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The Influence of Shear Strain on the Torsion Capacity of Hybrid Beams

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KEYWORDS

Shear strain,
Conventional concrete,
Hybrid concrete,
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concrete, Steel fibre.

ABSTRACT

This research discusses experimentally the shear strain of the reinforcement concrete hybrid beams composed of reactive powder concrete (RPC) at the peripheral and conventional concrete (CC) at the core beams under torsional strength tests. Shear strain is usually represented by (□), which is explained as the tangent of the angle and is be like the length of deformation at its maximum divided by the length of perpendicular in the plane of the force application. Twelve reinforced concrete beams are tested having the following dimensions: 100, 200 and 1500mm as width, height and length respectively with thickness of the RPC concrete were 40 and 20mm. The beams were cast and tested to failure in torsion by using two opposite cantilevers steel arms that contribute to transferring the torque to the centre of the beams. Two control (CC and RPC) beams were poured, and the ten other beams were all poured as hybrid ones. Experimental data of the three strain gauges locations in the middle of the beams in one of the side surface face, to calculate shear strain (γ). The percentage of shear strain at ultimate torsion capacity was reduced by about 76% for RPC (RP) to CC (NC) beams and 63% for hybrid beam (H1) to CC (NC) beam.

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1. Introduction

Recently hybrid reinforced concrete structures gained great interest by engineers due to their good performance under loading and lower cost. To explain the concept of the hybrid concrete section, a specific type of concrete in a specific zone of the section was used [1]. For shear, bending and torsion hybrid beams proved to be quite successful, as well as less costly compared to RPC ones. In the past few years, considerable efforts of research were dedicated to the studies of the torsional behaviour of concrete structural members. Many studies have been devoted to developing the analytical models to predict the distribution of elastic stress and strength limits of the concrete beams under torsion [2]. There are many different structures where torsional loading could be loading condition. Pure torsion is a twisting loading, with no axial, or lateral force. It is also possible to have a pure torque loading on a beam. A pure torque is two parallel but opposite separated forces of equal magnitude. It can be applied or reacted anywhere on a rigid body and have the same effect [3].

While explaining a stress it was indicated out that it is an abstract quantity which cannot be observant and is generally calculated indirectly. The strain differs in this respect from the stress. It is a complete quantity that can be seen and generally calculated directly as a relative change of shape or length. Generally, strain is the proportional relation of change in primary dimension to the primary dimension. The strain is the dimensionless constant quantity. Strain may be consisting of three types; normal strain, volumetric strain and shear strain [4].

2. Beam Details

In this paper two concrete mixes are used, the CC had the ratio of (1:1.5:1.75:0.5), (cement: sand: gravel: w/c), respectively and the RPC had the ratio of (1:1:0.25:6%:0.2) (cement: fine sand: silica: super plasticizer: w/c) respectively. The beams were designed and cast to have the same mixes, following the ACI 318M code procedure [5]. The five variables studied included: steel reinforcement (longitudinal and transverse steel), spacing of stirrups, thickness of RPC (20, 40mm) and steel fibre (Vf =1%, 0.5% and 1.5%). Details are given in Figure 2 to 6 and table 1. The load is applied on the steel plate above two steel arms put opposite side at the end beam to obtain torque. As shown in Figure 6. Table 1 and Figures 1,2,3,4 and 5 are shows beams details.

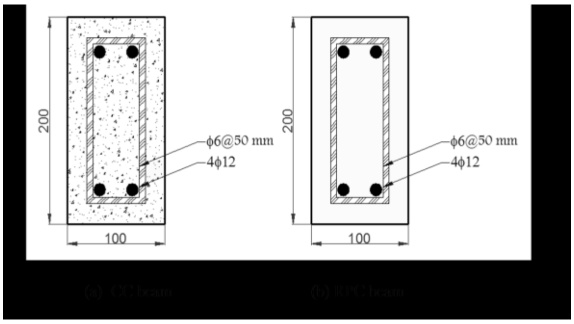


Figure 1: The CC beam and RPC beam

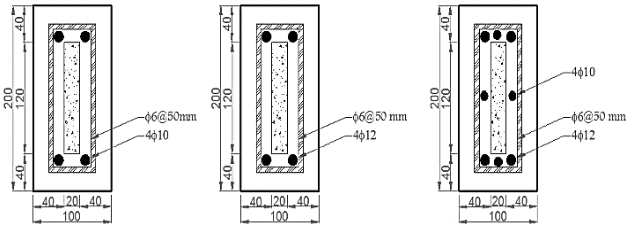


Figure 2: The hybrid beam with different longitudinal reinforcement

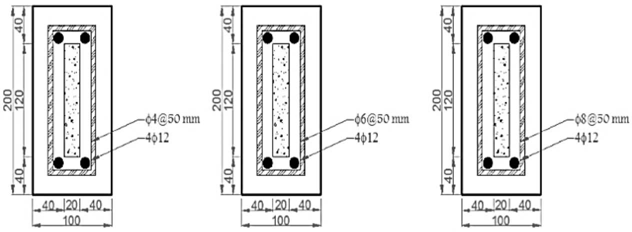


Figure 3: The hybrid beam with different transvers reinforcement (stirrups)

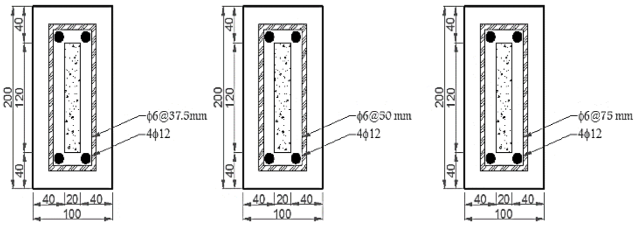


Figure 4: The hybrid beam with different spacing of stirrups

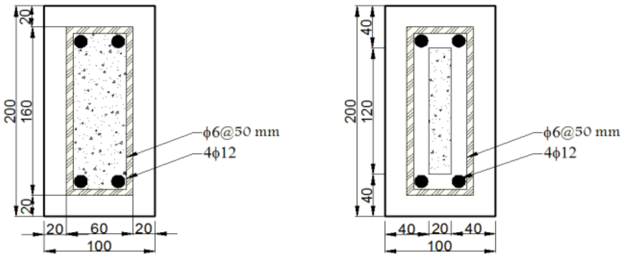


Figure 5: The hybrid beam with different thickness of RPC

Figure 6: the steel arms

Table 1: Description of the tested beams

Names of Beams	Classification	Longitudinal reinforcement (Al) mm^2	Transvers reinforcement (At) mm^2	Stirrups spacing mm	Thickness of RPC mm	Vf%
NC	CC	452.16	28.27	50	0	1
RP	RPC	452.16	28.27	50	All	1
H1	Hybrid	452.16	28.27	50	40	1
H2	Hybrid	314	28.27	50	40	1
H3	Hybrid	615.44	28.27	50	40	1
H4	Hybrid	452.16	50.27	50	40	1
H5	Hybrid	452.16	12.57	50	40	1
H6	Hybrid	452.16	28.27	50	20	1
H7	Hybrid	452.16	28.27	50	40	0.5
H8	Hybrid	452.16	28.27	50	40	1.5
H9	Hybrid	452.16	28.27	37.5	40	1
H10	Hybrid	452.16	28.27	75	40	1

3. Casting the Hybrid Beams

The procedure for casting the hybrid beams was follows a) the first layer of RPC concrete was cast in the bottom of the mold. b) the second layer contain two types of concrete (RPC and CC). c) the last layer of RPC concrete was cast to the top of the mold. As shown in the Figure 7.

a. The two plates in the side of mold. B. RPC cast in the bottom of the mold.

c. CC cast in the core. **D. RPC cast in the final layer.**

e. Finally, the beams

Figure 7: The procedure of casting the hybrid beams.

4. Strain Gauge Rosette

A strain gauge rosette is used consisting of two or more co-located strain gauges oriented at a fixed angle with respect to each other. At least three sovereign strain readings are needed to explain the 2D state of the strain if no other information is available, thus the three-gauge rosettes are the most popular. Rosette typically involve two, three or four strain gauges with relative orientations of (30, 45, 60, or 90) degrees. The delta rosette and the rectangular rosette are the most commonly used three strain gauges because of their simple geometry. Three strain gauges independent by measure which can be taken ε_x, ε_y and ε_{45} refers to the strain constituents with respect to xy-axis system. The most apparent access is to place three strain gauges together in a rosette with each the strain gauge oriented in a different direction (0, 45, 90degree special case of strain rosette). As shown in Figure 8.

All beams contained three strain gauges type electric strain gauges manufactured by the Japanese Company (TML) [PL-60-11-3LJC-F][6] in the middle of beams three strains putting: horizontal, vertical and 45 degree (strain rosette) on the concretely surface of a beam that is to measure not only the two extensional strains, ε_x and ε_y but also the shear strain (γ_{xy}) with respect to some given xy-axis system in reinforced concrete beams at torsion strength according to the following steps as seen in Figure 8:

1. The locations of strain gauges must be determined.
2. By grinding instrument at these locations to smooth the steel surface.
3. Cleaning the place very well by cotton material with a little amount of Acetone.
4. The CN-E adhesive put on strain gauge and spread uniformly and then put it on the surface of the concrete of the beam and keeps pressing it about 1 minute.

Figure 8: Three strain gauges (strain rosette)

5. Discussions of Results

I. Compressive strength (f’c)

The compressive strength (fc') tests were carried out in accordance to ASTM [7] (100mm diameter X 200mm long). The average of three cylindrical specimens is used to determine compressive strength for

RPC mix (75.8, 90.4,102.9) MPa, respectively depended on steel fibre ratio (Vf %) and CC mix about (28.1MPa).

II. Tensile strength (ft)

The splitting tests were carried out in accordance to ASTM [8] (100mm diameter X 200 mm long), the average of three cylindrical specimens is used to determine splitting tensile strength for RPC mix about (8.4, 10.6, 12.2)MPa, respectively depended on steel fibre ratio (Vf %) and CC mix about (2.8 MPa).

III. Modulus of elasticity

The modulus of elasticity tests were carried out in accordance to ASTM [9] (150mm diameter X 300mm long), the average of three cylindrical specimens is used to determine (Ec) the modulus of elasticity for RPC mix (38.1, 49.3, 56.7 GPa) respectively depended on ratio of steel fibre (Vf %) and CC mix (27.9 GPa).

IV. Shear strain γ

The shear strains are defined as the tangent of the angle and are equal to the length of deformation divided by the perpendicular length in the plane of the force applied. The angle is measured in radians. Shear strain is the percentage of the change in deformation to its original length perpendicular to the axes of the beam due to the shear stress. Shear stresses are stress in parallel to the sectional cross of the structural beam [10] (torsion). See Figure 9.

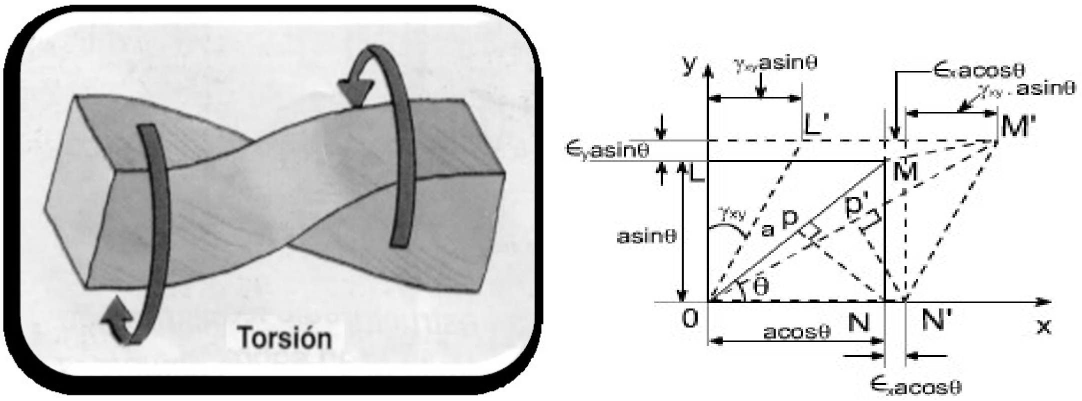


Figure 9: The shear strain (γ).

With a 45^0 rosette (special cases of strain rosette), ε_x and ε_y strain gauges are measured directly. γ is obtained with equation 1[11]:

$$\varepsilon_x=\frac{1}{2}\left(\varepsilon_x+\varepsilon_y\right)+\frac{1}{2}\left(\varepsilon_x-\varepsilon_y\right)\cos(2*0)+\frac{1}{2}\gamma_{xy}\sin(2*0)$$

$$\varepsilon_y=\frac{1}{2}\left(\varepsilon_x+\varepsilon_y\right)+\frac{1}{2}\left(\varepsilon_x-\varepsilon_y\right)\cos(2*90)+\frac{1}{2}\gamma_{xy}\sin(2*90)$$

$$\varepsilon_{45}=\frac{1}{2}\left(\varepsilon_x+\varepsilon_y\right)+\frac{1}{2}\left(\varepsilon_x-\varepsilon_y\right)\cos(2*45)+\frac{1}{2}\gamma_{xy}\sin(2*45)$$

$$\gamma = 2*\varepsilon_{45} - (\varepsilon_x + \varepsilon_y) \qquad \text{equation 1}$$

$$\gamma = 2*\varepsilon_{45} - (\varepsilon_0 + \varepsilon_{90})$$

Where: γ = the shear strain, $\varepsilon_x = \varepsilon_0$ = the horizontal strain at x-axis, $\varepsilon_y = \varepsilon_{90}$ = the vertical strain at y-axis, ε_{45} = the strain at 45 degrees.

This explains the strain state at the rosette with respect to the (x-y) axis system. It is a simple matter to constructs a Mohr's circle and from this to calculate the principal strains and their orientation with respect to the (x-y) axis, and therefore the rosette.

The conventional concrete beam NC reached maximum torque (6.30 kN.m) at maximum shear strain (γ) 0.035 rad. The RPC beam RP had shear strain (γ) 0.026 rad. The shear strain (γ) as shown in Table 2 and Figure 9 in all beams. So, with increased strength of beams torsional capacity decreased the shear strain at the middle of the beams. The hybrid beams strength under torsions load as close as strengthen of RPC beam lead the shear strain be closed. The value furthermore of the torsion capacity are the shear strain almost closely in hybrid beams and RPC beam. Specialty became very closely before occurred cracks in the hybrid beams with different variables used it.

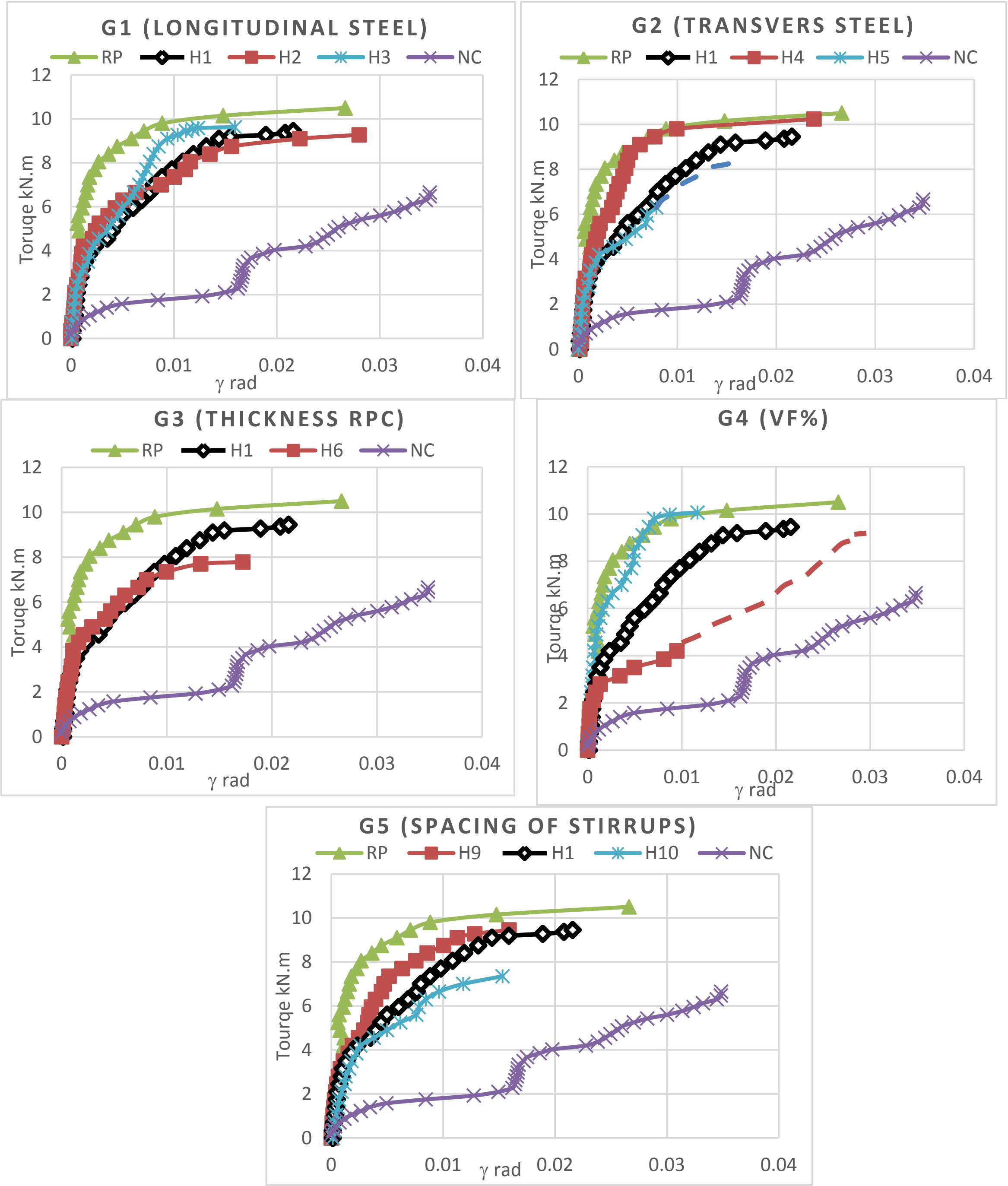


Figure 10: The shear strain (□) of groups

Table 2: Properties of materials

Name of Beams	Group	Shear Strain at crack	Shear Strain at failure	γu/γcr %
NC	Refer.	0.0230	0.0350	1.5
RP		0.0012	0.0266	22.2
H1		0.0040	0.0220	5.5
H2	G1	0.0100	0.0322	3.2
H3		0.0022	0.0159	7.2
H4	G2	0.0020	0.0238	11.9
H5		0.0056	-	-

H6	G3	0.0041	0.0172	4.2
H7	G4	0.0100	0.0296	3.0
H8		0.0016	0.0116	7.3
H9	G5	0.0024	-	-
H10		0.0062	0.0229	3.7

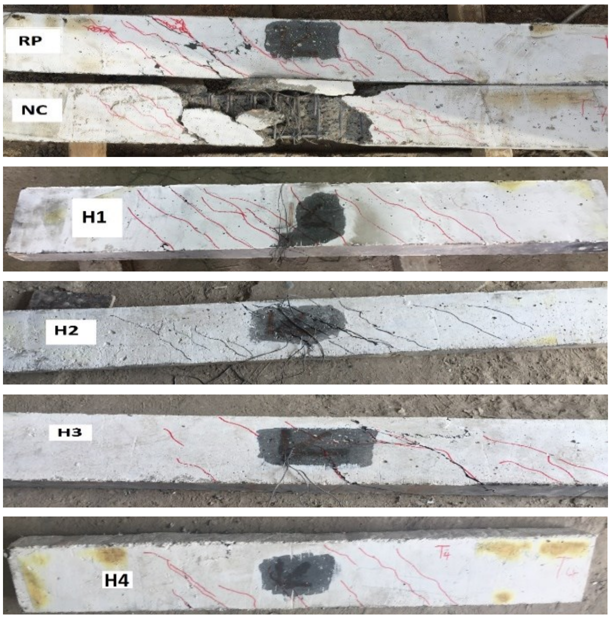
6. Testing Procedure and Failure of Beams

All beams including control specimens were removed from water curing after sixty days. Drying lasted about thirty days, then all have been cleaned and painted white in order to obtain clear observation of cracks and their spread patterns. Steel arms were placed at both ends of each beam in opposing ways. A load has been applied. With load increment gradually, hairline cracks have formed in the areas between supporting arms. Then, multiple cracks with wider propagation began to form in diagonal orientation. These cracks continued to propagate with increasing load until reaching failure point. Some of the cracks occurred under the strain gauges location causing failure in strain gauges during the test. Shear strain (γ) cannot be calculated if one of the three strain gauges failed until reached ultimate torsion. The failure in CC beam was beyond just cracking and reached to crushing into cover concrete, which is more dangerous than the other beams at failure. While in other beams failure is represented by cracks on the surface of the beams. Thus, hybrid beams are more reliable in terms of failure. The beams CC, RP and ten hybrid beams are shown in Figure 10 after failure at the side strain gauges location. H5 and H9 beams at test one of the strain gauges fail and continue the curve with hidden line.

7. Conclusions

A total of twelve beams are tested for pure torsion, so that determine the effect of the shear strain (γ) on the strength of the beams. Comments are given below:

1. Two mix procedures used in this work present a successful way to produce hybrid beams with different variables.
2. In general, the shear strain (γ) at the cracking and ultimate torsion capacity in hybrid beams are smaller than CC and slightly more than RPC beams.
3. The shear strain (γ) decreased in hybrid beams when compared with normal concrete beam (NC).
4. The shear strain (γ) decreased with small RPC thickness (H6) about 51% respect to CC beam at ultimate torsion capacity.
5. The The shear strain (γ) more decreased in hybrid beam at steel fibre ratio (Vf%=1.5) about 67% respect to CC beam at ultimate torsion capacity.



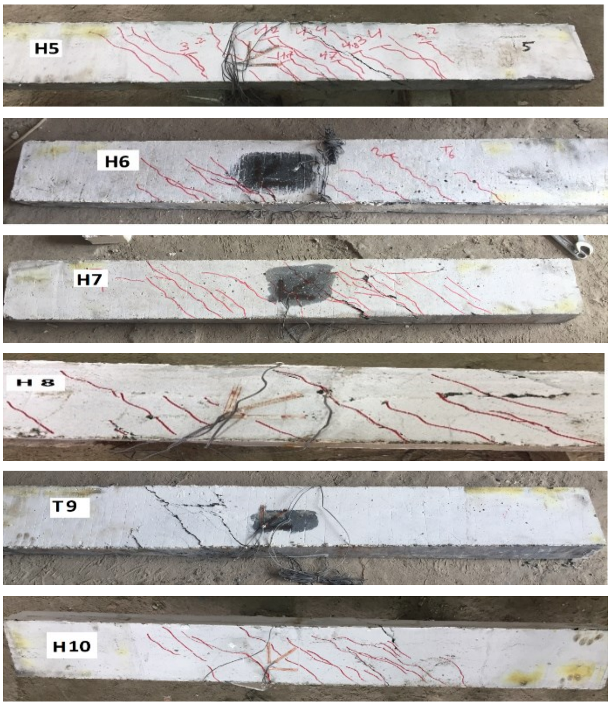


Figure 11: Beams fail in torsion.

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