Journal of Engineering and Sustainable Development
www.jeasd.org
Vol. 21, No.01, January 2017
ISSN 2520-0917

CRACK PATTERN AND MODES FAILURE INVESTIGATION OF REINFORCED CONCRETE INVERTED HOLLOW CORE DAPPED END BEAMS STRENGTHENED WITH LONGITUDINAL NORMAL STRAND BARS (BOLTS).

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Abstract: This study is part of the studies, conducted her study tested the Faculty of Engineering, University of Mustansiriya to investigate the behavior of reinforced concrete inverted hollow core dapped end beams under effect of static loads. Seven specimens with dimension (length 1220 x height 240 x width 130mm) with different section (i.e. without or with hollow core) and simply supports under concentrated load applied at two points. The main variable are section type (with or without hollow core), hollow core location (top or bottom fibers of beams) and the beam strengthened or unstrengthen with longitudinal normal bars (bolts of diameter 12.5 mm) work as installed after casting normal bars installing after finish curing of specimens at top fibers. Comparison between specimens are based on load carrying capacity, contrast deflection, load-deflection curves, crack patterns and modes of failures for all beams. Results show after test till failure the recess provided by PVC pipe (diameter of 50mm and length 500 mm) led to decreased in load capacity by about (6.5-9%) and give increase in deflections by about (33-35%) compare with solid beams section. The longitudinal normal strand bars used in strengthened led to increase in load carrying capacity and decrease in corresponding deflection compared with other unstrengthened beams by about (6-21%) & (13-29%). Also increasing strengthen ratio by longitudinal bars (bolts) to twice gives gain in strength capacity and by about (4-9%) for different case of recess location (top or bottom fibers). From crack patterns show some specimens fail in support due to lack of support during construction or to transmit more loads to it's by strengthen system. At last the crack patterns have same behavior with different intensity of same property when produced it, but when used longitudinal normal strands bolts as installed after casting bars that provide by geometry on gives increased load capacity and reduced in cracks. Also cracks are concentrated near support and distribute at mid of reinforced concrete Inverted Dapped ends girders to formulated compound failure.

Keywords: *Dapped-end Beams, Hollow core, Recess, Longitudinal bolts, post-curing.*

تحري انماط التشقق ووسائط الفشل للعتبات الخرسانية المسلحة المقلوبة المجوفة الغير مستمرة النهايات المقواة بالقضبان الاعتيادية (البراغي).

الخلاصة: هذه الدراسة هي جزء من الدراسات التي اجريت دراستها واختبارها في كليه الهندسة الجامعة المستنصرية لتحري سلوك العتبات الخرسانية المسلحة المقلوبة المجوفة والغير مستمرة النهايات تحت تاثير الاحمال الساكنه.الدراسة شملت سبعة نماذج بابعاد (الطول 1220 ملم والعرض 130 ملم والارتفاع 240 ملم) وبسيطة الاسناد تحت تاثير حمل مركز في نقطتين.المتغيرات الرئيسة كانت هي نوع المقطع (مع او بدون تجويف) وموقع التجاويف (اعلى او اسفل) العتبه وكذلك التقوية بواسطة البراغي الطولية الاعتيادية قطر 12.5 ملم الموضوعة في الجزء العلوي من العتبة بعد اكمال عمليه الانضاج للخرسانة.المقارنة بين هذة النماذج تمت بالاعتماد على قابليه التحمل القصوى والهطول المقابل ومنحني الحمل الهطول لكافه العتبات وانماط التشقق ونوع الفشل . بينت النتائج

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بعد الفحص الى حد الفشل ان التجاويف التي عملت بواسطة انبوب بلاستيكي قطر 50 ملم وطول 500 ملم تؤدي الى نقصان في قابليه التحمل بحدود (5.6 الى 9%) وزياده في الهطول بمقدار (33 الى 35 %) بمقارنة مع تلك التي لا تحوي تجويف. القضبان الطوليه المستخدمة في تقوية العتبات تزيد من قابليه التحمل لها حوالي (6-21%) ونقصان في الهطول بمقدار(13-29%). كذلك ان زيادة نسبة التقوية بواسطة البراغي الطولية الى الضعف يؤدي الى زيادة قابليه التحمل تقريبا (4 الى 9%) ولمختلف مواقع التجاويف (اعلى او اسفل) العتبة.لوحظ من انماط التشقق بعض النماذج حصل فشل في المساند نتيجة لضعف المسند اثناء الانشاء او زيادة الاحمال المنتقله اليه بسبب تقوية النموذج. اخيرا شكل التشقق اخذ نفس السلوك وبكميات مختلفه وذلك لتشابه خصائصها وحسب النموذج اما بالنسبة للنماذج المقواة بواسطة القضبان البراغي الاعتيادية تزيد من قابليه التحمل وتقلل التشققات لنفس الحمل المسلط .وكذلك يمكن ملاحظة ان التشققات تبدا قرب المسند وتتوزع في المنتصف للعتبات الخرسانية المقلوبة مشكلة الفشل المركب (القص والانحناء).

1. Introduction

The concept of inverted dapped-end beams is extensively used in buildings and parking structures as it provides better lateral stability and reduces or kept the floor height. The design of dapped-end connections is an important consideration in a precast concrete structure even though its analysis is complex. The concept of this study is similar to concept of using Inverted-Tee system but the girder is isolated by space or joints in fields to not construct caps this led to distributed and reduced the loads comes from combined loading or traffic loads applied on the superstructure then trans to columns.

1.2 Inverted-Tee System

A common design implemented by Caltrans utilizes cast-in-place box-girders integrally connected to a cast-in-place concrete cap beam (Caltrans, 2011). Cast-in-place designs are often still preferred because of the belief that such designs are more reliable in seismic events, tend to have lower construction costs, and can be better suited for longer spans. However, a different detail that utilizes an inverted-tee bent cap integrally connected to precast girders has been occasionally implemented for decades for bridges with shorter spans. This detail is increasingly desirable since its configuration tends to allow quick installation of girders and thus works well in projects (Thiemann, 2010). It is typically implemented by using a cast in-place column with an inverted-tee cap beam that can be either cast-in-place or precast and set in place. Once the cap beam is positioned, the ledge, or corbel, on each side of the cap beam stem works well to support the dapped end of precast girders which can then be attached to the cap beam by the use of a cast-in-place diaphragm. The dapped-end-girder to inverted-tee concept is shown in Fig.(1). (Note that this figure provides the concept only; specific details such as girder block ends, diaphragms, etc. that were incorporated into this research are shown in the details provide later in the report.) Finally, the bridge deck can be cast-in-place over the completed superstructure. Such a configuration has recently been used in projects where existing structures are widened, to allow for relatively quick construction time and reduced field work**.**

2. Objective Of The Present Study

The main objective of this study is to develop a method for strengthening for inverted dapped-end hollow core using available easy construct and economic materials by using longitudinal normal bolts as installed after casting at the top and bottom fibers of girders thereby simplifying the manufacturing process or the repair of inverted dapped ends girders. The variable under investigation was the design strengthen of longitudinal normal bolts as installed after casting for the inverted dapped-end hollow core girders. Secondary objectives were:

a- To investigate the contribution of longitudinal normal bolts as installed after casting with respect to the strength capacity of the inverted dapped-end girders.
b- To investigate the possibility of hollow recess in reducing or increasing load capacity when strengthen system.
c- To investigate the effects of location and ratio of hollow recess on the strength of the inverted dapped-end hollow core girders.
d- To develop new method of strengthening to evaluate the strength of the inverted dapped-end hollow core girders when longitudinal normal bolts as installed after casting.

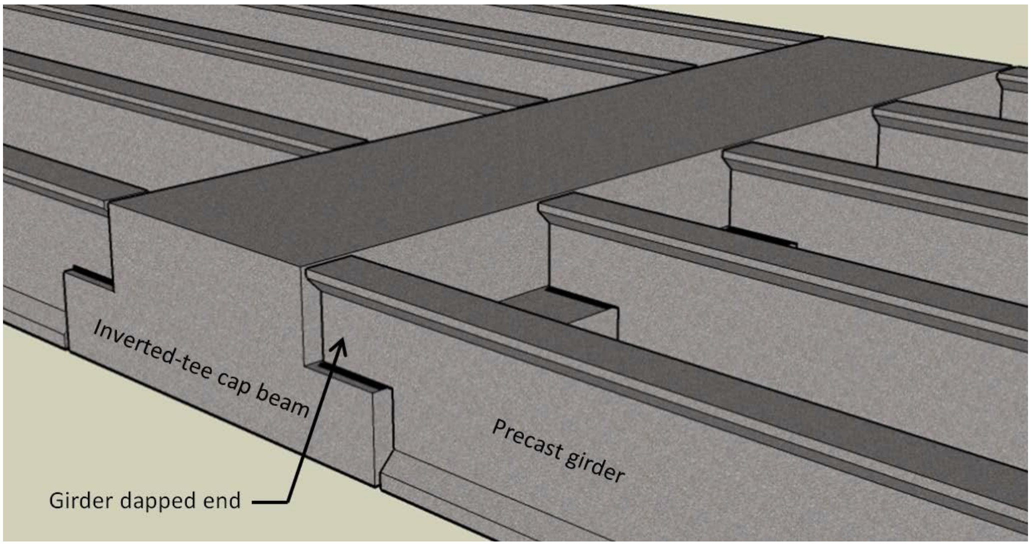


Fig.(1): Inverted-tee and girder dapped end connection [2].

3. Experimental Program

Seven reinforced concrete inverted dapped ends girders was conducted in the structural laboratory of the Civil Engineering Department at college of Engineering at the University of AL-Mustansiriya. The experimental program involves the strengthening of these girder by using longitudinal normal bolts of diameter 12.5 mm as installed after casting normal bars (bolts) for both girders with or without hollow cores. The specification and details of these girders are shown in Table (1) and Figs.(2-5).

3.1 Materials

In this study, the mixture of the concrete were consist of ordinary Portland cement (OPC) (type I) was used in this study, the cement was produced by United Cement Company (UCC) commercially known as "Tasluja-Bazian", Natural sand brought from Al-Ukhaider region was used in this study and irregular gravel of 10 mm maximum size from Al-Nebai quarry are used. Tap water was used for both mixing and curing of concrete in this work. Deformed steel bars (10) mm in diameter are used in this study. It was obtained from Ukrainian production. Three specimens of each bar are tested under tension according to (ASTM A615/A615M-05a)[21] requirements. The results of testing steel reinforcement are summarized in Table (4). The mix proportioning began with the selection of the unit weight (wet density) are given in Table(1) for all girders .The mix was then proportioned by the method of absolute volumes of one cubic meter are obtained by series test of trial mixes. Table (2) shows final adopted mix of designs. The average compressive strength of cylinder (150 x 300 mm) of concrete fc` of these mixer of 28 days are about 28 MPa.

Table (1) Mix proportions of Concrete (1 m^3).

Try mix.	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water/Cement Ratio	Water (kg/m3)
A	420	630	1260	0.5	210

Table (2) Table (3) Properties of Steel Reinforcement.

Type	Nominal Diameter (mm)	Measured Diameter (mm)	A_s (mm^2)	Yield Tensile Strength f_y (MPa)	Ultimate Strength f_u (MPa)
Bars	10	9.88	76.67	421	520
Bolts	12.5	12.2	116.89	480	576

*: According to ASTM A615/615M-08a

**: Average of three specimens (Bars of length 500mm).

Table (3): Details of R.C. Inverted Dapped end Beams Specimens

Beam Symbol	Bottom Reinforcing	Top Reinforcing	Vertical Stirrups Reinforcin	Horizontal Stirrups Reinforcin	Hanger reinforcing	Long. installed after	Hollow Region	Hollow ratio %
DE1NH	2Ø10	2Ø8	Ø10/100	2Ø10	3Ø10	---	---	---
DE2H	2Ø10	2Ø8	Ø10/100	2Ø10	3Ø10	---	Top	4
DE3HP	2Ø10	2Ø8	Ø10/100	2Ø10	3Ø10	1Ø12	Top	4
DE4H	2Ø10	2Ø8	Ø10/100	2Ø10	3Ø10	---	Bottom	4
DE5HP	2Ø10	2Ø8	Ø10/100	2Ø10	3Ø10	1Ø12	Bottom	4
DE6HP	2Ø10	2Ø8	Ø10/100	2Ø10	3Ø10	2Ø12	Top	4
DE7HP	2Ø10	2Ø8	Ø10/100	2Ø10	3Ø10	2Ø12	Bottom	4

Notes: All girders are inverted

DE: Dapped End : NH: Non Hollow : H: Hollow : HP: Hollow Installed Post Curing (bolts).

* : According to ASTM C39-86 and take average of three specimens (cylinder).

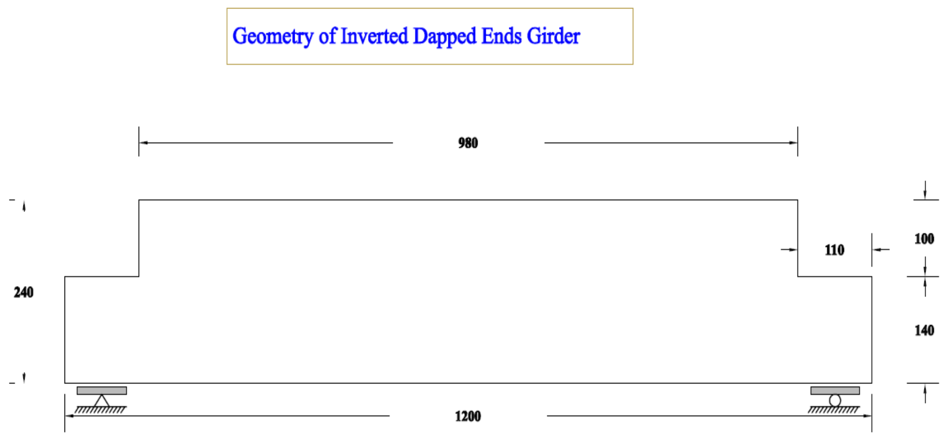


Fig.(2) R.C. Beam Inverted Dapped Ends Girder Layout & Dimensions (mm).

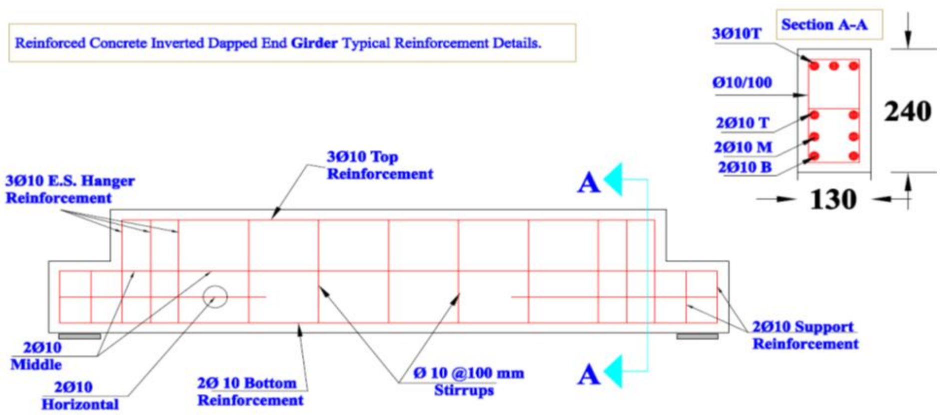
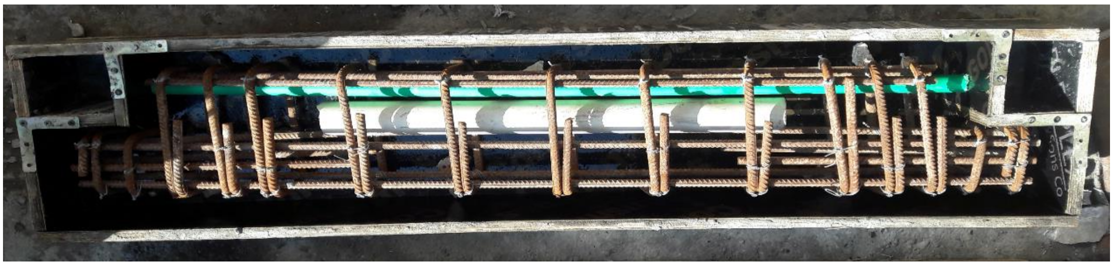


Fig.(3) Reinforcement Details of R.C. Inverted Dapped Ends Girders Layout.

1. Mould & Reinforcement of R.C. Inverted Dapped Ends Girder, (DE1NH)

2. Mould & Reinforcement of R.C. Inverted Dapped Ends Girder, (DE2H)



3. Mould & Reinforcement of R.C. Inverted Dapped Ends Girder, (DE3HP)

4. Mould & Reinforcement of R.C. Inverted Dapped Ends Girder, (DE4H)

5. Mould & Reinforcement of R.C. Inverted Dapped Ends Girder, (DE5HP)

6. Mould & Reinforcement of R.C. Inverted Dapped Ends Girder, (DE6HP), Double Bolts.

7. Mould & Reinforcement of R.C. Inverted Dapped Ends Girder, (DE7HP), Double Bolts.

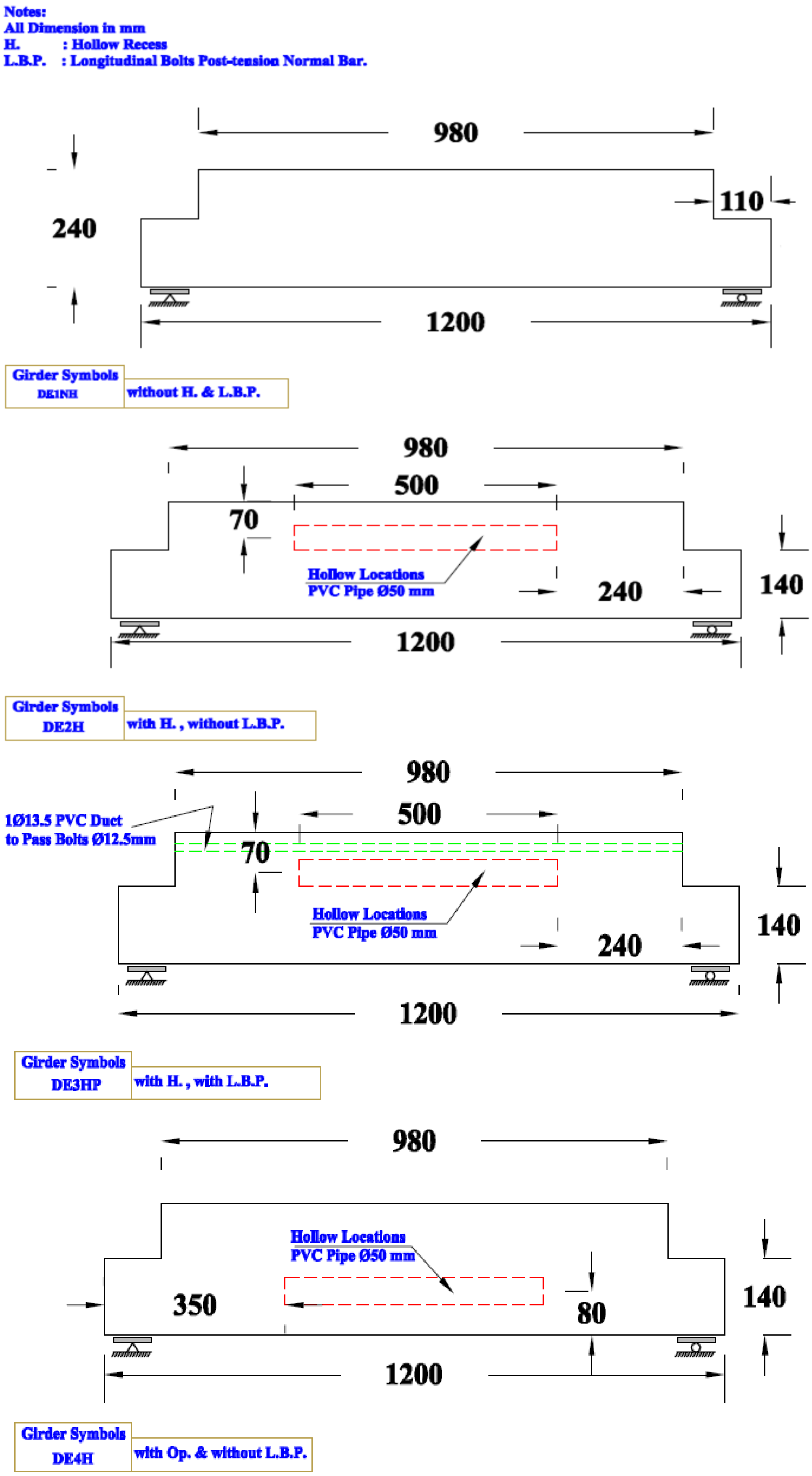


Fig.(4) Continue.

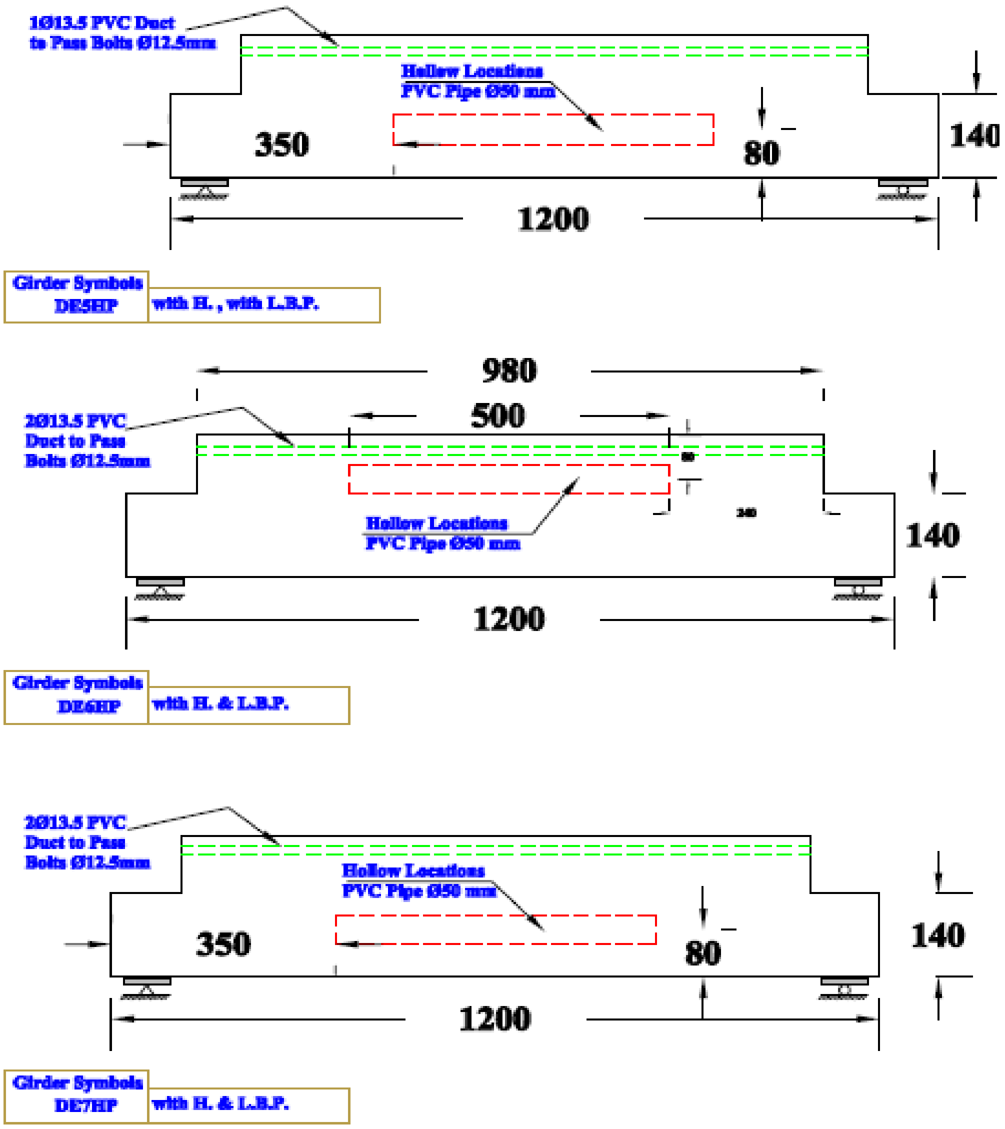
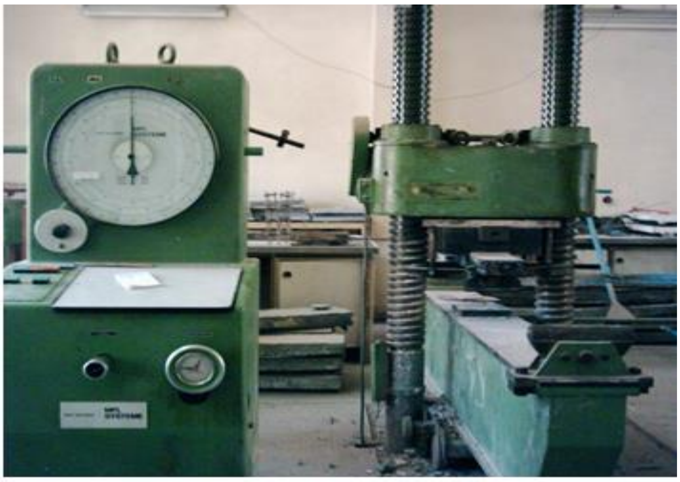


Fig.(4) Location of H. or L.B.P. of R.C. Inverted Dapped Ends Specimen.

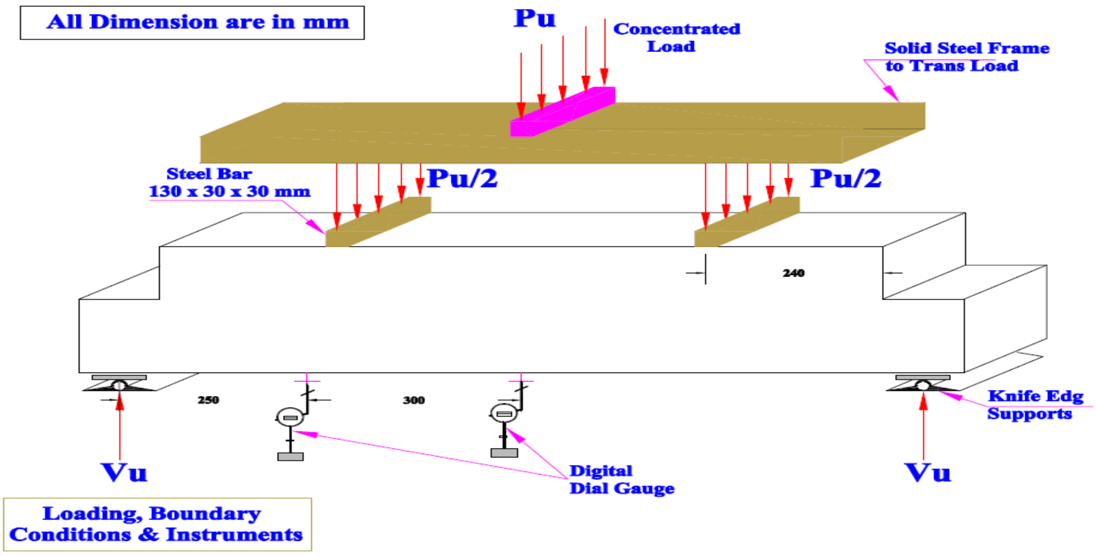
4. Instrumentation And Testing Procedure

After complete curing time, the girders are cleaning then painted with white color. When the dry surface of girders and become ready to test, the specimen is placed in position. The test specimens were subjected to two-point load in a universal testing compression machine with a total capacity of 3000 kN. Load was applied at the top face of reinforced concrete of Inverted Dapped ends girder as shown. A top steel spreader beam was used to transfer the applied load from the testing machine head into two equal point loads as shown in figures below. The load was applied in increments of 10 kN until failure. After each increment, the load was kept constant to allow marking of the new cracks and running of the dial gauge of accuracy (0.01). The deflections were measure at two positions, quarter and mid span. For all specimens, the test was under load control until the specimen reached its ultimate strength, also the first crack, ultimate loads, failure mode and crack patterns were recorded. Loading, boundary conditions and instruments layouts are shown in Fig.(5).

a. Testing Machine



b. Specimens Arrangement under Load Testing Machine.



c. Sample Supports and Layout.

Fig.(5) Loading, Boundary Conditions and Instruments Layouts.

5. Test Results

The test results of all specimens based on load carrying capacity, deflection and crack pattern are shown in the following:

5.1 First Crack and Ultimate Load

Table (5-6) show the results and comparison base on section types solid or hollow section also the effect of strengthening with longitudinal bolts as installed after casting and ratios of its. From results can show that when the section contain hollow recess led to increase in deflections and decreased in corresponding load capacity for the same other properties, also results show that using longitudinal bolts installed after casting to strengthening of specimens in inverted dapped ends beams gives more load capacity and decrease the deflection. Finally the comparison based on section types i.e. with or without recess can show the hollow section effect on strength capacity by reducing by about 10-15%. The first crack, ultimate load and maximum deflections are shown Tables (5 - 6).

Table (5) Fist Crack Loading, Ultimate Loading and deflection

Beam Symbol	DE1NH	DE2H	DE3HP	DE4H	DE5HP	DE6HP	DE7HP
Hollow Region	---	Top	Top	Bottom	Bottom	Top	Bottom
Long. installed after casting bolts	---	---	1Ø12	---	1Ø12	2Ø12	2Ø12
First Crack Load, kN	35	37.5	32.5	42.5	40	35	27.5
Ultimate Load, kN	96.5	87.5	102	90.5	108.5	110	116
Difference Load ,%	---	- 9.3	5.7	- 6.21	12.43	14	20.2
Deflection, mm	27	35	31.5	33	30.5	26	24.5
Difference deflection, %	---	29.6	16.66	22.22	13	- 4	- 9.3

The mode of failures of all Girders are Compound (flexure and shear failure).

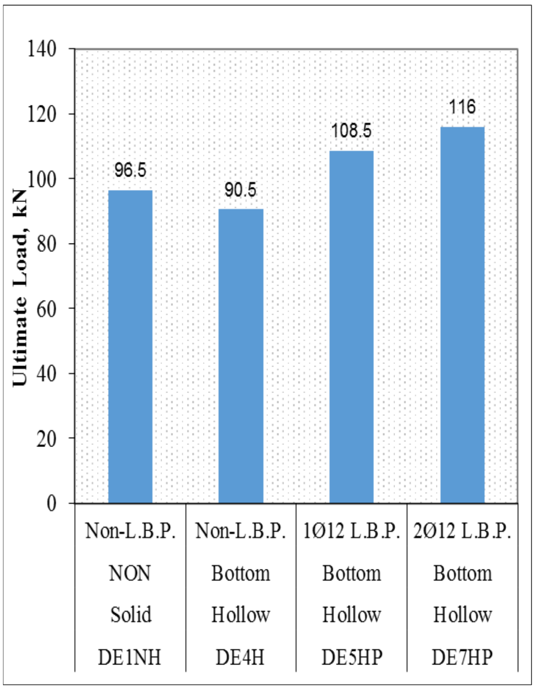
Table (6) Loads and deflections Central & near Dapped Ends.

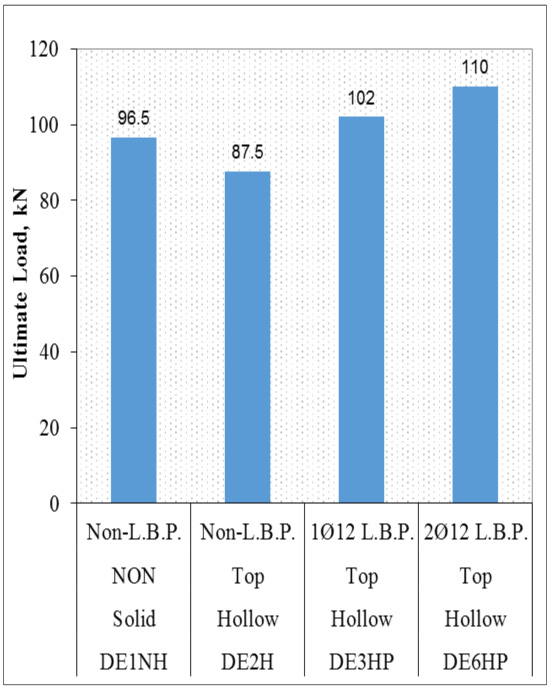
Beam Symbol	DE1NH	DE2H	DE3HP	DE4H	DE5HP	DE6HP	DE7HP
Hollow Region	---	Top	Top	Bottom	Bottom	Top	Bottom
Long. installed after casting bolts	---	---	1Ø12	---	1Ø12	2Ø12	2Ø12
Ultimate Load, kN	96.5	87.5	102	90.5	108.5	110	116
Max. Central Deflection, mm	27	35	31.5	33	30.5	26	24.5
Near Dapped Deflection, mm	15.6	18	16.4	18.5	14	12.5	11.2

5.2 Effect of Variables on Ultimate Load

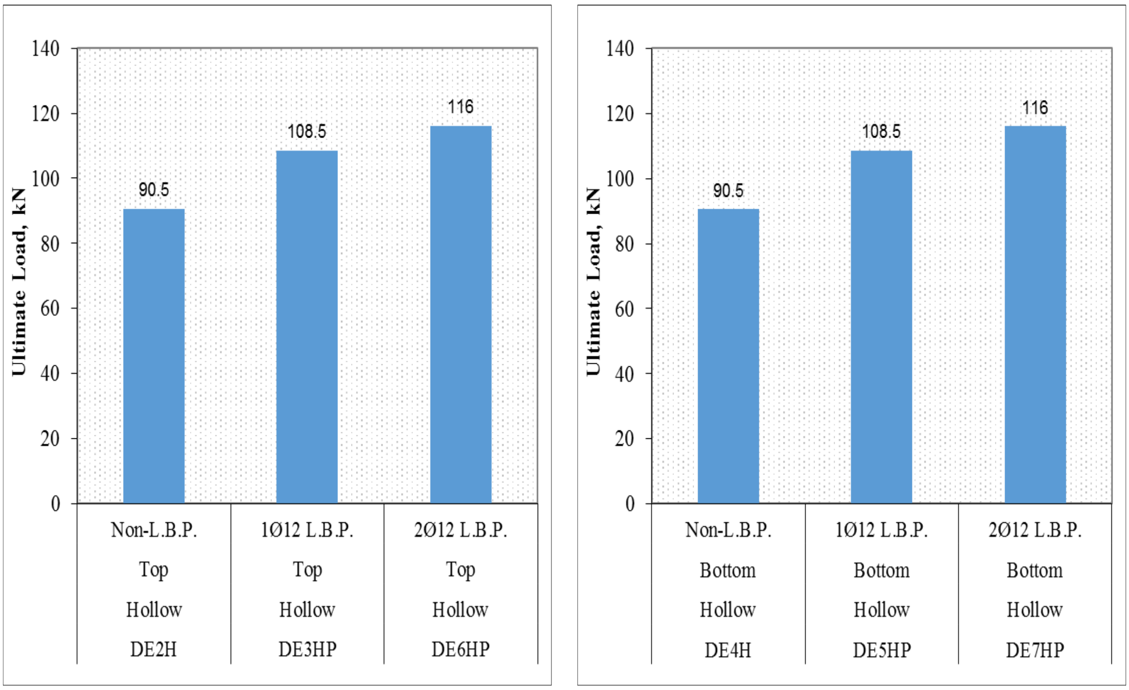
Figures below shows the effect of different variables on ultimate load of tested specimens. The comparison based on fc`, longitudinal bars (bolts) installed after casting, opening regions and section types.

Note: All Girders are Inverted: DE, Dapped Ends, NH: non Hollow, HP: Hollow Installed post curing : L.B.P.: Longitudinal Bolts Installed post curing.

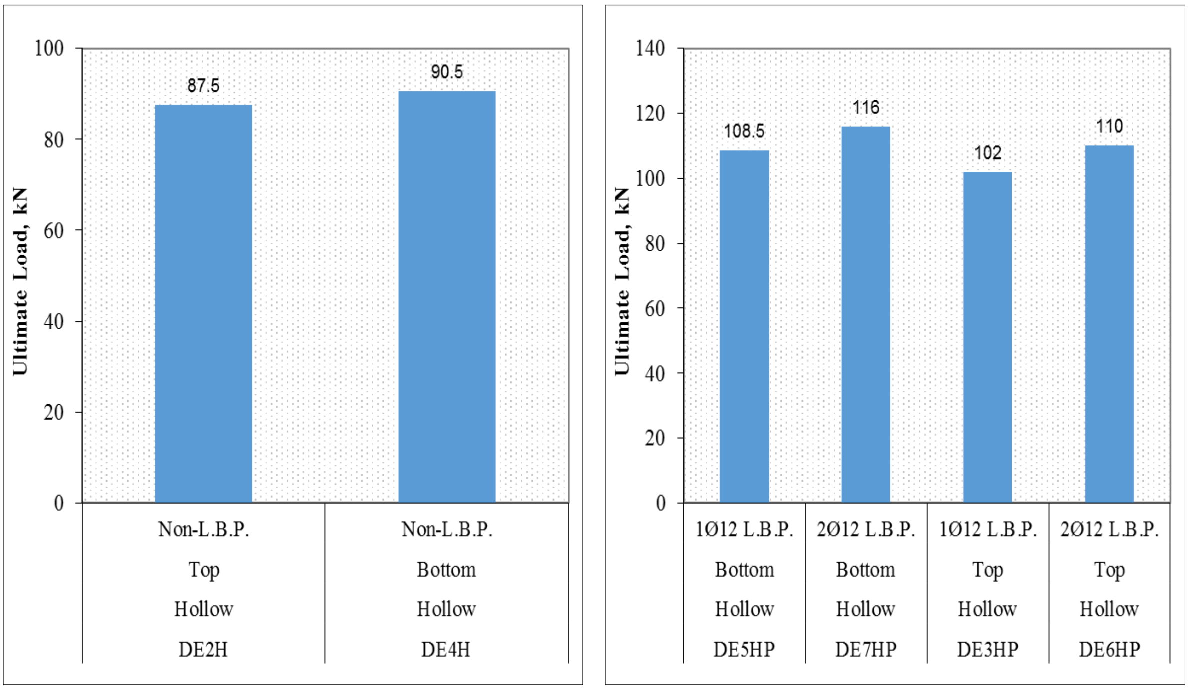




a- Effect of Section Type Solid or Hollow Section.



b- Effect of Strengthen with L.B.P. and ratio for Hollow Section.



c. Effect of Hollow (Recess) Location for Different Section (Non or Strengthen).

Fig.(6) Effect of Parametric Study on Ultimate Load carrying Capacity

Note: All Girders are Inverted: DE, Dapped Ends, NH: non Hollow, HP: Hollow Installed post curing Bars
L.B.P.: Longitudinal Bolts Installed post curing.

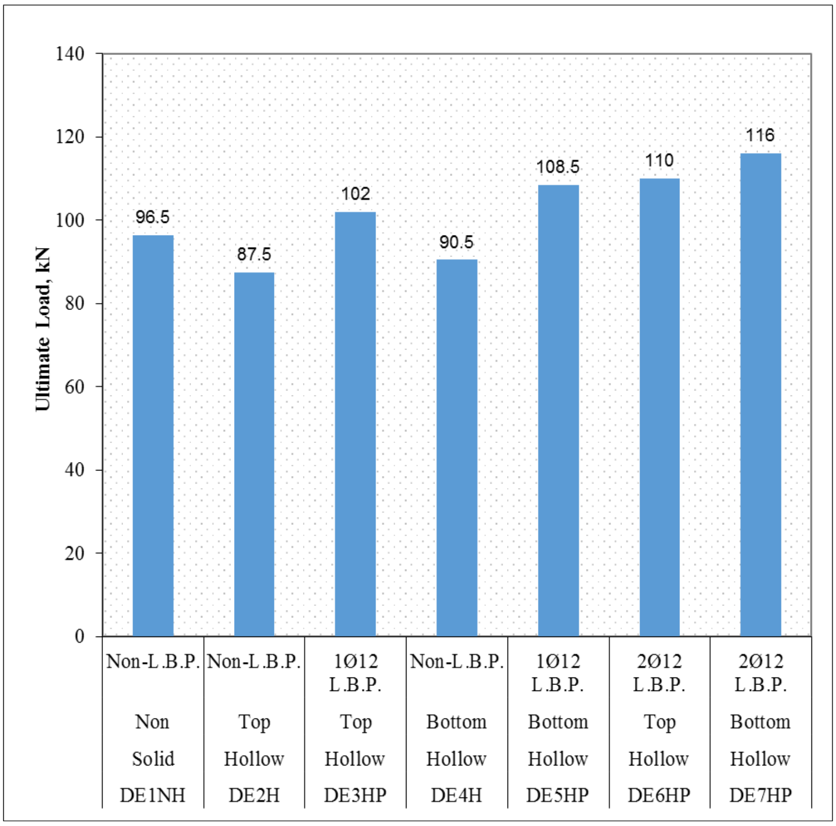


Fig.(7) Ultimate Load of All R.C. Inverted Dapped Ends Girders

5.3 Crack Patterns

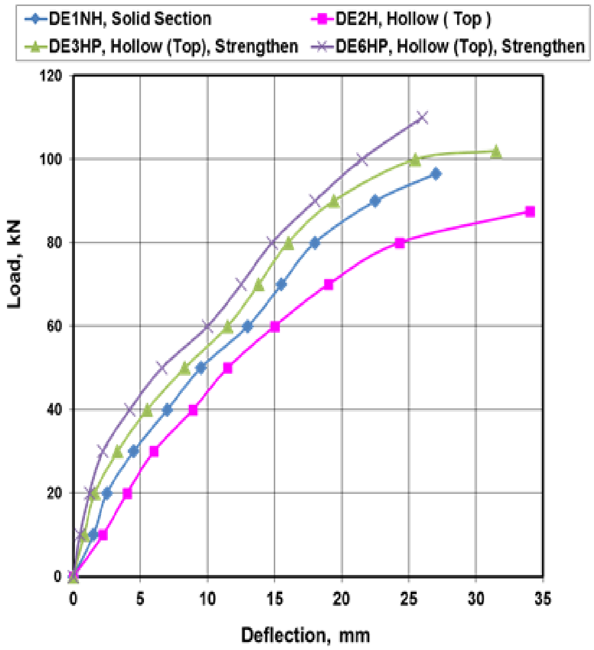
Figures below show the crack pattern and failure modes of all tested girders, some of tested girder were fail due to lack of support also it is clear that all girders fails in compound failure (flexural & shear). In general the crack start at mid span at bottom fibers then the numbers of these cracks increase and appear another cracks near supports with increasing applied load gradually up to failures. Girders strengthened with longitudinal bolts bars as installed after casting have strength capacity more than unstrengthen girders, this led to late appear of cracks at first duration but increased number of crack with increased load capacity. In the tests, cracks always initiated in mid and near dapped ends at approximate 30^o-70^o to the axis of the girder.

Fig. (8). Crack Pattern of All R.C. Inverted Dapped Ends Beams.

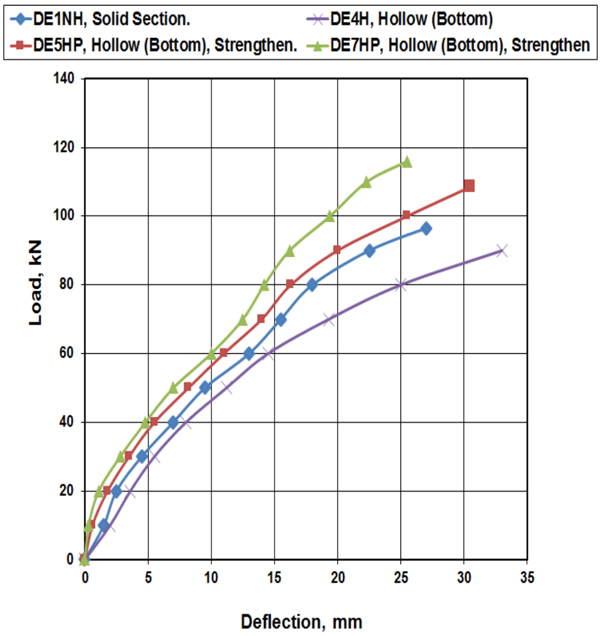
5.4 Load Deflection Behavior

The primary comparison of this study based on the load deflection curves of all R.C. inverted dapped end beams hollow core strengthened with longitudinal bolts installed post curing. The deflection has been measured at bottom fiber at mid span and near dapped ends of girders to evaluate the response of different cases with increasing applied load up to failure.

Figs.(9-10) show load deflection curves at mid span of girder and effect of different variables on this behavior, while the deflections near dapped ends gives same behavior of central point (mid span deflection), but different value of it's. In general the deflection increased when the strength capacity of beams is increased gradually. Strength capacity decreased when the section contain hollow recess at top fiber more than bottom fiber with increasing deflection by about 12 %. Also the deflection decreased when used longitudinal bolts installed post curing for same applied load and load capacity increase according to same reason by about (11- 33%), (10-25%) respectively.

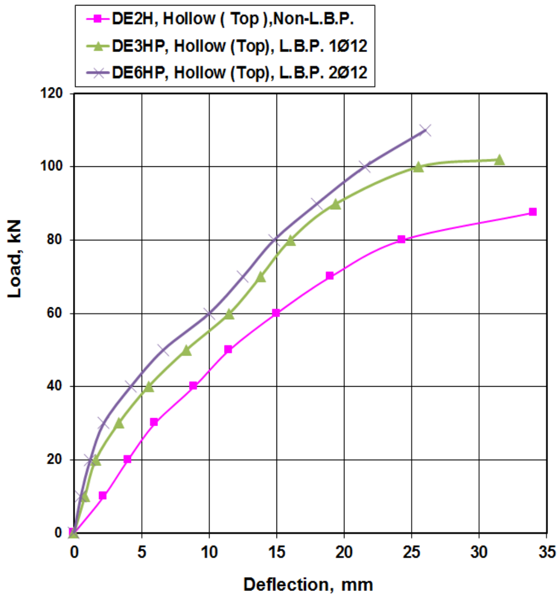


A- Effect of Section Type Solid or Hollow (Top Fiber).

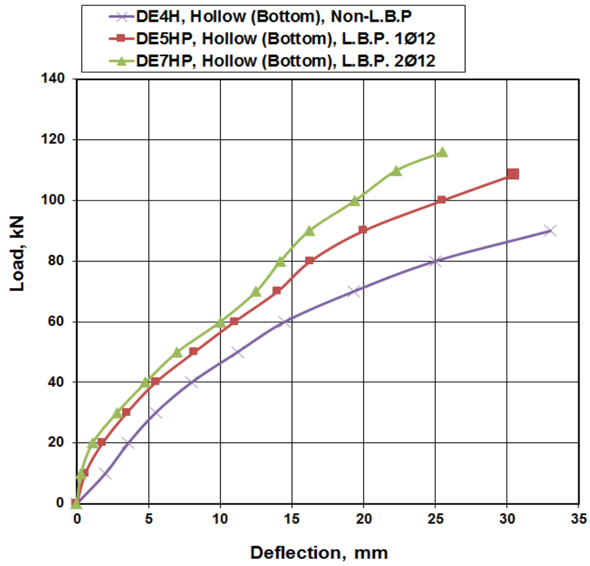


B- Effect of Section Type Solid or Hollow (Bottom

Fig(9). Effect of Section Type Load-Deflection



A- Effect of Strengthen ratio.



B- Effect of Strengthen ratio.

Fig.(10) Effect of Strengthen ratio on load- Deflection Curve of Inverted

6. Conclusions

Based on the experimental results, in terms of load-carrying capacity and load – deflection curves and crack patterns obtained from tests. It can be concluded that:

1. The (circle PVC pipe) is makes hollow recess in dapped ends R.C. beams that contribute at decrease of load carrying capacity by about (6.5% and 9%) when recess at bottom and top fiber respectively. These trend due to the concrete at tension fiber has less strength at tension i.e. the concrete at bottom fiber (tension face has little contribute on strength capacity compared with top fiber (compression zone) and increased in deflections by about (33% and 35%) for specimens when recess at bottom and top fiber respectively compared with solid non-hollow beams for same properties.
2. At two cases of hollow sections location (i.e. at top or bottom fibers) the strengthened specimens by longitudinal normal strand (bolts) led to increases in load capacity by about (6% - 21%) and decrease in deflections by (13% - 29%).
3. The increasing strengthen ratio (longitudinal normal strand (bolts)) to twice ratio leads to decreases decrease in deflections in range by about (4 to 9 %) for different location of recess.
4. Reinforced dapped-end beams made of normal concrete usually fail in shear at the nib area. However, increasing the reinforcement ratio will enhance the strength capacity of these beams.
5. Subsequent installed bars of diameter (12.5mm) at top fiber with different ratio enhances load capacity and ductility of dapped ends beams. These bars resists deformations due to the vertical concentrated loading, resulting in a confining stress to the concrete core, delaying rupture of the load capacity of the concrete. The enhancements of longitudinal normal bars (bolts) by about (24% to 33%).

6. Crack are concentrated near support and distribute at mid of dapped end beams to formulated compound failure.
7. The fail of support can show in some of specimens due to lack of support during construct or when strengthening of beams give more enhancement to strength capacity of its there for we recommended when using strengthening or retrofitting of beams should be strengthened the support or end points to increase the support capacity.
8. The cracks pattern of all specimens propagate at same behavior with different intensity due to same property when produced its, but when used longitudinal normal strands bolts as installed after casting that provide by geometry on gives increased load capacity and reduced in cracks. Also can show cracks are concentrated near support and distribute at mid of reinforced concrete Inverted Dapped ends girders to formulated compound failure.

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