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ORIGINAL PAPER

A novel means of improving the performance of reinforced concrete beams using the welded wire mesh as core zone reinforcement

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Abstract

The present practice of using shear reinforcement in the form of stirrups, which go round near to the periphery in reinforced concrete beams, leaves the core zone of the cross section, where there is existence of high shear stress, un-reinforced. This leads to sudden appearance and propagation of cracks, leading to brittle failures under shear. The performance of the reinforced concrete beam will get improved if such core zone is also reinforced. This paper presents a novel means of using prefabricated mesh either as transverse reinforcement in place of conventional stirrups or as longitudinal core reinforcement apart from stirrups/ties, which not only reinforces the core zone of reinforced concrete cross section but also provide resistance against diagonal tension due to shear in continuous manner. The pilot experimental investigation conducted on RC beams provided with welded wire mesh as core zone reinforcement indicated improved performance compared to the ultimate resistance of RC beams provided with only conventional stirrups.

Keywords RC beam · Core zone · Longitudinal reinforcement · Welded wire fabric · Shear strength

Introduction

Reinforced concrete (RC) is the most widely used construction technique in the modern day construction. The development of different design theories has advanced the use of reinforced concrete. Safety being the primary objective of the design of reinforced concrete (RC) beams, the occurrence of sudden failures should be avoided. The RC beams must have adequate safety margin against different types of failures. The reinforced concrete beams are designed primarily for flexural and shear. In the design of a reinforced concrete member, flexure is usually considered first, leading to the size of the section and the arrangement of reinforcement to provide the necessary resistance for moments. Beams are then designed for shear. The shear failure mechanism varies depending upon the cross-sectional dimensions, the geometry, the types of loading, and the properties of the member (Słowik 2014; ACI-318 2011). Since shear failure is frequently sudden with little or no advanced warning, the design for shear must ensure that the shear strength for every member in the structure exceeds the flexural strength. The main mode of shear failure in reinforced concrete beams is characterized by the formation of diagonal cracks near the support regions. Normally, the inclined shear cracks forms near support and extend toward the compression zone. It is understood that any form of effectively anchored reinforcement that intersects these diagonal cracks will be able to resist the shear forces to a certain extent (Al-Nasra 2013; Zakaria et al. 2009; Shuraim 2014). In general, the steel reinforcement is used in the tension zone of concrete elements since the concrete is weak in tension. Different types and strengths of steel reinforcements are used with cement concrete of different grades. The prefabricated reinforcement such as welded wire mesh also has been used as main reinforcement in RC slabs and as shear reinforcement in thin-webbed concrete beams (Pincheira et al. 1989; Ibrahim 2011). In addition to its use to resist tension in structural members, reinforcement is used in concrete construction for other reasons, such as: (1) to resist a portion of the compression force in a member, (2) to resist diagonal tension due to shear in beams, walls, and columns (Park and Paulay 1975). 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

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provide marginally high strength and cracking resistance (Gayathri and Kirthiga 2018; Alexander and Ramakrishnan 2016). Further, the investigations on the effectiveness of welded wire mesh as jacketing material indicated the improvement in the strength of damaged beams (Shaaban et al. 2018; Albidah et al. 2019; Mansuri et al. 2017). All the above-mentioned investigations have used the WWF only in the periphery of the cross section only. The published literature on the use of weld mesh as core zone reinforcement, where the intensity of shear stresses is large, is very scanty.

Research significance

In general the reinforced concrete (RC) beams subjected to transverse loading create non-uniform bending accompanied by internal shear forces. With the result, the reinforced concrete beam cross section experiences the normal and flexural shear stresses. The distribution of flexural shear stress across the depth of the cross section depends on the shape of the cross section. In the rectangular cross sections, the flexural shear stress is distributed non-uniformly across the depth of the cross section. In homogeneous rectangular cross sections, the intensity of flexural shear stress becomes zero in the outer edges and reaches maximum at the neutral axis i.e., near the core zone of the cross section as shown in Fig. 1.

At present, the reinforced concrete (RC)—vibrated or self-compacting concrete—elements are provided with rectangular stirrups (having required diameter, spacing, and number of vertical legs) for resisting shear force (Fig. 2). The stirrups go round near to the periphery. This kind of placement of stirrups in reinforced concrete beams leaves the core of the cross section where there is existence of high transverse stress, un-reinforced. The performance of the reinforced concrete elements under the influence of transverse stresses will get improved if such core zone is also reinforced. The present practice of using stirrups/ties cannot reinforce the core zone of the RC cross section. 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.

This paper presents a novel means of resisting shear and simultaneously improving the performance of reinforced concrete members by using a prefabricated mesh such as welded wire mesh (WWM) is presented. The welded wire mesh is used either as transverse reinforcement replacing totally the conventional stirrups (Fig. 3) or as longitudinal core reinforcement apart from conventional rectangular stirrups/ties (Fig. 4). The weld mesh placed either transversely or longitudinally in the core zone provides resistance against diagonal tension due to shear. The use of prefabricated mesh such as welded wire mesh as transverse or longitudinal core reinforcement will not involve any tedious bar bending work similar to that in making stirrups/ties. The simplicity in the means of resisting shear in reinforced concrete members by using a prefabricated mesh as longitudinal core reinforcement apart from conventional stirrups/ties enables rapid adoption of technology by the fabricators of reinforcement cages used in the construction field.

The main objective in the present investigation is to study the performance of RC beam wherein the welded wire mesh is used either as transverse reinforcement replacing totally the use of conventional stirrups or as longitudinal core reinforcement apart from conventional rectangular stirrups/ties,

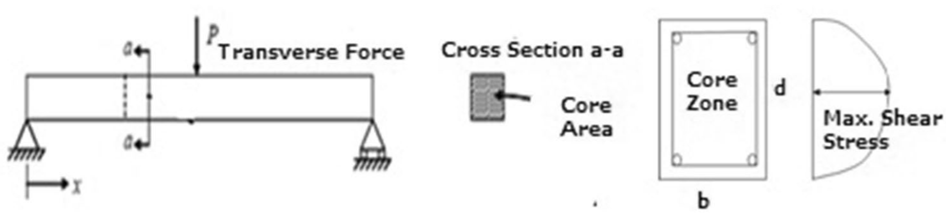

Fig. 1 Shear stress distribution across the rectangular beam cross section

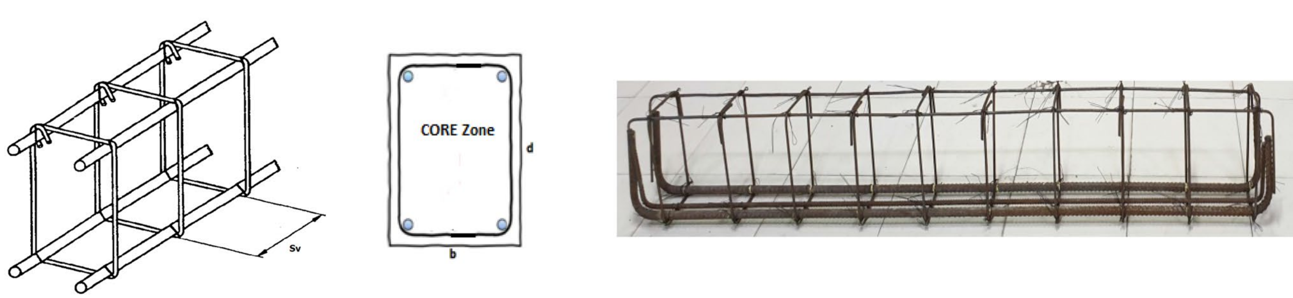

Fig. 2 Reinforcement cage and cross section with conventional stirrups

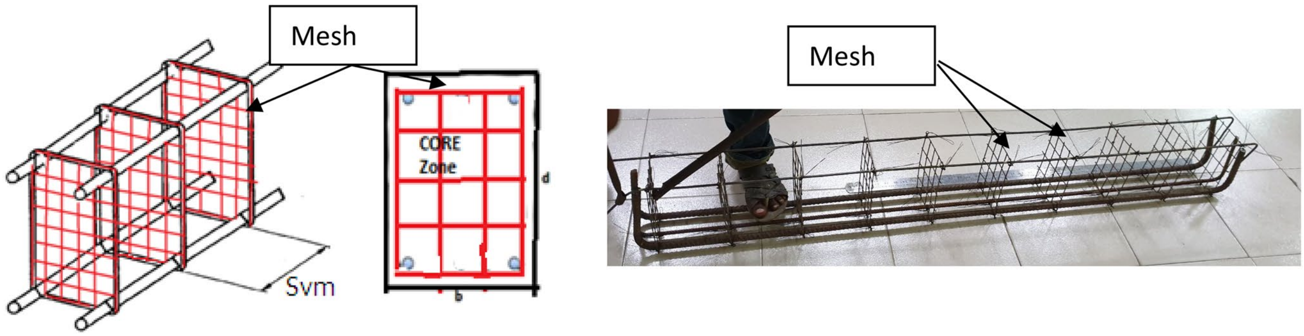

Fig. 3 Reinforcement cage with mesh as transverse reinforcement replacing the conventional stirrups and its cross section

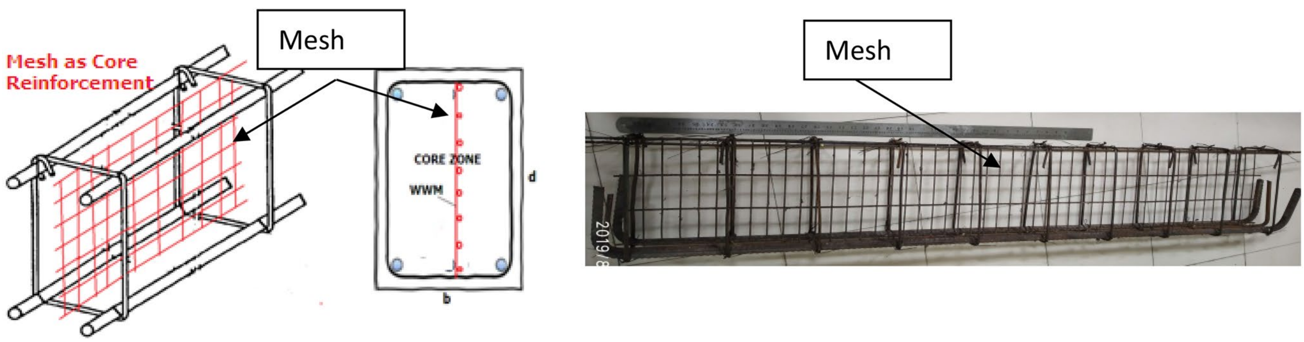

Fig. 4 Reinforcement cage with mesh as longitudinal core reinforcement apart from stirrups and its cross section

and compare the same with the shear performance of RC beam provided with only conventional stirrups.

Experimental program

The experimental program consisted of casting and testing of three numbers of reinforced concrete (RC) beams. Out of three RC beams, the first beam is a control beam (R160) in which the shear reinforcement consists of conventional stirrups. The control beam is specifically designed to fail in shear by adopting the spacing of stirrups as 160 mm against the required design stirrup spacing of 140 mm. The remaining two beams (M160 and L160) consisted of welded wire mesh in the core zone. The RC beam-M160 consisted of welded wire mesh as transverse reinforcement replacing totally the conventional stirrups. The spacing of weld mesh as transverse reinforcement adopted is 160 mm. In RC beam-L160, the mesh is placed longitudinally in the middle of the core zone of the cross section apart from conventional stirrups at a spacing of 160 mm. The spacing of wires in the weld mesh is chosen so as not to cause any hindrance to the flow of concrete. The shear span to effective depth ratio adopted for all the beams is three. The size of the RC beams adopted is 140 mm width, 300 mm overall depth, and 1650 mm in length. Three concrete cubes ($150 \times 150 \times 150$ mm) were cast and tested along with each specimen to determine the concrete compressive strength. The details of specimens tested are given in Table 1. The reinforcement cages used are shown in Figs. 2, 3 and 4.

Materials used in concrete

The cement used was OPC of 53 grade confirming to IS 269-2015. River sand conforming to Zone-II of IS: 383 (2016) was used as fine aggregate. The specific gravity and bulk density of sand are 2.65 & 1.45 g/cm^3, respectively. Well-graded aggregate conforming to IS: 383-2016 with 20 mm nominal size of granite is used as coarse aggregate 2.80 and 1.5 g/cm^3 are specific gravity and bulk density, respectively. Potable water was used in the experimental work. The details of concrete grade, mix proportion, and quantity of concrete making materials used are given in Table 2.

Casting and testing of beams

Steel channels of required height were placed back-to-back and were tightened by nuts and bolts to maintain the width of beam as 140 mm. The inner side of the moulds was lubricated by grease, and cover blocks of proper thickness

Table 1 Details of RC beam specimens tested

S. no.	Beam	Cross section size (mm) (b × D × L)	Longitudinal reinforcement		Core zone reinforcement	Transverse reinforcement
			Tension	Comp.	WWM	Stirrups
1	R160	140 × 300 × 1650	2–12Φ and 1–16Φ	2–6Φ	–	2 Lgd 6Φ @160 c/c
2	M160				WWM (Transverse) @160 c/c	–
3	L160				WWM (Longitudinal)	2 Lgd 6Φ @160 c/c
Concrete Compression strength = 27.5 MPa		*WWM: Welded wire mesh* Wire dia = 2.16 mm Φ, Spacing of wires: Vertical = 80 mm, Horizontal = 30 mm, Yield strength of Wires = 267.7 MPa, Ultimate strength of wires = 347 MPa Nominal mass per square meter = 1.316 kg				*Longitudinal reinforcement* Yield strength = 424 MPa Ultimate strength = 538 MPa *Transverse reinforcement* Yield strength = 285.6 MPa Ultimate strength = 361 MPa

Weight of one stirrup = 0.12 kg, Weight of one transverse mesh = 0.055 kg and Weight of longitudinal mesh per 160 mm length = 0.057 kg

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* super plasticizer (SP 430, make: fosroc chemicals)

were placed to maintain the effective depth of the beam as 265 mm. The reinforcement cage was placed on the cover blocks in the moulds. The required amount of materials was mixed in dry state on the platform, and then, water is added. The concrete was placed in the moulds and compacted with vibrator. After 24 h 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%, respectively. After the completion of curing period, the specimens were kept under the shade.

One day before testing the cured beams were white washed, and the location of supports and the positions of deflection gauges during the test were marked on it with pencil and kept ready for testing. Further, a speckle pattern was marked on the side face to enable capture of strains using digital image correlation (DIC) technique. The beams were tested under two point loading after a curing period of 28 days, on the TINIUS OLSEN testing machine of 200 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 achieved by adjusting carefully the inlet valve of the testing machine so that the movement of crosshead was controlled and is maintained at 1 mm per minute. This nearly simulated the displacement-controlled loading. The testing was continued till the ultimate load or the test setup became unstable whichever is earlier. The cracks noted on the beams were marked for comparison of crack pattern and nature of failure.

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

Results and discussions

During the testing, the RC beam (R160) provided with conventional stirrups at 160 mm spacing as transverse reinforcement has failed by developing a diagonal tension crack in shear span as expected (Fig. 8a). This is because the beam R160 was intentionally designed to fail in shear by keeping the spacing of stirrups (160 mm) larger than that required to avoid shear failure.

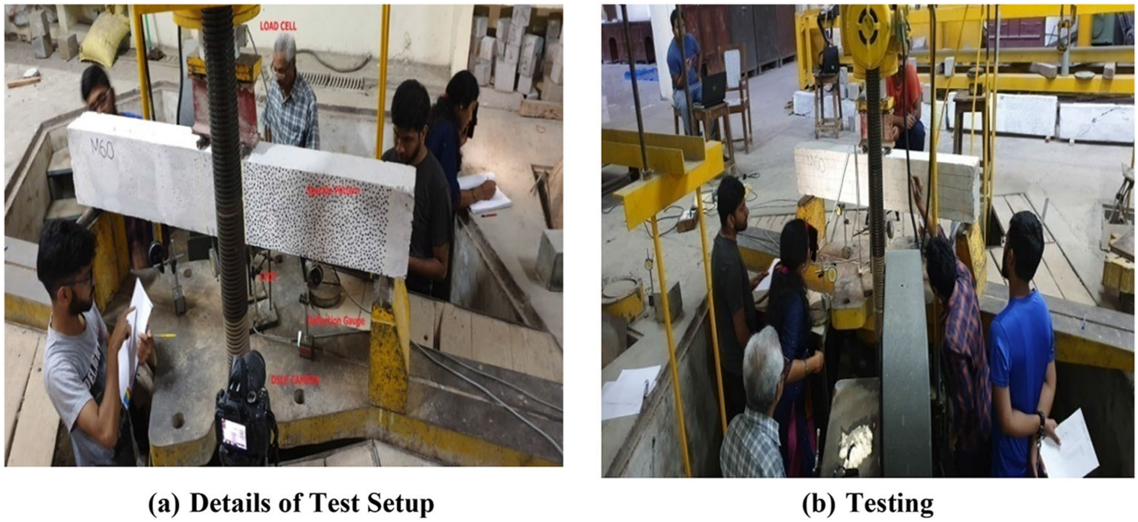

Fig. 5 **a** Details of test setup, **b** testing

Table 3 Loads and deflection values of tested beams

S. no.	Beam	At service		At ultimate		% increase in ultimate load	Nature of failure At ultimate	Slope of shear crack with vertical
		Ps (kN)	ds (mm)	Pu (kN)	du (mm)			
1.	R160	117.40	3.78	176.04	7.10	–	Shear	60.3^0
2.	M160	122.30	3.80	181.55	8.10	3.12	Shear	70.9^0
3.	L160	181.50	4.02	272.32	9.86	54.70	Flexure	57.1^0

Ps load at service; *Pu* load at ultimate; *ds* deflection at service, *du* deflection at ultimate

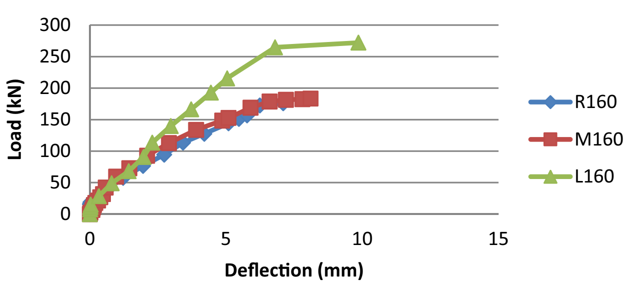

Fig. 6 Load versus deflection of RC beams

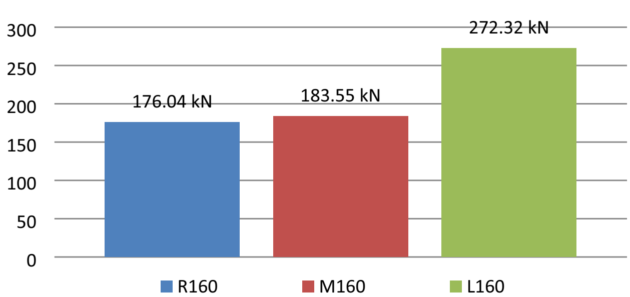

Fig. 7 Ultimate load comparison

Effect of welded wire mesh in place of stirrups as transverse reinforcement

The RC beam (M160) provided with welded wire mesh as transverse reinforcement at 160 mm spacing in place of conventional stirrups has failed in shear by developing a crack which almost joins the load point and support(Fig. 8b. The slope of the crack (Angle made by the shear crack with vertical, shown in Table 3) in M160 beam is more than that of R160. This type of failure can be considered as equivalent to an arch action in shear (Kani 1964). The increase in the slope of the shear crack may be attributed to the increased resistance to the diagonal tension cracks provided by the core zone transverse reinforcement in the form of welded wire mesh. This clearly indicates the effectiveness of mesh over conventional stirrups, in controlling/delaying the formation of shear crack. In both R160 and M160 beams, very few flexural cracks were noticed and the failure was due to the formation of a major shear crack that has developed suddenly. However, the ultimate (failure) load observed in M160 beam is only about 3% more than that of R160 beam. The ductility indicated by the area under load deflection plot (Fig. 6) remained more or less same in both R160 and

Fig. 8 The failure patterns of the beam specimens

(a) R160 Beam Crack pattern at Ultimate –Failed in Shear

(b) M160 Beam Crack pattern at Ultimate –Failed in Shear

(c) L160 Beam Crack pattern at Ultimate – Failed in Flexure

M160. Further, the weight of steel consumed in using the mesh as transverse reinforcement is almost less than half of the weight of steel consumed in conventional stirrups for the same spacing. This indicated the better performance of welded wire mesh as transverse reinforcement over the conventional stirrups from the point of both strength and economy.

Effect of welded wire mesh as longitudinal core zone reinforcement

The RC beam (L160) provided with welded wire mesh as longitudinal core zone reinforcement apart from conventional stirrups has failed by developing clear flexural cracks (Fig. 8c. Though the control beam was designed to fail in shear, the provision of longitudinal core zone reinforcement in the form of welded wire mesh made the beam L160 to fail in flexure. The beam L160 also developed shear cracks initially. However, these shear cracks were stopped extending further at about 80% of the ultimate load and allowed the flexural cracks near the middle of the span to grow and caused the crushing of concrete in the compression zone at ultimate. Finally, the L160 beam has failed in flexure. Further, the ductility indicated by the area under load deflection plot (Fig. 6) reveals that L160 has more ductility compared to R160. The total weight of steel consumed in using the welded wire mesh as longitudinal core zone reinforcement apart from stirrups is about 30% more than that consumed in using only conventional stirrups as transverse reinforcement. However, the ultimate (failure) load observed in L160 beam is about 54.7% more than that of R160 beam. The increase in the ultimate load may be attributed to the continuous resistance provided by the longitudinal core zone reinforcement in the form of welded wire mesh. Particularly, the mesh provided longitudinally in the core zone provides resistance in continuous manner unlike the discrete resistance provided by the regular stirrups. The continuity in resistance provided by the prefabricated mesh against diagonal tension due to shear delays the formation of shear cracks and improves the performance of reinforced concrete members. This indicated the superior performance of welded wire mesh as longitudinal core zone reinforcement over the performance of RC beam with conventional stirrups/mesh as transverse reinforcement.

Effect of welded wire mesh as core zone reinforcement on deflection at serviceability

The deflection at service load (taken as two-thirds of ultimate, shown in Table 3) in all the three beams tested is very much less than the allowable deflection (Span/250) as per the existing Indian code of practice (IS 456 2000) for the design of RC members. This indicates the use of mesh as transverse reinforcement replacing conventional stirrups did not violate the required serviceability norms.

The behavior of the beams as described above clearly indicates the superiority of the weld mesh as transverse reinforcement over the conventional stirrups for the same spacing from the point of shear performance and economy in the quantity of transverse steel. However, the performance of weld mesh as transverse/longitudinal core zone steel need to be investigated for the shear span to depth ratios other than three, adopted in the present investigation.

Conclusions

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

1. The ultimate load 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.
2. For the same spacing of stirrups as transverse reinforcement, the RC beam provided with weld mesh as longitudinal core zone reinforcement has shown not only increase in ultimate (failure) load but also changed the nature of failure from shear to flexure compared to that of the RC beams provided with only conventional stirrups.
3. There is an increase in the slope of shear crack with vertical 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.
4. The use of mesh either as transverse reinforcement replacing the conventional stirrups or as longitudinal core zone reinforcement did not violate the required serviceability norms.
5. For the same spacing of transverse reinforcement (in the form of mesh/stirrups) the weight of steel consumed in using the mesh as transverse reinforcement is almost half of the weight of steel consumed in conventional stirrups for the same spacing leading to the economy in the steel quantity.
6. The behavior of the RC beams tested clearly indicates the superiority of the welded wire mesh either as transverse reinforcement replacing the conventional stirrups or as longitudinal core zone reinforcement for the same spacing of transverse steel from the point of performance at ultimate.

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Compliance with ethical standards

Conflict of interest The authors hereby declare that they have no conflict of interest.

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