Study on FRP Bar Enhance the Ability to Resist Progressive Collapse for Reinforced Concrete Frames

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Abstract

To study the ability to resist progressive collapse for reinforced concrete frames, refer to the design process provided by GSA2003 and use SAP2000 to progressive collapse simulation analysis the 5 floors frame structure that designed according to our current standard. Suggest a new type of FRP reinforcement measures to enhance the ability to resist progressive collapse for the structure. Respectively, research the influence of reinforcement location and FRP bar diameter size to enhance the progressive collapse resistance. The nonlinear time history analysis results show that the measures can effectively enhances the progressive collapse resistance of the structure.

Keywords

FRP bar; progressive collapse; reinforced concrete; frame structure.

1. Introduction

Due to an initial local failure between components, it causes chain reaction in the structure, eventually leading to the collapse of the whole structure or the occurrence of a disproportionately large-scale collapse of the structure compared with the initial local failure, which is called a structure progressive collapse[1]. Since 1968 the accident of RONAN apartments event that people have begun to realize a progressive collapse accident, Collapse accidents have arisen at home and abroad every now and then, such as the US federal government office building in Oklahoma attacked by a car bomb that led to the progressive collapse accident, the US World Trade Center attacked by terrorists that led to the 911 progressive collapse accident, Building on fire resulting in a progressive collapse accident in Hengzhou, Hengyang, China. A structure progressive collapse accident has become a serious issue threat to public security for its great harm. Due to the arrangement of column members dispersed, a single-column is subjected to large vertical loads and other reasons. When column members are partial damaged, a progressive collapse accident is likely to happen in the entire structure of RC frame structure.

The ways to prevent a progressive collapse of structure are a local enhancement act, a joint strength way and a tie force method [2] and so on. A joint strength way requires the lower part of a beam at the beam-column joints should be reinforced through the whole arrangement. However, the actual construction of the point of the premises is often lapped, can provide scant joint strength. Even if reinforced is arranged through the whole part, due to the lack of rebar, it can’t guarantee the ability of anti-structure progressive collapse.

A FRP bar is, by the multi-strand continuous fibers and resin glued and then through special molding process extrusion and drawing a linear elastic reinforcement [3]. Based on the different fibrous material, they are divided into different GFRP (glass fiber), CFRP (carbon fiber), AFRP (aramid fiber), where the highest intensity of CFRP bar is up to 5-10 times of rebar strength [4]. And it also has an advantageous feature of a light weight, a corrosion resistance and so on. It has been successfully applied to an engineering practice at home and abroad. It is recommended a CFRP bar is arranged through beam-column joints for reinforcing structures against progressive collapse in the article. At the same time, it can effectively solve the problem that the beam-column joint of the lower reinforcement isn’t the whole arrangement. It can reach an effect of a small section of material providing a greater connection force, avoiding the waste of large section reinforced materials and difficulty of construction. A FRP bar arrangement ,see Fig.1, the left is the common beam section and the right is reinforcement beam section, FRP bar embedded into the beam before concrete pouring. The style of the arrangement will guarantee the early stage of the beam damage has a ductile phase, like the common beam damage and will prevent the suddenly brittle failure of the reinforced beam. It doesn't use the whole reinforcement as the FRP bars because there is no yield limit of FRP tendons, it will lead to suddenly brittle failure damage is happened when the beam is damage and it is not conducive to escape in advance.

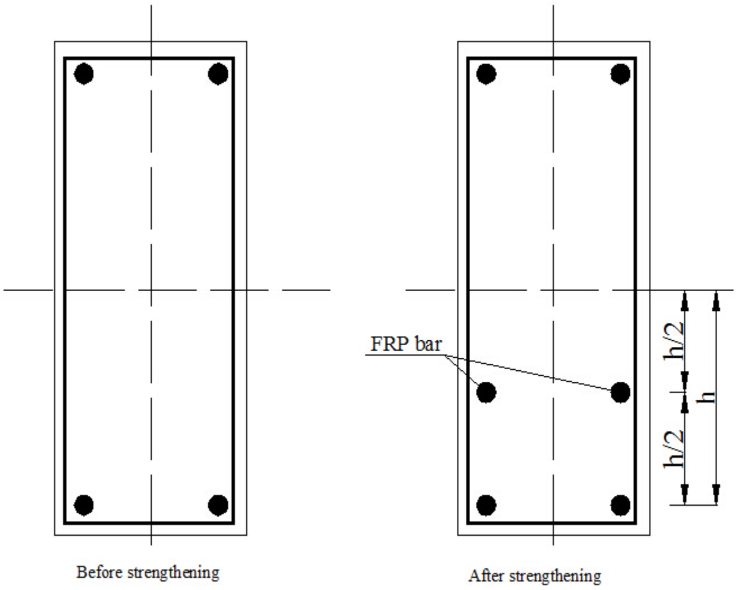

Fig.1 The location of the FRP bar.

2. Analysis methods of a progressive collapse

A structure progressive collapse is a complex nonlinear dynamic process [5], now the most widely used methods of analysis is a transformed load path method, namely an AP way. According to whether nonlinear and dynamic characteristics are considered or not, AP methods [6,7] is mainly divided into a linear static, a linear dynamic calculation, a calculation of nonlinear static and a nonlinear dynamic calculation.

A linear static calculation is the easiest and the most efficient method of analysis, but it doesn’t consider the material nonlinearity. By introducing a dynamic factor in consideration of dynamic characteristics, it doesn’t apply to the analysis of a complex and large-scale structure and the result is relatively conservative [8].

A linear dynamic analysis method is also known as the equivalent load transient uninstall method, which can consider dynamic effects, an inertial force and a damping factor and so on. But it doesn’t consider material nonlinearity, of whose subjects in the study confined to small plastic deformation. It isn’t recommended to use this method[9] in foreign specifications.

A nonlinear static way is a static pushover method, referred to as PUSH-OVER method. It is mainly used for analysis of horizontal seismic action. This method takes nonlinear material into account, but it doesn’t directly consider dynamic characteristics, instead of introducing a dynamic amplification factor.

A nonlinear dynamic calculation is the most reasonable method of simulating a structure of progressive collapse[10]. This method takes both dynamic characteristics of a structure and nonlinear characteristic of the material into account. It is consistent with the actual situation and the result is of high precision, but the calculation is complex [11]. By comparison of the advantages and disadvantages of the above methods, it is taken a nonlinear dynamic analysis SAP2000 in this paper.

3. Design of the model

3.1 Design parameters

Total information: Reinforced concrete frame, five floors, is the type of this structure. The floor height is 3.3m, horizontal column spacing is 4.0m × 5.4m, longitudinal column spacing is 6.0m × 3.0m. Respectively, 0.2m ×0.5m and 0.4m ×0.4m is the size of the beam and column. The thickness of floor plate is 0.1 m except the roof, 0.12m. Basic wind pressure is 0.35 KN/m2, ground roughness is class C, seismic intensity is 6 degrees and earthquake acceleration is 0.05 g.

Material information: The concrete strength is C30. Respectively, Steel grade of the longitudinal reinforcement and stirrups for beams and columns is HRB400 and HPB300. FRP reinforced using CFRP bar, ultimate tensile strength is 2500 Mpa, theoretical yield strength coefficient is 0.75[12].The contrast mechanical properties of CFRP bar andrebar, see Table 1.

Table 1 Comparison of performance among FRP bar and rebar

Parameters	Rebar	CFRP bar
Density (g/cm^3)	7.85	1.5~1.6
Limit of tensile strength (Mpa)	490~700	600~3700
Yield strength (Mpa)	280~420	/
The tensile elastic modulus (Gpa)	210	120~580
Elongation limit (%)	>10	0.5~1.0
Longitudinal thermal expansion coefficient(10^{-6}/%)	11.7	0.6~1.0
Transverse thermal expansion coefficient (10^{-6}/%)	11.7	25.0
The stress relaxation rate	/	1.0~3.0

3.2 Model building

First of all, design a reinforced concrete frame structure, five floors, according to our current standard. Calculate the reinforcement parameters and the size of beams and columns. And then, establish the finite element model by using SAP2000 and nonlinear dynamic analysis. The analysis model, see Fig. 2.

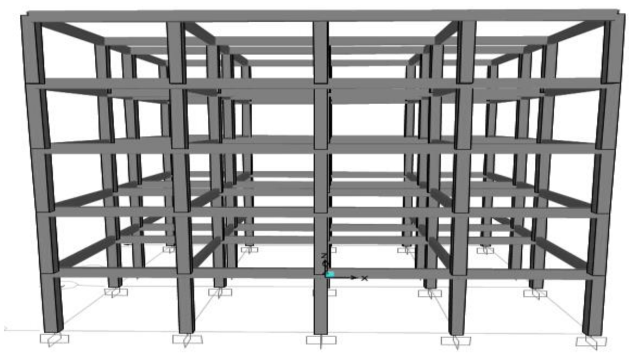

Fig. 2 The analysis model

3.3 The location of the removed component

This paper adopts the method for removing component recommended by GSA2003 specification [13]. The location of removed component is short side column, long side column and inside column, as is shown in Fig. 3. Because the bottom longitudinal reinforcement of corner post is not connecting, so this paper would not analysis the situation of removed corner post.

3.4 Failure criteria

DCR (Demand-Capacity Ration) can used as the standard for judging whether the component is damaged when carry on the linear elastic static analysis of reinforced concrete structures, advised by GSA2003 specification [13]. Plastic hinge can be used as the standard in the nonlinear analysis. when the plastic hinge is greater than 6°, the top point displacement value of removed column is greater than 1/10 of the beam span, that mean component damage happened. Nonlinear problems are considered by inserting the plastic hinge in SAP2000. The collapse trend of structure will not stop when the plastic hinge damage occurs, the top point displacement value of removed column will constantly increase. In this paper, the value of displacement and plastic hinge are both used as standard. Because the axial force of beam is small. So, the custom M3 plastic hinge is used to instead of the default M3 plastic hinge, which is mainly used in seismic effect analysis and the allowable principles of this plastic hinge is not accord with the requirement of progressive collapse analysis.

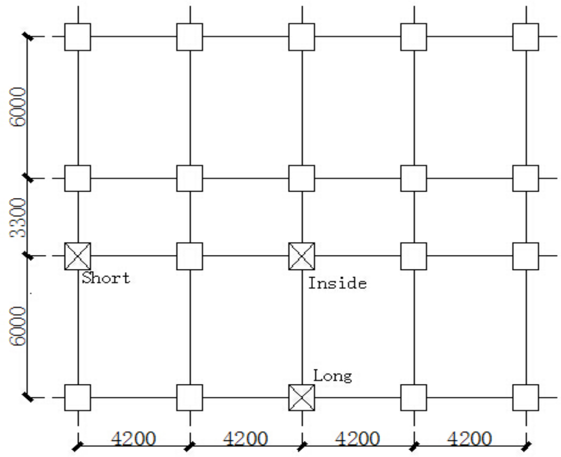

Fig. 3 The location of the removed column

4. Nonlinear dynamic analysis

4.1 Analyticalprocedure

The simulation of component's failure is divided into two steps: first, establish the complete structure model to nonlinear analysis, calculate the top point axial force F of failure column and reverse apply the axial force F on the top point of failure column after dismantle the component, and then conduct nonlinear analysis to simulate the initial state time of component failure; After that, load a ramp P along the gravity direction on the top point of failure column, as shown in Fig.4, to conduct nonlinear dynamic analysis. In the figure, t_0 is failure time of component and preferable for 1/10 of the remaining structure's fundamental period.

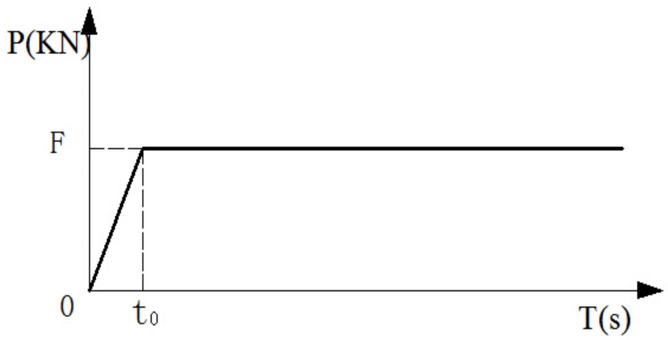

Fig.4 The slope load diagram

4.2 The failure of middle column on short edge

Supposing the column on short edge has a sudden failure and according to the analysis in front steps of nonlinear dynamic analysis, the axial force on the top point of failure column is 993KN, the top point displacement curves of failure column,see Fig. 5. We can see, the displacement curve of the failure column was a decline curve without horizontal part when the structure was without FRP reinforcement. Which indicate the collapse trend of structure did not stop after column was failure, so the structure collapsed. We can find that the top point displacement value decreases obviously with the increase diameter of FRP bar by comparing each displacement curve. At the time of 0.8 second, the top point displacement of failure column, after reinforcement, decrease amplitude were 41% (D16), 44% (D20), 48% (D25), 62% (D16-16). This indicated that FRP reinforcement can effectively enhance the ability to resist progressive collapse. The top point displacement curve of failure column has a significant horizontal level after 0.4 second when structure had FRP, diameter is 16, reinforcement both in bottom and top floor. This indicated that the structure is not collapse and the method of reinforcement can achieve good effect of prevention progressive collapse.

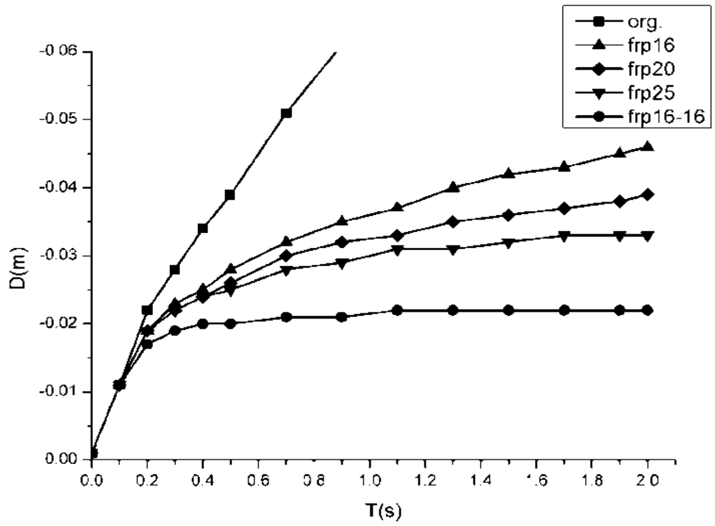

Fig.5 Displacement at the top of short side column

4.3 The failure of middle column on long edge

As summing that the middle column on long edge of structure has sudden failure, failure column's top point displacement curve, see Fig. 6. We can see, the displacement curve, without FRP reinforcement, has an obviously trend to decline without horizontal part. Structure collapsed. The displacement of failure column's top point decrease obviously when the bottom had FRP reinforcement. The middle column on long edge is complete failure at the time of 0.2 seconds and the top point displacements of failure column have little change at this time, but the displacement is increase continuously after this. At the time of 0.8 seconds, the top point displacements of failure column, structure without FRP reinforcement, is 178mm. Respectively, the displacement of structure with FRP reinforcement are 126mm (D16), 118mm (D20), 111mm (D25),53mm (D25-25) and displacement reduced amplitude are 29%, 33%, 37% and 70%. Because the spacing of middle columns on long side is big, displacement curve has no horizontal segment only with the bottom reinforcement, so structure collapsed. The displacement curve of failure column has obvious horizontal section and structure has not collapse when the bottom and top floor have FRP reinforcement with diameter of 25 at the same time. The figure shows that time cost to structure which has not reinforcement is 0.9 seconds but the reinforced is 1.5 seconds when displacement reach 200 mm. The time cost to structure collapsing is significantly delay after reinforcement, delaying rate reached 66%, which strive more time for people to escape.

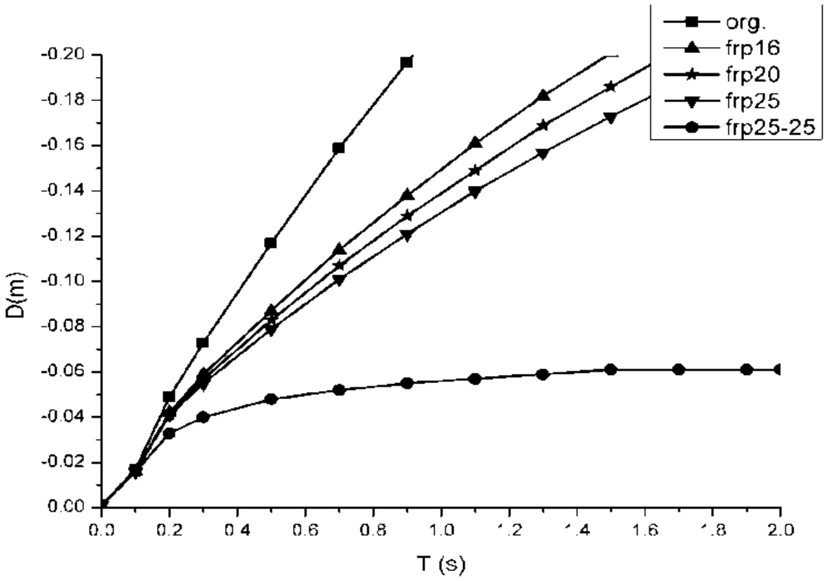

Fig.6 Displacement at the top of long side column

4.4 The failure of middle column inside the structure

As summing that the inside column of the structure is suddenly failure, the top point displacement curve of failure column, see Fig.7. We can see the failure of inside column will lead to the structure, which is not reinforcement, collapse. The top point displacement value of failure column is obviously decrease when FRP reinforcement both in longitudinal and transverse area. The displacement curve is a horizontal line after 0.4 seconds, maximum displacement is 30 mm, that mean this structure has not collapsed when use a diameter of 16 FRP bar reinforcement both in the bottom and top floor.

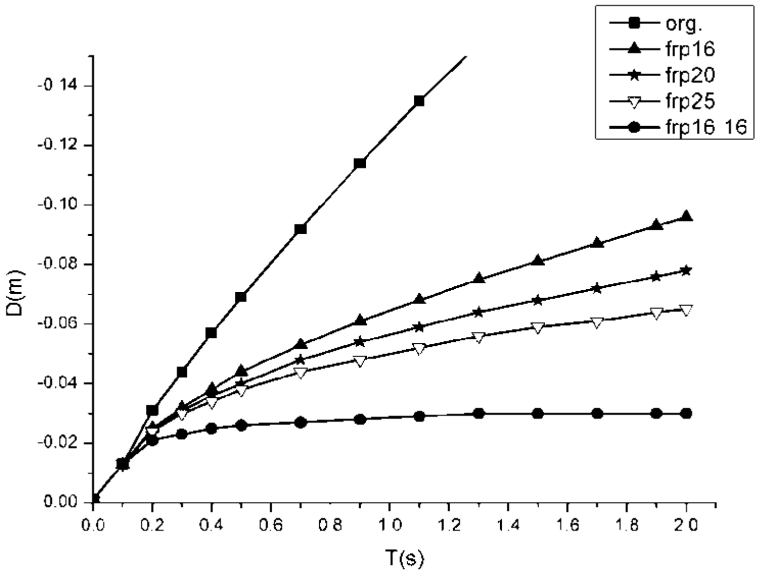

Fig.7 Displacement at the top of inside column

5. Conclusions

The reinforcement method of this paper can effectively reduce the top point displacement of failure column, can enhance the ability to resist progressive collapse for reinforced concrete frames, can delay the collapse time of structure that will increasing the probability to people's escape. It is an effectively method to prevent the progressive collapse that strengthening structure both in bottom and top floor. The relationship between the ability to resist progressive collapse and the diameter size of FRP reinforcement bar was positively proportional.

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