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Joints design of seismic strengthening reinforced concrete frame structure

Omary Kaheneko[a], Cheng Xuan Sheng[b],

[a]Masters Student School of Civil Engineering, Lanzhou University of Technology, Lanzhou-730050, China
[b]Professor School of Civil Engineering, Lanzhou University of Technology, Lanzhou-730050, China

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ABSTRACT:

Reinforced concrete frame structure is a common form of building structure, which is widely used in industrial and civil buildings. Because of the mechanical characteristics of the structure itself, its seismic performance is poor. Through strengthening technical measures and tapping material potential, it can be effectively improved. In view of the importance of joints in reinforced concrete frame structures, this paper puts forward the design references of reinforced concrete frame joints, probes into the mechanical mechanism of reinforced concrete frame joints, analyses the measures to improve the seismic performance of reinforced concrete frame joints and the key points of joint structure design to ensure the safety of structural design.

Key words: reinforced concrete; frame structure; joint design, seismic strengthening

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*E-mail address:*omarykaheneko@yahoo.com.

1. Introduction:

Frame structure is widely used in industrial and civil buildings because it can provide more spacious use of space and is conducive to the organization and segmentation of building functions. However, its lateral stiffness is weak, and large displacement is prone to occur under earthquake, which leads to serious damage to the structure, and it belongs to the disadvantageous anti-seismic structure. Frame structures are mainly used in multi-storey buildings with seismic fortification and high-rise buildings with few stories without considering seismic fortification. When there are seismic requirements, and the number of stories is large, or the height of the building is high, the frame-shear wall structure, shear wall structure, tube structure and other structural types are usually used. Reinforced concrete plays an important role. It can not only transfer and distribute internal forces, but also ensure the integrity of the structure. It is also an important part of connecting beams and columns. It plays the role of transmitting, distributing internal force and ensuring the integrity of the structure in the frame.

2. Mechanisms of reinforced concrete frame joints

The mechanical mechanism of reinforced concrete frame joints refers to the transfer of internal forces from beams, slabs and columns in the core area of frame joints and the various forms of failure resulting therefrom through reasonable calculation assumptions. Joints in a reinforced concrete moment resisting frame are crucial zones for transfer of loads effectively between the connecting elements (i.e., beams and columns) in the structure. In normal design practice for gravity loads, the design check for joints is not critical and hence not warranted. But, the failure of reinforced concrete frames during many earthquakes has demonstrated heavy distress due to shear in the joints that culminated in the collapse of the structure[1].

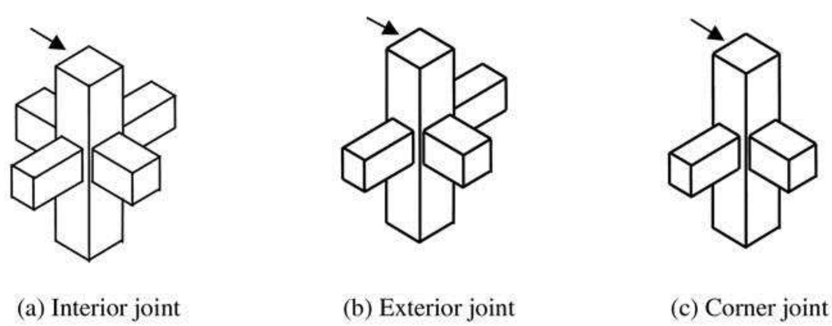

Figure 1: Types of joints in frame

Beam column joints are generally classified with respect to geometrical configuration and identified as interior, exterior and corner joints as shown in Fig. 1. Theoretical background on design of beam column joints has been reviewed in a number of publications[2].

3. Mechanical characteristics of reinforced concrete frame structures

The frame structure consists of a beam-column system that can withstand vertical and horizontal loads. Generally designed as a two-way beam-column anti-side force system, the main structure should adopt the rigid connection mode. In the seismic design, in order to coordinate deformation and rationally distribute internal forces, the frame structure should not be designed as a single-span structure. Under the vertical load, the frame structure takes the beam bending as the main force characteristic, and the beam end bending moment and the mid-span bending moment become the controlling internal force of the beam structure. Under the horizontal load, the frame column bears the horizontal shear force and the column end bending moment, and thus the horizontal side shift occurs. At the beam-column joint, the bending moment and the shear force are generated at the beam end due to the coordinated deformation. Therefore, the axial force, bending moment and shear force generated at the upper and lower end sections of the column are the control internal forces of the column. In multi-tall buildings, resistance to horizontal forces becomes a key issue in determining and designing structural systems. The structural systems commonly used in multi-tall buildings include frames, shear walls, frame shear walls, cylinders, and combined high-rise buildings with seismic and wind loads as the number and height of the building increase, the carrying capacity of high-rise buildings, seismic performance, The amount of materials used and the cost are closely related to the structural system used. Different structural systems for different layers, heights and functions[3].

4. Frame Joints Design Criteria

In reinforced concrete frame, the basic requirements of joint design are as follows:

- Joints should show the same service load characteristics as their adjacent members. The bearing capacity of joints should not be lower than that of their connecting members (strong joints, weak members).
- The longitudinal bars of beams and columns should be anchored reliably in the joint area (strong joints, strong anchorage);
- Joints should have enough strength to resist the internal forces of adjacent members under the most adverse load conditions, and enough safety factor to resist all kinds of occasional loads or loads not taken into account in design.
- In case of frequent earthquakes, the joint should be in the elastic range; in case of rare earthquakes, the bearing capacity of the joint may be reduced to a certain extent, but the transmission of vertical load must not be endangered.
- Under the condition of meeting the requirement of bearing capacity, the construction of joints should be as simple as possible, and the reinforcement of joints should not increase the construction difficulty excessively, so as to avoid affecting the construction effect.
- The ultimate strength design method can be used in the design of beam-column joints to make full use of materials.

5. Factors to be considered in the design of reinforced concrete frame joints

Under earthquake action, frame joints are subjected to large horizontal shear force, which makes the joints prone to shear brittle failure. Joint shear is considered to be transferred by both of compressive force in concrete strut formed between bent portion and beam compressive zone and tensile force generating in joint transverse reinforcement after concrete cracking[4]. Its failure characteristics are as follows: oblique cross cracks appear in concrete in the core area of the joint; bond cracks occur between concrete and column longitudinal reinforcement bars, and concrete protective layer peels off; longitudinal reinforced concrete buckling into a lantern shape, which eventually leads to failure of the core area of the joint, but also means failure of all beams and columns intersecting at the joint. The main factors affecting the shear strength of frame joints are as follows.

5.1 Material properties

The concrete strength directly affects the shear capacity of the frame joints. For frame joints subjected to a certain load, the higher the concrete strength, the smaller the section size of the beam and column, and the concrete shearing section of the core part of the frame joint is also reduced accordingly. However, under certain hoop ratio, the seismic performance is not good.

5.2 Axial compression ratio

Experimental studies have shown that axial pressure can increase the shear capacity of the concrete in the core of the frame joint within a certain range. Due to the axial pressure of the column, before the concrete is cracked in the core area of the frame joint, the area of the section of the column is increased, and the action of the bar is strengthened. When cracks occur in the concrete, a bite force is generated between the concrete blocks. As the axial compression ratio increases, the shear capacity increases correspondingly. However, when the axial compression ratio exceeds a certain critical value, the concrete in the compression zone of the frame joint produces micro-cracks, which crushes the concrete and reduces the shear bearing capacity.

5.3 Shear compression ratio

Increase of axial load ratio is favorable to energy dissipation capacity of joints with small shear, no significant effect is observed on the joints with moderate shear, and unfavorable effect is noticed on the joints with high shear, resulting in premature shear failure, that is, crush of the joint core concrete[5]. In order to prevent the core area of the frame joint from cable-stayed failure or diagonal compression failure, the shear compression ratio must be controlled to limit the stirrup ratio, so as to avoid the failure of the concrete in the core area of the frame joint prior to the yield of the stirrup.

5.4 Horizontal stirrups

It is beneficial to restrain the concrete in the core area of the frame joint and enhance the ability of transmitting the axial load. On the other hand, it bears part of the horizontal shear and improves the shear capacity of frame joints. The test results show that the shear bearing capacity of the core area of the frame joint with proper stirrups increases continuously after the through cracks appear, and the stirrups yield completely. The concrete and stirrups play a full role at the same time, so that the shear bearing capacity of the core area of the joint reaches the maximum at the time of failure. For the joints with high stirrups, when there are through diagonal cracks in the core area of the joint, the shear bearing capacity of the concrete reaches the extreme value, but the stress of the stirrup is still very low. The concrete failure precedes the yield of the stirrup, so that the shear bearing capacity of the core area of the joint does not reach the expected maximum value, and the role of the stirrup cannot be fully played[6].

5.5 Vertical stirrup

Under the action of horizontal repeated load, when the core concrete of the frame joint has cross diagonal cracks, the shear force transfer from the role of diagonal compression bar to the truss shear mechanism composed of the horizontal stirrup bearing the horizontal component, the column longitudinal reinforcement bearing the vertical component and the concrete aggregate biting force parallel to the diagonal cracks. The vertical stirrup can bear the vertical component of the Shear force of the frame joint. Reducing the burden of concrete can improve the shear capacity of frame joints, but the construction is not convenient.

5.6 Column longitudinal reinforcement

Generally, it is set according to the bending requirements, and along the height direction of the column section, a certain amount of longitudinal reinforcement is also configured according to the structural provisions. These longitudinal bars and horizontal stirrups combine to form a two-way constraint on the concrete in the core area of the frame joint. Therefore, reasonable arrangement of column longitudinal reinforcement can improve the shear capacity of frame joints, but increasing column longitudinal reinforcement can’t significantly improve the shear capacity of frame joints as increasing horizontal stirrups.

5.7 floor

The floor around the frame joint has a restraining effect on the core area of the joint, and the floor reinforcement parallel to the beam axis works at the same time with the stress reinforcement on the upper part of the beam. If considering the role of the slab as the beam flange in the bending process, the shear calculation value of the joint should be increased accordingly.

5.8 Design codes

Many countries have their own structural design codes, codes of practice or technical documents which perform a similar function. It is necessary for a designer to become familiar with local requirements or recommendations in regard to correct practice. In this chapter some examples are given, occasionally in a simplified form, in order to demonstrate procedures. They should not be assumed to apply to all areas or situations

6. Problems in the design process of the frame structure

- Two different structural types are not allowed in the frame structure.
  Floors, elevators, and rooms with partially protruding roofs are not allowed to bear the weight of brick walls. Because the frame structure is a flexible structural system, and the brick-concrete structure is a rigid structure. In order to coordinate the deformation of the structure, different structures should not be used for mixing forces.
- Strengthening the construction measures of short columns:
  During the construction process, the ceiling may have ceilings or other decoration. In order to save expenses, Party A often requires that the column-filled walls are not at the top or open the doors and windows at the walls, which often causes short columns. . Due to the high stiffness of the short column, the earthquake is subjected to shearing. When the shear strength of the concrete is insufficient, cross cracks and brittle fractures occur, which may cause damage or even collapse of the building or structure[7]. Therefore, the following measures should be taken in the design: try to weaken the floor constraints of the short columns, such as reducing the height of the connected beams, and using the hinges of the beams and columns; increasing the arrangement of the stirrups, the spacing of the stirrups should not exceed l00mm in the short column range. , the longitudinal steel bar spacing of the column is ≤150mm; use good stirrup type, such as spiral stirrup, composite spiral stirrup, double spiral stirrup, etc.
- Due to the needs of the building, it is sometimes necessary to pick the frame beam and place a reinforced concrete column under the beam[8].
  In the calculation of the internal force and reinforcement of the column, some designers have unclear the concept of the force. It is mistaken that the column is a structural column, and the reinforcement is structural reinforcement, and the cantilever beam is not calculated according to the calculation. The bearing capacity under the horizontal load is insufficient, which poses a hidden danger for the accident.

7. Key points of frame joints structure design

The concrete strength grade of the joint shall be the same or similar to that of the column as far as possible, so as to ensure the strength and ductility requirements of the joint. In the actual construction process, the difference between the concrete strength grade of the joint and the concrete strength grade of the column shall not be more than 5 MPa. Sufficient stirrups must be arranged in the joint, so as to play a sufficient constraint role on the concrete in the core area and make the concrete in multi-directional[9]. The favorable state of compression can improve its strength and deformation capacity, prevent the shear failure of concrete, and enhance the ductility of joints. During the seismic design, the reinforcement in the point shall not only meet the requirements of the calculated bearing capacity, but also meet the relevant structural requirements. The closed stirrup shall be used in the core area of the joint. During the seismic design, the end of the closed stirrup in the point shall have a 135 ° hook, and the straight length of the end of the hook is not the same. The stirrup diameter is less than 10 times to ensure that the reinforcement is firmly anchored. The longitudinal reinforcement in the column should be connected up and down within the node range, and the upper reinforcement of the beam should also be connected through the middle node. The reinforcement at the beam end and the column top should be set according to the corresponding structural requirements to ensure that its anchoring in the node is solid and reliable.

7.1 Calculation of strong column weak beam joint

According to the Chinese code for design of concrete structures of 2010, increasing the concrete strength grade can improve the shear bearing capacity of the core area of frame beam column joints when the beam column section remains unchanged. Therefore, the higher the concrete strength is, the smaller the section size of beam and column members and the core area of joints are. The cross section of concrete bearing shear force is also reduced correspondingly, which is not conducive to its earthquake resistance under the condition of certain stirrup ratio[10, 11].

When the lower strength concrete is used, the joint will be in the state of high average shear stress under the action of horizontal shear, which will lead to the premature occurrence of cracks in the joint area, resulting in concrete fragmentation. At the same time, the anchoring effect of the longitudinal reinforcement of the frame beam at the joint will also be affected. Under the action of horizontal shear, the bond force between the concrete at the joint and the longitudinal reinforcement of the frame beam will be degraded, and the longitudinal reinforcement and the concrete will be degraded. The relative movement affects the formation of the plastic hinge at the beam end, which is not conducive to the redistribution of internal force, and the design of strong column and weak beam can't meet the requirements[11].

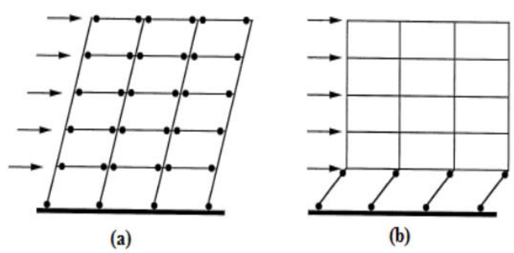

Figure 2: Mechanisms of Strong Column Weak Beam (a) and Weak Column Strong Beam (b)

According to seismic design philosophy, plastic hinging of columns is permitted only in the lower storey, while beam hinging is expected to occur at every storey level (Figure 2a). This type of mechanism allows for more rotation and uniform ductility demands in the structural components of the building, in contrast to "strong beam weak column" concept in which large ductility demands are likely to be concentrated in only a few structural components (Figure 2b)[12].

In general, the ductility of frame column is smaller than that of beam. Therefore, for the frame joints with seismic grade of I, II and the model paper, the design value of flexural bearing capacity of column end must be increased strictly according to the requirements of "strong column and weak beam", so that the flexural bearing capacity of column end is larger than that of beam end, so as to ensure that plastic hinge appears first on the beam, and prevent the first plastic hinge and then yield of frame column, leading to serious consequences.

7.2 Section design of frame joint

The investigation shows that there is a great relationship between the failure of the joint area of the frame and the sequence of the failure of the beam column at the joint, and the degree of the structure entering into the inelasticity is also different under the earthquake action of different intensity. In the seismic design, attention should be paid to ensure that the joint has certain strength reserve, and the section size of the joint and the strength grade of the concrete in the core area are important factors that directly affect the quality of the joint. At the same time, the beam to the joint has Obviously, when the four sides of the joint are constrained by beams, the concrete in the core area is in the state of multi-directional compression, and its strength is improved, which can improve the shear capacity of the joint[13]. These favorable factors should also be considered in the design.

7.3 Shear calculation of frame joints

The horizontal Shear force of the joint is usually borne by the concrete diagonal member and the stirrup. When the Non Seismic design and the four level seismic design are carried out, the joint can't carry out shear checking calculation, only need to configure the reinforcement according to the structural requirements. The test shows that in a certain range, with the increase of the axial force at the end of the column, the cross-sectional area of the concrete diagonal member increases correspondingly, but when the axial compression ratio increases to a certain extent, even if Therefore, in order to prevent the concrete collapse prior to the yield of the tensile steel bar and the shear failure of the column, the axial compression ratio of the column under the condition of large bias should be limited[14].

8. Conclusion

In summary, by analyzing the mechanical principle of reinforced concrete frame joints and improving the seismic performance of reinforced concrete frame joints and the analysis of joints design elements, we know that when designing reinforced concrete frame joints, we should integrate conceptual design and construction measures in order to ensure structural design safety and economy.

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