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Behaviour of steel-jacket retrofitted RC columns with preload effects

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ABSTRACT

Steel jacketing is an efficient way to retrofit reinforced concrete columns. Previous studies focused on the performance improvement without considering the preloads on the original columns. The preloads might inevitably affect the structural performance of the retrofitted columns. Comprehensive experimental and numerical studies on the behaviour of steel-jacket retrofitted RC columns with preload effects are presented in this paper. Twenty-nine steel jacketing columns with different steel tube thicknesses, axial preloading levels and load eccentricities are tested under concentrically or eccentrically compressive loading.

The experimental results are discussed and illustrate that the effects of preloading levels on the axial compression strength of the retrofitted columns are negligible while increasing the preloads could decrease the eccentric compressive strength. A fibre element model is developed to predict the behaviour of the retrofitted columns. The material non-linear behaviour of all the components considering the steel tube and stirrup confining effects on the concrete as well as the preloading action are taken into account in the model. The model is validated by comparing its results with the experimental results. Extensive parametric studies are undertaken by using the proposed numerical model to elucidate the effects of axial and moment preloading and the effects of preloads with various other parameters on the performance of the retrofitted columns.

1. Introduction

For reinforced concrete (RC) structures, columns are amongst the most important components as far as vertical load transferring is concerned. Column members in older RC building or bridge may need to be retrofitted or repaired due to their long-term deteriorations as a result of exposure to adverse environmental conditions, or sometimes they need to be strengthened to satisfy the reconstruction demands. Several RC columns retrofitting solutions have been suggested, including fibre-reinforced polymer (FRP) composite wrapping, steel and concrete jacketing [1]. In deference to the others, the steel jacketing method is probably preferred because of its high retrofitting effectiveness and economic efficiency, as well as ease of construction. In this method, the common RC column is encased by a thin steel jacket (e.g. Fig. 1). The gap between the tube and the original column is filled with grout for integration purpose. The steel jacketing approach can provide more effective confinement on the concrete and significantly improve the strength, stiffness, and deformation capacity of the strengthened columns. The steel jacketing construction process is also quite efficient as the steel stub acting as permanent formwork. Surprisingly, there is limited research reported in the open literature on the investigation of RC column retrofitted by steel jacketing method. Chai *et al.* [2,3] studied the influence of steel jacketing on the lateral response of circular bridge columns. The results showed that the steel jacketing increased the lateral stiffness and ductility capacity of the columns. Priestley *et al.* [4,5] performed a comprehensive two-part study to determine the enhanced shear strength of columns provided by steel jacket retrofitting. Xiao *et al.* [6,7] conducted a series of tests on the columns with a square or rectangular section retrofitted by partially stiffened steel jackets and indicated the effectiveness of the proposed method. Li *et al.* [8] proposed a constitutive model to describe the behaviour of concrete confined by steel reinforcement, steel jackets and both steel reinforcement and steel jackets used to retrofit and strengthen RC structures. Choi *et al.* [9,10] introduced a new steel jacketing method with lateral pressure externally applied on steel jackets to tightly attach the jackets on concrete surfaces of columns, and thus did not require the grout used in conventional jacketing. It was found that the jackets could increase the ultimate strength, bond strength and ductility of the column specimens.

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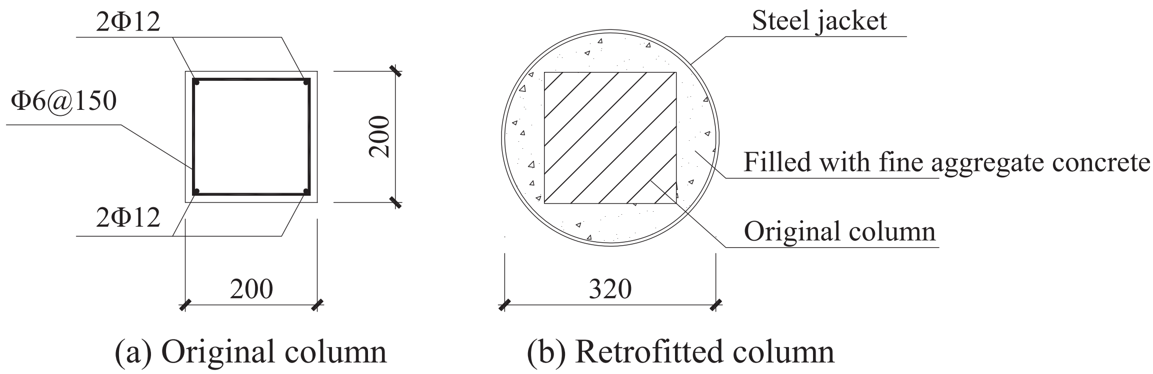

Fig. 1. Cross-sections of specimens. (a) Original column (b) Retrofitted column.

Table 1
Parameters and test results of specimens.

Specimen	t (mm)	e (mm)	η	P_u (kN)	Strength ratio
AZ1	–	0	–	990	1.00
BZ1	1.0	0	–	2202	2.22
BZ2	2.0	0	–	2990	3.02
BZ3	3.0	0	–	3820	3.86
BZ4	3.5	0	–	4180	4.22
BZ5	4.0	0	–	4460	4.51
BZ6	1.0	50	–	1728	1.75
BZ7	2.0	30	–	2540	2.57
BZ8	2.0	50	–	2108	2.13
BZ9	2.0	80	–	1797	1.82
BZ10	3.5	30	–	3450	3.48
BZ11	3.5	50	–	2636	2.66
BZ12	3.5	80	–	1850	1.87
CZ1	2.0	0	0.08	2780	2.81
CZ2	3.5	0	0.08	3678	3.72
CZ3	2.0	0	0.09	3030	3.06
CZ4	2.0	30	0.08	2040	2.06
CZ5	3.5	30	0.08	2741	2.77
CZ6	3.5	30	0.09	2988	3.02
CZ7	2.0	50	0.08	1727	1.74
CZ8	3.5	50	0.08	2190	2.21
CZ9	2.0	50	0.09	1980	2.00
CZ10	3.5	50	0.09	2136	2.16
DZ1	4.0	0	0.40	4290	4.33
DZ2	4.0	0	0.50	4230	4.27
DZ3	4.0	30	0.40	3380	3.41
DZ4	4.0	50	0.40	3000	3.03
DZ5	4.0	80	0.40	2560	2.59
DZ6	4.0	50	0.50	2920	2.95

Note: t is the thickness of steel jacket; e is the eccentricity from neutral axis; η is the preloading level and is defined as $\eta = P_{pre}/(f_{c1}A_n)$, where P_{pre} is the axial prestressed force on the original column, A_n is the net cross-sectional area of the original concrete; P_u is the experimental maximum load; strength ratio is the ratio of the value of P_u of each retrofitted column versus the value of P_u of unstrengthen column AZ1.

In practice, during the retrofitting construction, most of the pre-existing RC columns are subjected to preloads arising from the existing live and permanent loads from the upper floors or substructure. The stress and deformation induced by the preloads might inevitably affect the structural performance of the retrofitted columns. The effects of preloading on the behaviour of concrete-jacket retrofitted RC column have been addressed in some studies. Ersoy *et al.* [11] performed axial loading tests on concrete-jacket strengthened RC columns in both the preloaded and non-preload cases, and showed the ultimate strengths of the preloaded specimens were slightly lower than the non-preloaded ones. Takeuti *et al.* [12] presented rigorous experimental programme to evaluate the preload effects on the concrete jacketed columns, and stated that the preloading might not adversely affect the strength of the jacketed column but could reduce its deformability. Vandoros and Dritsos [13,14] compared the performance of preloaded and non-preloaded concrete jacketed RC columns under combined axial loading and bending moment. The comparison on the basis of flexural behaviour demonstrated the positive effects of preloading when considering the strength and deformation capacity although the preloading could reduce the initial stiffness. Recently, Papanikolaou *et al.* [15] analytically investigated the effects of core preloading on the strength of jacketed RC columns.

The purpose of this paper is to present experimental and numerical studies on the behaviour of steel-jacket retrofitted RC columns with preload effects. Tests of twenty-nine columns retrofitted by steel jackets subjected to concentrically or eccentrically compressive loading are reported and the experimental results are discussed. The variables among the tested specimens include the load eccentricity ratios, the thickness of steel tube and the axial preloading levels. A fibre element model using OpenSees software is proposed to predict the behaviour of the retrofitted columns. Both geometric and material non-linear behaviour of all the components and the preloading action are taken into account in the model. The model is validated by comparing its results with the experimental results. Parametric studies are then undertaken by using the proposed numerical model to further elucidate the effects of preloading on the performance of the retrofitted columns.

2. Experimental programme

2.1. Test specimens

Twenty-nine column specimens were fabricated and tested. The diameters of steel jackets D and the effective lengths of all the specimens were the same as 320 mm and 1000 mm respectively. The variables among the tested specimens include the thickness of steel tube t, the axial preloading levels η (the ratio of the axial preload to the predicted axial compressive strength of original column) and the load eccentricities e. Fig. 1 and Table 1 show the cross-sectional dimensions and the details of the specimens. The material properties are summarised in Table 2. In all the specimens, the unstrengthened one AZ1 was chosen as the control specimen. No preloads were applied on the specimens in Series BZ. The specimens in Series CZ were under relative low level of axial preloading from 0.08 to 0.09 while the one in series DZ were under relative high level of axial preloading from 0.4 to 0.5. The post-tensioned prestressing construction technique was implemented to simulate the preload actions on the specimens, as shown in Fig. 2. The original column was firstly fabricated with a pipe whose diameter is 36 mm along the central axis of the section. After 28 days concrete curing period, the steel bars were inserted into the pipe and the post-tensioning procedures were