Fixed Supports in Assessment of RC Beams' Behavior Under Combined Shear and Torsion

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Abstract

The effects of combined shear and torsion on reinforced concrete beams have been of much interest among civil engineers and researchers. To study the reinforced concrete beams, a suitable set up system is needed. In present investigation, a set up system has been built and evaluated based on structure analysis aspects. Evaluation is done by testing 5 beams which had actual sizes and an area of weaker section in their span. The samples were tested under different eccentricities, varied from zero (pure shear) to infinity (pure torsion). Among the advantages of this test set up, the possibility of testing the samples under pure shear, pure torsion and combined shear and torsion can be mentioned. Results showed that the set up worked properly and the shear-torsion interaction curve was linear.

Key words: fixed support, shear-torsion interaction, reinforced concrete beam.

1. Introduction

Studying the reinforced concrete beams under combined shear and torsion are routed back to more than 50 years ago. A variety of investigations are available in history. Some of the important ones can be mentioned as the studies which were done by Klus (Klus 1968), Zia (Zia 1970) and Elfern (Elfern et.al. 1974). There are different opinions about the interaction curves' shapes in references and in some of the reinforced concrete structures' codes. Among them there are linear, bilinear and a quarter of circle. Certainly, one of the best ways to study the shear-torsion behavior of the reinforced concrete beams is to test them and a test system is required. This system consists of a loading system, a measurement system and most importantly, suitable supports. To study reinforced concrete beams under combined shear and torsion, an area of fixed shear and torsion and slight flexure is needed (Klus 1968). To accomplish that a test system alike what had been used in Rahal investigations (Rahal 1993) can be built as a multi span beam with a flexural inclination point in the middle span which has fixed shear and torsion. The new system which has been invented by Dunstan (Dunstan 1989), requires the construction of multi span beams with two load carrier and other special equipments like actuators.

Another system which was introduced by Difalla and Ghobarah can be specified by a metal bar for applying eccentric loads (Deifalla & Ghobarah 2005, Deifalla & Ghobarah 2010 and Deifalla 2007). In this system, a beam with two hinged ends is tested and the test can only be done under one amount of eccentricity. Thus, to plot the shear-torsion interaction curves which require testing the beams under different eccentricities, the loading system should be changed for every eccentricity. In the current study, the test system is set up as a beam with two fixed ends which provides the possibility of testing the beam under different eccentricities. Also, to apply the eccentric load, a removable metal belt is tied around the middle of the beam. One of the most important results of using such a system would be the possibility of the pure torsion test. This system was evaluated under different loads with different eccentricities (zero to infinity), and then the shear-torsion interaction curve was plotted for the samples.

2. Support system

The test was done with beams' supports as fixed ones. Shorter beams with less weight and the possibility of using a hydraulic jack to test the beams under shear-torsion are of the advantages of this system. Figure 1 contains of the basics of the support's construction regarding the flexure and torsion rotational rigidity. So the supports were composed of the following parts:

1. Flexural rigidity provider
2. Torsion rigidity provider
3. Middle belt for eccentric loading
4. Accessories, used for pure torsion test

These parts are installed on a loading frame as shown in figure 1, and they can be used in other systems which have a hydraulic pomp.

3. Flexural rigidity of the support

To provide the flexural rigidity of the support, two fixed H-shaped decks were used on the beam's top and bottom at each end. The decks are shown in figure 2. Holes are similarly made on the upper flange of the bottom deck and the lower flange of the top deck. Decks' lengths are equal to the loading frame's width (in the perpendicular surface related to the frame), and as a result the beam can be placed and tested anywhere on the deck. Note that the loading bar is fixed in the middle of the frame. These decks are coupled together with welded stiffener plates on the outside and bolts on the inside (figure 2.a). The bolts are placed and tightened after the beam's installation. Also to prevent any flexural rotation on the ends, temporary frames (made from PVC) were used for grouting after the beam was installed on the appropriate spot (defined eccentricity). It is essential to note that the placement of the beam at the proper eccentricity was done; using a slipping table with adjustable height and after the setting of the grout the table was removed.

4. Torsion rigidity of the support

To provide the torsion rigidity, two stiffened L-shaped elements are used on the beam's sides at each end. These elements, shown in figure 2.b, are bolted to the H-shaped decks. Also their backs are welded to the decks. This is how the beams would gain torsion rigidity after the flexural part is ready. To avoid any torsion rotation, grouting was done with temporary frames to fill the distance between the L-shapes and the beam. Note that, these L-shapes are placed on beam's sides in a way that the torsion rotation would not occur.

5. Pure torsion test

To avoid the shear (and flexure) development in the beam, a secondary support was placed in the middle of the beam. This support (shown in figure 3) was a hinged member which absorbed the whole shear load. Two foam pieces were also placed on the top and bottom of the member at each end to diminish the vertical rigidity of the supports and guide the whole shear to the hinged member (figure 4). Also before grouting the distance between the L-shaped members and the beam, by using plastic sheets between the grout and the beam, the grouts bond with the beam would not occur and the vertical rigidity of the end supports remained low. This way, the grout was just resisting torsion.

As it can be seen in figure 3, there was a load cell under the hinged member (load cell #2 in figure 3). This device showed that the load in the vertical member was acceptably equal to the load that was applied to the beam as the eccentric load, only it was at the beginning of the loading which the load cell showed less amount of load than the eccentric applied load and that was because of the slight bonds which were separated later. This pattern seemed to emerge diversely at the end of loading. Because, there were no torsion rigidity left and even the weight of the beam had been tolerated by the hinged member. The amounts of the loads in pure torsion test which were applied through displacement control process and were shown by the load cells #1 and #2 are mentioned in figure 3. They also showed the same pattern. According to this, no shear and torsion would develop in the beam after the first steps are passed during loading.

6. Evaluation of supports' rigidity

If a beam with fixed supports is exposed to eccentric load, the curves of the shear force and the flexural and torsion moments would be as shown in figure 5. So, to evaluate the shear and torsion behavior of the beam, the test region would be at a quarter of the length from each end (the inclination point). To study the workability of the built supports, 5 reinforced concrete beams were made as samples. The sizes and the bars of the beams were the same and are demonstrated in figure 6. The main reason of selecting this shape was to place the shear-torsion failure around the inclination point. Also the increase in the beam's height in other regions would decrease the possibility of flexural fracture and the interaction of flexure with shear and torsion. To make sure that the support was flexural rigid, 4 gauges were used at the supports. 2 were installed along the beam and at the supports at each end and the other two were placed on the sides of the support to measure the torsion (figure 1.a).

The measures from the first two gauges, which showed the vertical displacement, divided by their distance would be the flexural rotation of the beam. Also the measures from the second two gauges, which showed the horizontal displacement (perpendicular to the beam's axis), divided to the section's width would be the torsion rotation of the beams end. Ideally, these two rotations should be zero. If they are, the internal forces would develop as it is shown in figure 5 and the required test region would be placed at a quarter of beams length from each end. Several tests were done and the results showed that the torsion rigidity of the supports were high. However, in this system, if the failure load of the sample or the loading capacity of it when it comes to combined shear and torsion is desired, a slight torsion rotation will have no significant effects on the failure load.

The amounts of the rotation in pure shear test (related to flexural rigidity) are shown in figure 6. In this figure, one can also see the beam's rotation vs. the applied load in an elastic and hinged condition (simply-supported). According to this curve, till the magnitude of the load reaches 60kN, the rotation would be around zero. Bigger loads would result in a rotation around 10% of the hinged rotation. However, higher loads result in shear cracks and based on the rigidity of the beam which is significantly less, the need to flexural rigidity would be not significant. Note that the rotation for hinged condition is calculated based on structure analysis and not cracked section. Also, since the other samples are exposed to eccentric loads, the tolerable load is much less and the support rigidity would be enough.

7. Tested beam's behavior

Each one of the 5 beams was tested under different eccentricities. The eccentricities are shown in table 1. The loading was done through the displacement control system. In table 1, the failure loads and the cracking loads are mentioned. Also some of the cracks, propagated in different samples are shown in figure 7. Cracks' being oblique shows that the behavior is shear or shear-torsion. It needs to be mentioned that the pure torsion test which was referred to as the test with infinite eccentricity, was done at the eccentricity of 470mm and by using the hinged vertical member and other preparations, the shear and the flexure were insignificant. The infinity phrase is just used to explain the pure torsion test. The behavior curve of each sample is shown in figure 8. This curve is plotted as load-displacement for the pure shear sample (E0) and as Torque-twist for other samples. To calculate the beam's rotation in the middle, there were two LVDT used in the beam section's width. The rotation would be resulted from dividing these two measures (showed by each LVDT) by their distance.

8. The shear- torsion interaction curve

Based on the loads, derived through the test and with multiplying them by the eccentricity and dividing the result by 2 (as the beam is symmetrical) the torsion capacity of the section is available. As the beam is weaker around the inclination point and the shear-torsion fracture happens in the same area, this can be accepted as the torsion resistance of the weaker section of the beam. Also the shear resistance will result from dividing the failure loads (table 1) by 2. Using this mentioned shear and torsion, the shear-torsion curve will be plotted as shown in figure 9. It is demonstrated in this figure that the curve is so close to being linear and the regression line (the solid one) is so close to the line that is resulted from connecting the point (the dotted line).

9. Summery and conclusion

In this investigation the original aim is to build a set up system to test the reinforced concrete beams under shear and torsion. To maintain that, a support system was constructed for a single span beam which consisted of flexural and torsion rigid supports. One of the most important specifications of this system is that using this system, testing the beam under different eccentricities can be done and the pure shear test and pure torsion test will be possible. To evaluate such a system, there were 5 concrete beams made as samples and they were tested under 5 different eccentricities (zero to infinity). Tests have shown that the samples' behavior were shear or shear-torsion according to crack pattern. They also implied that the flexural and torsion rigidity of the supports were enough. The tests also resulted in a shear- torsion interaction curve which were linear.

10- References

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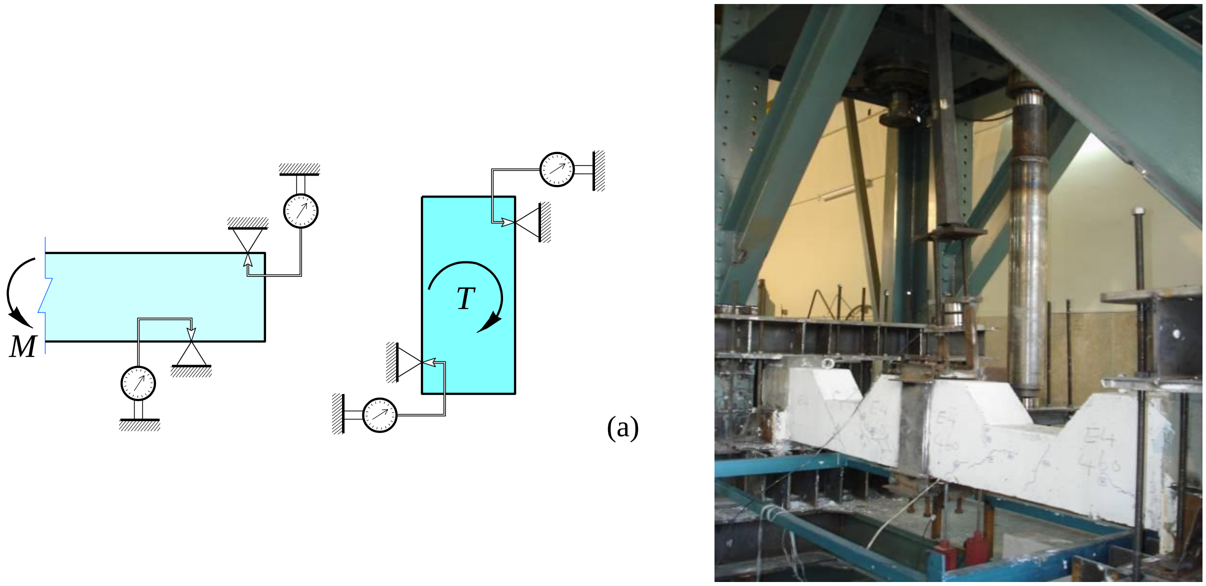

(a)

(b)

Fig. 1 (a): The basic concept of test setup; (b): sample loading frame

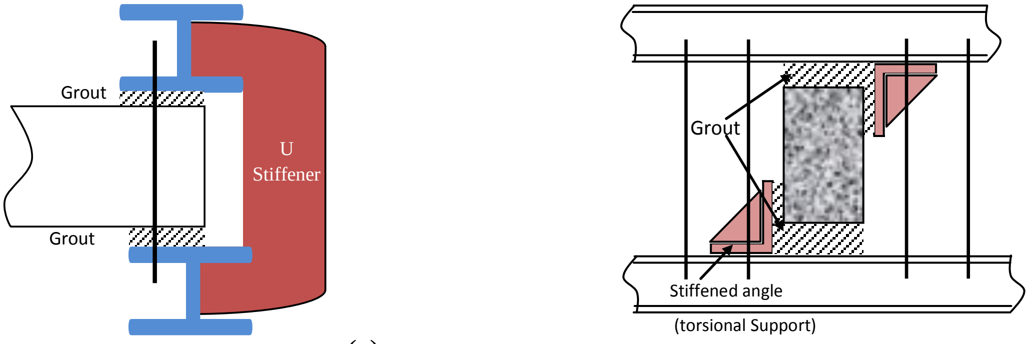

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Fig. 2 (a): Flexural fixity setup; (b): Torsional fixity setup

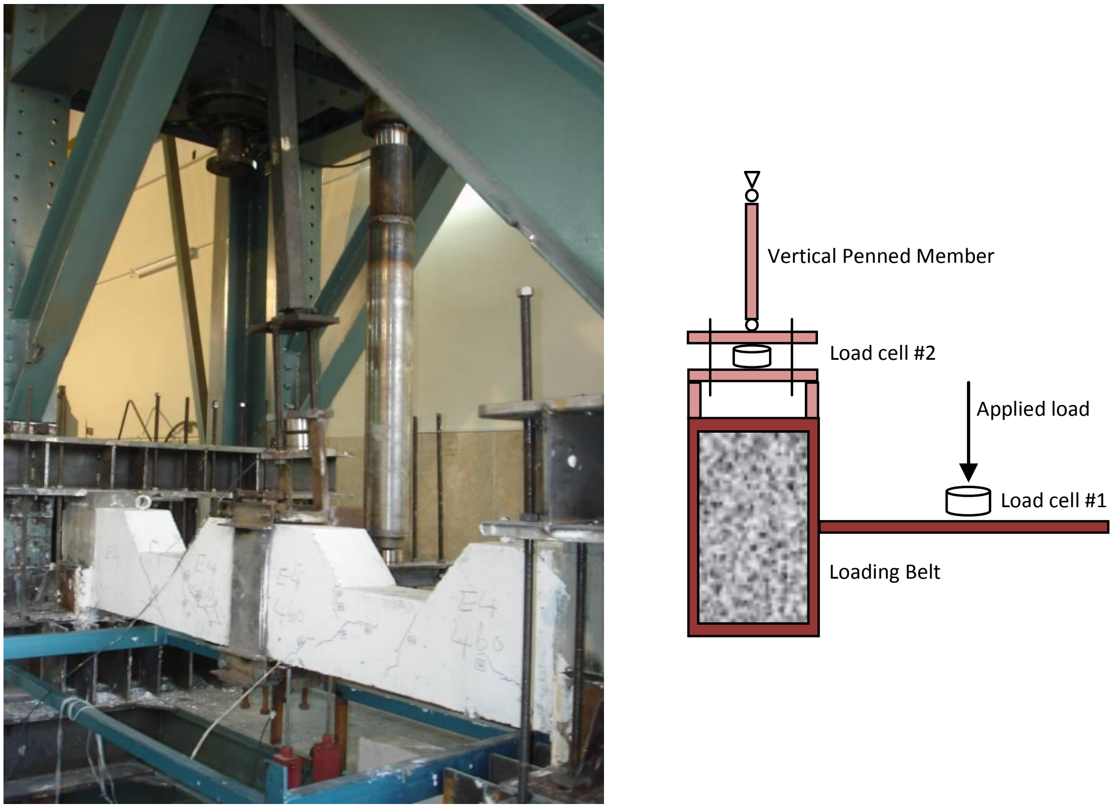


Fig. 3. Schematic and real view of loading system for pure torsion test

Fig. 4. Foam plates in the pure torsion test

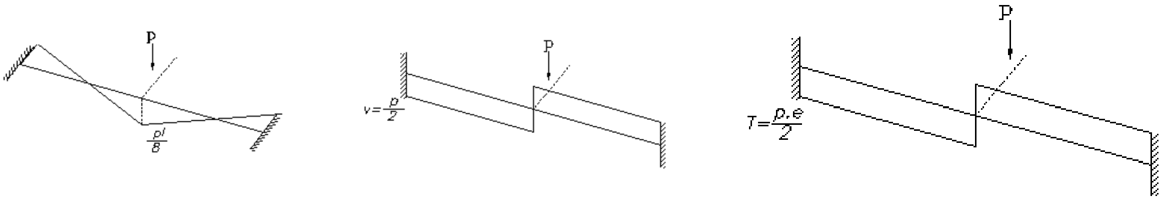


Fig. 5 Internal forces in the test beam under the proposed test setup

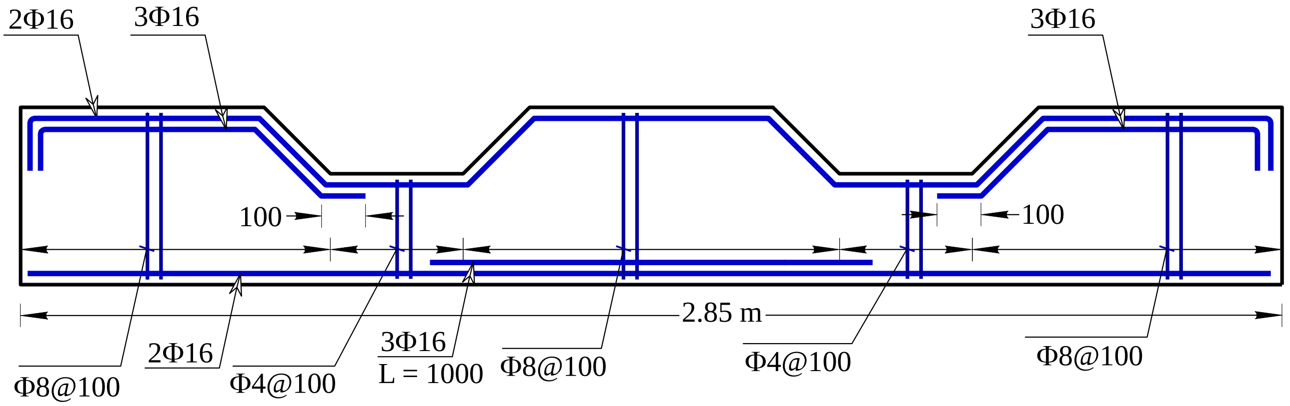


Fig. 6 Test setup testing beam

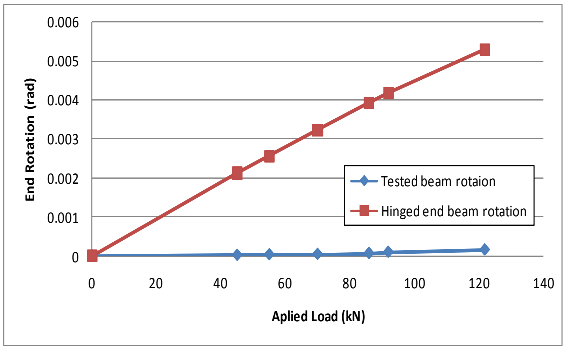
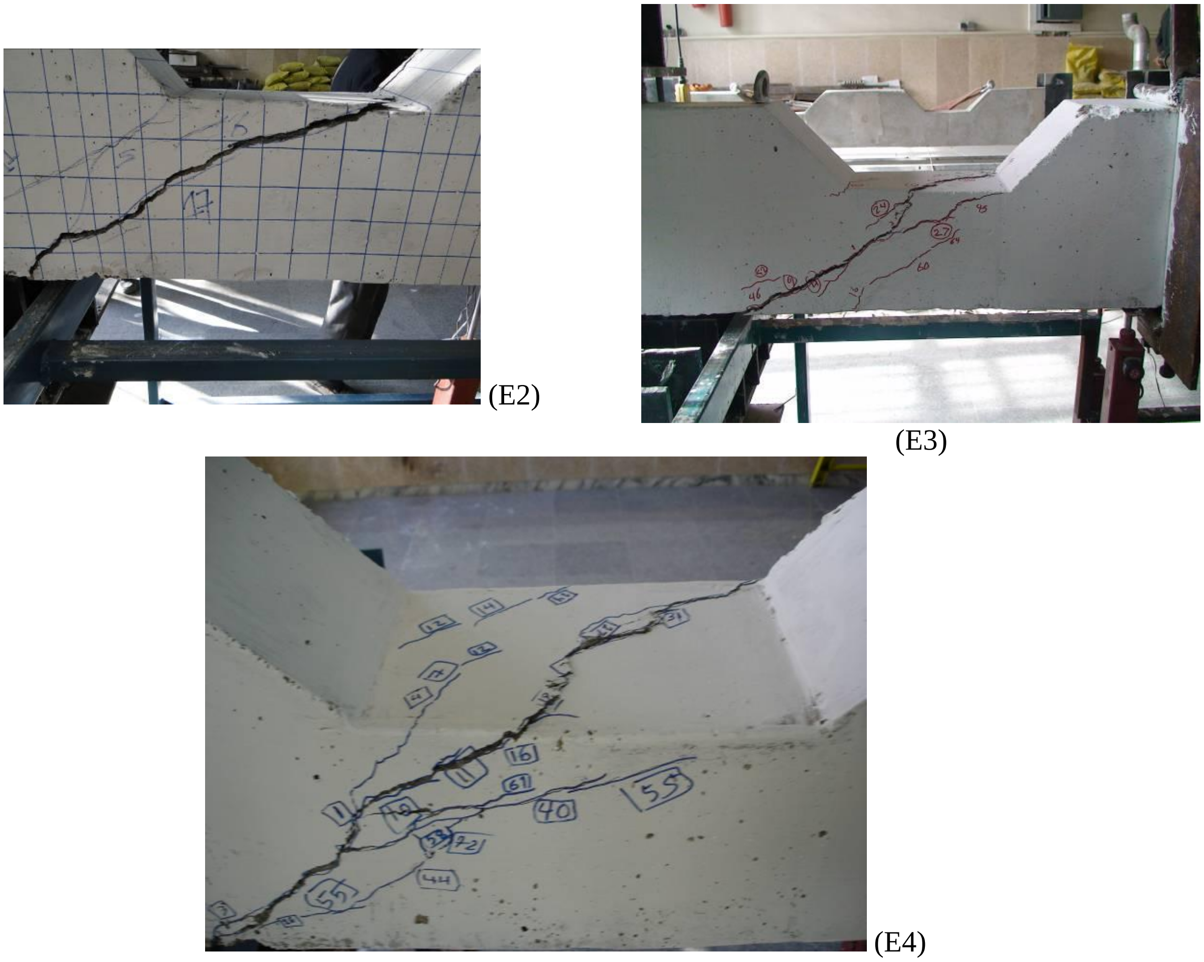


Fig. 7 the tested beam rotation and the hinged end rotation

(E0)

(E1)

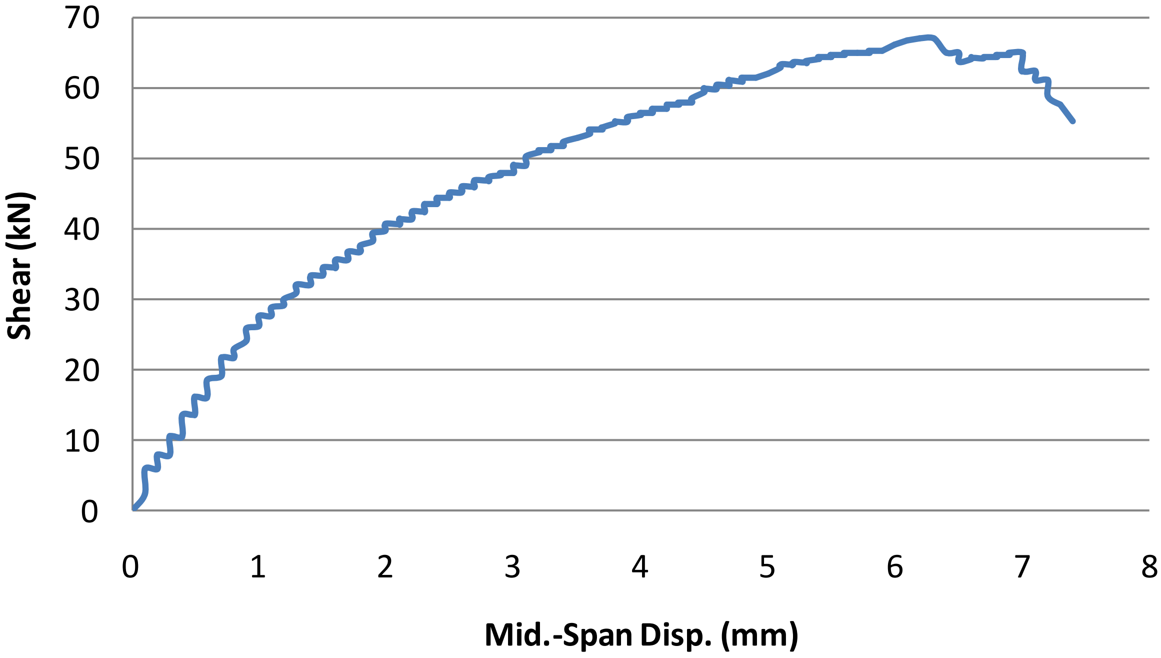


(E2)

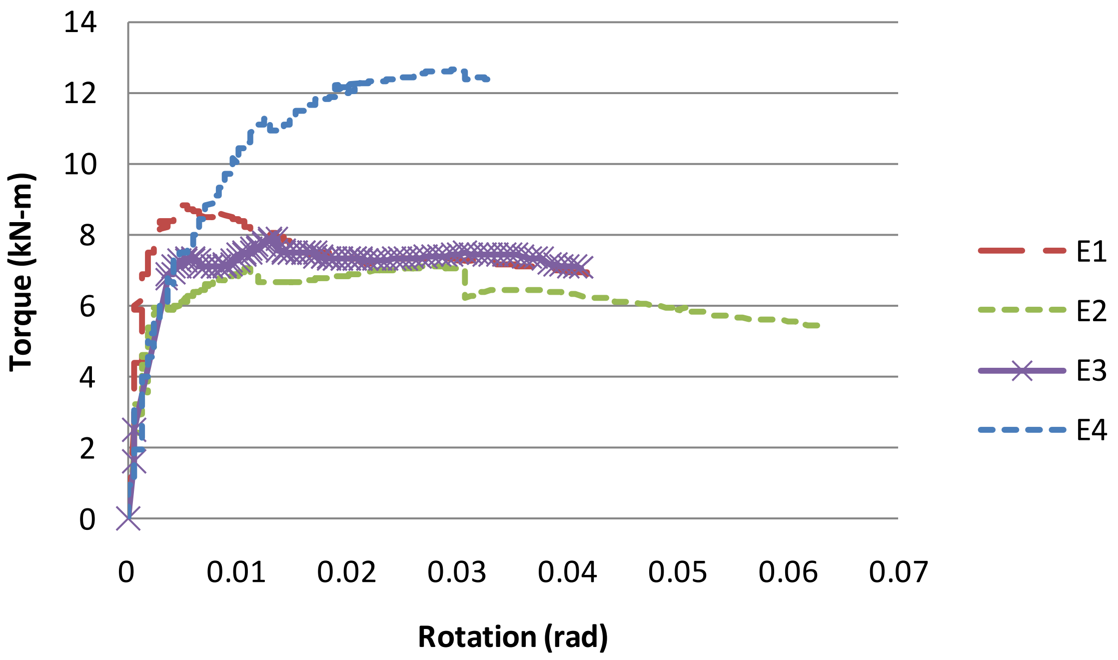
(E3)

(E4)

Fig. 8. Crack pattern in tested beams



(a)



(b)

Fig. 8. Specimens behavior curve; (a) E0 shear-mid-span displacement, (b) other specimens torque-twist.

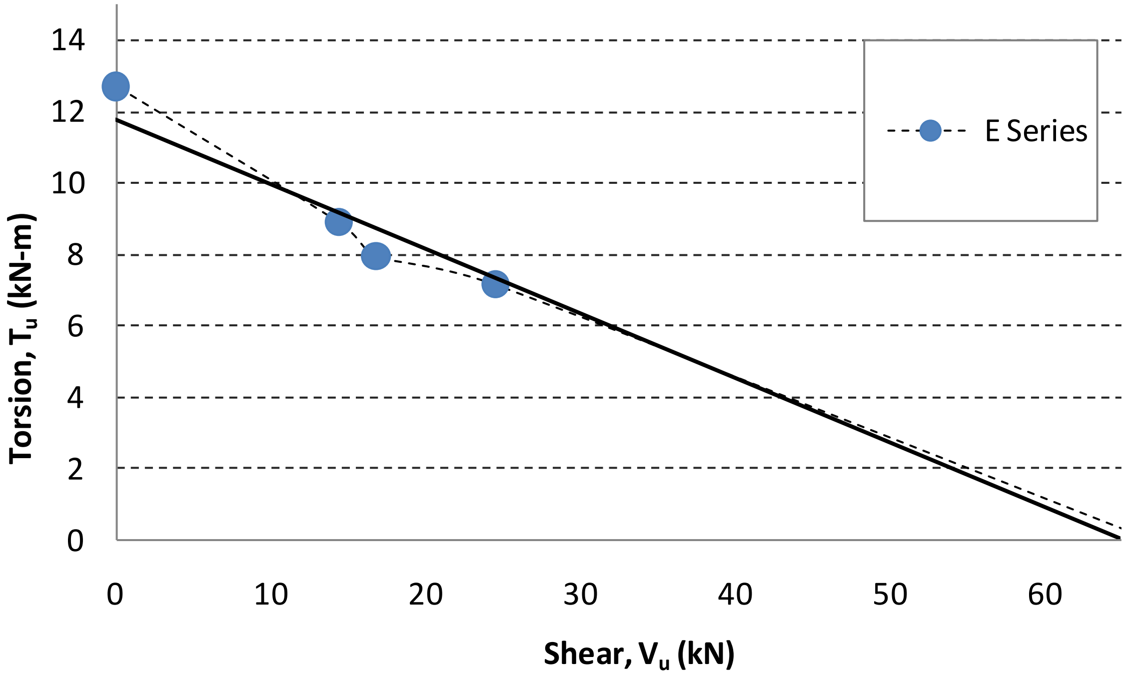


Fig. 9. Specimens shear-torsion interaction curve

Sample name	Eccentricity (mm)	Cracking load (kN)	Ultimate Load (kN)
E0	0 (pure shear)	100.0	134.0
E1	290	38.0	49.2
E2	470	21.0	33.7
E3	616	18.0	29.0
E4	∞ (pure torsion)	20.0	55.0