The Analysis on Frp Rebar Enhance the Ability to Resist Progressive Collapse for Reinforced Concrete Frames

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Abstract

This paper suggested a new type of FRP reinforcement measures to enhance the ability to resist progressive collapse for the structure Used SAP2000 to make nonlinear time history analysis between a five layer reinforced concrete frame structure with FRP reinforced and a same one but non-FRP reinforced. Studied the resistance to progressive collapse before and after reinforcement. The result showed that the structure with FRP reinforced can effectively enhance the capacity of resisting progressive collapse. The percentage of structural collapse is 0 after reinforcement. Also found that the vertex speed - time curve of invalid column divided into four stages: speed exploding stage, shock stage, slowly decreasing stage and increasing dramatically stage, this provided a new thought for practical applications.

Keywords

FRP Bar, Progressive, Collapse, Reinforced Concrete, Frame Structure, Invalid Column.

1. Introduction

The initial local damage of the structure led to the occurrence of chain reaction between components and eventually led to the collapse of the whole structure or occured disproportionate large range collapse which compared with the initial local failure in the structure ,this phenomenon was known as progressive collapse[1].Progressive collapse of buildings was a fast, complex and destructive process.When a continuous collapse happened, there was not enough time to escape, the accident will cause a lot of casualties and economic losses. For a long time, there had been frequent accidents at home and abroad,like the car bomb attacked the federal government Oklahoma office building which caused collapse accidents,the 911 terrorist attacks on the World Trade Center led to progressive collapse accident, the conflagration of Hengzhou edifice caused collapse accident in Hengyang etc.. The structural collapse accident was very dangerous,had become a serious threat to public safety. When the frame column was partially damaged, the whole structure was prone to collapse,due to the dispersive distribution of the frame column in the reinforced concrete structure and the single column was subjected to the vertical load.

However, many scholars at home and abroad had proved that the buildings designed according to the current codes did not meet the requirements of the progressive collapse resistance[2]. The basic reason for the continuous collapse of the structure was that the failure of the structural local supporting member leads to the vertical force greater than the structural resistance.The purpose of structural collapse resistance design was to enhance the structural resistance through a variety of measure.

The existing research results proposed two theories of structural resistance which known as beam mechanism [3] and catenary effect mechanism [4].The beam mechanism was that the structure provide resistance depend on the deformation compatibility of of beam . Catenary effect mechanism is that the reinforcement in beam and floor of each layer above the damage site just liked a few chains hanging in the sky which hold the floor above failure site,and prevented continuous damage caused by floor collapse. Due to the effect of the catenary mechanism,frame beam concrete damaged,the

vertical displacement of structural failure column increases significantly ,the structural progressive collapse resistance only depended on the longitudinal reinforcement of the frame beam ,the reinforcement would occur tensile yield rapidly.Therefore, it is difficult to reinforce the structure at this stage .The beam mechanism can provide continuous collapse resistance depend on the deformation compatibility of beam,so it is necessary to consider the corresponding reinforcement measures to increase the resistance of the beam at this stage.

FRP bar is a kind of linear elastic material which is made of multi strand continuous fiber and resin and formed by the extrusion and drawing .It has the advantages of high strength, light weight, corrosion resistance, etc.Therefore, this paper takes a five story reinforced concrete frame structure as the object ,proposes a new reinforcement beam that enhance the ability of resisting progressive collapse of structures , studies the performance of the reinforcement and the change of vertex displacement and velocity of the failure column.

2. Analysis Model Design

2.1 FRP Beam Design

This paper was suggested that the FRP bars should be through layout in the beam column joints in order to enhance the ability to resist progressive collapse .At the same time,it can effectively solve the problem that the lower reinforcement were discontinuous in the beam column joints and achieve the effect that the small cross section material can provide greater force,it also can avoid material waste and construction difficulties by using large section reinforcement. FRP reinforcement arrangement as shown in figure 1.

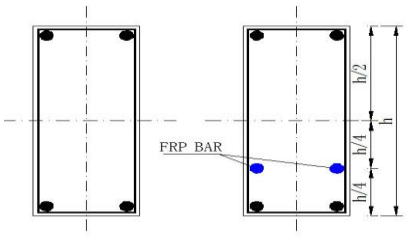

Fig. 1 Location of FRP bars

2.2 Progressive Collapse Analysis Method

The progressive collapse of structures is a complex nonlinear dynamic process [6]. Nonlinear dynamic analysis method is the most reasonable analysis method at present[7]. This method takes into account both the dynamic characteristics of the structure and the nonlinear characteristics of the material,which is in good agreement with the actual situation,and its calculation results are high-precision.In this paper, SAP2000 is used for nonlinear dynamic analysis of structures.

2.3 Site Selection of Removed Components

This paper adopted norm GSA2003[9] which suggested the demolition component method, the demolition site selection were column of short side,internal stele ,corner column and column of long side.The lower beam reinforcement of corner column were discontinuous ,so this paper did not carry out the progressive collapse analysis of corner column,the location of the removed component is shown in figure 2.

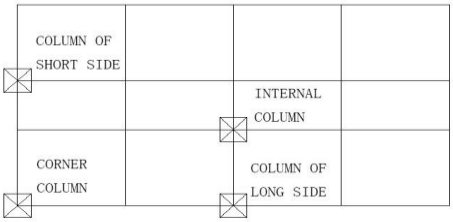

Fig. 2 Site selection of removing components

2.4 Failure Criteria

This paper adopted the criterion suggested by DOD2005 that the displacement of failure column is more than 10% of the beam span.In other words, the criterion is the plastic angle of the beam end is more than 6 degrees.At the same time,flat phase in the displacement time curve of the failure column vertex is used as an auxiliary criterion.

2.5 Unreinforced Structural Model

According to the current national standard, the analysis model chooses the five story reinforced concrete frame structure which is not reinforced with FRP bars. According to the current national standard, the analysis model chooses the five story reinforced concrete frame structure which is not reinforced with FRP bars.

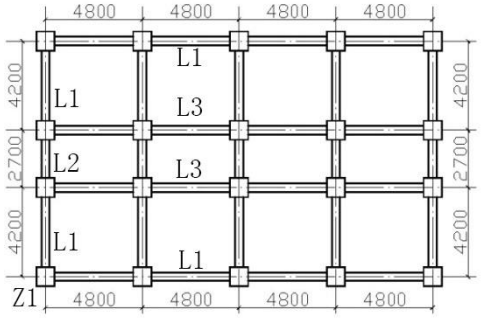

Fig. 3 Plain layout of structure

Using the PKPM structure analysis software compiled by China Academy of Building Research, the frame beam size of five story reinforced concrete frame structure is 200mm * 500mm, and the frame column size is 400mm * 400mm. The cross section of frame beam and frame column is shown in figure 4.

2.6 Reinforced Structure Model

The analyticcal model is consistent with the unreinforced structural model, but the FRP beam is used to reinforce the frame beam,The reinforcement method of beam section is shown in Figure 1 . Among them, the diameter of FRP bars is 20mm, and the reinforcement method is that all the frame beams are strengthened.

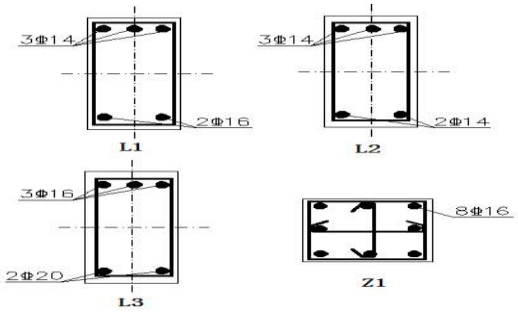

Fig. 4 Reinforcement of frame column and beam

3. Comparison of Analysis Results

Adopting demolition component method for the nonlinear time history analysis of syntactic model ,removing the column of short side,Internal stele ,corner column and column of long side of each layer respectively.

3.1 Comparison Of Failure Column Peak Speed

The time consumed in the process of structural collapse is an important reference factor to evaluate the capability of resisting progressive collapse,has respect to the severity of the consequences of the continuous collapse.The longer the process of collapse,the longer the escape time, the smaller the casualties caused by the accident. The peak velocity of failure column can show the change of the

speed of failure location with time, and how much time is consumed in the process of collapse. So it can assess the resistance to progressive collapse of structures.

Assuming the column of short side,internal stele ,corner column and column of long side of each layer are invalid respectively.The velocity time curve of the invalid column vertex of the unreinforced and reinforced structure was shown in figure 5 and figure 6.The column of short side in first floor was abbreviated to "coss1",and so on.

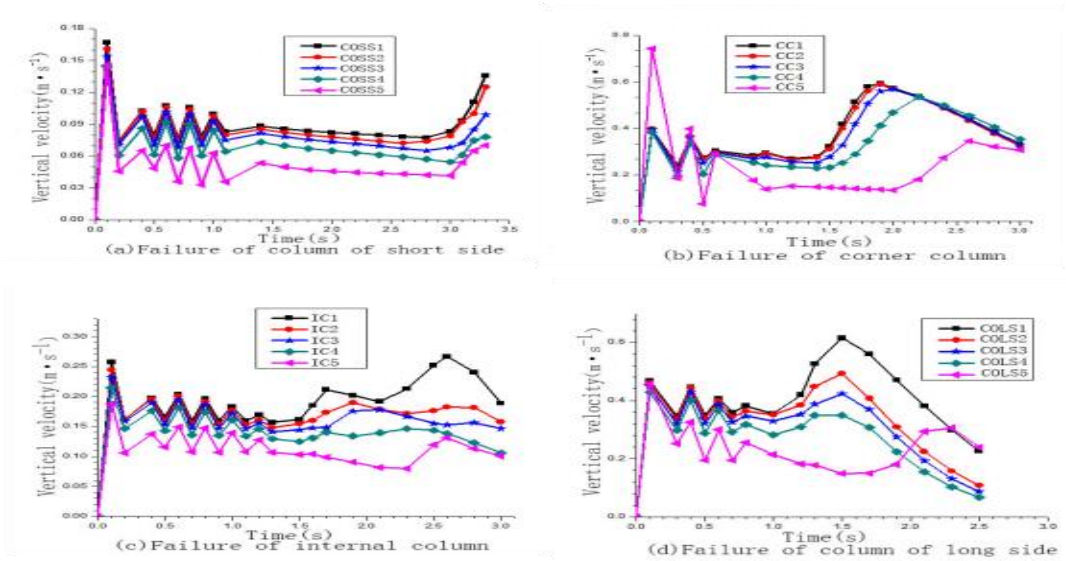

Fig. 5 Velocity-time curve of invalid column of unreinforced structure

It could be found from figure 5 that when various layers of failure column of the analysis model had damaged,The velocity and time variation law of the invalid column was similar .The velocity time curve of the failure column of each layer underwent four stages: the uprush of vertex velocity; shock stage; gentle decrease of apex velocity; uprush of vertex velocity. The first stage occurred in t=0.0~0.1s, the load gradually increased, reaching the maximum value at t=0.1s, which the failure column appeared to fail at the moment , so a sudden increase in vertex velocity occurred.The second stage occurred in t=0.1~1.3s,in this stage, the failure column appeared to be failure and suddenly quit, frame beam of failure position showed the phenomenon of elastic deformation in the sudden loss of the bottom vertical support, thus it showed the shock of the peak velocity. According to their different properties of frame beams, the duration of this phase was different. The third stage occurred in t=1.3~2.9s.Elastic shock stage of upper frame beam stopped.The peak velocity decreased gradually due to the resistance of the frame beam.The fourth stage occurred in t=3.0s ,at this stage, the self resistance of the frame beam reached the limit ,which led to structural collapse, showing a dramatic increase in the rate of vertex.

It could be found from figure 6 that the vertex speed - time curve of each invalid frame column was close to the the zero position of longitudinal axis.It showed that the growth of vertical displacement of the failure column vertex is small after the moment,and the displacement-time curve appeared the flat phase.This meaned that the structure does not collapse.It also could be found from Figure 6 that the vertex speed - time curve of each invalid frame column presented three stages: spurt of vertex speed , stage of shock , and the phase that the rate of vertex vertex velocity tends to zero .The first stage occurred in t=0.0~0.1s, in this stage the invalid frame column losed effectiveness gradually, was complete failure at time t=0.1s; the second stage occurred in t=0.2~1.5s,the duration of upper frame beam was different because of their different attributes; the third stage occurs after t=1.5s,the resistance of upper frame beam increased after reinforcement, could withstand the vertical loads without damage, so the ertical velocity of vertex gradually tended to zero.

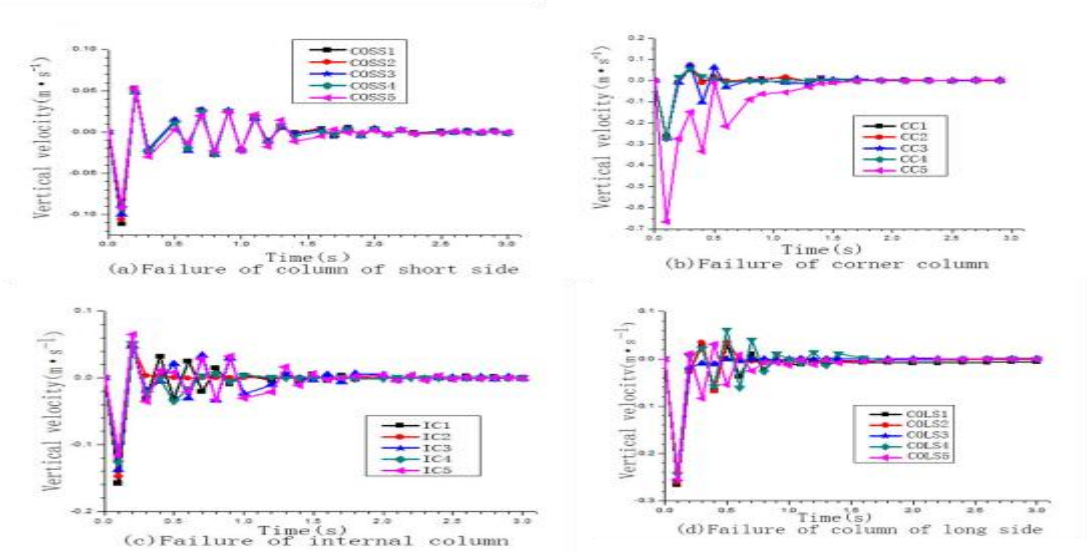

Fig. 6 Velocity-time curve of invalid column of reinforced structure

3.2 Comparison of Displacement of the Invalid Column

The collapse of the structure was judged by comparing whether the value of vertical displacement of the invalid column exceeds the 1/10 of the span of the upper frame beam. Assuming that the column of short side,Internal stele ,corner column and column of long side of two model losed effectiveness Individually,the comparison of the vertical displacements of the columns in each layer was shown in Figure 7.It could be found from Figure 7 that when the quasi invalid frame column damaged,the vertex displacement of each invalid position of the strengthened structure was obviously smaller than the unreinforced one;and the displacement-time curve of the strengthened structures appeared flat phase,the displacement-time curve of the unreinforced structure was oblique increasing curve, which indicated that the invalid location of the reinforcement structure were not collapse, every invalid site of unreinforced structure occurred collapse. In the two analytical models,In the two analysis model, vertical displacement of different invalid site from big to small in order:column of Long side,corner column, internal column ,column of short side.The column of short side of the unreinforced model in first floor was abbreviated to “ucoss1”,and so on.

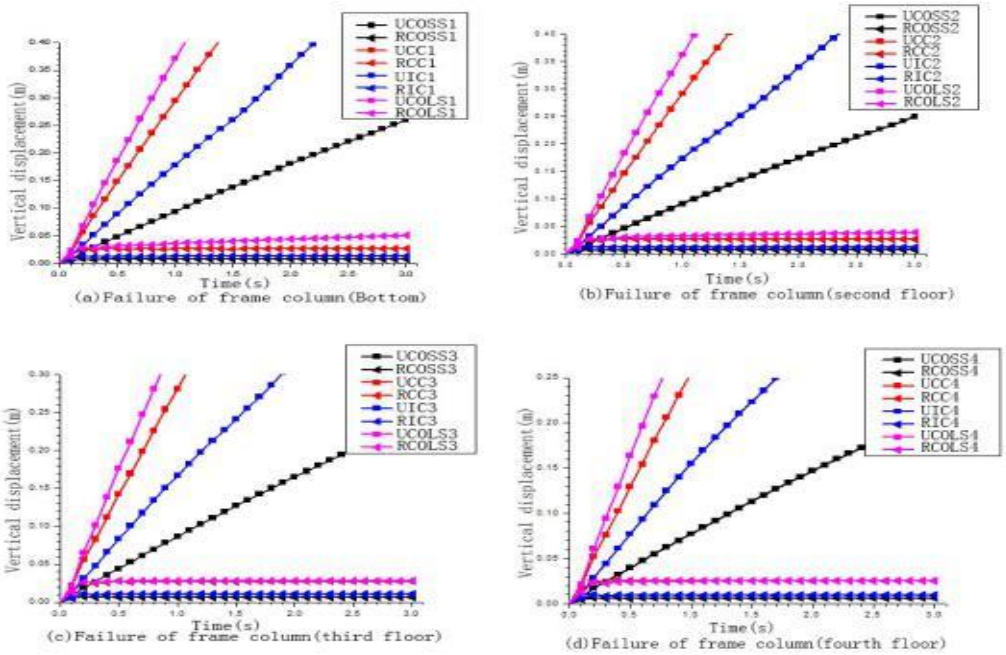

Fig. 7 Comparison of vertex displacement of invalid column

3.3 Comparison of Structural Collapse

The collapse of the structure was judged by comparing whether the value of vertical displacement of the invalid column reaches the limit of displacement specified by the component failure criterion.Assuming that the column of short side,Internal stele ,corner column and column of long side of two model losed effectiveness Individually,the nonlinear time history analysis of the reinforced structure model and the reinforced one was carried out by using SAP2000 finite element software .Then the vertex vertical displacement of invalid column cound be calculated ,which compared with the displacement limit specified by the criterion would analyze the situation of structural collapse .These was shown in table 1.

As could be seen from table 1, all the invalid parts of the unreinforced structure collapsed, and the invalid parts of the reinforced structures did not collapse.The analysis shows that the reinforcement of the whole frame beam of the structural model can be effectively enhanced by using the FRP bar with diameter of 20mm, which can effectively enhance the ability of resisting progressive collapse of the structure.

Table 1. Situation of structural collapse

Situation of Reinforcement	Site of removed components	Bottom	First floor	Second floor	Fourth floor
Unreinforced structural model	column of short side	collapse	collapse	collapse	collapse
	corner column	collapse	collapse	collapse	collapse
	column of long side	collapse	collapse	collapse	collapse
	internal column	collapse	collapse	collapse	collapse
Reinforced structural model	column of short side	No-collapse	No-collapse	No-collapse	No-collapse
	corner column	No-collapse	No-collapse	No-collapse	No-collapse
	column of long side	No-collapse	No-collapse	No-collapse	No-collapse
	internal column	No-collapse	No-collapse	No-collapse	No-collapse

4. Conclusions and Expectations

This paper described the the quasi analytical method and process firstly,then introduced the reinforcement method of FRP bar and the criterion for the adoption ,and then carried out the static and nonlinear time history analysis for the model,assessed the resistance to progressive collapse of unreinforced structures,and analyzed the continuous collapse capacity of the reinforced structure .Finally, the comparative analysis of the capacity of the continuous collapse of the unreinforced and reinforced structures was carried out.The main conclusions are as follows:

The reinforcement of the structure with the diameter of 20mm FRP could effectively enhance the ability of resisting progressive collapse of the structure,and the percentage of non collapse of reinforced structure was 100%,The best effect of reinforcement was internal column.

The sequence of time of the collapse of the unreinforced structure was : column of long side,corner column, internal column ,column of short side.

(3)The velocity time curve of the invalid column underwent four stages: the uprush of vertex velocity; shock stage ; gentle decrease of apex velocity; uprush of vertex velocity.If the structure did not collapse, the fourth stage would not appear,only show the first three stages.

(4)On the same floor,the value of vertical displacement of the invalid column from large to small was as follows:column of long side ,corner column, internal column ,column of short side. In the case of the same invalid site, vertical displacement of the invalid column decreased with the rise of the floor.

(5)The reinforced concrete structures strengthened with FRP bars had good theoretical effect on resisting progressive collapse, which provided a good way for practical application and had a good prospect in the study of continuous collapse resistance.

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