. Several

strengthening techniques have been developed in the past and used with some popularity including steel plate bonding, external prestressing, section enlargement, and reinforced concrete jacketing. Although these techniques can effectively increase the elements load carrying capacity, they are often susceptible to corrosion damage which results in failure of the strengthening system. Consequently, non-corrosive innovative strengthening systems, such as fibre reinforced polymers (FRPs), that have the potential for extending service lives of RC structures and reducing maintenance costs, are required to replace old strengthening systems.

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 [1]:

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.

3. Strengthening Techniques

In the past different repair/strengthening techniques have been developed in order to strengthen a given structure or a part of it so that its serviceability and strength can be restored. When the repair or strengthening of the structure is done is prudent to consider the durability aspect.

In this section classic repair techniques that have been with some popularity in the past and are still used in the present days are analysed and presented in detail. The techniques include

a) Cement grout.
b) Ferrocement cover.
c) Section enlargement.
d) External plate bonding.
e) External post-tensioning.

These techniques are used for the reinforced concrete slabs without cut-outs. In the case of the slabs which present cut-outs or need to accommodate new openings but with strengthening of the slab required there are several common strengthening methods that can be considered. The used method depends on several factors, such as the strengthening required, the location where strengthening is required, and architectural requirements.

3.1 Strengthening Techniques for RC Slabs with Cut-Outs

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.

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.

Another approach is possible when existing beams are present. In this case steel beams that span between the concrete beams can be installed. In order that this solution to be effective shims or non-shrink grout must be installed

between the top flange of the steel beam and the bottom of the slab to ensure uniform bearing.

3.2 Strengthening Techniques for RC Slabs without Cut-Outs

The presented techniques have the potential of increasing the structural capacity of the structural members or in case of damaged slabs, to restore the original capacity of the section.

a) *Cement grout*

In the grout pouring technique the existing cracks from the slabs, resulted from the excessive loading, are enlarged in width and in depth until the existing reinforcement is exposed. Before the cement grout is poured into the enlarged extends the exposed reinforcement and concrete surfaces must be cleaned using a steel brush, compressed air and water jet. In the Figs. 1 and 2 the results and the approach of the technique proposed by Waleed A. Thanoon *et al*. [1] in a study concerning the effects of different repair techniques on the structural response of one way reinforced concrete slabs are presented. The grout used in the experiment was a non-shrink premixed high strength cement grout.

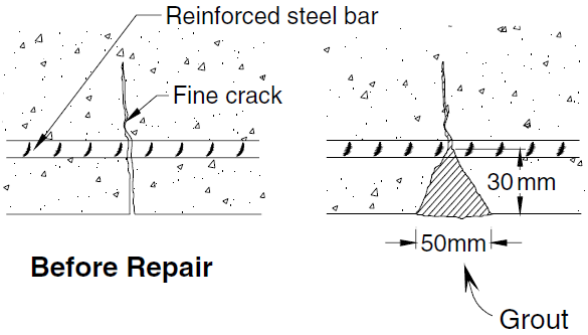

Fig.1 – Grout pouring technique.

Fig.2 – Cracks repaired using grout pouring technique.

b) *Ferrocement covers*

Ferrocement can be described as a type of thin composite material made of cement mortar reinforced with wire meshes. The wire meshes are uniformly distributed in continuous layers with relatively small diameters. In the early 1980s R o m u a l d i [2] and I r o n [3] were the first to introduce the technique of repair using ferrocement layers. They used the technique for repairing mainly liquid retaining structures such as pools, sewer lines, tunnels, etc. P a r a m a s i v a m *et al*. [4] started investigation concerning the use of ferrocement as strengthening components for the repair and strengthening of reinforced concrete beams. The ferrocement was used, in general, to replace the damaged concrete and reinforcement (if also damaged). The experiment's results shown that the strengthen beams presented improved cracking resistance, flexural stiffness and the ultimate loads compared to the original beams. One of the important conclusions from the experiment was that the improvements depend on the full composite action between the ferrocement layers.

The flexural behaviour of slabs strengthened with ferrocement was studied by A l – K u b a i s y and Z a m i n [5]. They tested twelve simply supported reinforced concrete slabs under flexural load. The concrete slabs were strengthened with ferrocement in the tension zone cover. In the study the effect of the percentage of wire mesh reinforcement in the ferrocement layer, thickness of the ferrocement layer and the type of connection between the ferrocement layer and reinforced concrete slab on the ultimate flexural load, first crack load, crack width and spacing and load–deflection relationship, have been taken into consideration.

In the Figs. 3 and 4*a*, *b* the results and the approach of the technique by Waleed A. Thanoon *et al*. [1] are presented:

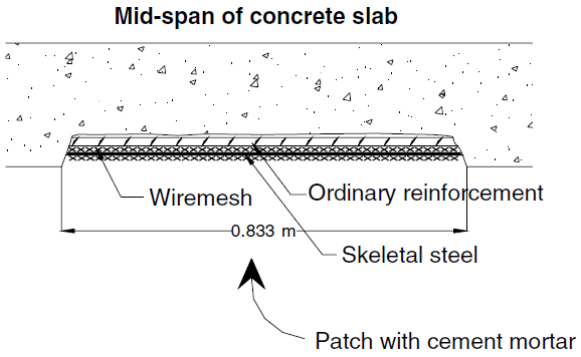

Fig.3 – Ferrocement layer technique.

The steps of applying this technique consist in removing the concrete from the cracked affected zone with the help of a concrete chisel and hammer. After that a layer of galvanized welded wire mesh and a layer of skeletal steel are fixed with the original reinforcement of the slab. The concrete surface must

roughened before the additional reinforcement is placed. The dimensions of the additional reinforcement result from the design and technological restrictions. Finally the cement mortar is applied and left to cure for 28 days.

Fig.4 *a* – Crack pattern before repair.

Fig.4 *b* – Wired mesh used for repair.

c) *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 [6]

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. The general requirements covering the depth of the new concrete layer are given.

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.

The stages in applying this method can be described as it follows: removal of the deteriorated concrete, corrosion removal from the exposed reinforcement, surfaces cleaning and preparation to ensure bonding with the repair material, replacement or addition of the supplementary reinforcement, reinforcement protection (in some cases), applying of the repair material.

In the Figs. 5 and 6 *a*, *b* the results and the approach of the technique proposed by Waleed A. Thanoon *et al*. [1] are presented. This method is considered to be a traditional strengthening method. The material costs are relatively low but the cost and consumption of the labour is rather high.

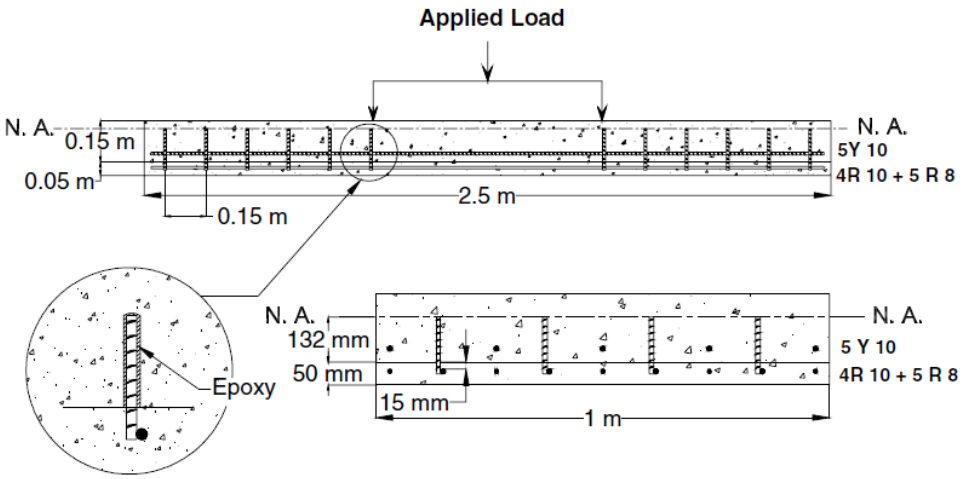

Fig.5 – Section enlargement technique.

a *b*

Fig.6 – Strengthening by enlarging the slab section: *a* – crack pattern before repair; *b* – roughened surface and steel provided.

d) *External 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 [6].

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 [7].

e) *External post-tensioning*

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. It can be applied to reinforced and

prestressed 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 [8].

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 constructions.

4. 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.

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SOLUŢII TRADIŢIONALE DE CONSOLIDARE A PLĂCILOR DIN BETON ARMAT

(Rezumat)

De-a lungul timpului diferite metode de consolidare a plăcilor din beton armat, cu sau fără goluri, au fost dezvoltate. Dezvoltarea acestor metode a apărut ca o necesitate datorită diferitelor cauze cum ar fi întreţinerea inadecvată, supraîncărcarea elementelor din beton armat, coroziunea armăturilor şi a altor situaţii întâlnite pe parcursul vieţii acestora. Fiecare dintre aceste metode se pretează mai bine pentru o anumită situaţie fiind însoţită de avantajele şi dezavantajele acestora. Aceste metode sunt considerate clasice datorită folosirii lor îndelungate de-a lungul timpului şi a materialelor de construcţii clasice cum ar fi betonul şi oţelul. Cele cinci metode prezentate sunt cele mai eficiente metode folosite, în trecut şi în prezent, şi o scurtă prezentare a acestora şi modul lor de aplicare se regăsesc în această lucrare. Alegerea uneia dintre aceste metode este caracteriată de o sumă de factori tehnologici şi economici.