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Inter shear transfer of unbonded prestressing precast segmental bridge column dry joints

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ABSTRACT

The shear performance of precast segmental bridge column (PSBC) epoxy-free dry joints was investigated. Ten PSBC dry joint specimens were tested under monotonic direct shear loading. The design parameters include sectional shape, with or without shear keys, key number and geometry, and confining stress. The shear resistance-relative vertical displacement curves were recorded. The damage patterns and failure mechanism of tested specimens were analyzed. Shear strength formulas for prismatic, castellated, and flat dry joint were derived through data regression. The applicability of proposed formulas together with those from literature was investigated. Finally a finite element (FE) model was calibrated to study the friction contribution to shear capacity at various confining stresses.

1. Introduction

Precast concrete construction is the representative innovative technology of concrete structures at the end of the twentieth century. Precast construction is a practical technology which utilizes all kinds of advantages of concrete, such as low cost, high strength, good durability performance, and at the same time reduces the impact to environment. Compared with monolithic structures, precast concrete structures have joints between precast segments, where concrete is discontinuous at these sections. Shear force and flexural moment are transferred through these joints. So the performance of these segment joints is the key factor for the overall behavior of bridge structures. Although the AASHTO LRFD Bridge Design Specification [2] requires the precast joint be epoxied for durability considerations, the precast epoxy-free dry joints are the trend for simplicity of construction which are less climate influenced during erection. The epoxy also makes precast structures vulnerable to brittle failure under service and limit state loads [6]. The shear keys are often provided at two ends of a precast deck or precast column segment, and act as alignment at construction stage, and transfer shear force between segments in service stage. More and more precast concrete bridge structures have been constructed till today, shear strength design equations for superstructure segment joint are proposed in specifications, but those for substructures are still not sufficiently addressed yet. For the obvious difference in configurations exists between superstructure segment joint and substructure segment joint, the shear strength design equations for superstructures segment joint cannot be directly applied to substructure segment joint.

The available research on segment joint performance conducted by researchers can be classified into two categories by the object of study, i.e. research on bridge deck or column systems and research on local segment joints. The research methods were normally model experiment, finite element simulation, analytical formulation, and test data regression. Wang et al. [23] tested six hollow precast bridge piers with different design details, such as monolithic cast-in-place pier, PSBC with cast-in-place joint and PSBC with dry joint. To understand the behavior of precast joints under direct shear, shear key joint specimens were commonly used. The test specimens can be classified into L type two parts specimen [6,24,7,8], sandwich type three parts specimen [14,20], and external prestressed precast beams (2006b and 2006d) [15]. The shear key shape normally has two types, castellated key [6,24,7,8,14,20,15] and prismatic key [7]. The parameters of the joint specimens include: (1) Confining pressure; (2) Flat and keys with varying number and geometry; (3) Cast in place [14], dry, and epoxied; (4) Plain concrete [6,24,7,8], steel fiber reinforced concrete [20,22,9], and ultra-high performance fiber reinforced concrete [14].

Except model test, finite element method is often used for analyzing the failure pattern and conducting parametric analysis. Shamass et al. [18] established a 2D numerical model of keyed dry joints under direct shear. Parametric analyses revealed the contribution of friction in the total shear capacity decreased with the increase of confining stress. Therefore Shamass et al. [18] recommended reducing the friction coefficient used in the AASHTO formula for joint shear capacity estimation with the increase of confining pressure. Jiang et al. [8] used a 2D FE model to analyze the sequential failure of two or three key dry

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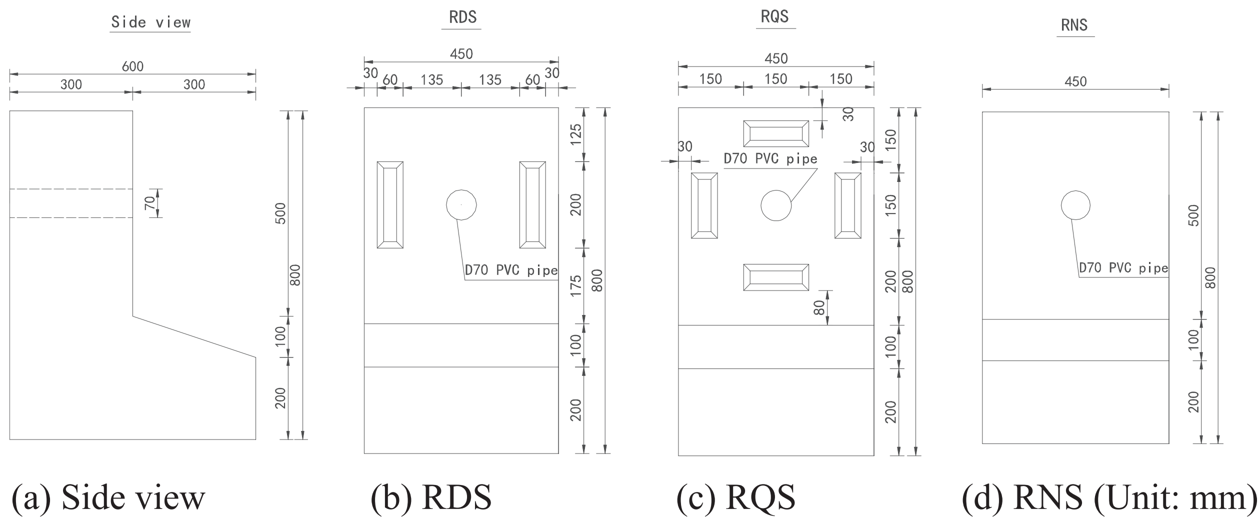

Fig. 1. Specimen with solid section.

joints. Alcalde et al. [3] developed a 2D finite element model of different types of joint with varying number of keys. The results showed that average shear stress transferred across the joint decreased with increasing of number of keys at lower confining pressure, but this effect became less prominent at high confining pressure. Turmo et al. [21] presented a 2D FE model study of segmental bridge decks with external prestressing. Three types of models with different levels of complexity were used, i.e. model with real joint dimensions, model with real joint dimension and discrete crack, and model with flat joint. The stress flow on the web after joint opened was analyzed.

Analytical model was also developed by researchers based on fracture theory of concrete. Kaneko et al. [10] developed an analytical mechanical model for predicting the entire shear stress-slip displacement behavior of keyed joints. The analytical model was verified to be effective in predicting the behavior of shear keyed joints through comparison with both experimental measurements and finite element analysis results [11].

Test data regression analysis was often used to get formulas from massive test data utilizing statistics and error analysis method applicable to future design of the same kind of structures. Buyukozturk et al. [6] derived regression formulae of flat dry joint, flat epoxied joint, keyed dry joint, and keyed epoxied joint from experiments, and concluded that the AASHTO formula might be unconservative when the confining pressure was higher than 300 psi. Zhou et al. [24] presented a formulation for flat epoxied joint based on experimental results. Jiang et al. [8] believed that the AASHTO formula was conservative for single-keyed dry joint, but was not conservative for three keyed dry joint, and suggested a reduction factor of 0.7 for the shear strength estimation of three keyed dry joint when using AASHTO formula. Alcalde et al. [3] suggested a formula for estimation of the shear capacity of dry keyed joints based on the numerical results of 2D model, which considered the influence of key number on the shear capacity of joint. Rombach and Specker [17] proposed a formula for estimation of shear capacity of dry keyed joints which stemmed from a numerical parametric study by finite element model. Turmo et al. [19] recommended a formula for Eurocodes for the evaluation of the capacity of interlocked joints from analysis of experimental results.

The preceding research work contributed much to the precast concrete research community, but these research had some limitations: (1) Most studies are about deck web or flange joint, seldom are for column joint; (2) The keys used in specimens mostly are castellated, seldom are prismatic; (3) Most of the joint specimen sections are solid section, seldom sections are hollow section; (4) Most of the FE models are 2D, seldom are 3D. In this contribution, a series of joint specimens were tested under direct shear with different confining stress, sectional key layout and sectional shape. The failure pattern, shear resistance-relative slip relation, shear failure mechanism, shear strength regression, validation of specification formulae with test data, and friction contribution to shear strength analysis using FE model were presented.

This contribution mainly deals with shear capacity of segment joints in precast bridge columns. Three objectives are focused on: (1) To study the damage pattern and process of epoxy-free dry joints under direct shear loading; (2) To study the influence of key configuration, number and contact surface shape on the shear capacity of dry joints; (3) To study the contribution of smooth area and keys on the shear capacity of dry joints.

2. Specimen design and experiment setup

2.1. Specimen design

Ten bridge column segment joint specimens were designed. The surface contact conditions include dry joints with or without shear keys, no epoxy was applied to the interface. The reason was that although studies showed that epoxies can enhance the shear capacity and ensure the durability of the reinforcement inside the segment [6], the epoxy may lead to brittle failure and its strength can be influenced by the moisture conditions [7]. Therefore in the present test, the increment of epoxy to shear strength of segment-segment joint was not considered, despite the fact that epoxy may be utilized in the joints in practical projects. When the specimen was assembled, the convex shear key part was put underneath the concave shear key part.

Among the ten specimens, five were applied 1 MPa confining pressure, and five were applied 2 MPa confining stress. The design variations include sectional shape, with/without keys, key number and key dimensions. The specimens can be divided into two groups according to the section shape, solid and hollow, to represent solid and box section of precast segmental columns, respectively. All the specimen parts have same external dimension, 600 mm × 450 mm × 800 mm for length, width and height, respectively.

The design details of solid and hollow section specimens were shown in Figs. 1 and 2, respectively. In the specimen name, the first letter R or H represents Rectangular or Hollow; The second letter D, Q, or N represents Double, Quard (four) or No shear keys; The third letter S means Specimen; The last number 1 or 2 represents confining stress, unit in MPa. For example, RDS-1 means the specimen has solid section with two shear keys and 1 MPa confining pressure. Fig. 3 shows the dimensions of long and short shear keys. The specimen main features were also shown in Table 1. The mix proportion of concrete was given in Table 2. The mix proportion C30-First and C30-Second were used for