DUCTILITY IMPROVEMENT OF PCA MEMBERS WITH SPLICE SLEEVE JOINT BY INTENSIVE SHEAR REINFORCING METHOD

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SUMMARY

The idea of Intensive Shear Reinforcing method (ISR) was presented at the last conference[1] and its applicability to PCa members with splicing sleeve joints was well evaluated. Recently high strength materials of both concrete and steel bars are available. At the same time, however, it is getting difficult to secure the ductility because of the increase of shear and bond stress level. The main objective of this study is to evaluate the contribution of ISR to the ductility improvement of PCa members with splicing sleeve joints.

In this paper, the bonding behavior of main bar in PCa members with splicing sleeve joints was experimentally investigated. And it was proved that PCa members with splicing sleeve joints would have more chance of bond splitting failure because of shortening of anchorage length of main bar. Then PCa specimens with splicing sleeve joints were designed to fail in the bond splitting failure mode and ISR was placed additionally. As was expected, ISR increased the bond splitting capacity. However, it was proved that only ISR is not enough to prevent the bond splitting failure and the reduction of bearing force. Some amount of normal shear reinforcement would be needed at least so that the flexural failure may proceed to the shear failure and the bond splitting failure. In the experiment of PCa columns with flexural failure mode, well satisfactory ductility was obtained even if fairly large amount of shear reinforcement was replaced by ISR.

It can be concluded that ISR would contribute to the improvement of deformability of PCa members with splicing sleeve joints. In the flexural members, ISR would much improve and assure the ductility. When the high strength materials would be used and a lot of shear reinforcement would be required, ISR would work more effectively.

INTRODUCTION

In PCa framed structures presented at 11WCEE[1], the splicing sleeves are mainly used for splicing the main bars of column members. Because of a misunderstanding that the sleeve would be an unacceptable object and it would reduce the performance of column members, more hoops are required in the sleeve zone. Then, the authors proposed the intensive shear reinforcing method (ISR) shown in Fig. 1 to avoid heavy and complicate reinforcing arrangement in the sleeve zone. In the intensive shear reinforcing, hoops are arranged at regular intervals in normal regions. At the joints, hoops are placed not in the sleeve zone, but intensively at both ends of the sleeves. The applicability of ISR to PCa members with splicing sleeve joints and its effectiveness were experimentally proved [1].

Even if the hoops in sleeve zone can be removed by placing ISR, however, it will not be accepted practically because of more shear reinforcing requirement in the hinge zone. There would be another contribution of ISR to bond resistance as well as that to the shear capacity gain. It would lead to the ductility improvement. This was

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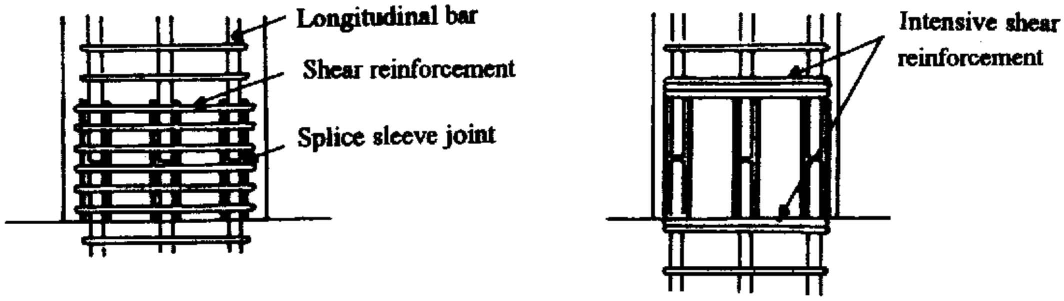
analytically discussed [1]. This paper describes the experimental discussion for the contribution of ISR to bond resistance and the ductility improvement of PCa members with splicing sleeve joints.



Traditional shear reinforcing method   Intensive shear reinforcing method

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

2 IDEA OF ISR AND ITS CONTRIBUTIONS

In PCa member with splicing sleeve joints, the cracks concentrate at both ends of the sleeve joint as shown in Fig. 2, because of the large rigidity in sleeve zone. And also because of large rigidity 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. If this occurs before reaching the flexural yielding, PCa member fails in the bond splitting failure mode and loses the deformability. Even after the flexural yielding, no ductility would be secured. The enough amount of ISR decreases the dowel deformation of main bar and restrains the development of shear crack and its opening. As a result, the bond resistance doesn't deteriorate and the deformability would be improved even in PCa members with less bond resistance. And also the ductility would be much improved in the flexural members.
When the enough amount of ISR was added and the good bond resistance of main bar would be secured, it was analytically proved that the compressive principal stress distributed uniformly in the sleeve zone[1]. This compressive stress distribution would perform a compressive concrete strut and it would balance the large tensile force of ISR as shown in Fig. 3. This is called "*Macro truss mechanism* [1] ", and this would be also a mechanism to increase the bond resistance of main bar as well as the shear capacity.

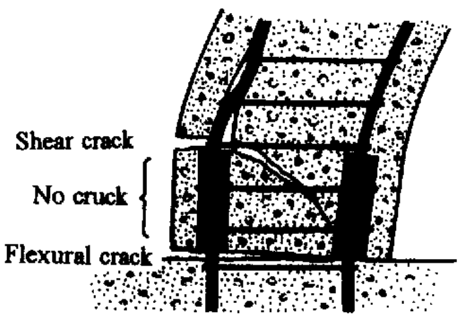


Fig. 2: Typical crack pattern of PCa members with sleeve joints

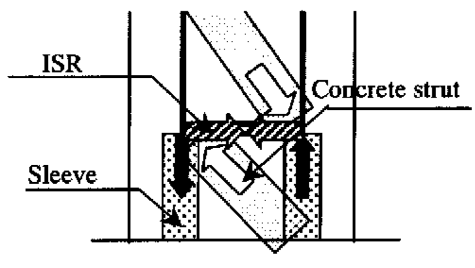


Fig. 3: Macro Truss Mechanism

3 BOND CHARACTERISTICS OF MAIN BAR WITH SPLICING SLEEVE JOINT

3.1 Experimental program:

The cracks concentrate at both ends of the sleeve joint. So, even before flexural yielding, the anchorage length of main bar seems to be shortened. The main objective of this experiment is to investigate the bonding behavior on the main bar of PCa members with splicing sleeve joints.

A monolithic specimen without splicing joint and a jointed PCa specimen with splicing sleeve joints were produced. The section size was 40cm x 40cm and the shear span to depth ratio was 2.0. Four deformed longitudinal bars (4-D22) were placed both in tension and compression side and 2-D19 were placed at the depth center as shown in Fig. 4. The deformed bars were grooved in the depth of 4mm and width of 3mm along the longitudinal ribs in order to install the strain gages. The sectional area of D22 was reduced by 20%. So, the full-sized sleeves for D19 were also used for the grooved D22. The parameters of two specimens are listed in Table 1. The difference of two specimens was just “monolithic” or “pre-cast with splicing sleeve joints.” The loading system is shown in Fig. 5. The reversed cyclic horizontal load was given keeping the axial force a constant value. The horizontal displacement (δ) was measured by LVDT at the level of loading point. The applied horizontal and axial loads were measured by load cells that were installed at the tips of loading oil jacks.

Table 1: Test specimens

Test specimen	Longitudinal bar SD345	Axial force ratio (σ_0/F_C)	Lateral reinforcement		Concrete Strength	Grouting SS mortar
			Hoops	P_w(%)		
PCA345-05	4-D22 - with grooves (σ_y=394MPa)	0.05	D10@100 (σ_y=335MPa)	0.36	25.1MPa	101 MPa
RC345-05	2-D19 -at depth center (σ_y=387MPa)					

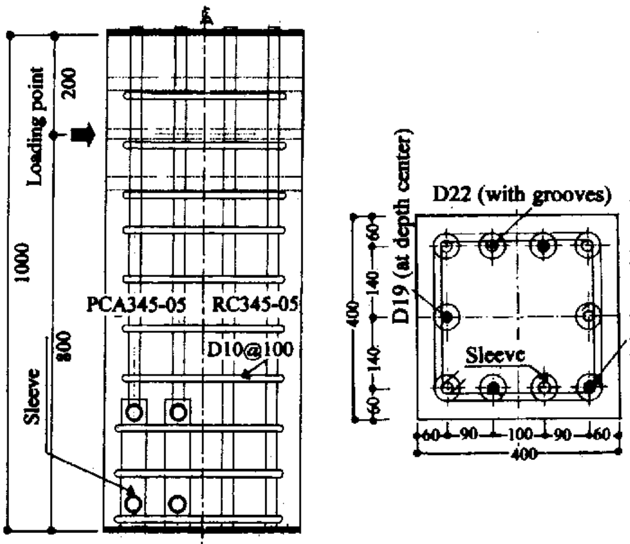


Fig. 4: Geometry of column specimens

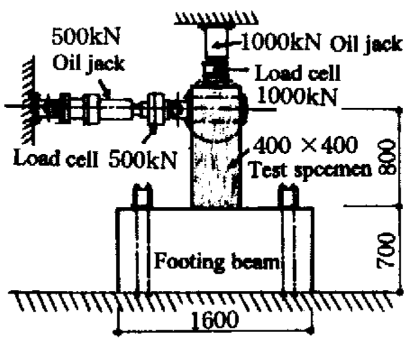


Fig. 5: Loading System

3.2 Tensile force distribution on the main bar:

The measuring points of strains on the main bars are shown in Fig. 6. The main bars were grooved along the longitudinal ribs. The strain gages were installed at the interval of 30~60mm on the bottom of the grooves and all the wires were embedded in the grooves to measure the strain without covering the surface of main bars.

In the sleeve zone, the measuring points on the sleeve and that on the main bar corresponds to each other. The measured strain was transformed into the tensile force by multiplying the sectional area and the young’s modulus. The tensile force carried by sleeve and that by main bar were summed up at the measuring points in the sleeve zone. The shape of sleeve was assumed to be a pipe with a fixed sectional area. The calculated tensile force distribution along the main bar is shown in Fig. 7. The maximum tensile force came at the bottom of column in the monolithic specimen without splicing joints, and the tensile force decreased to the direction of loading point. On the other hand, the tensile force at the upper end of sleeve was equal or larger than that at the bottom of column in PCa specimen with splicing sleeve joints. The critical section of PCa members looks as if it comes up to the upper end of sleeves. This suggests that the anchorage length of the main bar in PCa members would be shortened even before flexural yielding, and PCa members would have more chance of bond splitting failure than the ordinal RC members.

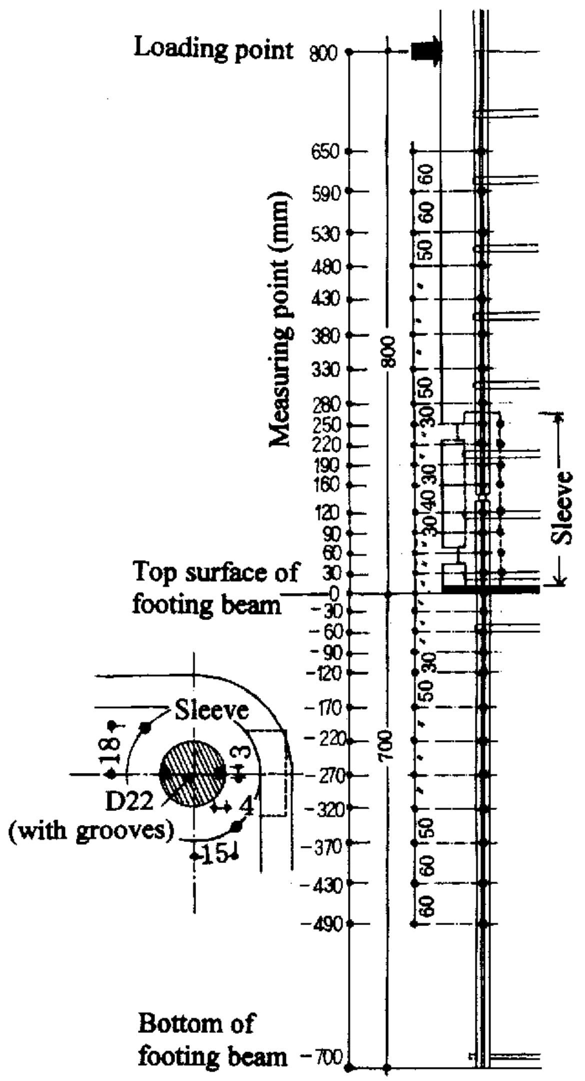


Fig. 6: Measuring points of strain on the main bar

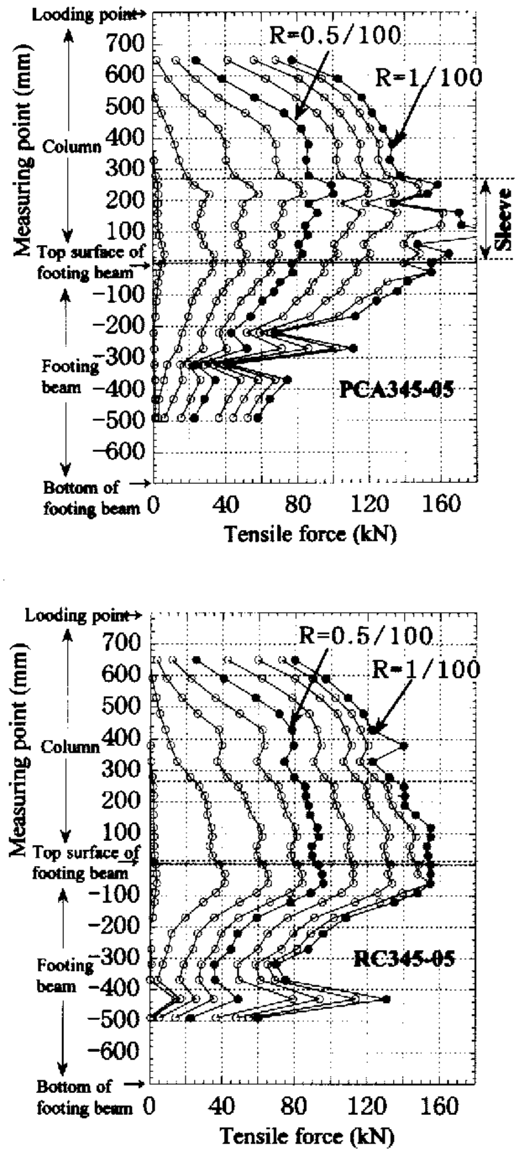


Fig. 7: Distribution of tensile force on main bar

4. CONTRIBUTION OF ISR TO BOND SPLITTING CAPACITY

4.1 Experimental program:

It was proved that PCa members with splicing sleeve joints had more chance of bond splitting failure. Here, ISR was expected to have a contribution to the increase of bond splitting failure strength as a role of ISR was discussed in Fig. 2. The test specimens were designed so that they would fail in the bond splitting failure mode before reaching the flexural capacity. And ISR was added expecting the increase of bond splitting capacity. The geometry of test specimen is shown in Fig. 8. The section size is 25cm x 30cm. The shear span to depth ratio is 2.0. To design the specimen that would fail in the bond splitting failure mode, the high strength steel bars, D19(SD490) were used for the longitudinal reinforcement. The calculated shear capacity[3] was almost equal to

the flexural capacity. The ratio of the calculated bond splitting capacity[3] to the flexural capacity was about 0.6. The specified concrete strength was 24MPa to cause the bond splitting failure and it was relatively small comparing with the strength of longitudinal reinforcement. The shear reinforcement was ϕ9(SR235) and ISRs were made of ϕ16 and ϕ19 (SS400). The splicing sleeves were full-sized ones for D19.
The tested four specimens are listed in Table 2. The specimen, PCA@100 had no ISR. The round bar of ϕ9 was laterally arranged at the interval of 100mm. The specimens, ISRϕ16 and ISRϕ19 had ISRs that were made of ϕ16-double and ϕ19-double respectively. The specimen, PCA@55 had no ISR and the round bar of ϕ9 was laterally arranged at the interval of 55mm. The total area of lateral reinforcement of PCA@55 was almost equal to that of the specimen, ISRϕ16, including ISR.
In the production of specimens, the longitudinal bars were not spliced. The splicing sleeves were installed on the continuous longitudinal bars and the SS mortar was grouted in advance. Then, all the reinforcing arrangement was done and the concrete was placed both in the tested parts and the stubs at one time.
The loading setup is shown in Fig. 9. The reversed cyclic load was given under the anti-symmetric bending moment condition. The relative displacement (δ) between the loading points was measured by LVDT.

Table 2: Test specimens

Specimen	Lateral reinforcement	pw(%)	Calculated Bond Splitting Capacity			Calculated Shear Capacity		
			τ_{bu} (MPa)	τ_f (MPa)	τ_{bu}/τ_f	Q_{su} (kN)	Q_{Mu} (kN)	Q_{su}/Q_{Mu}
PCA@100	9ϕ@100							
ISRϕ16	9ϕ@100 +ISR16ϕ-Double	0.51	3.78	5.96	0.63	173	173	1.00
ISRϕ19	9ϕ@100 +ISR19ϕ-Double							
PCA@55	9ϕ@55	0.92	4.50		0.76	262		1.51

τ_{bu} : Calculated bond strength[3]
τ_f : Average bond strength at flexural yielding
Q_{Mu}: Shear force at flexural capacity
Q_{su} : Calculated shear Capacity[3]

D19: σ_y=602MPa
9ϕ: σ_y=315MPa
16ϕ: σ_y=283MPa
19ϕ: σ_y=293MPa

Concrete: 25.1MPa
SS mortal: 69.7MPa

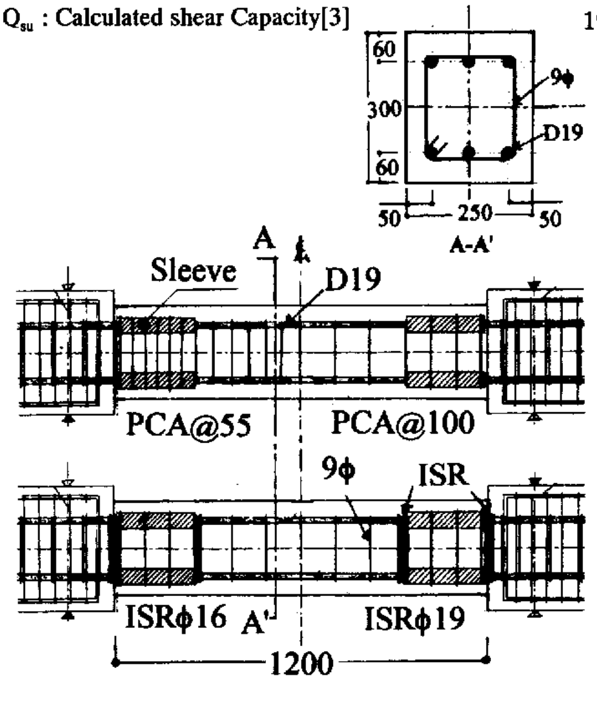


Fig. 8: Geometry of specimen

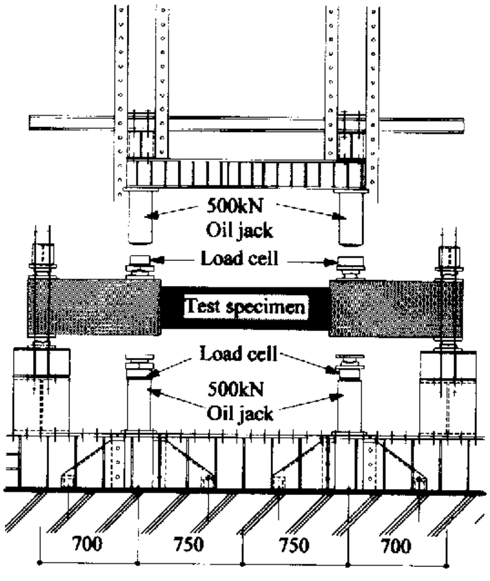


Fig. 9: Loading setup

4.2 Cracking behavior:

The cracking patterns are shown in Fig. 10 at the stage of 1/100 rotation angle of member (R). In the specimen, PCA@100 a diagonal crack connecting the compressive zone of both member ends was generated. In the specimen, ISRϕ16 more inclined cracks occurred and they reached the end of splicing sleeves. Probably this

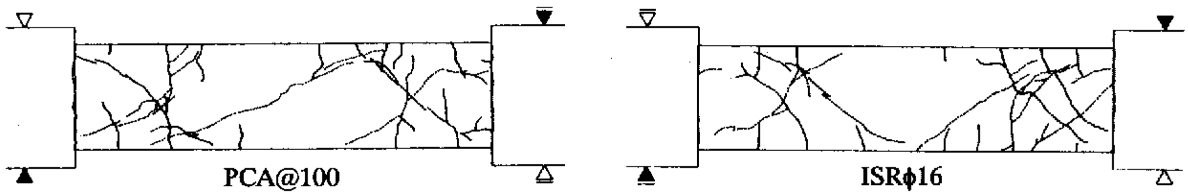


Fig. 10: Cracking patterns (R=1/100)

difference of cracking pattern would appear due to the shear transfer mechanism by ISR described in Fig. 3.

4.3 Shear force-displacement relations:

The shear force (Q)-displacement (δ) relations are shown in Fig. 11. The specimen, PCA@100 caused a bond splitting failure and reached the maximum load at R=1.5/100, and lost the bearing force quickly. In the specimens, ISRϕ16 and ISRϕ19, the bond splitting capacity increased depending on the amount of ISR. After reaching the maximum, however, the progress of bond splitting failure was not prevented by ISR. The bond splitting capacity gain by ISR was almost same in the specimens of ISRϕ16 and ISRϕ19. This suggests that some rigidity of ISR would be needed to perform the macro truss mechanism shown in Fig.3 and to restrain the dowel displacement of main bars, and that no excessive rigidity would be needed. The specimen, PCA@55 reached the flexural capacity at R=1.5/100 and the bond splitting failure occurred at R=2.0/100. After the occurrence of bond splitting failure, the reduction of bearing force was not so quick comparing with the other specimens. This means only ISR is not enough to prevent the bond splitting failure and the reduction of bearing force. Some amount of the normal shear reinforcement would be needed at least so that the flexural failure may proceed to the shear failure and the bond splitting failure. Then ISR would contribute to the ductility gain.

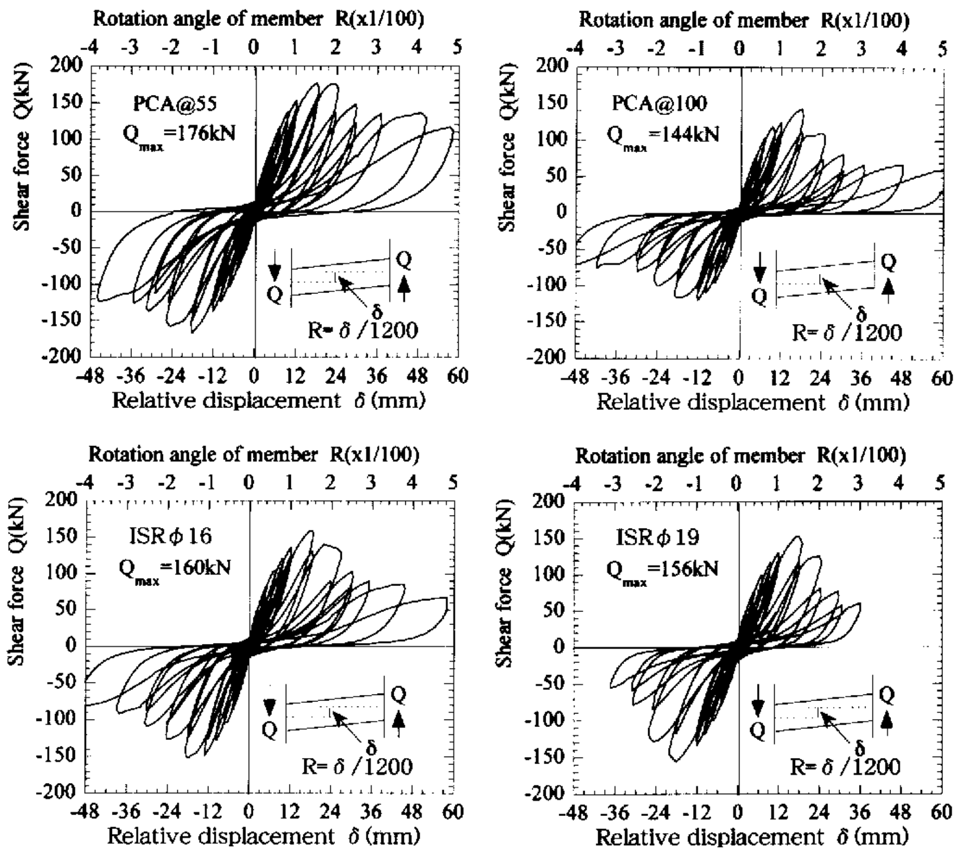


Fig. 11: Shear force (Q) – displacement (δ) relations

5. CONTRIBUTION OF ISR TO THE DUCTILITY OF FLEXURAL MEMBER

5.1 Experimental program:

The contribution of ISR to the ductility of flexural members with high strength materials was experimentally discussed. Two specimens listed in Table 3 were tested. The specimen, PCA@75 had hoops at 75mm intervals. In the specimen, PCA@100 the amount of hoops was reduced to 75% of that of the specimen, PCA@75 and ISR of D16-double was added that was equivalent to the reduced amount of hoops. The geometry of specimens are shown in Fig. 12. The shear span to depth ratio is 2.0. The section size is 40cm x 40cm. The tensile reinforcement ratio is 0.54%.

The PCa column members with splicing sleeves and the footing beams with splicing sleeve joint bars were produced separately. After confirming the appearance of concrete strength, they were jointed by grouting the SS mortar into the jointing interface and the splicing sleeves.

The axial force and the reversed cyclic horizontal force were given in the same way as described in the section three of this paper. The horizontal displacement (δ) was measured at the level of loading point and the given horizontal and axial forces were measured by the load cells that was installed at the tip of loading oil jacks.

Table 3: Test specimens

Test specimen	Longitudinal bar SD490	Axial force ratio (σ_0/F_C)	Lateral reinforcement		Concrete Strength	Grouting SS mortar
			Hoops	P_w(%)		
PCA@75	8-D19 (σ_y=558MPa)	0.1	D10@75	0.96	55.2MPa	101 MPa
ISR@100			D10@100 +ISR□2-D16	0.72		

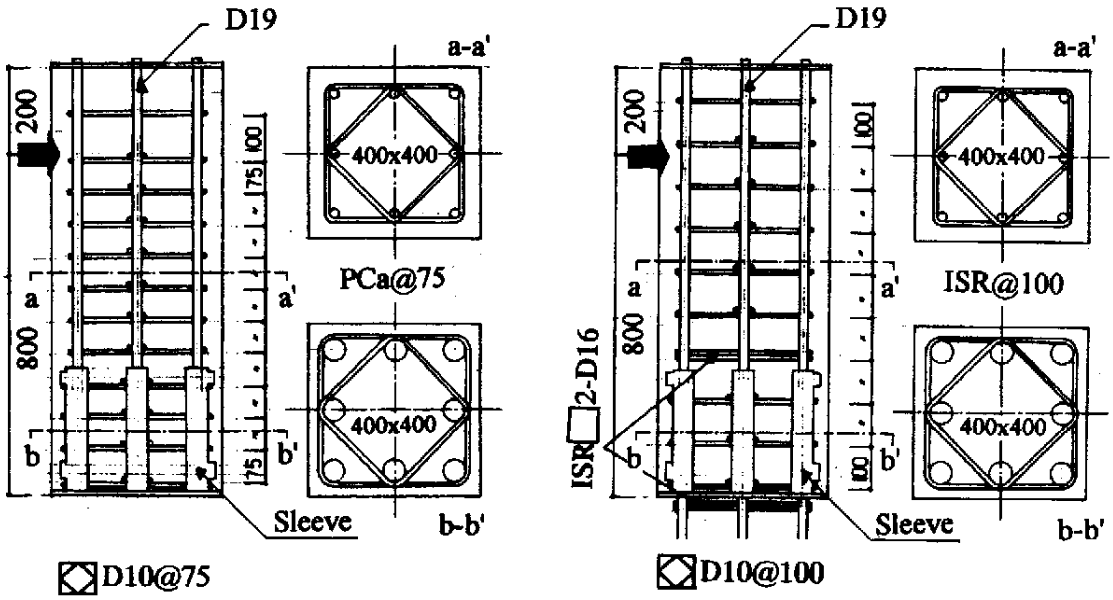


Fig. 12: Geometry of column specimens

5.2 Test Results:

The horizontal force (Q)-horizontal displacement (δ) relations are shown in Fig.12. Both specimens had an excellent ductility till 5/100 of the rotation angle of member. Completely no difference was found, even if one forth of hoops was reduced and replaced by ISR. It was found that ISR would have a contribution to the ductility gain as well as the increase of shear capacity and bond splitting capacity, especially when the shear stress level would be increased because of the use of high strength materials.

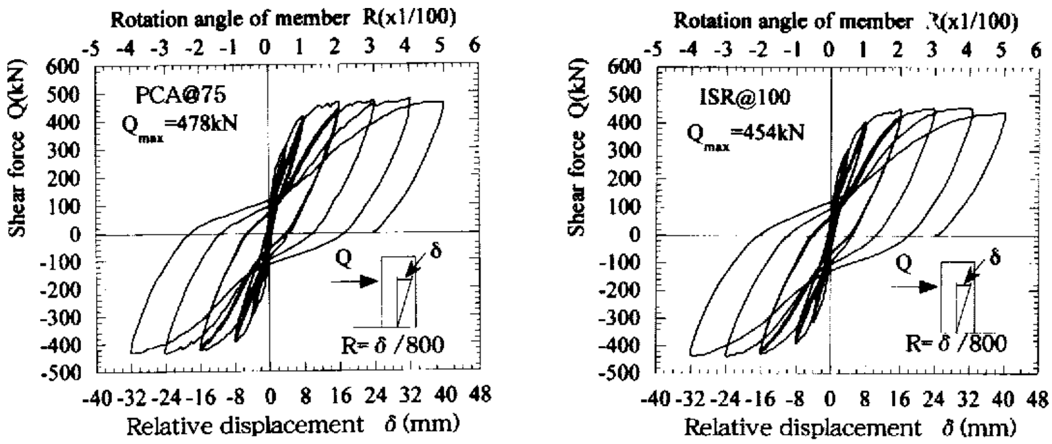


Fig. 13: Horizontal force (Q) – horizontal displacement (δ) relations

6. CONCLUSIONS

1. The critical section of PCa members with splicing sleeve joints looks as if it comes up to the upper end of sleeves. This suggests that the anchorage length of the main bar in the PCa members would be shortened even before flexural yielding, and the PCa members would have more chance of bond splitting failure than the ordinal RC members.
2. ISR could increase the bond splitting capacity. However, only ISR is not enough to prevent the bond splitting failure and the reduction of bearing force. Some amount of the normal shear reinforcement would be needed at least so that the flexural failure may proceed to the shear failure and the bond splitting failure.
3. Even if fairly large amount of hoops was replaced by ISR, a well satisfactory restoring force characteristic with large ductility was obtained.
4. ISR would work more effectively to increase the ductility when the shear stress level would be increased because of the use of high strength materials.

6. REFERENCES

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