

# Experimental Evaluation on Components of Shear resistance of Reinforced Concrete Beams with Shear Reinforcement Provided

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## Research Article

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# Experimental Evaluation on Components of Shear resistance of Reinforced Concrete Beams with Shear Reinforcement Provided

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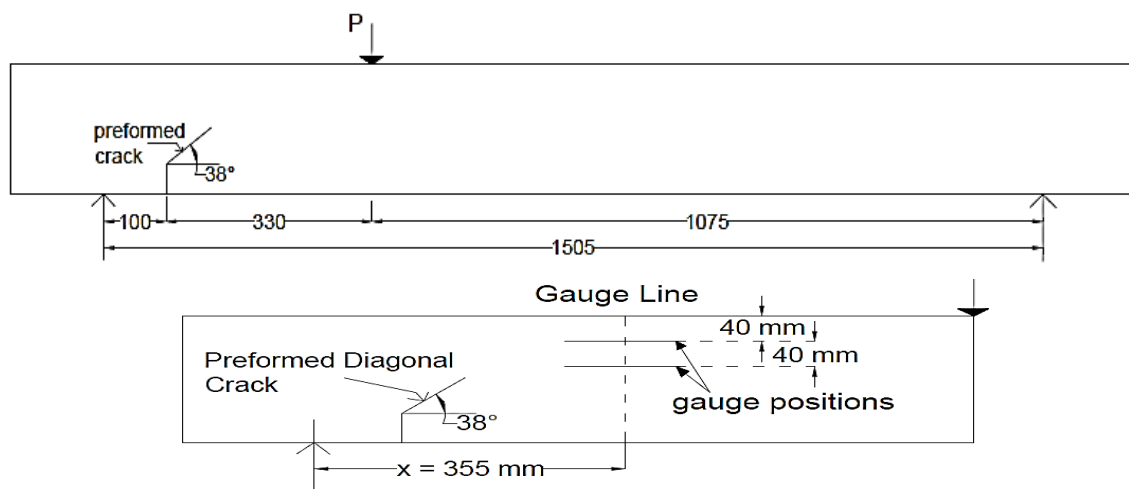
**Abstract:** The contribution of aggregate interlocking and dowel force in shear strength of reinforced concrete beams was topic of research for many years. The precise forecasts of shear behavior were challenging to determine due to complication involved. The existing theories had focused on aggregate interlocking force and shear resistance arising due to concrete compression zone, neglecting the contribution of dowel force despite considering as significant constituent in shear transfer mechanism. The present investigation focuses on cogitating all components in shear transfer mechanism by providing shear reinforcement and keeping clear cover and effective span to depth ratio constant. Sixteen specimens were considered for parametric study by employing suitable variables such as increase in strength of concrete and variation in flexural reinforcement. Eight specimens were conventional beams and the remaining eight specimens were provided with preformed cracks. Moment vs. displacement curvature and strain vs. moment curvature were plotted to evaluate shear at uncracked compression zone and accordingly aggregate interlocking force and dowel force were determined based on the empirical formulas proposed. From the result it was confirmed that contribution of aggregate interlocking force and dowel force were insignificant and shear resistance due to uncracked compression zone is the sole contributor in shear transfer mechanism. Structural behavior of concrete beams was also studied and it was confirmed that beams with preformed cracks exhibited better structural behavior when related to conventional beams.

**Key words:** Aggregate interlocking, dowel force, flexural reinforcement, preformed cracks, flexural loading.

## 1. INTRODUCTION

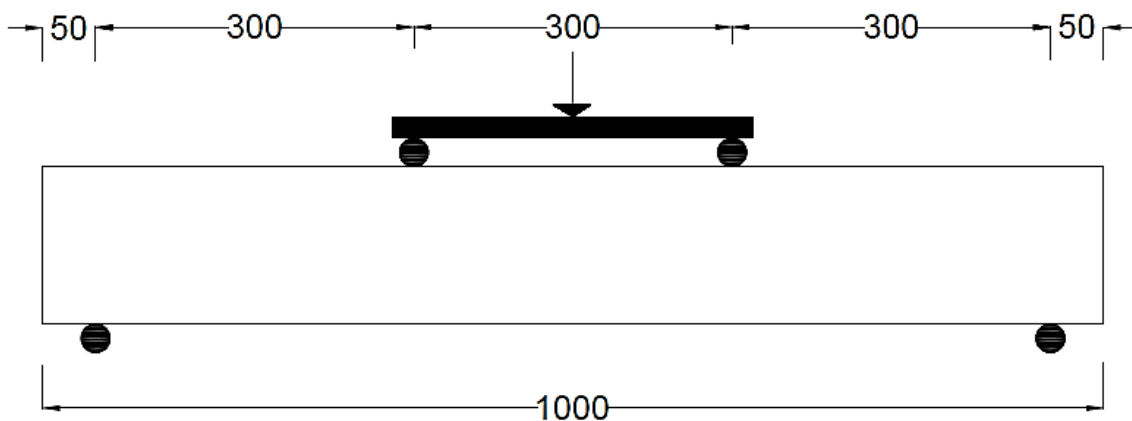
Shear failure is often sudden with little or no advanced warning and the design for shear must ensure that shear strength for every member exceeds its flexural strength. Shear resistance of reinforced concrete beams is provided by shear transfer in uncracked compression zone, aggregate interlocking across the crack surface, stirrups crossing through the shear crack and dowel action of longitudinal reinforcing bars crossing the crack in the concrete.

“ACI Committee 318 (2019)”, had suggested that in reinforced concrete beams the shear resistance is determined by the amount of the influence of concrete  $V_c$  and the influence of shear reinforcement  $V_s$ . Failure prediction and occurrence of shear cracks is tough to measure due to inconvenience involved in shear transfer mechanism. The initial study on shear failure was done by “Kani (1964)” and considered the arch action and ignored resistance of shear rising from aggregate interlock and dowel force and later several theories were proposed on the shear resistance of Reinforced concrete beams and their behavior. Several empirical formulas were proposed by considering varied design variables like bar size, flexural reinforcement ratio, characteristic strength of concrete in relation to effective span and shear depth ratio. “Taylor (1970)” had conducted experiments on reinforced concrete beams by providing shear reinforcement and concluded that shear due to concrete compression zone is the major contributor. Further “Paulay and Loeber (1974)” 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 “Walraven (1987)”, “Thomas (1988)”, and “Reineck (1991)” and concluded that with increase in strength of concrete, 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. “Sarkar *et al.* (1999)” conducted tests on high strength concrete beam as represented in Fig.1.



**Fig. 1:** Arrangement by “Sarkar *et al.* (1999)”

From the Fig 1, it was evident that aggregate interlocking was eliminated by initiating preformed diagonal tension cracks at an angle of 38°. Shear reinforcement were not provided and design variables such as  $a/d$  ratio was kept constant for all the specimens. They have decided that dowel force augment with increase in concrete strength. Extending to the work, “Jelic *et al.* (1999)” considered variable bar diameter and proposed that if dowel force is not considered, specimens will experience a fall in ultimate load.



**Fig. 2:** Arrangement by “Jelic *et al.* (1999)”.

Similar work was carried out by “Zararis and Papadakis (2001)” and as per them shear at compression zone is only contributor and other components hold minimum contribution for shear resistance. “Panda and Apparao (2017)” conducted test similar to “Sarkar *et al.* (1999)” and implemented factorial design

experiments by keeping  $a/d$  ratio constant without shear reinforcement. The preformed cracks were introduced at  $37^\circ$  as recommended by “Singh and Chintakundi (2012)”. As per them, when all design variables are considered together, dowel force is found to enhance with increase in strength of the concrete. Further “Kim *et al.* (2018)”, had concluded that aggregate interlock effect was 15%-25% and dowel force was 20%-27% by keeping shear span to depth ratio constant and proposed an empirical formula to evaluate various components in shear strength.

From the above literature, it was evident that flexural reinforcement, bar diameter and concrete compressive strength are significant in determining the dowel force and purely depends on the type of test setup.

## **2. RESEARCH SIGNIFICANCE**

It is a common agreement that structural behaviour of reinforced concrete members in bending is well understood. This is primarily due to various procedures mentioned for design strength in the codes are reasonably consistent. However, shear behaviour was not fully explained as there is a great variation between code-to-code provisions in determining the shear strength which is instigating the research for the last two decades. Understanding the shear behaviour is becoming a major challenge due to complexity involved and varying influence parameters are being corrected throughout the years through testing. It was also observed that magnitude of dowel force was given minimum attention due to wide-ranging nature of experimental observations and it was also observed that impact of aggregate interlocking force was overlooked which affords stages to calculate shear at uncracked compression which makes to determine dowel force accordingly. Limited efforts were done to establish the components in shear transfer with suitable design variables such as strength of concrete, flexural reinforcement effective span to depth ratio and clear cover.

The current experimental investigation emphasizes on establishing the dowel force by employing the suitable design variables as mentioned above.

### 3. EXPERIMENTAL INVESTIGATION

The present experimental investigation emphasizes on evaluating the dowel force of flexural reinforcement by increasing the percentage of flexural reinforcement and strength of concrete and keeping effective span to depth ratio and clear cover constant. One set of beams was conventional beams and in the second set of beams, diagonal tension cracks was initiated. Maximum shear load was recorded and structural behaviour of the beams were noticed and stress occurring at a depth 'y' from the neutral axis were calculated. M30 and M50 were considered with suitable mix proportions as represented in Table 1 and Table 2 respectively.

**Table 1:** Proportion Mix for M30

<b>Cement</b>	<b>CA</b>	<b>FA</b>	<b>W/C Ratio</b>
<b>1</b>	2.5	3.5	0.45

**Table 2:** Proportion Mix for M50

<b>Cement</b>	<b>CA</b>	<b>FA</b>	<b>W/C Ratio</b>
<b>1</b>	1.472	3.043	0.35

Sixteen specimens with minimum yield stress of 500N/mm<sup>2</sup> and aggregate size of 20 mm were cast for experimental study, as per code provision of IS: 456-2000. Eight beams were conventional beams and remaining eight were cast with preformed cracks as represented in the Table 3 and Table 4 respectively, by employing ratio of flexural reinforcement in the proportion of 0.30%, 0.60%, 0.90%. Clear span of the beam was 2200 mm with cross section 150 mm × 300 mm with a/d ratio 1.26.

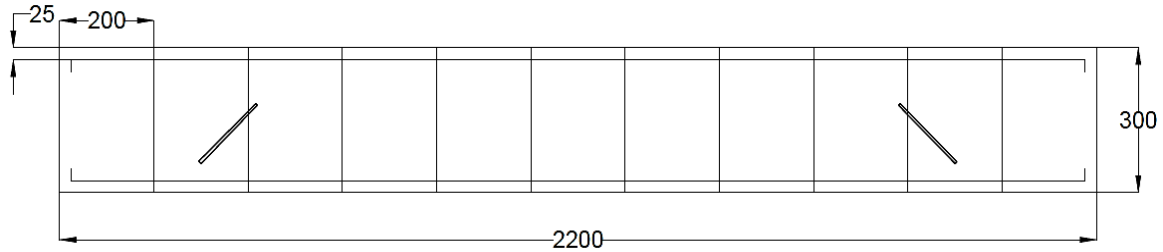
**Table 3:** Conventional Beams

<b>Beam</b>	<b>% of Steel</b>	<b>Concrete</b>
<b>A1</b>	0.00	M30
<b>B1</b>	0.30	M30
<b>C1</b>	0.60	M30
<b>D1</b>	0.90	M30
<b>E1</b>	0.00	M50
<b>F1</b>	0.30	M50
<b>G1</b>	0.60	M50
<b>H1</b>	0.90	M50

**Table 4: Preformed cracks**

Beam	% of Steel	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

Clear cover of 25 mm with shear reinforcement at 200 mm c/c was placed. Preformed cracks as suggested by “Sarkar *et al.* (1999)” was marked at 380 mm from supports and 60 mm away from the bottom reinforcement with iron plates 5mm thickness at an angle of  $45^{\circ}$  as presented in Fig. 3. Iron plates were taken away after four hours, and kept for curing for twenty-eight days as presented in Fig.4.

**Fig. 3: Pictorial representation of beam with preformed cracks.****Fig. 4: Preformed crack beam.**

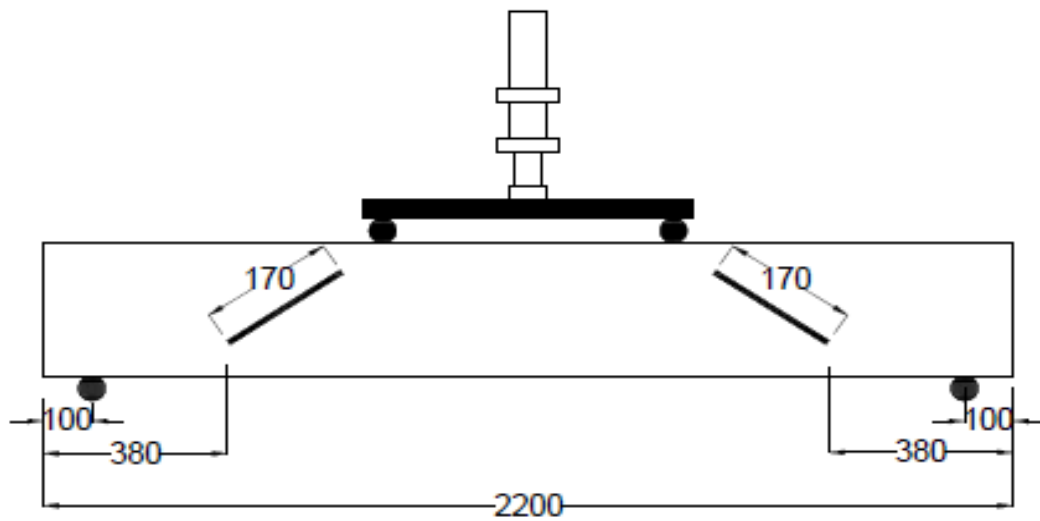
### 3.1 Procedure for Testing

The test was conducted on loading frame of 200-ton capacity and was similar to the set up by “Jelic *et al.* (1999)” Two support conditions were placed at a distance of 100mm from both the ends. Hinged support was placed at the left end and roller support was placed at right end. Failure of the beam was observed under four-point

bending load and ultimate load carrying capacity was recorded with LVDT placed at mid span. Specimen failure represented in Fig. 5. and pictorially represented in Fig. 6., was analysed from moment vs. displacement curvature, moment vs. strain curvature and shear components was determined accordingly.



**Fig. 5:** Specimen Failure.



**Fig. 6:** Pictorial representation of the Specimen.



### 3.2 Discussion on formulas for shear strength components of Reinforced Concrete Beams.

Fig. 7 represents longitudinal stress distribution of Reinforced concrete beams at shear failure. The beams subjected to moment and shear develop flexural cracks in the mid bottom as soon as it reaches the cracking moment. 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 occur in the range of "x". It is understood that distance of flexural cracks and shear cracks and shear strength are purely dependant on establishment of percentage of flexural reinforcement and shear span to effective depth ratio.

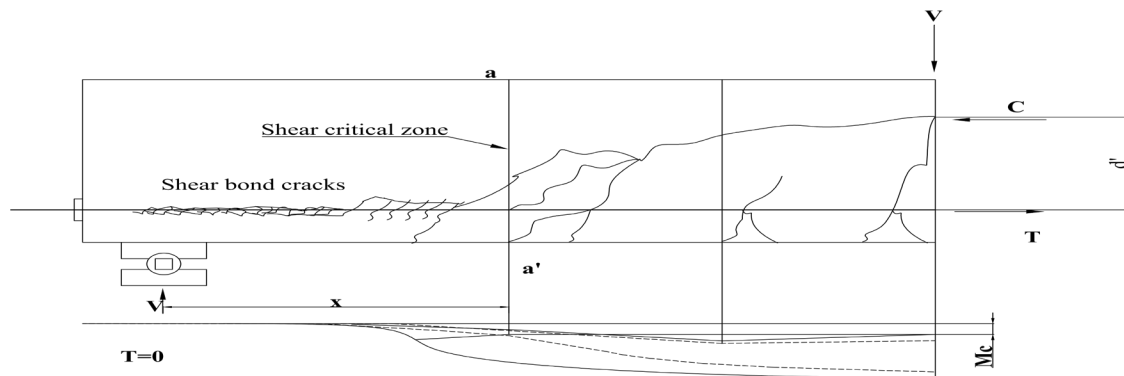


Fig. 7: Tensile stress distribution of Longitudinal flexural Reinforcement.

From the Fig. 7 due to complex shear transfer mechanism, components of shear strength were difficult to determine. Hence, formula suggested by "Taylor (1970)" as represented in Eq. (1) was considered to assess 'V' and 'V<sub>cz</sub>'

$$V_{cz} = E_c V \frac{\delta \varepsilon}{\delta M} \quad (1)$$

The  $V_{cz}$ , was calculated from strain vs. moment curvature as represented in Figs. 9 and 10 and slope represents  $\frac{\delta \varepsilon}{\delta M}$ .

$E_c$  was evaluated as  $5000\sqrt{f'c}$  as specified by IS 456-2000.

'V<sub>d</sub>' was calculated from formulas as presented.

For conventional beams, formula suggested by "Kim et al. (2018)" represented in Eqs. (2) and (3). was taken into consideration to calculate  $V_a$  and accordingly  $V_d$  was determined.

$$V_a = 0.4(0.21f'c^{2/3}/\gamma_c) b. d (f'c \leq 50 \text{ Mpa}) \quad (2)$$

and

$$V_a = 0.4 \left[ 1.48 \ln \left( 1 + \frac{f'c}{10} \right) \right] b. d (50 \text{ Mpa} \leq f'c \leq 90 \text{ Mpa}) \quad (3)$$

For preformed cracks, empirical formula suggested by “Panda and Apparao (2017)” as represented in Eq. (4) was considered.

$$vd = 0.311 + 0.221p\phi - 0.064pfcu + 0.294C0 - 0.484p\phi C0 + 1.201p\phi fcuC0. \quad (4)$$

#### 4. RESULTS AND DISCUSSIONS

The results obtained is represented in the method of moment vs. displacement curvature and moment vs. strain curvature and  $V$  and  $V_{cz}$  are determined consequently.

##### 4.1 Displacement vs. Moment Curvature

From Figs. 8 and 9, the moment vs. lateral displacement at each level is evaluated and slope at individual level represent  $V$  as proposed in Eq. (1).

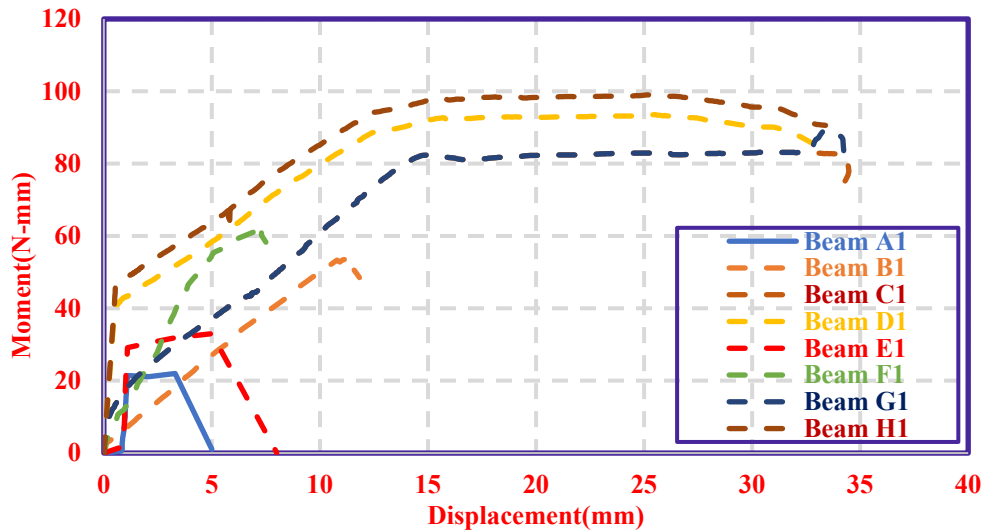


Fig. 8: Displacement vs. Moment curvature for conventional beams.

Fig. 8., shear cracks were noticed during initial stages of loading, and with intensification of the applied load, shear cracks have increased diagonally indicating tensile 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 drop 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.

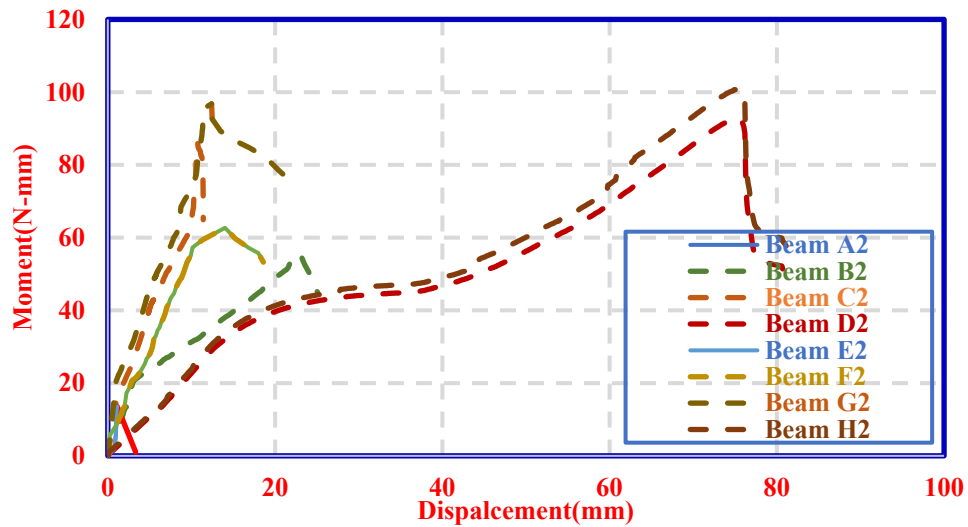


Fig. 9: Displacement vs. Moment curvature for preformed crack.

From the Fig. 9. steady reduction of shear cracks and steady drop in the load was seen for all the beams indicating the ductility. Following observations were made regarding the failure. Beam without shear and flexural reinforcement had failed immediately after the load was applied and beam with 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 had reached.

#### 4.2 Strain vs. Moment Curvature

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. 10 and 11.

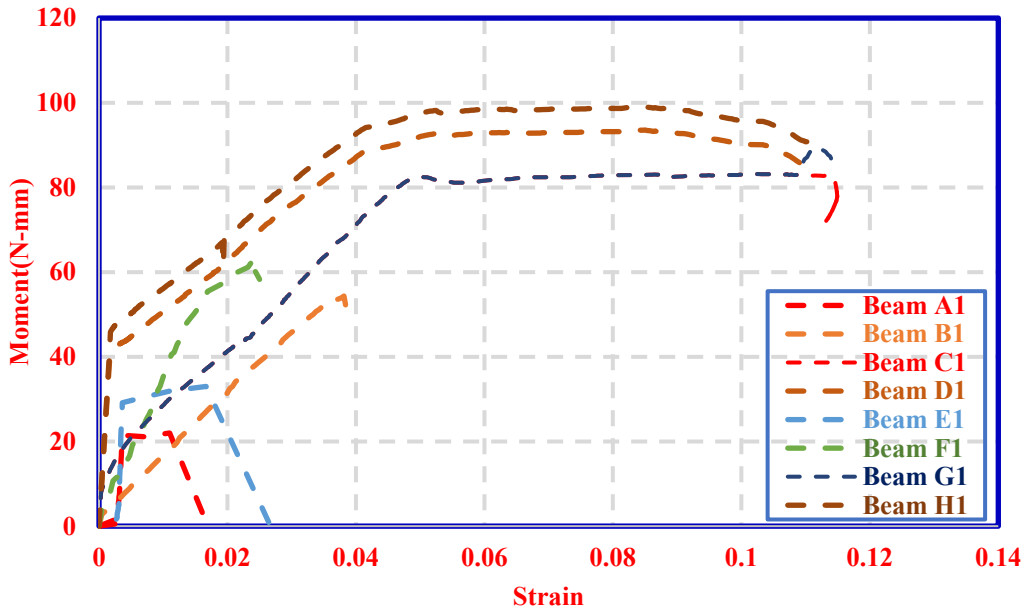


Fig. 10: Strain vs Moment. curvature for conventional beams.

From the Fig. 10., 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 concluded 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.

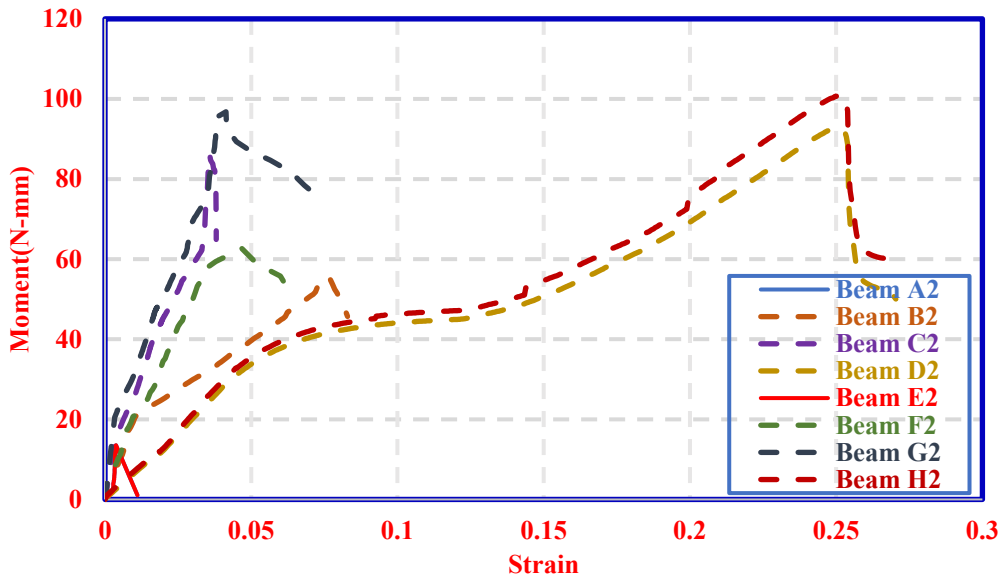


Fig. 11: Strain vs. Moment curvature for preformed cracks.

From the Fig. 11., 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, was used to determine ' $V$ ' and ' $V_{cz}$ ' as represented in Tables 5 and 6.

**Table 5: V and  $V_{cz}$  - Conventional Beams**

Beam designation	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**

Beam designation	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

#### Evaluation of $V_d$

After evaluating  $V$  and  $V_{cz}$ ,  $V_d$  was derived based on the equations mentioned in Eqs.(2),(3) and (4) as denoted below.

#### a) *Conventional Beams*

' $V_a$ ' was determined based on the Eqs. (2) and (3) and accordingly ' $V_d$ ' was determined as represented in Table 7.

**Table 7:  $V_d$  - Conventional Beams**

Beam	% of Reinforcement	$V_d$
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 Table 7. 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.

**b) Beams with preformed cracks**

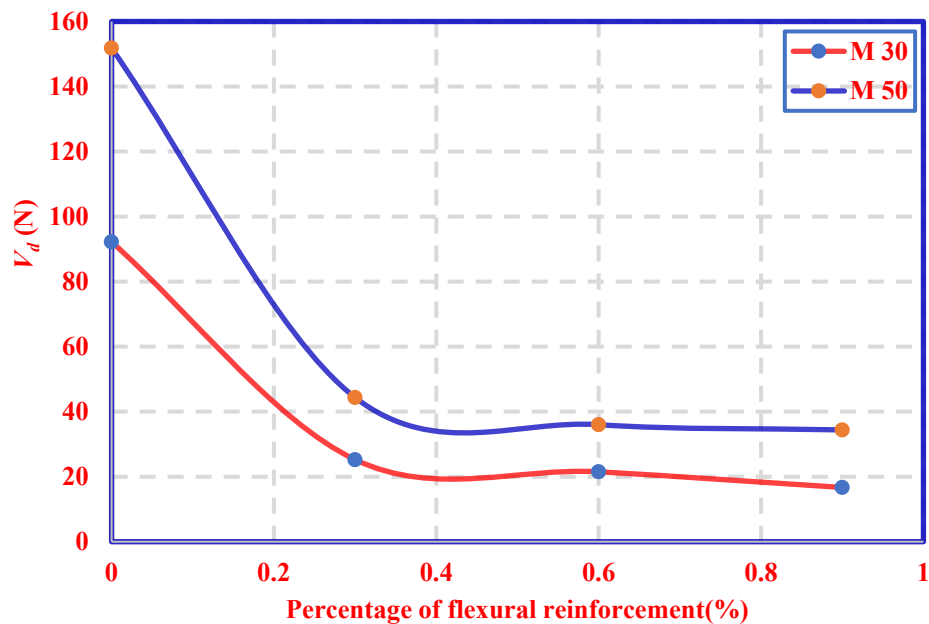
For the beams with preformed cracks, the contribution of ' $V_a$ ' was removed and ' $V_d$ ' was determined and the results obtained are presented Table 8.

**Table 8:**  $V_d$  – Preformed cracks.

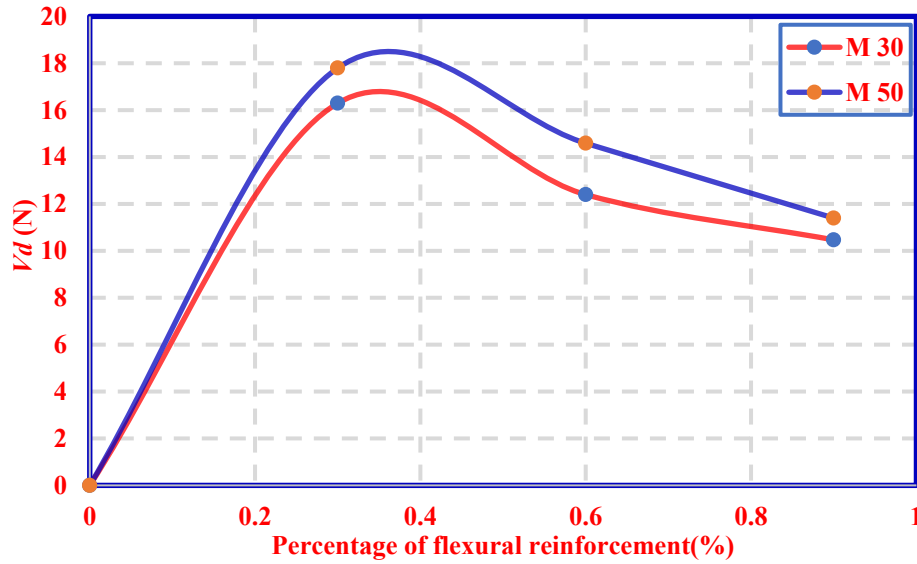
Beam Designation	% of Reinforcement	$V_d$
A2	0.00	0
B2	0.30	16.30
C2	0.60	12.40
D2	0.90	10.47
E2	0.00	0
F2	0.30	18.80
G2	0.60	15.59
H2	0.90	12.40

From Table 8, it was evident that influence of ' $V_d$ ' was zero for the beams without any shear and flexural reinforcement and tending to decrease with percentage variation 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. 12 and 13., for conventional beams and with preformed crack.



**Fig. 12:** Comparison of  $V_d$  for conventional beams.



**Fig. 13:** Comparison of  $V_d$  for preformed diagonal tension crack.

From the Fig. 12. and 13, with increase in characteristic strength of concrete and percentage of flexural reinforcement,  $V_d$  had decreased and tending towards for the beams with preformed cracks.

Eq.(4) was applied to determine  $V_d$  as represented in Table 9.

**Table 9:** Comparison of  $V_d$  for beams with preformed diagonal cracks

Beam designation	% of reinforcement	$V_d$	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 Table 9, huge variation was observed between numerical value and experimental value

### 4.3 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 specific shear force and the ultimate shear force as represented in Figs.14. and 15.

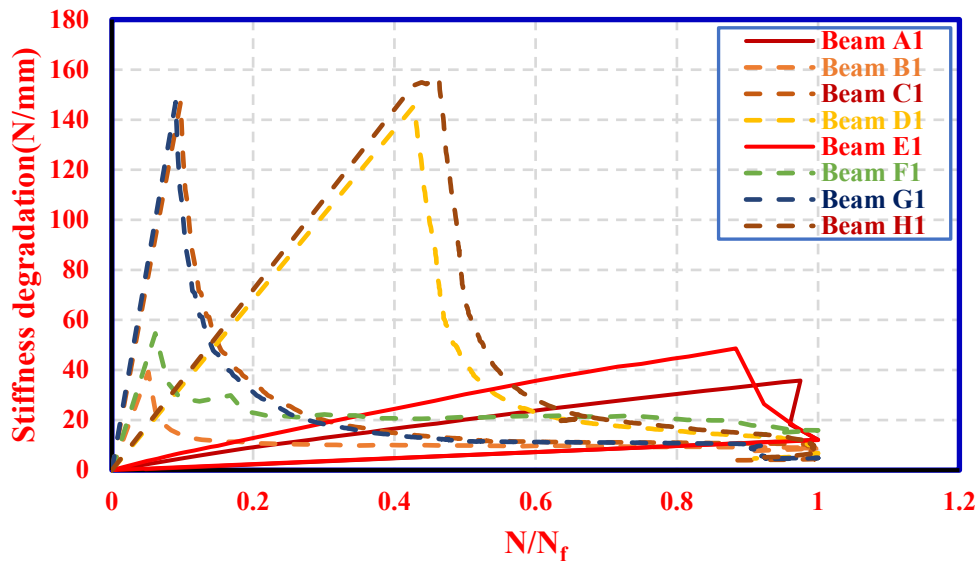


Fig. 14: Stiffness degradation for conventional beams.

From the Fig. 14, 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.

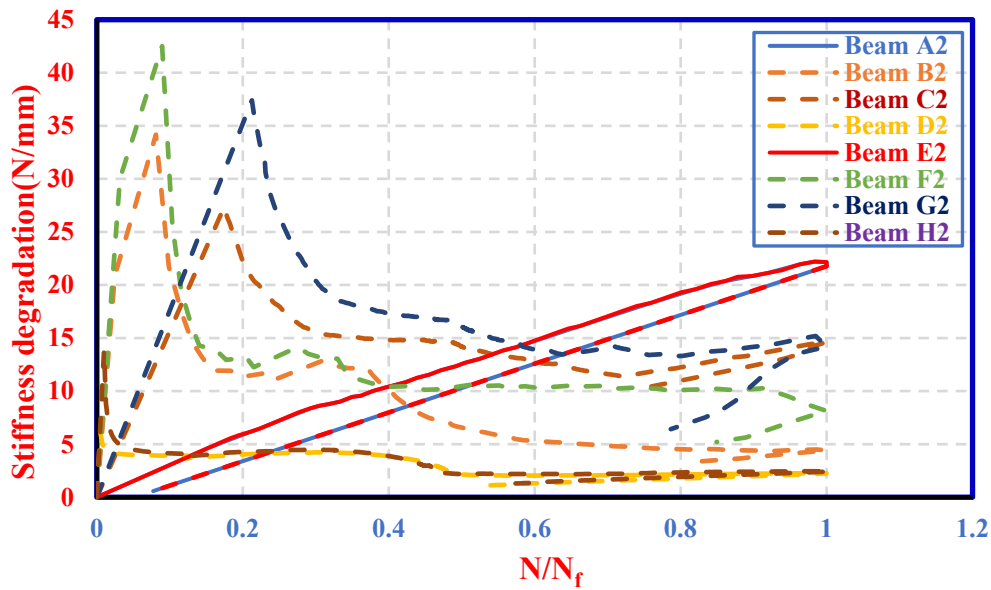


Fig. 15: Stiffness degradation for beams with preformed cracks.

In the Fig. 15 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.



## CONCLUSIONS

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

- i. 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.
- ii. It is also concluded that, by eliminating aggregate interlocking force, shear at uncracked compression zone is the major contributor for shear resistance and was in agreement with as concluded by “Taylor (1970)”.
- iii. Contribution  $V_a$  was 17% - 24%,  $V_{cz}$  was 50% - 55% which was in agreement with “Kim *et al.* (2018)”. Hence it can be concluded that empirical formula holds good in determining the shear strength of concrete beams with shear reinforcement provided.
- iv. From the discussions above, huge variation was noticed between numerical values and experimental values. As such, formula proposed by “Panda SS and Apparao G (2017)” is not applicable.
- v. From stiffness degradation curvature, it was observed that beams with preformed cracks had displayed better stiffness compared to conventional beams and there was decrease of cracks in shear. It can be decided that contribution of  $V_a$  holds minimum contribution to shear strength of concrete beams with shear reinforcement provided.
- vi. Finally, it can be decided that  $V_{cz}$  is major contributor in shear resistance of concrete beams which was in agreement with “Zararis and Papadakis (2001)” with shear reinforcement provided.

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## Nomenclature

$a$	shear span (mm)
$a/d$	shear-span-to-depth-ratio
$b$	width of beam (mm)
$d$	depth of the beam (mm)
$V$	shear force at support (N)
$V_{cz}$	shear stress at a depth $Y$ from the compressive face (N)
$\sigma$	longitudinal stress at a distance 'x' from the support
$M$	moment at a distance $X$ from support (N-mm)
$E_c$	modulus of elasticity of concrete (N/mm <sup>2</sup> )
$\varepsilon$	strain
$f'_c$	compressive strength of concrete (N/mm <sup>2</sup> )
$f_{ck}$	compressive strength of concrete as per IS 456-2000 (N/mm <sup>2</sup> )
$V_a$	aggregate interlocking force (N)
$V_d$	dowel force (N)
$P$	percentage of steel (%)
$\emptyset$	bar diameter (mm)
$C_0$	Cover (mm)
$f_{cu}$	grade of concrete
$\delta_m$	moment at the given load and displacement
$\delta_\varepsilon$	corresponding strain for the given displacement
$\delta_x$	corresponding displacement
CA	coarse aggregate
FA	fine aggregate
W/C	water cement rat

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