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Strengthening of R.C Flat Slabs with openings Subjected to Flexure by Using NSM Techniques

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الخلاصة:

هذه الدراسة تقدم نموذج محاكاة مناسب للبلاطات المسطحة الممتدة فى إتجاه واحد والتى تحتوى على فتحات مربعة يتم التدعيم حولها بمواد تدعيم مختلفة قرب السطح بإستخدام نماذج العناصر المحددة.يستخدم برنامج التحليل بالكمبيوتر (الأنسز) فى عمل عدد أربعة نماذج حسابية للبلاطات الخرسانية المسلحة ذات الفتحات. كل العينات منشورية الشكل ذات قطاع مستطيل بطول 2000 مم وعرض 1000 مم وسمك 120 مم مرتكزة على ركائز المسافة بينهم 1200 مم وكابولى بطول 700 مم يوجد بها شبكتين تسليح علوية وسفلية (7Ø10/m) فى الإتجاهين. البلاطات ذات الفتحات بأبعاد 200*200 مم التى تم عملها فى منطقة العزوم السالبة القصوى على مسافة 100 مم من خط الركائز الداخلى لها نفس تسليح وقطاع البلاطة المرجعية المصمتة. وفى هذا البحث يتم دراسة تأثير وجود الفتحات على سلوك البلاطات الخرسانية المسطحة وكذلك دراسة إستخدام قضبان الكربون البوليمرية وصلب التسليح كمواد تدعيم قرب السطح حول الفتحات الموجودة فى البلاطات المسطحة. نماذج البلاطات تم تحميلها تحت تأثير نقطتى خطى تحميل بطول 500مم أحدهما فوق خط الركيزة الخارجية والآخر على مسافة 100مم من حافة الكابولى وبتحليل النتائج يتضح أن قدرة التحميل القصوى للبلاطة تقل نتيجة لوجود الفتحة بها مقارنة بالبلاطة التى لاتحتوى على فتحات ثم بعد عمل التدعيم حول الفتحة تستعيد البلاطة قدرتها على تحمل الأحمال.

Abstract:

This study presents a model suitable simulate one way R.C flat slab with overhang have square opening strengthened by using NSM techniques by using finite element modeling. ANSYS computer program version 12 is utilized in the analysis and four models slabs were performed each slab 2000mm span and 1000mm width. The overall thickness of slab is 120mm, clear span (distance between supports) of 1200 mm and the cantilever length is 700mm. Upper and lower steel reinforcement mesh Ø10@160mm (7Ø10/m).The opening dimensions were (200*200 mm) and the opening positions were considered near the maximum negative (hogging) moment region at distance 100mm from the intermediate support. In this research the effect of opening presence on R.C flat slabs was discussed and also the effects of using CFRP and Reinforcing steel bars as NSM strengthening materials around opening were studied. Models were tested up to failure under two points

line loading with 500mm long up the external support and at a distance 100mm from cantilever edge. Based on results, the ultimate load of slab decreased due to presence of opening and then increase because of strengthening around opening compare to the slab without opening.

Keywords Strengthening, R.C Flat Slabs, Openings, NSM Techniques, Flexural Behavior and Finite Element Analysis.

1-Introuduction

Flat slabs are the most important structural elements that work on the transfer of loads directly to the columns; it is very often required to create openings in the room to enlighten and to pass pipes utilities ducts, services and others. Introducing openings in slabs can severely weaken the slabs due to the cut out of both concrete and reinforcing steel. There are several approaches to strengthen RC Flat slabs with openings and one of the most advanced methods in strengthening near the surface of the openings.

Enochsson et al. (2007) [1] performed an experimental and numerical evaluation of 11 RC two-way slabs strengthened with CFRP sheets. The simply-supported slabs had side lengths of 2600 mm and a thickness of 100 mm. A system of airbags was used to evenly distribute the applied loading along the slab surface. The two main variables considered are the size of the opening and the layout of the CFRP reinforcement. Two different sizes of openings located at the center of the slabs were considered to be 850 * 850 mm and 1200 * 1200 mm. The CFRP sheet configurations were as follows: parallel to each side of the cut-out only, diagonal at each corner only, and a combination of the first two configurations. The study followed a simplified approach to determine the amount of CFRP reinforcement required to replace the amount of steel reinforcement interrupted by the opening. The area of steel was converted to an effective area of CFRP. The test setup showed that to provide a uniformly distributed load on the slab, a new unique test is developed, Experimental results suggested for the homogeneous control slab cracking initiated at mid- span in the form of flexural cracks. For slabs with openings, cracking initiated at the corners of the openings and propagated diagonally. It was noted that crack widths were smaller for slabs strengthened with CFRP strips. Slabs with large and small openings exhibited a nearly identical load-deflection behavior and failure mechanism as the homogeneous control slab. The only significant difference is that the slabs with openings failed at a lower level of deflection. This behavior suggested that two-way slabs are able to effectively redistribute the internal stresses around a service opening. The ultimate deflection of the slabs with openings strengthened with FRP exhibit a similar ductile response as those with UN strengthened openings. Strengthening openings with CFRP is most effective on slabs with larger openings. Regardless of the orientation of the FRP strips, the capacity enhancement was 20-50% greater for the larger opening compared to the smaller opening. A possible explanation for this is that slabs with a smaller opening have better capacity to redistribute the internal stresses before the steel yields, Foret et al. (2008) [2] realized a comparative study on the strengthening of two-way RC slabs with composites using two different systems. First system was based on the external bounding method and the second one used the near surface mounted (NSM) method for strengthening the RC slab. For the NSM strengthened slab an increase of 67% was observed for the flexural strength. The experiments concluded that a more ductile behavior was observed compared to external bounding technique and an economical advantage of NSM technique relative to a lower carbon fiber quantity is observed too. The ACI 318-14 code [3], allows reinforced concrete slabs to have openings with the condition of performing full structural analysis to assure slab safety, strength, and service- ability under different expected loads. Whereas the code gives procedures and limits for opening location and size. If designer satisfies those requirements the analysis could be abandoned, hence, problem becomes more complex when openings are planned to be made in existing slab, the most common way to substitute additional steel reinforcement is to apply strengthening CFRP and RFT steel around the opening. The ACI 318-14 (ACI318-14) recommends the size and location of openings in two-way slab systems as shown in Figure. 1, Seliem et al. (2008) [4] investigated the effects of using CFRP to strengthen openings on five in- service RC slabs (3353 × 3000 mm) located in a multi-storey concrete structure. The parameter under consideration included the type of strengthening system: EB-CFRP laminates, EB-CFRP laminates with CFRP anchors, and the NSM technique. The slabs were tested under 4-point bending along the short direction to create a constant moment zone where the openings and the strengthening systems were located. In the long direction; the slabs were loaded at eight points to simulate line loads on opposite sides of the opening. The load was applied using four hydraulic jacks, connected in parallel to the same pump, that were reacting against the concrete walls at the lower floor. The applied load was measured by 133 KN load cells mounted on the hydraulic jacks. Testing concluded the addition of a 610 × 610 mm opening at the center of the slab reduced the ultimate strength by 18%, and resulted in a noticeable reduction in slab stiffness. At a service load of 65% of the ultimate load, the deflection was 60% greater when compared with the control specimen. Adding NSM-CFRP strips restored 10% of the slab’s capacity, with no noticeable increase in stiffness. Strengthening the slab using externally bonded strips improved the capacity by 6%, and reduced the ultimate deformation due to early de bonding of the laminates. At 65% of the ultimate load, the EB-CFRP laminates with end anchorages effectively improved the stiffness of the slab system, resulting in a reduced deflection of 28% for the un- strengthened slab with an opening. The EB laminates with CFRP anchors proved to be the most effective, completely restoring the slabs capacity and preventing complete detachment of the laminates, Mohamed Kadry et al. (2016) [5] Studied the using of near surface mounted techniques (NSM) in repairing RC flat slab exposed to fire, using steel bars, glass fiber bars and laminate carbon fibers. Several parameters were kept constant through the study, such as the characteristic strength of concrete (25 N/mm2), a) Concrete cover thickness (25mm, 30mm, 35mm and 40mm). b) Fire duration (1hr, 2hrs, 3hrs and 4 hrs. c) Type of repairing (high tensile steel, glass fiber bars and laminate carbon fiber). To achieve that, fourteen flat slabs were cast with dimensions of 1750*1750*150 mm and reinforced by two mesh of steel; the lower mesh of 8Ø12/m and the upper of 8Ø10/m

According to experimental program, two specimens (9), and (10) were strengthened with steel bars of 4Ø 12/m and 4Ø10/m respectively. While, two specimens (11) and (12) were strengthened with glass fibers bars of 4Ø 12/m and 4Ø10/m respectively .In the third set of repaired specimens (13,14) the laminate carbon fibers of length 1750 and 500 mm were used as strengthening materials. RC slabs were tested under main frame with load cell capacity of 1000 KN. Test specimens were tested under the effect of static point load at the center. The test results showed that repaiping of RC flat slabs using NSM Techniques increased the capacity of the slab and the ultimate failure load, Failure load for slab repaired with steal bars 4Ø 12 /m increase with 41.28% and for slab repaired with steal bars 4Ø 10 /m increase by about 29.29% to un repaired slab,also Failure load for slab repaired with glass fiber bars 4Ø 12 /m increase with 33.85% and for slab repaired with glass fiber bars 4Ø 10 /m increase with 27.65% to un repaired slab,and Failure load for slab repaired Laminate carbon fiber L=1750mm increase with 29.23% and m increase with 24.97% for slab repaired with Laminate carbon fiber L=500mm to un repaired slab, Eyad Kadhem et al. (2017) [6] presented an experimental investigation of the behavior of Sixteen simply supported two way reinforced concrete slabs, which were tested up to failure under the action of concentrated patch load to examine the effect of different types of strengthening on their behavior. All the slabs had the same overall dimensions and flexural steel reinforcement. Five types of strengthening were adopted. The first and second methods included applying either near surface mounted (NSM) or near reinforcement mounted (NRM) Ferro cement layers. While the third method included applying a concrete layer reinforced with welded wire fabric mesh of various diameters. The fourth and fifth methods included fixing CFRP rods and laminates, respectively, on the bottom face of slabs. Strengthening techniques were applied on the bottom surface of fifteen slab specimens. In addition, a control slab specimen without any strengthening was used for purpose of comparison. All the strengthening techniques made an enhancement in the ultimate and cracking strength. The test results showed that both carbon fiber laminates and rods greatly increase the cracking strength and also improved the ultimate load capacities and deflection response, and Syafiqah Shahrul Aman et al. (2020) [7] presented an experimental study on the structural behavior of slabs with openings coated with Carbon Fiber Reinforced Polymer (CFRP) sheet. In the experimental part, ten slabs were cast with a dimension of 1000 mm × 530 mm × 25 mm, among which nine slabs had openings and one slab was without opening (control slab). The configuration of the CFRP sheet includes coating in the form of single, double, and triples layers. Experimental results show that the slab with a triple coating of the CFRP layer offers the maximum resistance towards the loading rate. Moreover, with the increase in CFRP layers, the value of deflection is minimized.

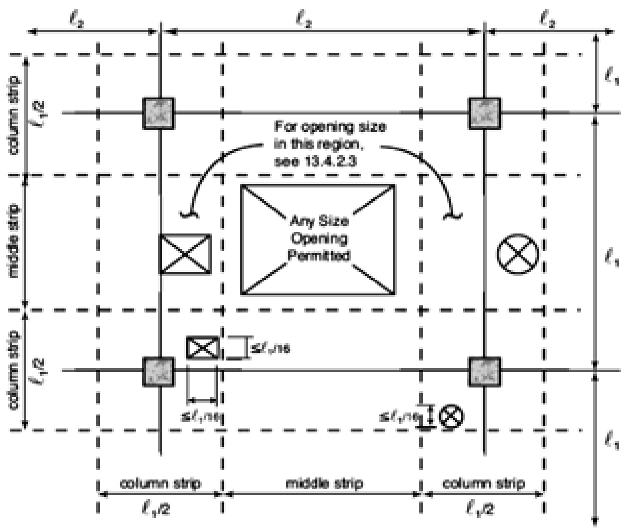


Figure. 1 Opening sizes and locations in flat plates (ACI318-14).

2. Finite Element Model

2.1 Introduction:

ANSYS computer program is utilized for analyzing all tested slabs. Structural components encountered throughout the current study, corresponding finite element representation and elements designation in ANSYS program will be represent below

2.2 Element types:

2.2.1 Concrete Element:

Solid65, an eight-node solid element is used to model the concrete, which is special for 3-D modeling for solid concrete elements with or without reinforcing rebar. The element allows the presence of three different reinforcing materials. The solid element has eight nodes with three degrees of freedom at each node translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The geometry and node locations for this element type are shown in Figure. 2.

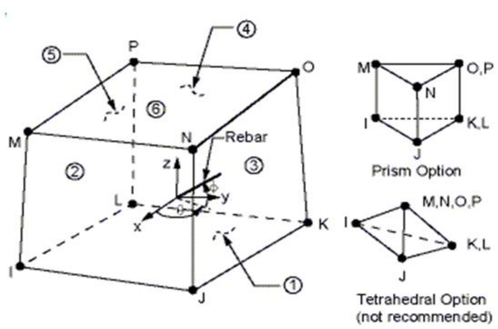


Figure 2. Solid 65 Element, ANSYS Manual.

2.2.2 Steel Reinforcement Element:

There are two techniques that exist to model steel reinforcement in finite element models for reinforced concrete as shown in Figure.3:

1. The discrete model.
2. The smeared model.

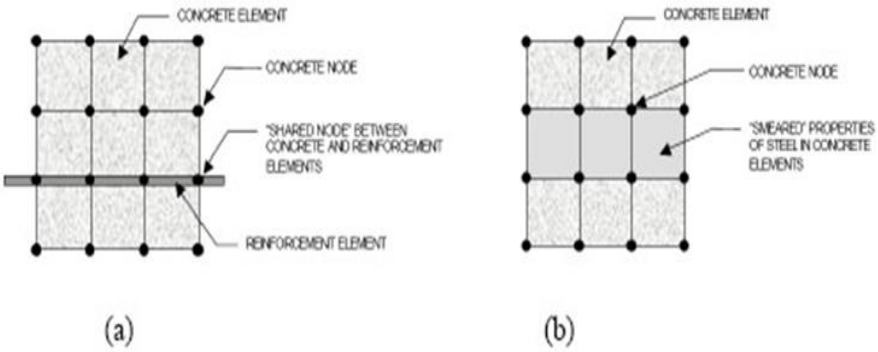


Figure.3 Models for Reinforcement in Reinforced Concrete (a) Discrete, (b) Smeared (ANSYS 12.0).

The reinforcement in the discrete mannequin Figure.3 (a) makes use of link elements that are connected to concrete mesh nodes. Therefore, the concrete and the reinforcement mesh share the same nodes and concrete occupies the identical areas occupied via the reinforcement. A dis advantages to this model is that the concrete mesh is confined by using the region of the reinforcement and the volume of the mild-steel reinforcement is not deducted from the concrete volume. The **smeared** model Figure.3 (b) assumes that reinforcement is uniformly spread throughout the concrete elements in a defined region of the FE mesh. This approach is used for large-scale models where the reinforcement does not significantly contribute to the overall response of the structure. For the discrete model, a Link8 truss element is used to model the steel reinforcement. Two nodes are required for this element. Each node has three degrees of freedom, translations in the nodal x, y, and z directions. The element is also capable of plastic deformation. The geometry and node locations for this element type are shown in Figure.4.

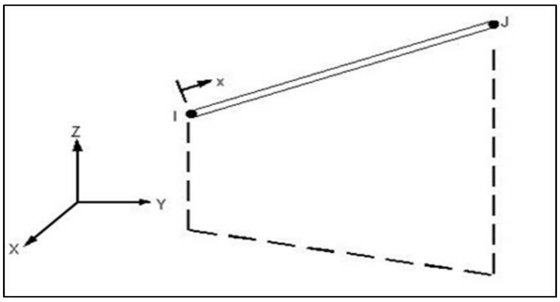


Figure.4 Link8-3-D Spar (ANSYS 12.0).

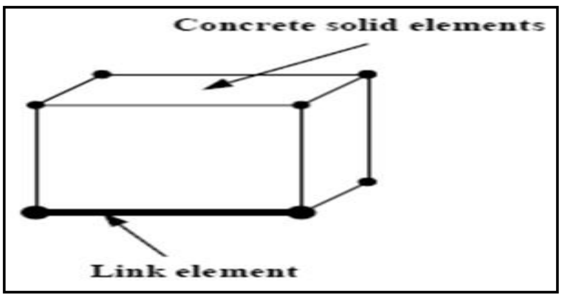


Figure.5 Element Connectivity, Concrete Solid and Link Elements.

To provide the perfect bond, the link element for the steel reinforcing is connected between nodes of each adjacent concrete solid element, so the two materials shared the same nodes as shown in Figure.5. For the smeared model, no Link8 element is used, because the reinforcement will be modeled smeared in the concrete element Solid65. The rebars are modeled as smeared elements with uniaxial stiffness in their directions. The rebars are capable of modeling the creep and plasticity characteristics. They are also capable of presented plastic deformations. Reinforcement direction orientation is defined through specified angles with the concrete element as shown in Figure.5.

2.3 Real Constants:

Element real constants are properties that depend on the element type, such as cross-sectional properties of a beam element. Not all element types require real constants, and different elements of the same type may have different real constant values and a single element type may reference several real constant sets.

2.3.1 Concrete Element:

Real Constant set used for the Solid65 element. Values can be entered for Material Number, Volume Ratio, Orientation Angles, and Crushed Stiffness Factor (CSTF). The Material Number refers to the type of material for the reinforcement. The Volume Ratio refers to the ratio of steel to concrete in the element. The Crushed Stiffness Factor (CSTF): A value of (0.002) is entered to simulate the negative stiffness of the stress strain curve of concrete.

2.3.2. Steel Reinforcement Elements:

Real Constant set is defined for the Link8 element. Values for cross-sectional area and initial strain are entered. A value of zero is entered for the initial strain because there are no initial stresses in the reinforcement.

2.3.3. Lead Plates:

No real constant set exists for the Solid 45 element.

2.4 Modeling:

2.4.1 Solid65:

An eight-node solid element, used to model the concrete. To create the concrete element, firstly create its eight nodes in the working plane, and then create the element through this eight-node, taking into consideration that the aspect ratio of the height to the width to the length should not be very large or some problems will occur when solving the model. After creating the element, it can be take a copy in the three directions X, Y, and Z to complete the model. Note that before creating the element its attribute for the model should be defined, for each created element we should know its element type number, material number, and real constant set number which is known as The Element Attributes. Another way of creating elements is creating lines, areas, and volumes then meshing them.

2.4.2 Link8:

A two-node link element, used to model the flexural reinforcement. The link element for the steel reinforcing is connected between nodes of each adjacent concrete solid element, so the two materials shared the same nodes. No mesh of the reinforcement is needed because individual elements are created in the modeling through the nodes created by the mesh of the concrete elements.

2.4.3 Solid45

An eight-node solid element, used to model the lead plates for loading and supports. To create the Solid45 element, firstly create its eight nodes in the working plane, which are connected between nodes of each adjacent concrete solid element, so the two materials shared the same nodes, and then create the element through these eight nodes.

Table.2 Material Properties for the Steel Reinforcement Elements.

<table>
<tr><td>Element Type</td><td colspan="4">Material Properties</td></tr>
<tr><td rowspan="3">Link8</td><td colspan="2">Linear Isotropic</td><td colspan="2">Bilinear Isotropic</td></tr>
<tr><td>EX (Mpa)</td><td>2 x 10^5</td><td>Yield Stress (Mpa)</td><td>490</td></tr>
<tr><td>PRXY</td><td>0.30</td><td>Tangent Modulus (Mpa)</td><td>6000</td></tr>
</table>

Table.3 Material Properties for the Lead Plate Elements.

<table>
<tr><td>Element Type</td><td colspan="2">Material Properties</td></tr>
<tr><td rowspan="3">Solid45</td><td colspan="2">Linear Isotropic</td></tr>
<tr><td>EX (Mpa)</td><td>2 x 10^5</td></tr>
<tr><td>PRXY</td><td>0.30</td></tr>
</table>

2.5 Analysis Process for the Finite Element Model:

In this study, for the reinforced concrete solid elements, convergence criteria are based on force and displacement, and the convergence tolerance limits are initially selected by the ANSYS program. It is found that convergence of solutions for the models is difficult to achieve due to the nonlinear behavior of reinforced concrete. Therefore, the convergence criteria used for the analysis is Displacement. Because, when the slab began cracking, convergence for the non-linear analysis using the two convergence criteria Force and Displacement is impossible. The displacements converged, but the forces did not. Therefore, the convergence criterion for force is dropped and the Displacement criterion is used in order to obtain convergence of the solutions.

2.6 Analysis of Slabs Models Results

2.6.1 Geometry and Reinforcement Models of Slabs

All specimen modeled as the same dimensions (2000*1000*120 mm) and the same Reinforcement have upper (Tension side) and lower steel reinforcement mesh 7ϕ10/m (ϕ 10@160mm). The upper concrete cover is (35 mm) as a clear cover. The lower concrete cover is (15 mm) as a clear cover. The RC one way flat slab (RCS.1) is control specimen modeled without opening and strengthening, slab (RCS.2) is control specimen modeled have square opening with dimensions (200*200*120mm) without strengthening, The specimen (RCS.3) is modeled have square opening with dimensions (200*200*120mm) and strengthened by NSM CFRP bars along edges of the square opening and also The specimen (RCS.4) is modeled have square opening with dimensions (200*200*120mm) and strengthened by NSM Reinforcing steel bars along edges of the square opening as shown in Figure.6 and 7.

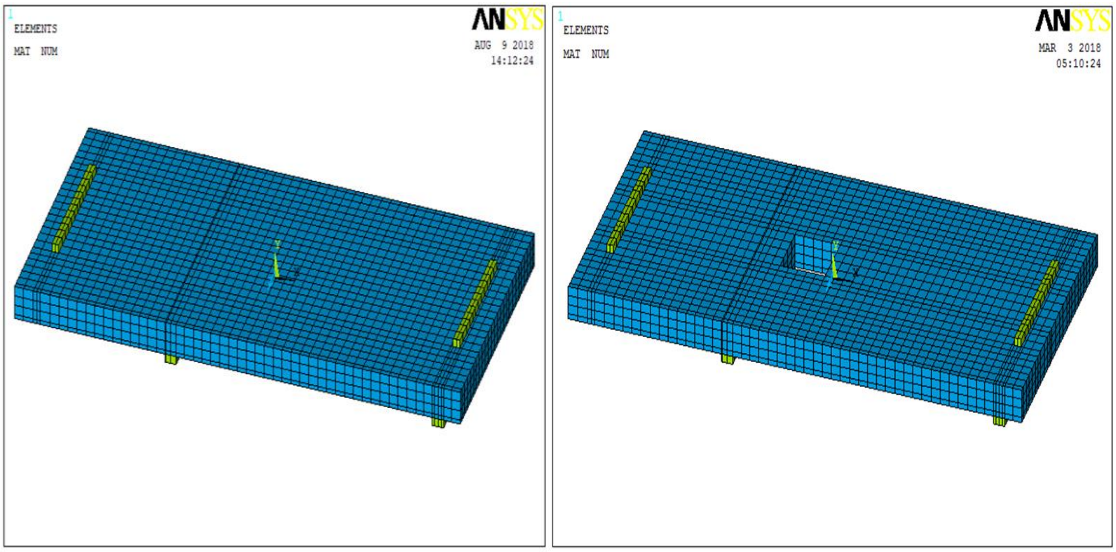
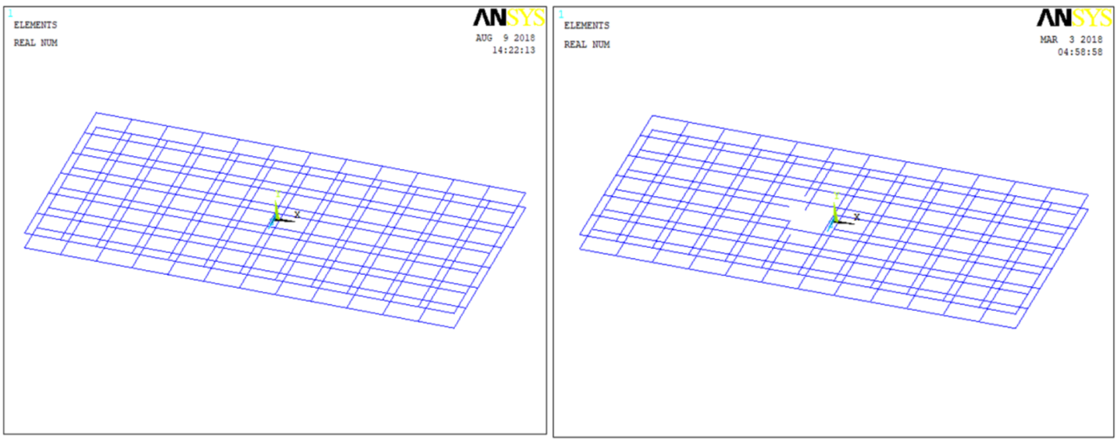


Figure.6 Model Mesh and the Element Dimensions of Specimens



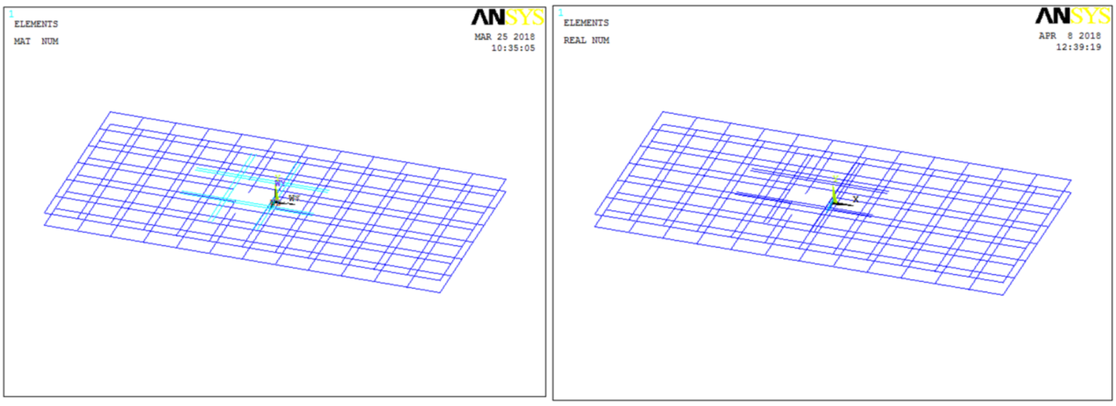


Figure.7 Details of Steel Reinforcement and strengthening CFRP bars around opening of Specimens

2.6.2 Results of Finite Element Model of Specimen:

The results included crack patterns, ultimate load, corresponding measured deflection, and measured strains at different locations along the reinforcing steel bars, concrete surface, and strengthening (CFRP, steel) bars.

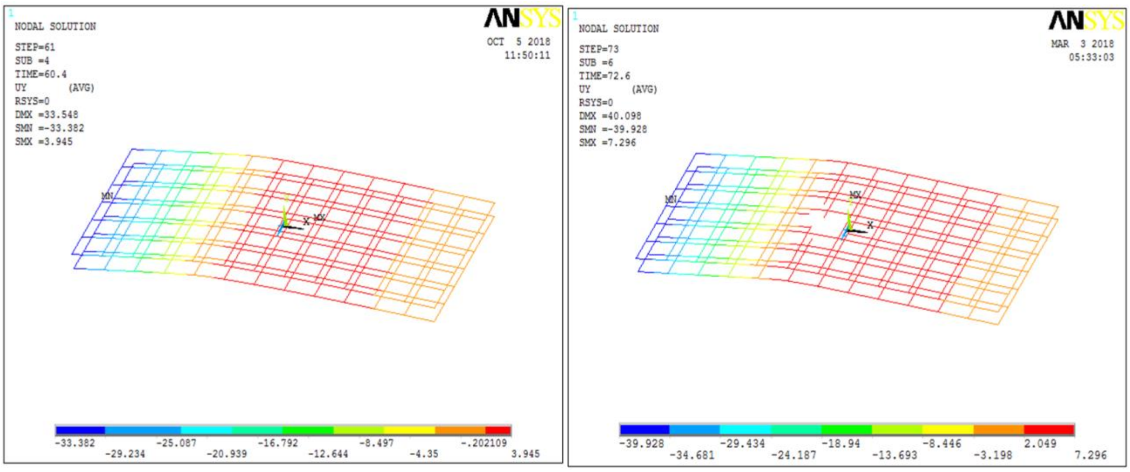
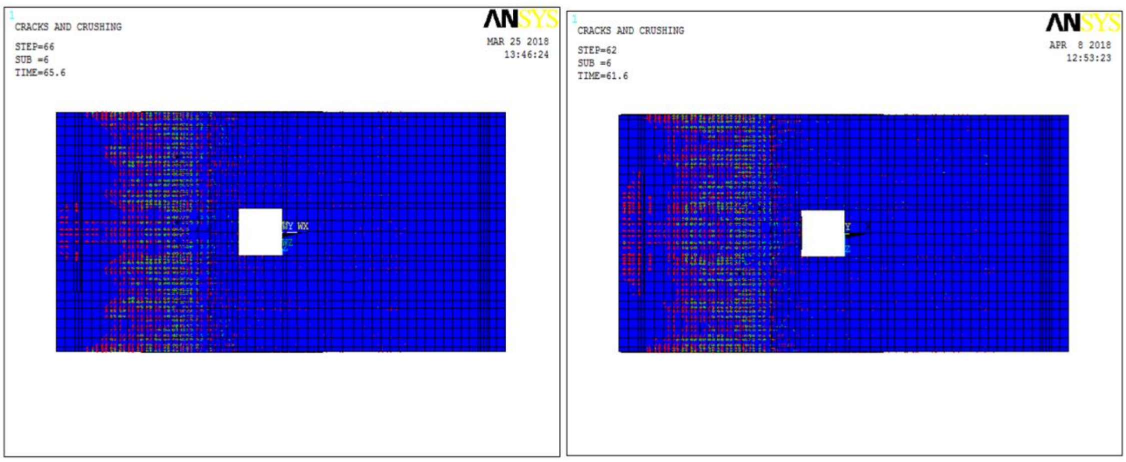


Figure.8 Deformed Shape of All Reinforcement Elements for control specimens.



Specimen no (3) Specimen no (4)

Figure.9 the Crack Pattern at the Top of strengthened Specimens.

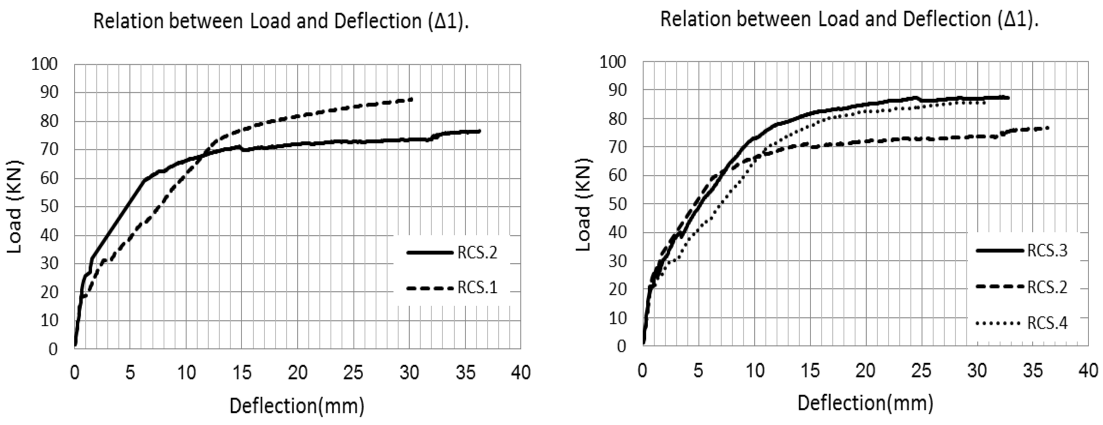


Figure. 10 load-deflection curves for modeled slabs.

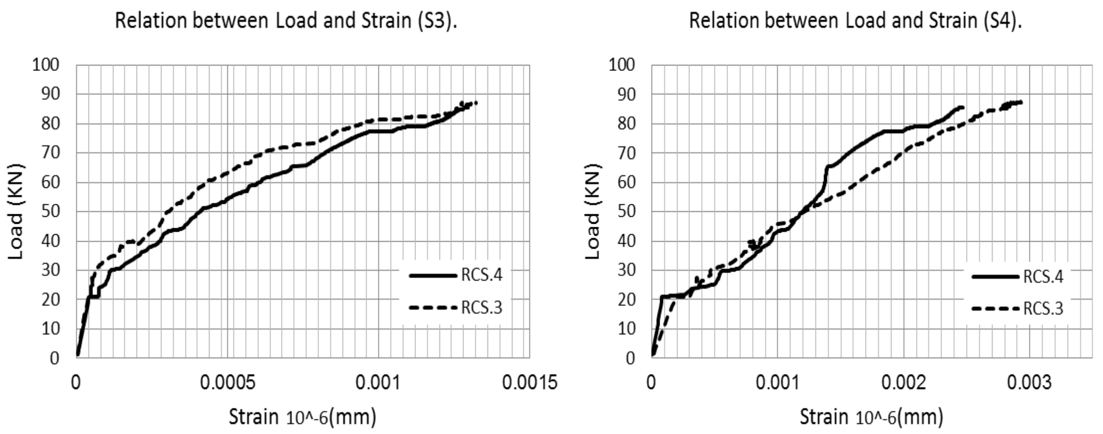


Figure.11 load- strain curves for strengthening CFRP and Reinforcing steel bars for modeled slabs

From Figure.10 clarify that the presence of square opening in the one way RC flat slab (RCS.2) decreased the ultimate total load by about 14.60% and increasing the amount of deflection at the edge of cantilever by about 18.62% and also Using of CFRP bars increased the ultimate load by about 13.77% more than that recorded for the slab with non-strengthened opening, on the other hand when using the reinforcing steel bars in strengthening, the ultimate load increased by about 11.77% more than that of the slab with non-strengthened opening. Moreover, at the ultimate load, the using of NSM CFRP bars in strengthening decreased the deflection at distance 100mm from under the point of loading the tip of cantilever (Δ_1) by about 10.67% less than that of the deflection measured for the slab with non-strengthened opening, also using of strengthening by NSM RFT steel bars decreased the deflection (Δ_1) by about 17.86% less than that of the amount of deflections calculated for the slab with non-strengthened opening. This indicated that using of NSM CFRP bars in strengthening is more efficient than using of NSM RFT steel bars.

From Figure.11 showing that when compare between the strengthening near the surface using CFRP bars around the square opening as (RCS.3) with the strengthening using NSM Reinforcing steel bars as (RCS.4), concluded that the strain is proportional to the loading.

Moreover, the strain measured at the lateral strengthening CFRP bars (S3) increased by about 1.23% with an increasing in the ultimate load of 1.79%, and also the strain measured at the longitudinal strengthening CFRP bars (S4) increased by about 19.15% with an increase in the loading capacity of the slab. The curve of the finite element model is more severe than that of the practical test which shows that the reinforcing steel works with the concrete in full bond capacity, which is differ from the reality in which the reinforcement steel loses a lot of bond with the concrete as the loading and the occurrence of cracks in concrete.

3- Conclusions:

1-The strengthened flat slabs were strained less than the un-strengthened flat slabs due to the effect of the encirclement and confinement

2-The presence of the openings in the RC flat slabs reduces the bearing capacity of the loads and reduces their stiffness lead to reduction of the slabs efficiency compared to the slab without openings

3-The strengthening using NSM CFRP bars is more efficient than NSM RFT steel bars in raising the efficiency of the RC flat slab and increasing its ability to carry loads

4-The bearing capacity and stiffness of flat slabs decreases as the openings move closer to the maximum moment zone.

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