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EARTHQUAKE RESISTANCE OF REINFORCED CONCRETE PIER DENSELY ARRANGED HOOP REINFORCEMENT

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SUMMARY

In this study, the effect on deformation capacity is examined by the hoop reinforcement spacing on the RC piers that has high strength ratio.

As the results of this experiment, even if the hoop reinforcement in RC pier is densely arranged and its strength ratio is large, the ductility ratio can't be improved. And the spacing of hoop reinforcement has an effect on the ductility ratio of RC pier that has high strength ratio and that is densely arranged hoop reinforcement. Furthermore in case of the densely arranged hoop reinforcement in RC pier that has the high strength ratio, there is a probability of breaking the axial reinforcement by repetition of loading.

INTRODUCTION

Earthquake resistance of reinforced concrete (RC) structure had been carried out by the statical earthquake intensity method in Japan until 1996[1]. However, it is necessary that the deformation capacity of RC structures should be improved in order to prevent the failure of RC structure by a large earthquake. A lot of experiments whose purpose is ductility evaluation of RC structures have been carried out. Based on these data, the evaluation equation of ductility ratio is proposed. Generally, the larger the hoop reinforcement ratio is, the larger ductility ratio becomes. And, the larger strength ratio is, the larger ductility ratio becomes. However, this evaluation equation is composed of two factors of strength ratio (Vc/Vmu and Vs/Vmu) and axial load. This method has a problem of accuracy in order to calculate the deformation capacity of RC structure that is affected by a lot of factors. Especially, it is considered that spacing of hoop reinforcement has an effect on ductility of RC pier.

In this study, the effect on deformation capacity is examined by the hoop reinforcement spacing on the RC piers that has high strength ratio.

PROCEDURE OF EXPERIMENTS

Properties of a specimen

A form measure of a specimen is shown in Fig.1.

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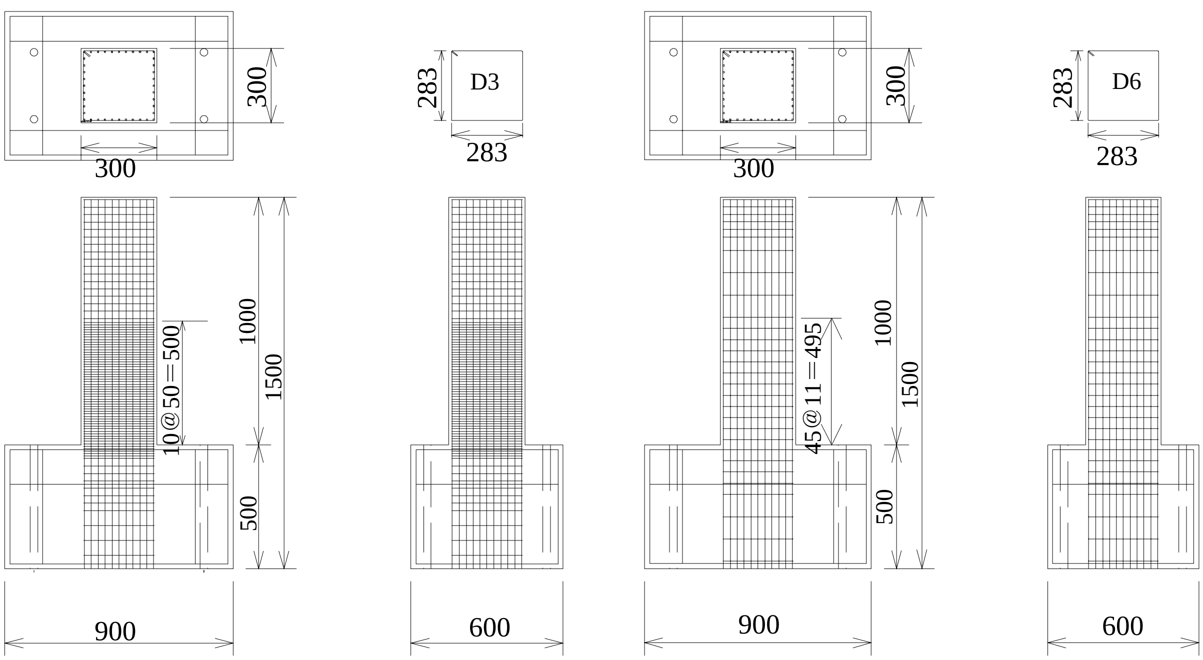
The form of a specimen was RC pier that was supported by the hooting. A columnar section size was 300x300mm, and a cover of axial reinforcement was 13mm. In the axial reinforcement, 40 deformed reinforcing bars (D6, SD295) were used on the foot of pier. As for the hoop reinforcement of specimen A, deformed reinforcing bars (nominal diameter was 3mm, D3) were used on the foot of pier at the space of 10mm. And, the hoop reinforcement of specimen B, deformed reinforcing bars (nominal diameter was 6mm, D6) were used on the foot of pier at the space of 45mm. The both specimen A and specimen B were designed on the basis of the standard of Japan Society of Civil Engineers (JSCE) in 1996. Therefore, they were bent at the ends of hoop reinforcement to an angle of 135 deg.

The properties of axial reinforcement and hoop reinforcement are shown in Table 1. Mix proportion of concrete and compressive strength at loading test time are also shown in Table 2. The ratio of hoop reinforcement, the ratio of axial reinforcement, the ratio of shear span and the ratio of strength are shown in Table 3.



(a) Specimen A (b) Specimen B

Fig.1 A form measure of a specimen

Table 1 Properties of reinforcement

	Nominal Steel Area (cm^2)	Yield Stress (N/mm^2)	Tensile Stress (N/mm^2)	Young's Modulus (N/mm^2)	Yield Strain (μ)
D6	0.3167	376	502	1.436×10^5	2632
D3	0.0707	325	444	—	—

Table 2 Mix proportion of concrete of Specimen A and B

Compressive strength (N/mm^2)	Ms (mm)	W/C (%)	Unit Content (kg/m^3)			
			Water	Cement	Fine aggregate	Chemical admixtures
38.7	5	55	247	450	1549	1.28*

(*notice : pozzolyth No.70)

Table 3 Properties of reinforcement

	Specimen A	Specimen B
a/d	3.86	3.86
Pt (%)	1.47	1.47
Pw (%)	0.47	0.47
Mud ($kgf \cdot cm$)	584852	583882
Vcd (kgf)	5229	5153
Vsd (kgf)	10421	10346
Vcd・a/Mud	1.01	0.99
Vsd・a/Mud	2.00	1.99
Vud・a/Mud	3.01	2.99

Loading method

The test of RC pier was carried out under the static horizontal alternative loading, the regular axis load (1.307N/mm^2) was added from the upper part, and the hooting of specimen was fixed with PC bars. The static horizontal alternative loading was applied by a load control until the axial reinforcement yields, and was carried out with a displacement control. In that case, the horizontal displacement at the time of a yield was regarded as the yield displacement after yielding.

The loading method is shown in Fig.2.

Measuring method of Load and displacement

The axial load and horizontal load were measured with a load cell at each point. The displacement at the loading point was measured with a displacement meter, which was fixed with hooting. And the height of loading point was 1125mm from the foot of pier including an instrument.

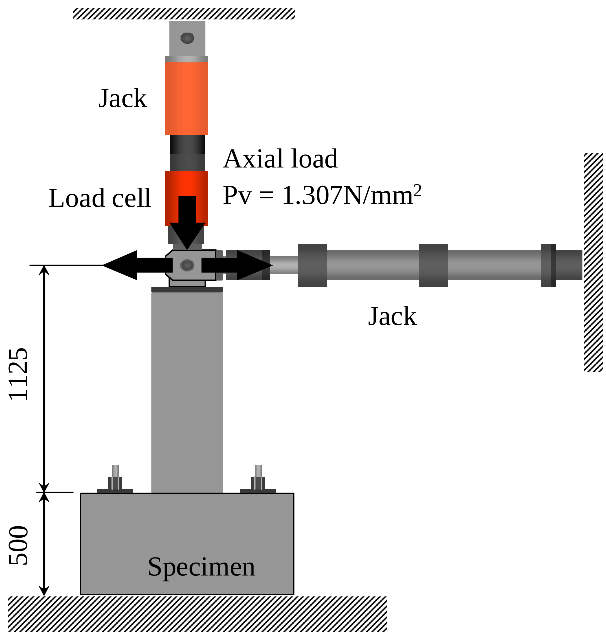


Fig.2 Loading method

Measuring method of strain

The strain of the axial reinforcements inside a specimen was measured with a strain gauge, and a yield of the axial reinforcement was judged by the strain that was measured. And the strain of the hoop reinforcement was also measured with a strain gauge.

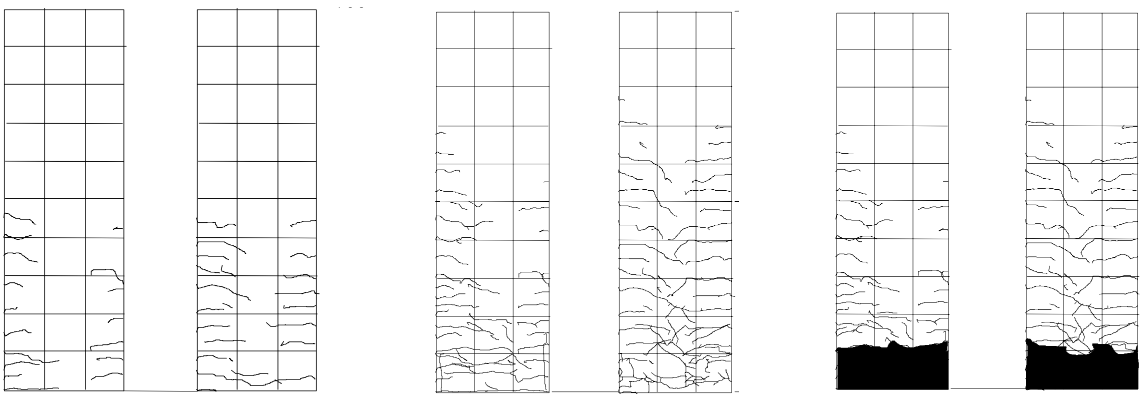
RESULT OF TESTS AND DISCUSSIONS

Failure condition

Progress situation of a crack is shown in Fig.3. On the specimen A occurred flexural cracks at yield displacement ($1\delta y$) from the hoot of pier to about 350mm height. And the cracks that occurred transversely at $\pm 3\delta y$ changed the diagonal ones. A cover concrete was broken away at $\pm 5\delta y$. Moreover, the axial reinforcement about 50mm away from the hoot of pier buckled up at $+6\delta y$. The axial reinforcement of angular parts was broken at $+10\delta y$, and the strength decreased sharply.

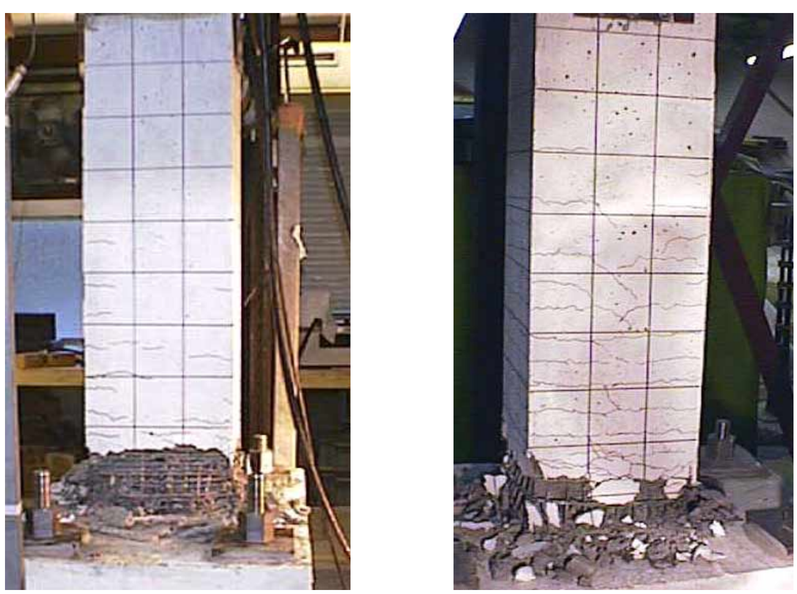
On the specimen B occurred flexural cracks at yield displacement ($1\delta y$) from the hoot of pier to about 450mm height. And the cracks that occurred transversely at $\pm 3\delta y$ changed the diagonal ones. A cover concrete about 50mm away from the hoot of pier was broken away at $+5\delta y$, and the axial reinforcement buckled up. The axial reinforcement of specimen B was also broken at $+9\delta y$, and the strength decreased sharply. The failure condition of specimen is shown in Photo.1.

The failure condition of the hoot of pier of specimen A and specimen B are also shown in Photo.2. The axial reinforcement of angular parts of both specimen A and specimen B were broken. The axial reinforcement that was positioned at center of hoop reinforcement, whose restraining force by the hoop reinforcement is small, buckled by repetition of loading. However, the axial reinforcement of angular parts was restrained by the hoop reinforcement from two directions. The restraining force of the axial reinforcement increased because the fixing of hoop reinforcement was an acute angle hook. As the result, it was difficult that the axial reinforcement buckled. That is to say, it is considered that the axial strain that occurred by the buckling of the axial reinforcement at the center point acts at angular parts, and that the axial reinforcement was broken by the fatigue of a reinforcement. In case that an area of hoop reinforcement increases and that restraining force increases in order to control strength drop, it is considered that the axial reinforcement is possibly broken at the point of plastic hinge.



Spacimen A ($1\delta y$)	Spacimen B ($1\delta y$)	Spacimen A ($5\delta y$)	Spacimen B ($4\delta y$)	Spacimen A ($10\delta y$)	Spacimen B ($9\delta y$)

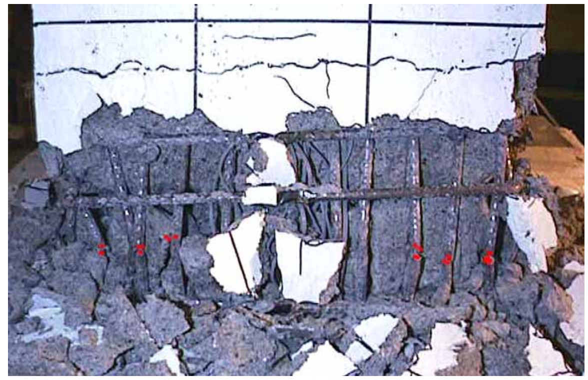
Fig.3 Progress situation of a crack



(a) Specimen A (b) Specimen B

Photo.1 The failure condition of specimen

(a) Specimen A



(b) Specimen B

Photo.2 The failure condition of the hoot of pier of specimen

Load and displacement curve

The relation between load and displacement of specimen A and specimen B is shown in Fig.4 and Fig.5. The axial reinforcement of specimen A yielded at 51.98kN, and the yield displacement was 4.52mm. The strength had been sustained until $\pm 9\delta y$. The displacement was 21.55mm at maximum load, and was 44.05mm at the displacement (ultimate displacement δu) that maximum load wasn't lower than the yield load. Therefore the ductility (ultimate displacement δu/yield displacement δy) of specimen A resulted in 9.75.

The axial reinforcement of specimen B yielded at 48.19kN, and yield displacement was 3.91mm. The displacement was 19.50mm at maximum load, and the ultimate displacement was 35.50mm. The ductility of specimen B was 9.08 according to the ultimate displacement and the yield displacement, and it was small in comparison with specimen A.

However, when the ductility of specimen was analyzed by the evaluation equation, which was described in Standard Specification for Design and Construction of Concrete Structures (1996) of JSCE, the both specimen A and specimen B were about 20.

Therefore the ductility changes by the space of hoop reinforcement, when both the ratio of hoop reinforcement and ratio of strength are large.

And relation between this result and result of past is shown in Fig.6 and Fig.7. There is a linear relation between the ductility and the ratio of strength (the ratio of shear strength covering concrete and flexural strength: Vc/Vmu) within an application range of the ductility evaluation equation, when the ratio of hoop reinforcement and ratio of strength are large. On the other side, the relation can not be calculated by the present evaluation equation between the ductility and the ratio of strength (ratio of shear strength covering of hoop reinforcement and flexural strength: Vs/Vmu). When the ductility is evaluated by the ratio of strength (Vs/Vmu), the ductility does not increase with the increment of the ratio of strength and has a limit. Therefore, it is considered that the ductility can not be improved, even if the hoop reinforcement is densely arranged.

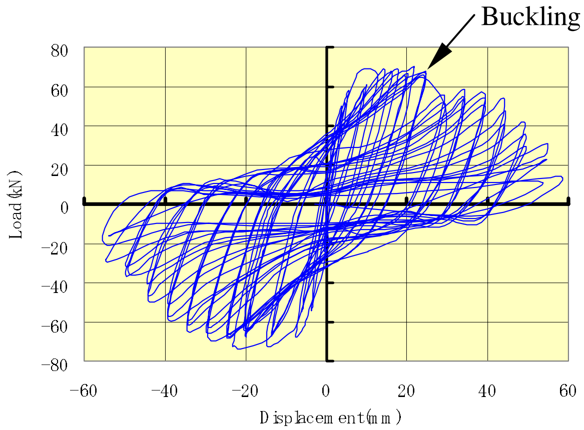


Fig.4 Relation between load and displacement of specimen A

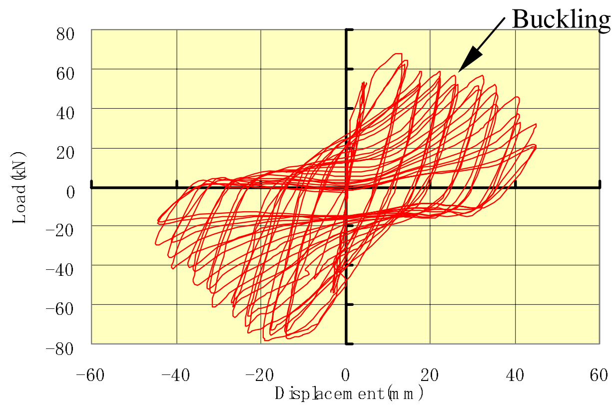


Fig.5 Relation between load and displacement of specimen B

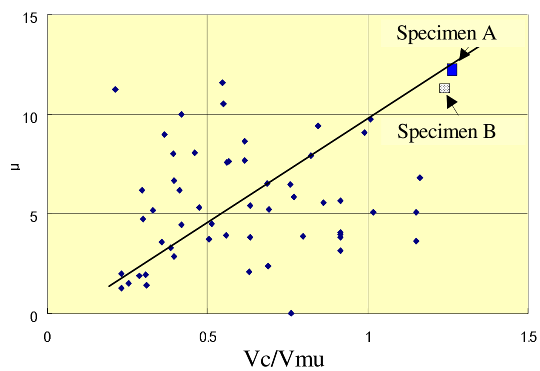


Fig.6 Relation between Vc/Vmu and μ

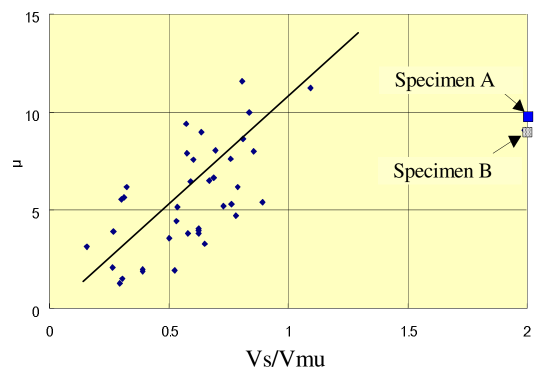
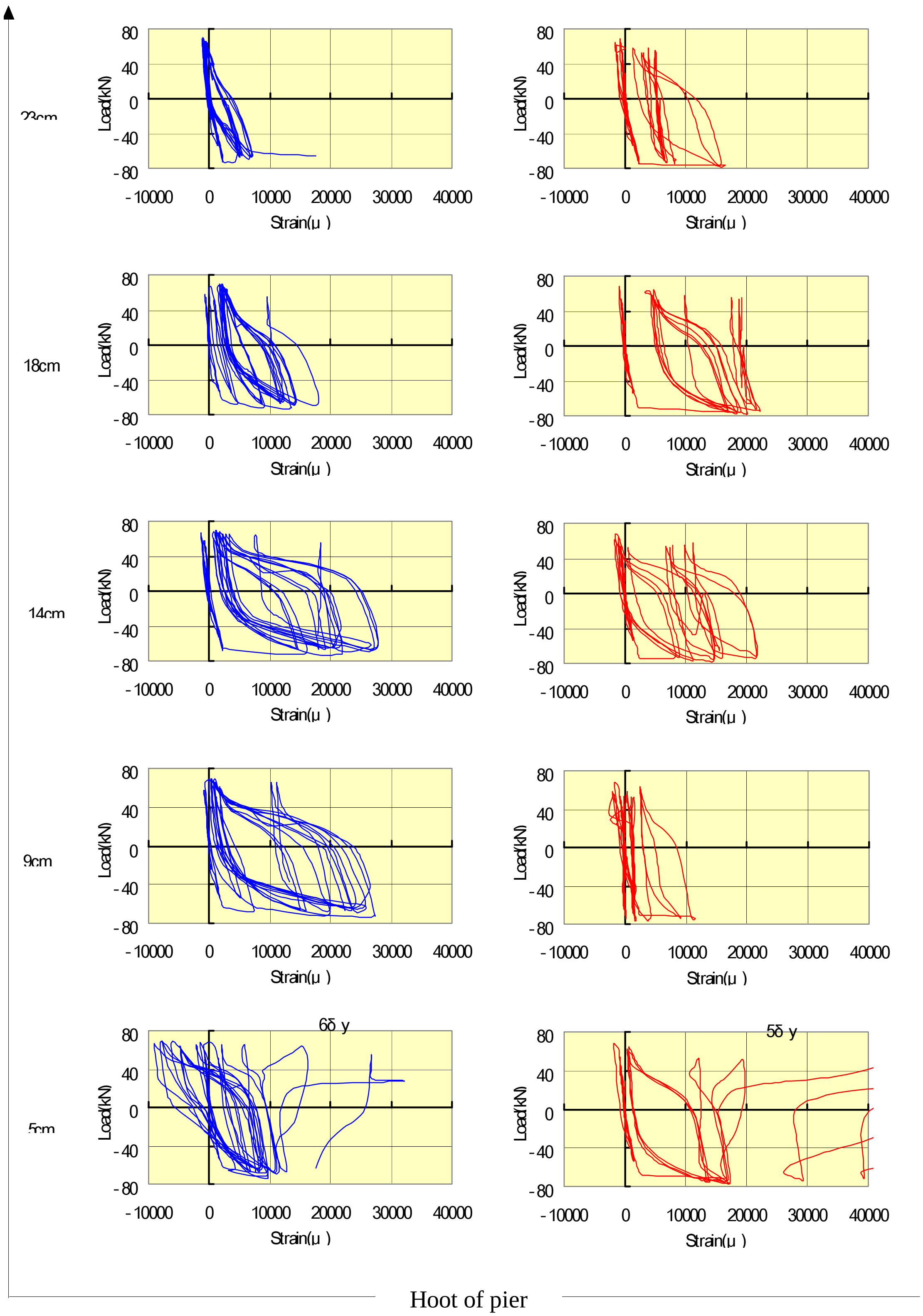


Fig.7 Relation between Vs/Vmu and μ

Load and strain curve

The relation between the load and the strain of the axial reinforcement is shown in Fig.8. The curve of the specimen A was inverted from $+6\delta y$ to $-6\delta y$. It is judged that this point is the buckling point, because the strain of the axial reinforcement at compressive side increased with increment of the load. The strength started to decrease from this point. The curve of the specimen B was inverted from $+5\delta y$ to $-5\delta y$. Therefore, it is considered that this point is the buckling point as the specimen A. The strength also started to decrease from this point at specimen B. Therefore, it is considered that the decline of strength can be controlled by preventing the buckling. However, the axial reinforcement may be broken by preventing the buckling as the axial reinforcement of angular parts. The strain of the specimen A was large at the hoot of pier from 9cm to 14cm, and was small above 14cm in comparison with specimen B. Therefore, the plastic deformation area is short. It is considered that the hoop reinforcement effects the result.

When the space of the hoop reinforcement is short, the axial reinforcement can not buckle at the space of hoop reinforcement. Because of this, it may buckle at a point where energy concentrates. However, when the space of hoop reinforcement is long, the axial reinforcement buckles at the space of the hoop reinforcement. Therefore the plastic deformation area of specimen A is shorter than that of specimen B.



(a) Specimen A

(b) Specimen B

Fig.8 Relation between load and strain

CONCLUSION

This study, the effect on deformation capacity is examined by the hoop reinforcement spacing on the RC piers that has high strength ratio.

As the results of this experiment, the following conclusion can be stated;

(1) Even if the hoop reinforcement in RC pier is densely arranged and its strength ratio is large, the ductility ratio can't be improved.

(2) The spacing of hoop reinforcement has an effect on the ductility ratio of RC pier that has high strength ratio and that is densely arranged hoop reinforcement.

(3) In case of the densely arranged hoop reinforcement in RC pier that has the high strength ratio, there is a probability of breaking the axial reinforcement by repetition of loading.

REFERENCES

1. Japan Society of Civil Engineers (1996). Standard Specification for Design Construction of Concrete Structures (Design). JSCE, Tokyo