Shear Resistance Mechanism of Reinforced Concrete Haunched Beams without Shear Reinforcement

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1. INTRODUCTION

Reinforced concrete haunched beams (RCHBs) are often used in simply supported and continuous bridges, structural portal frames, mid-rise framed buildings and cantilevers. Such beams are widely used for economic and esthetic reasons. However, the number of experimental data on shear behavior of RCHBs is insufficient and rational and economical design method is not established yet. The objective of this research is to explore shear-resistance mechanism of RCHBs without shear reinforcement.

2. EXPERIMENTAL PROGRAM

(1) Specimen details

Figure 1 illustrates the detail of tested beams. D25 steel bars which yield strength was 411 N/mm^2 were used for tensile bars of all three specimens. The designed compressive strength of concrete was 30 N/mm^2. The thickness of the cover concrete was 38 mm in all specimens. The inclinations of tensile bars and the bottom surface were fixed as: α = 11.3 degrees. The experimental parameters in this research were d_{emax} and d_{emin} of each specimen, which represent the maximum effective depth at the supported portion and the minimum effective depth at the mid portion, respectively.

(2) Instrumentations and test procedures

Four-point bending tests were conducted. The specimens were monitored in terms of applied load, mid-span displacements and strain of tensile bars. Also the crack propagation on the side surface of test-span during loading was recorded by taking pictures.

Table 1 Summary of the experimental results

No.	f_c'	P_1	d_e	a/d^*	$a/d\#$	P_2	V_c
1	30.26	31	200-300	2.17	3.25	121.1	60.5
2	29.62	37	200-250	2.6	3.25	77.1	38.5
3	31.14	37	250-300	2.17	2.6	129.6	64.8

f_c': Compressive strength of concrete (N/mm^2); P_1: Load at flexural crack (kN); d_e: Effective depth (mm); $a/d^*=a/d_{emax}$ (Minimum value); $a/d\#=a/d_{emin}$ (Maximum value); P_2: Peak Load (kN); V_c: Shear capacity (kN)

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

(1) Load-displacement relationships and crack patterns

Results of the loading tests and compressive strength of concrete are presented in **Table 1**. Crack patterns at the peak load are shown in **Fig. 2**. The thick lines represent main cracks. Crack pattern of beam 2 and beam 3 showed the similarity but that of beam 1 was different. It indicates that the shape of crack is related to the position where the direction of the tensile bars changes.

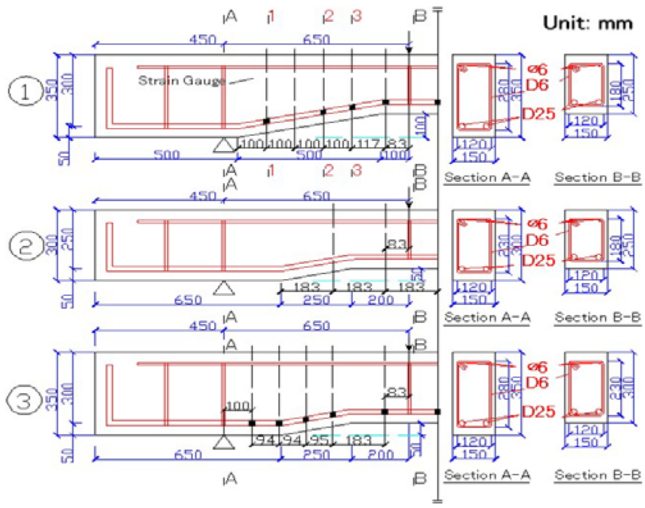

Fig. 1 Detail of the specimens

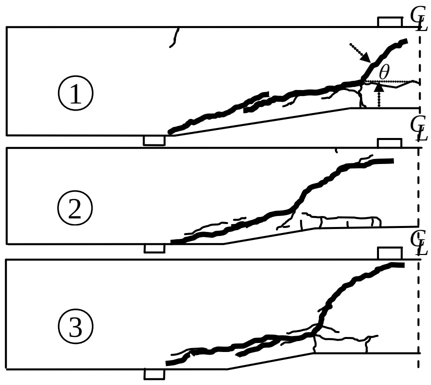

Fig. 2 Crack patterns

Table 2 Calculation for beam 1

Section	d_e	Strain (μ)	V_{hd}	V_c	V_c -V_{hd}
1	280	1337	53.1	76.7	23.6
2	240	1206	47.9		28.8
3	220	1017	40.4		36.3

d_e: Effective depth (mm); V_c: Shear capacity by using JSCE code [1] with d_{emax} (kN); V_{hd}: Vertical component of tension forces (kN)

keywords: RC haunched beam, Shear capacity, Crack pattern, Inclined tensile bars, Applied shear force, Arch action.
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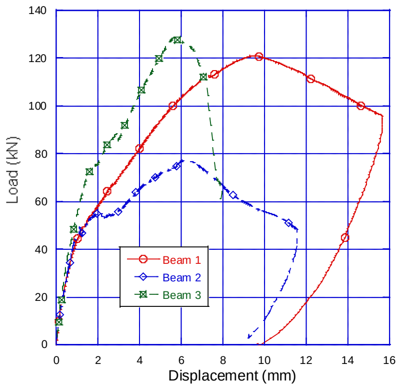

Fig. 3 Load-displacement curves

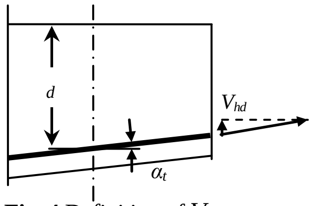

Fig. 4 Definition of V_{hd}

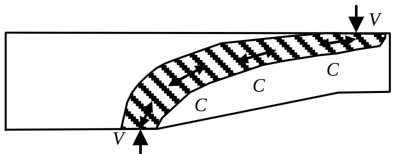

Fig. 5 Compression in compressive zones

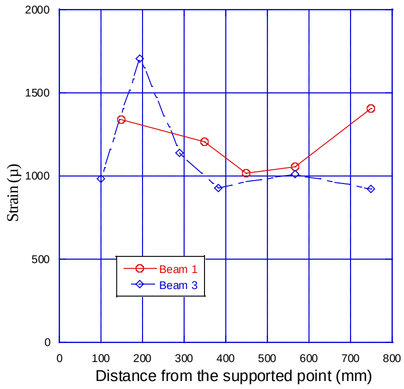

Fig. 6 Strain distributions of tensile bars

Load-displacement curves are illustrated in **Fig. 3**. It is found that the displacement of beam 1 at the peak load was about 10 mm, while those of beam 2 and beam 3 were about 6 mm. This difference of the deformation capacity is supposed to be caused by the difference of crack patterns. By comparison of the different crack shapes of three specimens, it is shown that the angle of the diagonal crack to member axis (θ) of beam 1 (**Fig. 2**) was larger than those of beam 2 and beam 3. It indicates that the aggregate interlock at diagonal crack was larger in beam 1 when the displacement level was the same.

(2) Effect of the inclined tensile bars

In JSCE specifications [1], the design shear force of the inclined beam is calculated by subtracting component V_{hd} (see **Fig. 4**). For RCHBs, the equation is shown as following:

$$V_{hd} = \left(\frac{M_d}{d}\right)(\tan \alpha_t) \qquad (1)$$

M_d: Flexural moment; d: Effective depth
α_t: The angle of the tensile bar to member axis

Availability of vertical component of tensile forces as V_{hd} for evaluating shear capacity of RCHBs is discussed. Strains of tensile bars of three sections in beam 1 (**Fig. 1**) at the peak load were measured and tabulated in **Table 2**. According to the calculation, even though d_{emax} was used to calculate V_c, the values after subtracting V_{hd} became much smaller than the experimental shear capacity. The reason is supposed that arch action existed in RCHBs and the compression force of concrete had vertical components which should be considered in V_{hd} (**Fig. 5**).

(3) Arch action, failure modes and shear capacity

The strain distributions of tensile bars in beam 1 and beam 3 at the peak load are illustrated in **Fig. 6**. It shows that the strain values along the tensile bars from the mid portion to the supported portion became larger or almost same. It indicates the existence of arch action in these two beams. The pictures

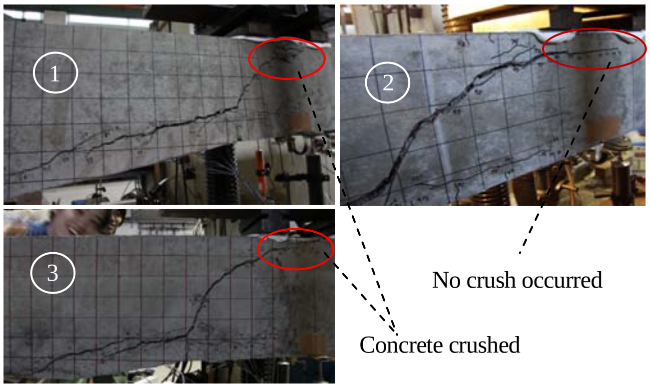

Fig. 7 Pictures of beams at the peak load

of the three beams at the peak load are illustrated in **Fig.** 7. Concrete crush was observed in beam 1 and beam 3 while no crush occurred in beam 2. It indicates that beam 1 and beam 3 were shear compressive failure and beam 2 was diagonal tension failure. It was consistent with the arch action in beam 1 and beam 3 while the arch action in beam 2 was not formed or made less contribution. By comparison of the data in **Table 1**, it is found that the shear capacities of beam 1 and beam 3 were close each other but that of beam 2 was much lower. It was supposed to be caused by the different failure modes which were mentioned in the above.

4. CONCLUSIONS

(1) The crack pattern of RCHBs is related to the position where the direction of tensile bars changes. The deformation capacity shows the consistency with crack pattern.

(2) Both the vertical components of compression force of concrete and tension force in the longitudinal steel bars should be considered to calculate the shear capacity of RCHBs.

(3) Failure modes of RCHBs govern the shear capacity. But more experiment data is needed to verify this conclusion.

REFERENCES

[1] Japan Society of Civil Engineers (JSCE): *Standard Specifications for Concrete Structures [Structural Performance Verification], 2002.*