Effect of Laying Service longitudinal and Transverse Openings on Reinforced Concrete Hollow Beam Web under Flexural Loadings

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Abstract. Laying of service pipes such as sewage pipes, electricity pipes, and sometimes water pipes ducts and others had presented some problems especially if it gathered in one place. One of the best solutions to minimize the problems and solve the piping and other services is using longitudinal and transverse opening in beams (BLTO), especially when high strength concrete (HSC) is used. HSC beam that performed experimentally by a researcher and implemented in this study by finite element method. ANSYS software was utilized to prove the experimental results with using the same properties, geometry, materials, and conditions which the comparison included the force-displacement relationship ultimate load capacity, maximum displacement, and crack pattern. The verification process between the experimental program and theoretical one demonstrated that there is a good convergence between the obtained results between the two results. The similarity in the outcomes showed that the matching between the experimental and numerical in force by (99%) and in displacement by (94%). These variances were due to the small difference in the condition of experimental and theoretical side which the numerical considered ideal condition. Also, this study examined the behavior of (RC) beam have longitudinal and transverse opening. The registered failure mode of beam was flexural failure although of presence of shear cracks but the flexural cracks were the controller in the behavior.

Keywords: Transverse opening, transverse opening, load capacity, crack pattern.

1. Introduction
Now a day in civil works such as building and houses and other reinforced concrete buildings the laying of service pipes such as sewage pipes, electricity pipes, and sometimes water pipes ducts and others led to some problems especially if it gathered in one place. Most of the designs didn't mention this problem or didn't deal with it in details. Therefor to solve this issue a longitudinal and transverse opening in the beam (BLTO) might be used. That openings in the beams presents many benefits such as low weight, decrease in construction materials quantities, decrease the dead space, organize and protect the service pipes and might give an aesthetic touch [1,2]. For structural enhancement it is required to increase the reinforcement amounts or using complex framework which led to difficult compaction and more workability concrete. By
using high strength concrete (HSC) the problems mentioned above were solved and more benefits were obtained such as reduction in member dimensions, ultimate durability, more economical [3,4]. Reduction in beams capacity occurs when longitudinal and transverse opening in the beam (BLTO) are made, so an enhancement on members resistance against shear, flexural, torsion stresses must take place [5,6]. In 2013, AL-Maliki Investigated the alteration of a five RC hollow core deep beams (with a single, double and a sides strips) [6]. Also, the investigation included the effect of hollow (shapes and materials) as (Ø50mm circular PVC and 50x50mm square steel). It was noticed from the results that a decreasing in strength capacity and an increasing in deflection and strain took place in hollow beams when it was compared with the solid section. Recently (HSC) and (UHPC) are used in civil structures. (HSC) manufacturing is considered a high cost comparing to the (NSC), but it is applicable in a various type of civil structures due to its high obtained advantages [16]. One of the particular types that attracted the attention of many civil engineers is (UHPC) for having extraordinary properties when it comes to strength and durability. In 2015, Yoo and Yoon carried out an investigation on the structural performance of UHPC beams using various kinds of steel fibers. The results obtained showed that the load carrying capacity, post cracking stiffness, and cracking response when a decrease in ductility was noticed. By including 2% of steel fiber the load carrying capacity was higher by 27%–54% and the ductility was lower by 13%–73%. Also, the post-peak response and ductility was enhanced by using smooth, twisted or longer steel fibers, on the other side no variance is noted for its load bearing capacity and post-cracking toughness [7]. HSC and UHPC are used in hollow beams because of its high strength properties. Hollow sections develop a good strength against bending moment but on the other hand it gave a weak tensional load. In civil constructions, the RC beams submitted to a torsion as an outcome of external load in the area of center of the shear for cross-section or deformations that produced from the continuation of beams [9]. Lopes and Bernardo the results of their studies indicate that the beams that contain (HSC) are experience four types of disadvantages depend on the reinforcement [8]. From taking in consideration the low ratio to the high ratio of reinforcement, failures of the beams includes the brittle fracture that occurs because of the reinforcement is not sufficient, the fragile fracture that occurs because of corner cracking, crisp failure that occurs because of the strength of the concrete is not sufficient and the ductile failure. In 2013, they carried out a plastic analzyation and evaluation of the twist ability of (HSC) hollow beams subjected to a clear torsion. They mentioned that the increasing in the concrete compressive strength leads to a small decreasing in plastic twist capacity [8]. In 2014, they studied the cracking patterns in vacuous beams subjected to torsion using HSC. The result obtained showed that by using HSC led to lower ductile and cracks in beams compared with NSC [17,18]. Hii and Al- Mahaidi studied an investigational and a numerical realization on the torsional strengthening of solid and hollow RC beams externally joined with using CFRP that causing a high values mutually in the cracking and the ultimate strengths to percentage reach to 40 % and 78 %, in sequence [12]. Usually RC sections with web holes are used in civil structures work intended for Laying of service pipes as shown in Figure 1. Taking Flexure in respect. A very substantial limitation for the structural design of service load [10,13-15]. Hafiz et al. the effects of openings on behavior the (RC) beams without using any specific reinforcing on the opening area was evaluated. The (RC) beams with rectangular shape having a circular openings of a diameter that takes a percentage lesser than 44 % of the total depth of beam (D) has no effect on the final loading capacity, on the other hand beams that have circular opening with a diameter that takes a percentage more than 44% of (D) witnessed a drooping in ultimate load capacity that reached up to 34.29% [11]. Also, the study showed that circular openings presents more strength comparing to the beams that have square opening, with a diversity of 9.58% in ultimate load.
2. Description of the tested beam
The numerical model is implemented similar to an experimental program done by Abtan and AbdulJabbar [20] which the tested RC beam had the same dimensions, reinforcement, concrete type, and holes dimensions of the experimental program. The dimensions of beam were (length 1910 x height 250 x width 150) mm and properties are shown in Figures 2 and 3. The beam was tested by simply supported over clear span of (1800 mm). The longitudinal opening is 50 x 50 mm in the middle of the cross-section while the opening in transverse direction was 50 x 50 mm in the mid-span area of the beam. Steel reinforcement were 6 mm for the stirrups and 16 mm for the main longitudinal reinforcement and 20 mm concrete over was used as shown in Figure 2.

Figure 1. Beams with openings.

Figure 2. Hollow beam details [20]
3. Material modeling:
Concrete represents a material considered semi-brittle with a different attitude in tension and compression. The curve of the stress-strain in compression condition for the concrete is appeared to be linearly elastic to around 30% percent of the maximum compressive strength ($\sigma_{cu}$). Further over this stage, the stress is gradually increasing to around about the maximum compressive strength. Once it reaches the point of maximum compressive strength ($\sigma_{cu}$), the curve goes down to the softening zone, till the point that crushing failure happens when it reaches the value of ultimate strain ($\varepsilon_{cu}$). On the other hand, when it comes to tension, the curve of the stress-strain becomes almost linearly elastic for the materials when it reaches the value of maximum tensile strength. Beyond that point, cracks in concrete occur and the strength decreases till it reaches zero. ($f'c$), ($f_r$), ($E$), ($\mu$) and reduction factor of stiffness for the tensile cracked condition are very important to know and define how the concrete behave in ANSYS. In all the conditions, the concrete tensile strength percentage was considered at 10% of the compressive strength. The plain concrete constitutive model explaining the response of uniaxial compression demonstrated by Kachlakev (2001 the simulation of the concrete constitutive behavior is done by the use plasticity based damage model with a three-dimensional continuum [19]. The concrete inelastic performance was done by the use of isotropic hardening plasticity. For the representing of the concrete elements A SOLID65 element was used. The element used includes eight nodes and it is capable of plastic distortion also capable of cracking and crushing. A 180 Link element is used for modeling longitudinal rebar and stirrups. The specimens examined here were a simply supported beam subjected to one-point load. Steel plates 25.4 mm thickness were used in both loading and support zone. The same behavior for compression and tension is used for steel reinforcement modeling according to Von Mises failure principle, where the steel reinforcement is shown as bilinear isotropic material. In this study, poison’s ratio value of $\mu= 0.3$ was applied for the steel reinforcement. For knowing the tangent modulus of steel and the yield stresses, linear behavior was taken in consideration for the steel bearing plates. Bearing plates were symbolized in ANSYS for the purpose of preventing stress intensity in such areas. A Young’s modulus of a value $E=200$ Gpa took place in this study. Link180 element was used to model longitudinal rebar and stirrups. Link 180 is considered as an element of a 3D bar and its formation contain two nodes with three degrees of freedom for each node. While, Solid 185 was also used in this beam for modeling the bearing steel plates that located at loading and supports points. For the simulation of the behavior of the simply supported BLTO in this numerical research, bearing plate elements of the concrete and steel were presented by employing solid elements, in order to increase efficiency of describing the limits of the elements and modeling the behavior. A solid element with fine mesh of 3D eight-node was used (Figure 5). Using the symmetry feature, a half of the beam is represented. For the behaviour simulation of the simply supported BLTO in this numerical research, the concrete and steel bearing plate elements were presented by employing solid elements, in order to increase efficiency of
describing the elements limits and modeling the behavior. Using the full-scale feature, a full beam is represented. Modeled supports were made in a way that a roller was formed. A node on the plates single lined was given constraint in the Y direction in the first plate of supports while the other one is supported like hinge in Y and Z direction. Mid-span is supported in X-direction for the stability condition. The line of nodes on the plate is existed at the plate center.

4. Comparing the results of experimental and numerical:
Verification is done to know and check the rightness and accuracy of the software. The results collected from using FEM are compared with the collected experimental results that was given by Abtan and AbdulJabbar [20]. As mentioned earlier, the verification procedure was executed on one beam (MS) analyzed by nonlinear FEM. The comparison was done by means of the load-deflection curves, ultimate load, cracking load, and crack patterns. Table 1 and Figures 5 & 6 show the results of numerical analysis, in which a good agreement with experimental tests can be notice.
Figure 5. Verification by load-deflection between the experimental and numerical beam (MS).

Figure 6. Verification by crack pattern between the experimental and numerical beam (MS).

Table 1. Comparing the results of numerical & experimental in load failure (V) and deflection (Δ).

| Beam | V_{ansys}(KN) | V_{exp}(KN) | V_{ansys}/V_{exp} | Δ_{ansys}(mm) | Δ_{exp}(mm) | Δ_{ansys}/Δ_{exp} |
|------|---------------|-------------|-------------------|---------------|-------------|-------------------|
| MS   | 210           | 207         | 99%               | 11.3          | 12          | 94%               |

5. Result and Discussion

In this analysis, the beams behavior is linearly elastic up to about (14%) for hollow beam of the load maximum failure. Above the mentioned point, an increasing in the load till it reach the maximum load capacity. It is noticed from the results of the analysis that hollow beam appear a linear behavior till the occurrence of the first diagonal cracks. It can be observed that hollow beam with shear reinforcement have deformation capacity distinctly different with respect to the solid beam. After the vertical cracks
occur, the prismatic hollow beam loses all capacity to carry the load through deformation. The nonlinear FEM is hardly predictable to present significantly more understandable shear failure mechanism and moreover to develop a reasonable concrete structure without a stirrups shear model design. The stiffness is decreased with existence of web and longitudinal opening. The first crack appeared at (14%) for the hollow beam. Number of cracks increase with increasing in the applied load. For hollow beam with stirrups, diagonal cracks developed in the area of shear span from the support toward the loading zone. At this stage, the failure is not occurring because the failure is controlled by flexural cracks at the mid-span under the opening location. Presence of longitudinal and transverse opening caused stress concentration in the openings corners which developed the cracks at these regions. Flexural stress distribution in beam presented various distribution. The intensity level consisted from colors (blue, green, yellow, brown to red) on sequence in concentration, the blue is shown as the minimum intensity while red is shown as maximum intensity as shown below in Figure 7.

Figure 7. Stress distribution and deflection shape of the tested beam MS.
Figure 8. Stress intensity of the analyzed beam MS.
6. Conclusion

The present numerical study is focused on the behavior on the flexural behavior of hollow beam with transverse opening. Based on the results obtained from the FEM, it is concluded that the manner in which flexural failure occurs varies widely. Many factors have significant effect on the flexural behavior of beam at failure, and these effects can be summarized as follows: These types of beams were affected by presence of transverse opening. Presence of longitudinal and web opening decrease the stiffness, on the other hand deflection of the beam increases.

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