EFFECT OF THE PRESTRESS ON SHEAR BEHAVIORS OF RC BEAMS WITH A VERTICAL CONSTRUCTION JOINT

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1. INTRODUCTION

In the present construction method for reinforced concrete structure, it is impossible to perform the continually casting of concrete because of some problems. For example, the heat of hydration occurred in the large amount of casting concrete can result in the thermal stress and the thermal crack may occur in the hardened concrete [1,2]. Therefore, in many structures such as slab or beam the vertical construction joint can be provided for solving these problems. However, the location of vertical construction joint, where the shear capacity of concrete is supposed to be lower than that of the other parts of the structure, should be more carefully considered. From many researches, the shear capacity of reinforced concrete beams with a vertical construction joint can be improved well by some strengthening methods such as by using steel plate, carbon fiber reinforcing polymer (CFRP) and also by prestressing.

This paper presents the experimental study of strengthening effect on shear behavior by introducing the prestressing force to reinforced concrete beams with a vertical construction joint (hereafter joint) located at the middle of shear span in one side of the beam. In this experimental program, the 1.0-meter span length beams were made by ordinary strength and high strength concrete with design compressive strength as 50 N/mm^2 and 80 N/mm^2, respectively. The differences of shear capacity and shear behavior between RC and PC beams with/without joint were studied. The other concerning variables examined through this experimental program were the strengthening effect by using different amount of applied prestressing force and the treatment method of joint surface.

2. EXPERIMENTAL DETAILS

2.1 MATERIALS

In this experiment, the main reinforcing materials are standard deformed reinforcing steel bars, which SD295 D6 was used for stirrup, SD 295 D10 for compression rebar and SD 345 D19 for tension rebar. The prestressing steel bar is 9.2 mm in nominal diameter, type C No.1 SBPR 1080/1230, with the tensile stress at 0.2% elongation being 1,080 N/mm^2. The mechanical properties of reinforcing materials, i.e. the yield strength, the tensile strength and the Young's modulus of elasticity are shown in **Table1**.

Table 1. Properties of reinforcing materials

Symbol	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Young's modulus (N/mm^2)
SD295 D6	374	541	1.87×10^5
SD295 D10	357	513	1.85×10^5
SD345 D19	386	569	1.87×10^5
SBPR 1080/1230	1,248	1,275	2.00×10^5

In this experiment, the method of introducing the prestressing force is performed by using the unbond type post-tensioning prestress system. In order to reduce the prominent loss of prestress due to the relaxation of prestressing steel bar and also the creep and drying shrinkage of hardened concrete that could occur in the time of curing period, the prestressing force was introduced just before performed the loading test. The eccentricity of prestressing steel bar is 30 mm under the centroid of beam section as can be seen in **Fig.1**. Therefore in this experiment, even if the maximum amount of prestressing force is applied to the beam, the tensile stress on the top fiber of concrete section would never occur.

The mix proportion of concrete used in this experiment and the fresh properties are shown in **Table 2**. The beams were designed in two types as ordinary strength and high strength concrete beams according to the design compressive strength 50 N/mm^2 and 80 N/mm^2, respectively. The 28-day compressive strength of these beams is also shown in this table.

Table 2. Mix proportion of concrete

Type of concrete	Slump	Air content	W/C	s/a	Unit weight of materials (kg/m^3)				Compressive strength (N/mm^2)	
	(cm)	(%)	(%)	(%)	W	C	S	G	Old concrete	New concrete
Ordinary strength	7.0	3.8	55	49	185	337	876	993	55.2	54.1
High strength	15.5	2.6	30	45	185	618	697	928	81.1	83.3

2.2 DETAIL OF SPECIMEN

The details of the typical beam specimen and the position of loading point are shown in **Fig.1**. The shear span to depth ratio (a/d) of beam specimen is 1.8. The section of the beam is 150mm×200mm rectangular cross section with 2.25% of the main tension rebar. The vertical construction joint is located at the middle of shear span in one side of the beam as shown in this figure.

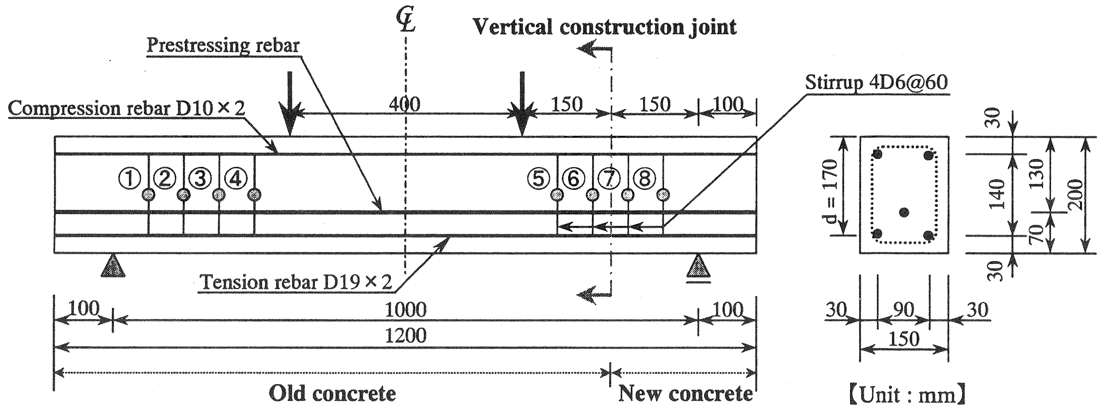

Fig.1 Details of typical beam specimen

The classification of all beams is shown in **Table3**. From this table the beams are named by alphabetical symbols, e.g. NJ is meant for beam without a vertical joint, "A" character is meant for beam with joint, where the surface treatment is done, while "B" is meant for beam with joint but the surface treatment is not done. RC is meant for a reinforced concrete beam, while PC is meant for a reinforced concrete beam prestressed

Table 3. The classification of beam specimens

Specimen		Vertical joint	Joint surface Condition	Amout of prestress (%)	Design strength (N/mm^2)
50～	RC-NJ	Without Joint	-	-	50
	RC-A	With Joint	With treatment (A)	-	
	PC40A			40	
	PC60A			60	
	PC80A			80	
	RC-B		Without treatment (B)	-	
	PC40B			40	
	PC60B			60	
	PC80B			80	
80～	RC-NJ	Without Joint	-	-	80
	RC-B	With Joint	Without treatment (B)	-	
	PC40B			40	
	PC60B			60	
	PC80B			80	

by unbond tendon. The numbers 40, 60 and 80 are the rates of prestressing, i.e. the level of tensile axial force applied to prestressing steel bar in the unit of percent of the load that causes 0.2% elongation of prestressing steel bar.

After 24 hours of casting old concrete portion, the surface of joint in some beams was treated and well polished with the steel brush and the sharp-edge hammer. This treatment of the joint surface had to be done until the rough surface of coarse aggregate in the matrix of concrete could be seen clearly. However, for the beams without treatment of the joint (B-series), this step was skipped. Then after 48 hours from casting old concrete, the new concrete was placed in the same mold. The beam was cured by the wetted cloth for 28 days. Then, the loading experiment was performed.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 FLEXURAL CRACKING LOAD

The experimental result of flexural cracking load and diagonal cracking load for all beams is shown in **Fig.2**. The flexural cracking load was determined by the load at which the tensile strain of concrete in bottom fiber suddenly changed in its magnitude and/or direction. The result shows that prestress can increase the flexural cracking load of beams made by both ordinary strength and high strength concrete even compared to beams without the vertical joint. Moreover, the flexural cracking load also increased with the amount of prestressing force. In the group of beams made by ordinary strength concrete, beams with joint surface treatment (A-series) exhibited higher flexural cracking loads than those of beams without joint surface treatment (B-series). Therefore, the treatment of joint surface resulted in having influence on the flexural cracking load of beam, even the position of the vertical construction joint is not in the equal moment span.

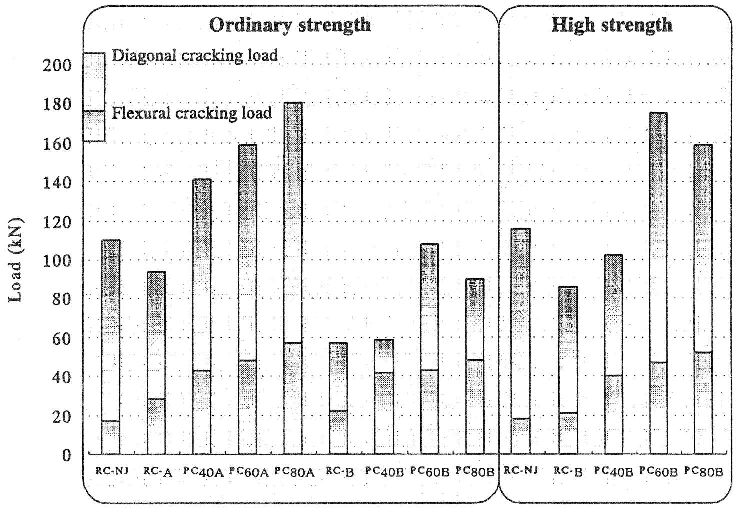

Fig.2 Flexural cracking load and diagonal cracking load of beam specimens

3.2 DIAGONAL CRACKING LOAD

In this experiment, the diagonal cracking load was determined by eye-observation method and also checked by the load-midspan deflection curve. From **Fig.2**, we can see that the beams exhibited lower diagonal cracking load because of the existence of joint in both ordinary strength and high strength concrete beams. Furthermore, in the group of beams made by ordinary strength concrete, those with the treatment of joint surface (A-series) both in RC and PC exhibited higher diagonal cracking load than those without joint treatment (B-series). Therefore, the treatment of joint surface should significantly have an effect on the magnitude of diagonal cracking load for the beam specimens, e.g. we can see that the diagonal cracking load of 50RC-B beam is lower than that of 50RC-NJ beam by almost 50%, while the reduction is only 15% for 50RC-A beam when compared to 50RC-NJ beam.

For the comparison among the group of beams with the same amount of prestress in B-series, the diagonal cracking load of beams made by high strength concrete was higher than those of beams made by ordinary strength concrete as was expected. This can be supposed that the bond strength, which occurs between the interface of old concrete and new concrete in beams made by high strength concrete is higher than that of beams made by ordinary strength concrete [3].

The results from same figure also show that the diagonal cracking load increased with amount of prestress for beams made by ordinary strength concrete that was well treated in joint surface. On the contrary, for the beams without joint surface treatment (B-series), the diagonal cracking load of beams applied with 80% prestressing force are lower than those of beams applied with 60% prestressing force. This was true for beams made by ordinary strength concrete and high strength concrete. Moreover, even though the prestress was applied in 50PC40B and 50PC80B beams, the diagonal cracking load of these beams are lower than that of 50RC-A beam. Therefore, we can state that the beneficial effect of prestress cannot be perfectly achieved unless the joint surface is well polished or well treated.

3.3 STRAIN BEHAVIOR OF STIRRUPS

The shear behavior of beam specimens with a vertical construction joint will be discussed here by examining the local strain distribution from stirrups located in shear span of beam. The stirrups were numbered from 1 to 8 as referred from **Fig.1**, i.e. the vertical joint is located at the middle between stirrup No.6 and No.7. The stirrup No.1 and No.8 are stirrup which placed near to the support.

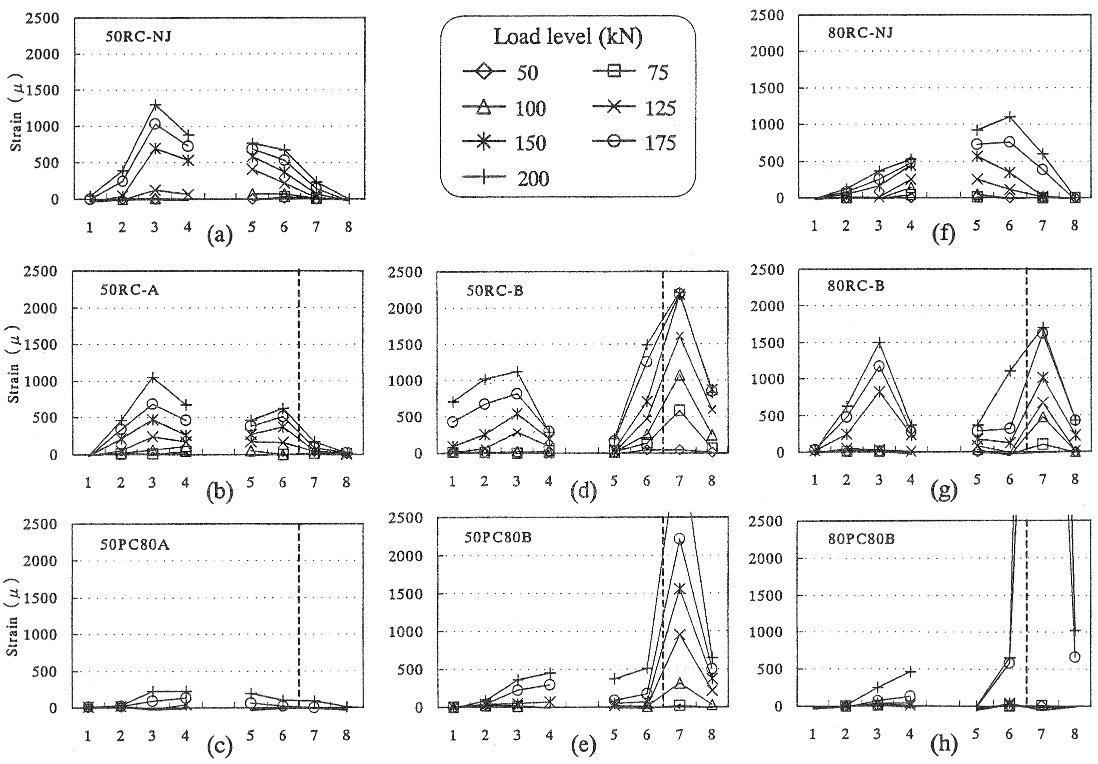

Figure 3. Strain distribution in stirrups at some load levels

The local strain distributions of stirrups for each load level of some beams are shown in **Fig.3**. Each point represents the strain at load level from 50kN to 200kN as shown in this figure.

From **Fig.3**, it can be found that 50RC-A beam, which was well treated at the joint surface shows favorable result that the strain of stirrups in location of the joint did not much different from that of 50RC-NJ beam. In the other words, a vertical construction joint will not behave as a weak point if the proper treatment is performed enough in the joint. Prestress also provided good result as we can see that the strain of stirrups is very low when compared to those of other beams at the same load level. Nevertheless beams without joint surface treatment (B-series) did not exhibit such good result in strengthening. According to the result even if the prestress was applied to beam, stirrups yielded immediately after the diagonal crack occurred. In addition, the result did not show any noticeable difference between beams made by ordinary strength concrete and those made by high strength concrete. This is considered to be because of weak point due to lack of joint surface treatment.

Therefore, as stated in previous section the treatment of vertical construction joint surface will also significantly have an effect on the strain of stirrup in the location which diagonal crack occurs.

3.4 MAXIMUM LOAD AND MODE OF FAILURE

The maximum load and the mode of failure for all beam specimens are shown in **Table 4**. The mode of failure for almost every beam was compression shear failure, while flexure failure occurred in only 50RC-A and 80RC-NJ beams. It can be considered that the surface treatment of joint in 50RC-A beam was perfect enough so that the decreasing of concrete shear capacity due to the existence of joint in this beam was minimized resulting in the flexure failure. The maximum load of 50RC-A beam was little higher than that of 50RC-NJ beam, which is without joint. Moreover, similar to the flexural cracking load and diagonal cracking load, beams made by ordinary strength concrete without joint surface treatment exhibited maximum load lower than those of beams with joint surface treatment in the same amount of prestress.

Table 4. Maximum load and mode of failure

Specimen		Maximum load (kN)	Mode of failure
50～	RC-NJ	300	Shear failure
	RC-A	303	Flexure failure
	PC40A	315	Shear failure
	PC60A	337	Shear failure
	PC80A	342	Shear failure
	RC-B	214	Shear failure
	PC40B	326	Shear failure
	PC60B	276	Shear failure
	PC80B	316	Shear failure
80～	RC-NJ	345	Flexure failure
	RC-B	299	Shear failure
	PC40B	345	Shear failure
	PC60B	353	Shear failure
	PC80B	311	Shear failure

In the comparison among the group of B-series with the same amount of prestress, the maximum load of beam specimens made by high strength concrete was higher than those of beam specimens made by ordinary strength concrete.

3.5 CRACK PATTERN AT FAILURE

The crack patterns of some beams at failure are shown in **Fig.4**. The typical failure for almost every beam is compression shear failure where the diagonal crack occurred from the support, then continually extended to loading point. Eventually, the beam could still sustain to some level of load until crushing of concrete occurred in the top fiber that causes the failure of beam.

From **Fig.4**, we can see noticeable aspects among beams with different characteristics. In the location of vertical joint, the slippage of joint occurred in the beams where joint surface treatment was not done. Therefore we found that in the beams such as 50RC-B, 50PC80B, 80RC-B and 80PC80B, there was the noticeable discontinuity of diagonal crack pattern because such slippage occurred. Even in beams which prestress was applied, this slippage also occurred if the joint surface treatment was not done The slippage, however, did not occur in 50RC-A and 50PC80A beams because the joint surface treatment was properly done in these beams. It can be considered that in the early stage of loading, the flexural crack will occur along the interface of joint [2], especially, beams with smooth joint surface where the effect of aggregate interlocking is little, the slippage of diagonal crack will occur after the beam sustains higher load. Eventually, it will result in failure at lower load value than that of beams with well treated in the joint surface. Therefore, the condition of joint surface is the most important factor for shear behavior of reinforced concrete beams with a vertical construction joint.

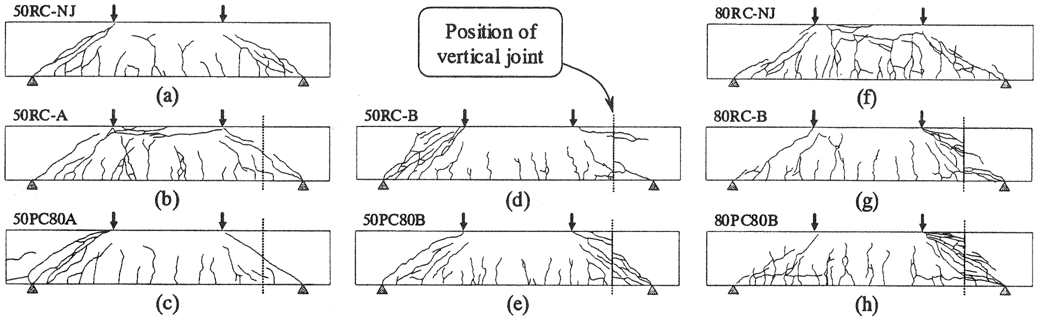

Figure 4. Crack pattern of beam specimens at failure

4. CONCLUSIONS

From the experimental result of shear test on reinforced concrete beams and prestressed concrete beams with a vertical construction joint in shear span, it is possible to give the following conclusions.

1) Introducing the prestress can improve the shear capacity and the shear behavior of reinforced concrete beam with a vertical construction joint as it can result in increased diagonal cracking load and delayed yielding of stirrup.
2) The treatment of joint surface significantly has an effect on the strengthening by introducing prestress to beam with a vertical construction joint. The efficiency of prestress cannot be achieved unless proper treatment is done.
3) The strength of concrete is also influential on the shear behavior of the reinforced concrete beam with a vertical construction joint.

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