EXPERIMENTAL EVALUATION OF PUNCHING SHEAR CAPACITY OF REINFORCED CONCRETE SLABS WITH VERTICAL CRACKS.

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1. INTRODUCTION

Reinforced concrete (RC) bridge deck slab deterioration becomes a serious problem as number of aged bridges increase. A main reason of deterioration is fatigue. It is well known that the fatigue process is strongly related to the occurrence of one direction vertical cracks, development to two direction vertical cracks and loss of shear transfer performance at vertical cracks. Many studies have been carried out regarding the fatigue life of RC slabs under moving loads. However, the impact of these vertical cracks related to fatigue process on the punching shear capacity of RC slab, which is a fundamental structural performance is yet to be clarified. Therefore, this study evaluated the punching shear capacity of RC slabs with several types of vertical cracks through experimental evaluation.

2. EXPERIMENTAL SETUP.

2.1. Specimen Outline with Vertical Pre-Cracks.

Series of load tests are carried out on RC slab specimens with vertical pre-cracks. Figure 1 shows the outline of specimens. The specimens are half size of actual bridge deck slab as specified by specifications for highway bridges in Japan (Ikehata et al., 2020). The dimensions of the specimen are 1.2 m x 1.2m with thickness of 85 mm. D10 (SD345) deformed bar is used with a minimum spacing of 50 mm and maximum spacing of 150 mm. The cover thickness is 15 mm.

In order to evaluate the influence of vertical pre-cracks on the punching shear capacity, vertical pre-cracks are introduced in the test specimens. Figure 2 shows the example of fixing of vertical pre-cracks. Vertical cracks are modeled by thin-soft-waved shaped cardboard paper extracted from an ordinary carton box. Cardboard paper is used because it could reproduce wavy-shape crack surfaces and would not affect the deformation of the specimen due to its small stiffness (Ikehata et al., 2020).

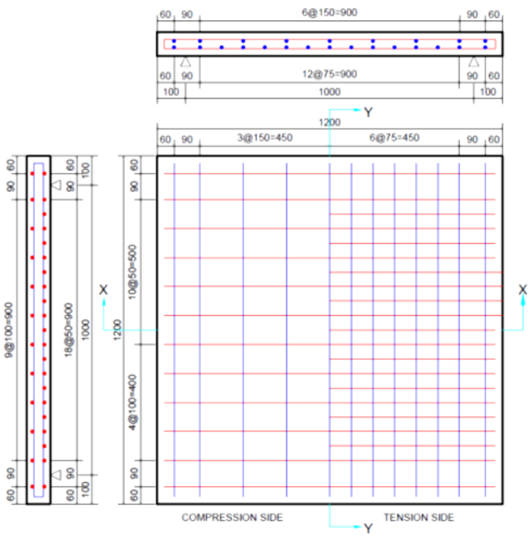

Figure 1: Outline of Specimens

Figure 3 shows the detail of vertical pre-crack layout in specimens. Vertical pre-cracks are arranged imitating fatigue process in RC slabs. The length and height of vertical pre-cracks are 800mm and 85mm respectively. In all the specimens, vertical pre-cracks are positioned at a distance of 50mm from the edge of loading plate. This is because when the cracks that initiates from the edge of loading plate during loading propagates diagonally at 45° towards bottom face intersect exactly at center of the vertical pre-crack. 800-P2-0.3 has two parallel vertical pre-cracks of 0.3mm width to represent one directional crack. 800-P4-0.3 has 4 parallel vertical pre-cracks of 0.3mm width which represents cracks that propagates over wider areas. 800-C4-0.3 has 4 cross-parallel vertical pre-crack of 0.3mm width and represents cracks propagating in two directions. 800-P2-0.6 has two parallel vertical pre-cracks of 0.6mm width representing larger crack width. A total of seven specimens are prepared with two sound specimens and two 300-P2-0.3 specimens. The compressive strength of all the specimens is shown in Table 1.


Figure 2: Vertical Pre-Crack

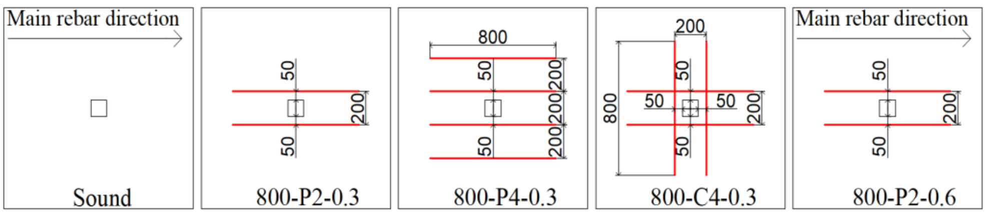

Figure 3: Vertical Pre-Crack Layout

Table 1: Compressive Strength and Punching Shear Load of Specimens.

Specimen	Compressive Strength (MPa)	Peak Load in Test (kN)	Corrected Peak Load (kN)
Sound(1)	33.90	147.80	150.18
Sound(2)	35.43	144.31	143.43
800-P2-0.3(1)	35.43	141.76	140.89
800-P2-0.3(2)	32.90	134.90	139.14
800-C4-0.3	26.79	115.56	132.09
800-P4-0.3	26.79	114.19	130.52
800-P2-0.6	35.43	112.52	111.84

2.2. Loading Test Results of Slabs.

Figure 4 shows the load-displacement relationship. The displacement is an absolute displacement measured at the center of the specimen. All specimens show constant initial stiffness and after cracking the stiffness show some variations until peak load. The load suddenly drops after the peak load. Then displacement keeps on increasing keeping a certain load until specimen reaches ultimate stage and failed in punching shear. This is the typical behavior of RC slabs failing in punching shear. Compared to sound specimen, specimens with vertical pre-cracks exhibit lower magnitude of peak load indicating vertical pre-cracks have influence on the punching shear capacity. The peak loads of all specimens are given in Table 1.

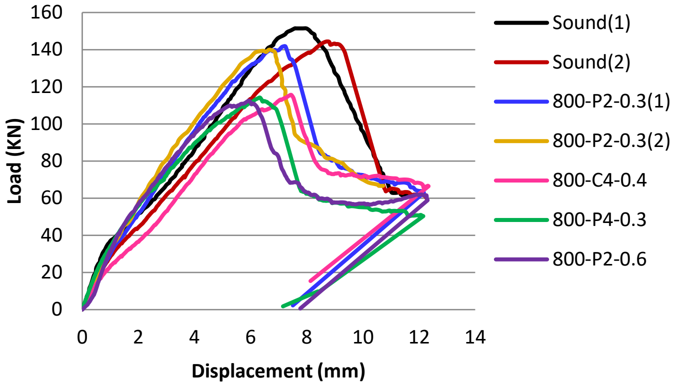

Figure 4: Load-Displacement Relationship

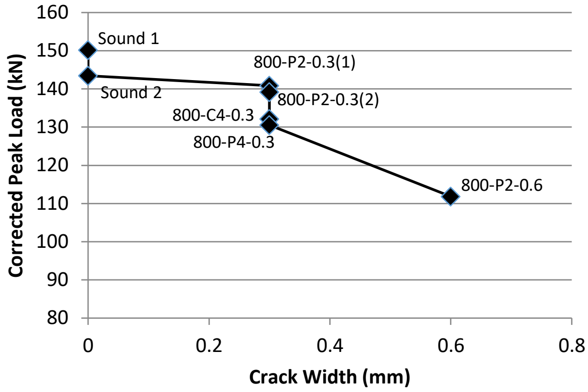

Figure 5: Plot for Corrected Peak Load

Since concrete strengths of specimens are different, the test results cannot be compared directly in terms of punching shear capacity. Therefore, the peak loads are corrected by a factor $\sqrt{f'c_{control}/f'c_{test}}$ having control strength as 35MPa as punching shear capacity correlates square root of concrete compressive strength (Ikehata et al. 2020). The corrected peak loads for specimens are given in Table 1. In order to find the decrease in punching shear capacity of RC slabs with vertical pre-cracks, the corrected peak loads are plotted against crack width for the entire specimens as shown in Figure 5. Specimen with one directional vertical pre-crack of 0.3mm width indicates 1.8-2.9% reduction of peak load as compared to sound specimen. A specimen having vertical pre-cracks in wider area and in two directions indicates peak load reduction of 7.9-9% from sound specimen. Largest reduction in the peak load is observed in specimen with vertical pre-cracks of 0.6 mm width with 22%. Since there is decrease trend in the peak load due to vertical pre-cracks and two same specimens show similar values, the test results can be considered reliable. This confirms the influence of vertical cracks on the punching shear capacity of RC slabs and as the crack area and width increase, it tends to have greater influence on the punching shear capacity.

2.3. Propagation of Internal Crack

The specimens are cut along the centerline in the direction perpendicular to main rebar in order to investigate internal crack propagation. The cut cross sections are shown in Figure 6. In the figure, the red line indicates the position of vertical pre-cracks and blue line indicates the observed cracks after the loading test. The Sound and 800-P2-0.3 specimens shows almost same crack propagation indicating minimum influence on punching shear capacity. On the other hand, in specimen 800-P2-0.6, it is observed that diagonal crack loses the continuity and irregular Z-shaped crack is formed by intersecting to vertical pre-crack. The bottom condition observed after loading test is shown in Figure 7. As seen from the figure, the failure area at the bottom is distinct along the vertical pre-cracks and it becomes less distinct as the vertical pre-crack width reduces. It is clarified from the observation that the vertical pre-crack has greater influence on the punching shear capacity of RC slabs.

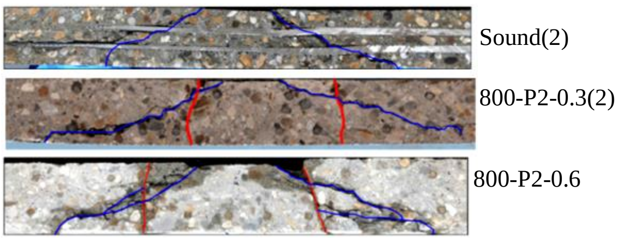

Figure 6: Cut Cross Section

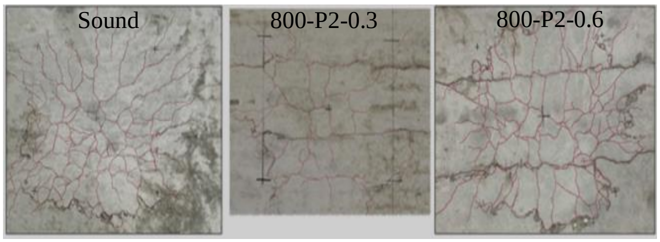

Figure 7: Crack pattern at the bottom face

3. CONCLUSION

In this study, the punching shear capacity and the internal crack propagation of bridge deck slabs with vertical pre-cracks were investigated through experimental evaluation. It was confirmed that with the increase in vertical pre-crack area and crack width, there is decrease in the magnitude of punching shear capacity. This means that fatigue life of RC slab is strongly related to punching shear capacity reduction according with the development and propagation process of vertical pre-cracks.

4. REFERENCE

Ikehata S, Ishiguro H, Nakano T, Nakamura H. (2020). Experimental Evaluation of Punching Shear Capacity of Reinforced Concrete Slabs with Horizontal Crack due to Compression Rebar Corrosion. Structural Concrete, 1-15.