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Experimental Study of Behavior of Reinforced Light-Weight Concrete Deep Beams with Web Openings

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ملخص البحث

يقدم هذا البحث نتائج تجارب معملية لدراسة سلوك القص للكمرات البسيطة و المستمرة من الخرسانة الخفيفه والتي بها فتحات . و قد تضمن برنامج الأختبارات سبعة كمرة عميقة بسيطة من الخرسانه الخفيفة ، و أهم المتغيرات التى تم دراستها فى اختبار الكمرات البسيطة هى مقاس القتحات ومكان الفتحات و مقاومة الضغط التصميمية للخرسانة و نسبة التسليح العرضى للكمرة . وأظهرت النتائج أن وجود فتحات جانبيه على الكمره (ارتفاعها يساوي من 20٪ الي 40٪ من إجمالي ارتفاع الكمره، على التوالي) في مسار الحمل يؤدي إلى انخفاض في قوة القص النهائي للكمرات العميقة البسيطة بنسبة حوالي من 15٪ الي 62٪ بالمقارنة مع الكمره العميقه التي ليس بها فتحات جانبية .

Abstract

In order to study the shear behavior of reinforced light weight Concrete (LWC) simply supported deep beams with and without web openings an experimental program has been conducted. The test program included seven reinforced concrete simply supported deep beams. The main parameters examined were the size and position of the opening and the magnitude of transverse reinforcement ratio. The results indicated that the presence of web openings (of height equal to 20% and 40 % of the total a web height, respectively) in the load path leads to a reduction in the ultimate shear strength of LWC simple deep beams by about 15% and 62 % when compared with a similar beam without opening.

Keywords: Light-weight concrete, Deep Beams, Shear.

1. Introduction

Most of the current concrete researchers focus on high-performance concrete, by which is meant a cost-effective material that satisfies demanding performance requirements, including durability. Light-weight concrete (LWC) is very important to the construction industry due to its lower cost and weight. The primary advantage of using LWC is to reduce the dead load of the concrete structure, and consequently, it leads to reducing the size of columns, footings and other load bearing elements. Light-weight foamed concrete is a new kind of Lightweight concrete, which combines the advantages of normal density concrete, cellular concrete, and self-compacting concrete through partially replacing the normal weight aggregates with polystyrene foam, hence, leading to concrete unit weight reduction while maintaining adequate strength. Therefore, the latter material can be produced using standard methods familiar to the construction industry with a dry unit weight of 18.5 kN/m^3, which in turn leads to dead load reduction by 15 – 20 % and the associated decrease in the structure's overall cost, hence, providing a feasible challenge to normal density concrete (NDC) with a dry unit weight of 25 kN/m^3.

Moussa, A., et al [3] tested eleven deep beams. Which was constructed and tested experimentally to establish the effect of the presence of the openings on the behavior of deep beam as well as the nature and magnitude of stress distribution. Test results showed that increasing the size of the opening leads to increase in the top deflections.

Moving the opening up wards lead to an increase in the top deflection and decrease in the bottom one due to the deviation of arch

action. For solid beams and beams that have openings not intercepting the load path. The shear capacity predicted by both Egyptian and ACI codes are quite close. Haque, M., et al [4] conducted a photoelastic investigation of the stress distribution in deep beams with and without web openings. The general form of stress diffusion has been established and the critical zones have been identified. The critical tensile and shear stresses have been evaluated and their sensitivity to various span-to-depth ratios and opening positions along the span has been established. Based on stress flow pattern and contour lines of principal tensile stresses, failure mechanisms have been predicted and recommendations have been made for the design of reinforced concrete deep beams. Danile F. Jensen [5] studied Reliability Analysis for Shear in Lightweight Reinforced Concrete Bridges Using Shear Beam Database (2014). The objective of this study is to analyze and calibrate the reliability indices for shear in reinforced concrete bridge girders. Existing statistical models are based on limited experimental data from only a few research tests. These existing models show that our current procedures for analysis are about 10-15% less conservative for lightweight concrete compared to an analysis for normal weight concrete. Accurate load models are used to find shear and moment envelopes of loads applied to bridges. The analysis is based on different span lengths, span number, and girder dimensions. Design calculations are performed using design values and loads calculated from load models. Different strength of concrete is also used to compare the reliabilities of various parameters. Results show that when using a professional factor of 1.0 and variability of 0.0 and a resistance factor of 0.8 can be applied to the AASHTO design equation for shear in reinforced concrete. C. H. Huang, L. H. Chen, Y. C. Kan, C. H. Wu and T. Yen [6] studied the shear behavior of full size reinforced lightweight concrete beam (2011). This study presents the results of experimental investigations on three lightweight aggregate concrete (LWAC) beams and three normal weight concrete (NWC) beams were designed and cast for shear investigation by conducting center load bending test. Test results showed that the shear failure modes of LWAC beams are similar to NWC beam, including shear-compression failure and shear-tension failure.

2. Experimental Program

The experimental study included seven reinforced concrete simply supported deep beams with and without web openings and constructed from light weight Concrete. The beams were tested under the effect of one concentrated load. All tested specimens had the same geometry and main longitudinal top and bottom reinforcement. The beams as shown in Table 1. All the tested deep beams had the same rectangular cross-section of 80 mm wide and 400 mm total height as shown in Fig.1 through Fig.2.

Mix Composition

From the mix design, the quantities required by weight for one cubic meter of fresh concrete for the L.W.C specimens are as given in Table 2. The longitudinal reinforcement for the beams were high-grade steel bars (f_y=550 N/mm^2, f_{ult}=700 N/mm^2).

Loading of specimens

The specimens were loaded in increments up to failure. The tested specimens were instrumented to measure the deformational behavior after each load increment. The recorded data include measurements in concrete, main steel, transverse reinforcement (stirrups) and longitudinal bars strain; deflection and crack propagation. After each load increment, the cracks were traced and marked on the painted sides of the specimen according to their sequence of occurrence.

Test procedure

The specimens were tested by using a hydraulic jack. At the beginning of each test, the specimen was installed on the two supports as a simple beam. The reading of the hydraulic jacks and the steel strain gauges were taken by special instruments.

3. Experimental Results

The seven tested models behaved in a different manner and the following remarks were noticed:

Crack Pattern and Failure Mode of Tested Beams

At the end of testing each deep beam, the marked crack pattern was used to provide the necessary information required for defining the failure mechanism of each specimen. Fig.3 shows the failure mode of all the tested specimens. For all specimens, the flexural cracks initiated on the tension side at the middle of the beam span, the cracks propagated upward with the increase of load. For solid beam, the first diagonal crack suddenly developed at mid depth within the shear span. Diagonal cracks were observed parallel to the compression strut and propagated towards the loading region and supports. For the beams with the small opening size the increase in the applied load, shear diagonal cracks began to appear and extend from the support plates to the edges of the openings. For the tested deep beams with large openings, diagonal cracks were the first and initiated at opening corners and propagated with the load increase towards loading zone and supports. With increasing the load; more diagonal cracks appeared parallel to the strut, passing through the opening corners and propagated in both directions towards the loading region and the supporting plates. Table 4 shows cracking and failure loads for all tested beams.

The following points can be made: -

1- The effect of opening size on the failure load for beams (BLW3, BLW5), (BLW4, BLW6), (BLW3, BLW4) and (BLW5, BLW6) on the failure loads compared with that of the solid beam BLW1. It may be noted that the failure load of BLW3 and BLW5 were 0.80 and 0.66 of that of beam BLW1, respectively. The failure load of BLW4 and BLW6 with respect to the solid deep beam BLW1were 0.60 and 0.38, respectively. The failure load of BLW3 and BLW4 with respect to the solid deep beam BLW1were 0.80 and 0.60, respectively. The failure load of BLW5 and BLW6 with respect to the solid deep beam BLW1were 0.66 and 0.38, respectively.

2- The effect of the opening located on the failure load for beams (BLW2, BLW3), (BLW6, BLW7) on the failure loads compared with that of the solid beam BLW1. It may be noted that the failure load of BLW2 and BLW3 were 0.86 and 0.80 of that of beam BLW1, respectively. The failure load of BLW7 and BLW6 with respect to the solid deep beam BLW1were 0.44 and 0.38, respectively.

Deflections

During testing of each beam, the deflection at mid-span was measured at the end of each load increment. The measured load-deflection curves are shown in Fig.4. From the figure, the following points are made:

1-The mid-span deflection curves of LWC deep beams with and without web openings are reported here. In early stages of loading, the beams behaved in a truly elastic manner. At higher levels of loading, beams with large web openings exhibited the highest deflection among all beams of the same level of loading. Beams with small web openings showed load deflection behavior very similar to that of the solid beam.

2- The effect of opening size on the mid span deflection it is obvious that existence of opening would reduce the deep beam stiffness. The effect of the opening size is also clear when the response of beams BLW3, BLW4, BLW5 and BLW6 are compared. For beams (BLW3, BLW4), (BLW3, BLW5), (BLW6, BLW4) and (BLW6, BLW5) are shown in fig.4. from the figure, it is noted that the mid span deflection of beam BLW3 with small opening (1A12) is lower than of beam BLW4 with opening (2A12) and beam BLW5 with opening (1B22), for beam BLW6 with large opening (2B22) the mid span deflection is higher than beam BLW4 with opening (2A12) and beam BLW5 with opening (1B22).

3- The effect of the opening located on the mid span deflection. The load deflection curves of beams BLW2 and BLW3 it can be noted that moving the opening towards the beam center reduces the deflection. On the other hand, the load deflection curves for the beams BLW6 and BLW7, beams, indicates that moving the opening towards the mid shear span increases this deflection.

STEEL STRAINS

The location of steel strain is three locations. The first locations at the bottom steel bars (main steel) in the mid span of the beam. The second location at the vertical stirrups around the web opening. The third location at the horizontal stirrups (longitudinal bars) around the web opening.

Fig.5 shows the measured load- main steel strain curves till failure for the beams. From the figure, the following observations are made:

Failure of all the tested deep beams with and without web opening occurred before yielding of the longitudinal bars. Formation of inclined diagonal cracks had no effect on the strain readings in the longitudinal bars.

The effect of opening size on main steel strain for beams (BLW3, BLW4), (BLW3, BLW5), (BLW6, BLW4) and (BLW6, BLW5) from these comparisons, we note that the main steel strain increases as the opening size increase at the same load. The effect of opening location on main steel strain for beams (BLW3, BLW2) it can be noted that moving the opening towards the beam center reduce the main steel strain at the same load. For beams (BLW6, BLW7) it can be noted that moving the opening towards the mid shear span increase the main steel strain at the same load.

Fig.6 shows the measured load- vertical steel strain curves till failure for the beams. From the figure, the following observations are made:

The strains in the stirrups before the initial diagonal crack were very small and increased suddenly after the formation of this crack.

The effect of opening size on vertical steel strain for beams (BLW3, BLW5), (BLW6, BLW4) and (BLW6, BLW5) from these comparisons, we note that the vertical steel strain increases as the opening size increase at the same load. For beams (BLW3, BLW4) it is noted that the vertical steel strain of beam BLW3 with small opening size is higher than of beam BLW4 with large opening size, however, it was expected that BLW3 lower than BLW4. This could be attributed to the facts that the small opening size decreases the vertical steel strain. The effect of opening location on vertical steel strain for beams (BLW3, BLW2) it can be noted that moving the opening towards the beam center reduce the vertical steel strain at the same load. For beams (BLW6, BLW7) it can be noted that moving the opening towards the mid shear span increase the vertical steel strain at the same load.

Fig.7 shows the measured load- longitudinal bars strain curves till failure for the beams. From the figure, the following observations are made:

The effect of opening size on longitudinal bars strain for beams (BLW3, BLW4), (BLW3, BLW5), (BLW6, BLW4) and (BLW6, BLW5) from these comparisons, we note that the longitudinal bars increases as the opening size increase at the same load. The effect of opening location on longitudinal bars strain for beams (BLW3, BLW2) it can be noted that moving the opening towards the beam center reduce the longitudinal bars strain at the same load. For beams (BLW6, BLW7) it can be noted that moving the opening towards the mid shear span increase the longitudinal bars strain at the same load.

4. CONCLUSIONS

1- The presence of web openings (of height equals to 20% and 40 %, respectively, of the total web height) on the load path leads to a reduction in the ultimate shear strength of LWC deep beams by about 15% and 62%, respectively, when compared with the similar beam without openings.
2- When an opening exists near the support region of LWC deep beam, it leads to early cracking and a reduction in the strength and stiffness of the beam.
3- Openings in the shear span of deep beams reduced the shear strength compared to that of the solid deep beam.
4- Opening in the shear span of deep beams increased deflections and concrete and steel strains.

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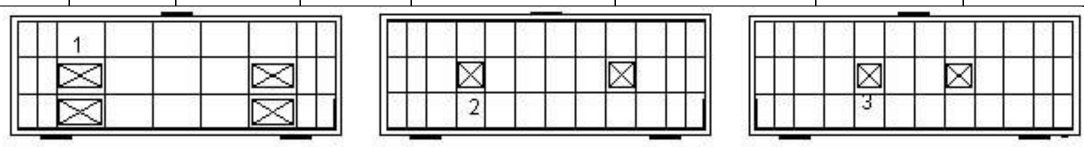
Table 1 Designation of experimental testing groups

Beam	Shear span to depth ratio a/d	Section b*t (mm)	Span (mm)	Upper Longitudinal Bars	Lower Longitudinal Bars	Stirrups Ø6 s_v (mm)	Opening Notation
BLW1	0.97	80*400	800	10Ø2	16Ø4	100	---
BLW2	0.97	80*400	800	10Ø2	16Ø4	100	1A3
BLW3	0.97	80*400	800	10Ø2	16Ø4	100	1A2
BLW4	0.97	80*400	800	10Ø2	16Ø4	100	2A2
BLW5	0.97	80*400	800	10Ø2	16Ø4	160	1B2
BLW6	0.97	80*400	800	10Ø2	16Ø4	160	2B2
BLW7	0.97	80*400	800	10Ø2	16Ø4	160	2B1
		80*400	800				



Location of openings
Opening Notation

the first part refers to the number of openings in the shear span (1 or 2); the second part indicated the size of opening (A= width* height=80*80 mm and B=140*80 mm); the third part referred to the web reinforcement arrangement (1 for Sv =100 mm and 2 for Sv=160 mm) and the fourth part referred to the location of the openings (location 1, 2 and 3).

Table 2 Material quantities specimens

Concrete type	Concrete strength (N/mm^2)	Cube strength		Cylindrical compressive strength N/mm^2 after 28 days
		7 days	28 days	
Light weight	25	19.7	28.9	23.3

Table 3 Mechanical properties of L.W.C mix (N/mm^2)

Concrete type	Materials	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	w/c ratio	Super-Plasticizer $(liter/m^3)$	Silica fume (kg/m^3)	Polystyrenes Foam $(liter/m^3)$
Light weight	Quantity	450	630	630	0.308	13.5	40	330

Table 4 Results of beam loading tests.

Specimen	BLW1	BLW2	BLW3	BLW4	BLW5	BLW6	BLW7
Failure load (KN)	250	215	200	150	165	95	110
Cracking load (KN)	100	70	80	60	80	60	60

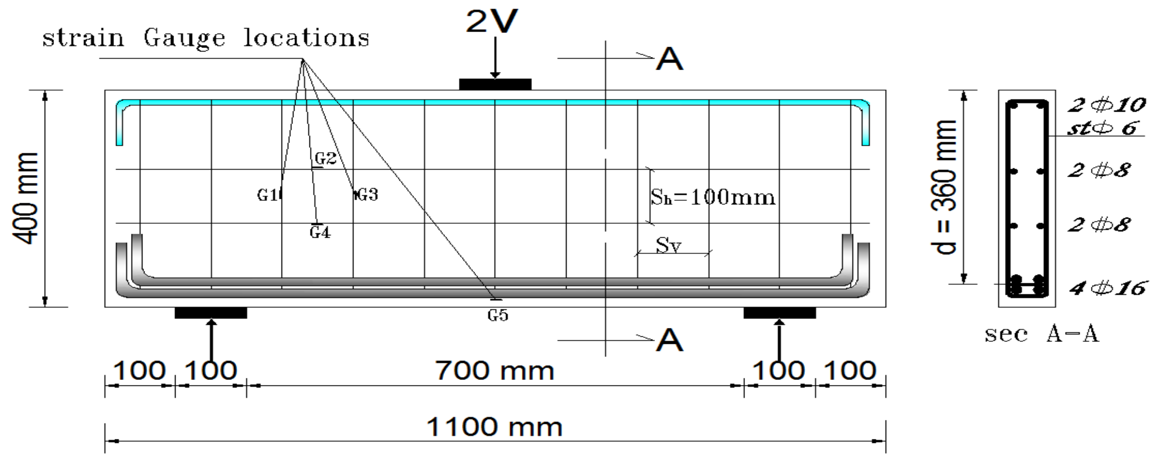


Fig.1 reinforcement Details

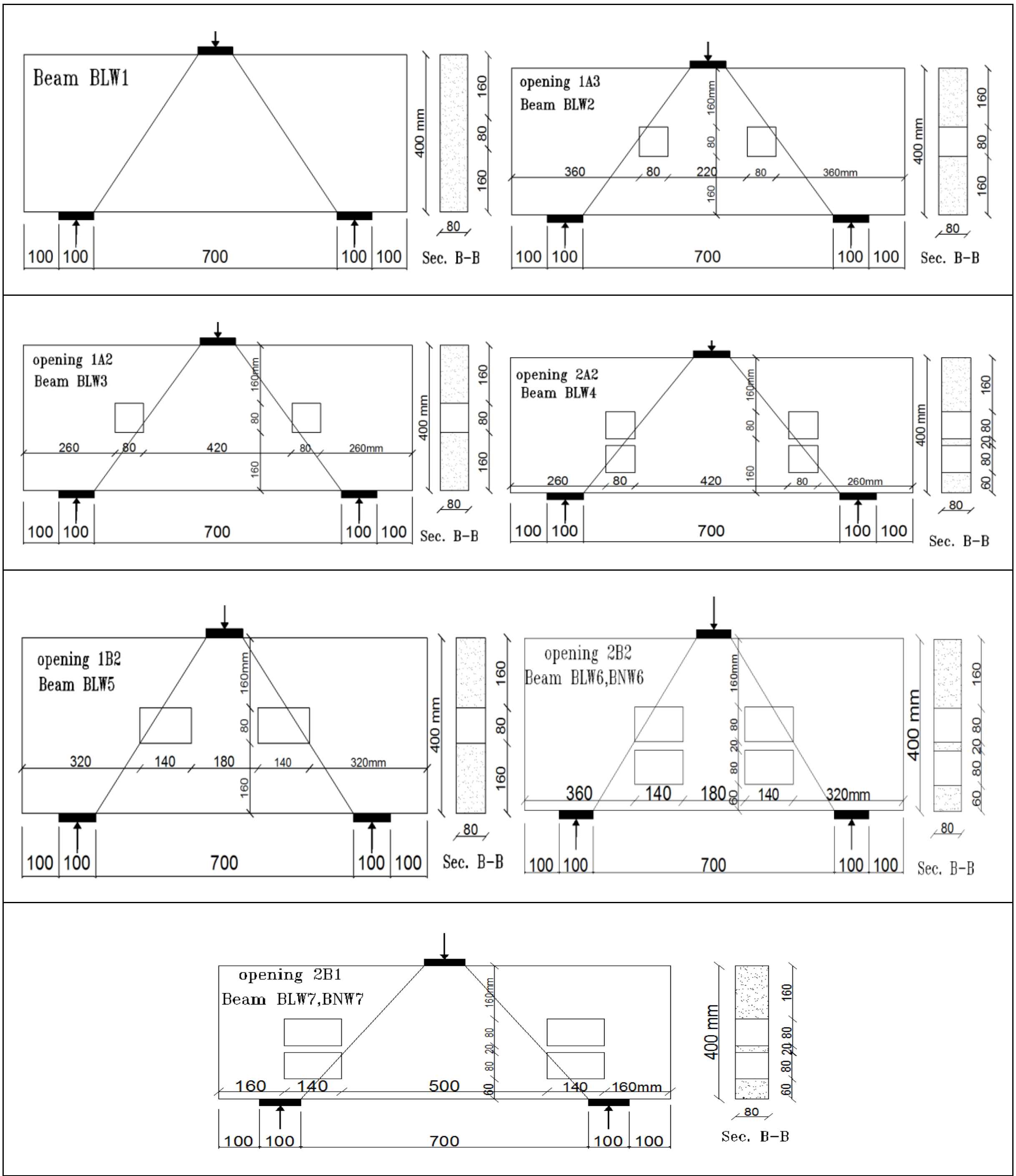


Fig. 2 Typical dimensions of tested beams

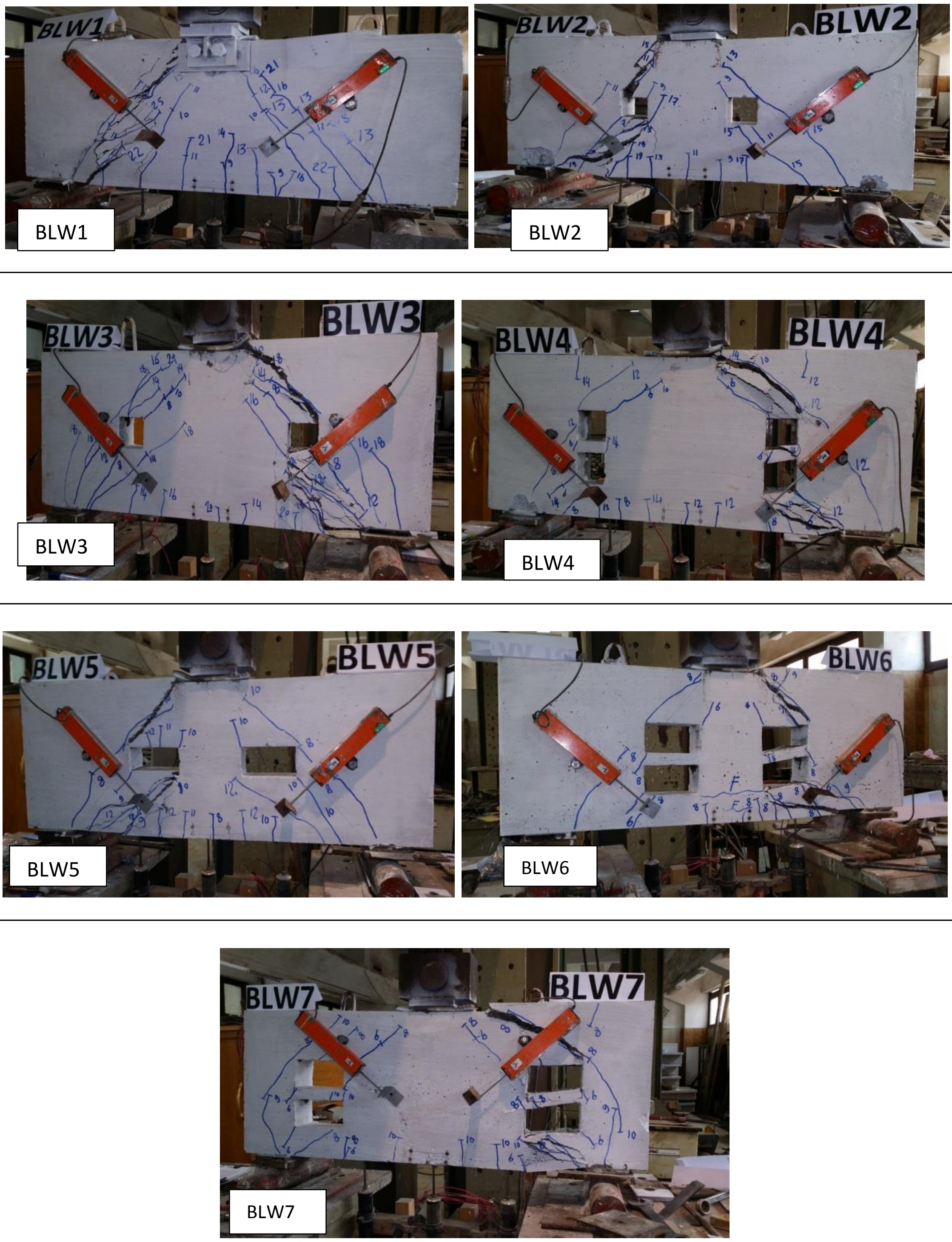


Fig. 3 Failure modes of tested beams

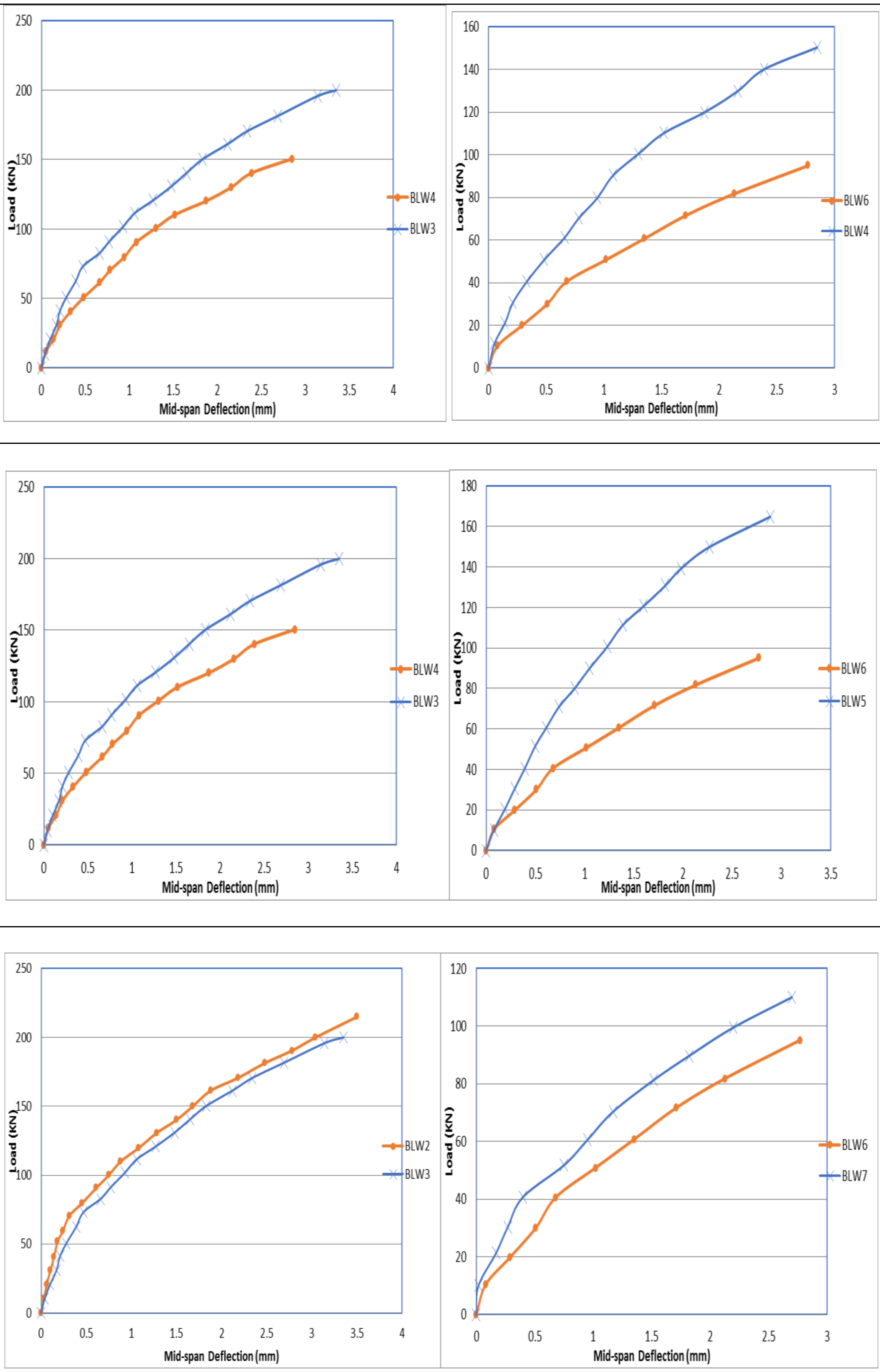


Fig. 4 Load deflection relationships for tested beams

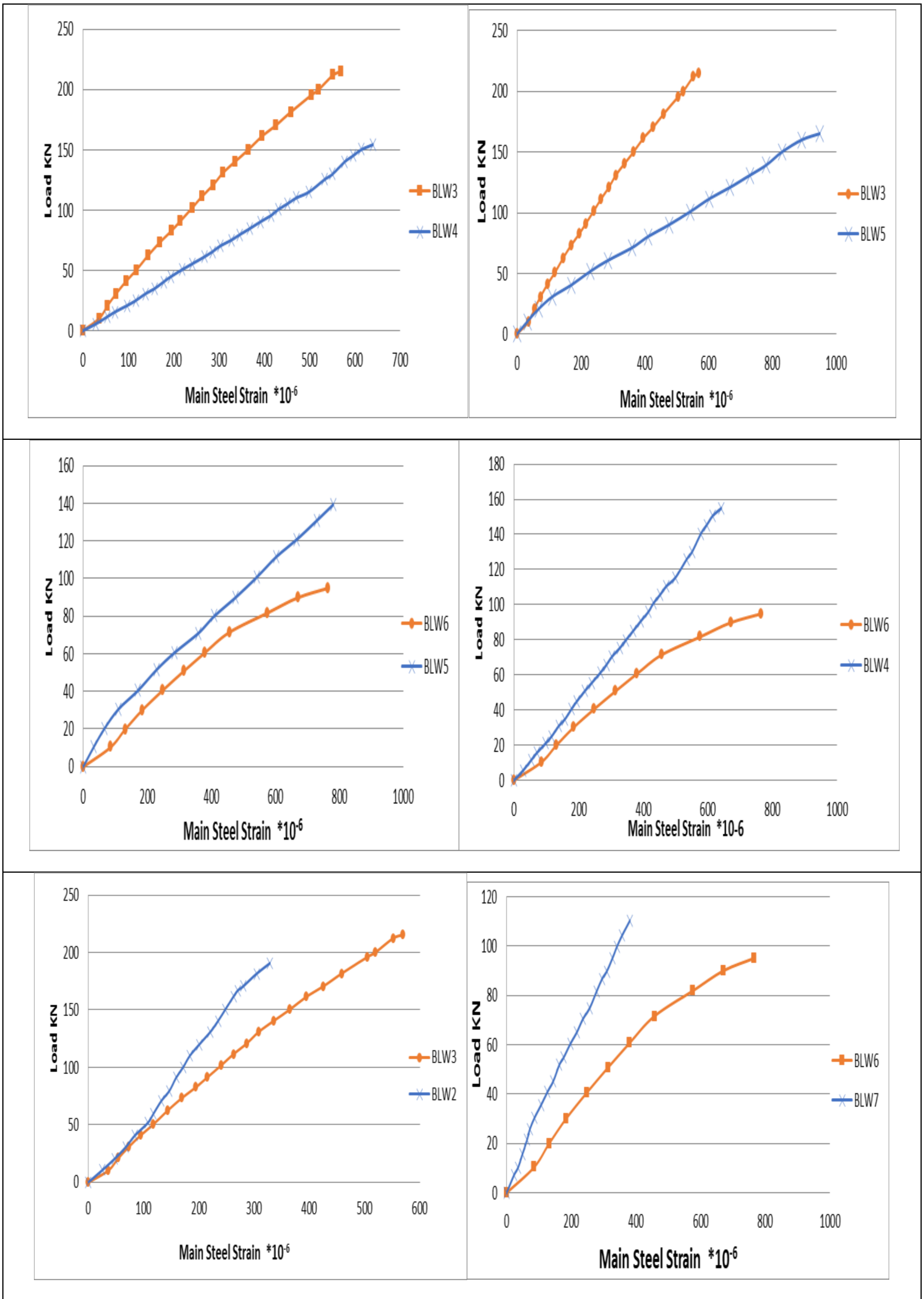


Fig. 5 Load Steel strain relationships in Main steel for tested beams

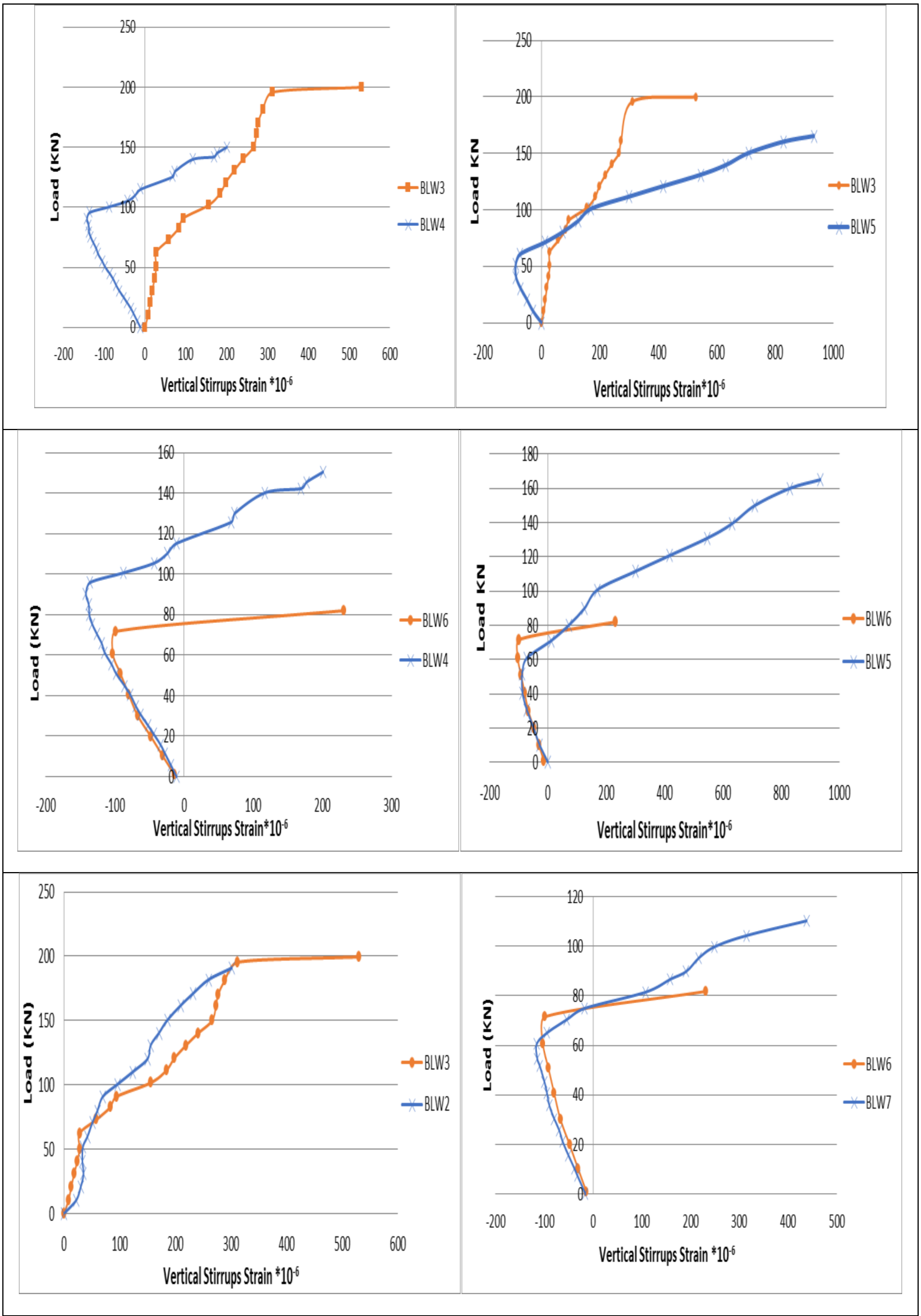


Fig. 6 Load Steel strain relationships in vertical stirrups for tested beams

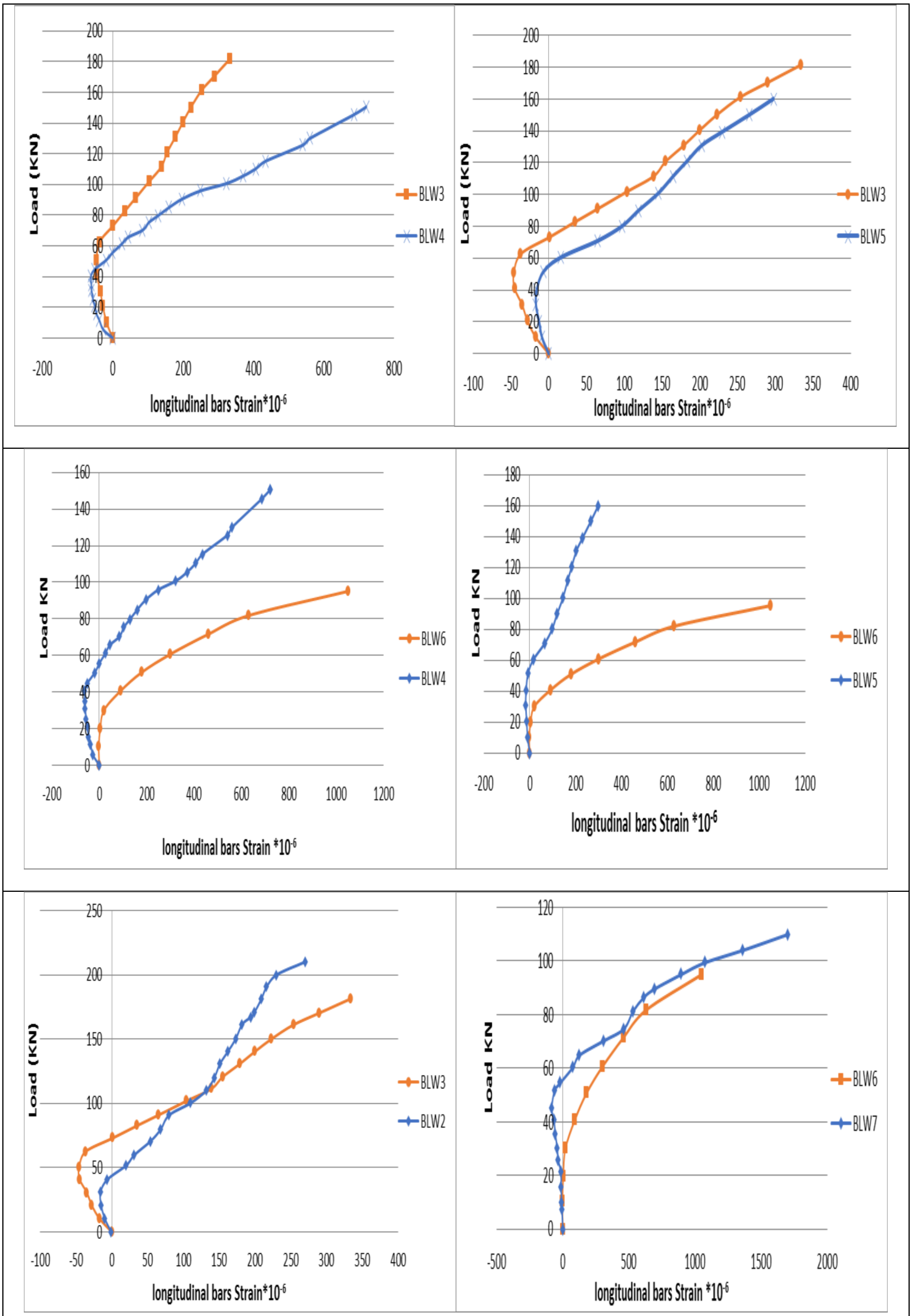


Fig. 7 Load Steel strain relationships in longitudinal bars stirrups for tested beams