Comparative Study on Experimental Behavior of R.C. Inverted Dapped-End Girders with Openings Strengthened by Vertical Normal Bolts

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Abstract

This paper is a part of some continuous researches done at Al-Mustansiriya university, college of engineering to investigate the behavior with comparison study of seven simply supported reinforced concrete inverted dapped-end beams and evaluate effectiveness of strengthening by vertical bolts working as post-tension normal strand bars under two point concentric loads. The investigated girders are of 1220 mm length,, 240 mm height and 130 mm width with different sections (i.e. without or with transverse opening). Five R.C. inverted dapped-end girders are strengthened by vertical bolts and nuts working as post-tension normal strand bars for both sections i.e. with or without opening. The main investigated variables are compressive strength, number of strengthening bolts (post-tension normal strand bars ratio), and effective type section (with and without opening). Test results show that when the compressive strength is increased by about 20%, an increase in strength capacity by about 10% is gained. Meanwhile, the section type i.e. the transverse opening in the reinforced concrete inverted dapped-end girders when compared with girders without openings results show a decrease in strength capacity and an increase in the girder deflection in ranges of (8-16%) and (15-20%), respectively. The third effect involves ratio of vertical bolts, which when used in strengthening they led to increase in ultimate strength capacity and decrease in corresponding deflection compared with other girders without bars by about (8-20%) and (20-30%). Furthermore, results show that only some of them provide significant load ultimate capacity increase. The observed failure modes ranged from a sudden failure up to the desired progressive failure of the strengthening system.
Key words: inverted dapped-end girders, opening, transverse and post-tension.

1. Introduction:

Reinforced concrete (RC) girders with inverted dapped ends are frequently found in bridge girders and precast concrete construction. The inverted dapped-end girder provides an economical and efficient means of connecting precast to precast and precast to cast in place concrete members. It enables reduction in the construction depth of a precast concrete floor or roof structure, by recessing the supporting corbels or legging into the supported beams [21]. Reinforced concrete dapped-end girders have many applications as drop-in girders between corbels or beam-to-beam [16].

Sudden change of cross-section in a reinforced concrete structural element results in a complex flow of internal stresses. Such regions are disturbed regions (D-regions), so called dapped-ends for reinforced concrete girders, and represent areas where severe reductions of the cross-section are created so that the girder is supported on other structural elements. The load carrying capacity of dapped-end girders may be insufficient for reasons such as design errors, code changes, increases in loads or structural damage. Fiber - Reinforced Polymers (FRP) applied using the Externally Bonded Reinforcement (EBR) or Near Surface Mounted Reinforcement (NSMR) techniques have been proven to be reliable for strengthening RC structures [2]. To the authors' knowledge, only four experimental investigations on dapped-end girders strengthened with FRPs have been reported [21,8,19, and 9].

Taher [18] considered the effectiveness of the following techniques for improving the capacity of dapped-end girders: externally bonding steel angles; anchoring unbonded steel bolts in inclined, pre-drilled holes; externally applying steel plate jackets; and wrapping carbon fiber around the beam stem. Testing 50 small-scale rectangular beams, he indicated that the FRPs were the most viable solution for strengthening / retrofitting applications, but he did not consider any possible scale effects of the girders tested for deriving the model.

The current research presents a parametric study of the vertical bolts as post tension normal strand bars strengthening systems used for a real case application. Also it shows effect of opening in the strength capacity of inverted reinforced concrete dapped ends girders.

2. Objectives of Research:

The objectives of this study were the evaluation of the effect of opening in section and strengthening girders in terms of ultimate capacities and the failure modes involved.

Variables included, concrete strength, opening region and vertical bolts to strengthen as post-tension bars arrangement and layout.

3. Experimental Program:

3.1 Specimens description:

Seven reinforced concrete inverted dapped-end girders with details shown in Table (1) were designed, fabricated and tested up to failure. All the girders were of simple supports, two of the were without openings, three girders had transverses recesses in their top faces and five girders were strengthened by vertical bolts to act as post-tensioning normal strand bars with different ratios as shown in Figs. 1,2&3. The transvers vertical post-tensioning normal strand bar system was used in this work to provide more strength capacity and strengthen the discontinuous edges of girders. when 28 days of curing were completed, the specimens were ready to strengthen by transvers vertical bolts as post-tension. The properties of materials are shown in Tables (2 & 3).

3.2 Materials:

In this study, the mixture of the concrete consisted of ordinary portland cement (type I), natural sand, irregular gravel of 10 mm maximum size and Potable water for both mixing and curing of concrete. Deformed steel bars of 10 mm diameter were used in this study. Three specimens of each bar were tested under tension according to (ASTM A615/A615M-05a) [5] requirements. The results of testing steel reinforcement are summarized in Table (3). The mix proportioning began with the selection of the unit weight (wet density), they are given in Table (4) for all girders. The mix was then proportioned by the method of absolute volumes of one cubic meter, they were obtained by series test of trial mixes. Table (4) shows the two final adopted mixes of design. The average compressive strength of concrete f'_c of these mixes at 28 days were about 25 to 30 MPa.

3.3 Inverted dapped-end reinforced concrete girders details:

To verify the efficiency of the applied strengthening configurations, seven girders were casted and tested in the structural laboratory, each was with two dapped-ends. The arrangement, spacing, diameter and strength class of the reinforcements were identical to those of the original girders. The dapped-end specimen's details are shown in Table (1) and Fig.(4).

4. Instrumentation and Testing Procedure:

When the duration of curing was completed before testing, the girders were cleaned then painted with white color. When the surfaces of girders become dry and ready to test, each specimen was placed in position, and load was applied at the top face of the reinforced concrete inverted dapped-end girder as shown in Fig.(5). The load was applied as two concentrated points loads and increased gradually at increments of (10 kN). The deflections were measured at two points of specimens (center & near inverted dapped ends) at each load increments using digital dial gauge of (0.01) accuracy as shown in Fig.(5). Tests of girders continued till failure. First crack, ultimate loads, failure modes and crack patterns were recorded. loading, boundary conditions and instrumentation layouts are shown in Fig.5.

Table 1. Details of R.C. inverted dapped-end girders specimens

Girder Symbol	Bottom R.	Top R.	Vertical Stirrups R.	Horizontal Stirrups R.	Hanger R.	Opening Diameter, (mm)	Vertical bolts	Mix. No.
DENT 1	2Ø10	2Ø10	Ø10/100	2Ø10	3Ø10	---	---	A
DENT 2	2Ø10	2Ø10	Ø10/100	2Ø10	3Ø10	---	---	B
DET 3	2Ø10	2Ø10	Ø10/100	2Ø10	3Ø10	---	2Ø12	A
DET 4	2Ø10	2Ø10	Ø10/100	2Ø10	3Ø10	2Ø50	2Ø12	A
DET 5	2Ø10	2Ø10	Ø10/100	2Ø10	3Ø10	---	4Ø12	A
DET 6	2Ø10	2Ø10	Ø10/100	2Ø10	3Ø10	2Ø50	4Ø12	A
DET 7	2Ø10	2Ø10	Ø10/100	2Ø10	3Ø10	4Ø50	6Ø12	A

Notes: All girders were inverted

DENT: Inverted Dapped-End Non Transverse (vertical bolts strengthening).

DET: Inverted Dapped-End Transverse (vertical bolts strengthening as normal post-tension).

R: Reinforcing

Table 2. Values of compressive strength of concrete cylinders (28 days).

Mix. No.	Diameter (mm)	Height (mm)	Load, (kN)	Compressive Strength f_c, (MPa)
A	150	300	442	25
B	150	300	512	30

Table 3. Properties of steel reinforcing bars.

Nominal Diameter (mm)	Measured Diameter (mm)	A_s (mm^2)	Yield Tensile Strength f_y (MPa)	Ultimate Strength f_u (MPa)
10	9.88	76.67	421	520
12	12.2	116.89	480	576

Table 4. Mix proportions for 1 m^3 of concrete.

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
B	550	825	1650	0.5	275

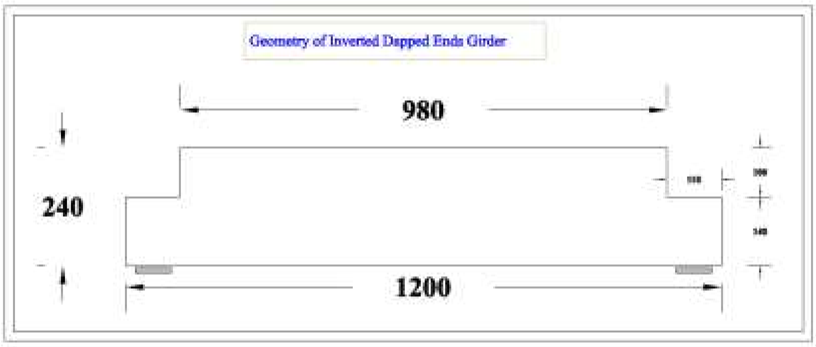


Fig.1 R.C. Inverted dapped-ends girders layout and dimensions (mm).

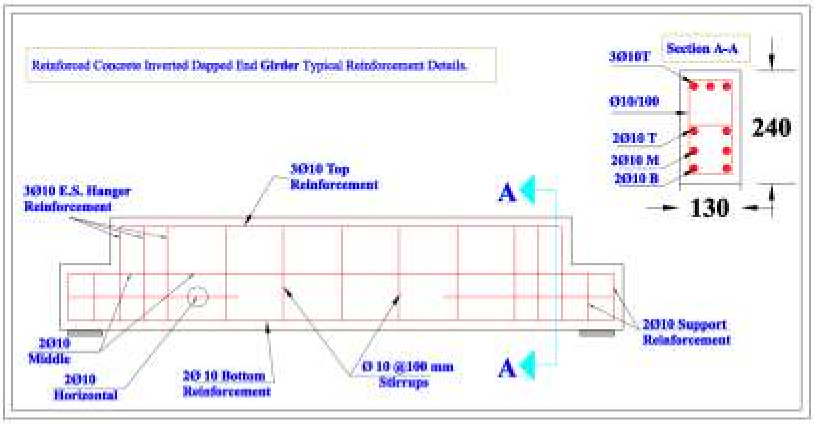
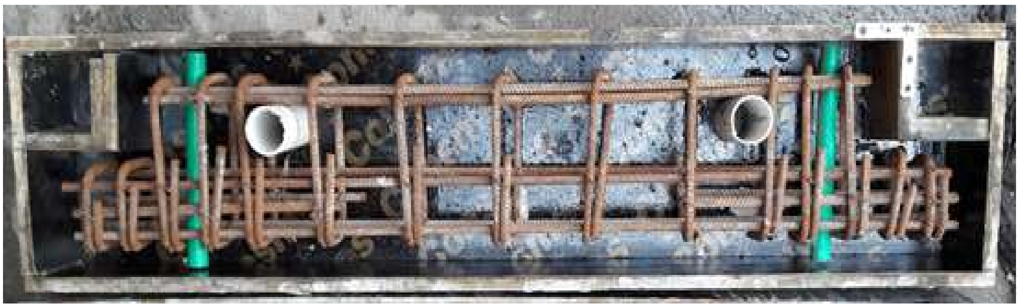


Fig.2 Reinforcement details of R.C. inverted dapped-end girders layout.

a. Mold of R.C. inverted dapped-ends girder.

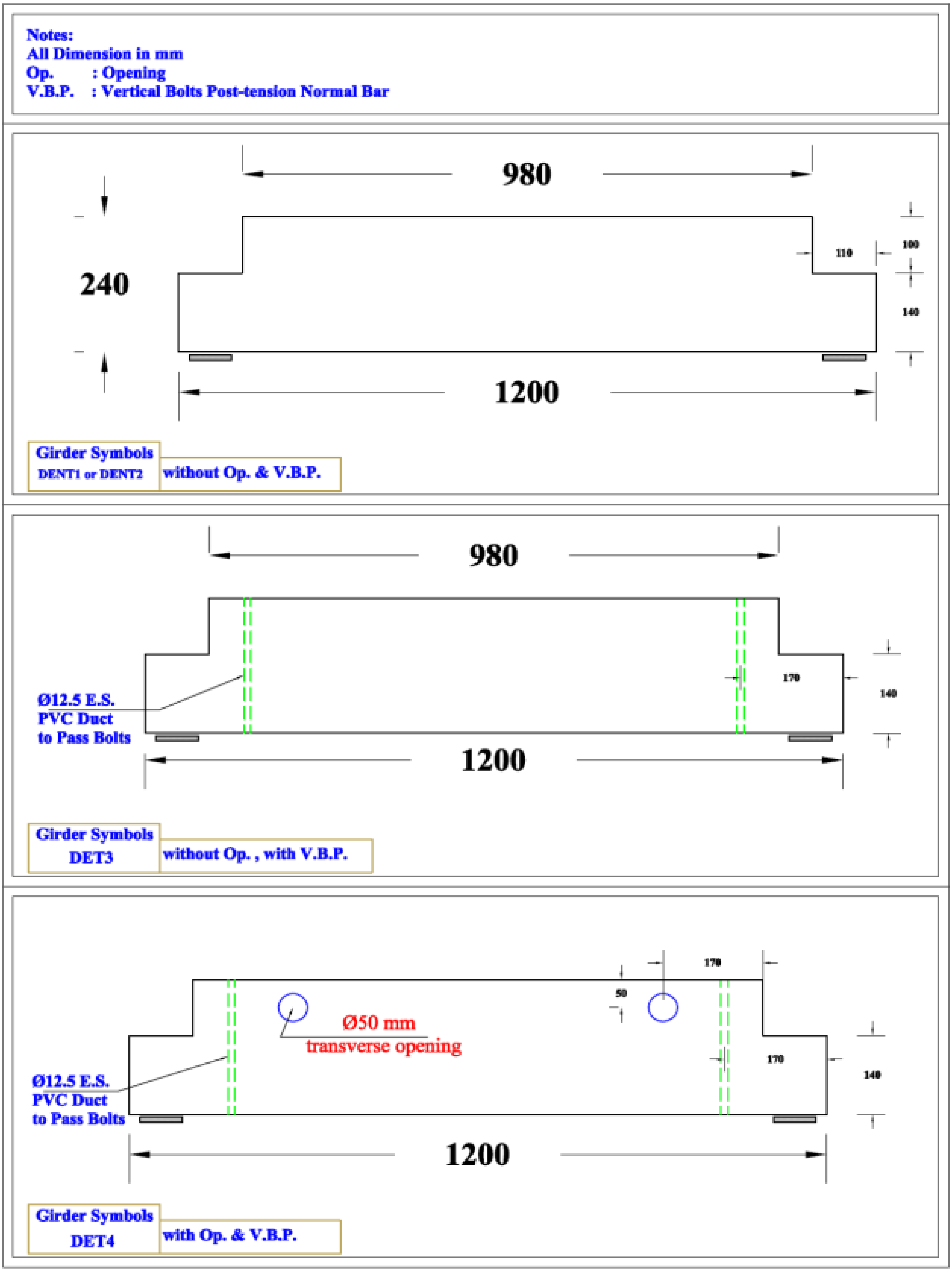
b. Typical molds and reinforcement of R.C. inverted dapped-end girder, without opening and strengthening.

c. Typical molds and reinforcement of R.C. inverted dapped-end girder without opening with strengthening.



d. Typical mold and reinforcement of R.C. inverted dapped-end girder, with opening and strengthening.

Fig.3 Molds Details of R.C. beams of inverted dapped-ends.


Notes:
All Dimension in mm
Op. : Opening
V.B.P. : Vertical Bolts Post-tension Normal Bar
980
240
110
100
140
1200
Girder Symbols
DENT1 or DENT2
without Op. & V.B.P.
980
170
140
Ø12.5 E.S.
PVC Duct
to Pass Bolts
1200
Girder Symbols
DET3
without Op. , with V.B.P.
170
50
Ø50 mm
transverse opening
170
140
Ø12.5 E.S.
PVC Duct
to Pass Bolts
1200
Girder Symbols
DET4
with Op. & V.B.P.

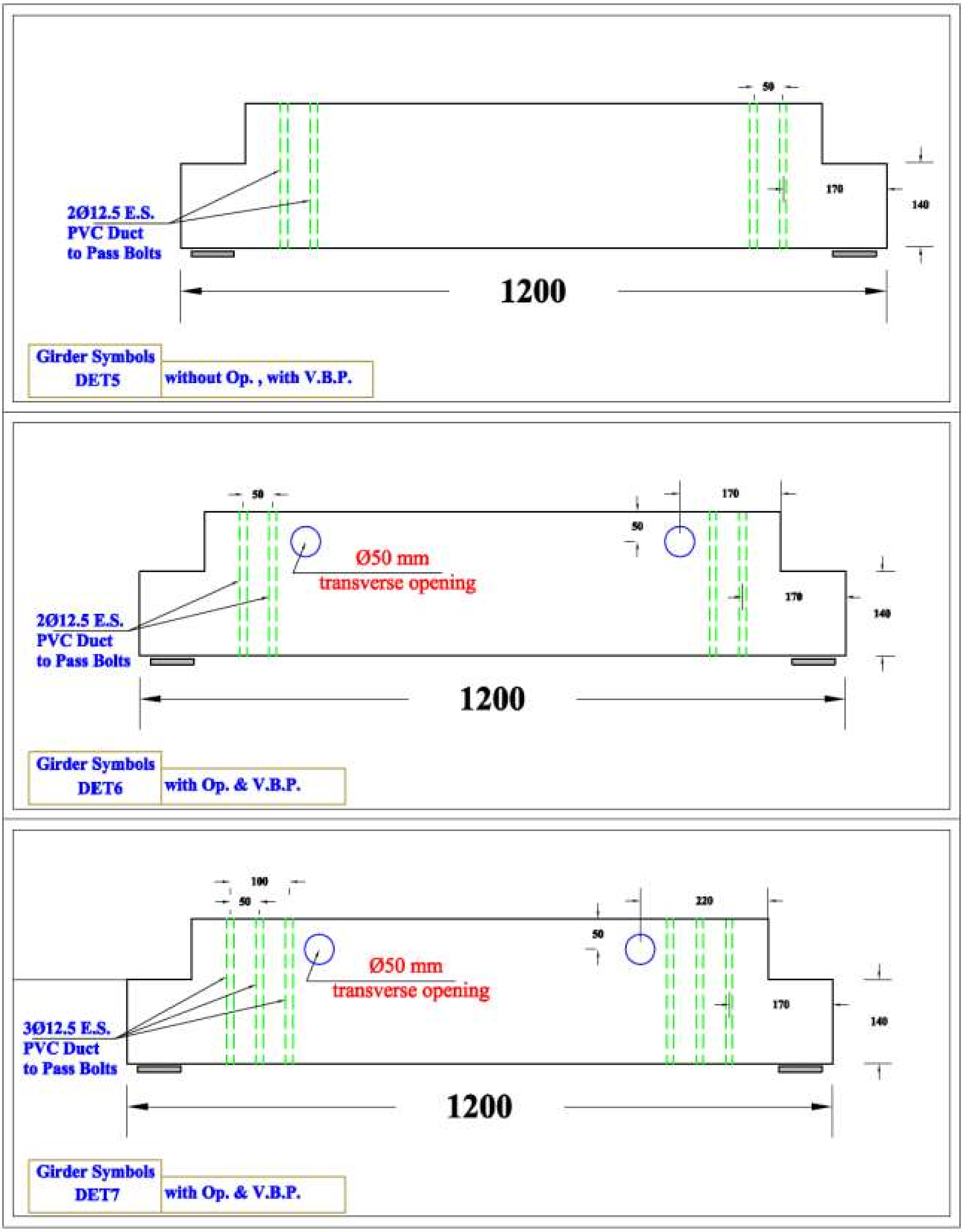
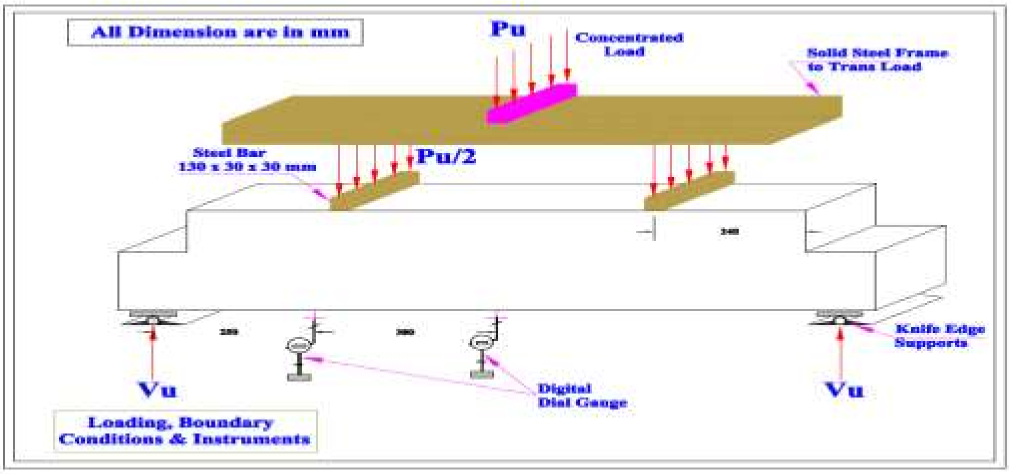


Fig.4 Continue, Location of openings. or V.B.P. in R.C. dapped-ends specimens.

a. Testing Machine

b. Typical specimens arrangement under load testing



c. Schedule test setup.

Fig.5 Loading, boundary conditions and instrumentation layout.

5. Experimental Test Results:

The test results of all specimens are based on load carrying capacities, deflections and crack pattern.

Their comparisons are shown in the following:

5.1 First crack and ultimate load:

From test results given in Tables (5&6), it can be shown that increase of f'_c led to decrease in deflections and increase in the corresponding load capacity for the same other properties. It can be also shown that using transverses post-tension normal 12mm diameter strand bars provided by bolts to strengthen in inverted dapped-end girders gave higher load capacity and lower deflections. Finally the comparison based on section types, i.e. with or without openings can show the opening effect on non strengthened capacity by reducing it by about 10-15%. The first crack, ultimate load and maximum deflections are shown in Tables (5&6).

5.2 Effect of variables and ultimate load:

This study involves the comparison effects of compressive strength of concrete f'_c, transverses openings and strengthening of girders (by using vertical bolts as post-tension normal strand bars) on strength capacity and deflection of inverted dapped-end girders. These effects of parameters are shown in Figs.(6 and 7).

5.3 Crack patterns:

Fig.(8) shows the typical crack patterns and failure modes of these inverted dapped-end girders. From crack pattern it is clearly shown that the inverted dapped-end girder became more stiff due to path of load effect on more critical region compared with non-inverted dapped beams. This permits less crack appearance when loading value was little, while when the load increased more cracks appeared. Test results show that the first crack appeared at mid span then propagated with different intensities to other region mid or near support. They also show that strengthening by vertical bolts as post tension gave gain in strength capacity and controlled on crack propagation and numbers of cracks. In general the most cracks in the tests, always initiated at the reentrant near support or in flexural region of the inverted dapped-end girder at approximate angle of 30^o-75^o to the axis of the girder, resulting in a redistribution of stresses causing increasing steel stresses, bond stresses and some bond slip [8]. Under an additional load these cracks spread, increased in number, thus reduced the compression zone of the girder considerably. At one or a few load increments before failure, more inclined cracks, occurred at the reentrant corner of the majority of inverted dapped-end girders, and steeper (55^o-80^o) than the first inclined crack up to the vicinity of the load point. Some of girders failed at support due to lack of support or high strength capacity of the girder which gave more loads to end supports.

In summary, the higher load carrying capacity led to more crack appearance, which enlarged the difference in the cracking loads due to conditions as shown in Fig.(8).

5.4 Load deflection behavior:

The load deflection curves of all R.C. inverted dapped-end girders only at central point and points near dapped ends of tension face (bottom fiber) are shown in Fig.(9). From test results the

Table 5. Fist crack, ultimate load and deflections of the seven dapped-end test beams

Girder No.	First Crack Load, kN	Ultimate Load, kN	Difference Load, %	Deflection mm	Difference deflection, %	Failure mode
DENT 1	38.0	110.5	---	3.2	---	Compound
DENT 2	42.0	125.0	13.12	4.1	28.00	Compound
DET 3	47.0	137.5	24.50	4.0	25.00	Compound
DET 4	41.0	122.0	10.40	4.8	50.00	Compound
DET 5	55.0	143.0	29.41	3.5	9.40	Compound
DET 6	47.5	132.0	19.45	3.8	18.75	Compound
DET 7	45.0	135.0	7.23	3.3	4.00	Compound

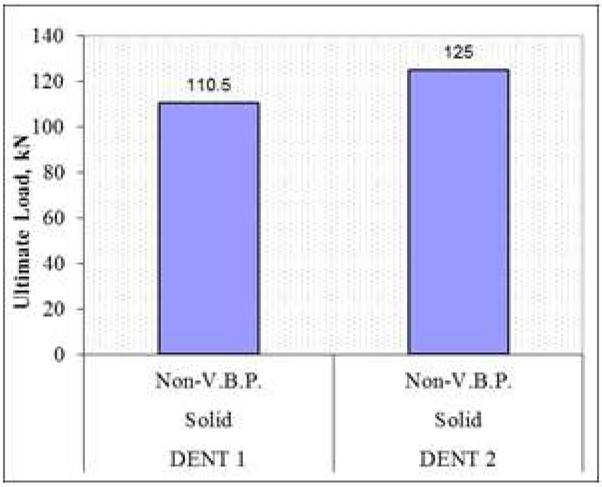
load - deflection of points near the dapped ends that's gave similar behavior to central point. These figures show the same behavior of load – deflection curve owing to the same properties and strength of materials used in construction of girders. However, the deflection increased when the strength capacity of girders was evaluated.

Table (6) Loads and deflections at centers and near the dapped-ends of the test beams.

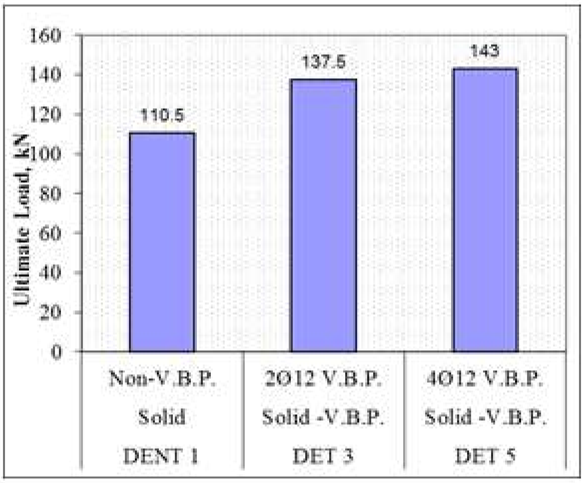
Girder No.	Opening Diameter, (mm)	Vertical bolts strengthening	Mix No.	Ultimate Load, (kN|)	Max. Central Deflection, (mm)	Near Inverted Dapped Deflection (mm)**
DENT 1	---	---	A	110.5	3.2	2.2
DENT 2	---	---	B	125	4.1	2.49
DET 3	---	2Ø12	A	137.5	4	2.6
DET 4	2Ø50	2Ø12	A	122	4.8	2.45
DET 5	---	4Ø12	A	143	3.5	2.1
DET 6	2Ø50	4Ø12	A	132	3.8	2.4
DET 7	4Ø50	6Ø12	A	135	3.3	2.1

** Deflection measured at distance 250 mm from support (Near Inverted Dapped Ends).

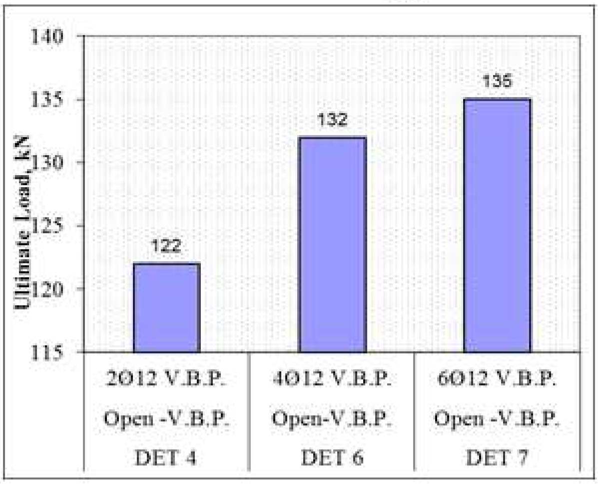
Note: V.B.P. : Vertical Bolts Post-tension



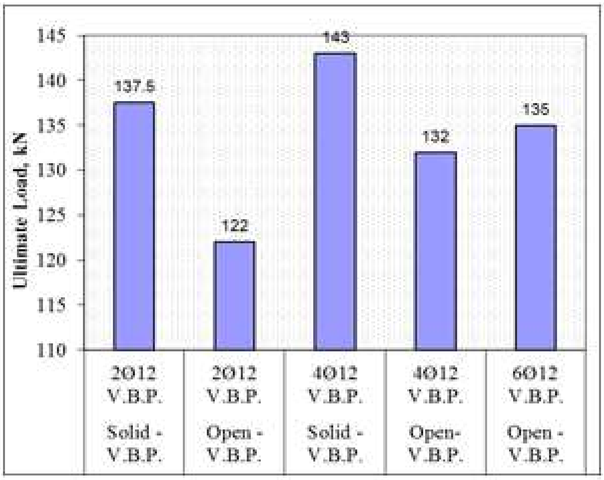
a- Effect of f'_c.



b- Effect of Vertical Bolts (Post-



c- Effect of Open & Vertical Bolts (Post-tension).



d- Effect of Section Type (Open & Vertical Bolts).

Fig.6 Effects of parameters on the ultimate loads.

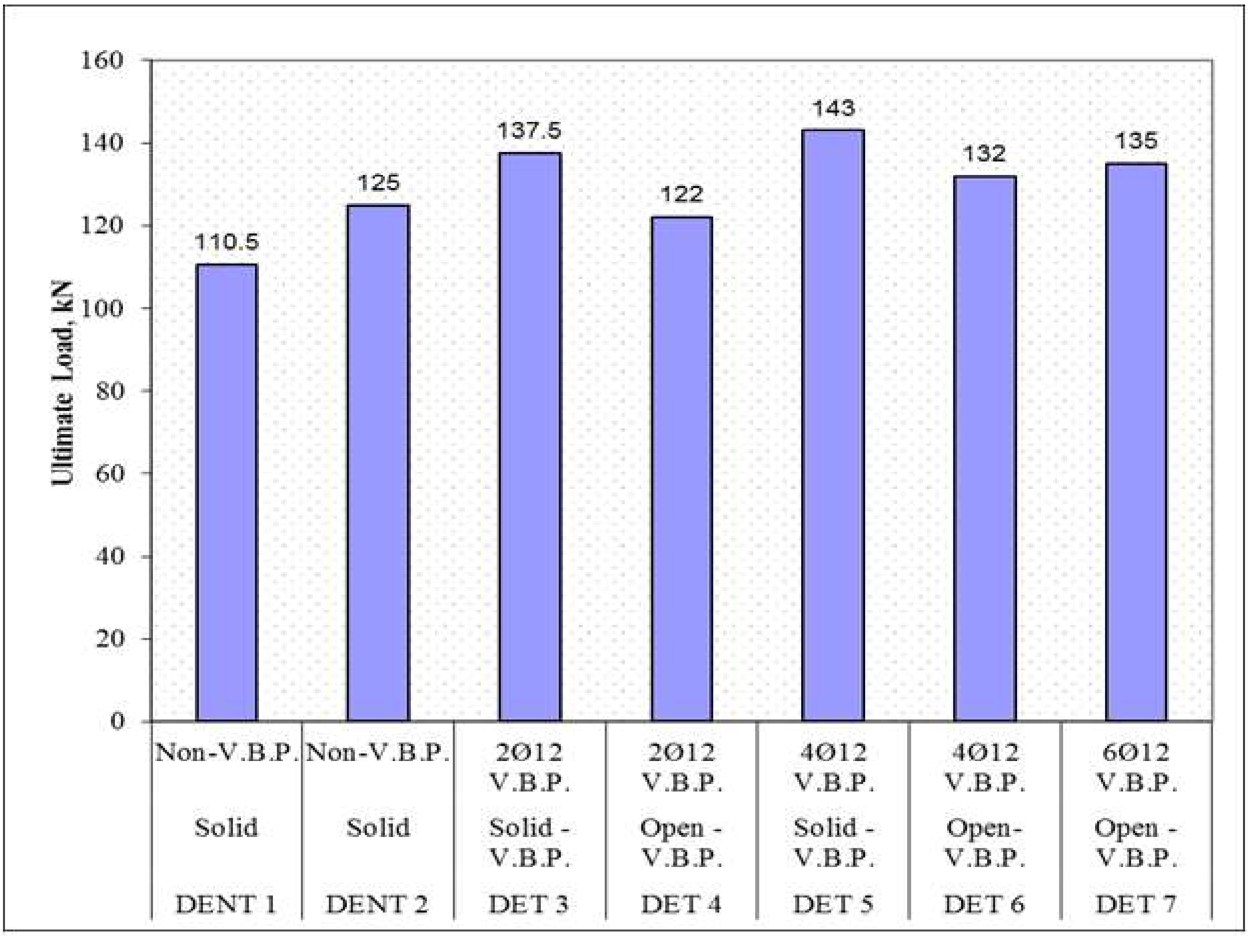


Fig.7 Ultimate load of all R.C. inverted dapped-ends girders. Beams

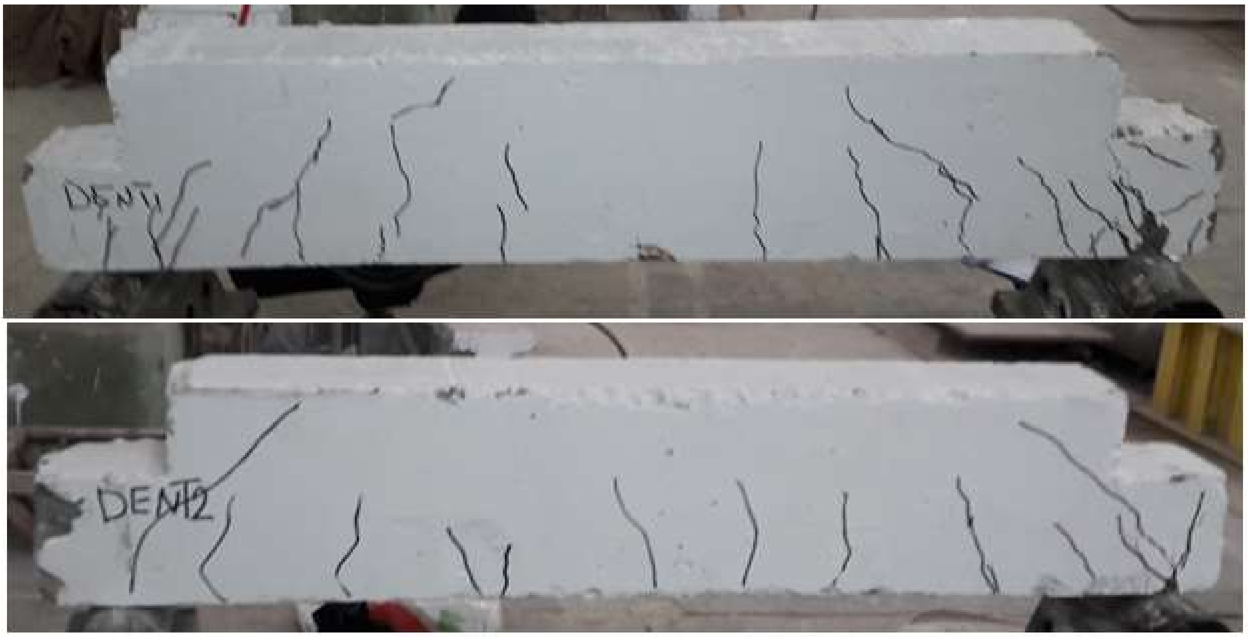


Fig. 8 Crack pattern of R.C. inverted dapped-ends girders.

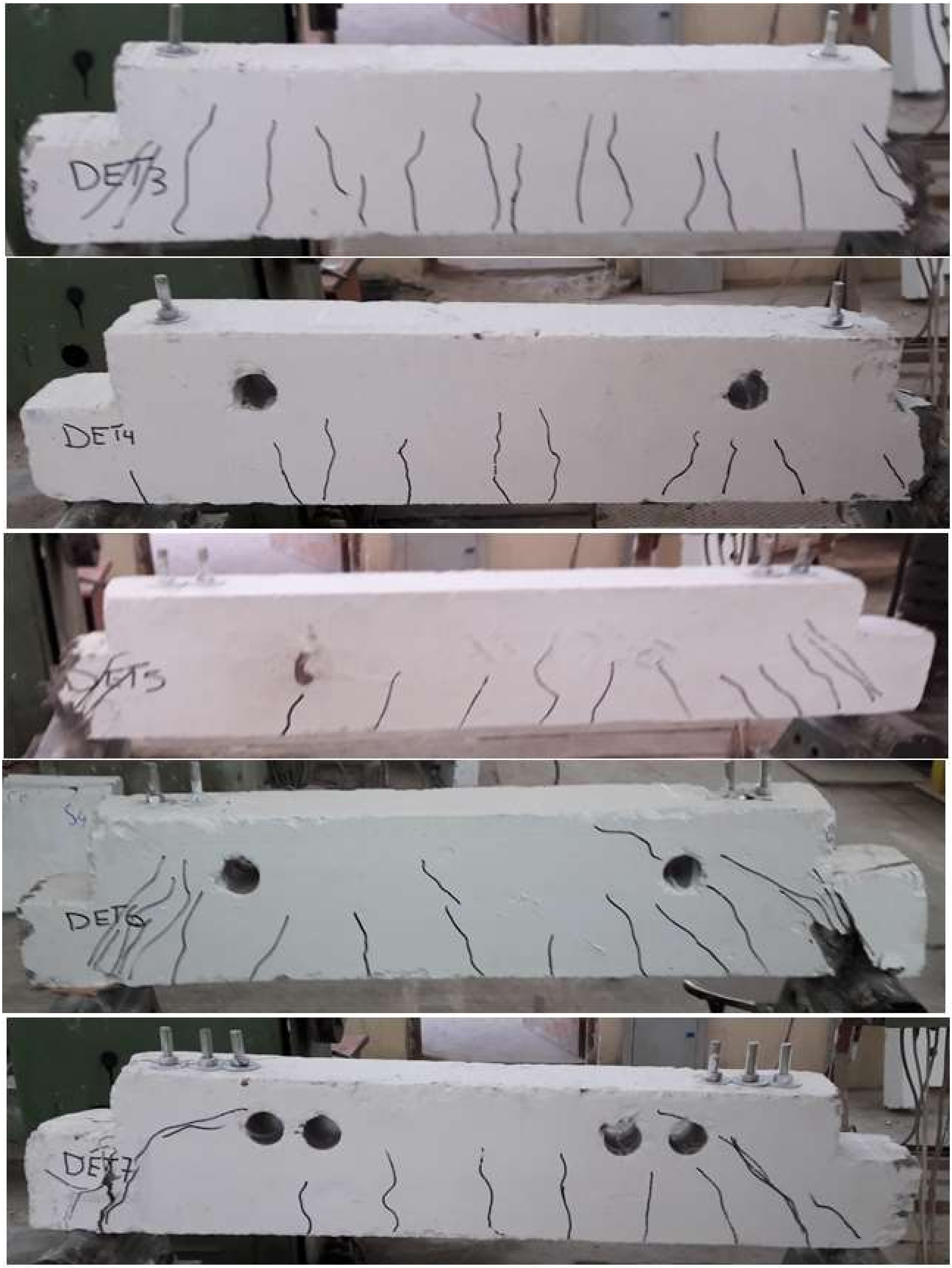
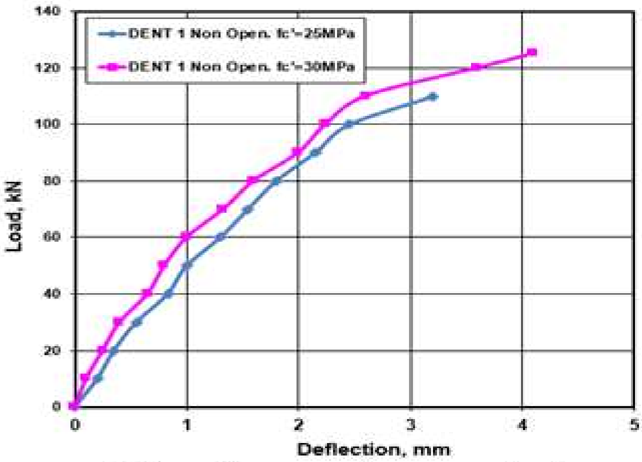
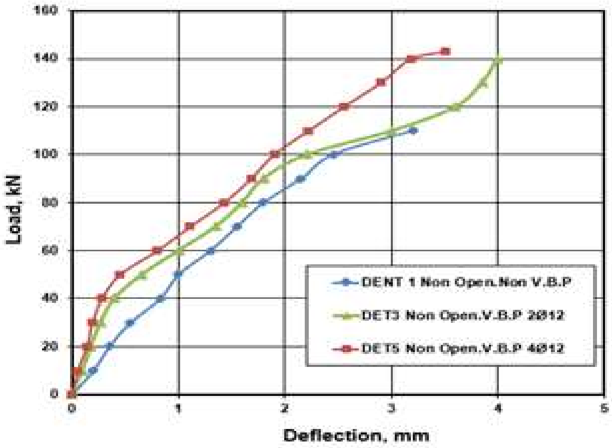


Fig. 8. Continue Crack Pattern of R.C. Inverted Dapped Ends Girders.

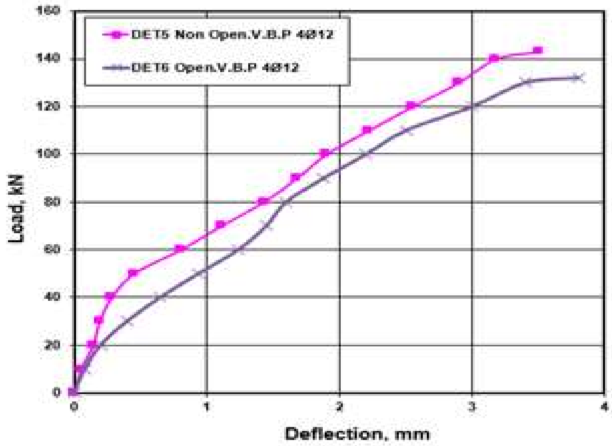


a. Effect of compressive strength of concrete.

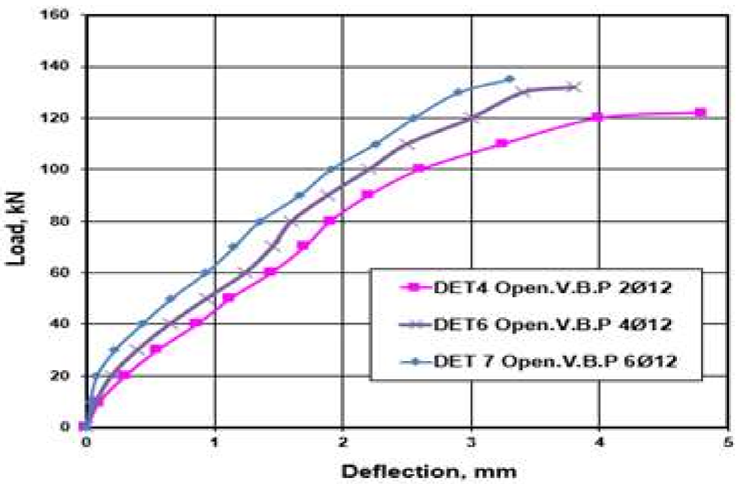


b. Effect of post-tension normal strand bars.

c. Effect of opening and strengthen (post-tension normal strand bolts).



d. Effect of opening and strengthen (post-tension normal strand bolts).



e- Effect of strengthen ratio of post-tension normal strand bolts.

Fig.9 Load versus deflection relations of the R.C. inverted dapped-ends girders.

6. Conclusions:

In this research seven reinforced concrete inverted dapped-end beams were tested to study effects of the compressive strength, opening section, section type and vertical bolts as post-tension normal strand bars on the ultimate strength, and the crack patterns and deflection responses. From test results the following conclusions have been drawn:

1. The crack patterns of all specimens propagate in the same manner with different intensities due to same properties when they were manufactured, but when vertical bolts were used as post-tension normal strand bars, the load carrying capacity increased and cracks decreased. In addition, cracks are concentrated near supports and distributed at centers of reinforced concrete inverted dapped-end girders which created compound failure.
2. Increasing the compressive strength of concrete f'_c by about 20% led to increase in load carrying capacity and decrease in deflection by about 13.63% & 21.87% respectively.
3. The strengthening system by using vertical bolts as post-tension normal strand bars of 12 mm diameter provides additional stirrups (hanger reinforcement near dapped end zone). Inverted dapped-ends girders led to an increase in the load carrying capacity by about 11% to 30% and a decrease in the corresponding deflections by about 23% to 33% compared to girders without transverses bars of same properties. This strengthening system can be easily performed due to the availability of these materials in local market.
4. In all cases of inverted dapped-end sections, the increases in shear reinforcement provided by vertical bolts as post-tension normal strand bars lead to increases in load capacity by about 11 to 30% and decreases in deflections by 20 to 30%.
5. Increasing the ratio of vertical bolts (as post-tension normal strand bars) to double or triple lead to increases in the load carrying capacity and decreases in the corresponding deflections by about 5 to 11 % and 20 to 30% respectively.
6. The vertical bolts (used as post-tension normal strand bars) enhance the resistance to deformations an average of 25%. This resistance results from contribution of the confining stress in concrete, delaying rupture of the concrete due to applied excessive loading.
7. The load carrying capacities of inverted dapped-end girders are decreased by about 7.5% accompanied by increases in the corresponding deflections by about 20% when transverse openings of 50 mm are provided at compression zone compared with girders without openings.
8. Reinforced inverted dapped-end girders made of normal concrete usually fail in shear at the nib zone. However, crack pattern shows that all

specimens failed in compound failure (shear-flexural).

At last some of these girders, failed at end supports due to lack of support, or to the strengthening system which increases the load carrying capacity. This fact led to transmitting more loads to end supports. Therefore, we suggested strengthening these support when strengthened system of girders are used.

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الدراسة المقارنة للسلوك العملي للعوارض الخرسانية المسلحة المقلوبة غير مستمرة النهايات مع الفتحات والمقواة بالبراغي العمودية الاعتيادية.

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بغداد / العراق

الخلاصة

هذا البحث هو جزء من البحوث المستمرة في الجامعة السمتنصرية كليه الهندسة لتحري سلوك ومقارنة لدراسة سبعه عتبات خرسانيه مسلحة مقلوبة غير مستمرة النهايات وتأثير التقوية بواسطة براغي عمودية تعمل كقضبان اعتيادية عرضية مشدودة بعد الصب تحت حمل مركز في نقطتين وكل العتبات كانت بسيطة الاسناد. ابعاد العتبات هي (الطول 1220 ملم والعرض 130 ملم والعمق 240 ملم) وبمقاطع مختلفة مع او بدون فتحات عرضية تم تحريها. خمسة من هذه العوارض مقواة بواسطة براغي عمودي مع وصلات تعمل كقضبان الاعتيادية المشدودة بعد الصب لكلا المقطعين مع او بدون فتحات.المتغيرات الرئيسة التي تم تحريها هي مقاومة الانضغاط للخرسانة وعدد براغي التقوية (نسبه القضبان للتقوية) وتأثير نوع المقطع (مع او بدون فتحات). نتائج الفحوصات بينت عند زيادة مقاومة الانضغاط بنسبه 20٪ تعطي زيادة في قابليه التحمل للعتبة بمقدار 10٪. بينما نوع المقطع اي الفتحات العرضية الموجودة في منطقة الضغط للعوارض المقلوبة بمقارنه مع تلك التي لا تحوي فتحات نتائج الفحص بينت نقصان في قابليه التحمل وزيادة في الهطول المقابل بمقدار(8 الى 16 ٪) و(15 الى 20٪) على التوالي. التأثير الثالث شمل نسبه القضبان العمودية التي قويت المقطع (بواسطة براغي قطر 12 ملم) تؤدي الى زيادة في قابليه التحمل ونقصان في الهطول المقابل بالمقارنة بالعتبات بدون تقويه عرضية بمقدار (8 الى 20٪) و (20 الى 30٪) على التوالي.كذلك نتائج بينت هنالك فقط بعض الزيادات في قابليه التحمل القصوى للنماذج.انماط الفشل تراوحت من الفشل الفجائي الى الفشل التدريجي المطلوب للنظام التقوية المستخدم.

الكلمات المفتاحية : نهايات العوارض - المقلوبة، الفتحات، العرضية والمشدودة.