Behavior of Pre-stressed Concrete Deep Beams

Zuhear Abed Hajam 1, Kamal Shahada Mahmoud 2 and Mustafa Ahmed Yousif 3

1 Lecture, Water and Resources Engineering Department, Al-Mustansiriyah University, Baghdad, Iraq
2 Lecture, Civil Engineering Department, Al-Mustansiriyah University, Baghdad, Iraq.
3 Asst. Prof., Civil Engineering Department, Al-Mustansiriyah University, Baghdad, Iraq

Abstract: Six simply supported deep beams were tested to show the influence of prestressing strand on the behavior of reinforced concrete deep beams. All tested beams have same gross sectional area (42000) mm², compressive strength (30) MPa, clear span length (1000) mm, longitudinal and vertical reinforcement and the strengthened beams are strengthening by one strand with (12.7mm) diameter. Tested beams were divided into two groups according to the existence of prestressing strand, the first group consist of one deep beam without prestressing strand and it is considered as a reference, while, the second group consist of five Pre-stressed concrete deep beams divided according to the magnitude of jacking stress (fjp) ranging from (250 to 450) bar. During the test, it was found that, the load deflection curves for Pre-stressed concrete deep beams are stiffer compared with the reference beam and the percentage of stiffness was increased with the increase in the magnitude of jacking stress (fjp), and the maximum applied load increased to 8.89%, 13.68%, 18.00%, 24.77% and 33.55% with increasing the jacking stress respectively, compared with the refer beam. on the other hand, the deflection values at mid span increase with decreasing rate to 46.34%, 31.71%, 19.51%,9.75% and 2.44% with increasing the jacking stress respectively, compared with reference beam and the maximum applied load at first crack was increased to 13.64%, 15.56%, 17.4%, 20.84% and 26.93% with increasing jacking stress respectively, compared with reference beam. Finally, the failure mode for deep beam changed from flexural-shear failure to diagonal splitting failure when prestressing strand has been added.

1. Introduction
Reinforced concrete deep beam is structural element which has depth is larger than normal, in relative to their length, on other hand, the thickness of section in perpendicular direction is less than either length or depth. The stress and strain in any section of the deep beam calculated from elastic analysis adds nonlinear behavior. The ACI Code 318-19 explains reinforced concrete deep beams as those with clear span does not exceed four times of the overall depth of the member or the point load exist at a distance two times of the whole member depth from the face of the supports[1]. Reinforced concrete deep beams are commonly used in structural engineering for instance, pile caps in foundations ,deep girders, load bearing walls, coupling beams in buildings, bunkers, etc. .Behavior of deep beam is affected by several parameters, like clear span to effective depth ratio (ln/d), shear span to effective depth ratio (a/d), loading type, location of applied load, percentage of tension reinforcement, quantity and type of web

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
reinforcement, width of the support region, anchorage of reinforcement and compressive strength of concrete. Because of this large number of variables it is difficult to formulate an inclusive design method [2, 3, and 4].

Internal prestressing criterion main put all the concrete under compression, so that no tensile crack is permitted at working loads, and this criterion may be called prestressing. Internal prestressing can be achieved by two approaches pre-tension and post-tension. In pre-tensioning approach's, pre-stressing is generated (i.e. strands are subjected to tension stress) before pouring of concrete. It is prepared in manufacturing works. In this approach, the strands are bounded temporarily against some struts and then they are pulled out by using jack machines. Then the concrete is poured. As soon as, concrete is hardened, the strands are released. The tension force will be transferred from strands to concrete through the bond. While in the post-tension the pre-stress is generated after the concrete has been hardened. In this approach, poring of concrete has been done first and a duct is molded in the member with tube or with a metal sheathe. When concrete has been hardened then strand is transferred from the member through anchorage wedges. There are many advantages of post-tensioning approach, it can be achieved in manufacturing works and at the site, as well, the total loss of pre-stress strand is a lesser amount as compared to pre-tensioning approach and post-tension approach is designed for heavily loaded structures and large spans. Since post-tensioned approach is a very common form used in both statically determinate and statically indeterminate structures, so it was adopted in this study [5].

2. Aim and Idea of the Present Study
The main objective of the present research is to understand the influence of magnitude of jacking stress \( f_{pj} \) on the behavior of reinforced concrete deep beams. The behavior of deep beams is indicated by their levels of load deflection responses, maximum applied load at failure stage, maximum deflection at mid span, maximum applied load at first crack stage, cracks pattern and failure modes.

3. Experimental Work
Six simply supported deep beams were tested to show the effect of prestressing strand on the behavior of reinforced concrete deep beams. All deep beams had the same dimensions (420x100) mm\(^2\), compressive strength (30) MPa, span length (1100) mm, amount of flexural reinforcement (2 Ø 20 mm) and shear reinforcement (1 Ø 4 mm @100 c/c and the strengthened beams were strengthening by one prestressing strand with (12.7mm) diameter. Tested beams were divided into two groups with and without pre-stressed strand, the first group consist of one deep beam considered as a reference, while, the second group consist of five Pre-stressed concrete deep beams divided according to the magnitude of jacking stress \( f_{pj} \) ranging from (200- 450) bar. The clear length between supports was 1000 mm and the ratio of clear span to generally depth is equal to 2.564 which its less than four as suggested by the limitation of the ACI 318M-19 Code for deep beam requests. Descriptions and the Properties of tested beam are shown in Fig.1 and Table.1
Table 1. Properties of Pre-stressed concrete deep beams

| Groups | Specimen No. | $f'_c$ (MPa) | b (mm) | h (mm) | a (mm) | d (mm) | Ln (mm) | a/d | ln/d | Jacking Stress, $(f_p)_{j}$, Bar |
|--------|--------------|--------------|--------|--------|--------|--------|---------|-----|------|------------------------------|
| 1      | DB 0         | 30           | 100    | 420    | 333    | 390    | 1000    | 0.854 | 2.564 |                             |
|        | DB 250       | 30           | 100    | 420    | 333    | 390    | 1000    | 0.854 | 2.564 | 250                          |
|        | DB 300       | 30           | 100    | 420    | 333    | 390    | 1000    | 0.854 | 2.564 | 300                          |
| 2      | DB 350       | 30           | 100    | 420    | 333    | 390    | 1000    | 0.854 | 2.564 | 350                          |
|        | DB 400       | 30           | 100    | 420    | 333    | 390    | 1000    | 0.854 | 2.564 | 400                          |
|        | DB 450       | 30           | 100    | 420    | 333    | 390    | 1000    | 0.854 | 2.564 | 450                          |

3.1. Test Procedure

All specimens were tested in the structural lab of engineering College of Mustansiriyyah University. The (MFL) universal hydraulic device of (3000kN) capacity had been used. Specimens were tested under two concentrated point load at third span with clear span length of (1000) mm. (12x50) mm steel plate was used to transform the concentrated load to line load over the surface of tested beam, tested beam was placed over supports; a dial gauge of (0.01 mm) accuracy with (30 mm) capacity is fixed at mid span, then load of (5kN) was applied and removed, in order to adjust the zero reading of dial gauge. Tested beams were subjected to load step about (1.5kN/sec) and reading of dial gauge was taken every (10kN) increment. Failure occurred if the tested beam had been failed suddenly when the load guide...
was stopped in record or when the applied load was dropped with increasing deformation rapidly, then the maximum load has been recorded and the load has been removed to allow taking some pictures of the cracking pattern at failure stage.

4. Results and Discussion.
The experimental results of tested specimens are listed in Table 2 and some of important parametric study such as load deflection responses, maximum applied load at failure stage, maximum deflection at mid span, maximum applied load at first crack stage, cracks pattern and the failure modes had been listed as follows:

Table 2. Summary of Experimental Results of Tested Specimens*

| Groups | Beams No. | Jacking Stress, \( (f_p) \), (Bar) | Series Symbols | Max. Exp. applied load \( (Pu) \), (kN) | Max. Exp. deflection at mid span, (mm) | Mode of Failure               |
|--------|-----------|-----------------------------------|----------------|--------------------------------------|--------------------------------------|-----------------------------|
| 1      | Ref.      | DB 0                              | 410.0          | 4.10                                 | Flexural-Shear Failure              |
| 2      | 1         | 250                               | DB 250         | 450.0                                | Diagonal- splitting Failure         |
|        | 2         | 300                               | DB 300         | 475.0                                | Diagonal- splitting Failure         |
| 3      | 3         | 350                               | DB 350         | 500.0                                | Diagonal- splitting Failure         |
|        | 4         | 400                               | DB 400         | 545.0                                | Diagonal- splitting Failure         |
|        | 5         | 450                               | DB 450         | 617.0                                | Diagonal- splitting Failure         |

*All tested beams have the same \( (a/d) \) ratio = 0.854

4.1. Load deflection responses
From the testing, it can be found that the load deflection curves for tested beams were stiffer compared with reference and the percentage of stiffening was increased when the magnitude of jacking stress has been increased from (250 to 450) bar; that as, a result of Pre-stressed action which can be improved the properties of concrete as well as, contributing with deep beam to resist the applying load and that lead to make the behavior of pre-stressed concrete deep beams have been less ductility and more brittle as compared with a reference deep beam[2], the effect magnitude of jacking steers on the load deflection curves of tested beams at mid span are shown in Fig.2.
4.2. Maximum applied load for tested specimens.

From the test results, it was found that the maximum applied load was increased to 8.89%, 13.68%, 18.0%, 24.77% and 33.55% with increasing the jacking stress from (250 to 450) bar respectively, compared with reference deep beam. It is also clear that the maximum applied load was increase with increasing the jacking stress; that as a result of Pre-stressed action which enhanced the concrete properties, as well as contributing with deep beam to resist the applied load which lead to increase in the maximum load applied compared with reference deep beam[2]. The percentage increasing in maximum applied load of tested beams are listed in Table 3.

Table 3. Percentage increasing in maximum applied load of tested beams

| Beams No. | Series Symbols | Jacking Stress, (fpj) (Bar) | Maximum Exp. applied load (Pu) (kN) | Percentage of maximum load(%) as compare with reference |
|-----------|----------------|-----------------------------|-------------------------------------|---------------------------------------------------------|
| Ref.      | DB 0           | -------                     | 410                                 | 0                                                       |
| 1         | DB 250         | 250                         | 450.0                               | 8.89                                                   |
| 2         | DB 300         | 300                         | 475.0                               | 13.68                                                  |
| 3         | DB 350         | 350                         | 500.0                               | 18.00                                                   |
| 4         | DB 400         | 400                         | 545.0                               | 24.77                                                   |
| 5         | DB 450         | 450                         | 617.0                               | 33.55                                                   |

Figure 2. Load deflection curves of tested beams.
4.3. Deflection values of the tested specimens
From the test results, it was found that maximum deflection values at middle span are so little with relational to the applied loading, and the percentage of increasing in deflection at mid span increased with decreasing rate to 46.34%, 31.71%, 19.51%, 9.75% and 2.44% with increasing the jacking stress from (250 to 450) bar respectively, compared with the reference. It is also clear that the maximum deflection at mid span increases with decreasing rate when the jacking stress \((f_p)\) are increased from (250 to 450) bar, that as a result of pre-stressed action which improved the concrete properties, as well as contributing with deep beam to resist the applied load which lead to increase the deflection at mid span compared with the reference [2], the experimental results deflection values for tested beams are listed in Table 4.

Table 4. Experimental results deflection values for tested beams

| Beams No. | Series Symbols | Jacking Stress, \((f_p)\),(Bar) | Max. Exp. deflection at mid span,(mm) | Max. Percentage increase in deflection at mid span of tested beams,(%) as compare with reference |
|-----------|----------------|---------------------------------|------------------------------------|-------------------------------------------------------------------------------------------------|
| Ref.      | DB 0           | ------                          | 4.10                               | 0                                                                                               |
| 1         | DB 250         | 250                             | 6.00                               | 46.34                                                                                           |
| 2         | DB 300         | 300                             | 5.40                               | 31.71                                                                                           |
| 3         | DB 350         | 350                             | 4.90                               | 19.51                                                                                           |
| 4         | DB 400         | 400                             | 4.50                               | 9.75                                                                                             |
| 5         | DB 450         | 450                             | 4.20                               | 2.44                                                                                             |

4.4. Maximum load at first crack of the tested beams
From the test results, the first web shear crack was observed at the diagonal zone in the distance between the applied load position and support location. The first flexural crack appeared in the bottom of the tested beam at the mid zone between load locations; the beams remained stable after cracking occurs. With the increase in applied load lead to form a diagonal crack at 45° toward the compression region between support and location of loading, finally, crushing failure occurs in concrete [6,7]. Also, it was found that the load at first crack was increased to 13.64%, 15.56%, 17.4%, 20.84% and 26.93% with increasing the jacking stress from (250 to 450) bar respectively, compared with the reference. The maximum applied load at first crack values for tested specimens is illustrated in Table 5. It is also clear that the load at first crack increased with increasing in the jacking stress; that as a result of pre-stressed action which improved the concrete properties, as well as contributing with deep beam to resist the applied load, so that lead to increase the first cracking load.
Table 5. Percentage increasing in maximum load at first crack of tested beams

| Beams No. | Series Symbols | Jacking Stress, \( f_{pj} \) (Bar) | Load at first crack (kN) | Max. Percentage of load at first crack(%) as compare with reference |
|-----------|---------------|-------------------------------------|--------------------------|---------------------------------------------------------------|
| Ref.      | DB 0          | --------                            | 95.0                     | 0                                                             |
| 1         | DB 250        | 250                                 | 110.0                    | 13.64                                                          |
| 2         | DB 300        | 300                                 | 112.5                    | 15.56                                                          |
| 3         | DB 350        | 350                                 | 115.0                    | 17.4                                                           |
| 4         | DB 400        | 400                                 | 120.0                    | 20.84                                                          |
| 5         | DB 450        | 450                                 | 130.0                    | 26.93                                                          |

4.5. Crack Patterns and Modes of Failure

The slenderness of the deep beams (shear span to effective depth ratio) determines the failure mode of the beam. For deep beams with \((a/d) < 1.0\), there are three types of failure can be occur [8].

- Flexure: The deep beam had a low ratio of reinforcements at bottom religion and collapse in tension zone at mid span.
- Flexural-shear: The deep beam fails in shear, with major cracks growing from support towards the applied load. In this case, there is a sufficient quantity of steel reinforcements at tension zone and the growth of shear-crack is generally followed by flexural cracks at mid span.
- Diagonal splitting: The deep beam fails in diagonal splitting and it's the typical failure mode, then final shear crack once more spreads between the applying load and support region, but it is try to grow away from middle depth of section, so, the diagonal splitting failure became more brittle as comparing with other two failure modes [9].

In this study the mode failure of reference deep beam was flexural-shear mode, while, all Pre-stressed concrete deep beams were failed in perfect diagonal splitting mode and the Flexure-shear type cracking will seldom control the failure of this type of member, that as a result of pre-stressed action which improved the concrete properties, as well as contributing with the deep beams to resist the applied load, so that tries to stoppage of flexural-shear cracking, the failure will be inclined crack for deep members between the point load and the support reaction [10]. Typical crack pattern and failure modes of tested specimens are shown in Fig.3.
5. Conclusions

Based on the results of experimental investigation on behaviour of Pre-stressed concrete deep beams, the following conclusions can be obtained.

- Load deflection curves for Pre-stressed concrete deep beams are stiffer compared with reference deep beam and the percentage of stiffening was increased with an increasing in the jacking stress \( f_{pj} \).
- The maximum applied load increase to 8.89\%, 13.68\%, 18.00\%, 24.77\% and 33.55\% with increasing the jacking stress from (250 to 450) bar, respectively compared with reference beam.
- The percentage increasing in deflection at mid span increase with decreasing rate to 46.34\%, 31.71\%, 19.51\%, 9.75\% and 2.44\% with increasing the jacking stress from (250 to 450) bar, respectively compared with reference beam.
- The first cracking load increases to 13.64\%, 15.56\%, 17.4\%, 20.84\% and 26.93\% with increasing jacking stress from (250 to 450) bar, respectively when compared with reference beam.
The failure mode for deep beams change from flexural-shear failure to diagonal splitting failure when prestressing strand has been added.

6. Acknowledgments
Authors are wishing to acknowledge Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad _ Iraq

7. References
[1] ACI Committee 318-19,"Building Code Requirement for Structural Concrete and Commentary", American Concrete Institute, Farmington Hills, Michigan, 2019.
[2] K. Sh. Mahmoud, "Nonlinear Analysis of Pre-stressed concrete Deep Beams", M.SC. Thesis, University of Technology, Iraq, 2004.
[3] D. Birrcher, R. Tuchscherer, M. Huizinga, O. Bayrak, S. Wood and J. Jirsa,"Strength and Serviceability Design of Reinforced Concrete Deep Beams", CTR Technical Report, December, Center for Transportation Research at The University of Texas at Austin, 2009.
[4] S. A. Hassan and A. H. Mheb," Behavior of High Strength Hybrid Reinforced Concrete Deep Beams under Monotonic and Repeated Loading" The Open Civil Engineering Journal, vol.12, 2008, pp. 263-282.
[5] P. Bhatt, "Pre-stressed Concrete Design to Euro codes", Simultaneously published in the USA and Canada by Rout ledge, 711 Third Avenue, New York, NY 10017, 2011.
[6] N. Zhang and K. H. Tan, "Direct Strut-and-Tie Model for Single Span and Continuous Deep Beams, Science Direct, Engineering Structures Journal, vol.29, March, 2007, pp. 2987-3001.
[7] K. H. Tan and H. Y. Lu, "Shear Behavior of Large Reinforced Concrete Deep Beams and Code Comparisons", ACI J., vol. 96, no. 5, September-October, 1999, pp. 836-845.
[8] A.A. Abdel-Razzak, “The Effect of Low Shear Span Ratio on the Shear Strength of RC Beams”, M.Sc. Thesis, University of Technology, Baghdad, (2001).
[9] N.K. Subbedi, E.V. Alan, and N. Kubatm, "Reinforced Concrete Deep Beams -Some Test Results ", Magazine of Concrete Research, Vol.38, No.137, Dec. 1986, pp.206-219.
[10] A. Alshegeir and J. A Ramirez, "Strut-Tie Approach in Pre-tensioned Deep Beams". ACI Structural Journal. Vol. 89, 1992 pp. 296-304