sciendo

Civil and Environmental Engineering
Vol. 17, Issue 2, 644-653, DOI: 10.2478/cee-2021-0064

ANALYSIS OF DOWEL ACTION IN REINFORCED CONCRETE BEAMS WITH SHEAR REINFORCEMENT

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Abstract

The shear transfer mechanism was examined to view the contributions of different components of shear transfer such as aggregate interlocking, dowel force and uncracked compression zone. Understanding the role of various shear transfer components with transverse reinforcement provided was complex due to traditional difficulties involved in detail assessment of accompanying kinematics during the failure. In the present paper, the issue was addressed by employing sixteen specimens and grouped under two categories representing conventional beams and beams with preformed cracks and were tested under four - point bending load with a shear span to depth ratio of 1.26 by increasing the characteristic strength of concrete. From the results obtained, empirical formulas proposed were also evaluated and it was concluded that the results were consistent and contribution of shear transfer across uncracked compression zone was maximum in shear resistance with transverse reinforcement provided. Later structural behaviour was also assessed and it was concluded that beams with preformed cracks had exhibited greater stiffness thus nullifying the effect of aggregate interlocking in shear transfer.

Keywords:

Shear transfer;
Preformed cracks;
Four-point bending load; Shear resistance;
Structural behavior.

1 Introduction

Shear design of reinforced concrete beams had attracted significant research from few decades. The majority of studies were conducted on beams without providing transverse reinforcement and eliminating the aggregate interlock force by providing preformed cracks. Traditionally, shear transfer mechanism can broadly be classified into beam shear transfer action (tensile stress develop) as represented in Fig. 1. and arching action (no tensile stress develop).

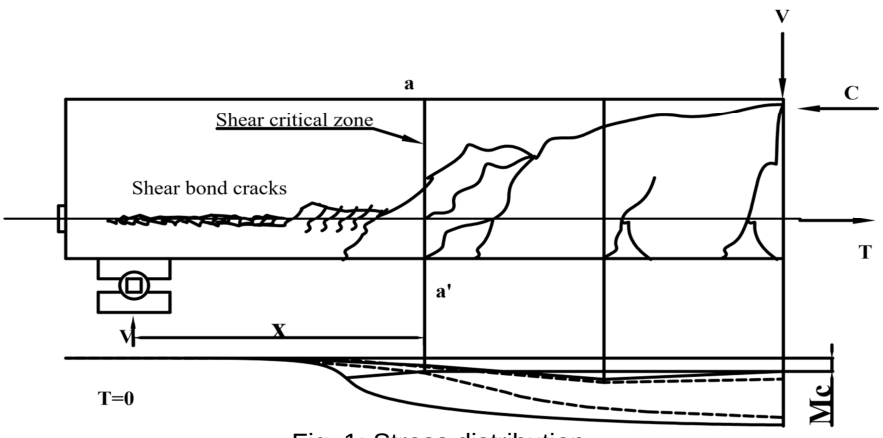


Fig. 1: Stress distribution.

Fig. 1 represents longitudinal stress distribution of Reinforced concrete beams at shear failure. The beams undergo flexural cracks initially at the mid bottom and once reaches the cracking moment starts shear cracks will appear. With increase in the load, flexural cracks increase and reaches to a-a' position. As the concrete undergoes multi axial stress rather than the tensile stress, flexural cracks do not arise in the range of "x". It is understood that distances (both flexural and shear) are purely dependent on establishment of percentage of flexural reinforcement and shear length to effective depth ratio. Based on the theoretical approach mentioned, various approaches to determine the components in shear design was developed considering either one of the actions or combining them. The initial study on shear failure was done by [1] and considered the arch action and ignored resistance of shear rising from aggregate interlock and dowel force and later several theories were proposed with respect to shear resistance and its behavior. Several pragmatic methods were formulated by considering varied design variable quantity like bar size, ratio of flexural reinforcement, concrete strength with respect to effective span and shear depth ratio. In literature were conducted experiments on reinforced concrete beams by providing shear reinforcement and concluded that shear due to concrete compression zone is the major contributor. Further [3] considered arch action of the concrete and neglected bond action caused by dowel force of longitudinal reinforcement and concluded that aggregate interlocking force holds major contribution in shear resistance but majorly depends on flexural reinforcement provided. Comparable works was carried out by [4-6] had concluded that with increase in concrete strength, the contribution of aggregate interlocking force decreases. This led to modelling the relationship between bond action of longitudinal reinforcement and further intensified to develop empirical formulas in predicting various components in shear transfer mechanism. In literature [7] conducted tests on high strength concrete beam by eliminating aggregate interlocking force and concluded that dowel force augment with increase in concrete strength. Extending to the work, [8] considered variable bar diameter and proposed that if dowel force is not considered, samples will encounter a fall in ultimate load. Similar work was carried out by [9] and as per them contribution from uncracked concrete is only contributor and other components hold minimum contribution for shear resistance. Literature [10] conducted test similar to [7] and implemented factorial design experiments by keeping constant *a'/d* (shear span to effective depth) ratio without shear reinforcement. The preformed cracks were introduced at 37^{o} as recommended by [11]. As per them, when all design variables are considered together, dowel force is found to enhance with enhance concrete and projected pragmatic method to evaluate dowel force in the absence of aggregate interlocking as mentioned in Eq. (1).

$$vd = 0.311 + 0.221p\emptyset - 0.064pfcu + 0.294C0 - 0.484p\emptyset C0 + 1.201p\emptyset fcuCo, \quad (1)$$

where: *vd* - dowel force,
p - percentage of steel,
Ø - diameter of the bar,
fcu - compressive strength of concrete,
Co - effective cover (concrete cover).

Further [12] had determined that effect of aggregate interlock was 15 % - 25 % and dowel force was 20 % - 27 % by keeping *a'/d* ratio constant and proposed an empirical formula as mentioned in Eqs. (2) and (3) to evaluate various components in shear strength.

$V_a = 0.4(0.21f'c^{2/3}/\gamma_c)\, b\cdot d$ ($f'_c \leq 50$ MPa), (2)

and

$$Va = 0.4\left[1.48\ \mathrm{In}\left(1+\frac{f'c}{10}\right)\right] b\cdot d \ \ (50\mathrm{MPa} \leq f'c \leq 90\ \mathrm{MPa}), \quad (3)$$

where: *Va* - aggregate interlocking force,
f´c - represents compressive strength of concrete,
γ_c - partial safety factor of concrete,
b - beam width,
d - beam depth.

Despite rigorous approach being carried, there is no detail consensus arrived on the main parameters of shear resistance and mechanisms involved in triggering the failure. In this context, a detailed experimental work was carried on sixteen specimens involving normal beams and beams with preformed cracks with increase in concrete strength and flexural reinforcement. A complete analysis was carried out to evaluate numerous shear transfer actions while loading and after reaching the maximum load by using fundamental mechanics and identify mechanism causing the shear failure. Similarly work carried [15], for non-prismatic beams had concluded that shear strength increases by adding steel fibres (Paragraph 2).

2 Experimental investigation

As discussed in the introductory remarks, various approaches were carried out to evaluate the parameters involved in shear transfer and in the present study sixteen specimens were considered by employing two set of beams. One set of beams was considered with preformed cracks as represented in Fig. 2. With clear cover of 25 mm and shear reinforcement at 200 mm centre to centre. Preformed cracks were initiated with iron plate of 5 mm thickness and with 265 mm × 170 mm before laying of concrete and reinforcement.

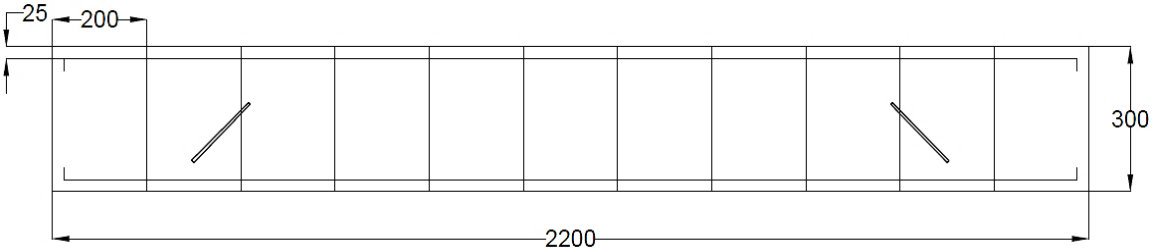


Fig. 2: Beam with preformed cracks.

As per [14], shear failure normally occurs on plane inclined at an angle 30^o to the horizontal. If it is required to be inclined more steeply, then the shear force required to produce failure is increased. As such in the present investigation, inclination of 45^o was considered, as equilibrium of forces across diagonal tensile cracks was assumed to be 45^o.

3 Design procedure

In the present experimental work, M30 and M50 grade of concrete were considered and the design mix was calculated as per [15] and suitable mix proportions were represented in Table 1 - 2 respectively. Aggregates of 20 mm size was taken into consideration.

Table 1: Mix for M30.

Cement	***CA***	***FA***	***W/C* ratio**
1	2.5	3.5	0.45

Table 2: Mix for M50.

Cement	***CA***	***FA***	***W/C* ratio**
1	1.472	3.043	0.35

The investigated sixteen specimens had rectangular cross section of 150 × 300 mm^2, with minimum yield stress of 500 N/mm^2 and aggregate size of 20 mm were cast for experimental study, as per code provision of [13]. Eight beams were conventional beams and remaining eight were cast with preformed cracks. Four amount of longitudinal flexural reinforcement ratio was considered η (increase in percentage of flexural reinforcement) = 0.00 % (without longitudinal and shear reinforcement), 0.30 %, 0.60 % and 0.9 % (corresponding to two bars of 12 mm diameter for 0.3 %, three bars of 12 mm diameter for 0.6 % and four bars of 12 mm diameter for 0.9 % at bottom) as represented in the Table 3 and Table 4 respectively. Beam span was 2200 mm with *a*'/*d* (shear span to effective depth) ratio 1.26.

Table 3: Conventional beams.

Design	η	Concrete
A1	0.00	M30
B1	0.30	M30
C1	0.60	M30
D1	0.90	M30
E1	0.00	M50
F1	0.30	M50
G1	0.60	M50
H1	0.90	M50

Table 4: Preformed cracks.

Design	η	Concrete
A2	0.00	M30
B2	0.30	M30
C2	0.60	M30
D2	0.90	M30
E2	0.00	M50
F2	0.30	M50
G2	0.60	M50
H2	0.90	M50

3.1 Procedure for testing

The test was conducted on loading frame of 2000 kN capacity and was similar to the set up by [8]. Two support conditions were placed at a distance of 100 mm from both the ends. Hinged support was placed at the left end and roller support was placed at right end as represented in Fig. 3. Failure of the beam was observed under four-point bending load and ultimate load carrying capacity was recorded with LVDT placed at mid span. The test set up was allowed to carry static loading conditions and the shear slenderness.

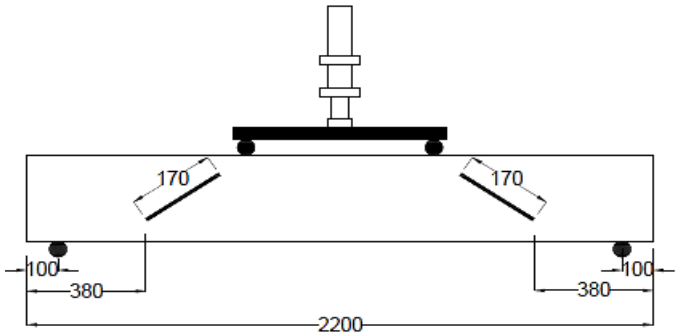


Fig. 3: Pictorial representation of the specimen.

4 Discussion on results

Results were given with moment vs. displacement curvature and moment vs. strain curvature and V and V_{cz} are determined by Eq. (4) proposed by [2]

$$V_{cz} = E_c V \frac{\delta\varepsilon}{\delta M}, \tag{4}$$

where: V - represents shear at support,
V_{cz} - represents shear at uncracked concrete,
E_c - represents modulus of elasticity of concrete,
$\delta\varepsilon/\delta M$ - corresponding strain to moment.

4.1 Displacement vs. moment dependence

From Figs. 4 and 5, the moment vs. lateral displacement at each level is evaluated and slope at individual level represent *V* as proposed in Eq. (1).

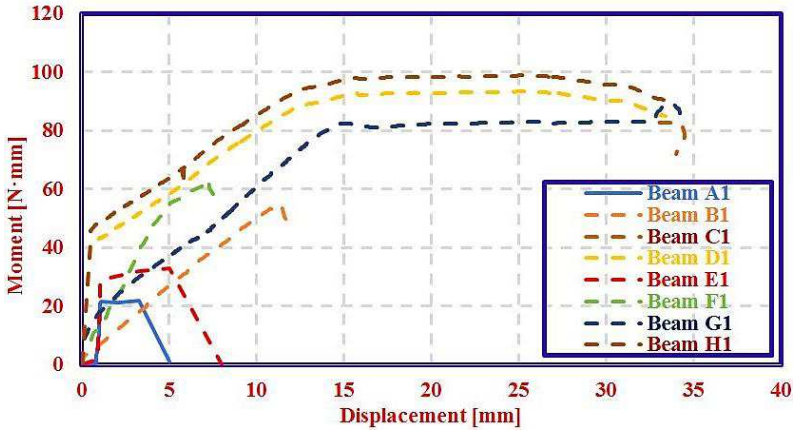


Fig. 4: Displacement vs. moment dependence for conventional beams.

Fig. 4 shear cracks were noticed during initial phases of loading, and with escalation of the load applied, shear cracks have increased diagonally indicating flexural stresses occurring from shear. Similarly inclined shear cracks were observed due to occurrence of debonding arising from lateral displacement. Up on reaching the ultimate strength, failure had occurred. For M 30 grade concrete, following observations were noted for failure. Beam A1, before reaching the elastic limit. B1 at yield point. Beams C1 and D1 underwent strain hardening and reached ultimate load before the failure. Ductility was observed for beam D1 as there was steady drop in the load after the failure.

Similarly, for M 50 grade concrete, with increase in lateral displacement, ductility was observed for all the beams as steady drip in the load had taken place. Following observations were noted regarding the failure. Beam short of shear and flexural reinforcement failed before reaching the elastic limit. Beam with 0.30 percentage, failure occurred at yield point. Beams with 0.60 and 0.90 percentage, underwent strain hardening and reached ultimate load before the failure.

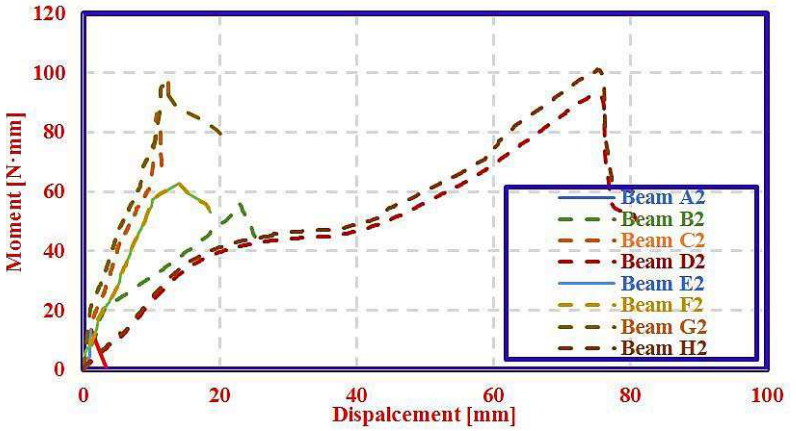


Fig. 5: Displacement vs. moment dependence for preformed crack.

From the Fig. 5 steady reduction of shear cracks and sturdy drip (drop) in the load was detected for every beam indicating the ductility. Following observations were made regarding the failure. Beam without shear and flexural reinforcement had failed instantly after the load was applied and beam for 0.30 and 0.60 variation of flexural reinforcement had failed after the yield. Beam with 0.9 percentage of flexural reinforcement had failed once final load was attained.

4.2 Strain vs. moment dependence

The response of longitudinal strain vs. moment at each level as represented in Eq. (1) and slope at each level gives the value of V_{cz} as represented in Figs. 6 and 7.

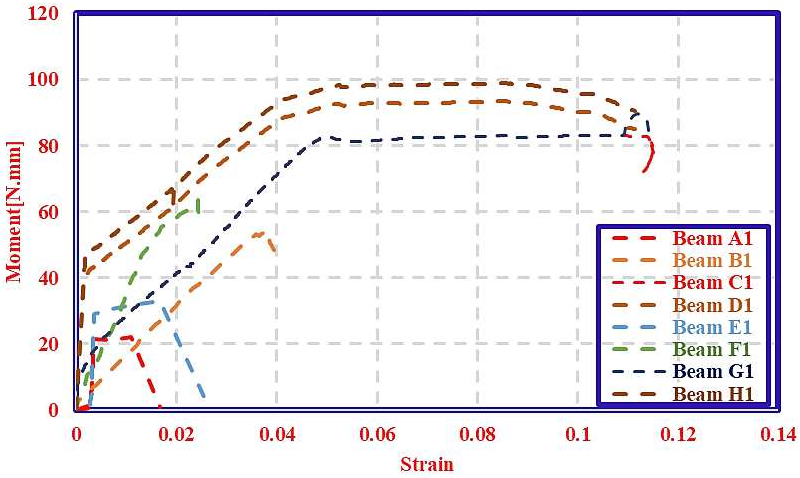


Fig. 6: Strain vs. moment dependence for conventional beams.

From the Fig. 6 it was observed that beams with 0.6 and 0.9 percentage of flexural reinforcement had shown gradual drop in the load due to ductility. It was resolved that shear at uncracked compression zone is the main contributor for shear resistance with increase in characteristic strength of concrete and increase in variation of flexural reinforcement.

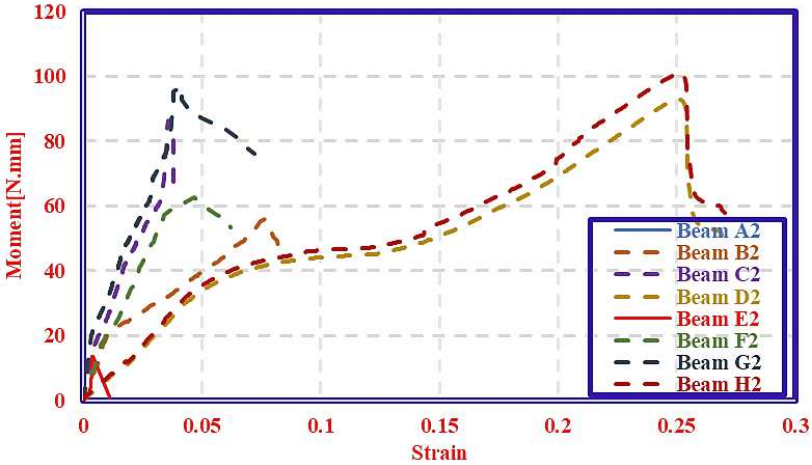


Fig. 7: Strain vs. moment curvature for preformed cracks.

From the Fig. 7 it was witnessed all the beams underwent a gradual drop due to ductility with increase in lateral strain. It was concluded that, shear at compression zone is the main contributor for shear resistance with increase in characteristic strength of concrete and increase in percentage of flexural reinforcement. Results obtained from Figs. 8 - 11 were used to determine V and V_{cz} as represented in Tables 5 and 6.

Table 5: V and V_{cz} - conventional beams.

Design	V	V_{cz}
A1	22.00	22.00
B1	50.65	50.65
C1	83.66	83.66
D1	93.51	93.51
E1	36.46	36.46
F1	64.74	64.74
G1	92.05	92.05
H1	98.50	98.60

Table 6: V and V_{cz} - preformed cracks.

Design	V	V_{cz}
A2	25.00	25.00
B2	53.68	53.68
C2	85.68	85.68
D2	92.60	92.60
E2	26.10	26.10
F2	60.37	60.37
G2	97.85	97.85
H2	101.85	101.85

From the above table, it was evident that shear at supports and at uncracked compression zone are equal and maximum for beam with preformed cracks at 0.90 flexural reinforcement.

4.3 Evaluation of V_d

After evaluating V and V_{cz}, V_d was derived based on the equations mentioned in Eqs. (1), (2) and (3) as denoted below.

4.3.1 Conventional beams

V_a was determined built on the Eqs. (2) and (3) and accordingly V_d was determined as mentioned in Table 7.

Table 7: V_d - conventional beams.

Design	η	V_d
A1	0.00	92.22
B1	0.30	25.24
C1	0.60	21.51
D1	0.90	16.69
E1	0.00	152.82
F1	0.30	45.35
G1	0.60	37.00
H1	0.90	35.39

From the above table, for conventional beams, with the presence of V_a, contribution of V_d had reduced with increase in strength of concrete and percentage of flexural reinforcement and is maximum for the beam with preformed cracks without any shear and tensile reinforcement provided.

4.3.2 Preformed cracks

As mentioned, the contribution of V_a was removed and V_d was determined and the results obtained are presented Table 8.

Table 8: V_d - preformed cracks.

Design	η	V_d
A2	0.00	0
B2	0.30	16.30
C2	0.60	12.40
D2	0.90	10.47
E2	0.00	0
F2	0.30	18.80
G2	0.60	15.59
H2	0.90	12.40

From above table, it was clear that influence of V_d was zero for the beams without any shear and flexural reinforcement and tending to decline with variation of percentage in flexural reinforcement and found to be maximum for beams with 0.30 percentage of reinforcement.

Later, values obtained for V_d were presented graphically as presented in Figs. 8 and 9 for conventional beams and with preformed crack.

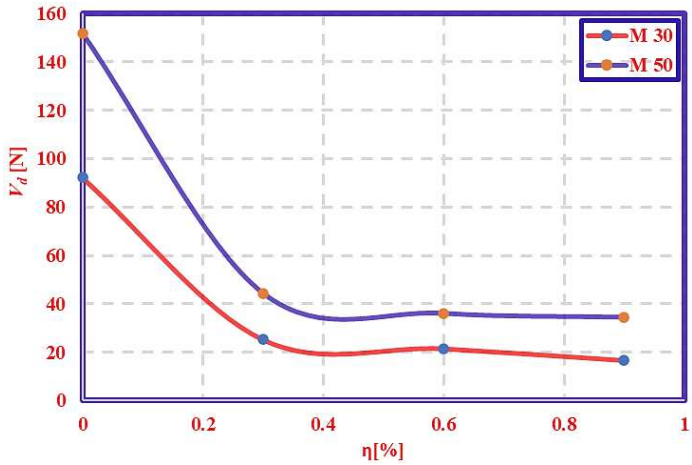


Fig. 8: Comparison of $V_{d.}$ for conventional beams.

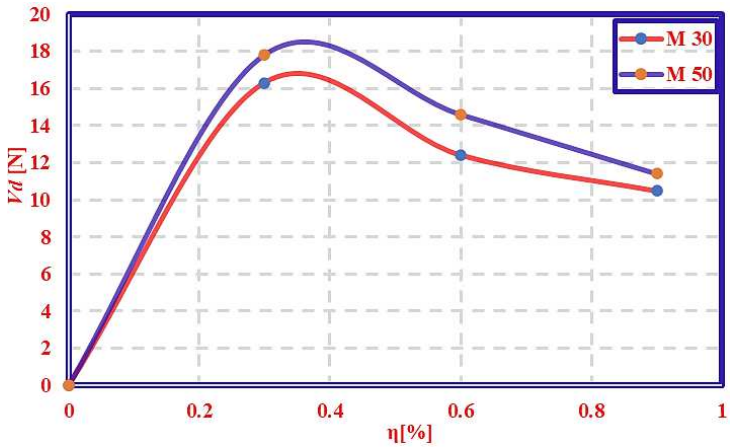


Fig. 9: Comparison of V_d for preformed crack.

From the Fig. 8 and 9, with rise in characteristic strength of concrete and variation of η, V_d had decreased and inclining towards for the beams with preformed cracks.

Eq. (1) was applied to determine V_d as mentioned in Table 9.

Table 9: Comparison of V_d for beams with cracks.

Design	η	Vd	Researcher
A2	0.00	0	0
B2	0.30	16.30	27.20
C2	0.60	12.40	52.47
D2	0.90	10.47	78.67
E2	0.00	0	0
F2	0.30	18.80	44.90
G2	0.60	15.59	88.88
H2	0.90	12.40	132.79

From the above table, huge variation observed between numerical value and experimental value.

4.4 Degradation curvature

After shear components were determined, structural behaviour was examined by employing stiffness degradation. As the stiffness is trivial under the load, degradation was observed with respect to the crack propagation by calculating with ratio of definite shear force and the ultimate shear force as signified in Figs. 10. and 11.

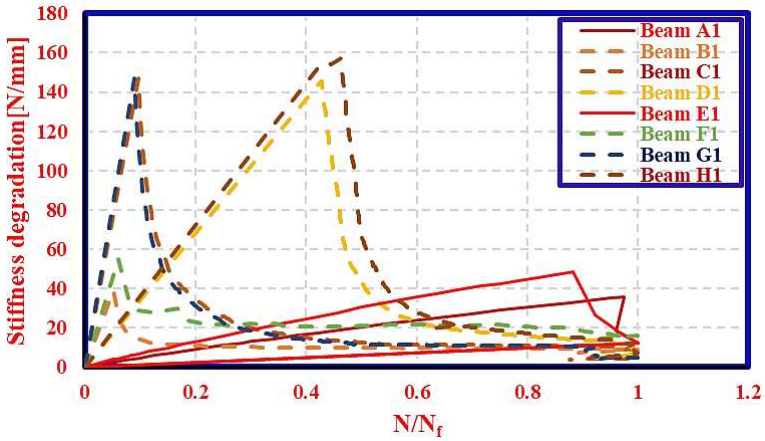


Fig. 10: Stiffness degradation for conventional beams.

From the Fig. 10, it was understood that, plain concrete beams varied linearly and with provision of flexural reinforcement, linear curve was observed initially and later S shaped had taken place indicating stiffness before the failure and found to be maximum for beam H1.

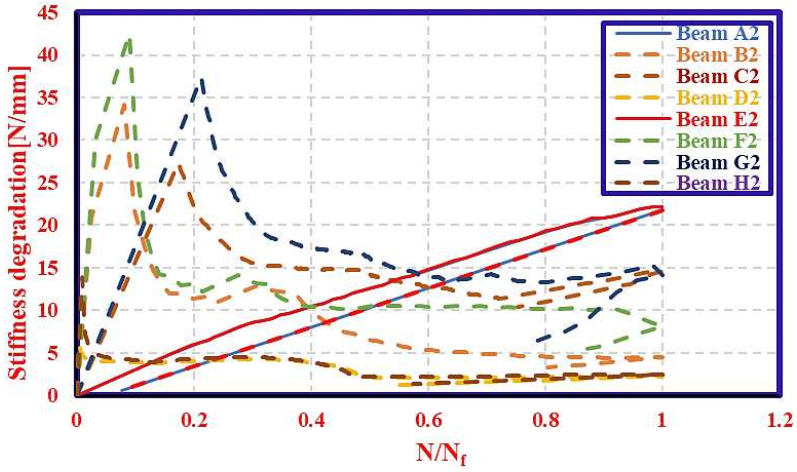


Fig. 11: Stiffness degradation for beams with preformed cracks.

In the Fig. 11 it was understood that, plain concrete beams varied linearly and with provision of flexural reinforcement, linear curve was observed initially and later S shaped had taken place indicating stiffness before the failure and found to be maximum for beam H2.

5 Conclusion

From the above discussions, components of shear strength were extensively studied under for point bending load and the following conclusions were derived:

1) From moment vs. displacement curvature, it can be concluded that design variables as discussed above does not contribute significantly as shear resistance was found be minimum at supports.

2) It is also concluded that, by eliminating aggregate interlocking force, shear at uncracked concrete is the major contributor of shear resistance and was in agreement with as concluded by [2].

3) Contribution $V_{a,}$ was 17 % - 24 %, V_{cz} was 50 % - 55 % which was in agreement with [12]. Hence it can be concluded that empirical formula holds good in determining the shear resistance of beams with transverse reinforcement provided.

4) From discussions above, huge variation was noticed between numerical values and experimental values. As such, formula proposed by [10] is not applicable.

5) From stiffness degradation curvature, it was observed that beams with preformed cracks had displayed better stiffness to conventional beams and decrease of cracks in shear was noticed. It can be decided that contribution of V_a holds minimum contribution to shear strength of concrete beams with transverse reinforcement provided.

6) Finally, it was decided that V_{cz} holds major contribution in shear resistance which was in agreement with [9] with transverse reinforcement provided.

Acknowledgement

Author would like to thank Head, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation (Deemed to be University), for permitting to conduct experimental work in structural engineering laboratory. Author would like to express his gratitude to Dr. P. Poluraju for his esteemed guidance during the experimental work and motivation to continue the work during the difficult times and continuous monitoring of the project and in writing research proposal.

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