STUDY ON DAMAGE MECHANISM AND DESIGN METHOD OF R.C. ABNORMAL FRAME JOINTS IN THERMAL-POWER PLANT

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ABSTRACT:
The R.C. large-scale thermal power plants commonly contain abnormal joints. Based on the pseudo-static results of four 1/5-scale specimens and failure characteristic in the pseudo-dynamic structural test, the damage mechanism and the failure of abnormal joints under the shear force are analyzed. Two typical failure modes are presented: small core shear failure and the column shear failure. The factors affecting the shear failure mode of abnormal joints such as: axial compressive ratio, the stiffness ratio of big beam with small beam, stirrup ratio of small core and column etc. are present. According to experimental result, joints the diagonal loads very near to the yielding load and abnormal joints seismic behavior was poorer than normal joints, the formula for calculation of the shear-bearing capacity of abnormal joints are given. It is helpful for design the abnormal joints in the thermal power plants.
KEYWORDS: abnormal frame joints, seismic behavior, mechanism of failure, design proposition

1.INTRODUCTION

The design of beam-column joints is an important part of earthquake resistant design for reinforced concrete moment-resisting frame. The earthquake damages have shown that the reinforced concrete frame joints can became the weakest links in the chain of earthquake resistance. Many research of normal joints have been done in many researches of reinforced concrete frame past investigation (Tang J.R. (1989), T. Paulay and R. Park (1984)). In large-scale thermal power plants, to satisfy with the demand of craft, contained the abnormal joints that adjacent to joints changed column section and changed beam sections. To ensure the safety of the building, the abnormal joints seismic behavior and design methods was researched.

2.EXPERIMETAL RESULTS

The prototypes were design to satisfy the seismic requirements for 7 intensive zones in accordance with GBJ11-89, with design peak ground acceleration of 0.2g. Prototype with frame-bent in the longitudinal direction and frame-shear wall in the transverse direction. In the longitudinal direction of the structure, to satisfy with demand of craft, abruption in the column and beam cross-section formed abnormal joints. The detailed dimension and steel arrangement can refer to reference (Wu T., Bai G.L., and Liu B.Q.(2005)).

2.1 Test result of abnormal plane joints

The specimen of test, including four abnormal interior abnormal joints, is deduced from prototype, and the model ratio is 1/5. Dimension and steel arrengemnt of J-2shown in figure 1.The detail dimensions and reinforcement of specimens and test methods can refer to reference (Bai G.L., Zhu J.N. and Li H.X. (2003)). The design joints were intend to reveal the influence of the concrete compressive strength, the stiffness ratio of big beam with small beam, stirrup ratio of small core and column and axial compressive ratio on the resulting joints behaviours.

In test series, the top and bottom of the columns were supported by pin joints. The free ends of the beams were deflected laterally by the same amplitude, but in opposite direction. The specimens were subjected to reverse cyclic loading with increasing amplitudes to failure.

Most of specimens showed joint shear failure, a typical crack pattern shown in figure 2. The first crack occurred in the small core that composed with the upper column and the small beam. The diagonal crack was widely opened and spalling of concrete due to local crushing of concrete at the small core zone. Joints the diagonal loads very near to the yielding load. Although cracks on the beams were observed, the widths of the cracks on the beams were reminded small. Experimental result shown: small core zone was the weakest chain in the abnormal joints and abnormal joints seismic behaviour was poorly than normal joints. The main results of test are shown in table 1. Hysteretic loops of four specimens were shown in figure 3.

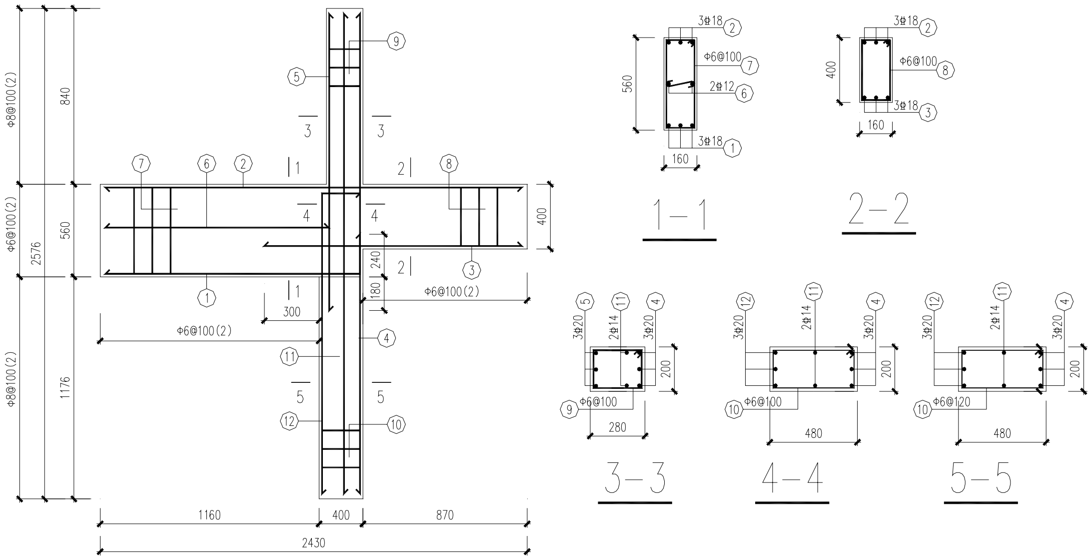
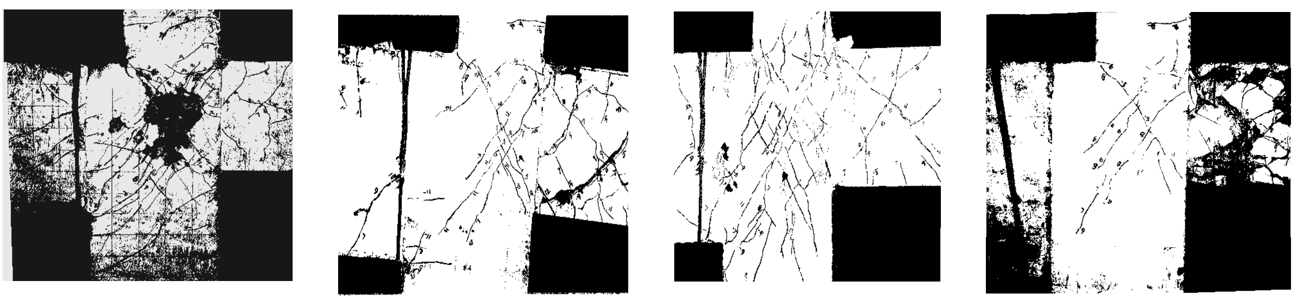


Figure1 Dimension and steel arrangement of J-2

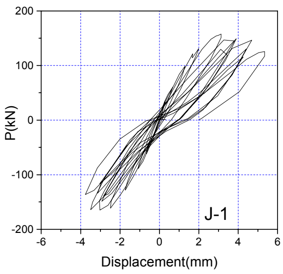
Table 1　List of tested results

Specimen No.	f_c(MPa)	N（kN）	n	Cracking Shear(kN)	Failure Shear(kN)	Failure mode
J-1	37.22	403	0.193	185.2	398.4	Shear failure
J-2	37.22	403	0.193	205.0	-	Bend failure
J-3	37.22	535	0.257	215.8	396.2	Shear failure
J-4	37.22	535	0.257	245.3	438.1	Shear failure

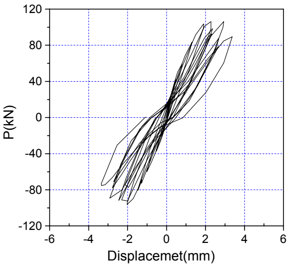


(a)J-1　　(b)J-2　　(c)J-3　　(d)J-4

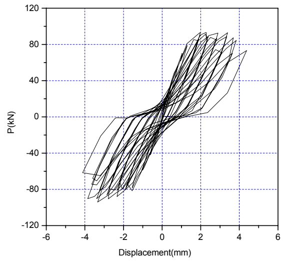
Figure 2 Destruction of abnormal joints



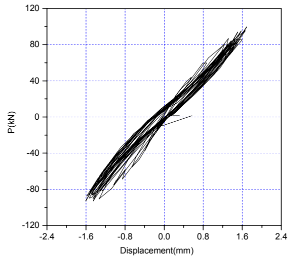
(a)Small beam



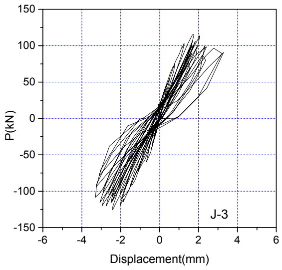
(b) Big beam



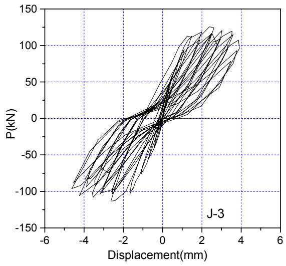
(c)Small beam



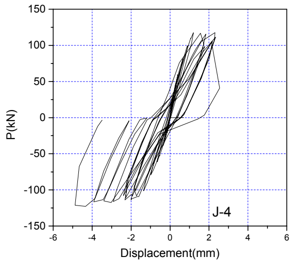
(d) Big beam



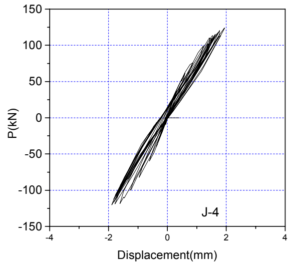
(e)Small beam



(f) Big beam



(g)Small beam



(h) Big beam

Figure 3 Hysteretic loops of abnormal frame joints

2.2 Test result of abnormal space joints

The structure was designed for similar requirements in accordance with GBJ11-89, and their 1:7 scaled models were subjected to pseudo-dynamic tests. The space abnormal joints in the R.C. frame-bent model were carried out under the pseudo-dynamic experiment. The detail reinforcements of structure model and test method can refer to reference (Wu T., Liu B.Q. and Bai G.L. (2005)). The photo of the specimen showed in figure 4(a). The abnormal joints damage pattern and damage mechanism was discussed in this paper. The structural model under the peak acceleration of 0.15g EL-Centro earthquake waves, a few minor crack were detected on abnormal joints area. Rather distinction crack pattern apparent after the peak acceleration of 0.3g. Under the finally pseudo-static tests, the bottoms of abnormal joints shear failure.

The joints shear failure shown in figure 4(b). The monotonic crack was widely opened in the bottom of abnormal joints and severe spalling of concrete and bucking of reinforcement were observed. Experimental result shown: the abnormal joints were designed in accordance with GBJ11-89 can't coincide the demand "strength joints".

（a）Structural model

（b）Destruction of space joints

Figure 4 Structure model contained abnormal joints

3. DAMAGE MECHANISM AND INFLENCE FACTOR ANALYSES

3.1 Damage mechanism

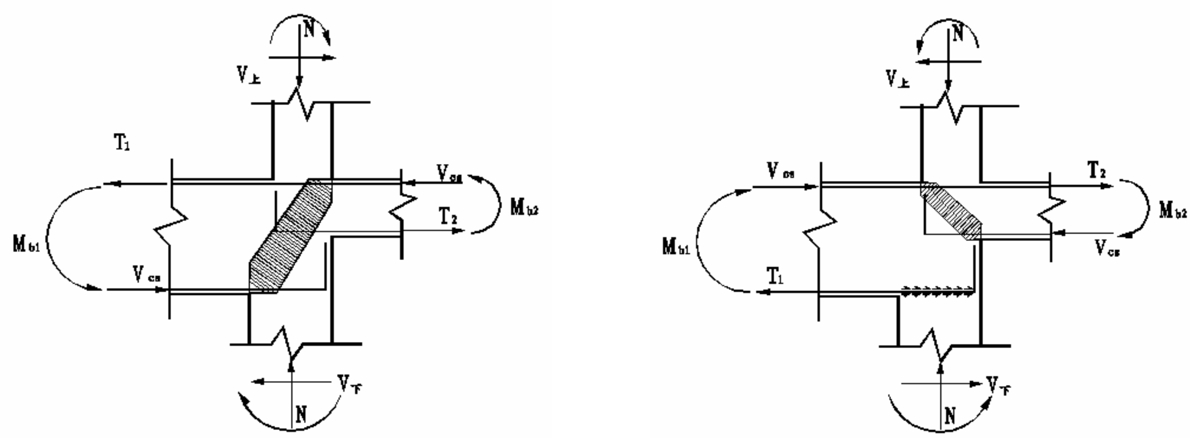
An existing behaviour model for beam-column connections, such as the truss mechanism or the strut mechanism (Pauly (1978), Hitoshi S.(2001)) can used to account for normal joints accurately. Failure models using the strut mechanism regard joint shear failure as compressive failure of the diagonal concrete strut.

The abnormal joints bearing the shear force were shown in figure 5. When the big beam bearing the positive bend moment, the oblique constrain bar formed in the "big core zone" area that composed by the big beam and the big column. Definition of abnormal joints shear shown in figure 5(a). The abnormal joints can safely resistant the joint shear force V_j.:

$$V_j = T_1 + T_2 - V_c \tag{3.1}$$

where T_1 and T_2=tensile force in top and bottom reinforce bars in beam pass through the connection; V_c = column shear force (Figure 5).

In the opposite condition, the big beam bearing the negative bend moment, the compressive bar formed in the "small core zone" areas that consist of the small beam and upper column. In the lower of the joints, the big beam bottom bar transfer the shear force to the lower of the joints. Base on the experimental data, two typical shear failures were occurred.



(a) Big beam bearing the positive bend moment (b) Big beam bearing the negative bent moment

Figure 5 Diagram for mechanism of abnormal joints

3.2 Influence factors analysis

3.2.1Axial compressive ratio

According to experimental result of normal joints, the ultimate bearing shear force of joints can increase when the axial compressive force conducted. Because of the abruption in the column section, the abnormal joints bearing the additional moments that caused by the eccentric axial compressive force. Meanwhile the compressive stress in the joints distribution uneven seriously. To ensure the safety of the abnormal joints under the earthquake, the formula for calculated the capacity of the abnormal joints do not considering the influence of axial compressive ratio.

3.2.2Stiffness ration of big beam with small beam

Joints shear measurements are necessary to determine tensile force and in the top and the bottom reinforcements. Since beam height was abruption, abnormal joints core area can divide into two type: one is "small core zone" which composed by small beam and upper column; other is "big core zone" consisted by big beam and column.

According to experimental result, the beam height abruption more than 50 percent big beam height or 500mm, the abnormal joints easily damaged under the earthquake. When the height of beam abruption no more than 10 percent height of big beam or 200mm, the abnormal joints seismic behaviour similar to normal joints.

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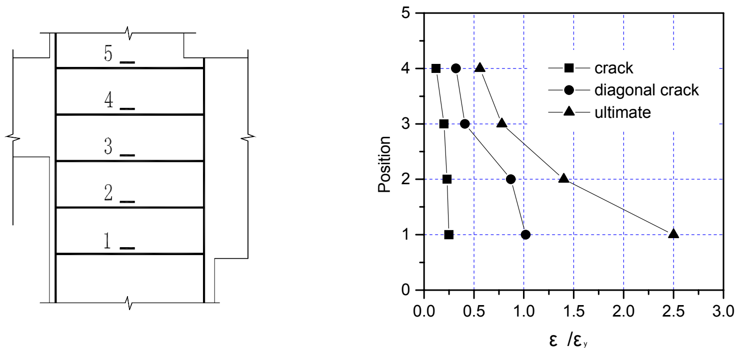
3.2.3Stirrup volume ratio

In space abnormal joints, the strain distribute of stirrup along the height shown in figure 6. When the joint minor crack, the stirrup stress distribution along the height even. Since the joints damage development, the stress of the stirrup distribution along the height showed very uneven. When the joints reach the ultimate state of strength, the bottom stirrup stress equal to the three multiply of upper stirrup of the joints. It exhibition the all stirrup in the abnormal joints can't reach yielding simulate.



(a)Position of the stirrup **(b) Strain distribution of the height**

Figure 6 Strain distribution of stirrup along the height

4.SHEAR CAPACITY OF ABNORMAL JOINTS

Based on the two typical failure modes, formula for calculate the ultimate strength of abnormal joints were present:

4.1"Small core zone" shear failure

Based on experimental result of abnormal joints, the "small core zone" showed shear failure. To coincide with the seismic code of China (GB50011-2001), the joints should satisfy the demand:

$$V_j \le [0.8\eta_j \frac{A_{bz}}{A_{sz}} f_t b_j h_j + 0.5\eta_j n f_t b_j h_j + 0.8\frac{f_{yv} A_{sv}}{S}(h_0 - a_s')] \quad (42)$$

where A_{bz} denotes the area which consisted with the big beam and big column; A_{sz} denotes the area which consisted with the small beam and upper column; n=axial compressive ratio; η_j denoted diagonal beam effect; b_j and h_j=joints dimension in width and height; f_{yv}=yield stress of the stirrup; f_t=tensile strength of the concrete; S= space of the stirrup.

4.2Column shear failure

The space abnormal joints shown shear failure in bottom of the joints. Mechanism of the column shear failure was shown in figure 7. In this condition, the shear force of bottom abnormal joints can be decided:

$$V_{cj} = T_1 - V_c \quad (4.3)$$

where V_{cj} the bottom joint shear force.

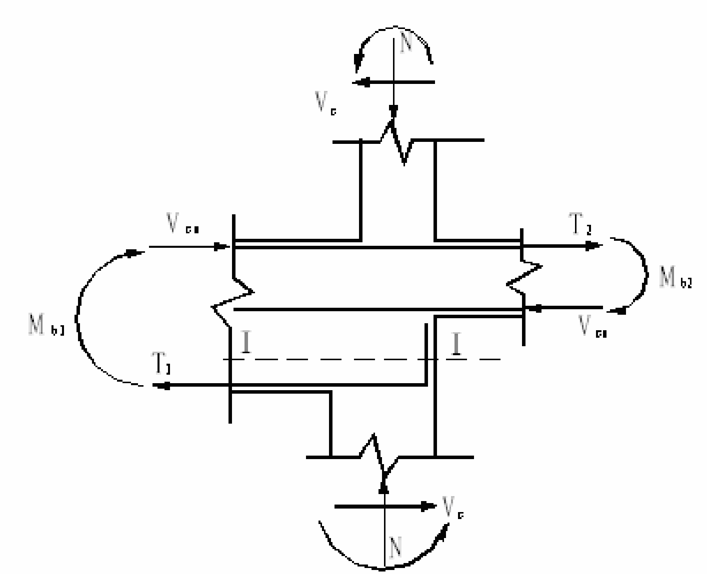


Figure 7 Mechanism of the column shear failure

To avoid this type shear failure, the equation should be satisfy:

$$T_1 - V_c = V_{cj} \le V_{cs} \tag{4.4}$$

$$V_{cj} = \frac{\eta M_{b1}}{h_0 - a_s'} - V_c \le V_{cs} \tag{4.5}$$

where V_{cj} the bottom joint shear force; V_{cs} column capacity of shear force; η=the multiply factor of column moments.

$$V_{cs} = 0.7 f_t b_c h_c + \frac{f_{yv} A_{sv}}{S} 0.9 h_0 + 0.056N \tag{4.6}$$

Where N denotes column axial compressive force; b_c and h_c=column cross-section in width and height; h_c=the effective height of the column cross-section.

4.3Equation of the two type shear failure

"Small core zone" shear failure:

$$\frac{\eta M_{b2}}{h_{b20} - a_s'} - V_c = V_j \tag{4.7}$$

Column shears failure:

$$\frac{\eta M_{b1}}{h_{b10} - a_s'} - V_c = V_{cs} \tag{4.8}$$

where h_{b10} and h_{b20} denote big beam and small beam effect cross-section height respectively; h_{b20}-a_s'=0.9 h_{b2}, h_{b10}-as'=0.9h_{b1}, V_{col}=(1/4~1/6)T:

$$\frac{M_{b2}}{M_{b1}} \cdot \frac{h_{b1}}{h_{b2}} = \frac{V_j}{V_{cs}} \tag{4.9}$$

$$\alpha = \frac{M_{b2}}{M_{b1}} \tag{4.10}$$

$$\alpha = \frac{h_{b2}}{h_{b1}} \cdot \frac{1.5 f_t b_j h_j + \frac{f_{yv} A_{svj}}{S} \cdot 0.9 h_0 + 0.05N}{0.7 f_t b_c h_c + f_{yv} A_{sv} / S \cdot 0.9 h_c + 0.056N} \tag{4.11}$$

where f_c=10f_t，and commonly axial compressive ratio no more than 0.3,，the axial compressive effect can neglect。f_{yv}=210N/mm2. According to china code, f_t=1.7 N/mm2，f_{yt}/f_t=120。

The factor “a” can be redefined:

$$\alpha = \frac{h_{b2}}{h_{b1}} \cdot \frac{A_j(1.5+108\rho_{svj} \cdot h_0/h_j)}{A_c(0.7+108\rho_{sv})} \tag{4.12}$$

According to Eq.(4.12), the factors affecting the shear failure mode of abnormal joints such as: axial compressive ratio, the stiffness ratio of big beam with small beam, stirrup ratio of small core and column etc.

When $\frac{M_{b2}}{M_{b1}} \geq \alpha$， abnormal joints easy occurred small core zone shear failure;

When $\frac{M_{b2}}{M_{b1}} \leq \alpha$， abnormal joints easy occurred column shear failure.

5. CONCLUSIONS

Abnormal frame joints the diagonal loads very near to the yielding load and abnormal joints seismic behavior was poorer than normal joints, the abnormal joints were designed in accordance with GBJ11-89 couldn’t coincide with the demand “strength joints”.

According to experimental result, the beam height abruption more than 50 percent big beam height or 500mm, the abnormal joints easily damaged under the earthquake. Two typical failure modes were presented: small core shear failure and the column shear failure. The formula for calculation of the shear-bearing capacity of abnormal joints was given.

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