International Journal of Impact Engineering 95 (2016) 105–124

Contents lists available at ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

Experimental investigation of the response of precast segmental columns subjected to impact loading

Xihong Zhang *, Hong Hao, Chao Li

Department of Civil and Mechanical Engineering, Centre for Infrastructural Monitoring and Protection, Curtin University, Kent St., Bentley WA 6102, Australia

ARTICLE INFO

Article history:
Received 18 December 2015
Received in revised form 19 April 2016
Accepted 8 May 2016
Available online 12 May 2016

Keywords:
Precast concrete
Segmental column
Posttension
Impact loading

ABSTRACT

Although precast concrete segmental columns have been more and more widely used in constructions, there is a lack of study on its behaviour under dynamic loading especially impact loading. In this paper, the fundamental behaviour of precast segmental columns under impact loading is investigated through laboratory tests. Scaled precast segmental columns with unbonded posttensioning tendon were constructed and tested using pendulum impact system. Two segmental columns of the same height, but with different numbers of precast segments were designed and tested. A conventional monolithic reinforced concrete (RC) column was also casted and tested as a reference column to compare the performance with segmental columns under impact loading. The impact load time history and column displacement time histories at column top, mid-height and column base were recorded. The deformation-to-failure processes of the columns were monitored by a high-speed camera, and used to investigate the response of different columns under impact loads. The test results showed the segmental column is more flexible than monolithic column, which leads to lower peak impact force, but longer duration compared to those on the monolithic RC column. It was also found that compared with monolithic columns, segmental columns show better performance against impact load with better self-centring capability, similar energy dissipation capability and less residual displacement and concrete damage.

1. Introduction

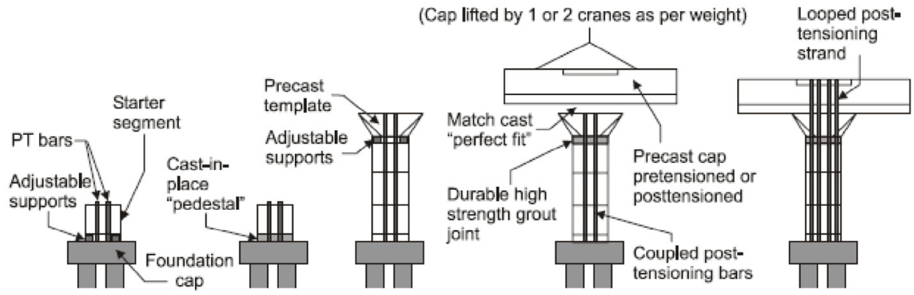
Recently, much interest and attention have been directed to prefabricated structures, especially precast segmental structural members. This is mainly because precast structural elements can greatly reduce on-site construction time and cost, minimize traffic disruption due to construction work, improve work zone safety, reduce environmental impact, and improve construction quality. Time efficiency that can be achieved through utilizing precast segmental element is enormous. A study sponsored by the US Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA) concluded that using precast segmental element could reduce up to 50% construction time [1] (Fig. 1a). Apart from the above advantages, new materials such as ultra-high performance concrete and fibre reinforced concrete, etc., which sometimes require heated curing and/or careful mixing, can be easily applied in prefabrication factory to precast segmental elements.

Segmental columns have been popularly used in construction ever since ancient times. Many iconic structures around the world today were built hundreds or even thousands of years ago with segmental stone pillars, such as Brandenburg Gate, Germany built in 1788–1791 (Fig. 1b), Tempo in Rhodes island, Greece built around 7th Century B.C. (Fig. 1c). One of the earliest modern constructions that utilized precast segmental concrete elements was Lavaca Bay Causeway, Texas, US in 1961 [1]. The application of precast segmental columns has gained its popularity globally ever since. Numerous modern constructions have successfully used precast segmental concrete columns. Examples of buildings and bridge structures that employed segmental concrete columns can be found in References 2 and 3. Despite all the above advantages, a major setback for precast segmental structures is that there is a lack of knowledge on its behaviour and performance under dynamic loadings, i.e. seismic loading, impact loading and blast loading.

So far, most existing studies on segmental columns under dynamic loadings have focused on the evaluation and improvement of its seismic performance. Very limited studies are reported on the behaviour of segmental columns under impact and blast loading. Many studies have reported the response and failure mode of segmental columns under seismic loading. For instance, Ou et al. [5] carried out numerical and analytical studies. It was found that under cyclic loading, segmental columns exhibited flag-shaped behaviour, and could undergo larger drift than monolithic columns. Shim et al. [6] performed a laboratory test on scaled segmental columns. It was observed that the tested columns all exhibited

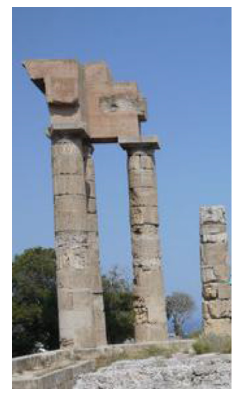
* Corresponding author. Department of Civil and Mechanical Engineering, Centre for Infrastructural Monitoring and Protection, Curtin University, Kent St., Bentley WA 6102, Australia. Tel.: +61 8 9266 5287; Fax: +61 8 9266 2681.
E-mail address: xihong.zhang@curtin.edu.au (X. Zhang).

http://dx.doi.org/10.1016/j.ijimpeng.2016.05.005
0734-743X/



a) Erction sequence for a segmental column [4]

b) Brandenburg Gate, Germany, built in 1788-1791



c) Tempo in Rhodes island, Greece built around 7th Century B.C.

Fig. 1. Ancient and modern constructions of segmental columns [4].

flexural failure in the plastic hinge region near column base. Shear failure such as shear slip at segmental joints or concrete shear failure within segments was not found [7]. Under earthquake excitation, the primary response modes of segmental columns are mainly flexural. Friction force at the column joints is generally sufficient to transfer shear force. However, this observation may not be true for segmental columns under impact loading, where shear deformation may govern the response and damage of the columns.

The influences of various column specifications, such as the number of segment/joint, prestress level, etc., have also been investigated in previous seismic analyses of segmental columns. For instance, ElGawady and Dawood [8,9] performed experimental and numerical studies on unbonded circular segmental columns. It was found that before joint opened, large and small segments had the same shear stresses at a given drift angle; after joint opened, the smaller segment had higher shear stress. Shim et al. [6] also conducted scaled cyclic tests on a series of segmental columns. It was concluded that the number of segmental joints had no effect on the ductile behaviour if the location of the segmental joint was far from the plastic hinge region. Therefore, it was recommended by Shim et al. that focus should be paid to the base connection between the segment and the footing in seismic analysis. For the effect of prestress level, Wang et al. [10] found that under seismic loading, prestress tendon helped to reduce column residual displacement. Nikbakht et al. [11] derived analytical solution and concluded that increasing prestress level would lead to higher column stiffness, increased column strength and improved energy dissipation capability. The influences of these factors on the performance of segmental column under impact loading are not known.

As emphasized above, despite many studies on segmental column response under seismic loading, research on impact resistance of segmental column is rare. The only article available in the literature is a recent numerical study on segmental columns under vehicle impact [12]. A precast segmental column 2.3 m in diameter and 16.25 m high together with a detailed truck was modelled in the analysis. Under the impact from the truck with an impact velocity of 60 km/h, a slight lateral slip was observed at the base joint between the first segment and the foundation. Therefore under lateral impact, shear resistance of the segmental column could be a major issue. Comparison was made to the responses between segmental column and cast-in-place monolithic column. A similar trend of concrete stress was found on the segmental column and the monolithic column. Due to the relatively lower stiffness, the response period of the segmental column was longer. Because of the large size of the columns modelled, no apparent column damage or failure was observed in the study. The failure of segmental columns under impact load is therefore not investigated in that paper. Till now, no experimental study or analytical solution of segmental columns subjected to impact loading can be found in the literature.

A few studies on the impact resistance performance of monolithic reinforced concrete column have been previously carried out, which might provide some reference to the possible response of segmental columns. Sha and Hao [13] performed experimental study on monolithic RC pier under barge impact. Pendulum impact system was utilized in the tests. Flexural failure was observed on the monolithic column at column mid-span where it was impacted, and also at column base. A numerical model of monolithic columns under impact loading was also built and validated with laboratory test results. A parametric study was carried out to investigate the influence of column parameters, such as column height, diameter, and concrete strength, etc., on its responses. Some case studies on vehicle crash resistance of monolithic RC columns and steel columns were previously reported. For example, Buth and his co-workers [14,15]