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The Seismic Reinforcement Technology of External Cable Stayed Steel Strand on Frame Structure

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Abstract: *In this paper, a comparative study of three enhancement methods is carried out for the practical application of the external attached cable-stayed steel strand seismic enhancement technology in multi-storey frame structure buildings. Moreover, Midas civil finite element software is used to conduct the time-history research on the building structure under the influence of rare occurrence earthquakes. In this paper, the improvement effects of different reinforcement models on structural strength are studied from the perspective of maximum displacement angle, natural vibration period and total inter-story shear force. The results show that the integrity and seismic resistance of the reinforced concrete frame structure treated with external cable-stayed steel strand components are significantly improved compared with the original components. However, the middle part of the result curves of different models is quite different. Based on this, this paper combines the simulation results to sort out the practical engineering applications of different reinforcement schemes.*

Keywords: *Frame structure; Cable stayed structure; Seismic reinforcement; Direct dynamic method*

1. Introduction

A large number of existing buildings cannot meet the requirements of people's anti-seismic fortification due to various factors. The traditional seismic reinforcement methods are simple in operation and low in cost, but have little effect on the improvement of the structure seismic performance[1]. In recent years, the emerging seismic strengthening technologies has achieved good effect. For example, Baojiang Yin et al.[2] proposed a method of enhancing the frame structure with external steel frame, as well as carried out simulation experiment research. Peng Gao et al.[3] performed the research on the reinforcement of a teaching building with buckling restrained brace, which can make the building have a better hysteretic behavior. Cui Ye et al. proposed a new three-dimensional self-centering reinforced concrete frame structure, and verified that the structure has good seismic performance and small residual displacement[4].

Up to now, there are relatively few studies on the seismic reinforcement for existing buildings. In this paper, the cable stayed steel strand is used in the seismic reinforcement of the existing reinforced frame structure, and the midas civil finite element simulation software is adopted to verify the effectiveness of such seismic reinforcement technology[5].

2. Finite Element Simulation Experiment Research

2.1. Model parameters

The main structure body adopts a steel frame structure, with a total of three floors. Among them, the height of the first floor is 3.6m, that of the second floor and the third floor is 3.3m. The span in the length and width directions is 5m, and the total construction area is 102. The plan layout of the specific structure plane is shown in Figure 1. The seismic classification of the structure is designed into two groups, with Magnitude-8 seismic precautionary intensity (0.2g), Category-II site and the characteristic period of 0.4s.

Referring to the structural design specification, the steel bar adopts ideal elastoplastic model: Elastic modulus: 1.95×105N/mm2; Poisson ratio: 0.3; Coefficient of linear thermal expansion: 1.2×10-51/[C]; Volumetric weight: 7.85×10-5N/m3; Nominal diameter of the steel strand: 15.2mm; Min. tensile strength: 1,860MPa. The column section adopts pure steel box section: H=508mm; B=304.8mm;

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tw=12.7mm; tf1=12.7mm; C=292.1mm; tf2=12.7mm. The beam section adopts pure steel I-shaped cross-section: H=300mm; B1=300mm; tw=10mm; tf1=15mm; B2=300mm; tf2=15m displacement, without limitation of rotation.

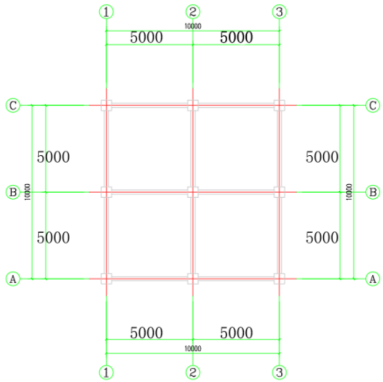
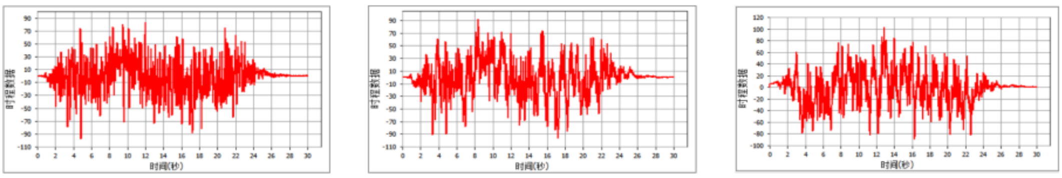


Figure 1: Plan layout (mm)

2.2. Selection of seismic wave

Three artificial waves are selected in this project, setting the amplification coefficient to 25. The specific waveform is shown in Figure 2, hereinafter referred to as X-wave, Y-wave and Z-wave. Among them, the main, secondary and vertical peak value accelerations are 0.23g, 0.26g and 0.24g, respectively.



Z-wave ground motion X-wave ground motion Y-wave ground motion

Figure 2: Waveform (waveform)

2.3. Layout scheme of external cable stayed structure

The original model without reinforcement is shown in Model 1 in Figure 3 below; By considering the safest reinforcement mode, cable stayed steel strands are arranged between all frames, as shown in Model 2; But in the actual engineering, if all of them adopt cable stayed structure, it is not only costly, but also affects the aesthetic appearance of the structure. Therefore, it is considered to arrange the cable stayed structure in a certain floor, as shown in Model 3; The reinforcement principle of the external cable stayed structure is to improve the integrity of the structure, so the existing building can be regarded as a whole to be reinforced through cable staying, as shown in Model 4.

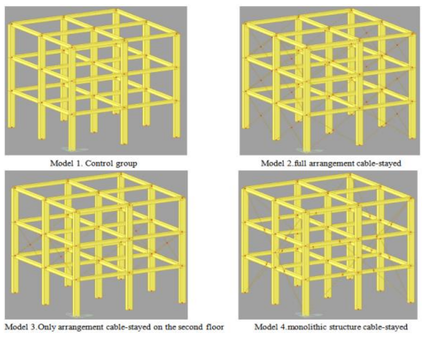


Figure 3: Layout scheme of the external cable stayed structure

2.4. Model design

Since the post and beam construction is built in this model, without consideration of the wallboard

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self-weight, concentrated load of 10kN is added at each joint, and the direction is vertical downward to equivalently replace the structural self-weight. The bottom of the structure is rigidly coupled to the foundation and the beam-column joints are fixedly connected. The external cable stayed structure is hinged to the main structure,with a fixed constraint action at the intersection of the cable stayed components.

3. Comparative Analysis of Reinforcement Effect

3.1. Analysis of the maximum interstory drift of the structure

Through the finite element analysis by taking the earth as the reference system, the maximum interstory drift of each model is shown in Table 1.

Table 1: Maximum interstory drift(unit:mm)

Model	Main direction earthquake action	Secondary direction earthquake action
1	18.35	1.85
2	12.25	0.89
3	15.55	1.26
4	13.84	0.95

The maximum interstory drift refers to the ratio of the maximum horizontal interstory drift between floors to the storey height calculated by the elastic method under the influence of the wind load and the standard value of occurrence of frequent earthquakes, which is used to determine the stiffness that a multi-layer organization shall have. $\theta = \frac{\Delta u_i}{h}$ .It is a kind of macro-control indicator for the section size and stiffness of the building structure.

Table 2: Maximum interstory drift(unit:rad)

Model	Maximum storey drift under the action of the direction earthquake			Maximum storey drift under the action of the secondary earthquake		
	the 1st floor	the 2nd floor	the 3rd floor	the 1st floor	the 2nd floor	the 3rd floor
1	0.002045	0.001897	0.001326	0.000213	0.000153	0.000099
2	0.00144	0.001136	0.001184	0.000116	0.000072	0.000088
3	0.001753	0.001503	0.00123	0.000156	0.000098	0.000074
4	0.001522	0.001181	0.001178	0.000125	0.000073	0.000083

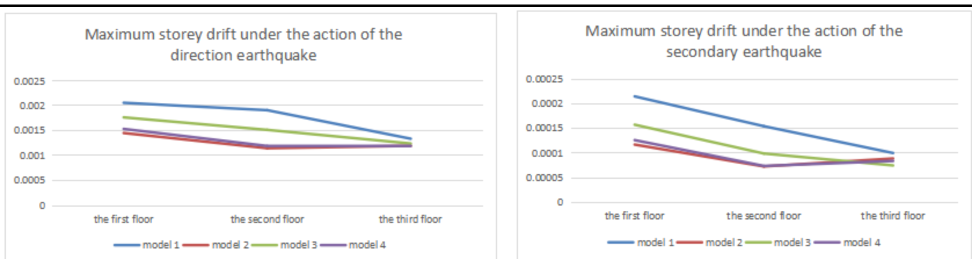

Figure 4: Maximum interstory drift

Define the general displacement of the columns of each floor of the model and carry out elastic direct dynamic method on the structure. The obtained interstory drift of the structure under the influence of the main and secondary direction seismic waves is shown in Table 2 above. In order to obtain the results more intuitively, the line chart of interstory drift of the model is shown in Finger. 4 below.

According to the above table, the maximum interstory drift appears on the first floor, Model 2 shows the best reinforcement effect under the influence of the main direction earthquake, whose maximum interstory drift is reduced by 29.85% compared with the control group; Model 3 shows a relatively poor reinforcement effect, whose maximum interstory drift is only reduced by 14.28%.

According to the figure, the maximum interstory drift decreases with the increase of the story height in the case of no reinforcement; The larger interstory drift of each floor in Model 2, Model 3 and Model 4 decreases compared with the situation of no reinforcement, and the straight slopes in Figure. 4 all change. Among them, the maximum interstory drift of the second floor of Model 2 is smaller than that of the third floor; It can be seen that the external cable stayed structure can not only effectively improve the original structure stiffness, but also change the mechanical characteristics of the structure.

3.2. Stiffness of the structure

The natural period of vibration "T" refers to the reciprocating time required by the structural system to complete a free vibration according to a certain mode of vibration, which shall be only related to its own mass "m" and stiffness coefficient "k". The weight of the tensile steel strand in this model can be ignored. Therefore, the natural vibration period response model may be used to reflect the change in stiffness before and after reinforcement. The smaller the natural period of vibration, the larger the stiffness of the structure[6].

The calculation formula of the natural period of vibration is as $T = 2\pi\sqrt{\frac{m}{k}}$.

Table 3: Changes in the natural period of variation

	Model	Vibration mode									
		1	2	3	4	5	6	7	8	9	10
Natural period of vibration (s)	1	0.190	0.163	0.160	0.119	0.103	0.097	0.059	0.054	0.052	0.047
	2	0.154	0.140	0.132	0.111	0.085	0.069	0.052	0.044	0.039	0.033
	3	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.049	0.042
	4	0.170	0.147	0.137	0.108	0.098	0.092	0.059	0.047	0.047	0.046
Rate of change (%)	2	19.007	13.915	17.535	6.953	17.260	28.745	12.098	18.111	24.710	29.142
	3	7.792	-7.804	-9.528	-46.961	-70.655	-81.047	-196.358	-226.284	4.819	9.406
	4	10.820	9.524	141.161	9.432	4.797	4.632	0.419	12.136	9.492	1.698

In Table 3, it can be found that for the new models of Model 2 and Model 4 reinforced by the external cable stayed steel strand structure, the period of vibration mode at each order decreases significantly, and the overall strength of the structure increases obviously. For the reinforcement method of Model 3, the structural stiffness of the second floor is significantly larger than that of other floors, and the structural stress changes greatly. In addition, the decay law of the natural vibration period is significantly different from other models, while the vibration mode at the first order decreases slightly, and that at the second to eighth orders increases significantly compared with the same period of different models. However, the vibration mode at the ninth order decreases significantly, and the final periodic frequency is smaller than that of the unreinforced model.

3.3. Analysis on the interlaminar shear force of the structure

Table 4 below shows the total interlamination shear force of each floor of different models under the action of the main direction earthquake and that of the secondary direction earthquake. According to Figure 5, For the reinforcement method of Model 4, the total shear force value of each floor decreases proportionally, but the shear diagram slope remains unchanged; For Model 2, the shear force attenuation value of the top floor is similar to that of Model 4, about one-third of the shear force attenuation value of the unreinforced model. However, the absolute value of the shear force attenuation slope of the first to second floors increases and the total interlamination shear force of the second floors decreases, indicating that such reinforcement method is suitable for buildings with high requirements for the reinforcement of middle floor; For Model 3, only the second floor is reinforced. Figure 5 shows that the total interlamination shear force of the reinforced floor is similar to that of the unreinforced model, while

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the total interlamination shear force of the reinforced floor is much lower than that of the unreinforced model, indicating that such reinforcement method is suitable for the reinforcement of buildings with insufficient floor strength in a specified floor.

Table 4: Total interlamination shear force(Unit:kN)

Model	Total interlamination shear force under the action of the main direction earthquake			Total interlamination shear force under the action of the secondary direction earthquake		
	The 1st floor	The 2nd floor	The 3rd floor	The 1st floor	The 2nd floor	The 3rd floor
1	479.52	386.67	212.75	41.33	28.38	16.53
2	370.14	142.02	57.67	12.44	6.85	5.46
3	528.28	250.91	214.68	42.08	15.22	14.11
4	252.82	167.66	58.28	15.61	10.54	6.74

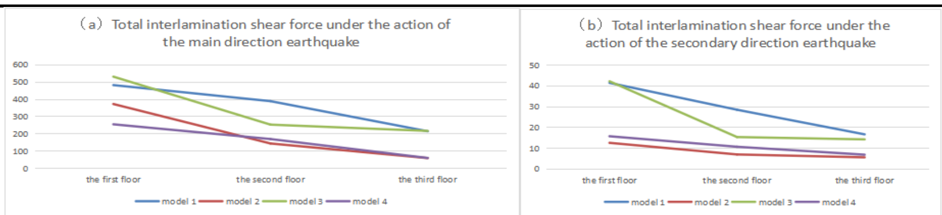

Figure 5: Total interlamination shear force

4. Analysis on Seismic Reinforcement Technology of External Cable Stayed Structure

Seismic reinforcement technology of external cable stayed structure refers to adding a steel strand substructure that can withstand strong tensile force at the nodes of the original structure through some methods, such as riveting or welding with high-strength bolts.In the case of large lateral load in earthquake or gale, the tensile force provided by the steel strand can effectively improve the integrity and stability of the structure, and play a role in seismic reinforcement. Steel strand has many advantages, such as low cost, easy manufacturing and transportation, high strength and good relaxation characteristics. In addition, it has good toughness, which is beneficial to limit the residual displacement of components and better realizes the self-centering function of the structure.

5. Conclusion

Through the numerical analysis on the analysis results, the following conclusions are obtained:

(1) Establish three reinforcement models of external steel strands in combination with the actual engineering. The analysis results show that the first method has better reinforcement effect than the third method, which is suitable for structures with higher requirement of reinforcement; The second method is suitable for the reinforcement of a specified floor.

(2) Compared with the initial structure, the interstory drift and interlaminar shear force of each floor in the model with external cable stayed steel strand decrease significantly, and the interstory drift meets the specification requirements. The decrease rate of shear force of the structural frame column that is reinforced by the method of Model 2 reaches 23%, and the maximum decrease rate of bending moment reaches 24%, both of which have achieved the design objective of seismic reinforcement.

(3)The energy dissipation of steel strand itself can play a role of shock absorption for the original structure. Furthermore, the application of prestress on the steel strand can enhance the toughness of the structure, thus making the structure have the ability to reset itself after deformation.

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