SHEAR STRENGTH OF DRY JOINTS IN PRECAST CONCRETE MODULES

In-Hwan Yang[1*†], Kyung-Cheol Kim[2], and Young-Joon Kim[2]

[1]*Department of Civil Engineering, Kunsan National University, Korea*
[2]*Graduate School of Civil Engineering, Kunsan National University, Korea*

ABSTRACT

This study aims to investigate the structural behavior of concrete module joints under various compressive strength of concrete, configurations of shear key, and horizontal confining stress levels. The joint behavior, shear capacity, and crack patterns of dry joints in concrete module have been studied. Test results indicated that the shear capacity of joints increased as shear key inclination increased. In addition, shear capacity of concrete module joint increased with the increase of confining stress levels. The results obtained in these tests have been compared with design formulae for assessing the load-carrying capacity of dry joints.

Keywords: concrete module, shear key, shear strength, crack, confining stress

1. INTRODUCTION

The structural behavior of dry joints in precast concrete modules was investigated in this study. The behavior of structures constructed with precast concrete modules is dependent on that of joints between the concrete modules (Annmalai et al., 1990; Kaneko et al., 1993a, 1993b; Yang and Kim, 2012; Zhou et al., 2005). To accurately predict the structural response under the ultimate severe loading, knowledge of joint behavior is essential (Buyukorzturk, 1999; Koseki and Breen, 1983; Turmo et al, 2006). In this study, systematic experimental work that was conducted to study the behavior of typical dry joints subjected to shear is presented.

2. EXPERIMENTAL PROGRAM

2.1. Test specimens

The specimens used for the single-keyed dry joint tests are shown in Fig. 1. The overall shape of the specimens-height of 500 mm, width of 300 mm, 100 mm of thickness-was fabricated. The interval of 25 mm at the top and bottom of each specimen was placed to ensure a sufficient displacement of the shear key. A shear key was fabricated by modeling a precast concrete connection. The shear key of joint surface in the test specimen had the height of 170 mm and the shear key length of the

[*] Corresponding author: Email: ihyang@kunsan.ac.kr

[†] Presenter: Email: ihyang@kunsan.ac.kr

bottom surface was 70 mm. The depths of the shear key were 10, and 20 mm, respectively and inclination angles of the shear key were 45˚, 60˚, and 70˚, respectively.

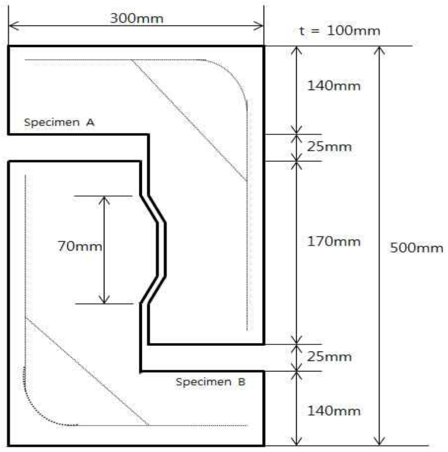

Figure 1: Details of specimen.

Figure 2: Test setup.

2.2. Material property

The compressive strength of concrete cylinder was measured after 28-day curing was carried out. The concrete mix was designed to make a compressive strength of 60 MPa. Compressive strength test results ranged from 61 to 67 MPa. The average compressive strength was measured to be 64 MPa.

2.3. Test setup and test procedure

The vertical actuator and horizontal actuator consisted of 300 and 150 kN capacity, respectively. The vertical loading was applied at the upper part of the specimen while the horizontal confining loading kept constant. The vertical actuator applied the load on the top of the center plane of each specimen. The displacement-control tests for all specimens were conducted at a constant stroke rate of 2mm/min. The horizontal confining stress levels were 1, 2, and 3 MPa, respectively. Data acquired during tests included the applied forces measured by a calibrated internal load cell, vertical displacement measured by LVDTs, and horizontal confining load measured by a load cell in hydraulic pump as shown in Fig. 2.

3. TEST RESULTS

An identification system of test specimens was adopted. The test speimen identifier is represented as S00-H00-P0, where S represents inclination angle, H represents shear key depth, and the numeral following P represents the horizontal confining stress. A total 18 of single-keyed specimens were tested under different combinations of parameters. A complete list of the test results is presented in Table 1.

3.1. Cracks and failure behavior characteristics

The initial diagonal crack occurred in the bottom part of the joint surface. At the second stage of loading, intensive multiple cracking or diagonal multiple cracks occured at a shear key zone. At the maximum load, the cracks at the root of joint separated the female key from the male part. This was accompanied by a brittle slip between the two parts of the specimen. This is the typical shear-off-failure mode of keys in concrete modules joint. The crack initially formed at the root of the key and closed after the key suffered shear-off- failure. Higher confinement stresses would delay development of cracking and slow the separation of the shear key at the joint. The shear strength of dry joints increased as confining stress increased.

Table 1: Detail of test specimen and test results

Specimens	Inclination Angle (degree)	Shear key depth (mm)	Confining stress (MPa)	Experimental maximum load (kN)	Predicted maxiumum load (kN)
S45-H10-P1	45	10	1	34.3	70.6
S45-H10-P2	45	10	2	83.5	87.7
S45-H10-P3	45	10	3	114.1	104.7
S45-H20-P1	45	20	1	56.7	70.6
S45-H20-P2	45	20	2	101.1	87.7
S45-H20-P3	45	20	3	84.5	104.7
S60-H10-P1	60	10	1	75.5	70.6
S60-H10-P2	60	10	2	105.0	87.7
S60-H10-P3	60	10	3	130.9	104.7
S60-H20-P1	60	20	1	54.4	70.6
S60-H20-P2	60	20	2	113.0	87.7
S60-H20-P3	60	20	3	140.1	104.7
S70-H10-P1	70	10	1	86.3	70.6
S70-H10-P2	70	10	2	107.9	87.7
S70-H10-P3	70	10	3	135.0	104.7
S70-H20-P1	70	20	1	86.5	70.6
S70-H20-P3	70	20	3	111.8	104.7

3.2. The load-displacement relationship

Typical load-relative vertical displacement curves for concrete joints are shown Fig. 3. The load and relative vertical displacement curves were almost linear up to the maximum shear stress. The load increased linearly up to approximately 60% of the maximum stress. A reduction in stress was observed just after peak load, indicating that a large slip occurred between the male and female parts of the specimen. Figure 3 indicates that failure loads increased as the confining stress increased.

3.3 Shear strength

Test results of joint shear strength are shown in Table 1. Shear strength at various horizontal confining stresses are shown in Fig. 4. Confining stress simulated the effect of prestress force in concrete modules. Maximum load increased as the horizontal confining stress increased from 1 up to 3 MPa. It indicated that the prestressing effect was very effective to shear strength. Test result of the shear strength at various inclination angle of the shear key is shown in Fig. 5. When the inclination angle of shear key increased to 45˚, 60˚, 70˚, the maximum shear load increased.

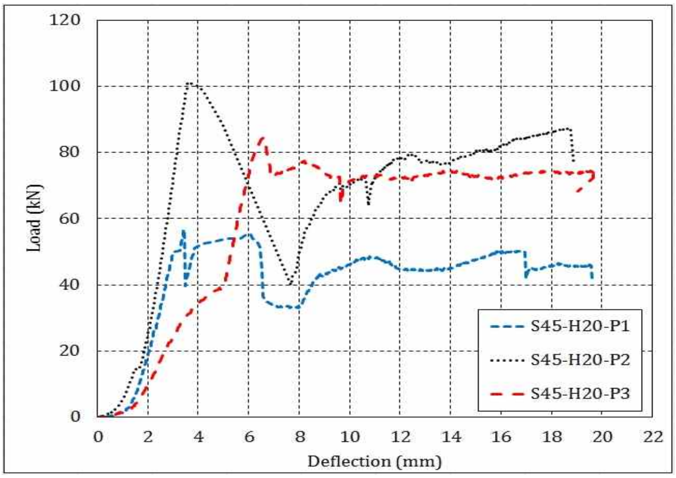

Figure 3: Load-deflection curve (S45-H20 series).

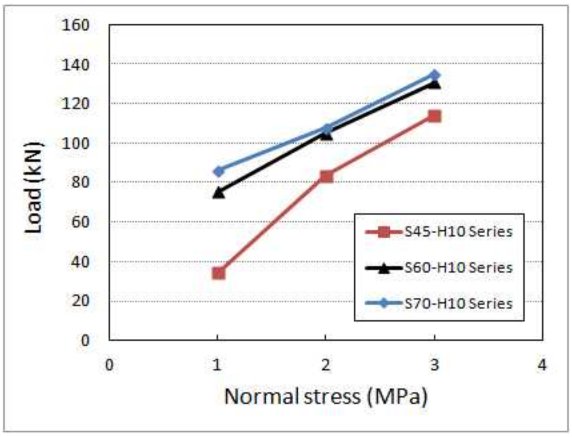

Figure 4: Confining stress effect.

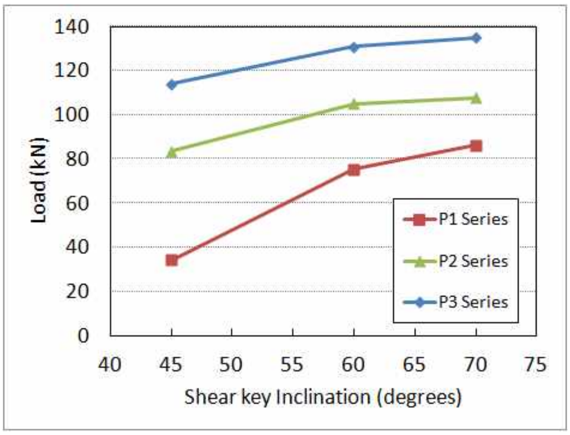

Figure 5: Shear key inclination effect

4. COMPARISON OF TEST RESULT AND PREDICTED STRENGTH

The measured shear strength of joints has been compared with AASHTO recommendation (1999). AASHTO recommendation (1999) gives the following design formula to estimate the shear capacity of joints in precast concrete modules.

$$V_j = A_K \sqrt{6.792 \times 10^{-3} f_c'(12 + 2.466\sigma_n)} + 0.6 A_{sm} \sigma_n \quad \text{(MN)} \qquad (1)$$

Where, A_K (m^2) is the area of all base of keys in the failure plane; f_c' (MPa) is the compressive strength of concrete; σ_n (MPa) is the normal compressive stress in concrete after allowance for all prestress loss determined at the centroid of the cross section; and A_{sm} (m^2) is the area of contact between smooth surfaces on the failure plane.

Table 1 presents the comparison of measured shear strength with predicted strength by using AASHTO suggestion. Predicted shesr strength by using AASHTO recommendation underestimated the test results.

5. CONCLUSIONS

A series of tests of joint in precast concrete module was conducted to study the shear behavior and strength of the joint. The experimental and predicted shear strength were compared and analyzed. The formation of the first crack of the shear key generally occured from the bottom of the shear key and tend to progressed towards the top. The shear-off-failure occurred in the shear key. As the horizontal confining stress increased from 1 to 3 MP, the shear strength of the joints increased. This means that the concrete module, the prestressing effect is very effective in increasing the shear strength in the joints for concrete modules. In addition, the shear strength of joints increased as the inclination angle of shear key increased from 45˚ up to 70˚

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