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REINFORCEMENT DETAILING FOR OPENING CORNERS

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ABSTRACT

In the present study conventional arrangements of detailing of rebars in the opening corners have been shown to be structurally inadequate and an improved but simple detailing of opening corners has been proposed which gave corner efficiencies in the range of 90 to 95%. The work includes performance review of three recommended detailing systems namely, L-type (SP1), inverted U-type with corner stirrups (SP2), U-bars lap spliced with the main reinforcement (SP3) and on the basis of observed behavior, a modified detailing arrangement, to be used in the corner joints subjected to opening moment has been recommended. The experimental work consisted of testing nominally identical planer portal-type opening corner specimens made of normal strength concrete under monotonically increasing static loads. The results obtained are analysed in terms of crack widths, ultimate load and corner efficiencies of the specimens.

KEYWORDS: Detailing Systems, Diagonal tension,Corner Efficiency.

INTRODUCTION

The behavior of joints connecting beams and columns is quite complex and thus the reinforcement detailing in the joints is very crucial for the satisfactory structural performance of joints. Figure1.1 represents the common examples of opening corner joint are found in portal frames, water tanks and retaining walls.

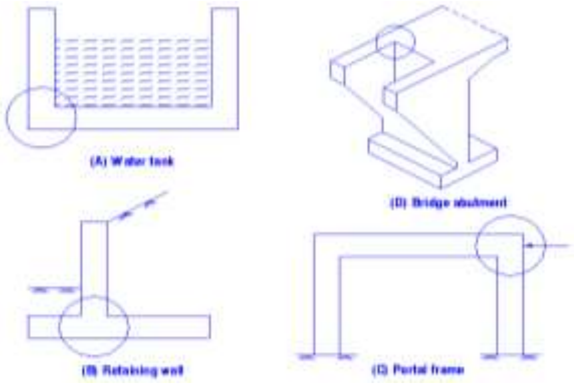


Figure1.1 : Examples of Opening Corners Joints

For statically determinate structures, such as in bridge abutments, retaining walls and tanks, there is no redistribution of moments to adjacent structural elements so the strength of the corner is critical to the integrity of the entire structure. Hence the first requirement is that the joint should be capable of withstanding a moment of at least the same magnitude as that of the adjoining cross sections.

The reinforcement layout must be that it should have sufficient yield capacity and should be able to undergo substantial deformations without significant loss of strength. If the joint has a certain yield capacity and is capable of acting as a plastic joint then moment redistribution will occur and the adjacent members will carry more load then what was intended.

In opening corner joints, the re-entrant corners, where there is a concentration of tensile stresses, acts as a notch at which corner cracks are initiated the limitation of corner crack widths to the same magnitude as for crack widths at other sections is the third demand on the design of the joint. Also the design of joint in general and detailing of reinforcement in particular is that it should be easy to fabricate and place.

A number of detailing arrangements systems have been investigated,Sandbye (1968), Swann (1969), Mayfield and Bennison (1972), Balint and Taylor (1972), Nilsson (1973), Taylor (1974), Park and Paulay (1975), Noor (1977), Skettrup etal (1984), Schlaich and Jennewein (1987), Abdul-Wahab and Ali (1989), Schlaich and Schafer (1991), Singh and

Kaushik (2002), Singh and Kaushik (2003), Dhar and Singh(2004),Campana etal (2013) and their relevant recommendations have been reported in the literature. A review of the detailing arrangements which yield good structural performance shows that a majority of them are complicated and may be cumbersome to implement and are thus not suitable for routine site implementation. Therefore, a need was felt for a performance review of the commonly used detailing arrangements for opening corner joints so that on the basis of such a review a new method of detailing opening corner joints can be suggested. This method of detailing is expected to be efficient and practical and should lead to better all-round structural performance of opening corner joints.

EXPERIMENTAL PROGRAMMME

2.1Test Programme

Cement

In the present investigation, 43 grade Ordinary Portland Cement conforming to IS: 8112-1989 was used. The cement was tested in accordance with the methods of test specified in IS: 8112-1989. Table 2.1 represents the physical properties of the cement used.

Table 2.1: Physical Properties of Cement

Sr. No.	Property	Experimental value
1	Consistency of Cement	30%
2	Specific Gravity	3.14
3	Initial Setting Time	92 minutes
4	Final Setting Time	298 minutes
5	Comp. Strength (N/mm^2) 3 days 7days 28 days	 24.67 35.04 47.28
6	Fineness (Dry Sieving)	2.5 %

The experimental values conforms to specified values as per IS:8112-1989.

Aggregates

The results of sieve analysis of fine and coarse aggregates are listed in Table 2.2 and 2.3. The physical properties of fine and coarse aggregates are listed in Table 2.4 and 2.5

Table 2.2: Sieve Analysis of Fine Aggregates

IS Sieve	Weight Retained on Sieve (gm)	Cumulative Weight Retained (gm)	%age Passing
10 mm	0.00	0.00	100.00
4.75 mm	15.20	15.2	98.48
2.36 mm	25.10	40.30	95.97
1.18 mm	250.20	290.5	70.95
600 µ	160.10	450.60	54.94
300 µ	320.30	770.90	22.91
150 µ	217.20	988.10	1.19
Pan	11.90	1000	-

Cumulative percentage wt. retained =255.56
Fineness Modulus (F.M.) = 255.56/100= 2.55

Table 2.3 : Fineness Modulus of Proportioned Coarse Aggregates

I S Sieve	Wt.Retained on Sieve (10mm Agg) (gm)	Wt. Retained on Sieve (20mm Agg) (gm)	%age Passing
80mm	0.00	0.00	100.00
40 mm	0.00	0.00	100.00
20 mm	0.00	39.10	99.61
10 mm	2160.30	4881.20	29.19
4.75 mm	2832.10	73.20	0.14
Pan	2.80	6.50	-

Cumulative percentage wt. retained = 171.06 + 500
= 671.06
Fineness Modulus (F.M.) = 671.06/100= 6.71

Table 2.4: Physical Properties of Fine Aggregates

Characteristics	Results Obtained
Grading	Grading Zone II
Fineness Modulus	2.77
Specific Gravity	2.64
Water Absorption (%)	0.48%
Free Moisture Content (%)	Nil

Table 2.5: Physical Properties of Coarse Aggregates

Property	Results Obtained
Fineness Modulus	6.71
Specific Gravity	2.66
Water Absorption (%)	0.52
Moisture Content (%)	Nil

Water

As per IS: 456-2000, potable water is generally considered suitable for mixing and curing concrete.

Reinforcing Steel

High Yield Strength Deformed (HYSD) 'TOR' steel bars of nominal diameters 8mm and 10mm were used as longitudinal reinforcement in the test specimens; and 8 mm diameter bars were used as hanger bars. Mild steel plain bars of 6 mm diameter were used as nominal shear reinforcement in the form of two-legged closed stirrups in all the specimens at a spacing of 95 mm center to center. The reinforcing bars conformed to the requirements of IS: 1786-1985.

Design of Concrete Mix

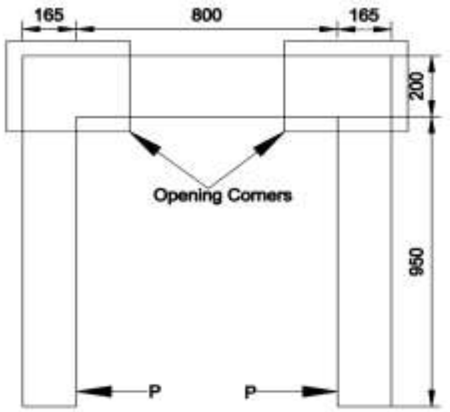
The concrete mix was designed as per the codes IS: 10262-1982 and SP: 23-1983. The new information given in IS: 456-2000 was incorporated and the procedure was modified to that extent. A summary of the mixture proportions is presented in Table 2.6.

Table 2.6: Concrete Mixture Proportions
(Material Quantities Per Cubic Meter of Concrete)

Cement (kg)	Fine Agg. (kg)	Coarse Agg. (kg)	Water (Litres)
424	584.68	1143.60	194

Specimen Details

Scaled portal-type planer specimens were used for studying the behavior of opening corner joints. The specimen shape (Plan view) and dimensions are shown in Figure 2.1. The breadth to depth ratio of the vertical framing member adopted in this investigation is 0.825. The out-of-plane dimension of the specimens was 200 mm. Detail of control test specimens is shown in Table 2.7.



All Dimensions are in mm

Figure 2.1: Plan of Test Specimen

Table 2.7: Detail of Concrete Test Specimens

Specimen Designation	Reinforcement Detail	%Tension Reinforcement	% of Splay Steel
SP1	L- Type	0.76	---
SP2	Inverted -U + Diagonal Steel	0.76	---
SP3	U- Spliced	0.76	---
SP4	Inverted-L+Splay Steel	0.76	50

Detailing Arrangements

The detailing arrangements employed in opening corner joints selected for review in this investigation are shown in Figure 2.2.

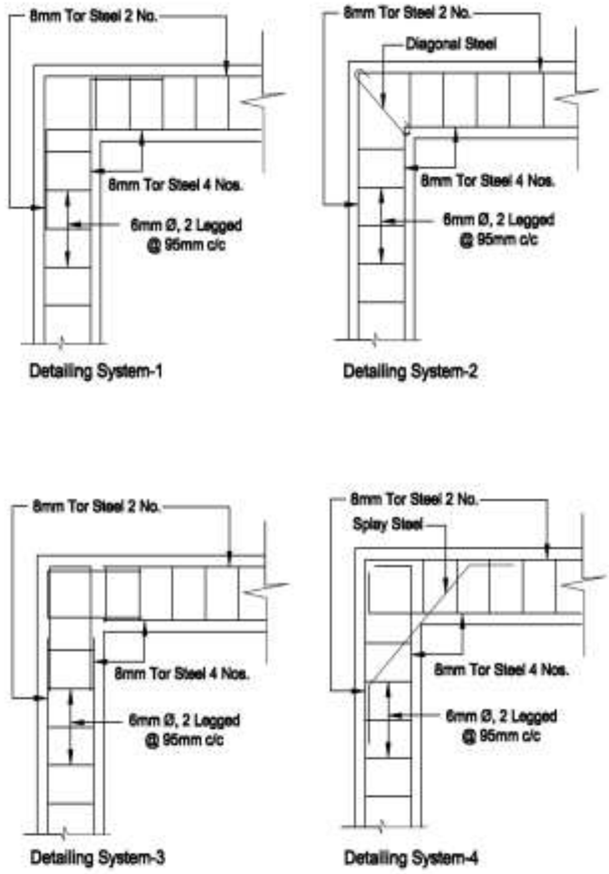


Figure 2.2: Plan View of the Detailing Arrangements Investigated in the Opening Corner Specimens

In detailing system 1, the main tension reinforcement from either of the framing members is simply extended into the other framing member and anchored on the outer face with a 90 degree hooked extension taking care that the outer face with a 90 degree hooked extension taking care that a nominal anchorage length equal to 50 times the diameter of rebars was available to this steel beyond the critical section.

In detailing system 2, the main tension reinforcement from either of the framing members was simply bent in the continuous manner along the same face of the adjoining framing member .Hence, in this arrangement; the same tension reinforcement was continued through a 90 degree bend from one framing member into the other. In addition, two 10 mm diameter open links were provided as diagonal steel in order to resist the diagonal tension in the opening corner specimens reinforced with detailing system 2. In detailing system 3, overlapping U-bars spliced to the longitudinal reinforcement in the framing member was used to confine the concrete in the corner region. The U-bars had the same diameter as the longitudinal reinforcement and the splice length was nominally kept equal to fifty times the rebar diameter.

The Detailing system 4, main steel from either of the framing members was extended along the same face into the corner region and then bent back into the corner through 90 degree turn. This arrangement of longitudinal steel from either of the framing members serves to confine the corner concrete. In addition to the aforesaid reinforcement, splay steel with an area equal to 50% of the main tension reinforcement in either of the framing members was provided in detailing system 4 to reinforce the re-entrant corner. The straight length of the splay bars in either of the framing member kept nominally equal to 200mm.

Test Instrumentation

The schematic loading arrangement is shown in Figure 2.3 and 2.4.The applied load was measured with the help of a sensitive proving ring of 50 KN capacity, the proving ring being securely mounted between the loading jack and the cover plate. Baty dial gauges with magnetic base were used to measure the deflections in the vertical framing members at the points of load application. Concrete surface crack widths were measured with a hand-held illuminated optical microscope having a least count of 0.01 mm. DEMEC strain gauges of 100 mm gauge length were used for measuring concrete surface strains at selected locations along the corner diagonal of specimen. The least count of the gauge was 0.0001 inches.

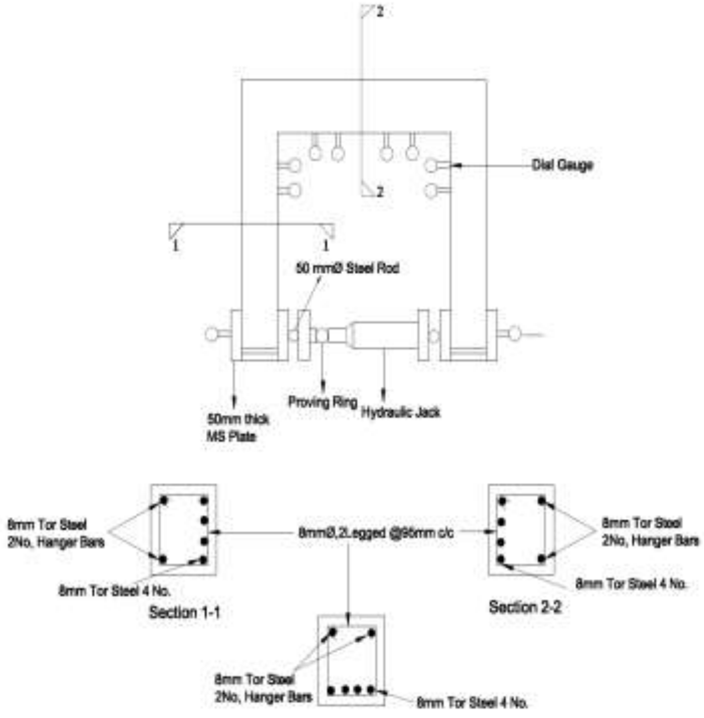


Figure 2.3: Typical Test Set-up for the Opening Corner Specimen

Figure 2.4: Schematic Loading Arrangement

Testing of Hardened Concrete:

The results of the compressive strength, split tensile strength and flexural strength of the non-fibrous concrete specimens are tabulated in Tables 2.8

Table 2.8: Test Results for Non Fibrous Concrete Specimens.

Specimen Designation	Compressive Strength (N/mm^2)	Split Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
SP1	37.52	3.52	4.33
SP2	39.24	3.92	4.51
SP3	38.25	4.01	4.46
SP4	37.50	3.89	4.21

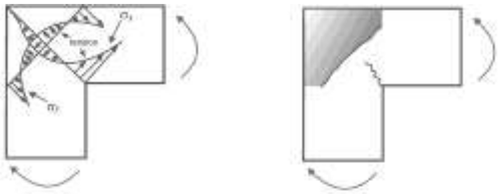
RESULTS

The experimentally obtained crack widths, failure moments and joint efficiencies obtained for various specimens tested in the study are reported in Table 3.1.

Table-3.1: Test Results of Specimens with Different Detailing Arrangements

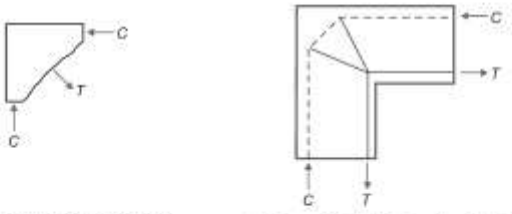
Specimen Designation	Crack Width Before Failure (mm)	Theoretical Ultimate Moment, M_{UC} (kN-m)	Test Failure Moment M_{UC} (kN-m)	Corner Efficiency M_{UT}/M_{UC} x100 (%)
SP1	0.40	10.23	5.40	52.72
SP2	0.95	10.24	7.14	69.74
SP3	1.05	10.22	8.58	83.97
SP4	1.15	10.21	9.55	93.50

The elastic distribution of stresses in an opening corner is shown in Figure-3.1.



(a) Distribution of Stresses

(b) Cracking Pattern in an Opening Corner



(c) Equilibrium of Corner

(d) Truss Model for Opening Joint

Figure 3.1: Elastic Distribution of Stresses in an Opening Corner

It can be observed from this stress distribution that there is a higher concentration of tensile stresses at the re-entrant corners of the opening joints. This stress concentration results in development of cracks at the re-entrant corners, due to the poor tensile strength of concrete. Therefore, in the specimen reinforced with the detailing arrangement 1, SP1, the crack was initiated, as expected, at the re-entrant corner and it gradually progressed for some distance along the corner diagonal as the loading was further increased. Subsequently, this crack followed the main reinforcement, bent from one member into the other, and then branched out towards the compression zone of the specimen in a direction more or less normal to the corner diagonal. At higher load increments, the outer portion of the corner had a tendency to be pushed off because of the diagonal tension crack and finally this portion of the corner get detached in the form of a wedge leading to the failure of the corner due to loss of structural integrity.The failure of specimen SP1 was abrupt and brittle.

The failure of specimen SP1 was abrupt and brittle. The corner efficiency was recorded as 52.72% which is higher than the efficiency of 32% obtained by Nilsson (1973) for his specimen U21, which was detailed in a manner identical to SP1. However, the efficiency is comparable to the efficiency of 50.50%, reported by Singh (2002) for his corner specimen detailed in a manner comparable to the specimen SP1 of this investigation. The behavior of opening corners with L-type detailing is controlled by the ability of the concrete to resist diagonal tension and since a higher grade of concrete was used in SP1 compared to the concrete grade used by Nilsson (1973) in his specimen U21, the efficiency factor of the former was higher than that of the latter.

It may be noted that there was no diagonal reinforcement provided in the corner to resist the diagonal tensile force induced due to external loading and therefore compressed concrete which was not confined by any reinforcement in the corner was pushed off. The presence of hanger reinforcement around the outside the corner served little purpose, since this reinforcement is also compressed on loading and would cause spalling of the cover concrete which in turn would exacerbate failure of the corner.The diagonal crack which had a tendency to push off the portion of the concrete outside the bent reinforcement, in the form of a wedge, resulted in the failure of the opening corners.

The mode of failure of specimen SP1 suggests that a mechanism to strengthen the corner diagonal in terms of shouldering the diagonal tensile force would result in higher efficiencies.

The discussion presented above shows that in order to improve the structural performance of opening corner, the steel aligned diagonally and perpendicular to the diagonal tension crack should be provided to resist the diagonal tension induced in the corner and the same has been explored in specimen SP2, which was reinforced with the detailing arrangement 2.

The main reinforcement in specimen SP2 consisted of four numbers 8 mm diameter inverted U-type deformed bars. Two number of 10 mm diameter tie bars aligned, as far as possible, along the corner diagonal were provided to resist the diagonal tension in the corner. It was observed that the introduction of diagonal steel in the corner improved the structural behavior of the corner. The diagonal steel was apparently effective in carrying a significant amount of the diagonal tension so the premature diagonal tension failure of the kind witnessed in specimen SP1 was avoided and the joint efficiency increased to 69.74%. The relatively lower efficiency factor for the specimen SP2 of this investigation is attributed to possible opening of tie bars at their hooked ends. If hooks of the tie bars open then end anchorage is lost and the diagonal tension force acting along the corner diagonal can no longer be resisted and failure is inevitable.

The testing of specimen SP2 showed that inspite of the provision of diagonal steel in the corner joint, 100% efficiency factor was still not obtained. The failure of this specimen was marked by formation of a diagonal tension crack which had a tendency to push the concrete in the outer part of the corner away, in the form of a wedge.

This is due to the reason that for the diagonal steel to be effective, it should be extended far into the compression zone and should be wrapped or welded around to the main steel bars in the corner, in addition to being anchored around compression steel, so that the concrete does not undergo large strains before the load is transferred to the diagonal steel. This is, however, difficult to achieve while detailing the reinforcement in the joints. Practically, the use of diagonal steel in the form of stirrups or links as provided in the present study may be possible in beam-column corners, but in wall slab corners as encountered at the junctions of wing walls and abutments or at junctions of the stem and the base slab in cantilever retaining walls, such a detailing could be quite complicated to carryout.

In order to overcome the limitations of detailing system 2, another modification in detailing of the corner was investigated and it was decided to provide four straight bars of 8 mm diameter along the tensile face as well compression face of all members. The corner was confined with over-lapping U-shaped bars spliced to the longitudinal reinforcement in the framing members. The arrangement of this detailing used in the specimen may be seen in the Figure 2.2 (Detailing System 3).

This detailing was comparable to the one used by Johansson (2001) in his specimen RV10. The schematic cracking pattern and mode of failure obtained by Johansson (2001) is shown in Figure 3.2.

The advantage of the detailing adopted in SP3 is that presence of reinforcement loop in the form of overlapping U bars will confine the corner concrete and the 180° bent bars provide additional amount of reinforcement perpendicular to the diagonal crack marked as member 2 thus improving the behavior of the opening corner.

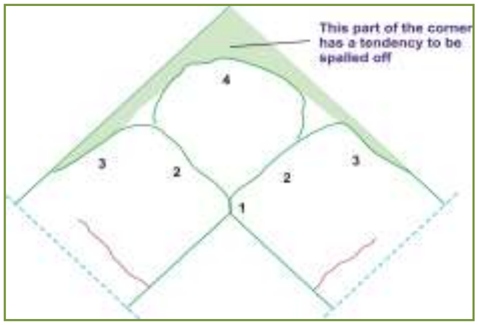


Figure 3.2: Schematic Cracking Pattern in an Opening Corner for U-type Detailing (Johansson,2001)

On loading of specimen SP3, as anticipated, the first crack appeared at re-entrant corner at a load of 4 kN and on further loading followed the loops and progressed towards the compression faces of the framing members. Specimen SP3 exhibited an efficiency of 83.97%. The maximum crack width observed at failure load was 1.05 mm. Though a relatively improved structural behavior was observed in this specimen, 100% efficiency was still not achieved. This is attributed to the fact that cracking around the loop reinforcement reduced their anchorage and consequently the load carrying capacity decreased, more so because of apparent rotation of the loops..

In order to further improve the corner strength, the arrangement of reinforcement bars should be such that they are in a position to carry the tensile force setup in the corner effectively.

A perusal of the elastic stress distribution (Figure 3.1) in the opening corner reveals that the bending stresses acting along the corner diagonal reach a peak at the re-entrant corner whereas the radial tensile stresses acting normal to the corner would cause spalling of corner if it were not tied by reinforcement. The detailing of corner reinforcement SP4 was adopted keeping this stress distribution in mind.

Upon the loading specimen SP4, a crack was initiated at the reentrant corner as anticipated and on subsequent loading the crack travelled along the corner diagonal then branched into many cracks and progressed towards compression zone of the framing members. The terminal stages of the test were marked by appearance of diagonal tension crack. The occurrence of these diagonal cracks caused the failure of the corner. The failure cracking pattern for this specimen is shown in Figure 3.3. The joint efficiency for this specimen was obtained as 93.5%. The maximum crack width at failure was recorded as 1.15mm. The effect of splay steel on the behavior of the corner could be clearly seen and it is postulated that inclined steel stiffened the corner and delayed the widening and propagation of crack initiated at the reentrant corner of the joint.

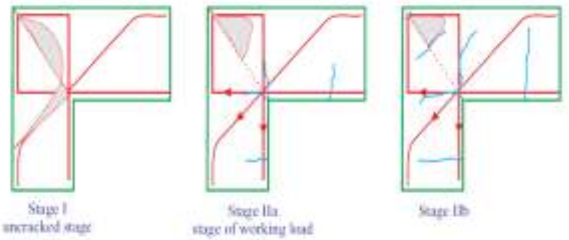


Figure 3.3: Stress Distribution in an Opening Corner at Different Load Levels

In stage-I, at relatively small loads, the corner is uncracked and the stress distribution more or less complies with the theory of elasticity. Most of the stresses are carried by concrete and to a small extent by the reinforcement. The cracking at the re-entrant corner is initiated at the working load stage-II (a), when the concrete in the tensile zone at the re-entrant corner is replaced by forces in the reinforcement bars. At stage-II (b), the crack at the re-entrant corner progresses along the reinforcement bends and a diagonal crack is developed inside the reinforcement bends. The compression zone then moves into the outer part of the corner within the reinforcement bends. The bent portions of the reinforcement, which provides anchorage, carry the tensile forces into the compression zones of the corner and are, therefore, relieved of the stresses through bond and contact pressure with the concrete. The bends in the reinforcement have the effect of holding the sections meeting at the corner together and prevent separation of the corner thus contributing effectively to the resistance of the radial stresses in the corner. In specimen SP4, it was observed that at the terminal stages of the test, the crack from the re-entrant corner which had been progressing along the reinforcement bends turns rapidly towards the compression zone in the diagonal direction. The occurrence of these types of diagonal cracks caused failure of the corners.

CONCLUSIONS

Efficiency factors significantly smaller than the ideal value of 100% were obtained for the corner joints detailed with two randomly selected reinforcement arrangements which are commonly used in practice.On further investigation, a relatively better efficiency factor of 84% was obtained in the specimen detailed with overlapping U-shaped bars spliced with the longitudinal reinforcement in the members framing into the corner. Inspite of its relatively superior performance, this detailing arrangement is not considered to be suitable for practical application and is therefore not recommended.

An efficiency factor marginally in excess of 90% was obtained in the corner specimen detailed with a reinforcement arrangement which was conceived as a modification of detailing commonly used at construction sites. In this detailing, the main tension reinforcement of the framing members was extended to the far end of the corner and then bent in the corner joint as a 90˚ hooked extension. This detailing was further complimented by the provision of splay steel at the re-entrant corner in an amount equal to 50% of the tension reinforcement. Because of its relative ease of fabrication and acceptable, it is recommended for practical application.

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