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Experimental study on the behavior of precast segmental column with domed shear key and unbonded Post-Tensioning tendon under impact loading

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ABSTRACT

Precast segmental columns have been more and more popularly used in constructions of prefabricated reinforced concrete (RC) structures in recent years. During its servicing life the precast segmental column might be subjected to lateral impact loads from hazards such as falling rock and vehicle collision etc., which however has not been well understood. It is therefore necessary to properly understand the response and vulnerability of segmental column under impact loading. A previous experimental study revealed that the trapezoidal prism shear key on concrete segment could effectively reduce lateral slippage between segments under lateral impact loading, but stress concentration near the shear key led to crushing damage to concrete segment. A new shear key design, i.e., domed shear key with smoothed curvature is proposed in this study. Precast segmental columns with domed shear key are fabricated and tested. This paper presents the test results of scaled segmental columns with this new shear key design. The performance of segmental column with the new dome shear key is compared with previously tested columns with trapezoidal shear key and plain segmental column without shear key. Furthermore, the segmental columns with the new domed shear keys were impacted at different locations along the column including the column mid-span, the segmental joint, and the bottom segment to examine the influences of different impact locations on their impact resistant capacities, and the response and failure modes.

1. Introduction

The application of precast segmental concrete columns has been increased substantially in construction industry in recent years. This is primarily because prefabrication of reinforced concrete structures such as beam, column, slab etc. in workshop and erecting on site can greatly reduce site construction duration, ease traffic congestion, improve construction quality, and enable the applications of new materials such as fibre reinforced concrete and ultra-high performance concrete etc., which require careful mixing and curing [1]. Despite intensive researches and increased applications, there is still a general lack of understandings about the performance of precast concrete columns under extreme dynamic loading conditions such as earthquake, blast and impact.

Implementation of the concept of precast segmental column dates to thousands of years ago when many historic structures used segmented stone pillars or segmented columns made of stone blocks. This was because the required 'giant' dimension of these columns could only be achieved through segmented construction, which reflects the feature and advantages of segmental column for construction. With the development of reinforced concrete and prestress technology, prestress system has been introduced to precast segmental concrete column to improve the integrity and load carrying capacity. According to the bonding type of prestress system, a segmental column can be categorized with bonded or unbonded prestress system. With unbonded post-tensioning prestress system, the segmental column is erected on site and then the tendon is post-tensioned. Such system exhibits outstanding self-centring capacity which could bring the deformed column back to its original position. However, because of the gap between adjacent concrete segments, the unbonded tendon is vulnerable to corrosion damage [2–4]. For segmental column with bonded prestress system, the preserved duct for prestress tendon are grouted with cementitious materials after the tendon is stressed. The bonded prestress system has been found to increase column lateral strength, and is capable of

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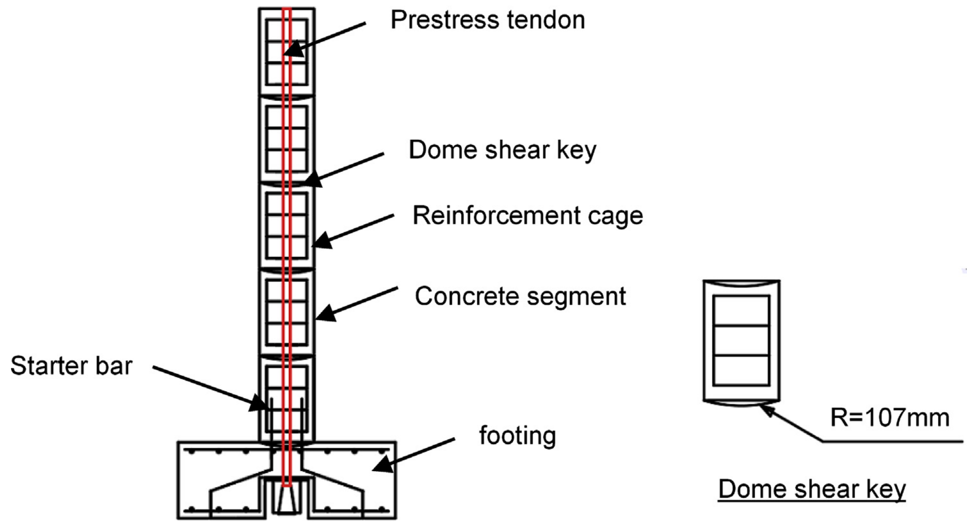

Fig. 1. Illustration of segmental column design.

dissipating more energy because of the yielding of the bonded tendon when the column is laterally loaded. However, the yielding of tendon reduces the self-centering capacity of the column [5,6].

To widen the application of precast segmental columns in high seismic areas, many studies have been performed to assess and improve its seismic performance. The influences of column design specifications such as aspect ratio (segment height/cross-sectional dimension), shear key and prestress level on seismic responses of segmental columns have been investigated [7–10]. Failure mode of segmental column under seismic loading was always found to be flexural dominated while shear damage to concrete segments and/or shear slip between adjacent segments were seldom developed [11,12]. Therefore, the necessity of shear key was found negligible since friction between segments was normally sufficient to resist shear force.

Study of the impact resistance capacity of segmental column is rare. Due to the fundamental difference in the characteristics of impact load and earthquake excitation, the response of segmental column under these two different loading conditions could be very different. For instance, when a segmental column is subjected to lateral impact loading, shear response could be the dominant response mode while flexural bending response is the dominant mode when the column is subjected to earthquake ground excitation. Moreover, shear slippage between adjacent segments without shear key usually occurs because friction is not sufficient to resist the shear force induced by impact load [13–15], but as mentioned above shear slippage usually does not occur when the column is under seismic excitation. Therefore, existing understanding of the performances of segmental columns under seismic loading cannot be applied to the segmental columns under impact loading. Proper study is needed to understand the response of segmental column under impact loading.

Recently, Zhang et al. [13,14] experimentally investigated the response of segmental column under impact loading at mid-span of the column. Through comparison with monolithic column, it was found that segmental column showed more resistance capacity and exhibited better self-centering ability. Because the segmental column was more flexible, under impact loading lower peak impact loads were resulted as compared to those on the monolithic column subjected to the same impact. However, it was also found that friction between segments was not sufficient to resist shear slippage at the segmental joints of the column under impact loads. To resist shear slippage, concrete segment with trapezoidal prism shear key was fabricated and tested [15]. Impact tests found that comparing with segmental column without shear key, introducing the prism shear key could effectively reduce the relative displacement between adjacent segments. However, because of the sudden change in segment geometry around the tenon and mortise of shear key, more severe crushing damages to concrete segment were also observed due to stress concentration [15]. A more effective shear key design is therefore needed to optimize the performance of segmental column under impact loading. It should be noted that the previous studies [13–15] only examined the response and failure of segmental column under impact at the mid-span. The behavior of segmental column under impact at other locations, e.g. near the column base, which might cause different response and failure mode of the column from those owing to impact at the mid-span, also needs be investigated.

In this study, pendulum impact tests on segmental columns with domed shape shear key, which was designed with smooth surface to hopefully relieve the stress concentration problem of the prism shear key, were carried out. The test results are compared with those obtained in [15] with trapezoidal prism shear key to examine the performance of the segmental column with new shear key design in resisting lateral impact loads. To study the response of segmental column under lateral impact at different locations, the columns were impacted at column mid-span, segmental joint between the bottom two concrete segments, and at the centre of the bottom segment. The response and failure mode of the segmental columns subjected to impact at different locations were recorded and analyzed.

2. Experiment setup

2.1. Column design

Fig. 1 illustrates the design of the segmental columns. The segmental columns were 800 mm in height and 100 mm × 100 mm in cross-section. They were the quarter-scale model of 3.2 m tall column. Some previous researches proved that similar scaled reinforced concrete column was capable of representing their response under extreme dynamic loading [16]. Each segment was 160 mm tall and each column comprised of five reinforced concrete segments. 4 pieces of 6 mm diameter ribbed bars were used as longitudinal reinforcement, and 4 mm diameter plain steel bars at 40 mm spacing were used as reinforcing ties. The longitudinal reinforcement did not extend through adjacent segments. The reinforcement cage was designed to increase the strength and integrity of the concrete segments. Concrete shear keys were designed for each segment to improve the shear resistance between adjacent concrete segments. As depicted in Fig. 1, the shear keys were in dome shape with 107 mm radius curvature created with plastic mold. It had smooth curve shape which was expected to relieve the stress intensity due to stress concentration. The effectiveness of the domed