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Effect of joint panels on elastic-plastic behavior of moment resisting frames

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ABSTRACT: In moment resisting steel frames under lateral force, joint panels of beam-to-column connections are deform by high shear stress. The shear deformations in the joint panels contribute adequately to the energy absorption of the structures. In this paper, the elastic-plastic analyses of four storied buildings under statical lateral force are carried out by using a modified slope-deflection method in consideration of the shear deformations in the joint panels. The effects of the number of spans and the proportion of the structural elements (column, beam and joint panel) on the contribution of the joint panels to the total energy absorption of a structure are investigated and a design guide for practical use is proposed.

1 INTRODUCTION

Moment resisting steel frames are widely used in Japan. When those frames are subjected to lateral force, high shear stress occurs in joint panels of beam-to-column connections. It is well-known that the joint panels in shear possess stable hysteretic behavior in plastic region (Bertero 1972 and Tabuchi 1984). However, in usual practical design, the frames are analyzed without consideration of the joint panels.

In the Japanese national building code, it is assumed tacitly that the energy absorption in the joint panels contributes to the total energy absorption of the frame under severe earthquake motion and that the contribution can be estimated empirically as about one third of the total (Kanatani 1990), which is based on the studies of beam-to-column sub-assemblages (Nakao 1975 and Popov 1975). However, a contribution of joint panels to the energy absorption of a frame varies with the number of its stories and spans as much as the proportion of its structural elements.

The purpose of this paper is to study quantitatively the effects of the pattern of frames and the strength ratio of joint panels to beams or columns (called the panel yield ratio in the following) on the contribution above mentioned.

For this purpose, a series of statically elastic-plastic analyses of frames are carried out by using a modified slope-deflection method in consideration of shear deformations of joint panels.

The frames dealt with here are four storied building frames and consist of rectangular hollow-section steel (RHS) columns, H-shaped steel beams and RHS joint panels. The variable parameters are the number of spans and the panel yield ratio. The effects of these parameters on the behavior of frames will be discussed and a design guide for practical use will be proposed.

2 PROCEDURE OF ANALYSIS

The statically elastic-plastic analyses are carried out by using the modified slope-deflection method in consideration of shear deformations of joint panels (Yamanari 1988). The assumptions in the analyses are as follows:

1.Flexural and shear deformations are considered both in beams and columns, and the axial deformation is only considered in columns.

2. In joint panels, only shear deformation is considered

3.Restoring force characteristics of members and joint panels are bi-linear type as shown in Figure 1. Each stiffness in the plastic range is 1/30 of the elastic stiffness.

4.Elastic limits of members and joint panels are given as follows;

for members $M_p = F \cdot Z_p$ (=full plastic moment) (1)

for joint panels $_pQ_y = \frac{16}{9} D_c T \frac{F}{\sqrt{3}} \sqrt{1-n^2}$ (2)

where F is the specified yield stress of the material (=235 N/mm² in this study), Zp the plastic modulus of members, Dc the distance between center lines of column flanges, T the thickness of joint panels and n is the axial force ratio of columns. For the strength of joint panels pQy refer to the previous paper (Tabuchi 1988).

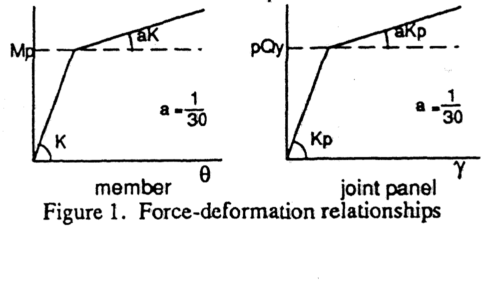

Figure 1. Force-deformation relationships

3 MODEL FRAMES

Four frames consisting of four stories and various spans, as shown in Figure 2, are analyzed. The panel yield ratio Rpp is defined by the following equation. The panel yield ratios in the interior joint panels of each frame are varied 0.4 to 1.2.

$$R_{pp} = \frac{{}_pM_y}{\min\{|{}_bM_p^L + {}_bM_p^R|, |{}_cM_p^U + {}_cM_p^L|\}} \quad (3)$$

where ${}_bM_p^R$ and ${}_bM_p^L$ are the full plastic moments of right and left beam ends and ${}_cM_p^U$ and ${}_cM_p^L$ are the full plastic moments of upper and lower column ends, respectively. pMy is the yield strength of joint panel expressed by bending moment (=pQy · Db · (1−λ)/(1−λ−μ), called panel yield moment) which is deduced from the equilibrium in an interior joint panel shown in Figure 3.

The Rpp defined above is a nominal value in actual frame where the values λ and μ corresponding to shear span ratio of beams and columns vary with the stiffness of members. In this paper, the Rpp value of multi-span frames indicates the value in the interior beam-to-column connection of each frame.

Table 1 shows the list of the analyzed model frames.

Each cross-sectional dimension of structural elements in those frames is determined by following process.

1. Two frames which consist of one span and two spans respectively (called prototype frame in the following) are designed by usual practical procedure in Japan.

2. Vertical design load on each beam is assumed as 39 kN/m and lateral shear force distribution (Umemura 1984) is calculated from the following equation,

$$Q_i = A_i \cdot C_o \cdot W_i,\ C_o = 0.2 \quad (4)$$

The elstic-plastic analyses of model frames are carried out by increasing lateral force at each floor level corresponding to the above shear force distribution (Figure 4) step by step.

3. The cross sections of joint panels are same as those of lower story's columns. The panel yield ratio of the prototype frame with two spans varies in every story, i.e., Rpp=0.59~0.69.

4. To obtain the required panel yield ratios in the model frames, the thickness of joint panels in the prototype frames are modified to suitable thickness.

5. As to the three span frames and the five span frmes, the same structural elements as the two span frames are used.

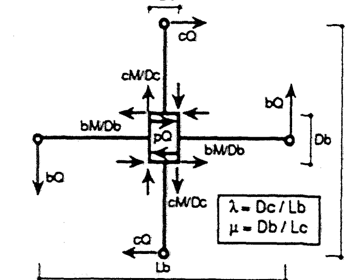

Figure 3. Equilibrium in interior joint panel

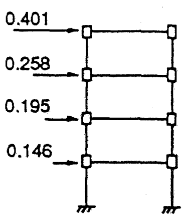

Figure 4. Lateral force distribution factor

4 RESULTS AND DISCUSSIONS OF ANALYSIS

4.1 Developing process of yield hinges

Figure 5 shows the developing process of yield hinges in the two span frames until the maximum story-drift θ3=0.03 rad. which occurs at the 3rd story. In the figure, white circles indicate occurring the yields at joint panels and members and the number shows the order of the hinge development.

In the frames with Rpp<1.0, the yieldings at joint panels occur prior to hinge developing at member ends. In

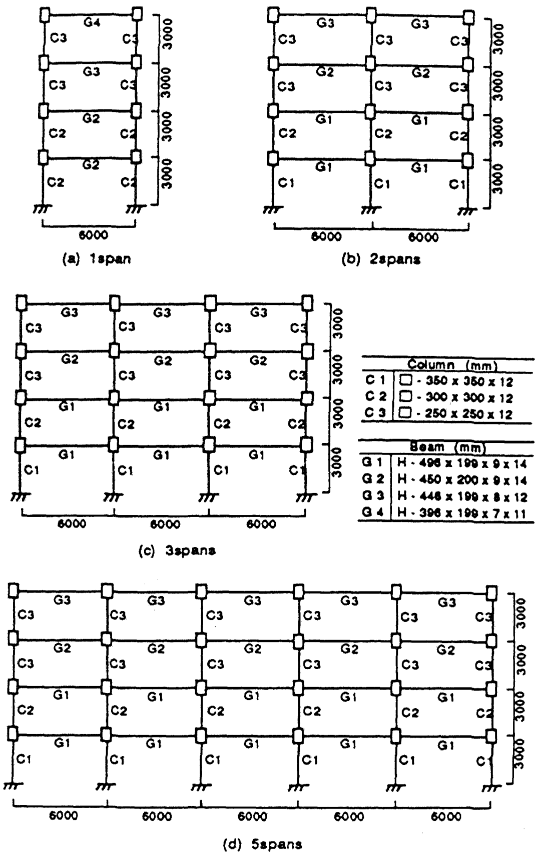

Figure 2. Model Frames

Table 1. The list of analyzed frames

RPP	1span	2spans	3spans	5spans
0.40	–	R4204L	–	–
0.60	R4106L	R4206L	R4306L	R4506L
0.80	R4108L	R4208L	R4308L	R4508L
1.00	–	R4210L	–	–
1.20	–	R4212L	–	–

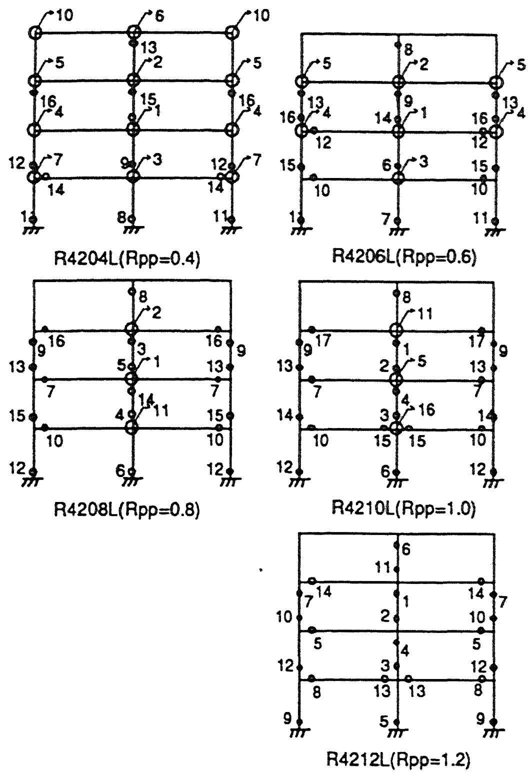

Figure 5. Development of yield hinges until θ=0.03rad.

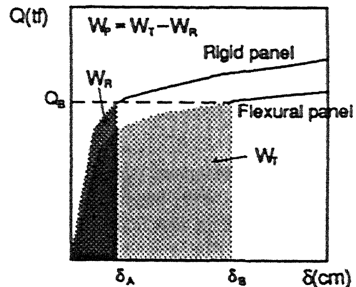

Figure 6. Calculation method of energy absorption in joint panel

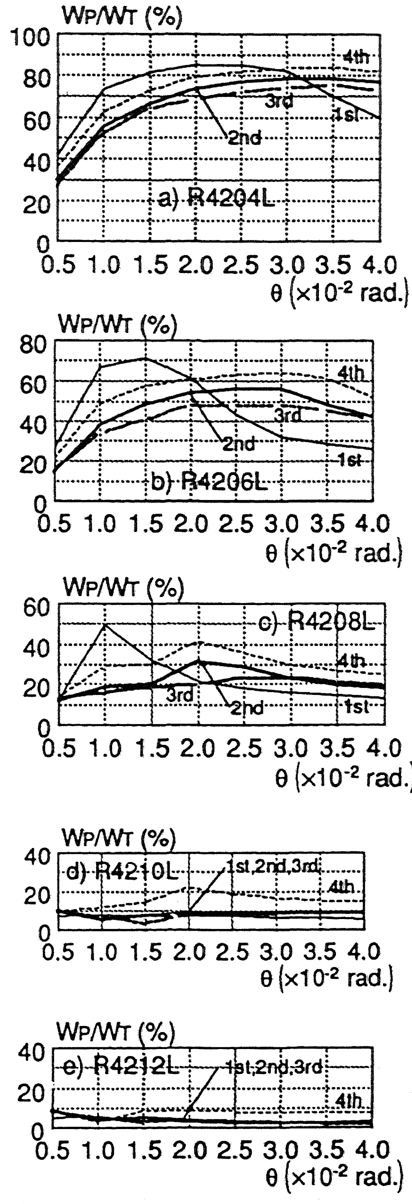

Figure 7. Energy absorption in joint panel

the frames with Rpp=0.4 and 0.6, the yieldings are observed both in interior and exterior panels.

In the frames with Rpp≥1.0, yield hinges at member ends occur prior to yieldings at joint panel, and in the frame with Rpp=1.2 no yielding at any joint panel is observed until θ_3=0.03 rad..

Although premature yieldings occur at joint panels in the frames with Rpp=0.6 and 0.8, hinges develop at top and bottom of all columns of the 3rd story when the story drift θ_3 reaches 0.03 rad..

4.2 Energy absorption in joint panels

The energy absorption in the joint panels, WP, can be obtained as the difference between WT and WR as shown in Figure 6. Where, WT is the energy absorption obtained from story shear force versus story drift relationships of the frames with the flexural panels and WR is that of the frames with perfectly rigid panels which are analyzed separately for comparison.

Figure 7 shows the contribution of the energy absorption in the joint panels to the total energy absorption of the frames with two spans. It is shown in the figure that the WP/WT ratio decreases as the Rpp increases.

The contribution of the energy absorption in the joint panels cannot be much expected in the frames with Rpp≥1.0.

In the frames with Rpp=0.8, the WP/WT ratios are 20 to 30% when the story drift θ becomes 0.02 to 0.03 rad. corresponding to the story drift under severe earthquake motion.

Figure 8 shows the effect of number of spans of the frames with Rpp=0.6 and 0.8 on the WP/WT ratios in the 2nd story. It is clear that the WP/WT ratio increases as the number of spans increases, because the increase of the number of spans means the increase of the interior joint panels. The frames with only one span which has no interior joint panels possesses very small WP/WT ratio.

4.3 Ductility factor

Figures 9-11 show the effect of Rpp on the maximum ductility factor of the joint panel γ/γy, the column θc/θcp and the beam θB/θBp at θ3=0.03 rad. in the 3rd story of two span frames. Where, γy is the shear distortional angle of the joint panel at pQ=pQy, θCp and θBp are slopes at the column and beam ends respectively when those section reaches the full plastic moment.

Figure 12 shows the effect of Rpp on the WP/WT ratio at θ3=0.03 rad. in the 3rd story of two span frames.

The ductility factor of the joint panel, γ/γy, increases as the Rpp decreases. In the frames with Rpp=0.4 and 0.6, the γ/γy ratio is expected about 20 (See Figure 9), and then the WP/WT ratio becomes more than 50% (See Figure 12).

From figures 9 and 10, it is implied that in accordance with the progress of the plastification in joint panels, the ductility factors of columns connecting to those joint panels become small (See Figure 10).

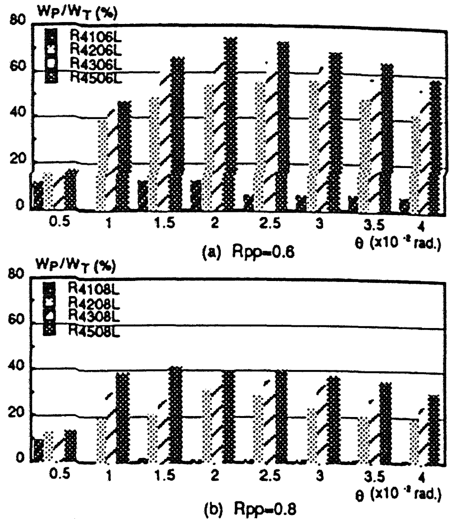

Figure 8. Effect of number of spans on energy absorption in joint panels

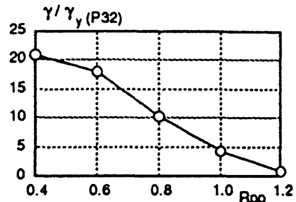

Figure 9. Effect of Rpp on ductility *factor in joint panel*

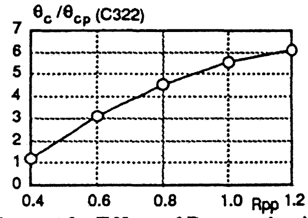

Figure 10. Effect of Rpp on ductility factor in column

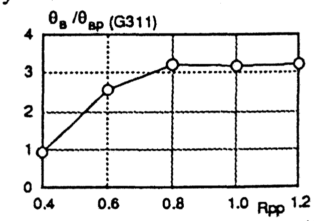

Figure 11. Effect of Rpp on ductility factor in beam

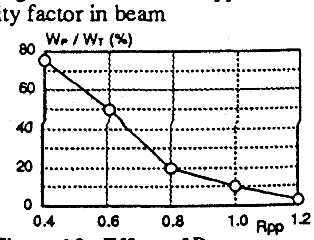

Figure 12. Effect of Rpp on energy absorption in joint panel

5. SUMMARY AND CONCLUSIONS

The contribution of the joint panels to the total energy absorption of the frames varies with the number of spans, the panel yield ratio and the story drift. Therefore, it cannot be shown as a general rule how much value of the panel yield ratio is adequate to assure the contribution to one third of the total energy absorption of the moment resisting steel frames. But it is obvious that, when the panel yield ratio is larger than unit, adequate contribution of the joint panels cannot be expected.

The authors propose a design guide for the joint panels that the panel yield ratio should be in the range of 0.6 to 1.0.

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