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The weld coefficient - a new parameter accounting for shear resistance of welded wire mesh in place of conventional stirrups as shear reinforcement in RC beams

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A vast majority of structural elements such as Reinforced Concrete (RC) beams loaded with transverse loads develop both shear and bending moments at different sections along their span. From the safety point of view the RC beams must be designed to have adequate safety margin against various kinds of failures. Keeping in view of the nature of the shear failures which are in general associated failure with little or no advanced warning, the design for shear in RC members normally ensure that the shear strength for every member in the structure exceeds the flexural strength. The shear failure mechanism depends upon the cross-sectional dimensions, the geometry, the types of loading, and the properties of the member[1-3].

From the point of principles of structural mechanics, the shear stress distribution is parabolic and reaches maximum in the core zone of the rectangular cross section as shown in Fig. 1. The failures of reinforced concrete beams in shear are characterized by the development of diagonal cracks near the high shear zones such as near to the support regions. With increase in shear loads these diagonal cracks extend towards the compression zone and disrupts the integrity of concrete by reducing the aggregate interlocking action. The design codes recommend effectively anchored transverse reinforcement that intersects these diagonal cracks in order to increase the shear resistance[4-8].

The prefabricated reinforcement such as Welded Wire Mesh (WWM) also has been used in several forms such as main reinforcement in RC slabs and as shear reinforcement in thin webbed concrete beams[9,10]. The experimental investigations reported on the use of welded wire mesh as flexural / shear reinforcement placed near the periphery of the cross section indicated that the combination of weld mesh with conventional stirrups provide marginally high strength and cracking resistance[11,12]. Further the investigations related to the use of WWM as jacketing material indicated the improvement in the strength of damaged beams[13-16]. All the above-mentioned investigations have used the WWM only near to the periphery of the cross section only and thus left the core zone of the cross section unreinforced. The shear reinforcement in the form of stirrups placed near to the periphery of the beam cross section (Fig. 2) leaves the core of the cross section where there is existence of high transverse stress, unreinforced. Further the stirrups provide resistance against diagonal tension due to shear only in discrete manner. This leads to sudden appearance and propagation of cracks, leading to brittle failures under shear. The published literature on the use of such core zone reinforcement across the cross section of an RC member, where the intensity of shear stresses is large is very limited[17]. In this paper a study on the effect of using welded wire mesh as transverse (shear) reinforcement that not only replaces totally the conventional stirrups / ties but also reinforces the core zone of RC cross section is presented.

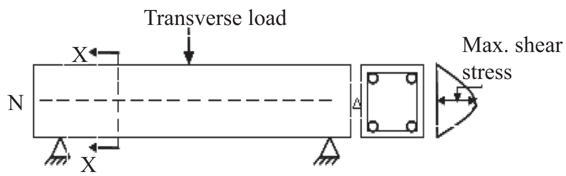


Fig. 1 Shear stress distribution across the rectangular beam cross section

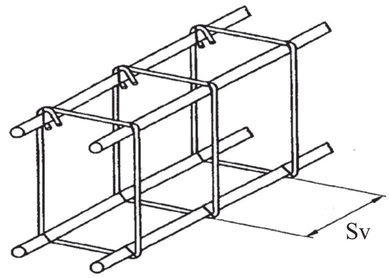


Fig. 2 Reinforcement cage with conventional stirrups

RESEARCH SIGNIFICANCE

The existing practice of using stirrups (Fig. 2) for resisting shear leaves the core zone of the cross section un-reinforced and thus leading to the rapid propagation of shear cracks. Further the practice of reinforcing the core zone of RC elements using fibers cannot eliminate completely the use of conventional stirrups / ties. Further in view of the soaring costs of labor and steel involved in tedious bar bending work in making stirrups / ties, the prefabricated mesh such as welded wire fabric would be an economically viable alternative. Several investigations in the past confirm that the RC elements such as slabs, wall panels reinforced with welded wire fabric showed better structural performance as compared to conventionally reinforced ones. The use of prefabricated mesh in core zone as transverse reinforcement in place of conventional stirrups / ties as shown in Fig. 3 will also bring in simplicity and enable rapid fabrication of reinforcement cage required for RC members.

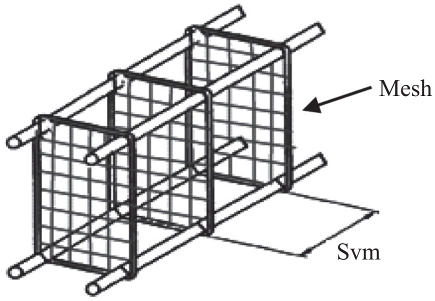


Fig. 3 Reinforcement cage with mesh as transverse reinforcement replacing the conventional stirrups

A pilot study reported by the authors[16], consisted of testing of RC beam in which a prefabricated WWM has been used as transverse reinforcement in place of conventional stirrups. The observations reported in the pilot study were based on limited number of beams. The pilot experimental investigation indicated improved performance compared to the ultimate resistance of RC beams provided with only conventional stirrups. Keeping in view of the encouraging result a detailed investigation is conducted and reported herewith.

In this paper an experimental investigation conducted on RC beams provided with welded wire mesh in the core zone of the cross section as transverse reinforcement in place of stirrups is presented. The main objective in the present investigation is to study and quantify the performance of RC beams wherein the welded wire mesh is used in the core zone as transverse reinforcement and compare the same with the shear performance of RC beams provided with conventional stirrups.

EXPERIMENTAL PROGRAM

The experimental program consisted of casting and testing of seven numbers of RC beams tested under symmetrical two-point loading (i.e Four-point bend test). Out of seven numbers of RC beams, one beam C100 has no stirrups in maximum shear zone i.e. near supports. However, the RC beam C100 has stirrups only in middle 500 mm length at 100 mm *c/c* so that there is no premature failure due to flexure. The C100 beam is meant for assessing the shear strength of RC beam without any stirrups in the shear zone. The remaining six beams are divided in to two sets. The first set consisted of three RC beams (R160, R100 and R60). In the first set of RC beams the variable parameter was the spacing of stirrups i.e. the conventional stirrups (2 legged 6Φ) are used as shear reinforcement at spacing of 160mm, 100mm and 60mm respectively. The second set of three RC beams (M160, M100 and M60) consisted of welded wire mesh as transverse reinforcement in place of conventional stirrups. The spacing of weld mesh as transverse reinforcement along length of the RC beam adopted includes 160mm, 100mm and 60mm. The diameter of weld mesh wire is 2.34 mm spacing of wires is 50mm vertical and 30mm horizontal. The spacing of wires in the weld mesh is chosen so as not to cause any hindrance to the flow of concrete. Each

RC beam specimen cast and tested was designated by the type of transverse reinforcement adopted (i.e Stirrups (R)/ Mesh (M)) and the spacing of transverse steel. Thus, the RC beam specimen whose designation is M60 stands for RC beam provided with welded wire mesh at 60 mm spacing as transverse reinforcement. The volume (or) weight of transverse reinforcement in the form of weld mesh in the RC beam M160, M100 and M60 beams is roughly about half of the volume (or) weight of transverse reinforcement in the form of stirrups used in the RC beam R160, R100 and R60 respectively as given in Table 1. Hence the RC beams provided with weld mesh in place of conventional stirrups as transverse reinforcement consumed less volume or weight of steel for a given spacing of transverse reinforcement. The longitudinal steel adopted was maintained constant in all the seven RC beams tested. The control beam R160 is specifically designed to fail in shear by adopting the spacing of stirrups as 160 mm against the required design spacing of 140mm. The shear span to effective depth ratio adopted for all the beams is 3. The size of the RC beams adopted is 140 mm width, 240mm overall depth and 1650mm in length. Along with the RC beams the concrete cubes of standard size (150×150×150mm) were cast and tested to ascertain the concrete compressive strength. The details of specimens tested are given in Table 1. The reinforcement cages used are shown in Fig. 4.

Materials used in concrete

The materials used consist of ordinary Portland cement of 53 grade confirming to IS 269-2015, the river sand as fine aggregate conforming to zone-II of IS: 383-2016, the coarse aggregate of 20mm nominal size, the potable water and super plasticizer. The specific gravity and bulk density of sand are 2.65 and 1.45g/cm^3 respectively and that of coarse aggregate are 2.80 and 1.5g/cm^3 respectively. The detail of concrete mix proportion is given in Table 2.

TABLE 1

DETAILS OF RC BEAM SPECIMENS TESTED

<table>
<tr><th rowspan="2">S.No</th><th rowspan="2">Beam</th><th rowspan="2">Details of RC beam cross section and longitudinal reinforcement</th><th colspan="3">Transverse reinforcement</th><th rowspan="2">Total weight of reinforcement cage (kg)</th></tr>
<tr><th>Details</th><th>Vol. percent of transverse steel per unit length of beam</th><th>Total number and weight of trans. steel N (wt. in kg)</th></tr>
<tr><td>1</td><td>R160</td><td rowspan="7">$b \times D \times L$: 140 × 240 × 1650 mm
Tension reinforcement 2-12Φ and 1-16Φ
Compression reinforcement: 2-6Φ
Total weight of long. reinforcement per RC beam: 7.55 kg</td><td>2 Lgd 6Φ @160 c/c</td><td>0.157</td><td>10(1.21)</td><td>8.76</td></tr>
<tr><td>2</td><td>R100</td><td>2 Lgd 6Φ @100 c/c</td><td>0.252</td><td>16(1.92)</td><td>9.47</td></tr>
<tr><td>3</td><td>R60</td><td>2 Lgd 6Φ @60 c/c</td><td>0.421</td><td>26(3.12)</td><td>10.67</td></tr>
<tr><td>4</td><td>M160</td><td>WWM @160 c/c</td><td>0.085</td><td>10(0.53)</td><td>8.08</td></tr>
<tr><td>5</td><td>M100</td><td>WWM @100 c/c</td><td>0.136</td><td>16(0.88)</td><td>8.43</td></tr>
<tr><td>6</td><td>M60</td><td>WWM @60 c/c</td><td>0.226</td><td>26(1.43)</td><td>8.98</td></tr>
<tr><td>7</td><td>C100</td><td colspan="2">No stirrups in maximum shear zone i.e. near supports. Six numbers of stirrups are provided only in middle 500 mm length at 100 c/c. Two more stirrups, one at each end of the beam</td><td>8(0.96)</td><td>8.51</td></tr>
<tr><td colspan="2">Concrete:
compression strength = 31.8 MPa</td><td colspan="2">Longitudinal reinforcement:
Yield strength = 424 MPa
Ultimate strength = 538 MPa

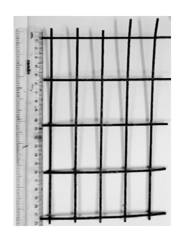
Transverse reinforcement:
Yield strength = 285.6 MPa
Ultimate strength= 361 MPa
Average weight of each stirrup = 0.12 kg
Diameter of stirrup bar = 5.1 mm</td><td colspan="3">WWM: Welded Wire Mesh:
Wire dia= 2.34mm Φ,
Spacing of wires:
Vertical=50mm, Horizontal=30mm,
Yield strength of wires= 267.7 MPa,
Ultimate strength of wires = 347 MPa.
Average weight of each mesh = 0.055 kg
</td></tr>
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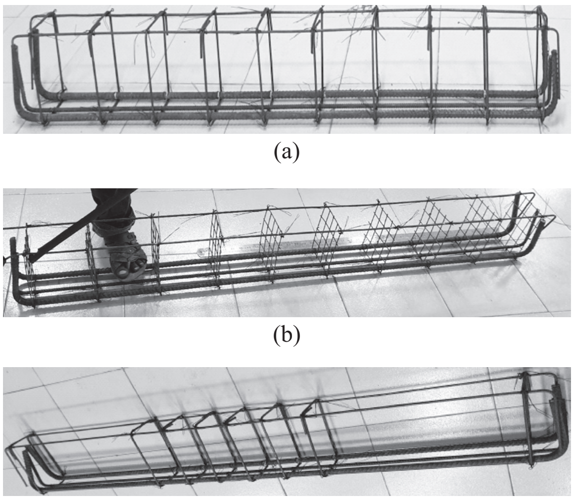
TABLE 2 MATERIALS USED (PER Cu.m)						
Concrete grade	Mix proportion	Quantity of concrete making materials per Cu.m				
		Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)	SP* (kg)
M25	1: 1.8: 3.1 *w/c* 0.45	380	685	1180	170	2.7
*SP: Superplasticizer (SP 430, make: fosroc chemicals)						



(a)

(b)

(c)

Fig. 4 (a) The reinforcement cage with steel stirrups as transverse steel; (b) the reinforcement cage with welded wire meshes as transverse steel; (c) the reinforcement cage with stirrups only in the middle 500 mm length

Casting and testing of beams

For casting the RC beams the steel channel moulds of required size were used. After placing the prefabricated reinforcement cages the concrete was placed in the moulds and compacted with vibrator. After 24 hours of casting, the beam specimens were de-moulded and water cured for a period of 28 days. The average room temperature and relative humidity measured during the period of curing were 35±2°C and 75% are respectively. After the completion of curing period the specimens were removed from the curing pond and kept under the shade. A day before testing the cured beams were white washed and marked on it with pencil the location of supports, the positions of deflection gauges during the test and kept ready for testing. Further a speckle pattern was marked on the side face to enable capture of strains for analysis in future using Digital Image Correlation (DIC) technique. The beams were tested under two-point loading (four-point bend test) after a curing period of 28 days, on the TINIUS – OLSEN testing machine of 2000 kN capacity. The deflection of the beam was measured using LVDT and deflection dial gauges. The details of test setup were shown in Fig. 5. The displacement control loading was adopted by moving the loading cross head at 1 mm per minute i.e equal to 1/1500 of span per minute[18]. The testing was continued till the point of ultimate load or the test set up became unstable whichever is earlier. The cracks formed on the beams were noted and marked for comparison of crack pattern and nature of failure.

(a) (b)

Fig. 5 (a) Details of test setup; (b) testing

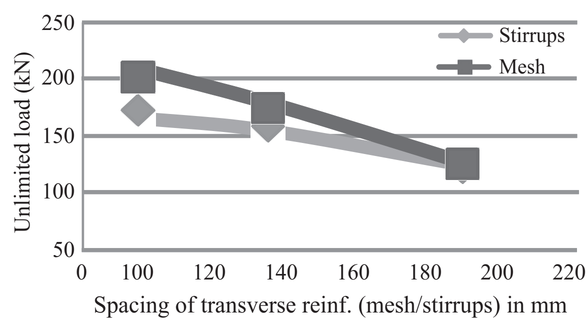


Fig. 6 Ultimate load vs. spacing of transverse reinforcement (mesh / stirrups)

The Table 3 gives the experimentally recorded failure loads (ultimate load), maximum deflections. From the above results the observed ultimate load of the beam and corresponding spacing of transverse reinforcement (mesh or stirrups) in the beam is shown in Fig. 6. The load deflection diagrams of all the tested beams were drawn and are presented in Fig. 7. Also, the failure patterns of the beam specimens are shown in Fig. 8.

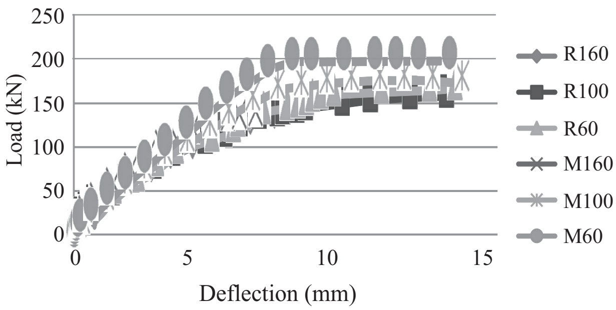
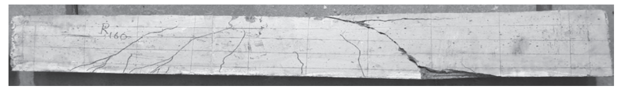


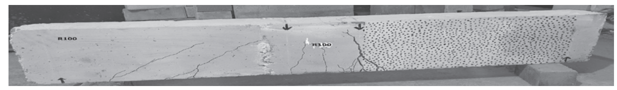
Fig. 7 The load deflection diagrams of all the tested beams

DISCUSSION OF BEHAVIOUR AND ANALYSIS OF TEST RESULTS

The observations made during the testing indicated that the RC beam C100 having no stirrups in the shear zone and the RC beam R160 provided with conventional two-legged stirrups at 160mm c/c have failed by developing a major diagonal shear cracks (Fig. 8(a) and (g)) as expected because they were designed to be shear deficient. The propagation of the cracks was sudden near the ultimate load. In the case of RC beam M160 having WWM in place of conventional stirrups, also failed in shear (Fig. 8(d)). However, the ultimate (failure) load observed in both R160 and M160 beams is nearly same. In case of R100 and R60 beams wherein there is closer spacing of the stirrups, the ultimate load observed is more than that of R160. Further both R100 and R60 beams though the shear cracks have developed initially but have failed in flexure at ultimate by developing clear flexural cracks (Fig. 8(b) and (c)). The RC beams M100 and M60 wherein the conventional stirrups are replaced by the welded mesh, have also failed in flexure by developing a clear flexural crack near the mid span of the beams (Figs. 8(e) and (f)) and also the crushing of compression concrete was noticed. However, the ultimate load of beams M100 and M60 observed are more than that of R100 and R60 respectively. As the spacing of transverse reinforcement (in the form of mesh / stirrups) reduced, the rate of increase of load in beams with weld mesh as core zone transverse reinforcement is observed to be more than that in beams with conventional stirrups (Fig. 6). The improvement in shear strength of RC beams with weld mesh as transverse reinforcement over that with conventional stirrups is ranged from 1.41% to 20.9% as the spacing of transverse reinforcement is reduced from 160mm to 60mm (Table 4). The improvement in shear strength may be attributed to the effectiveness of mesh over conventional stirrups, in controlling / delaying the formation of shear crack.

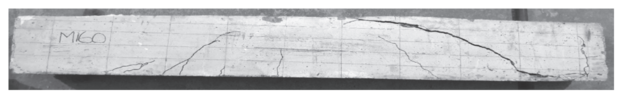


(a) R160 beam crack pattern at ultimate –failed in shear

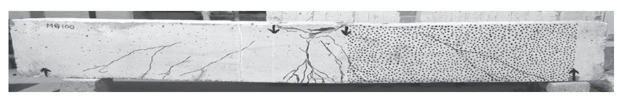


(b) R100 beam crack pattern at ultimate –failed in flexure

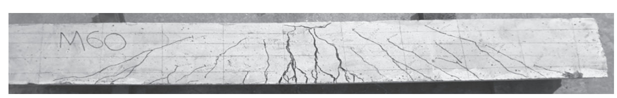
(c) R60 beam crack pattern at ultimate –failed in flexure



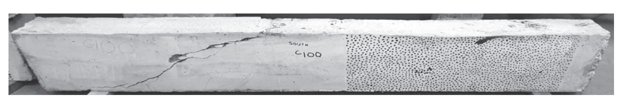
(d) M160 beam crack pattern at ultimate –failed in shear



(e) M100 beam crack pattern at ultimate –failed in flexure



(f) M60 beam crack pattern at ultimate –failed in flexure



(g) C100 beam crack pattern at ultimate –failed in shear

Fig. 8 The failure patterns of the beam specimens

The control beam R160 is specifically designed to fail in shear by adopting the spacing of stirrups as 160mm against the required design spacing of 140mm. The other two beams R100 and R60, were provided with conventional stirrups at a reduced spacing and made the beams to fail in flexure. The experimentally observed behavior of beams indicated that the replacement of conventional stirrups with WWM, did not make any difference in the nature of failure i.e when R160 failed in shear the corresponding M160 also failed in shear. Similarly, when R100 failed in flexure the corresponding M100 also failed in flexure. Similar is the case with R60 and M60. However, the ultimate load of the beams provided with WWM as transverse steel in place of conventional stirrups at similar spacings have always indicated higher loads. At this point it is to be noted that the volume (or) weight of transverse reinforcement in the form of weld mesh used in the RC beams: M160, M100 and M60 is roughly about half of the volume (or) weight of transverse reinforcement in the form of stirrups used in the RC beam R160, R100 and R60 respectively (as given in Table 1). Hence it can be concluded that for the similar spacing of transverse steel, even the less quantity of transverse steel in the form of WWM will be able to provide similar or better performance of RC beams compared to that of RC beams having conventional stirrups. This clearly indicates the effectiveness and economy of WWM over the conventional stirrups. Further it can be concluded that the nature / behavior of the RC beam remained more or less similar with the replacement of conventional stirrups with welded wire mesh as transverse reinforcement for the same spacing of transverse steel in the form of mesh / stirrups.

In general, the slope of the shear cracks (angle made by the shear crack with vertical, as shown in Table 3) in RC beams with WWM as transverse reinforcement is more (on an average by 50) than that with conventional stirrups. The increase in the slope of the shear crack indicates the effectiveness of mesh over conventional stirrups, in enhancing the shear strength. Further the ductility as indicated by the area under load deflection plot (Fig. 7) is more in the case of RC beams with WWM as transverse reinforcement compared to the RC beams with conventional stirrups.

The observation of the deflections at service load i.e at 0.66 times the ultimate load, in al the tested beams is well within the permissible serviceability limits (i.e deflection less than span/250) as per the existing Indian standard code of practice. Hence it can be considered that the use of WWM in place of conventional stirrups has not violated any serviceability criteria. Further there is an increase in the slope of shear crack with vertical (Table 3) in the RC beams provided with weld mesh as transverse reinforcement indicating the enhanced effectiveness of weld mesh compared to that of the conventional stirrups.

Analysis of test results and weld coefficient

The experimental results presented above has indicated that even the less volume or weight of transverse steel in the form of mesh, which distribute uniformly across the cross section of RC beam performed better than conventional two-legged stirrups in enhancing the shear strength. Hence in order to quantify the effect of welded wire mesh as transverse reinforcement in enhancing the shear resistance of RC beams a simple and new parameter termed as 'weld coefficient' has been proposed and quantified. The weld coefficient (K) proposed takes in to account indirectly the effect of the presence of horizontal wires (i.e the wires of the weld mesh parallel to the width of the RC beam) welded to the vertical wires in WWM in improving the shear performance of RC beam having WWM as transverse reinforcement in place of conventional stirrups. The following simplified analysis has been carried out based

TABLE 3
LOADS AND DEFLECTION VALUES OF TESTED BEAMS

S.No	Beam	At service		At ultimate		Nature of failure at ultimate	Slope of shear crack with vertical	
		P_s (kN)	δ_S (mm)	P_u (kN)	δ_u (mm)			
1.	R160	91.30	4.73	136.92	7.10	Shear	60.3°	Ave. slope 61.760
2.	R100	107.60	4.60	161.50	13.2	Flexure	61°	
3.	R60	113.7	5.10	170.50	13.5	Flexure	64°	
4.	M160	92.03	3.64	138.85	6.43	Shear	66.9°	Ave. slope 68.160
5.	M100	121.03	5.46	181.55	12.7	Flexure	68.6°	
6.	M60	137.40	5.61	206.14	13.3	Flexure	69°	
7.	C100	78.15	2.2	117.25	4.3	Shear	61°	—

Notation: P_s = Load at service, P_u = load at ultimate, δ_s = deflection at service, δ_u = deflection at ultimate on the philosophy of the current shear design practice adopted in the structural concrete design codes[2,19,20]. In general, the mechanism of shear resistance in RC beams is based on the parallel chord truss analogy. As per the analogy the web of equivalent truss consists of stirrups acting as tension members and concrete struts remaining parallel to the diagonal cracks formed in the presence of shear. The flexural concrete compression zone and the flexural reinforcement form the top and bottom chords of the truss. For a beam with web reinforcement the shear resistance may be regarded as being made up of the sum of the concrete resistance and the web steel resistance. Following the truss analogy, the shear resistance of the RC beam can be written as

Shear strength of RC beam provided with conventional stirrups (Vvs) = $Vc + Vs$

Shear strength of RC beam provided with welded mesh as transverse reinforcement (Vvm) = $Vc + Vm$

where, Vc = shear resistance of concrete without any web reinforcement = shear strength obtained by testing C100 beam, which has no stirrups in the maximum shear zone = 117.25 / 2 = 58.62 kN.

Vs = shear resistance of web steel in the form of stirrups = $fys\ As\ d/Sv$, where fys = yield strength of stirrup reinforcement = 285.6 MPa, As = cross sectional area of two vertical legs the stirrup = $2 \times 3.14\ (\Phi s)^2/4$, where Φs = diameter of the vertical leg of stirrup = 5.1mm, d = effective depth of the beam = 220mm, Sv = spacing of the stirrups along the length of the beam.

Vm = shear resistance of web steel in the form of stirrups = $fym\ (KAm)\ d/Sm$, where fym = Yield strength of mesh wires parallel to the depth of the beam i.e yield strength of the vertical wires of the WWM = 267.7 MPa, Am = cross sectional area of all vertical wires of the weld mesh = $Nvm \times 3.14\ (\Phi m)^2/4$, where Φm = diameter of vertical bar of the WWM = 2.34mm and Nvm = number of vertical wires of the weld mesh = 5 and Sm = spacing of weld mesh along the length of the beam and K = weld coefficient.

Comparing the failure load at ultimate (given in Table 3) of RC beam provided with WWM as transverse reinforcement with that of RC beam with conventional stirrups, the improvement in the shear resistance can be written as

$$Vvm - Vvs = Vm - Vs = [(fym\ (K\ Am) / Sm - (fys\ As / Sv)]\ d$$

In the present investigation the comparison of shear resistance is done for the similar spacing's of transverse reinforcement i.e $Sv = Sm = S$. Three different spacing's were considered in the investigation i.e. 60, 100 and 160 mm. Hence

$$Vm - Vs = [(fym\ (K\ Am) - (fys\ As)]\ d/S$$

On simplifying, the weld coefficient (K) - a non-dimensional parameter, can be calculated as

$$K = [(Vm - Vs)\ (S/d) + fys\ As] / (fym\ Am)$$

The percent improvement in the shear strength (100*((Vm–Vs) / Vs) of RC beams having WWM as transverse reinforcement in place of conventional stirrups is given in Table 4 and its variation with spacing of transverse steel is shown in Fig. 9.

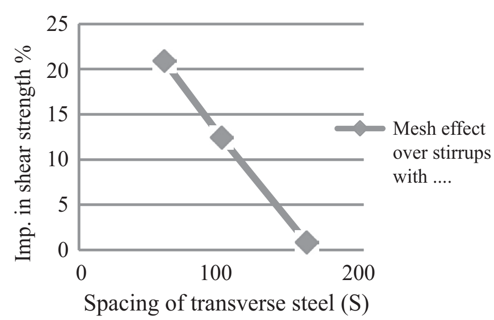


Fig. 9 The percent improvement in the shear strength of RC beams having WWM as transverse reinforcement in place of conventional stirrups, with spacing of transverse steel

TABLE 4
EVALUATED WELD COEFFICIENT OF TESTED RC BEAMS HAVING WWM AS TRANSVERSE REINFORCEMENT IN PLACE OF CONVENTIONAL STIRRUPS

S.No	*S* (mm)	*S/d*	*Pum* (kN)	*Pus* (kN)	*Pc* (kN)	*Vm*	*Vs*	*Vc*	*Vm-Vs* (kN)	*Ism* (%)	*K*	*Pum* (calc) (kN)
1.	160	0.727	138.85	136.92	117.25	69.42	68.46	58.62	0.56	1.41	2.098	148.89
2.	100	0.454	181.55	161.50	117.25	90.77	80.75	58.62	10.02	12.41	2.819	167.87
3.	60	0.272	206.14	170.50	117.25	103.07	85.25	58.62	17.82	20.90	2.871	201.63

The improvement in shear strength due to the use of weld mesh as transverse reinforcement in place of conventional stirrups is more as the spacing of transverse steel is reduced. Knowing the experimental shear strengths *Vm* and *Vs* for the similar spacing's of transverse reinforcement, the weld coefficient (*K*) was evaluated and the same is tabulated in Table 4. The variation of weld coefficient with *S*/*d* i.e the ratio of spacing of transverse steel (*S*) and effective depth (*d*) of the RC beam is shown in Fig. 10. The analysis indicated that the weld coefficient (*K*) is equal to 2.098 for M160 which failed in shear and it is equal to 2.819 and 2.871 for the beams M100 and M160 respectively, both have failed in flexure. The weld coefficient is about 35% more on an average for RC beams failed in flexure compared to the RC beam that have failed in shear. The weld coefficient $K > 2.0$ reinforces the observation of superiority of the weld mesh as transverse reinforcement over the conventional stirrups for the same spacing and it concludes that the volume of steel consumed in using the weld mesh as transverse reinforcement is almost half of the volume of steel consumed in conventional stirrups for the same spacing. A comparison between the calculated and experimental ultimate load of RC beams with WWM as transverse reinforcement is shown in Fig. 11. The correlation coefficient of 0.91 between the calculated and experimental ultimate load of RC beams with WWM as transverse reinforcement indicate a good correlation. The following is the best fit equation for the weld coefficient (*K*) in terms of the ratio of spacing of transverse steel (*S*) in the form of WWM in place of conventional stirrups to the effective depth (*d*) of RC beam.

$$K = 2.309 + 3.474\,(S/d) - 5.175\,(S/d)^2$$

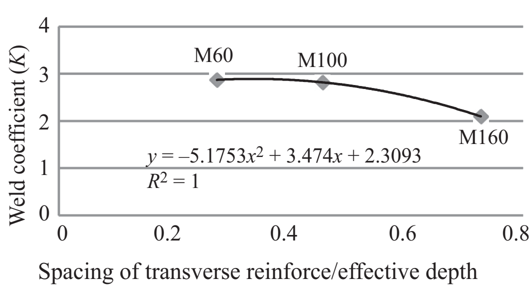


Fig. 10 Variation of weld coefficient (*K*) with *S*/*d*

If the weld coefficient goes below 2 then the *S*/*d* value i.e the ratio of spacing of transverse steel to the effective depth will be greater than 0.75. At present the IS 456-2000[19] allows maximum *S*/*d* for conventional stirrups as 0.75. As there is a similarity in the load deflection behavior between the RC beams provided with conventional stirrups and that with WWM, the minimum value of 'weld coefficient' may be taken as 2. Further the maximum value of weld coefficient may be arrived at based on the minimum spacing limits for transverse steel imposed by the standard codes of practice.

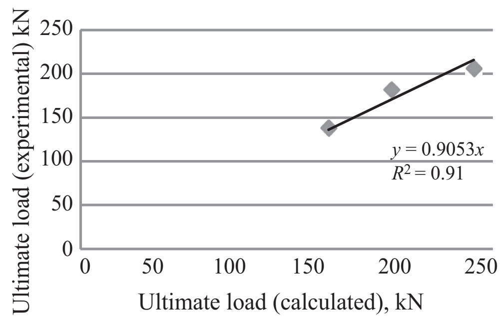


Fig. 11 Comparison between the calculated and experimental ultimate load of RC beams with WWM as transverse reinforcement at different spacing's

The above discussion on the behavior of the beams have clearly indicated the better performance of the weld mesh as transverse reinforcement over the conventional stirrups for the same spacing from the point of shear strength and economy in the required quantity of transverse steel. However, the effect of different diameters and spacing of wires of the WWM on the weld coefficient '*K*' and the performance of weld mesh as transverse reinforcement need to be investigated for the shear span to depth ratios other than 3, adopted in the present investigation.

CONCLUSIONS

The following are the conclusions arrived at after the study of welded wire mesh as transverse reinforcement replacing the conventional stirrups.

- For the same spacing of transverse steel in the form of mesh / stirrups the ultimate load of the RC beam with welded wire mesh as transverse reinforcement is more compared to the RC beams with conventional stirrups.
- For the similar spacing of transverse steel, even the less quantity of transverse steel in the form of WWM will be able to provide similar or better performance of RC beams compared to that of RC beams having conventional stirrups.

- The nature of failure / behavior of the RC beam remained more or less similar with the replacement of conventional stirrups with welded wire mesh as transverse reinforcement for the same spacing of transverse steel in the form of mesh / stirrups.
- As the spacing of transverse reinforcement (in the form of mesh / stirrups) reduced, the rate of increase of load in beams with weld mesh as core zone transverse reinforcement is observed to be more than that of beams with conventional stirrups
- The effect of welded wire mesh as transverse reinforcement in enhancing the shear resistance of RC beams is quantified using the new parameter termed as 'weld coefficient (*K*)'. The weld coefficient proposed is considered to take in to account indirectly, the effect of the presence of horizontal wires (i.e the wires of the weld mesh parallel to the width of the RC beam) welded to the vertical wires of WWM in the improved shear performance of RC beam having WWM as transverse reinforcement in place of conventional stirrups.
- The *W*eld coefficient (*K*) can be expressed in terms of the ratio of spacing of transverse steel (*S*) to the effective depth (*d*) of RC beam provided with the WWM as transverse reinforcement in place of conventional stirrups and is given by:

$$K = 2.309 + 3.474\,(S/d) - 5.175\,(S/d)^2$$

- The increase in the ultimate loads, satisfactory serviceability behavior together with increase in the slope of shear cracks with vertical and reduced consumption of transverse steel justifies the enhanced effectiveness of welded wire mesh over the conventional stirrups as transverse reinforcement the same spacing of transverse steel.

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NOTATION

Am	-	Cross sectional area of five vertical wires of weld mesh = 21.49 sq.mm
As	-	Cross sectional area of two vertical legs of the stirrup = 40.83 sq.mm
Ism	-	Percent improvement in shear strength of RC beams with weld mesh as transverse reinf. over that with conventional stirrups for different spacing's
K	-	Weld coefficient = [(*Vm* –*Vs*) (*S*/*d*) + *fys As*] / (*fym Am*)
Pc	-	Expt. ult. load RC beam (C100) with no shear reinforcement = 117.25 kN
Pum	-	Expt. ult. load of RC beam with weld mesh as transverse reinforcement
Pum (*calc*)	-	Calculated ult. load of RC beam with weld mesh as transverse reinf. considering the average weld coefficient (*K*) equal to 2.0
Pus	-	Expt. ult. load of RC beam with conventional stirrups as transverse reinforcement
S	-	Spacing of transverse reinf. (weld mesh or stirrups)
Vm	-	Shear force at ultimate of RC beam with Weld mesh as transverse reinforcement = *Pum*/2
Vs	-	Shear force at ultimate of RC beam with conventional stirrups as transverse reinf. = *Pus*/2
Vc	-	Shear force at ultimate of RC beam with no shear reinforcement = *Pc*/2 = 58.62 kN
d	-	Effective depth = 220 mm
fym	-	267.7 MPa
fys	-	285.6 MPa

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