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INTENSIVE SHEAR REINFORCING METHOD FOR PCA MEMBERS WITH SPLICE SLEEVE JOINT

T. YOSHINO, K. KOBAYASHI and M. ASE

Industrial Technology Research Department,
Technical Research Institute of Fujita Corporation
74 Ohdana, Tsuzuki, Yokohama 224 JAPAN

Department of Architecture and Building Engineering, Fukui University
3-9-1 Bunkyo, Fukui 910 JAPAN

Engineering Department, Splice Sleeve Japan
1-5-9 Iidabashi, Chiyoda, Tokyo 102 JAPAN

ABSTRACT

Proposed was the Intensive Shear Reinforcing method (ISR) for the precast concrete members with splice sleeve joints at the member ends. All the shear reinforcement in the sleeve zone is shifted and placed at the ends of sleeve intensively. At first, the construction systems for PCa framed structures and the performance of members with splice sleeve joints are introduced in this paper. Next, the applicability of ISR is experimentally discussed and the role of ISR in PCa members is clarified by FEM analysis. ISR works much effectively as a substitute of the ordinary arranged shear reinforcement in the sleeve zone. It performs the macro truss mechanism at the member end and mitigates the concentration of the compressive stress of concrete. There is no problem of the ductility under the limited conditions.

ISR is also applicable to the shear reinforcing for the ordinary reinforced concrete members. This will increase the ultimate shear capacity without heavy shear reinforcing. Also it is applicable to the splices joints in the pre-fabrication system for reinforcing arrangement work.

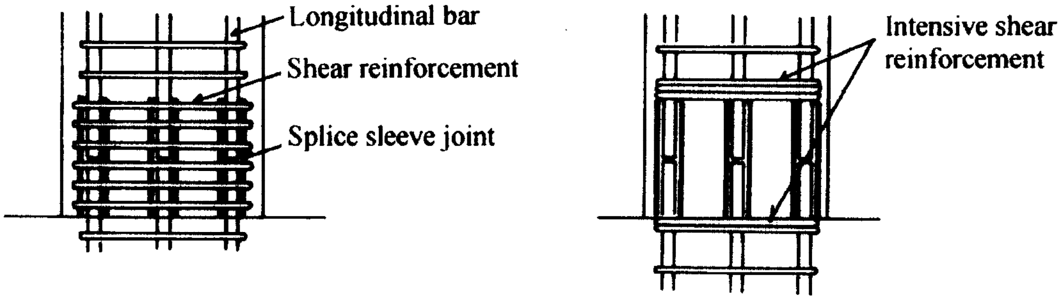
KEYWORDS

Precast concrete; Framed structure; Sleeve joint; Shear reinforcing method; Shear capacity; Shear transfer mechanism; Ductility; FEM analysis

INTRODUCTION

The authors have developed the construction systems for PCa framed structures, whereby all members such as columns, beams and slabs are cast separately at precast concrete plants and integrated on the construction site by pouring concrete in the connections of those members, to streamline the reinforced concrete construction. Splice sleeves are mainly used for jointing the main bars of column members for these framing systems. Because the sleeve diameter is larger than the main bar diameter, the hoop size in the sleeve zones has to be increased. There is a misunderstanding that the sleeve would be an unacceptable object and it would reduce the performance of column members. Then, many hoops are required in the sleeve zone, complicating the reinforcing arrangement work. The existence of sleeves would be an advantage, however, if the rigidity of the sleeve would be properly estimated. So, the authors have proposed the intensive shear reinforcing method (ISR) shown in Fig. 1. In the intensive shear reinforcing, hoops are arranged at regular intervals in normal regions. At joints, hoops are placed not in the sleeve zone, but intensively at both ends of the sleeves. It would be significantly advantageous for the systems, if the hoops required for the sleeve zones could be shifted to and placed on the ends of sleeves intensively.

This paper describes the experimental and analytical discussion for the applicability of ISR to PCa members that have mortar-filled sleeves at the member ends.



Traditional shear reinforcing method

Intensive shear reinforcing method

Fig. 1 Shear reinforcing method for PCa members with splice sleeve joints

OUTLINE OF THE SYSTEMS

Construction Systems for Framed Structures

Figure 2 shows a typical construction procedure by these framing systems developed by the authors. Splice sleeves for jointing the main bars of columns are built in at the column bottom as shown in Fig. 3. When such a precast column is placed on the floor slab, the bedding mortar is grouted at the column-slab interface, and the column bars are simultaneously spliced by filling the non-shrink high strength grout into the sleeves. A mortar-filled splice consists of a cast-iron sleeve that has deformations on the inner wall. The reinforcing bars are inserted from both ends and these are integrated by filling non-shrink high strength mortar in the space between the bars and the sleeve. The shape of a mortar-filled sleeve is shown in Fig. 4.

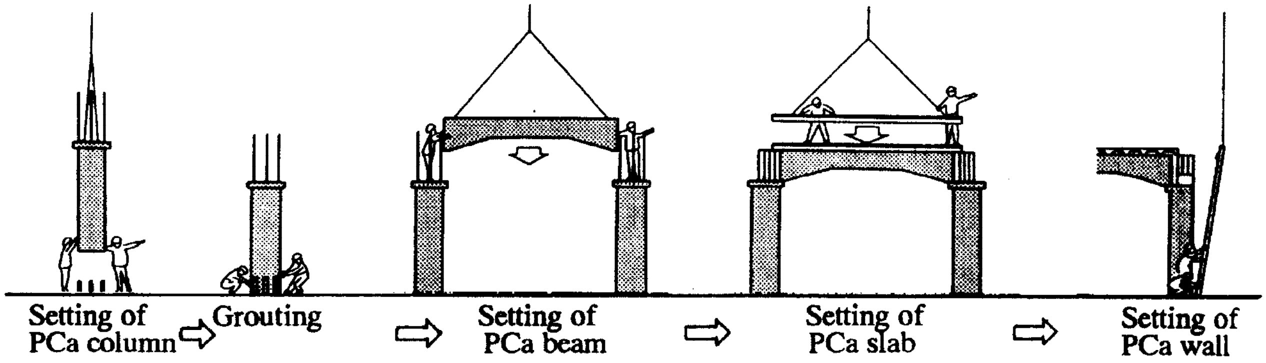


Fig. 2 Typical construction procedure by the precast reinforced concrete frame systems

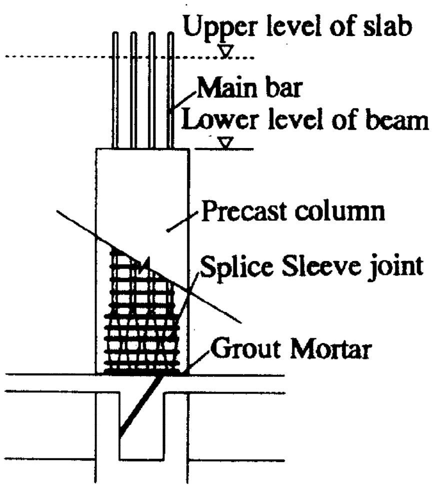


Fig. 3 Connection of PCa members

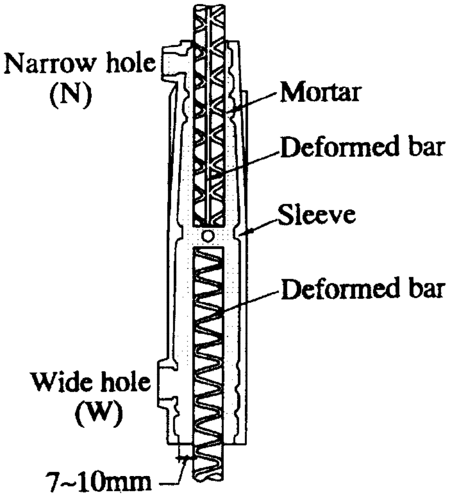


Fig. 4 Shape of a mortar-filled sleeve

The characteristics of the systems are as follows:

1. Each member is produced separately, and therefore has a simple shape.
2. There are few limitations of transportation. Applicable to large-scale buildings.
3. Stable supply of high quality members is feasible, as the members are manufactured at precast concrete plants.
4. The joints of members are highly monolithic, as they are integrated by pouring concrete.

Earthquakes frequently occur in Japan, and strong earthquakes can hit anywhere in Japan. Buildings should therefore be designed to have high seismic performance. Column members are particularly required to have the highest seismic performance, as they are subjected to axial and lateral forces at the same time.

Performance of PCa Members with Splice Sleeve Joint

Mortar-filled splices are optimum for splicing the reinforcing bars of PCa members. The authors have investigated the performance and stress transfer mechanism of mortar-filled splice sleeve units since 1972. Mechanical performances of PCa members including such joints have also been investigated. Twenty-five such PCa members have been tested by the authors. A number of experimental results have also been reported on this type of PCa members by other institutions. These results have been collected and analyzed to investigate their mechanical performance. Seventy-three columns and 18 beams (91 members in total) were investigated. These specimens were classified according to the structural factors as shown in Fig. 5.

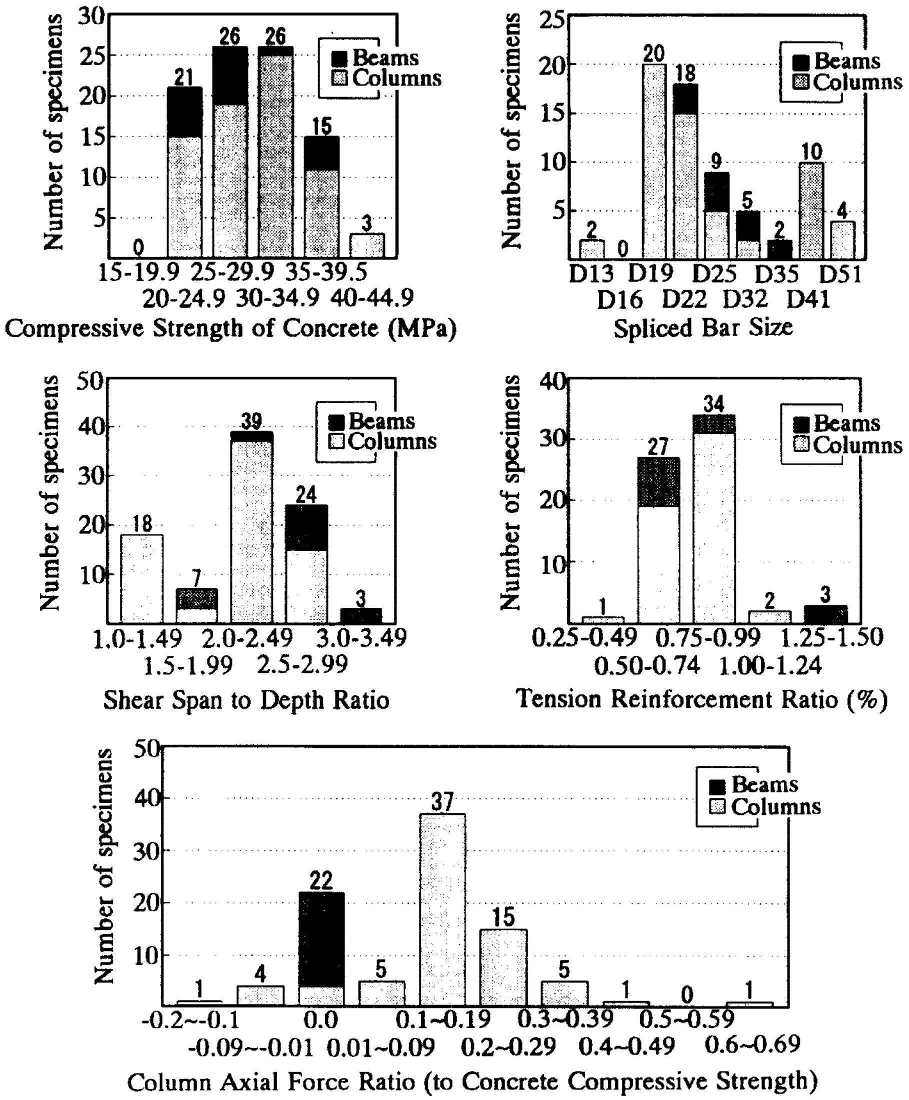


Fig. 5 Classification of structural factors

The investigation revealed that the strength of PCa members can be evaluated by means of calculations for the ordinary reinforced concrete members. This result means that PCa members have performance equivalent to, or better than that of ordinary reinforced concrete members. It was also found that the deformability of such members is not affected by the mortar type or sleeve shape. In some cases, PCa members have an excellent performance rather than the ordinary reinforced concrete members, because of the existence of sleeve joints. The rigidity of the sleeves is so high that no buckling of main bars is observed, even in the case of columns subjected to high axial compressive loads. Also the sleeves share the high compressive loads and mitigate the stress of concrete. The cracks concentrate at both ends of sleeves and no crack is observed in the sleeve zone. These characteristics suggested that ISR would be more effective than the regular arrangement in the sleeve zone. Consequently, such intensive shear reinforcing arrangement was investigated.

EXPERIMENTAL VERIFICATION

Contribution of ISR to Shear Capacity

A pilot test was conducted on two specimens with and without ISR. High strength bars (σ_y=940 MPa) were used for the main bars. The concrete strength was 29.5 MPa. For Specimen SN4, round bar shear reinforcements 4 mm in diameter (σ_y=710 MPa) were placed at regular intervals. For Specimen SC9W, round bar ISR 9mm in diameter were placed double at each end of the sleeves. Non-shrink mortar was filled in the sleeves. The reinforcing arrangement is shown in Fig. 6. The monotonic loading was given up to the maximum load and repeated loading in one direction thereafter, generating the antisymmetric bending moment condition. These specimens are intended to undergo shear failure before flexural yielding. The relationships between the shear force and the relative displacement are shown in Fig. 7. The experiment indicated that ISR did not impair the shear behavior of the specimen. SC9W showed a higher shear capacity corresponding to the larger amount of ISR. The loss in the load after the maximum was also small. The strain of the shear reinforcement was measured and their tensile force was calculated. The tensile force of ISR was larger than the total of the tensile force of shear reinforcement in the sleeve zone of SN4.

The experiment exhibited that ISR is sufficiently effective and the enough shear capacity can be obtained. The effectiveness of ISR has been also confirmed by other experimental research work (Koyama *et al.*, 1995).

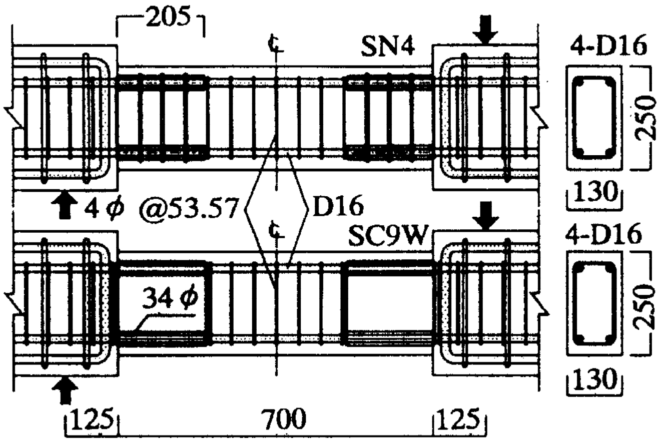


Fig. 6 Reinforcing arrangement of the specimens

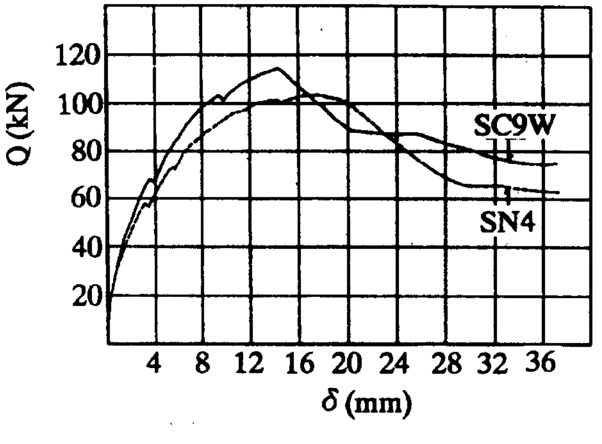
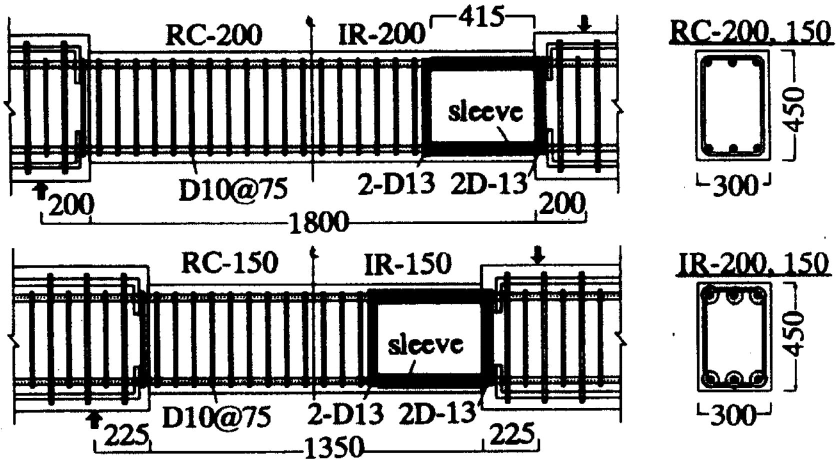


Fig. 7 Shear force - relative displacement relations

Deformability of PCa Members with ISR

A loading test on large-scale specimens was conducted under the antisymmetric bending moment condition, to confirm the deformability of PCa members with ISR. The size of the specimens was 2/3 scaled. The details of the specimens are shown in Fig. 8. The shear span-depth ratios of specimens were 2.0 and 1.5. RC series have no splicing joint and IR series have mortar-filled sleeve joints and ISR. Each series consisted of two specimens. The shear reinforcement was arranged so that the calculated shear capacity was nearly the same as the calculated flexural capacity. The amount of ISR of IR series was nearly the same as the amount of shear reinforcement that was required for the sleeve zone. The parameters were common in all specimens excepting the shear span-depth ratio. The cyclic loading was applied alternatively so that the relative displacement between the loading points and the center of the beam were the same on both left and right sides.



Concrete strength : 31~35 MPa
Main bar : D25, σy=430 MPa
Stirrup : D13, σy=315 MPa
D10, σy=388 MPa

Fig. 8 Details of the specimens

Cracking and Failure Properties. The cracking condition of the RC and IR series were the same up to the rotation angle of member (R) of 1/100 rad. The inclined cracks at the member ends increased in RC-200 specimen as the cyclic loading proceeded. The inclined cracks in IR-200 specimen developed along the top bars, but the number of cracks in the sleeve zone was small. No sign of crack concentration was observed in the hoopless area, that is, the sleeve zone. The cover concrete for the sleeve zone peeled off, as the cyclic loading proceeded. As for those with a shear span-depth ratio of 1.5, the inclined cracks at the member ends of both RC-150 and IR-150 specimens developed along the top bars. The bond splitting cracks became significant as the number of cycles increased, and the cover concrete peeled off.

Strengths and deformability. The load-displacement hysteresis diagrams are shown in Fig. 9. The measured flexural yield loads were 0.91 to 0.98 times the calculated values. Measured maximum loads were 0.99 to 1.07 times the calculated flexural capacity. Regarding IR series, the intensive shear reinforcement ratio and the shear reinforcement ratio in the normal region were calculated separately. The overall amount of shear reinforcement was calculated by adding both. The shear capacity was calculated by the AIJ equation (AIJ, 1988). The measured values were 0.95 to 1.07 times the calculated values.

The loading was terminated at the rotation angle of member (R) of ±4/100 rad. No difference was observed between RC and IR series up to the maximum load in either the deformation or the carrying force. The bearing force of RC-200 at the end of loading was 87% of the maximum load in both directions, but that of the other three specimens showed relatively large losses. In the negative side of IR-200 and the positive side of IR-150, the bearing force diminished down to 70% of the maximum load. Judging from the condition of crack development, however, these losses are not attributed to ISR, but to bond splitting failure. These experiments revealed that the deformability and load carrying ability of the specimens with ISR are the same up to the maximum load as those of the members reinforced with regular shear reinforcement.

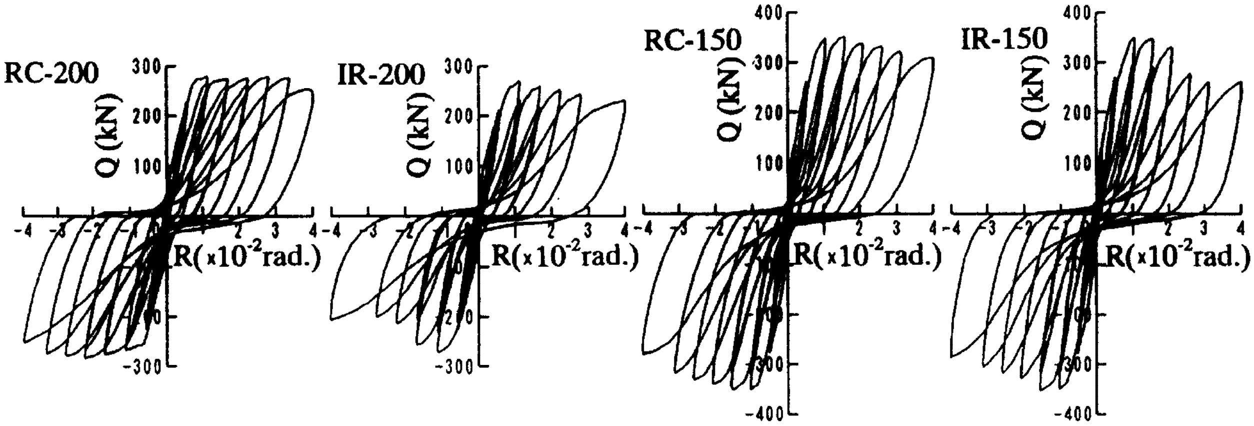


Fig. 9 Shear force - relative displacement relations

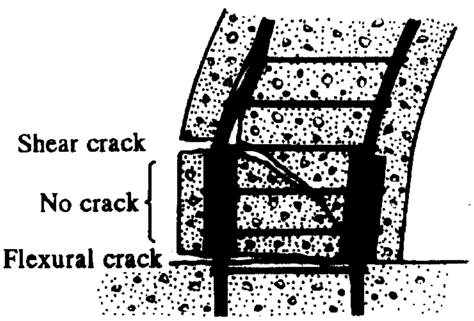


Fig. 10 Typical crack pattern of PCa members with sleeve joints

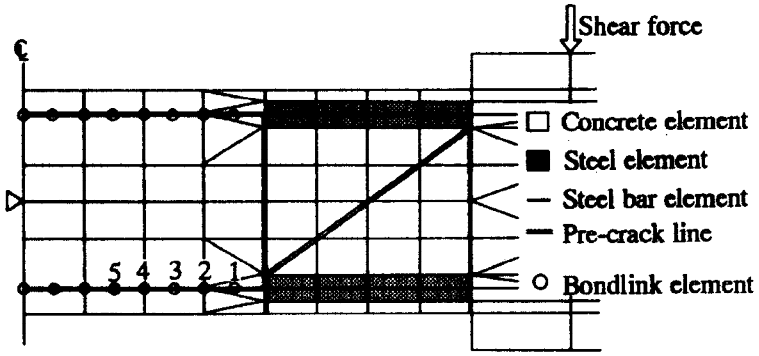


Fig. 11 Analytical model

ROLE OF ISR IN PCa MEMBERS

Expected Function of ISR

As mentioned above, the cracks concentrate at both ends of the sleeve joint as shown in Fig. 10. Because of large stiffness of the sleeve, it causes the dowel action on the main bar and the shear crack develops along the main bar. As a result, the bond resistance deteriorates. The shear crack opens widely. Then the shear reinforcement yields. Finally the shear resistance reaches capacity. The enough ISR decreases the dowel deformation of main bar and restrains the development of shear crack and its opening. As a result, the bond resistance does not deteriorate and the large shear force could be carried by the truss mechanism.

Analytical Discussion by FEM Analysis

The beam specimen shown in Fig. 8 was analyzed by finite element method (FEM). Here, the strength of main bar was enhanced up to obtain the shear capacity. The parameters were the bond resistance of main bar and the amount of ISR. The analytical model is shown in Fig. 11. The bondlink elements were introduced between the main bar elements and the concrete elements. Their characteristics were given as shown in Fig. 12. The area (A) and yield strength (σ y) of ISR were assumed to be constant to have a constant large tensile capacity. The young's modulus (E) was variable as shown in Fig. 13. The analyses were done on the combined parameters of bond resistance and ISR. Table 1 is a part of combination of parameters.

Figure 14 is the analyzed load-displacement relations of Series-I that has a plenty of ISR. When there is good bond resistance, the large shear capacity was obtained. But, the shear capacity does not depend on the bond resistance so much. Even if the bond resistance deteriorated, that is, there was almost no bond, the shear capacity did not decrease so much. This suggests that ISR would perform some shear transfer mechanism and carry large shear force, even if there would be no shear transfer by truss mechanism (AIJ, 1990) of ordinary shear reinforcement. Figure 15 is the analytical load-displacement relations of Series-V that has less ISR. In all cases, ISR did not reach the yield stress and kept elastic. When there was not enough bond resistance, the shear capacity decreased very much.

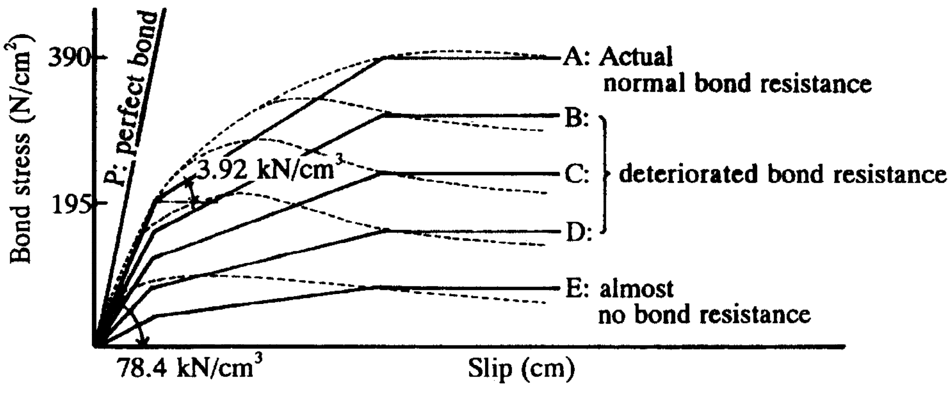


Fig. 12 Bond-Slip characteristics for bondlink elements

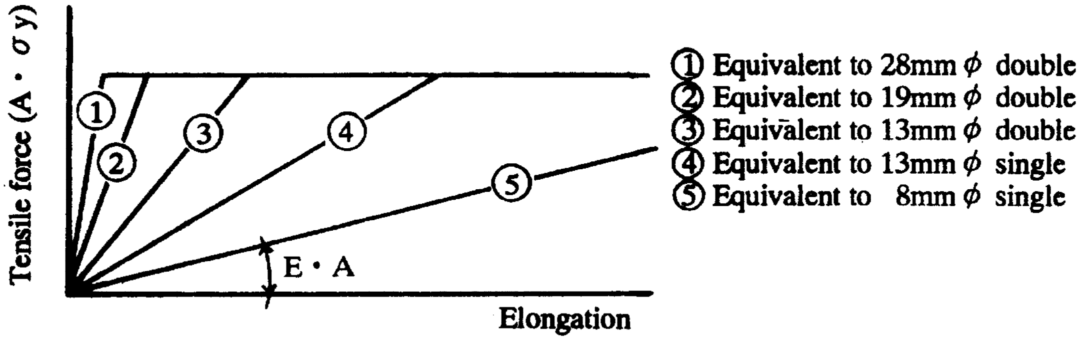


Fig. 13 Characteristics of ISR

Table 1 Combination of parameters

	Analysis No.	Bond-Slip characteristics for bondlink elements in Fig.12 Location in Fig.11 5	4	3	2	1	ISR in Fig.13	Remarks
Series - I	1	P	P	P	P	P	①	Complete bond
	2	A	A	A	A	B		with large
	3	A	A	B	C	D		ISR
	4	B	C	D	D	E		↓
	5	D	E	E	E	E		Almost no bond
Series-V	6	P	P	P	P	P	⑤	Complete bond
	7	A	A	A	A	B		with less
	8	A	A	B	C	D		ISR
	9	B	C	D	D	E		↓
	10	D	E	E	E	E		Almost no bond

On the other hand, when there was good bond resistance, the shear capacity did not decrease so much. The large shear force would be transferred by both truss and arch mechanism (AIJ, 1990), even if there would be no shear transfer by ISR. But actually, a plenty of ISR would be needed to get the good bond resistance. It can be concluded that ISR restrains the dowel deformation of main bar and the development of shear crack, and then keeps good bond resistance of main bar. Eventually ISR enables the shear transfer by arch and truss mechanism (AIJ, 1990) and additionally performs another shear transfer mechanism.

Figure 16 and Fig. 17 are the principal stress distribution diagrams. When there is enough ISR and good bond resistance of main bar, the compressive principal stress distributes uniformly at the member end, that is, the sleeve zone. From this stress distribution, it could be considered that there must be a concrete strut at member end to balance the large tensile force of ISR as shown in Fig. 18. The authors call this macro truss mechanism by ISR. When there is less ISR and poor bond resistance of main bar, the compressive principal stress

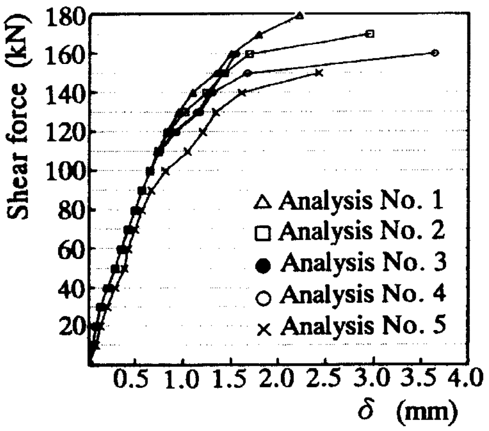


Fig.14 Shear force-displacement relations of Series-I

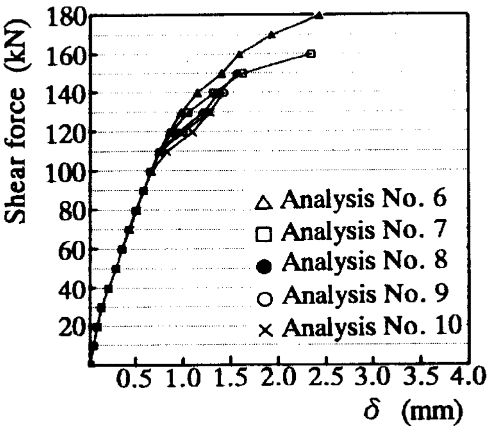


Fig.15 Shear force-displacement relations of Series-V

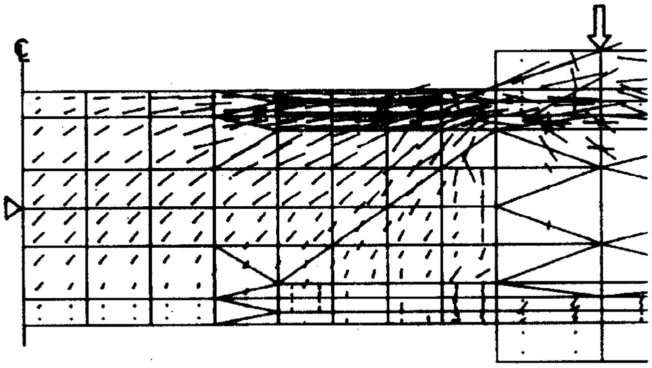


Fig. 16 Stress distribution in case of analysis-1

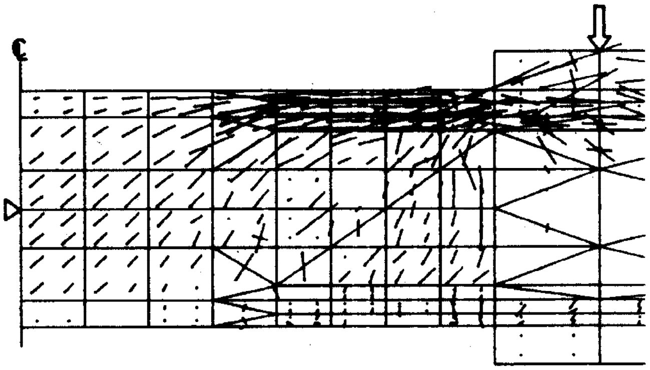


Fig. 17 Stress distribution in case of analysis-10

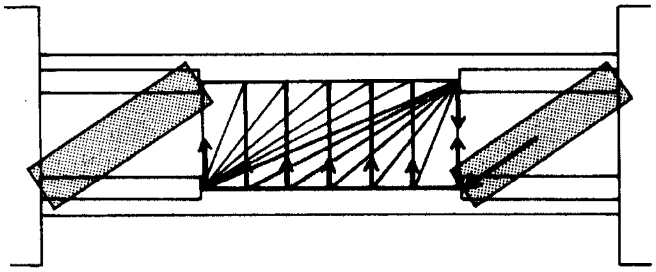


Fig. 18 Macro truss mechanism by ISR

distribution by arch mechanism is outstanding. The stress distribution corresponding to macro truss mechanism is not clearly recognized. The existence of another shear transfer mechanism by ISR beside arch and truss mechanism has been experimentally confirmed by another study (Koyama *et al.*, 1995). The evaluation of shear capacity has been successfully tried by combining this macro truss mechanism with arch and truss mechanism (Kobayashi, 1993).

CONCLUSION

In this study, proposed was the intensive shear reinforcing method (ISR) for PCa members with splice sleeve joints. It was experimentally proved that there was completely no difference of deformation behavior and capacities between PCa members with ISR and the ordinary reinforced concrete members without splices . As a result, it was found that ISR is much applicable to PCa members with sleeve joints. In general, the result of this study is to have presented one of resolutions in the improvement of performance of PCa members and the rationalization of construction work.

Recently pre-assembling systems of reinforcing bars are getting popular to streamline the reinforcing arrangement work. In these systems, the reinforcing bars of each unit are jointed by using mechanical splice. And all the joints come to the same section. ISR would be also applicable to such systems in the same way as of PCa members with sleeve joints. It would be much advantageous for the systems, if the shear reinforcement could be placed at the mechanical joints intensively. Furthermore, ISR is expected to be used additionally in the ordinary shear reinforced both PCa and RC members. It would increase the ultimate shear capacity without heavy shear reinforcing and eventually improve the deformability.

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