Research on the Phenomenon of Shear Force Over Limit in the Upper Shear Wall of Frame Supported Beam

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Abstract. With the development of high-rise buildings, part of the frame structure is usually used to support the upper reinforced concrete shear wall, in order to form a large space. Thus a framed shear wall structure is formed. The shear force design value of the shear wall which is on top of the frame supported beam often exceeds limit value that a shear wall can bear during the construction design process. This does not meet the requirements of the current national code. A high-rise building with transfer story in 7 degree earthquake area is taken as an example to analyze the reason of shear wall over limit by using structural design software PKPM in this paper. Through numerical simulation analysis, it is concluded that the main reason for the shear force over limit is that the increase of constant load, which results in the increase of relative deformation of the frame supported beam and the shear wall, as well as the axial force of the coupling beam. Specific measures to reduce the shear force over limit are proposed by using a finite element analysis software MIDAS, which provides references for a structural engineer to carry out the design.

Keywords: Frame supported beam; shear wall; shear force over limit; finite element simulation.

1. Introduction

With the improvement of people's living standards and continuous progress of building technology, high-rise buildings gradually develop towards comprehensive direction of complex shape and diverse functions. For example, more and more real estate developers put forward the "Integration of Commerce and Housing" mode, with the upper floor for housing and the lower floor for shopping malls, catering and entertainment facilities. Some office buildings or hotels also require the lower part of the building to have as much free and flexible space as possible. This requires that the column grid at the bottom of the building should be large, and some vertical members, such as shear walls, frame columns, can not fall to the ground, so that framed shear wall structures are widely used in high-rise buildings.

Jinxuan Huang, Jian Cai [1] set up a frame supported shear wall structure model with weak connection slabs to carry out earthquake platform test, and discussed the dynamic characteristics, failure mode and other contents of the test model. The test results show that the displacement angle of the model basically meets the requirements of the code. It is suggested that the strength and ductility of the connection between the weak connecting slabs and the substructure on both sides of the corridor should
be strengthened properly, and the structural response under the velocity pulse earthquake should be investigated. Lei Chang and Yun Liao [2] proposed a orthogonal double section design method based on the stress and deformation mode of a frame supported shear wall, and verified the method through a calculation example to solve the problem that the current design process of the frame supported shear wall section is inconsistent with the actual stress and deformation mode. Li Rao [3] uses SATWE module of PKPM software to study the seismic performance of buildings from the determination of key nodes of shear wall transfer structure, storey displacement, displacement angle and storey shear. The experimental results confirm the reliability of the theory. Anmin Hao [4] uses the finite element software ANSYS and ETABS to establish a typical framed shear wall model, and studies the influence of the coupling beam stiffness on the structural response. Through numerical simulation, it is concluded that with the reduction of coupling beam stiffness reduction coefficient, the overall stiffness and base shear force of the structure decrease, and the corresponding structural vibration period and structural lateral displacement increase.

Many structural engineers found that a shear wall above the frame supported beam is easily to exceed the shear force limit during the design process. That means the shear design value is greater than the maximum shear force that a shear wall can bear, which does not meet the requirements of the current national code JGJ3-2010 "Technical Code for Concrete Structures of Tall Buildings" [5] and national code GB50011-2010(2016 Edition) "Code for Seismic Design of Buildings" [6]. Simply increasing thickness of a shear wall will affect the function of buildings. However, the research on this kind of engineering problems has not been reported in literature. Therefore, it is valuable to analyze the reason of shear force over limit of frame supported shear wall for solving such engineering problems. The method of finite element analysis is used to explore the deep reasons in this paper. Specific solutions are proposed to provide reference for engineering designers.

2. Analysis of reasons of shear force over limit of frame supported shear wall

A ten story office building of framed shear wall structure is taken as an example for the analysis, which is located in 7-degree earthquake area, and the basic seismic acceleration is 0.15g. The maximum value of horizontal seismic influence coefficient under frequent earthquakes is 0.12. The site category is class II. The characteristic period value is 0.35s. The building plan is shown in Figure 1 and Figure 2. Column grid of the transfer layer has a spacing of 8m in X direction and 13m in Y direction. There are 9 floors in the upper part of the building. The thickness of the wall is 200mm, and the section size of frame beam is 900mmx1600mm.

![Figure 1. Plan of transfer floor](image1)

![Figure 2. Upper floor plan](image2)

A structural design software PKPM [7] is used to build the model. It is found that in the upper layer of the transfer floor, shear walls at both ends of the building exceeds the limit seriously, basically over 75% of the limit. In order to analyze the reason, the internal force of shear wall located at the end of the building is extracted from the software, the total shear design value of the wall and the shear design value of each working condition numbered by floor are listed and analyzed, as shown in Table 1. The
data in Table 1 is transformed into a curve with the shear design value as the abscissa and the floor number as the ordinate, which is shown in Figure 3.

**Table 1. Shear design value of shear wall under different working conditions/kN**

| Floor | Total shear force design value | X direction earthquake | Y direction earthquake | X direction Wind load | Y direction Wind load | Constant load | Live load |
|-------|--------------------------------|------------------------|------------------------|-----------------------|----------------------|---------------|-----------|
| 2     | 2517                           | 224                    | 640                    | 57                    | 252                  | 1235          | 218       |
| 3     | 1387                           | 81                     | 479                    | 7                     | 231                  | 527           | 108       |
| 4     | 839                            | -93                    | 405                    | 16                    | 191                  | 193           | 46        |
| 5     | 591                            | -98                    | 335                    | -21                   | 154                  | 82            | 22        |
| 6     | 468                            | -87                    | 227                    | -19                   | 120                  | 53            | 15        |
| 7     | 388                            | -70                    | 231                    | -13                   | 88                   | 45            | 14        |
| 8     | 314                            | -54                    | 186                    | -7                    | 54                   | 39            | 15        |
| 9     | 222                            | 38                     | 128                    | -1                    | 21                   | 33            | 15        |
| 10    | 123                            | 23                     | -61                    | 4                     | -7                   | 25            | 16        |

It can be seen from Figure 3 that the total shear design value has a sudden change in several layers above the frame supported beam, and the shear force increases rapidly. After comparing and analyzing curves of each working condition, it is found that the trend of the curve under the constant load working condition is similar to the trend of total shear design value, while the curve of other working conditions does not show a particularly obvious shear mutation. This shows that near the bottom of the building, the increase of constant load is the main reason for shear force over limit.

**Figure 3. Trend of shear design value under different working conditions/kN**

In order to carry out further analysis, the data of design value of axial force for the coupling beam is extracted, and the curve is drawn, see Table 2 and Figure 4 for details. It can be seen from Figure 4 that the trend of design value curve of axial force for coupling beam is similar to that of the shear wall, and there is also a sudden change in the floor above the frame supported beam. This shows that the sudden change of shear design value of shear wall is mainly caused by the increase of coupling beam axial force, that is, the increase of axial deformation.

Based on the above analysis, it can be concluded that the main reason for the shear force of the shear wall above the frame supported beam to exceed the limit, is that the frame supported beam will have a large vertical deformation with increase of constant load, and the shear wall supported by the beam will also have a large relative deformation at the same
The deformation will lead to a large axial deformation of the coupling beam which connects shear walls, and the axial force will be transferred to the wall again, which will be converted into shear force of the shear wall. After the combination of constant load and other working conditions, such as live load, seismic load and wind load, the shear design value of the wall is significantly increased, which results in shear force exceeding the limit.

Table 2. Design value of axial force for coupling beams of each floor under constant load

| Floor | Design value of axial force for coupling beam under constant load/kN |
|-------|---------------------------------------------------------------------|
| 2     | 289                                                                 |
| 3     | 156                                                                 |
| 4     | 62.7                                                                |
| 5     | 29.7                                                                |
| 6     | 20                                                                  |
| 7     | 16.8                                                                |
| 8     | 15.1                                                                |
| 9     | 13                                                                  |
| 10    | 17                                                                  |

Figure 4. Design value of axial force for coupling beam of each floor under constant load/kN

At the same time, it can be found that the structural design software PKPM uses a rod element to simulate the frame supported beam during the calculation process, which does not reflect that a frame supported beam is a deep beam, and the mechanical performance is quite different from a ordinary one. Under the action of load, the shear deformation caused by a transverse shear force in a deep beam will cause the additional deflection of the beam, as well as a warpage of the beam section, which makes the normal section strain of a deep beam no longer conform to the plane section assumption. On the other hand, due to the height of a frame supported beam is larger than that of a ordinary beam, a rigid zone with a certain height at the beam-column joint is formed, while a rod element does not fully consider the favorable influence of a rigid zone at the beam-column joint constrains deformation of the frame supported beam. Therefore, whether a finite element selection is reasonable or not will also affect the calculation results.

3. Suggestion to control shear force over limit

3.1. Change the rigidity of coupling beam

The influence of increasing or reducing the rigidity of coupling beam on shear force and axial force is studied by using finite element analysis software MIDAS. The section size of the second floor coupling beam is changed from 200mmx500mm to 400mmx900mm and 200mmx350. Values of the before and after adjustment are listed in Table 3.
It can be seen from Table 3 that shear force and the axial force on the second floor increase significantly after the section size of the coupling beam increases, shear force of shear wall increases by 22%, and the axial force of coupling beam increases by 53%. However, forces on the third floor are reduced by about 30%. When the section size of the coupling beam is reduced, the shear force and axial force of the components are reduced, and the reduction range of the axial force is more obvious. Shear force and axial force on the third floor are increased by about 10%. It is concluded that reducing the section size of coupling beam, that is to say, reducing its rigidity, has an obvious effect on reducing shear force and axial force, which can effectively reduce the shear force over limit.

**Table 3. Internal force changes of main members after the change of coupling beam rigidity/kN**

| Design value of internal force of the second and the third floor | Dimension of coupling beam | Difference after increasing section | Difference after section reduction |
|---------------------------------------------------------------|-----------------------------|-------------------------------------|----------------------------------|
|                                                               | 200x500                     | 400x900  200x350                     |                                   |
| Shear force of shear wall on the second floor                 | 1065                        | 1295  999  22%  -6%                 |
| Shear force of shear wall on the third floor                  | 475                         | 330  520  -31%  9%                  |
| Axial force of coupling beam on the second floor              | 626                         | 956  478  53%  -24%                 |
| Axial force of coupling beam on the third floor               | 359                         | 243  394  -32%  10%                 |

3.2. **Change the rigidity of the frame beam**

A finite element model is established to study the influence of increasing or reducing the rigidity of the frame beam on the shear force and axial force. The original section size of the frame beam is 900mmx1600mm, the increased section size is 900mmx2000mm, and the reduced section size is 600mmx1200mm.

**Table 4. Internal force changes of main members after change of frame supported beam rigidity/kN**

| Design value of internal force of the second and the third floor | Dimension of frame supported beam/mmxxmm | Difference after increasing section | Difference after section reduction |
|---------------------------------------------------------------|------------------------------------------|-------------------------------------|----------------------------------|
|                                                               | 900x1600  900x2000  600x1200               |                                    |
| Shear force of shear wall on the second floor                 | 1065  941  1141  -12%  7%                  |
| Shear force of shear wall on the third floor                  | 475  418  518  -12%  9%                   |
| Axial force of coupling beam on the second floor              | 626  522  622  -17%  -1%                  |
| Axial force of coupling beam on the third floor               | 359  314  389  -13%  8%                   |

It can be seen from Table 4 that shear force on the second and the third floor decreases by 12% and the axial force also decreases by 12% when the section size of frame supported beam is increased. When the section size is reduced, shear force on the second and the third floor increases by 10%. The reduction of axial force on second floor is small, which is only about 1%, and the third floor increases by 8%. It
can be concluded that increase of section size of frame supported beam can reduce relative deformation of the shear wall which supported by the beam, thus the shear design value and axial force are reduced.

3.3. Adjust the layout of components

Increase the span of frame supported beam from 13m to 18m, and make two shear walls set in the middle of frame supported beam, which is far away from frame column, other conditions remain unchanged.

| Table 5. Comparison of internal forces before and after the structural arrangement adjustment / kN |
|-----------------------------------------------|----------------|----------------|----------------|
| Design value of internal force of the second and the third floor | Before the adjustment | After the adjustment | Difference |
| Shear force of shear wall on the second floor | 1065 | 376 | -65% |
| Shear force of shear wall on the third floor | 475 | 196 | -59% |
| Axial force of coupling beam on the second floor | 626 | 106 | -83% |
| Axial force of coupling beam on the third floor | 359 | 55 | -85% |

It can be seen from Table 5 that after the span of the frame supported beam is increased and the position of the shear wall is changed, the internal force of the member changes obviously. The shear design value of the second and the third floor is reduced by about 60%, and axial force is reduced by about 80%. It is concluded that increasing the span of a frame supported beam, adjusting the structural arrangement of shear walls reasonably can solve the problem of shear force over limit.

4. Conclusion

Structural design software PKPM and finite element software MIDAS are used in this paper to carry out numerical simulation of high-rise buildings with frame supported beams, and the phenomenon of shear force over limit is studied. The conclusions are as follows:

1. The main reason for the shear force over limit is that the increase of constant load causes the relative deformation of the frame supported beam and shear wall to increase, and axial force transmitted by the coupling beam to the shear wall also increases.

2. Through repeated calculation, several effective measures to solve the problem of shear force over limit are put forward, such as reduce the rigidity of coupling beam, increase the section size of frame beam. In addition, by reasonably adjusting the structural arrangement, making the shear wall as close to the mid span of the frame supported beam as possible, increasing the span of the frame supported beam, the shear force over limit can be improved.

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