Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.IV)

6-6-11

SEISMIC RESISTANCE OF DIAGONALLY REINFORCED CONCRETE BEAM-COLUMN JOINTS

Ioannis A. TEGOS[1], Alexander G. TSONOS[2] and George G. PENELIS[3]

[1]Lecturer, Dept of Civil Eng., Aristotle University of Thessaloniki, Greece
[2]Researcher, Dept of Civil Eng., Aristotle University of Thessaloniki, Greece.
[3]Professor, Dept. of Civili Eng., Aristotle University of Thessaloniki, Greece.

SUMMARY

An experimental investigation to study the behavior of beam-column joints reinforced with crossed diagonal steel bars under seismic conditions is presented. Ten beam-column specimens were studied. The results showed that the joints with diagonal reinforcements performed considerably better than those with conventional or non conventional reinforcement of other types. The testing program also served to help develop an ultimate strength model.

INTRODUCTION

In the last years, several experimental investigations on the behavior of beam column joints in monolithic concrete structures subjected to alternating loads, have been conducted, mainly in the United States and New Zealand and valuable knowledge has resulted. However most of these investigations were based on conventional way of arranging the so called "shear" or "confinement" or "transverse" reinforcement that is rectangular closed hoops placed transversely to column axis as shown in Fig. 1(a). The latest recommendations for design of beam-column joints, reported by ACI-ASCE Committee 352 (Ref. 1) have been developed based on a thorough review of all appropriate research up to 1983. However, several design questions have not been addressed because of insufficient information. Among the areas where further research is needed,non-conventional ways for the strengthening of the joint such as use of fiber reinforcement and / or high strength concrete, have been reported. Using fiber reinforcement may be an effective way to reduce the required confinement steel in the joint or to increase the maximum allowable shear capacity of the beam-column joint. Experimental data are needed to quantify these effects (Refs 2,3).

Paulay et al (Ref. 4) first introduced the idea of using diagonal main reinforcements to prevent brittle failure in short reinforced concrete coupling beams. Following the proposal of Paulay et al, Minami, Wakabayashi (Ref. 5), Tegos and Penelis (Ref. 6) applied the idea in short columns and carried out some experiments. Beam-column joints have many similarities in a) geometry, b) stress state and c) mechanical behavior with short columns and coupling beams. For these reasons the above simple technique of crossed diagonal bars is proposed here for the first time to impove the seismic-resistance mechanical properties Fig. 1 (b).

The objectives of the tests reported in this paper are: a) To study the efficiency and describe some basic properties of beam-column joints with diagonal

Table 1 Summary of experimental program

Series	No of Specim.	Main Shear Reinf. of the joint	Concrete Compressive Strength in MPa	Yield[1] Stress of Shear Reinf. in MPa	Yield Stress of Long-Reinf. in MPa	Values of Primary Variables		
						M_R	γ	ρ_t%
I	1	Convent.	33	495/485	485	1.0	12	0.75
	2	Diagon.	27			1.0	13	0.75
	3	Convent.	30			1.4	10	0.75
	4	Diagon.	31			1.4	10	0.75
	5	Convent.	37			2.7	6	0.75
	6	Diagon.	26			2.7	7	0.75
II	7	Fibers	17	375	485	1.0	17	-
	8	-	16	-		1.0	17	-
	9	-	23	-		1.0	14	-
	10	Convent. +Fibers	24	495/375		1.0	14	0.75

[1] The first number corresponds to stirrups and the second to lateral or diagonal or fibers.

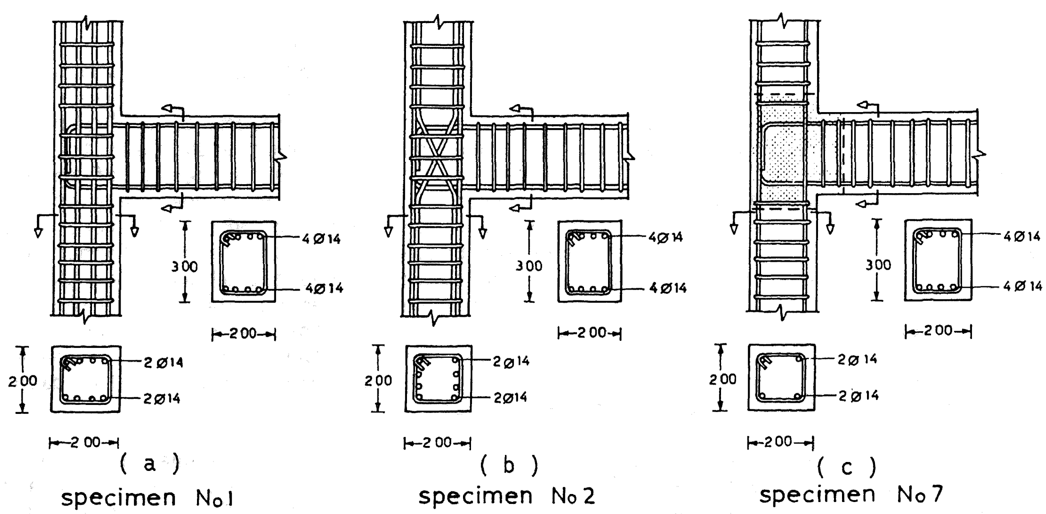


Fig. 1 Typical specimens tested in this investigation

reinforcing bars under large cyclic loading. b) To compare the behavior of the proposed diagonal reinforcing pattern with those of other conventional or non conventional reinforcing patterns of other types (mainly steel fibers).

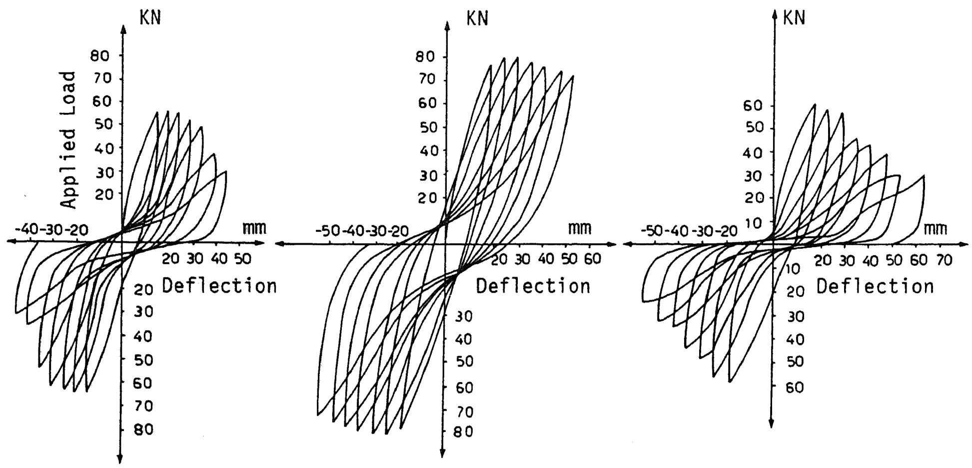
TESTING PROGRAM

Specimens and variables. The experimental program included 10 specimens in two series as detailed in Table 1. The series I consisted of three pairs of specimens. Each pair of specimens included one conventionally reinforced beam-column specimen and one diagonally reinforced identical specimen. The bars of reinforcement of beam and columns were the same in both specimens of each pair. The specimens of each pair differed only in the reinforcement of the joint region. The second specimen of each pair was reinforced with four crossed diagonal bars in the joint region instead of the four lateral longitudinal bars in the column of the first conventionally reinforced specimen. The rest of the specimens were tested to investigate the efficiency of other non conventional reinforcing patterns, such as steel fibers and several combinations of steel fibers, stirrups and high strength concretė and to compare their behavior with that of the proposed diagonal reinforcing arrangement. The characteristics of the four specimens of series II, in joint region, were the following: The first specimen had steel fiber concrete, the second one had plain concrete (of the same quality with the matrix of the previous specimen), the third specimen had plain concrete with modulus of rupture equal to that of fiber concrete and the fourth specimen had stirrups, higher concrete quality and steel fibers in the joint region as shown in Fig. 1c.

The principal variables of the testing program were: a) The amount of diagonal reinforcement b) The ratio M_R of column-moment strengths versus beam-moment strength at the joint. c) The amount of transverse reinforcement ρ_t d) The value of parameter γ which is related to the nominal shear stress at the joint. The axial load of one column kept constant 0,25 $A_c f_c$ approximately during the test.

TEST RESULTS

Plots of the applied load versus the displacement at the load point for representative specimens are shown in Fig. 2. In the following, the influence of the test variables on the seismic behavior is described: It can be seen that in specimens with diagonal bars in the joint region, despite the low values of M_R ratio,there was no strength reduction,nor appreciable deterioration after reaching the maximum capacity, and satisfactory-shaped hysteresis loops with large energy dissipation capacity were developed. All the specimens of the series I with conventional reinforcement, stirrups and lateral longitudinal bars in the joint region, except for the specimen No. 5 which had the highest value of M_R ratio, showed comparatively large deterioration in shear carrying capacity, beyond the ultimate capacity point, as the amplitude of loading cycles was increasing. From the specimens of series II, the specimen No. 7 with fiber concrete in the beam-column joint region, showed better behavior than specimens No. 8 and 9 with plain concrete in the joint, although the modulus of rupture of the joint concrete of No. 9 specimen was not less than that of fiber concrete. However, the specimen No. 7 with fiber concrete and without stirrups,did not show better earthquake-resistance, compared to the conventionally reinforced specimens of series I. A clear improvement of the shear capacity under earthquake conditions results from the combination of higher strength concrete, addition of fibers and transverse reinforcement. In the case of the specimen 10, the shear capacity is large and the energy absorption capacity seems also very satisfactory, for the same loading conditions as in the case of the diagonally reinforced specimens of series I. It is worth noting that specimens with diagonal bars and steel fibers in the joint regions exhibited cracks at significantly later stages than the conventionally



Specimen No. 1 Specimen No. 2 Specimen No. 7

Fig. 2 Load-deflection relationship for typical beam-column joint specimens

Specimen No 1 Specimen No 2 Specimen No 7

Fig. 3 Crack patterns of typical beam-column joints reinforced and unreinforced specimens. The presence of steel fibers or diagonal bars results in a favourable redistribution of diagonal splitting cracks in the joint region.

ANALYSIS FOR STRENGTH

The presence of diagonal bars in the joint introduces a new mechanism of shear transfer, except for the two known mechanisms of conventionally reinforced joints. Thus the main mechanisms of shear transfer are the following (Fig. 4):

a) The truss model of transverse reinforcement.

b) The concrete compression field mechanism.

c) The truss model of diagonal bars.

The determination of the portion of shear carried by the third mechanism of the above list can be based on the statically determinate model whose equilibrium is illustrated by the force polygon of Fig.4 (c). This is reasonable for a member subjected to constant shear and antisymmetric bending, in which the diagonal arrangement of reinforcing bars is in accordance with the shear and moment distribution. After first yielding, the shear carried by the diagonal bars is

$$V_{sx} = 2A_s f_y \sin\theta \qquad (1)$$

where

A_s is the area of diagonal bars

f_y is the yield stress of these bars and

θ is the inclination of the diagonal bars to the column axis.

Generally, under various stiffness conditions the inflection points of the joint do not necessarily lie at members midlengths. This causes larger moments at one column of the joint. In this case extra longitudinal bars for bending are required. It is known that a nonantisymmetric bending moment diagram can be analyzed to an antisymmetric and a uniform bending moment diagram. The antisymmetric state of stress was already examined before. For additional uniform bending, an extra longitudinal reinforcement is required, determined by half of the difference of bending moments at the ends of the two columns of the joint.

CONCLUSIONS

Based on the test results reported in this study, the following conclusions are drawn:

1) Beam-column joints with diagonal reinforcements showed high shear strength, no appreciable deterioration after reaching their maximum capacity, and hysteresis loops with large energy dissipation capacity.

2) The presence of diagonal bars introduces an additional new mechanism of shear transfer and for this reason a smaller amount of hoops is required for this arrangement of reinforcement than for the conventionally reinforced joints. Thus, a considerable improvement in the ultimate shear capacity is observed in the case of diagonally reinforced joints in comparison to conventionally reinforced joints.

3) The tests showed that the proposed arrangement of crossed diagonal bars is a simple, cheap and easily applied technique to improve the earthquake resistant mechanical properties of the beam-column joints. Also, beam-column joints with diagonal reinforcements performed considerably better than those with conventional reinforcements (stirrups) and non conventional reinforcement of other types steel fibers or higher strength concrete in the joint region.

4) The requirements of ACI-ASCE recommendations (Ref. 1) about the values of the primary variables M_R γ and ρ_t may be decreased by using diagonal crossed bars.

The authors are currently planning to conduct further experiments and hope to have more test results accumulated on the applications of reinforced concrete beam column-joints with crossed diagonal arrangements.

REFERENCES

1. ACI-ASCE Committee 352, "Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures", ACI JOURNAL, Vol. 82 No. 3, May-June 1985, pp. 266-283.
2. Henager, C.H., "Steel Fiber Reinforced Concrete in Seismic Structures", A Review of State of the Art, Columbus, Ohio 43201, 1982, pp. 1-20.
3. Tsonos, A., Tegos, I., Penelis G., "Seismic behavior of Exterior Beam-Column Joints of Conventional and Fiber Reinforced Concrete", Proceedings of COMP'88 Symposium on Phase Interaction in Composite Materials, University of Patras, GREECE, August 1988, 6 pp.
4. Paulay, T., Park , R., and Phillips, M.,H., "Horizontal Conctruction Joints in Cast-in-Place Reinforced Concrete", Shear in Reinforced Concrete, SP-42, ACI, Detroit, 1974, pp. 599-616.
5. Minami, K., and Wakabayashi, M., "Seismic Resistance of Diagonally Reinforced Concrete Columns", Proceedings, 7th World Conference on Earthquake Engineering, Istanbul, Sept. 1980, V.6, pp. 215-222.
6. Tegos, I., and Penelis, G., G., "Seismic Resitance of Short Columns and Coupling Beams Reinforced with Inclined Bars", ACI Journal, Vol. 85, No. 1, Jan.-Feb., 1988, pp. 82-88.

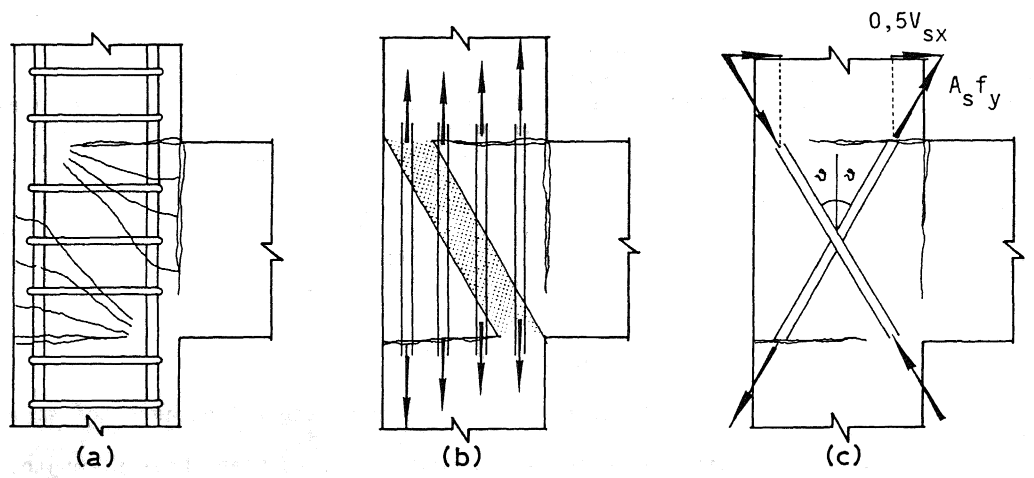


Fig. 4 Mechanisms of shear transfer