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Numerical study on Role of Shear Key in Precast Beam to Beam Connection Subjected to Torsion

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Abstract

Connections playan important role in behaviour of precast concrete structures. It is also observed that the failure of precast building took place because of connection failure. Generally connection between precast elements are designed for axial force, shear force and bending moment. But when the precast beam supports precast slab of different span on both the side, torsional moment cannot be neglected. Therefore, it is important to study the behaviour of precast connections under the effect of pure torsional loading. In this paper effectiveness of shear key on behaviour of precast beam to beam connection under pure torsion is presented. A numerical simulation is carried out to investigate the torsional behaviour of three different type of precast wet connections with and without shear key using Finite Element Method based software ABAQUS. Projected longitudinal reinforcement of precast beam elements are welded after their erection and the gap is filled with concrete. The damaged plasticity model is employed for modelling the behaviour of concrete and elastic perfectly plastic models are employed for the modelling of behaviour of steel reinforcement. A prefect bond is assumed between the steel reinforcement and concrete. The damage along cracks, are modelled through concrete damage parameters. Precast beam connection with out shear key is considered as control beam. While other beam to beam connections have shear key of different configuration. Torque v/s twist behaviour and damage patterns as obtained from numerical analysis of different precast beam connections with shear key are compared with control specimen. Analysis results exhibited enhanced torsional strength of precast beam connection with shear key in comparison of connection without shear key.

Keywords:Precast concrete, Beam to beam connection, Torsion, Shear key, Finite element analysis

1. Introduction

In precast concrete construction, majority of structural components are produced in yards or plants under controlled environment and then transported to the site for assembly. The precast elements are connected either by mechanical means or by embedded reinforcement in preformed ducts which are subsequently filled by grouting. Accordingly, the precast connections are known as dry or wet connection. Failure of precast building took place mainly due to connection failure only. Therefore, connections playa key role in behaviour of precast structure. Torsional failure is unpredictable and often catastrophic. The precast connections under torsional loading behave indiscriminately. Therefore, it is important to study the behaviour of precast connections under the effect of torsional loading.

Experimental and numerical research have done in past on various aspects related to the torsional behaviour of RC beam. Owning the fact that experimental investigations are costly and time consuming, the finite element analysis for numerical study is adopted for the present work. Mondal and Prakash [1] developedFE model of RC bridgecolumn under torsion and axial compression loading. The study was conducted to know the effect of different cross-section and the effect of transverse reinforcement. Square column exhibited more localized damage whereas in circular column damage distributed over larger length. FE model showeda better agreement of damage and progression of failure with experiment data. FE model also accurately predicted values of torque and twist of RC beam. Nzabonimpa et. al. [2] presented experimental and FE study of the beam-column joint of precast frames. In the beam-column joint of the precast frame, the connection was modelled as a surface to surface interaction between metal plates andconcrete. FE model accurately validated with experimental results. Ganganagoudar et al.[3] presented analytical and numerical simulation of FRP strengthened RC beam under torsionalloading. Softened membrane model for torsion developed by Jeng and Hsu [4] was modified to include the effect of FRP strengthening. Analytical and numerical

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results accurately predicted cracking and ultimate torque-twist value.

Review of past work indicates thatresearch work has been carried out on the torsional behaviour of reinforced concrete elements but as such no research reported for the torsional behaviour of precast beam to beam wet connection with shear keys. The main objective of the present study is to understand the effect of a shear key on the ultimate torque and corresponding twist and failure mode of the precast beam with the help of numerical analysis. The numerical simulation of Precast beam under the pure torsion is carried out using finite element based software ABAQUS [5].

2. Specimen Details

2.1 Cross-sectional Details and Specification

Three different types of precast wet connections are considered for analysis.All beams have cross-sectional dimensions of 150mm × 150mm and length of 1300mm. Beams are reinforced with 4 nos. of 10mm diameter longitudinal reinforcement bars with 20mm clear cover and 8mm diameter transverse reinforcements at 150mm c/c spacing. Cross-sectional, precast connection and shear key details are shown in Fig.1. Nomenclature of the specimensare given in Table 1.

2.2 Material Properties

Concrete of grade M25 is used for precast concrete and M50 grade of micro concrete is used for wet connections. Fe500 grade of steel is used for reinforcement.

3. Finite Element Modelling

3.1 Material Modelling

Concrete damaged plasticity (CDP) model is used to define nonlinear property of concrete and CDP model is simulated in ABAQUS [5]. This model consists of the combination of non – associated multi hardening plasticity and isotropic elasticity to describe the damage that happens during the fracturing process. Thetwo mode of failure are considered such as compressive crushing and tensile cracking of concrete [3].The concrete damaged plasticity variables are shown in Table 2.

Table 1. Nomenclature of Specimen

Sr. No.	Specification Identification	Description of Wet Connection
1	WOSK	**W**ith**O**ut**S**hear **K**ey type wet connections
2	OSK	**O**utward **S**hear **K**ey type wet connection
3	ISK	**I**nward **S**hear **K**ey type wet connections

Table 2. Concrete Damaged Plasticity Parameters

Dilation Angle	Eccentricity	Biaxial to Uniaxial compressive strength ratio	K	Viscosity Parameter
37	0.1	1.16	0.67	0

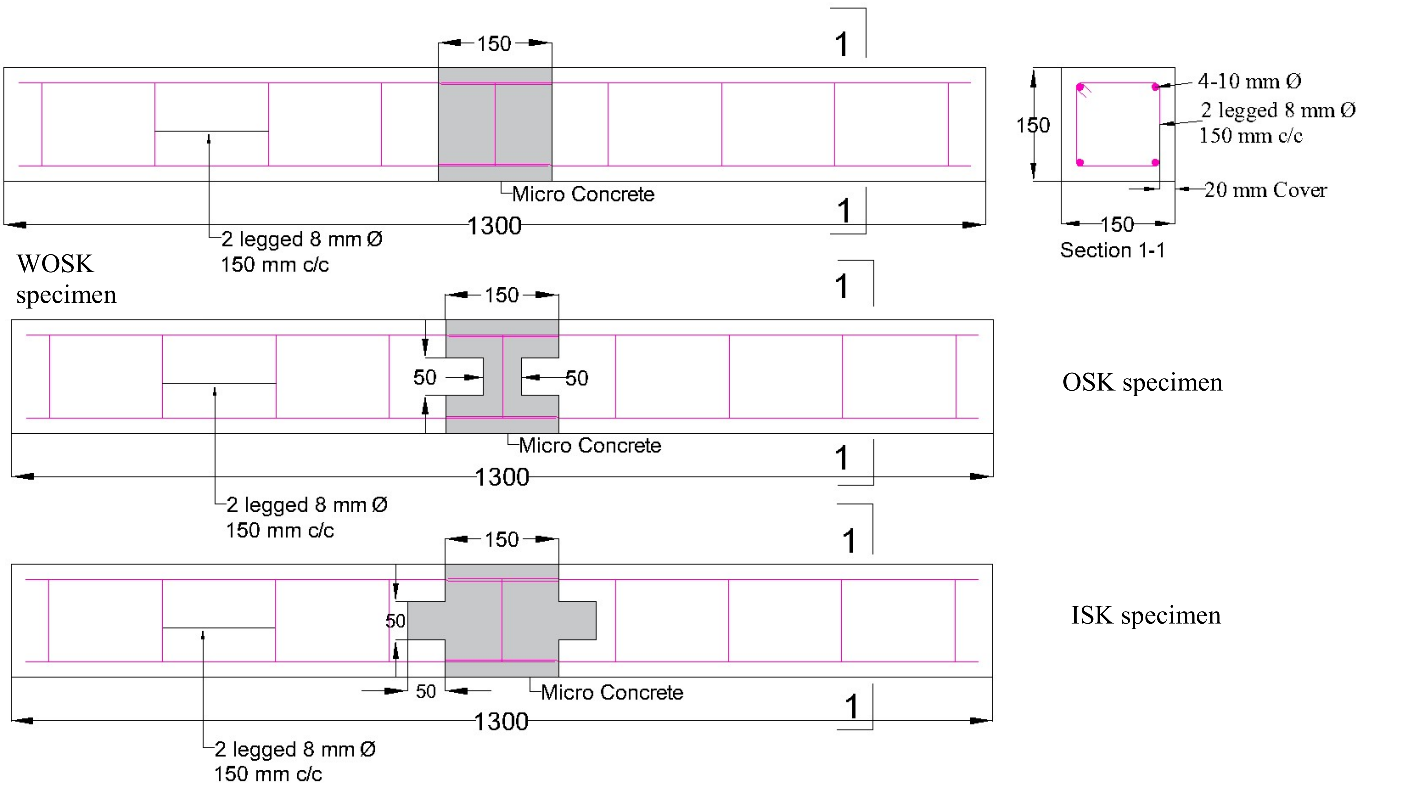


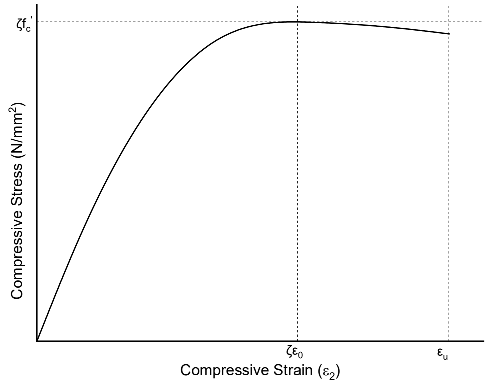
Fig.1: Cross-sectional details of precast wet connections

Concrete compressive behaviour proposed by Jeng and Hsu [4] is used for compressive stress-strain curve as shown in Fig.2(a)and to draw the ascending branch of stress and strain equation (1) and descending branch of stress and strain equation (2) is used.

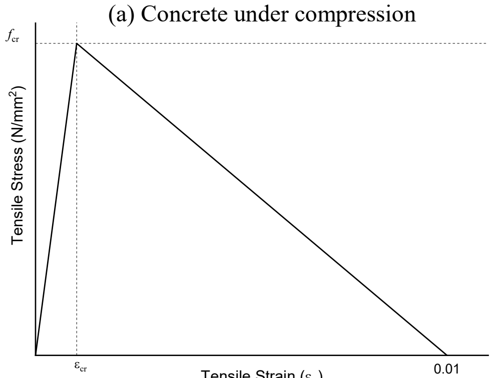
$$\sigma_2^c = \zeta f_c' \left[2\left(\frac{\varepsilon_2}{\zeta\varepsilon_0}\right) - \left(\frac{\varepsilon_2}{\zeta\varepsilon_0}\right)^2 \right] \text{for } \frac{\varepsilon_2}{\zeta\varepsilon_0} \le 1 \qquad (1)$$

$$\sigma_2^c = \zeta f_c' \left[1 - \left(\frac{\frac{\varepsilon_2}{\zeta\varepsilon_0} - 1}{\frac{4}{\zeta} - 1} \right) \right] \quad \text{for } \frac{\varepsilon_2}{\zeta\varepsilon_0} > 1 \qquad (2)$$

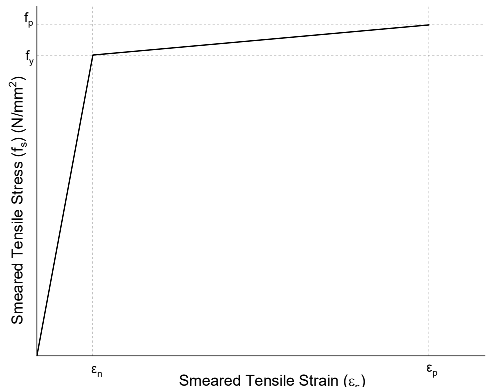
Where,
σ_2^c = stress in concrete
f_c' = compressive strength of concrete
ε_0 = concrete strain at peak concrete strength (i.e. 0.002)
ε_{2s} = strain in concrete
ζ = softening coefficient of concrete taken as 1.



(a) Concrete under compression



(b) Concrete under tension



(c) Steel reinforcement bars

Fig.2:Stress-strain relationship of materials

Concrete tensile stress-strain behaviour as shown in Fig.2(b) is defined linear up to cracking of concrete after that tension stiffening part defined linearly decreasing and become zero at strain value 0.01.
Where, $f_{cr} = E_c\varepsilon_{cr}$
$E_c = 5620\sqrt{f_c'}$
$\varepsilon_{cr} = 0.000116$ = Cracking strain in concrete

Stress-Strain curve for reinforcement bars embedded in beam is proposed by Belarbi and Hsu [6] as shown in Fig.2(c)and equation (3) and (4) are used to represent the stress – strain relationship of reinforcement. Young's modulus of elasticity for steel is taken as 200000 N/mm^2 and Poisson's ratio is taken as 0.3.

$$fs = E_s\varepsilon_s for\ \varepsilon_s \le \varepsilon_n \qquad (3)$$

$$f_s = f_y\left[(0.91 - 2B) + (0.02 + 0.25B)\frac{\varepsilon_s}{\varepsilon_y}\right] for\ \varepsilon_s > \varepsilon_n (4)$$

Where,
$\varepsilon_n = \varepsilon_y(0.93 - 2B)$
$B = \frac{1}{\rho}\left(\frac{f_{cr}}{f_y}\right)^{1.5}$
f_s = stress in steel bars
f_y = yield stress of steel bars
E_s = modulus elasticity of steel bars
ε_s = strain in steel bars
ε_y = yield strain of steel bars
ρ = steel bar ratio

3.2 Interaction Properties

In numerical analysis, prefect bond between the surrounding concrete and the reinforcement bars is assumed for full compatibility. Therefore concrete to steel reinforcement interaction is defined as embedded region. In embedded constraint reinforcement is selected as embedded region and concrete is selected as host region. Reinforcement embedded in concrete is shown in Fig. 3.

As micro concrete is done after the casting of precast element. The contact interaction properties between micro concrete and precast concrete is defined as tangential behaviour with coefficient of friction 1. Surface to surface interaction is used to defined contact between micro concrete and precast concrete. Precast concrete and micro concrete are selected as master and slave surfaces respectively. Surface to surface contact interaction between precast concrete and micro-concrete is shown in Fig. 3.

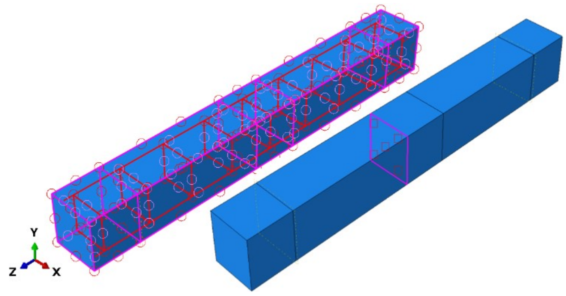


Fig. 3: Embedded region constraint and surface to surface contact interaction

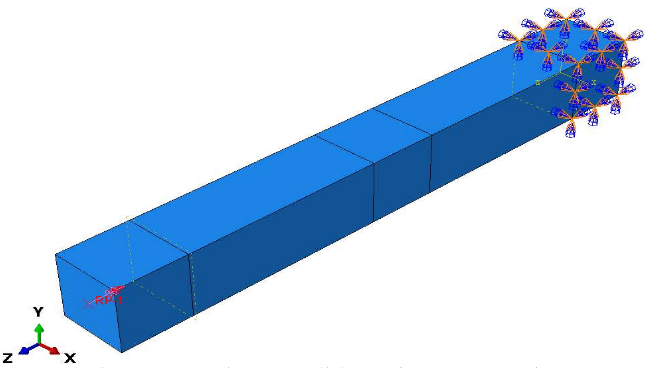


Fig. 4: Boundary condition of RC precast beam

3.3 Boundary Conditions

Fixed support condition is provided at one end and twist is applied along the member axis on another end of beam as shown in Fig. 4. Reference point is created using coupling constraint on one end to provide rotation. Displacement controlled scheme is used for simulation because it can give better results in post peak behavior.

3.4 Element Selection and Meshing

Precast concrete and micro concrete are modelled using three-dimensional 8 node linear brick element (C3D8R) and reinforcement is meshed with three-dimensional 2 node truss element (T3D2). Problem is considered as quasi static problem and analyzed using dynamic explicit scheme available in ABAQUS [5]. Explicit analysis gave better convergence and less time consumption for three-dimensional non-linear FE analysis. The numerical model is validated before modelling of the torsional behaviour of precast concrete beams.

4. Validation problem

Validation of finite element modelling of RC beam subjected to torsion is carried out by considering geometrical and material properties reported byAmeli et al [7]. RC beam have cross sectional of 150 mm × 350 mm and length of 1900 mm. Longitudinal reinforcement bars are 4 Nos. of 16 mm diameter bars each at every corner and stirrups of 6 mm diameter at 80 mm c/c spacing. Concrete cover of 25 mm is provided. Concrete compressive strength at 28 days is 39 MPa. Yield strength of longitudinal reinforcement and stirrups are 502 MPa and 251 MPa respectively.
Torque v/s twist result obtained from FE analysis is compared with experimental results of Ameli et al. [7] and FE analysis results of Ganganagoudar et al. [3]. It is observed that good agreement is found between Experimental results and FE analysis as shown in Fig. 5. Variation in results of ultimate torque and ultimate twist is observed as 0.08% and 5.35% respectively. Diagonal crack on central portion and spalling of concrete cover is observed as damage pattern shown inFig. 6.

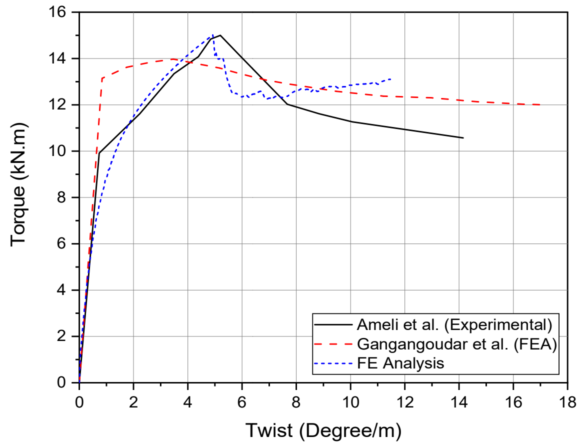


Fig. 5: Torque v/s twist behaviour of RC beam from validation example.

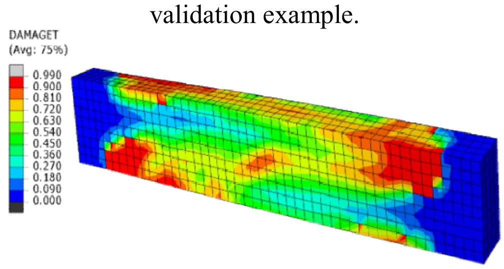


Fig. 6: Damage pattern of RC beam from validation example

5. Results and Discussion

Torque v/s twist behavior obtained from numerical analysis and ultimate values of torque-twist of all three wet connections is compared. Failure pattern of precast concrete specimens is observed to understand the contribution of shear key in precast beam.

5.1 Torque v/s Twist Behavior

Torque v/s twist behaviour of all three specimens is presented in Fig. 7. Specimen with shear key have higher initial stiffness compares to WOSK type specimen. Both OSK and ISK type specimen are depicted similar initial behaviour. Stiffness reduced and increase in WOSK and ISK type specimen respectively due to transfer of damage from one precast surface to another surface as shown in Fig.9.

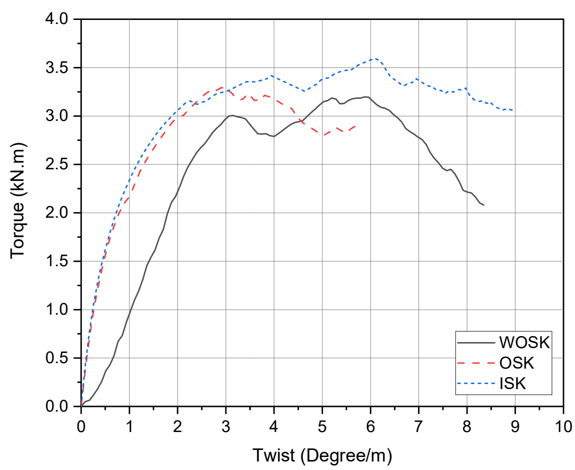


Fig. 7:Torque v//s twist results of precast beam

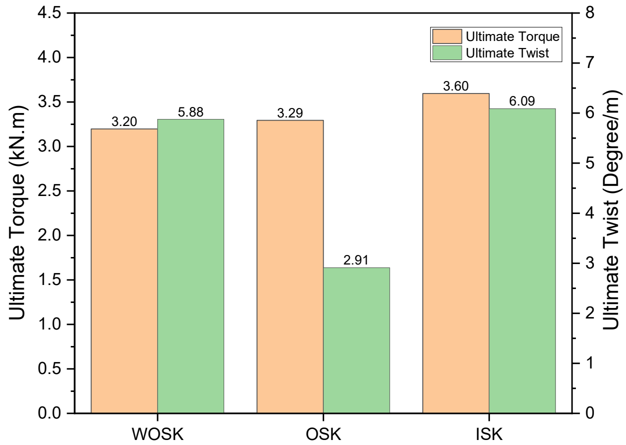


Fig. 8: Ultimate torque and corrosponding twist results of precast beam

5.2 *Ultimate Torque-Twist Results*

Ultimate torque and ultimate twist value of all three specimen are compared as shown in Fig.8.Ultimate torque is increased in specimens with shear keycompared to WOSK type specimen. ISK type specimen has exhibited maximum ultimate torque-twist value compared to other specimens. ISK type specimen is observed increment of 12.5% in ultimate torque compare to WOSK type specimen. ISK type specimen has exhibited 109.27% increment in ultimate twist compare to OSK specimens which show better ductility. OSK type specimen is given least ultimate twist value. In OSK type wet connection has shown minor increment in ultimate torque 2.81 % but 50.51 % reduction in ultimate twist as compared to WOSK type specimen.

5.3 *Damage Comparison*

Damage pattern from numerical analysis of all three specimen is shown in Fig. 9. Major damage is appeared on

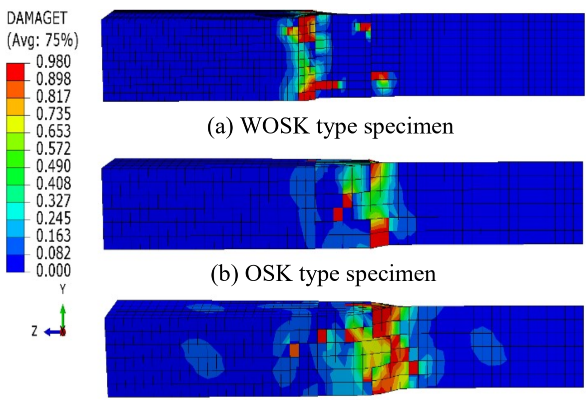


Fig. 9: Damage pattern of precast beam

portion of wet connections. Damage is initiated from edge of the shear key. Large tensile damage over edge of wet connections shows that spalling concrete cover after peak load. In WOSK type specimen damage is only observed on edge of wet connection and spalling of concrete cover is observed. In OSK type specimen damage is propagated near the shear key region and spalling of concrete cover is observed. Similarly, in ISK type connection damage is propagated from edge of wet connection to the precast member.

6. Conclusion

A finite element model is developed to find out effectiveness of shear key in torsional resistance of precast elements. From this numerical study following conclusions are derived:

- ISK type precast wet connection has exhibited better ultimate torque result compared to other wet connections.
- ISK type wet connections has revealed higher ultimate torque value and good ductility.Micro concrete in form of shear key is helped to improve the torsional resistance.
- OSK type wet connection has shown minor increment in ultimate torque 2.81% and 50.51% reduction in ultimate twist as compared to WOSK.
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Disclosures

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