Soil Dynamics and Earthquake Engineering 106 (2018) 90–100

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Seismic behavior of low-corroded reinforced concrete short columns in an over 20-year building structure

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ARTICLE INFO

Keywords:
Reinforced concrete column
In-service
Quasi-static cyclic test
Seismic behavior
Corrosion
Shear strength

ABSTRACT

In reinforced concrete (RC) structures, reinforcement corrosion, concrete carbonization, and chloride ion erosion occur during service life, which deteriorate the seismic structural capacity of the structures. Most researchers have focused on the effect of the reinforcement corrosion on the seismic behavior of RC columns showing flexural behavior. On the other hand, research on the influence of the combined reinforcement corrosion and concrete carbonization on the seismic behavior of in-service RC columns showing shear-flexural behavior has not been performed. The present study evaluates the seismic performance of low-corroded in-service RC columns showing shear failure under cyclic load. Four RC columns with shear-span ratio 2.3 and light transverse reinforcement were obtained from an in-service RC moment frame building constructed in 1987, and quasi-static cyclic tests were conducted to investigate the seismic behavior of these columns. For the test parameters, axial compression force ratios and longitudinal bars arrangements were considered. The test results showed that as the compression force ratio increased, the failure modes of the in-service RC columns shifted from shear-bond failure to shear-compression failure, and the ductility and energy dissipation capacity decreased. The shear strength of the column specimens was evaluated by five existing shear strength models, considering the effect of reinforcement corrosion. Finally, seismic performance of RC short columns with corroded bars was discussed.

1. Introduction

Reinforced concrete (RC) moment frame structures have been widely used in seismic regions in the world due to easy spatial segregation, and cost effectiveness of construction and maintenance [1]. RC moment frame structures designed in accordance with modern seismic design code can satisfy the requirements of earthquake-resistant performance. In seismic regions of China, a number of masonry filled RC moment frame structures that use low transverse bar ratio in columns were constructed in the 1970s and 1980s [2]. As shown in Fig. 1, in the masonry filled RC moment frame structures, short columns are usually designed in the opening of the masonry walls. The failure mode of the short columns is dominated by shear-flexural behavior, which exhibits lower deformation capacity compared with the columns governed by flexural behavior. Furthermore, the increased lateral stiffness of the short columns increases seismic force demand, but the effect on the short columns was ignored in the past design process.

Various investigations after Wenchuan earthquake in 2008 and Yushu earthquake in 2010 demonstrated that short columns were widely damaged under earthquake loads. Some structures even collapsed due to the heavily damaged short columns at the first floor. In particular, during the service life of RC moment frame structures, reinforcing bars have been corroded and concrete has undergone the process of carbonization and chloride ion erosion, which deteriorate the earthquake resistance of the masonry infilled structures with short columns. Thus, in the old building structures subjected to earthquake load, the structural behavior of the short columns should be investigated, and seismic performance assessment method for the structures needs to be proposed.

Rebar corrosion causes the spalling of cover concrete, ductility decrease of rebars, and bond strength degradation between rebars and concrete [3]. When the corrosion of rebars is heavy, RC structures even lose the load-carrying capacity, and should be demolished and rebuilt [4,5]. Although the seismic behavior of RC columns has been widely studied in literature, relatively fewer literatures have focused on the seismic performance of the corroded RC columns. Particularly, structural behavior of the corrosion damaged RC short columns obtained from actual structures has not been studied.

Niu et al. [6] found that the corrosion level of rebars and axial compression ratio of columns were two main factors that affect the

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https://doi.org/10.1016/j.soildyn.2017.12.006
Received 4 July 2017; Received in revised form 9 October 2017; Accepted 3 December 2017

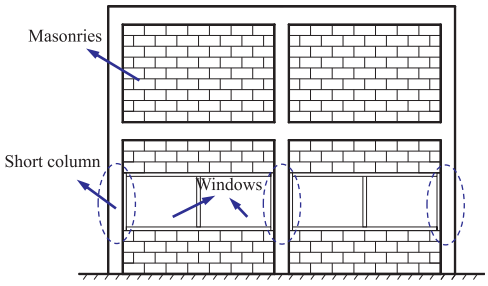
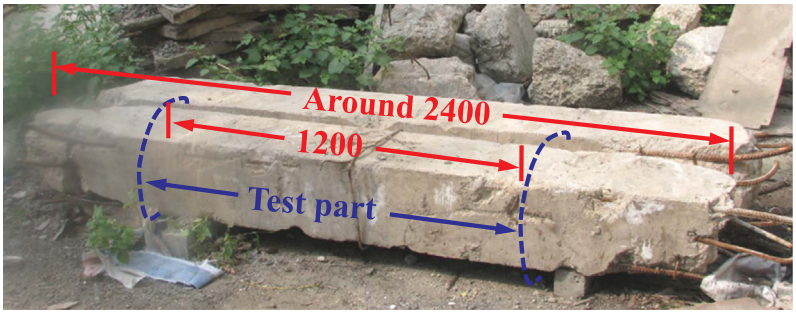


Fig. 1. Short columns effect in the openings of masonry walls.

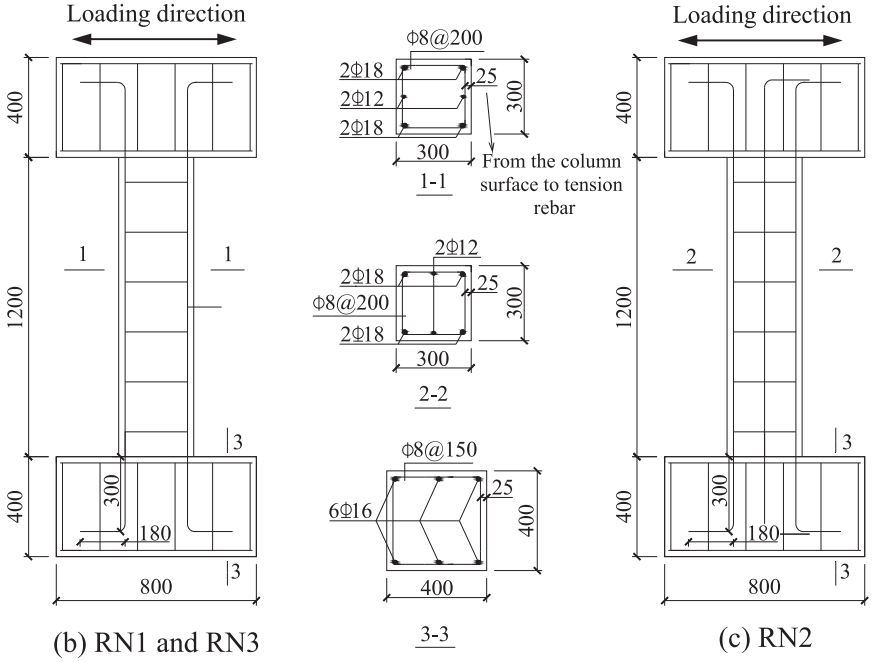
seismic performance of corroded RC columns. Aquino and Hawkins [7] investigated the seismic behavior of corroded circular RC columns, and reported that the bond strength degradation between rebar and concrete decreased the load-carrying capacity and ductility of the corroded circular RC columns. Simon et al. [8] carried out fragility analysis of a bridge with a corroded column and two spans. The analysis result showed that corrosion of rebars was not critical to the seismic performance because the bond strength degradation between the corroded bars and concrete was not considered in the analysis model. Ma et al. [9] studied the seismic behavior of circular RC columns with corroded bars in cyclic loading test. As the corrosion level of rebars increased, the lateral load-carrying capacity, stiffness, ductility, and energy dissipation capacity decreased. Meda et al. [10] reported that pitting corrosion was more common for embedded rebars compared with bare rebars, and found that the yield, ultimate and deformation capacities of the corroded RC column (with corrosion loss ratio of 20%) were significantly reduced due to the great mechanical degradation of corroded rebars.

An old RC structure can be damaged by carbonization of concrete as well as rebar corrosion. According to Jerga [11], and Chang and Chen [12], though compression strength of concrete increases after carbonization, the descending branch of the stress-strain curve becomes obvious steeper compared with non-carbonated concrete, which decreases the structural performance including ductility and energy dissipation capacity of the old RC structure. On the other hand, lateral stiffness of RC columns can be increased up to about 20% due to the increase of concrete modulus after carbonization of cover concrete [13], which increases the seismic demand of the RC columns. Thus, carbonized RC structure is vulnerable to earthquake loads.

In the present study, earthquake resistance of corrosion damaged in-service RC short columns was investigated by cyclic loading tests and analysis. Four RC columns with shear span ratio 2.3, which show shear-flexural behavior, were obtained from a masonry infilled RC moment frame structure used for over 20 years. Three RC columns were tested under quasi-static cyclic loading, and one RC column was used to measure the material properties of concrete and rebars. Three axial compression ratios and two different reinforcement details were considered. The structural performance including load-displacement relationships, deformation capacity, failure mode, stiffness degradation, and energy dissipation capacity were discussed. Five shear strength models from previous studies were applied to predict the shear strength



(a) Old RC columns obtained from a frame structure



(b) RN1 and RN3 (c) RN2

Fig. 2. Dimensions and details of test specimens (units: mm).