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Dynamic behaviour of axially-loaded RC columns under horizontal impact loading

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ABSTRACT

This paper presents an experimental study undertaken for investigating the dynamic responses of axially-loaded reinforced concrete (RC) columns under horizontal impact loading. A total of 15 square RC columns, categorised by three different types of cross-section dimensions, were tested using horizontal impact facilities. The test specimens had fixed boundary condition at their bottoms. The impact load was realised by a test truck and applied at the top position of the RC column. Three main parameters, namely the slenderness ratio, the impact weight and the impact velocity, are considered in the study. Based on the experimental results, the crack pattern, impact force, deformation, strain development and energy dissipation are discussed. Through the recording of the relative movement between hammer and specimen, the repeated process of contact and separation was observed. Compared with that of the conventional drop weight impact test, the impact force-time history curves obtained from the horizontal impact test show more fluctuation at the stabilisation stage, because the existence of gravitational acceleration of drop hammer and larger velocity in drop weight impact test accelerates the repeated process of contact and separation between the hammer and specimen. As the input impact energy increases, the flexure-controlled failure of column was observed, which is characterised by the yielding of tensile reinforcement and the spalling of concrete cover. The experimental results presented herein provide benchmark data for the further research study of RC columns subjected to horizontal impact forces. The equivalent static force calculated by empirical formula of AASHTO is adopted to compare with the experimental results, which indicates that the empirical equation only related to the impact weight and velocity could overestimate the equivalent static force that would leads to too conservative impact-resistance structural design.

1. Introduction

In the modern infrastructure, profiting from the convenience and practicability, reinforced concrete (RC) columns and piles are widely used to support the vertical loads from superstructures. During their service life, these vertical structural members may undergo various kinds of extreme loading conditions, such as earthquake [1–5], collision [6,7] or blast [8,9] loading, which result in the dynamic structural responses that significantly differ from that in static condition. Typical collision scenarios are common in the bridge structure, port wharf and so on. These structures are susceptible to the collision of large-size vessels during their service life. The accidental collisions can lead to a strong impact loading with large impact weight and low impact speed acting on the RC columns or plies, which could cause serious damage to and even subsequent collapse of entire structures. Therefore, it is of great significance to investigate the dynamic responses and damage conditions of vertical axially-loaded RC structural members under impact loading.

Currently, vertical drop weight impact facility [10] is the most common experimental method adopted to study the impact-resistant behaviour of structural elements, such as RC beams [11–13], RC slabs [14], concrete filled steel tubular (CFST) columns [15,16] and timber beams [17]. In the drop weight impact tests, a drop hammer free falls from different heights, which produce impact loads that are applied laterally in the mid position of specimens with two ends fixed or simply supported. However, using the drop weight impact tests to investigate the dynamic behaviour of vertical structural members under horizontal impact loads could overstate the structural behaviour and damage conditions, since the gravitational acceleration of the impacting objects should not be taken into consideration.

Few experimental modelling of vertical structural members subjected to horizontal impact loads as being similar to real situation, has been undertaken and reported in the open literatures. In order to feature the

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Nomenclature

Symbol	Description
A_s	section area of longitudinal rebar
DWT	deadweight tonnage of vessel
E_{ab}	absorbed energy
E_k	initial kinetic energy
f_{cu}	compressive cubic strength of concrete
f_u	tensile ultimate strength of rebar
f_y	tensile yield strength of rebar
F_{ave}	average impact force
F_p	peak impact force
F_{su}	static flexural strength
h	effective height
I_p	impulse
l_3	length of sheet-metal
m	impact weight
n_0	axial compression ratio
N_0	axial compressive force
P_s	equivalent static force
t_d	impact duration time
t_3	time period of the sheet-metal covering the infrared ray
u_{max}	maximum displacement
v	design impact velocity of test truck
v_0	measured impact velocity of test truck
w	cross-section dimension
α_s	thickness of concrete cover
$\Delta\varepsilon_p$	strain increment of prestressed tendon
$\Delta\varepsilon_s$	strain increment of reinforcement
ε	strain
$\dot{\varepsilon}$	strain rate
λ	slenderness ratio
ρ	longitudinal reinforcement ratio

real characteristics of RC bridge piers subjected to the vehicular collision, Demartino et al. [6] conducted the experimental investigation on the behaviour of shear-deficient reinforced circular RC columns using a novel horizontal collision facility. With the boundary conditions of cantilever and fixed-simply-support, a total of ten RC columns with two types of volumetric transverse reinforcement ratio were designed. The impact force position was in 1/4 of column height. The post-impact damage of all specimens exhibited brittle shear-type damage, which is characterised by one main diagonal crack starting from the impact point to the bottom of RC columns. Silva et al. [18] designed a pendulum impact facility to conduct the field tests of RC members under various impact velocities, and the corresponding post-damage state was observed. In the pendulum impact test, the impact loading was realised by the swing hammer releasing from a certain height. Pendulum impact tests on full-scale square hollow glass columns were conducted by Bedon et al. [19,20]. Hao et al. carried out the laboratory tests of scaled CFRP strengthened RC piers [7] and precast segmental columns [21] using pendulum impact system. In the test, an added mass consisted of a concrete block and steel plates were placed on the top of the specimens to model the actual axially loading from superstructure. It can be observed from these impact tests that without the presence of gravitational acceleration, the impact force-time histories are significantly different from those of the drop weight impact tests. In the drop weight impact tests, the impact force versus time curves can be generally divided into three phases namely oscillation stages, stabilization stage and attenuation stage [22]. In the stabilization stage, impact force develops steadily for certain duration, which is also the main dissipation stage of initial impact energy. While in the aforementioned impact tests using horizontal collision facility or pendulum impact system, the time histories of impact force at the stabilization stage show more fluctuation compared with that of the drop weight impact tests. Besides, the applied axial loads have a significant influence on the dynamic response of the columns under horizontal impact loading, effect of which is usually neglected in the drop weight impact tests [23].

The object of the current paper is to perform an experimental study to investigate the dynamic responses of axially-loaded RC columns under horizontal impact loading by adopting a modern horizontal impact test facility. The horizontal impact tests of 15 RC columns with different column slenderness ratio, impact weight and impact velocity were reported. The experimental results including the time responses of impact force, displacement and strain and the corresponding characteristic values such as the absorbed energy are presented and discussed.

2. Experimental overview

2.1. Specimen preparation

A total of 15 square RC columns were designed and fabricated. As shown in Fig. 1, each specimen consists of a concrete base with

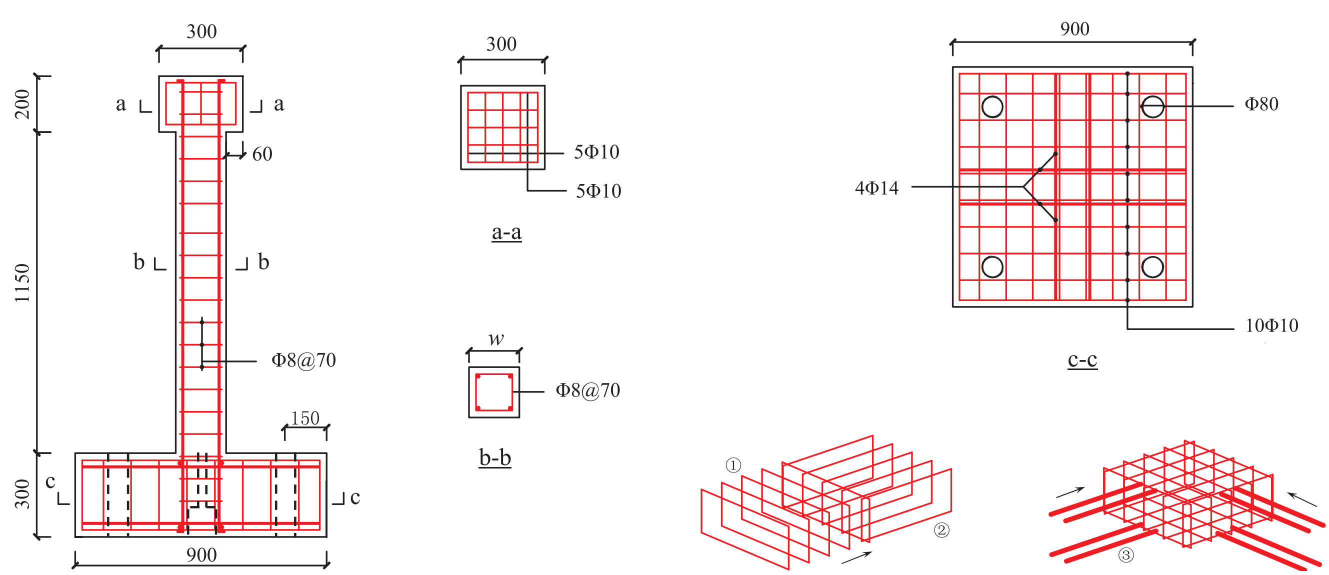

Fig. 1. Details of specimens (unit: mm).