Engineering Structures 134 (2017) 125–137

Contents lists available at ScienceDirect

Engineering Structures

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

Numerical study of precast segmental column under blast loads

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ARTICLE INFO

Article history:
Received 10 July 2016
Revised 13 December 2016
Accepted 15 December 2016

Keywords:
Segmental column
Blast
Shear key
Energy dissipation bar
Prestress

ABSTRACT

Constructions with precast technology have seen a fast development over the past several decades. Despite advantages including short construction period, better quality control, less environmental and traffic impact, a lack of study on their behaviour under dynamic loads have prevented the widespread use of precast constructions in high seismic zones and where terrorist attack could be a concern. Among all precast structural components, precast segmental columns have been found one of the construction techniques with great potentials. Intensive research efforts have been spent on investigating the segmental columns under seismic loadings in recent years. During its service life, besides seismic action, structure may subject to other dynamic loads like impact and blast. It is therefore important to perform multi-hazard analyse to better understand structural performance. This study investigates the blast loading resistance capacities of segmental reinforced concrete (RC) columns. RC segmental columns with or without shear keys and energy dissipation bars are considered. Influence of the number of segments and different levels of post tensioning forces on column dynamic performance is also investigated. Commercial code LS-DYNA is used to perform numerical simulations of the segmental columns under different blast loadings. Accuracy of the numerical model is verified against available testing data on RC columns. Numerical results of the segmental columns under different blast loadings are calculated and compared with those of the monolithic RC columns. Discussions on the capabilities of segmental RC columns in resisting blasting loads are made with respect to those of the monolithic RC columns.

1. Introduction

Increasing development and demand on precast technology is shown over the past few decades. Prefabricated structural components such as slabs, columns and beams can be constructed off site and assembled on site in a short period of time. Better quality control as well as efficiency can be achieved in prefabrications of structural components, and interruption to the environment and traffic which used to be obstacles in conventional onsite structural construction can be minimised. Among all the precast elements and systems, precast segmental columns are now widely used in bridge constructions. Fig. 1 shows some existing structures with segmental column construction technology.

Despite great advantages of precast technology, concerns remain among researchers and engineers when planning precast structures. Among them, there is a lack of knowledge of the seismic behaviour of such type of construction and thus the widespread use in seismic regions is limited. Secondly, with the rising threat from the terrorism activities in recent decades, the vulnerability of such structures under impact and explosive loads is also of significant importance. Thus, it is imperative to conduct multi-hazard risk assessment against such structures before a wide application in civil structures.

Regarding the seismic performance of the segmental column, Hewes and Priestley [1] reported testing of unbonded post-tensioned precast concrete segmental bridge columns under simulated lateral earthquake loading. Two columns with a high aspect ratio and two columns with a low aspect ratio were tested under simulated lateral seismic loading. An analytical model, which described the column force-displacement behaviour, was used for predicting column response prior to testing. It was found that the model reasonably predicted the column force-displacement response. Billington and Yoon [2] designed a precast segmental concrete bridge pier system for use in seismic regions. The proposed system uses unboned posttensioned tendon to join the precast segments. As pointed out by Kim et al. [3], the behaviour of a precast segmental column under seismic loading differs fundamentally from that of a conventional reinforced concrete column. The response of a precast segmental column is similar to a rocking foundation, where the foundation lifts off the ground once the

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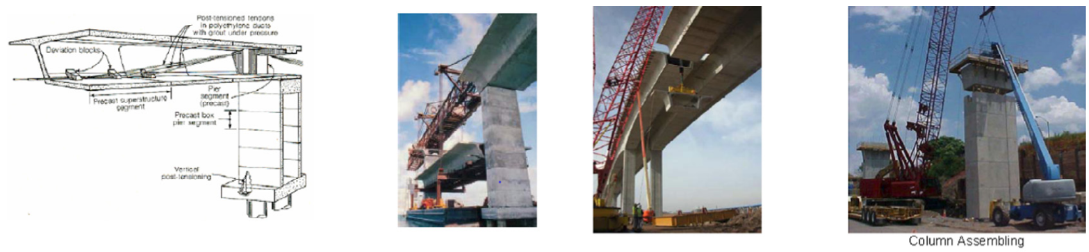
http://dx.doi.org/10.1016/j.engstruct.2016.12.028
0141-0296/



Seven Mile Bridge, USA, 1982.
(http://structurae.net/structures/seven-mile-bridge-1982-1)

Victory Bridge, USA, 2005.
(http://structurae.net/structures/route-35-victory-bridge)

US 183 elevated in Austin, USA, 1997.
(http://www.pestructural.com/projects/exotic-bridges.php)

Fig. 1. Precast segmental bridge construction.

moment resistance provided by gravity is overcome. Under seismic load, segmental columns exhibited flag-shaped behaviour, and could undergo larger drift than monolithic columns [4]. They showed high self-centring capabilities compared to conventional reinforced concrete piers.

Bonded or unbonded prestress tendon/strand is commonly applied in segmental columns to increase the energy dissipation and lower the residual displacement. Wang et al. [5] found that under seismic loading, prestressed tendon helped to reduce column residual displacement. Nikbakht et al. [6] derived analytical solution and concluded that increasing prestress level would lead to higher column stiffness, increased column strength and improved energy dissipation capability. Dawood et al. [7] discussed the design parameters that potentially affect the lateral seismic response of segmental precast post-tensioned bridge piers. It was observed that an initial tendon stress in the range of 40–60% of its yield stress and initial axial stress on concrete of approximately 20% of the concrete's characteristic strength is appropriate for most typical designs. These design values will prevent tendon yielding until lateral drift reaches approximately 4.5%.

The rocking mechanism of precast segmental columns prevents the formation of the plastic hinge, leading to less damage and cracks on the structure. However, although segmental column performed well and showed excellent re-centring capability, Yamashita and Sanders [8] noted that significant damage could occur at the base of the first segment under seismic load. In a typical precast segmental bridge column design, gravity load and compressive force from stressed prestress tendon/tendons provide the required flexural and shear strength. Longitudinal reinforcements in each segment are not continuous across the joints and only used for positioning the transverse reinforcement and controlling the shrinkage and creep [9], their contribution to the strength and energy absorption is quite limited. Under large lateral force, the column performs in the same way as a monolithic column prior to opening of the joints. Once the joints open, the column exhibits a nonlinear behaviour with a small residual drift upon unloading. In the whole process, the post-tensioning strands perform largely elastic. The whole segmental column therefore shows little energy dissipation which limits the application of segmental column in high seismicity area where a high capability of structural energy dissipation is required.

To improve the energy dissipation capacity, longitudinal mild steel reinforcement crossing the column segment joints were proposed, tests concerning their application on bridge piers were carried out by Ou et al. [9] and Wang et al. [10]. Although these joint-connecting mild steel bars (so-called "ED bar") significantly enhanced the column energy dissipation capacity, premature fracture on these bars were noted when large lateral displacement occurred. In a later study, Ou et al. [11] adopted high performance steel reinforcing bars as the ED bars, these steel bars have better ductility which further increase the column energy dissipation under seismic loads. However, increased energy dissipation capacity is usually associated to a larger residual deformation, which is an undesired side effect because it affects the post-earthquake serviceability of the structure. To solve this problem, researchers adopted shape memory alloy (SMA) as the ED bars to reduce residual deformation of segmental columns under large seismic loads [12].

So far, the majority of the studies related to the dynamic behaviour of segmental columns have focused on their seismic performance, other accidental load like vehicle impact is rarely considered despite its obvious influence on structural performance. Vehicle crash should be a concern when the bridge overpasses another road or railway or when the bridge piers located in urban area. Until now, extensive studies were carried out on monolithic columns under impact loads. EL-Tawil et al. [13] evaluated the