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Quasi-static cyclic tests of precast bridge columns with different connection details for high seismic zones

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ABSTRACT

In this study, seven 1/3-scale bridge column specimens are investigated under the same quasi-static cyclic loading protocol both experimentally and numerically. The specimens consist of one cast-in-place (CIP) reference column and six precast columns. The precast columns are designed with different connection details, and they are tested for the feasibility study of the urban viaducts of highway S6 in Shanghai, China. The seismic performance of the precast columns needs to be investigated and verified prior to the practical application of these connection designs. Based on the experimental results, the precast specimens solely using mild reinforcement exhibit similar hysteretic behavior to the CIP reference column, though various grouted connection approaches are employed. The differences between these precast specimens and the CIP reference column are less than 15% for all indices. The precast specimens with bonded tendons (prestressing strands or prestressing bars) retain higher strength, but no less than 30% decrease of energy dissipation capacity is found. The bonded prestressing strands give at least 10% increase in strength compared with the CIP reference column, while the bonded prestressing bars provide approximately 50% improvement. The precast specimen utilizing unbonded tendon (prestressing strands) shows unique self-centering capability with equivalent energy dissipation capacity of the CIP reference column, but it has 33% lower ductility. Finite element modeling is performed and calibrated with the test data. Bond-slip behavior near column-to-footing interface is modeled by using a ZeroLength element at the interface. Buckling, fatigue and strength reduction of reinforcement are also considered in the model. Hysteretic behaviors of the specimens can be effectively simulated, and differences of ultimate strengths between the experimental and numerical results are less than 9%.

1. Introduction

Accelerated bridge construction has gained increasing popularity in the past decades, due to the fast construction speed, slight traffic interruption, high structural robustness, minor environmental impact, and low cost [1]. Although wide applications can be found in low seismic regions [2,3], investigations of seismic performance of the precast bridge columns in medium-to-high seismic zones are scarce. Therefore, investigations of the precast bridge columns are needed to understand the engineering feasibility in high seismic zones.

Among the connection types, the grouted ducts and sleeve couplers retain acceptable construction convenience and low cost. Grouted corrugated duct connection (GCDC) was used for both column-to-cap and column-to-footing connections with promising results [4,5]. The performance of GCDC usually relies on several factors including grout strength, embedded length and duct properties. Good strength and displacement capacity can be found in the substructures with GCDC according to several studies [1,6–9]. Precast structures with grouted splice sleeve couplers (GSSCs) showed equivalent strength, when compared with the corresponding cast-in-place (CIP) Refs. [6,10–13]. However, lower displacement capacity was found for these structures. Improvement can be made by allowing debonding of reinforcement bars [14], since such approach can prevent premature low cycle fatigue failure and stress concentration.

Another commonly used connection type is with post-tensioned tendons, which provides good self-centering ability for post-earthquake rehabilitation [15]. These post-tensioned structures can be categorized into bonded and unbonded systems. For bonded post-tensioned

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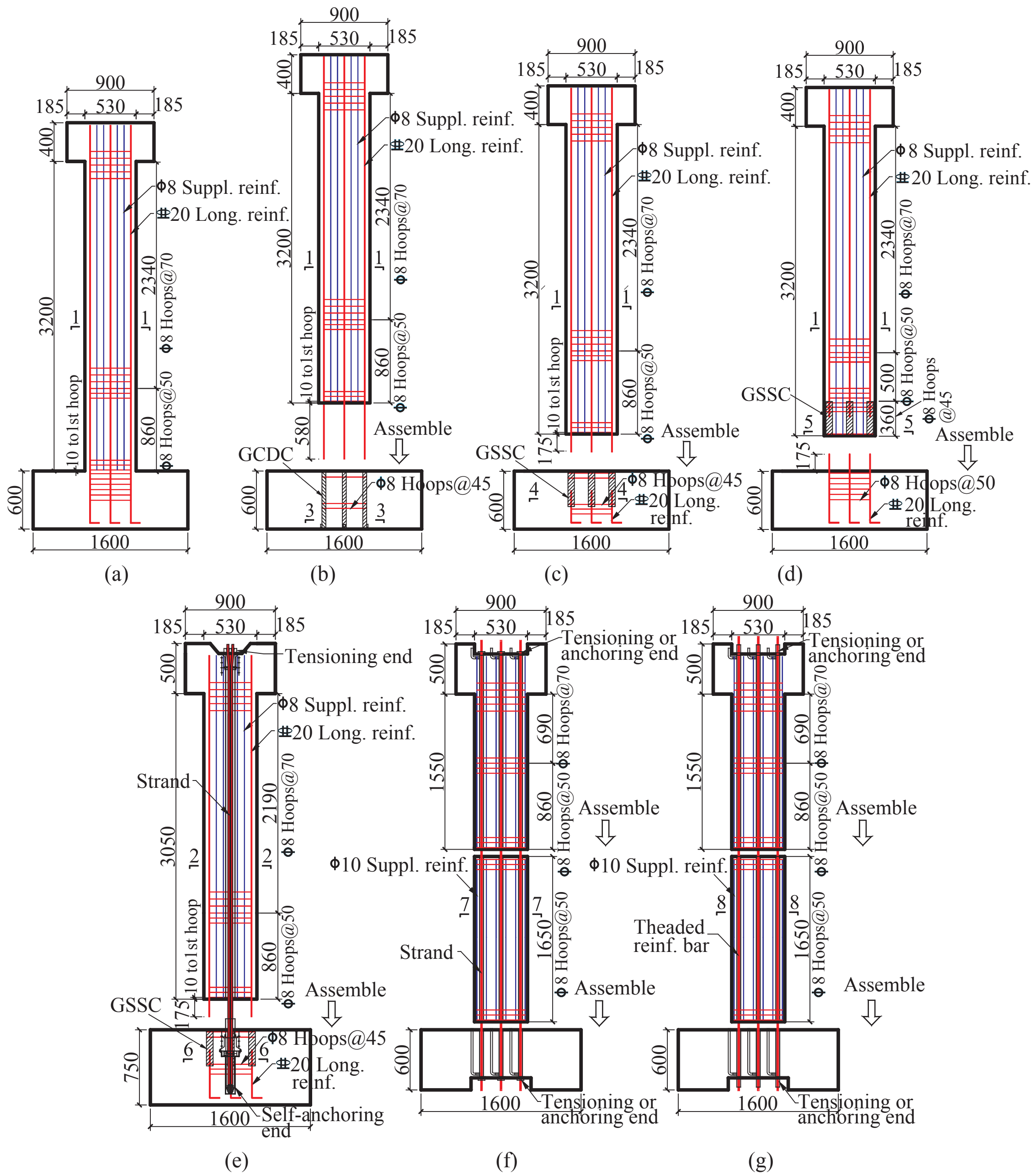

Fig. 1. Overview of all specimens (unit: mm): (a) #1; (b) #2; (c) #3; (d) #4; (e) #5; (f) #6; (g) #7.

columns, the ducts where tendons are guided through are grouted with cementitious materials. This helps maintain the bonding between the tendon and concrete. Investigations regarding precast bridge columns with bonded tendons were conducted [16,17]. Such bonding helps the tendon make full use of its strength and function better, thereby increasing the strength of columns. Moreover, it reduces the corrosion effect in tendons and thereby preventing the possible strength degradation of columns. For the unbonded post-tensioned columns, the ducts are not grouted. It leaves the tendons separated with the concrete, and the possible yielding of tendons during strong earthquakes can thus be delayed. At the same time, it reduces the residual displacement of precast bridge columns [15,17–19].

Numerical simulations were conducted to better understand structural behaviors. Nonlinear finite element analyses of CIP bridge columns were conducted [20,21]. A continuum plasticity-based isotropic damage model was used to represent inelastic behavior of the concrete. The generated finite element model (FEM) exhibited excellent convergence and numerical stability, and it also successfully simulated the experimental responses of columns under torsion. A two-dimensional (2-D) FEM was introduced to simulate the bridge column using GCDC with modified elastic modulus of the rebars to consider bond-slip effect [4]. GSSC was modeled in 2-D with a nonlinear rotational spring to simulate the bond-slip effect [14,22]. Different hysteretic models (e.g. the ideal and stiffness-degrading flag-shape model) were developed to simulate precast columns with unbonded post-tensioned tendons subjected to cyclic loading and ground motions [23–25]. The unbonded post-tensioned tendons adopted in precast wall systems were modeled as truss elements [26,27]. The top node of the tendon was coupled to the loading beam, and the bottom node was restrained to represent the anchorage in the foundation. Numerical results showed good agreement with the experimental results, and unbonded tendon stress can be accurately calculated. A 3-D FEM for the precast column with bonded post-tensioned tendons was developed [28]. Two-node truss elements were used to model post-tensioned tendons. Bilinear