Construction and Building Materials 167 (2018) 20–32

Contents lists available at ScienceDirect

Construction and Building Materials

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

Influence of Non-uniform corrosion of steel bars on the seismic behavior of reinforced concrete columns

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HIGHLIGHTS

- Seismic behavior of corroded RC columns was studied.
- Effects of non-uniform corrosion on the seismic behaviors were investigated.
- Bilateral and unilateral failure criteria were proposed to assess the performance.

ARTICLE INFO

Article history:
Received 15 September 2017
Received in revised form 22 January 2018
Accepted 25 January 2018

Keywords:
Corroded RC column
Non-uniform corrosion
Seismic performance
Ductility
Energy dissipation

ABSTRACT

Corrosion of reinforcing steel bars is a major factor in the degradation of the seismic performance of reinforced concrete (RC) structures. In this work, a pseudo-dynamic test was carried out on six corroded square RC columns with different axial compression ratios and corrosion levels. The hysteresis curve, skeleton curve, ductility and energy dissipation of the RC columns were compared and discussed. The influence of the non-uniform corrosion of the reinforcing steel bars on the seismic performance of the RC columns was analyzed accordingly. The results show that with the increase of the corrosion level the energy dissipation significantly decreased, whereas the ductility ratio was slightly increased, indicating the corrosion of the steel bars seemingly improved the ductility of the columns. The non-uniform corrosion had led to the significant difference in the post-peak behaviors of a RC column under the positive and negative loadings. Two different failure criteria of bilateral and unilateral failure criteria were thus proposed to address this difference. It was found that the seismic performance of the corroded RC columns evaluated by these two failure criteria differed greatly. The bilateral failure criterion had overestimated the seismic performance, while the use of the unilateral criterion can better reflect the effect of non-uniform corrosion.

1. Introduction

Corrosion of reinforcing steel leads to the reduction of steel cross section and degradation of mechanical properties [1–5]. Although small corrosion ratio is advantageous to improve the bond performance [6–8], the volume expansion of the corrosion products will finally weaken the bonding between the reinforcing steel bar and concrete, resulting in a deterioration of the seismic performance of reinforced concrete (RC) structures. The seismic performance of corroded RC structures [9–18] has thus attracted significant attentions; however, most of existing studies mainly focus on the rehabilitation of their performance [19–26] by the most efficient technique of externally bonded fiber reinforced polymer (FRP) [24–28]. To date, there is still lack of a systematic study to consider the effects of non-uniform corrosion of steel bars. For instance, Meda et al. [14] carried out a pseudo-dynamic test of two circular corroded RC columns and found that corrosion significantly reduced the seismic performance of the specimen. Considering the difference of the surrounding environments of RC columns, Guo et al. [15] studied the influence of corrosion on the plastic hinge region of RC columns with three target corrosion ratios in the marine tidal and splash zones. The results indicated that the lateral displacement of the corroded columns was significantly enhanced due to the deterioration at the plastic hinge region and the columns with more serious corrosion resulted to the poorer seismic behavior. Ma et al. [11] studied the seismic behavior of RC columns with different axial compression ratios and corrosion ratio. A total of 13 RC columns were designed with a corrosion ratio ranging from 0% to 15% and an axial compression

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https://doi.org/10.1016/j.conbuildmat.2018.01.149
0950-0618/

ratio of 0.15 to 0.9. The results showed that with the increase of the corrosion level and axial compression ratio, the deterioration of the seismic performance of the RC column became more severe. It should be noted that in existing studies, the failure of corroded RC columns was defined as the attainment when the post-peak load of columns under both positive and negative loadings dropped to a critical value, e.g., 85% of the peak load, and hereafter it is referred to as the bilateral failure criterion.

However, due to the inhomogeneity in the thickness of the concrete cover and the difference of the surrounding environments, the reinforcing steel bars on each side of the RC columns may be subjected to different degrees of corrosion, and the damage to the concrete cover may be also significantly different. The weakest side of the RC columns with the more severe deterioration will fail first and would have been severely damaged when the other side starts to fall apart. With the increase of the difference of corrosion level, the difference of the seismic performance on each side becomes more pronounced. Hence, the seismic performance is normally over-estimated when bilateral failure criterion is used for the evaluation. Therefore, a unilateral failure criterion is proposed, in which, only the mechanical performance of the side, which fails first (e.g., the lateral load is reduced to 85% of the peak load), is used to evaluate the seismic performance the RC column. Due to the non-uniform corrosion of the reinforcing steel bars on each side, the column is likely to fail first on the side where the corrosion is heavier. Hence, the unilateral failure criterion can lead to a more safety and suitable assessment of corroded RC structures than that using the bilateral failure criterion.

Non-uniform corrosion of the reinforcing steel is very common in the RC structures. In this paper, the seismic performance of corroded RC columns was evaluated using the unilateral failure criterion. Two axial compression ratio and three target corrosion rates were considered. The seismic performance of the corroded RC columns was compared. The crack development, hysteresis curve, skeleton curve, energy dissipation capacity, yield load and ultimate load were analyzed.

2. Experimental program

2.1. Column design

In this paper, six T-shaped square RC columns were designed, including two comparative columns. Each column had a cross section of 300 × 300 mm and a height of 1370 mm. The cross section of the column base was 1100 × 300 mm with a height of 400 mm, which was fixed to the experiment desk, providing a rigid constraint for the column, as shown in Fig. 1. For the following analysis, the four sides of the specimen were named S1, S2, S3, and S4, respectively, and the first forward push was applied on S2. The reinforcement information of all the specimens is also detailedly shown in Fig. 1, where each specimen was reinforced with 6 longitudinal steel bars with a diameter of 20 mm. The reinforcement ratio was 2.1%. Three steel bars were placed on each loading side of the specimen, which were labeled as L1, L2, L3, R1, R2, and R3 from bottom to top and from left to right, respectively. The diameter of the stirrups was 8 mm, the spacing was 100 mm, and the transverse reinforcement ratio was 0.87%. The outer edge of the concrete to the outer edge of the stirrup had a thickness of 25 mm. The yield strength of the longitudinal reinforcement was 441 MPa and the ultimate strength was 614 MPa.

The average 28-day compressive strength of the concrete was 50.2 MPa. In the experiment, two axial compression ratios n (i.e., $n = 0.1$ and 0.3) and three target corrosion ratio ρ (i.e., $\rho = 0\%$, 10% and 20%, hereafter, unless explicit stated, representing the mass loss of steel bars) were designed. The detailed program of the six specimens is listed in Table 1. The specimen was named following the format NxCy, where, N stands for axial compression ratio, x represents the value of the axial compression ratio, C stands for the corrosion ratio and y denotes the target value of the corrosion ratio. For example, the specimen N3C10 had an axial compression ratio of 0.3 and a target corrosion ratio of 10%. Table 1 also provides the measured average actual corrosion ratio of all the reinforcing bars.

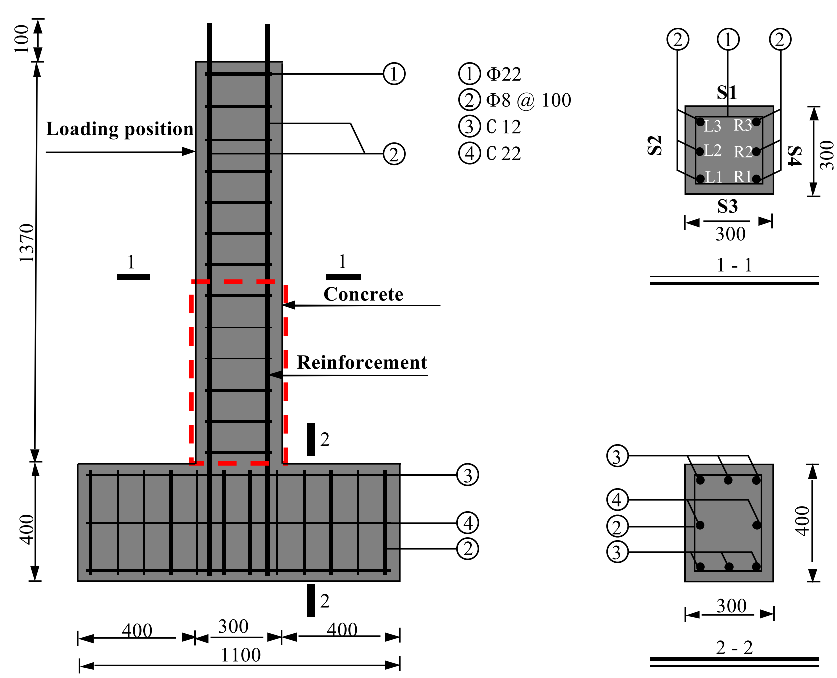

Fig. 1. Details of the specimen (unit: mm).