Seismic Performance Degeneration of Assembled Concrete Columns with Grouting Defects

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Abstract. In order to evaluate the influence of internal defects of semi-grouting sleeve connection on seismic performance of assembled monolithic columns, four specimens of assembled monolithic concrete column with semi grouting sleeve connecting reinforcement bar were fabricated with 10%, 20%, 30% internal defects. The test results show that (1) the assembled columns are all damaged by bending, the grouting layer of the assembled column can be pulled apart easily and the cracks develop more closely on the upper part of the sleeve; (2) the larger the internal defects in the sleeve, the less the cracks on the column, and the less sufficient the cracks development; (3) the seismic energy dissipation capacity of the column without defect is better than that of the defective columns.

Keywords. Assembled concrete column, grouting sleeve, quasi-static test, seismic performance degeneration

1. Introduction

Grouting sleeve connection is one kind of steel bar connection method commonly used in prefabricated concrete structure. It has been studied for 50 years. Ahmad's experiment show that the addition of shear bond can significantly improve the connection, and sufficient anchoring length can ensure the connection capacity of grouting sleeve [1]. Yu Wenmao's test show that the horizontal bearing capacity of prefabricated columns is about 90% that of the cast-in-place columns [2]. Yang Xu conducted a test and found out that assembled frame and the cast-in-place frame are damaged by the plastic hinge at the end of the beam; the assembled frame is easy to appear wide cracks in the slurry layer during failure [3]. Gao Rundong investigated that the outstanding problems in the practical operation of grouting such as unstandardized grouting materials, insufficient anchorage length, no slurry outlet and slurry reflux [4]. So far, the studies of seismic performance of prefabricated concrete structures with grouting sleeve connection are mainly focused on the specimens without connection defects. However, internal defects always exist in the grouting sleeve connection and cause adverse effects on assembled structures. Therefore, it is necessary to study the influence of internal defects of grouting sleeve connection on the seismic performance of assembled columns.

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2. Materials and Methods

2.1. Preparation of Specimens

The specimens are designed to simulate a concrete column connected with semi-grouting sleeve and internal defects. The ratio of similitude size is 0.2. The contrast specimen (ZP) is fabricated with semi-grouting sleeve connection without internal defects, the other three specimens (ZP10, ZP20, ZP30) with different degrees of internal defects. Detail and dimension of the specimens are shown in figure 1. The degree of internal defects of semi-grouting sleeve connection is simulated by the length of anchorage reinforcement bar. According to the grouting coupler for rebars splicing [5], the anchorage length of reinforcement bar should not be less than 8 times of the diameter. The anchorage length of ZP without internal defect is 8d. The internal defect degrees of ZP10, ZP20 and ZP30 are 10%, 20% and 30% respectively. In response to the internal defect degrees, the anchorage length of ZP10, ZP20 and ZP30 were reduced by 10%, 20% and 30% respectively. The specimen numbers and defect designs are shown in table 1.

Figure 1. Reinforcements detailing and dimensions (mm).

Table 1. Internal defects design.

Type	Internal defect degrees/%	Anchorage length of reinforcement bar/mm	Thickness of slurry layer/mm	Length of reserved bar/mm
ZP	0	112	20	132
ZP10	10	101	20	121
ZP20	20	90	20	110
ZP30	30	79	20	99

2.2. Material Properties

The size and mechanical properties of reinforcement bars in the specimens are listed in table 2. All the mechanical properties of concrete and grouting material are obtained by normative testing. The concrete grade is C30. The modulus of concrete is 3×10^4 MPa, the converted axial compressive strength of concrete is 23.5 MPa. The grouting material adopted CGM sleeve grouting material and the water/material ratio is 12.5%. The compressive strength and bending strength of grouting material are 89.2 MPa and 13.4 MPa respectively. The sleeve adopts the ductile iron semi-grouting sleeve

corresponding to the size of the reinforcement bar of the prefabricated column. The relevant technical parameters of the sleeve are shown in table 3.

Table 2. Properties of steel reinforcements.

Category	f_y /MPa	f_u /MPa	E_s /MPa
14	335	457	2.1×10^5
20	434	642	2×10^5
8	463	651	2×10^5

Table 3. Technical parameters of semi-grouting sleeve

Length/mm	External diameter/mm	Thread connection length/mm	Tensile strength /MPa	Extensibility /%	Extensibility /%
162	39	27	≥ 600	≥ 5	≥ 85

2.3. Loading Device and Loading Sequence

The loading equipment are showed in figure 2. The horizontal push-pull force is applied by the MTS electro-hydraulic servo actuator through the loaded beam. The loading direction is specified as push positive and pull negative. The vertical axial pressure is applied by the hydraulic jack applied on the top of the column.

Figure 2. Loading strategy.

Figure 3. Loading strategy.

According to Specification for seismic test of buildings [6], hybrid loading of force and displacement is adopted to control the horizontal force in the test, the loading strategy shown as figure 3. Before yielding, the test uses force control and each loading step repeats once. After yielding, the test uses displacement control and each loading step repeats thrice and increased by the yielding displacement of ZP.

3. Test Results and Analysis

The test results of ZP, ZP10, ZP20 and ZP30 are obtained and compared as following. The yield load F_y , yield displacement Δ_y , Peak load F_p , the displacement corresponding to Peak load Δ_p , ultimate load F_u , ultimate displacement Δ_u , are shown in table 4. The crack distribution and destruction patterns of all tested specimens are shown in figure 4.

Table 4. Main test parameters of specimens.

SN of specimen	Loading direction	F_y (kN)	Δ_y (mm)	F_p (kN)	$\bar{F}_p$ (kN)	Δ_p^* (mm)	F_u (kN)	Δ_u (mm)
ZP	(+)	60.44	14.29	77.17	77.14	26.47	65.11	69.48
	(-)	65.67	16.39	77.11		44.06	65.53	70.42
ZP10	(+)	63.68	17.87	73.07	72.67	44.15	64.40	79.29
	(-)	63.28	21.69	72.26		44.05	70.08	70.42
ZP20	(+)	57.34	18.44	69.03	69.36	44.12	58.87	70.43
	(-)	57.16	21.82	69.69		44.05	65.91	61.68
ZP30	(+)	50.70	22.96	64.68	64.67	44.16	57.57	79.24
	(-)	54.58	28.31	64.66		44.05	58.19	79.25

* Δ_p represents the displacement corresponding to peak load

Figure 4. Typical damages and crack patterns of the specimens.

The load-displacement hysteretic curves of ZP, ZP10, ZP20 and ZP30 are as shown in figure 5.

Figure 5. Hysteresis loops.

By comparison, ZP has the fullest hysteretic curve and possess excellent seismic energy dissipation capacity. For ZP10, ZP20 and ZP30, with the increase of the internal defects, the hysteretic curves squeezed more obviously and in the same displacement

loading, the area of the hysteresis loop decreases. The energy dissipation capacity of the specimens decreases when the internal defects of the semi-grouting sleeve connection increases. When ZP30 was loaded to -40 kN, the displacement increased sharply, causing some degree of damage inside the specimen. Especially the rapid development of the cracks on ZP30 at the slurry layer leads to obvious decrease of the stiffness.

3.1. Skeleton Curves

The skeleton curves of ZP, ZP10, ZP20 and ZP30 are shown in figure 6. The skeleton curves of the specimens appear differences after the loading displacement exceeding 13.2 mm. The slopes of the skeleton curves and horizontal bearing capacities of ZP10, ZP20 and ZP30 decrease with the increase of internal defects degrees. When positive loading, The peak load of ZP is 77.17 kN, and the peak loads of ZP10, ZP20 and ZP30 are 94.8%, 89.3% and 84% that of ZP respectively. When negative loading, the peak load of ZP is 77.07 kN, and the peak loads of ZP10, ZP20 and ZP30 are 93.7%, 90.9% and 84% that of specimen ZP respectively.

Figure 6. Skeleton curves.

3.2. Ductility

The ductility coefficient μ is calculated according to Eq. (1). Table 5 lists the yield displacement Δ_y , the ultimate displacement Δ_u and the ductility coefficient of ZP, ZP10, ZP20 and ZP30 respectively. For ZP, ZP10 and ZP20, the ultimate displacement is the displacement when the horizontal bearing capacity of the specimen drops to 85% of the peak load. While ZP30 is obviously damaged and not suitable for the continued loading, its ultimate displacement is determined by its last stage loading displacement. The ductility value of specimens as shown at table 5.

$$\mu = \Delta_u / \Delta_y \quad (1)$$

Table 5. Ductility value of specimens.

SN. Of specimen	ZP	ZP10	ZP20	ZP30
μ	4.58	3.84	3.32	3.12

3.3. Energy Dissipation

In order to evaluate the energy dissipation capacity of the specimens, figure 7 indicate the cumulative energy dissipation E , respectively. The equivalent viscous damping coefficient h_e is calculated according to Eq. (2).

$$h_e = \frac{S_{(ABC+BED)}}{2\pi \times S_{(OAG+OEF)}} \quad (2)$$

Where $S_{(ABC+BED)}$ is the hysteretic loop area of the first cycle at each stage of loading, $S_{(OAG+OEF)}$ is the sum of the area of the triangles OAG and the OEF [7].

The cumulative energy dissipation curves of ZP10 and ZP20 are similar with that of ZP, while the cumulative energy consumption curve of ZP30 is obviously lower than others. When the loading displacement reaches 70.4 mm, the cumulative energy consumption of ZP30 is only 72.3% that of ZP. It can be seen that when the degrees of internal defects are 10% and 20%, the effects of internal defects on the energy dissipation performance of the specimens are relatively weak, but when the internal defects reach 30%, the energy dissipation capacity of the specimen will be greatly weakened.

Figure 7. Cumulative energy dissipation.

4. Conclusion

Based on the test result, the conclusions can be obtained: (1) The failure modes of the assembled monolithic concrete columns are bending failure. With the increase of internal defects inside the sleeves, the cracks at the combination of prefabricated column and slurry layer will appear earlier. (2) The hysteresis curve of the specimen ZP without internal defect is the fullest. With the increase of internal defects inside the sleeves, the hysteretic curves of ZP10, ZP20 and ZP30 squeeze more and more obviously, and the energy dissipation capacity of the specimens decreases. (3) The internal defects have great influence on the ductility of the assembled columns connected with the semi-grouting sleeve. The ductility coefficients of ZP10, ZP20 and ZP30 are 84%, 72% and 68% that of ZP respectively. The seismic deformation ability of the columns has been seriously weakened by the internal defects.

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