EFFECT OF STEEL PLATES ON SHEAR STRENGTH OF WIDE REINFORCED CONCRETE BEAMS

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Abstract

In this study, shear behavior of reinforced concrete wide beams was investigated experimentally. The experimental program consisted of four wide beams of 45 MPa concrete compressive strength tested with a shear span-depth ratio (a/d) equal to 4.52. One of the tested wide beams had web reinforcement as a control specimen, and the other three specimens had no transverse reinforcement but contained vertical shear steel plates. The flexure mode of failure was secured for all of the specimens to allow for shear mode of failure. The key parameters covered in this investigation were the effect of the existence solid and hollow vertical steel plates on the shear capacity of the tested wide beams. The study shows that the contribution of vertical steel plates to the shear capacity was significant and directly proportional to the existence and direction of the steel plates. The increase in the shear capacity ranged from 9.52% to 47.62% for the range of the tested beams compared with the control beam. Transverse vertical steel plates with voids were more effective in the contribution of the shear strength of wide beams and enhances the ductility of the wide beams.

Keywords: *wide reinforced concrete beam, shear reinforcement, steel plates, stirrups.*

تأثير صفائح الحديد على مقاومة القص للعتبات الخرسانية المسلحة العريضة

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الخلاصة

مقاومة القص للعتبات الخرسانية المسلحة العريضة تم تحريها عمليا ، تضمن البرنامج العملي صب وفحص اربع نماذج من العتبات الخرسانية المسلحة العريضة ذات مقاومة انضغاط للخرسانة مقدارها 45 MPa فحصت العتبات بنسبة فضاء قص الى العمق ا لفعال بمقدار 4.52، كانت احدى هذه العتبات العريضة لها تسليح قص وهي العينة المرجعية ، اما

العتبات الثلاثة الاخرى فكانت بدون حديد تسليح للقص وانما احتوت على صفائح من الحديد ثبتت بصورة طولية وعرضية لمقاومة القص . نمط الفشل للانثناء قيد او أمن من اجل الحصول على نمط فشل قصي، العوامل الاساسية التي تناولها هذا البحث هي تأثير وجود صفائح الحديد الشاقولية الصلدة والمجوفة على تحمل القص للعتبات العريضة تحت الاختبار .
اظهرت الدراسة ان مساهمة صفائح الحديد الشاقولية في تحمل القص مهمة ولها علاقة مباشرة بوجود واتجاه هذه الصفائح.
ان زيادة تحمل القص للعتبا ت تحت الاختبار تراوح (9.52% to 47.62%) مقارنة مع العتبة المرجعية . وان صفائح الحديد الشاقولية بالاتجاه العرضي للعتبة كان لها تأثير ومساهمة اكثر في زيادة تحمل القص للعتبات العريضة وساهم في تحسين المطيلية لها.

الكلمات المفتاحية: العتبات الخرسانية المسلحة العريضة، تسليح القص، صفائح الحديد، الاطواق.

1- INRODUCTION

Large, wide reinforced concrete beams and thick slabs are frequently used as economical transfer elements where the total structural depth must be kept to a minimum. The wide beams may be used to carry direct forces, or to serve as primary transfer elements. A system of wide beams may provide a simple and economical solution to transfer column loads from the tower portion over required column free spaces in the podium or parking areas below. Thick one-way transfer slabs can serve similar roles when the column layout to be transferred is irregular in the plan and for roofs of under-ground stations [1,2].

2- LITERATURE REVIEW

Recently, some researchers directed their efforts to study the shear behavior of wide beams. Lubell [2] investigated the influence of the shear reinforcement spacing on the one way shear capacity of wide reinforced concrete members. Shear reinforcement spacing was a primary test variable. A series of 13 normal strength concrete specimens were tested. The specimens contained web reinforcement ratios close to ACI 318-02 [3] minimum requirements. The study concluded that the effectiveness of the shear reinforcement decreases as the spacing of web reinforcement legs across the width of a member increases, the use of few web reinforcement legs, even when widely spaced up to a distance of approximately 2d, has been shown to decrease the brittleness of the failure mode compared with a geometrically similar member without web reinforcement. Sherwood et al. [4] carried out an experimental study to investigate the shear behavior of the wide beams and thick slabs as well as the influence of member width. They tested five specimens of normal strength concrete with a nominal thickness of 470 mm and varied in width from (250 to 3005) mm. The study demonstrated that the failure shear stresses of narrow beams, wide beams, and slabs are all very similar. It is worth mentioning that the basic expressions for one way shear in ACI 318-02 [3] is the same for narrow beams and wide beams. Dino et al. [5] investigated the effect of concrete strength and minimum stirrups on shear strength of large members. They conducted an experimental program of twelve 1000 mm deep beams with concrete strength varying from (21 to 80) MPa. They concluded that changing the concrete strength by a factor of 4 had almost no influence on the shear strength of these large beams while changing the longitudinal reinforcement ratio from (0.5% to 2.09%) increased the observed shear strength by 62%. James et al. (6) investigated the shear behavior of reinforced concrete exterior wide beam-column-slab connections subjected to lateral earthquake loading. An experimental program of three reinforced concrete exterior wide beam-column-slab specimens was conducted. Wide beams were constructed with concrete strengths varying from (29 to 34.5) MPa. Upon examining the beams after failure, they observed that the wide beams never exhibited any inclined cracking that could be characterized as related to shear. Observed cracks were narrow, vertical flexural cracks that opened very little. Stirrups strain gages never measured strains in the stirrups vertical legs greater than one-third of the yield strain, hence, they concluded that the wide beams performed well in the shear. On the other hand, the influence of member width on the shear stress at failure was investigated by Kani (7). The test series compared the capacities of 610 mm wide by 305 mm deep beams with 162 mm wide by 305 mm deep companion beams, at shear span-to-depth ratios (a/d) of 3, 4, 5, and 6. The failure shear stresses in the wide beams were within 10% of the failure shear stresses of the corresponding narrow beams and as such he concluded that the width-to depth ratio had no significant influence on the shear stress at failure. Khalil (8) carried out an experimental study to investigate the shear behavior of wide beams in hollow block slabs. The experimental investigation included nine medium- scales simply supported by wide beams and five full-scale hollow block one way slabs with normal concrete strength. He concluded that the shear capacity of the wide beam with shear reinforcement reached as high as 300% compared to those without shear reinforcement. The study did not mention any test results about the ductility of the tested beams.

3- SIGNIFICANT RESEARCH

In Middle East, the use of wide beams is popular in hollow block reinforced concrete slabs for constructional and architectural advantages. It is apparent that the shear design procedures for wide beam are not covered adequately in the current American Concrete Institute Code of practice ACI-12 (9). According to the ACI-12, the contribution of shear reinforcement in the wide beam is totally discarded and the shear strength provided by concrete equals 67% of the concrete shear strength for slender beams. The current ACI-12 provides specified minimum shear reinforcement to impart reserve shear strength by preventing sudden shear failure upon first diagonal tension cracking as a result of unexpected tensile forces or catastrophic loading. In addition, the ACI-12 requires the stirrups to be arranged so that the distance between stirrups branches across the beam section does not exceed 250 mm. All the previous requirements of the code may lead to a highly conservative and uneconomic shear design of wide beams. On the other hand, three international codes

(9,10,11) requirements were reviewed and no similar provisions were found. As such, there is a need for experimental data on the shear behavior of wide beams. The objective of this study was to evaluate the effect of the existence of steel plates on the shear resistance of reinforced concrete wide beams.

4- EXPERIMENTAL PROGRAM

4.1 TEST SPECIMENS

The experimental program consisted of cast and test four beams made with 45 MPa concrete compressive strength tested in a one-point load. The specimens were constructed in the Structural Laboratory of the College of Engineering / Diyala University. The tested beams were 560 mm wide, 215 mm deep, 1800 mm long and were tested at shear span of 800 mm. This gives a shear span-depth ratio (a/d) equal to 4.52. The beams were reinforced with identical longitudinal steel bars with ten bars of 16 mm diameter to achieve reinforcement area of 2000 mm^2. In order to investigate the shear behavior, the specimens were designed to fail in shear (i.e. the flexural capacity was designed to exceed the shear capacity of the tested beams). For vertical shear reinforcement of control beam, deformed bars of 12 mm diameter are used provided at a spacing of 100 mm center to center, this amount of reinforcement results in steel ratio of 0.0025, (0.25%) which represents the minimum reinforcement ratio according to the ACI-318 [9] Code provisions. These stirrups dividing in to four legs in width of control beam.

The specimens were designated (B1, B2, B3, and B4). Beam B4 represented the control specimen with web steel reinforcement (stirrups). No transverse steel reinforcement in the other three specimens. Beam B1 contains a vertical solid steel plates on longitudinal. Beam B2 contains a vertical steel plates with hollow on longitudinal while Beam B3 contains a vertical steel plates with hollow on width (transversally) of the beam. The vertical steel plates used in these three specimens (B1, B2 and B3) have a thickness of 4mm. Specimen B1 replace the stirrups by a vertical solid steel plates, specimen B2 also replace the stirrups by a vertical hollow steel plates with circle holes calculate it by equal the area steel of stirrups to area steel plates, specimen B3 also replace the stirrups by a vertical hollow steel plates with circle holes calculate it by equal the area steel of stirrups to area steel plates but the vertical hollow steel plates put on width and equal to the number of stirrups on conventional wide beam. Typical concrete dimensions and reinforcement details of the test specimens were illustrated in Figure (1). Table (1) shows the details of the test specimens.

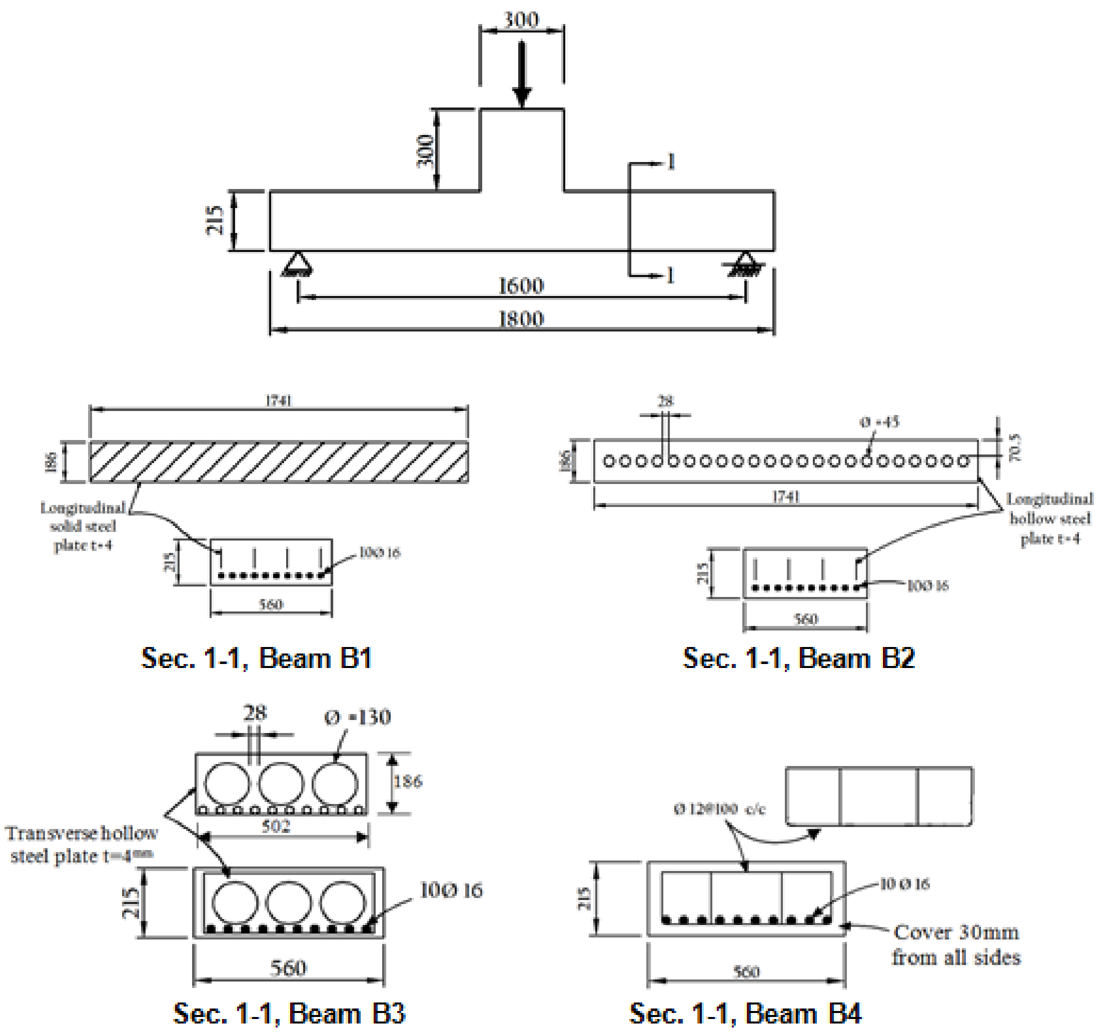

Figure (1) Test setup and details of tested beams (all dimension in mm)

Table (1) Details of test specimens and results

Beam designation	Stirrups (mm)	Vertical steel plate	Crack load (kN)	Ultimate load $P_{u.}$ (kN)	% Increase in $P_{u.}$	Ultimate deflection $\Delta_{u,}$ (mm)	% increase in Δ_u
B1	--	4 solid longitudinal	65	471	12.14	11.50	16.16
B2	--	4 hollow longitudinal	71	460	9.52	10.0	1.01
B3	---	Hollow transverse @100	65	620	47.62	18.37	85.56
B4*	Φ12@100	--	65	420	0	9.90	0

*Reference Beam

4.2 MATERIALS

All tested beams were made with concrete compressive strength of 45 MPa. The concrete mix proportions are presented in Table (2). For each series of casting, the specified concrete compressive strength was measured by testing three concrete cylinders of (150×300) mm.

Deformed steel bars were used in this work with nominal diameters of (16mm) for longitudinal reinforcement in tension side (bottom side) with 100mm length hooked at both ends using 90° standard hook. While deformed steel bars (12mm) were used as web reinforcement in control beam B4. Tensile tests of steel reinforcement are carried out using three (500mm) long specimens for each nominal diameter with (20mm) catch length test was performed by using the tensile testing machine available at the Laboratory of Materials at the College of Engineering / Daiyla University to determine the average yield stress and the ultimate stress, the test results are listed in Table (3).

Gagger steel plates 4mm thick were used, as show in Figure (2). The steel plates were tested in the lab, and the following properties were obtained; equivalent yield strength = 490 MPa; ultimate strength = 610 MPa; ultimate elongation = 11%; and the elastic modulus 200 GPa.

Table (2) Concrete Mix design

Mix designation	Cement kg/m^3	Aggregate kg/m^3		Water kg/m^3	w/c for Slump 120±10 mm
		Sand	Gravel		
C45	470	750	900	235	0.50

Table (3) Mechanical properties of reinforcing bars

Nominal diameter, mm	Measured diameter, mm	Cross-sectional area, mm^2	f_y, MPa	f_u, MPa
12	12.06	114.23	671	831
16	15.96	200.06	650	807

Figure (2) Gagger steel plate used in B1, B2 and B3

4.3 INSTRUMENTATION AND TEST PROCEDURE

All beams were tested using a hydraulic universal testing machine of (2000kN capacity) under monotonic loads up to ultimate load at the Structural Laboratory of the College of Engineering / Diayla University as shown in Figure (3).

Figure (3) Preparation for loading test machine

The tested beams were simply supported at ends over span of (1600mm) center to center of supports, and loaded with one-point loads. To avoid local failure at point load application and to insure uniform bearing stress at this region, steel blocks of (400x400x50mm) dimensions were used as shown in Figure (4). Also rubber pieces of (300x300x10mm) was placed between load blocks and top face of beams to ensure even surface under load positions, and rubber pieces of (560x150x10mm) were placed between supports and bottom face of beams.

The vertical deflections wsa measured at one point as central deflection using mechanical dial gauge of (0.01mm) accuracy with (50mm) total stroke. The dial gauge had been attached to the soffit of the tested wide beams. Concrete strains had been measured using Demec points which were mounted in five locations on the top face of the beam in both directions and along the diagonal. A digital extensometer with (0.001mm) accuracy, as shown in Figure (5), was used to measure relative movement of the Demec points, from which the longitudinal strain was calculated for each load increment. The digital extensometer is capable of measuring displacement changes between two Demec strain discs fixed at (100mm) gauge length.

To measure crack widths, an optical micrometer with an accuracy of (0.02mm), as shown in Figure (6), was used for all beams specimens. The beam surfaces were painted with white color to make it easy to see the crack and measured it.

Figure (4) Steel block and rubber position

Figure (5) Digital extensometer and demec disc

Figure (6) Optical micro-meter

5- TEST RESULTS

5.1 CRACKING BEHAVIOR

Typical behavior of beams was introduced through cracks pattern distributions recorded at applied load increments are shown in Figures (7 to 10). For all specimens, the first crack development, crack propagation, and plane of failure were observed during the test. As stated before; all tested specimens were designed to fail in one way shear and this presumption was investigated for all tested specimens. The general behavior of all tested specimens was relatively similar and the crack development followed a similar pattern in all tested specimens. The tested beams were free of cracks in the early stages of loading. All beam specimens failed in shear and shear cracks crossed the compression zone of beam section. For specimens B1, B2 and B4, the shear cracks started without the appearance of flexural cracks. For specimen B3, it was observed that the first early cracks were vertical flexural cracks occurring in the specimens mid-span and near mid-span sections and upon increasing the applied load, a series of flexural cracks were formed at the bottom in the shear span region and gradually propagated toward the loading point while no crack had been observed at beam ends. By increasing the applied load and at intermediate loading stages, a new series of flexural cracks was formed in the shear span region then rotated to form flexural- shear cracks joining the loading and supporting points. During subsequent loading stages, additional diagonal shear cracks appeared and developed through a substantial depth of the specimen section and propagated towards the top of the specimen. Figure (11) shows the first crack width development for tested wide beams, Table 1 summarizes the results of the tested beam specimens. The table gives the main characteristics of each specimen, the shear cracking load, the ultimate load and the corresponding mid-span deflection.

Figure (7) Crack pattern for (B1)

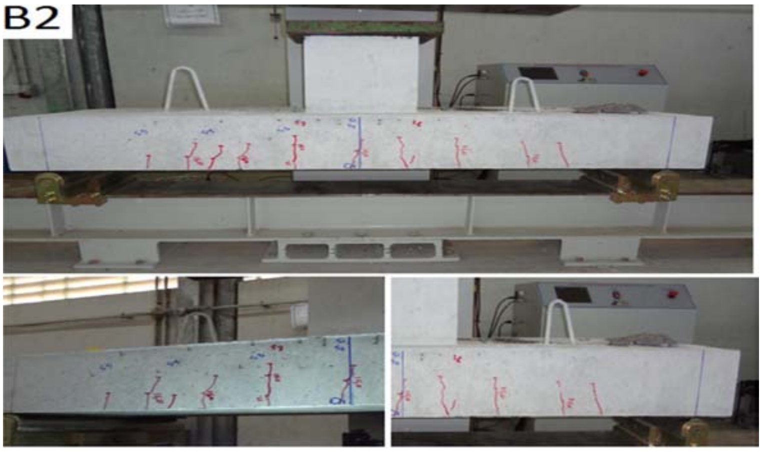

Figure (8) Crack pattern for (B2)

Figure (9) Crack pattern for (B3)

Figure (10) Crack pattern for (B4)

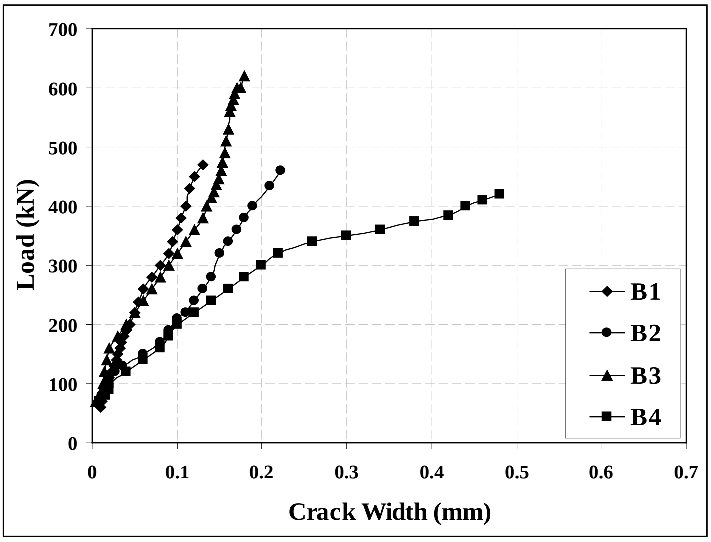

Figure (11) First crack width – load curve

5.2 MODE OF FAILURE

All tested beams were failed in diagonal compression mode except beam (B4) which failed by shear diagonal splitting mode. This different mode of failure was due to the use of gagger plate (4mm) instead of (12mm) bars of stirrups which had been used in other wide beams, where the inclined cracks do not penetrate into the shear zone due to the presence of this stiff gagger plate. Therefore, the crushing of concrete in the strut region was caused by reaching the compressive stress in concrete to its ultimate value before yielding or rupturing these gagger plates. This behavior was clear in Figures (7) to (11) where the main crack does not penetrate into the top face of the beam while the crushing takes place in the concrete strut especially at regions near the support. This type of failure (diagonal compression mode) makes the behavior more brittle. This means the necessity for determination of a maximum limit for shear reinforcement ratio to avoid brittle failure in wide beams. Further studies are required to reach values and equations to specify this limit.

The presence of gagger plates contributes in delaying appearance of cracks and hampers their development. It is clear in Figures (7) to (9), where the cracks were few and short especially at the mid-span of wide beams (B1), (B2) and (B3) in comparison with crack pattern of wide beam (B4).

5.3 LOAD-DEFLECTION RELATIONSHIP

The applied load was plotted against the vertical deflection which measured at mid-span for all tested beams as shown in Figure (12). The load–deflection curves of the tested specimens show that vertical steel plates had no significant impact on the deflection values at pre-cracking stage. On the other hand, the vertical steel plates had noticeable impact on the ultimate load and the maximum deflection (Δ_u). In addition to the previous remarks, the following findings can be noticed:

1. The control beam B4 with web reinforcement had a sudden shear failure with lowest value of ultimate deflection (9.9 mm).
2. Beams (B1 and B2) which have longitudinal vertical steel plates showed improving in ultimate load. The ultimate loads of these beams were greater than the control beam B4 by 12.14% and 9.52% respectively. Also, the maximum deflections of these beams (B1 and B2) are greater than the control beam by (16.16% and 1.01%) respectively.
3. Regarding Figure 12, Beam B3, which have transverse vertical steel plates, significantly showed improving in ultimate load and maximum deflection. The ultimate load and maximum deflection of this beam is greater than the control beam by 47.62% and 85.56% respectively.

From Figure 12, it can be observe that the presence of steel plate enhances the load-deflection curve characteristics. The presence of steel plate was increases the area under the load-deflection curve i.e. increases the energy absorption capacity. Also at any load level, the deflection is smaller when the steel plates are present. The advantage of steel plate is more pronounced when used. This effectiveness of steel plate is may due to two positive actions:

1. Increasing the tension zone capacity of wide beam section and decreasing crack width and crack number in this region.
2. Increasing the mechanical properties of wide beam section causing increasing in compression zone depth depending on equilibrium of internal forces. This action causes an increase in moment of inertia of cracked section which increases the rigidity of the wide beam, thereby the deflection becomes smaller.

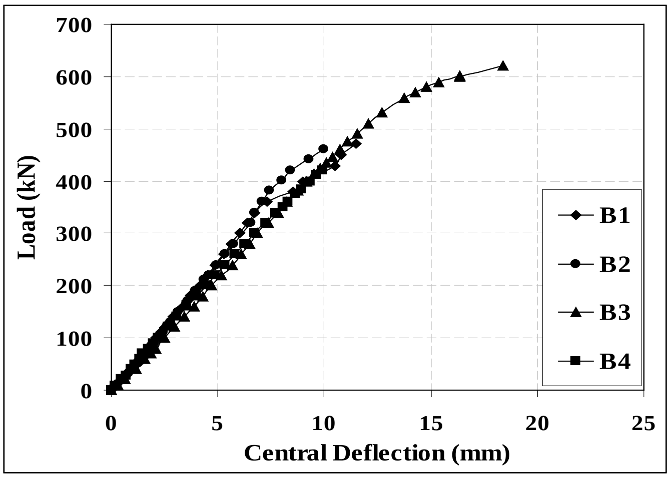

Figure (12) Load-deflection curve

5.4 CONCRETE COMPRESSIVE STRAIN

As shown in Figure (13), the wide beams (B1, B2 and B3) show decreasing in concrete compressive strain in comparison with the reference wide beam (B4) this may be due to presence of vertical steel plate, and the study observe that maximum strain in B1 is ($8*10^{-4}$mm/mm) at ultimate load (471kN), and the maximum strain in B2 is ($7.54*10^{-4}$ mm/mm) at ultimate load (460kN), and the maximum strain in B3 is ($12*10^{-4}$ mm/mm) at ultimate load (620kN), and the maximum strain in reference beam B4 is ($10.8*10^{-4}$ mm/mm) at ultimate load (420kN).

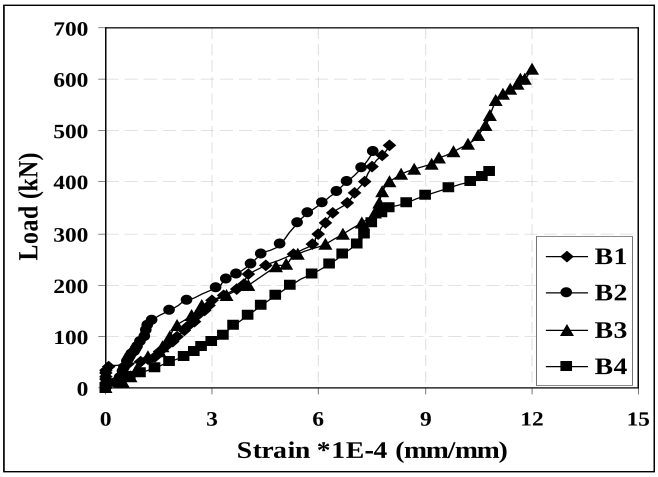

Figure (13) Load- concrete compressive strain curve

6- CONCLUSIONS

Based on the study presented herein, the following conclusions are drawn:

1. The vertical steel plate was significantly contributes to the shear behavior of wide beams by improving the contribution of the dowel action, and limiting the opening of inclined shear cracks, thus its effect on shear capacity of wide beams should be considered.
2. The increase in the shear capacity ranged from 9.52% to 12.14% for wide beams contains longitudinal vertical hollow steel plates and longitudinal vertical solid steel plates respectively instead of web reinforcement.
3. The increase in the shear capacity by about 47.62% for wide beams contains transverse vertical hollow steel plates instead of web reinforcement.
4. The increase in the maximum deflections ranged from 1.01% to 16.16% for wide beams contains longitudinal vertical hollow steel plates and longitudinal vertical solid steel plates respectively instead of web reinforcement.
5. The increase in the ultimate displacement by about 85.56% for wide beams contains transverse vertical hollow steel plates instead of web reinforcement.

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