# THE INFLUENCE OF THE ELASTIC PLASTIC DEFORMATION OF BEAM-TO-COLUMN CONNECTIONS ON THE STIFFNESS, DUCTILITY AND STRENGTH OF OPEN FRAMES

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## 1. SYNOPSIS

In design of steel beam-to-column connection, it is necessary to know the influence of the deformation of that part on the restoring force characteristics of frame. From this point of view, the restoring force characteristics of beam-to-column connection composed of H-shape is investigated experimentally and its influence on the restoring force characteristics of frame is investigated analytically using a frame model.

## 2. INTRODUCTION

In the conventional design and analysis of frames, the beam-to-column connection(panel-zone) was usually idealized as a rigid point or a rigid zone, however, the necessity to take the deformation of panel-zone into consideration in the design and analysis of frames subjected to lateral force was pointed out previously(1)(2).

Two items are treated in this paper. One is the characteristics of the elastic plastic deformation of panel-zone and the other is the influence of the elastic plastic deformation of panel-zone on the restoring force characteristics of frames.

## 3. CHARACTERISTICS OF THE ELASTIC PLASTIC DEFORMATION OF PANEL-ZONE

Two types of specimens of half scale composed of H-shape members were tested. One type of specimens(as shown in Fig.1 and Tab.1) represents the model of higher story(with small axial force of column) while the other type of specimens(as shown in Fig.2 and Tab.2) represents the model of lower story(with large axial force of column).

$\tau_N$-$\gamma_N$ relationships obtained from these experiments are illustrated in Fig.3 and Fig.4, where $\tau_N=\tau/\tau_y$, $\tau$ is mean shear stress of panel-zone, $\tau_y$ is mean shear stress of yielding panel-zone disregarding axial force of column, $\gamma_N=\gamma/\gamma_y$, $\gamma$ is shear deformation of panel-zone and $\gamma_y$ is $\tau_y/G$.

These experiments brought following three results.

(a) The application of Von Mises' criterion considering axial force showed well prediction of the actual yielding of panel-zone.

(b) The existence of axial force of column showed no significant influence on the post yielding behavior of panel-zone.

(c) The following tri-linear approximation of elastic plastic deformation of panel-zone can be usable practically.

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$$\left.\begin{array}{ll}\tau_N=\gamma_N & (\gamma_N \leq 1) \\ \partial\tau_N/\partial\gamma_N=0.05 & (1\leq\gamma_N\leq 20\alpha-19) \\ \partial\tau_N/\partial\gamma_N=0 & (20\alpha-19\leq\gamma_N) \\ \alpha\fallingdotseq 2.0 \text{ for usual H-shaped panel-zone.} & \end{array}\right\} \quad 1.$$

## 4. INFLUENCE OF THE ELASTIC PLASTIC DEFORMATION OF PANEL-ZONE ON THE RESTORING FORCE CHARACTERISTICS OF FRAMES

Using the model shown in Fig.5 to represent a typical frame, the elastic stiffness reduction ratio $\xi$(the ratio of lateral stiffness of frame considering the deformation of panel-zone to that of frame assuming the panel-zone to be rigid zone) and the ductility of frame $\mu_F$ associated with the ductility of panel-zone $\mu_P$ are represented by the following equations(3)(4),

$$\left.\begin{array}{l}\xi=1-g \\ \mu_F=\dfrac{Q}{Q_y}\left\{(1-g)+g\dfrac{\mu_P}{\tau_N}\right\}\end{array}\right\} \quad 2.$$

where $Q_y$ is the lateral force when the panel-zone yields.

The upper and lower bounds of $\mu_F$ can be written as in the following equations,

$$\mu_F=(1-g)\alpha+g\mu_P \qquad \text{upper bound} \quad 3.$$

$$\mu_F=(\mu_P^*-\alpha)(1-g)/(\mu_P^*-1)+\{g(\mu_P^*-\alpha)+(\alpha-1)\}\,\mu_P/(\mu_P^*-1) \qquad \text{lower bound} \quad 4.$$

where $\mu_P^*$ is the maximum ductility of panel-zone.

The governing factor g in these equations is calculated for about 60000 combination of actual H-shapes(JIS G 3192) and approximated by the following equation.

$$g=(\lambda\mu)^{\beta} \quad , \quad \beta=k_2^{0.64}\{0.0639(\alpha_n)^2-0.134\alpha_n+0.281\} \qquad 5.$$

where $k_2$ is the ratio of the yield strength of panel-zone to the yield strength of column and $\alpha_n$ is the ratio of column axial force to column yield force in axial loading.

One case of the relationships of $\mu_F$ and $\mu_P$ is exemplified in Fig.6.

An example of the influence of the deformation of panel-zone on the restoring force characteristics calculated for the story frame model shown in Fig.7 and Tab.3 is illustrated in Fig.8. Moment-curvature relationships of beam and column are assumed as elastic perfectly plastic. As in the usual design, the strength of the model of which the panel-zones are not reinforced is much lower than that of the model of which the panel-zones are idealized as rigid points. Equal or double reinforcement of panel-zone give the frame enough strength.

## 5. CONCLUSIONS

The restoring force characteristics of panel-zone is approximated experimentally by a tri-linear model whether the axial force of column is large or small.

The approximate equations which give the elastic stiffness reduction ratio of frame due to elastic deformation of panel-zone and the upper and lower bound of frame ductility due to plastic deformation of panel-zone are presented.

## 6. BIBLIOGRAPHY

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(4) Masami NAKAO, "Influence of the Plastic Deformation of Beam-to-Column Connection on the Ductility of Open Frame Composed of H-shapes", Ann. Rep. of Eng. Res. Inst., Univ. of Tokyo, 1972.

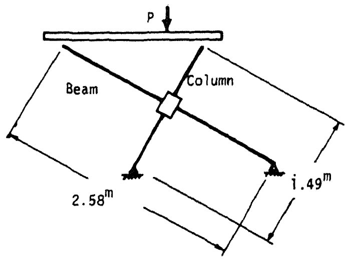




Fig.1 Type-1 Specimen

Tab.1 Type-1 Specimens

| Name | Column | Beam | Material | Mark |
|---|---|---|---|---|
| X-1 | H-180x180x9x12 | H-240x150x9x9 | SS41 | ● |
| X-2 | H-180x180x9x12 | H-240x150x9x9 | SM50 | ▲ |
| X-3 | H-180x150x9x12 | H-240x120x9x9 | SS41 | ■ |
| X-4 | H-180x150x9x12 | H-240x120x9x9 | SM50 | ○ |
| X-5 | H-180x180x4.5x12 | H-240x150x4.5x9 | SS41 | △ |
| X-6 | H-180x150x4.5x12 | H-240x120x4.5x9 | SS41 | □ |

Thickness of panel-zone is $9^{mm}$ for all specimens.

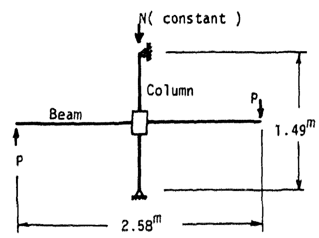
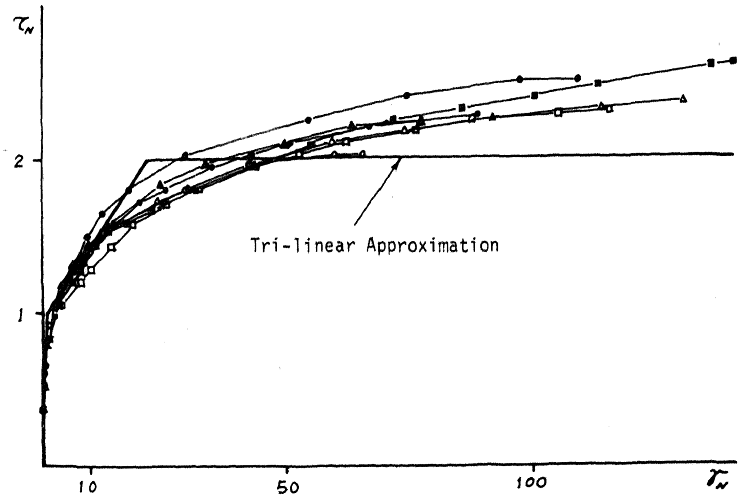



Fig.2 Type-2 Specimen

Tab.2 Type-2 Specimens

| Name | $t_p^{mm}$ | $\alpha_n$ | Material | Mark |
|---|---|---|---|---|
| XN-1-A | 9 | 0.437 | SS41 | ● |
| XN-1-B | 9 | 0.612 | SS41 | ○ |
| XN-2-A | 9 | 0.485 | SM50 | △ |
| XN-3-B | 6 | 0.679 | SM50 | × |

Column is H-180x180x9x12 and beam is H-240x150x9x9 for all specimens.



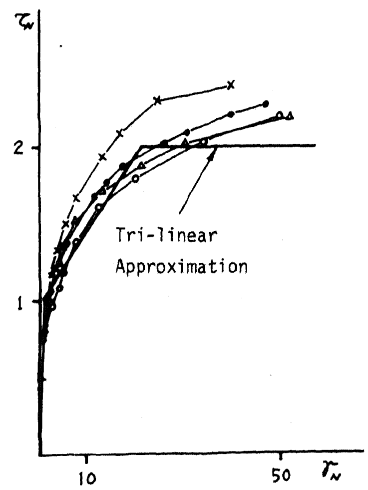




Fig.3 ( $\tau_N$-$\gamma_N$ Relationship Obtained from Experiment ) Fig.4

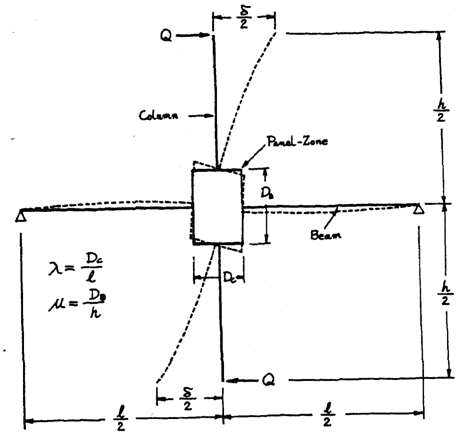



Fig.5 Model of Frame

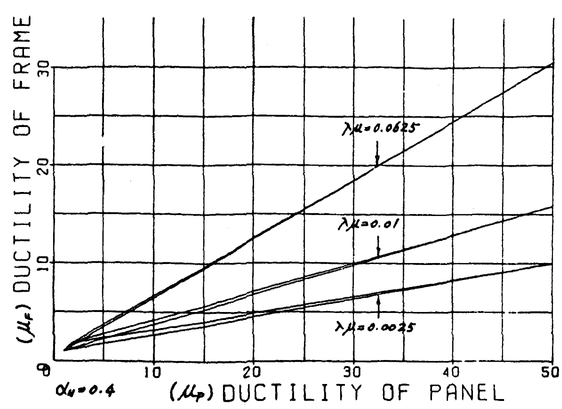



Fig.6 An Example of $\mu_F$-$\mu_P$ Relationship

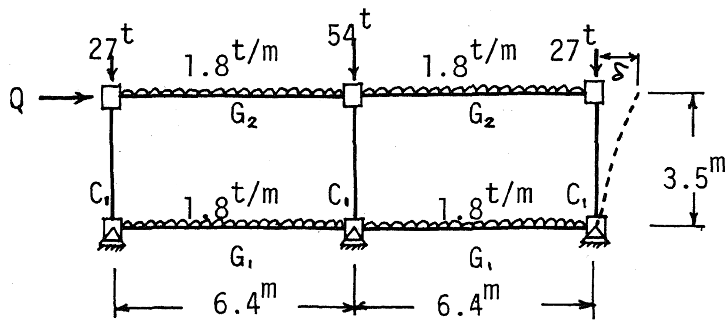



Fig.7 Story Frame Model

Tab.3 List of Member

| | |
|---|---|
| $C_1$ | H-390x300x10x16 |
| $G_1$ | (H-488x300x11x18)x$\frac{1}{2}$ |
| $G_2$ | (H-500x200x10x16)x$\frac{1}{2}$ |
| $t_p$ | $1.0^{cm}$x$\frac{1}{2}$ |

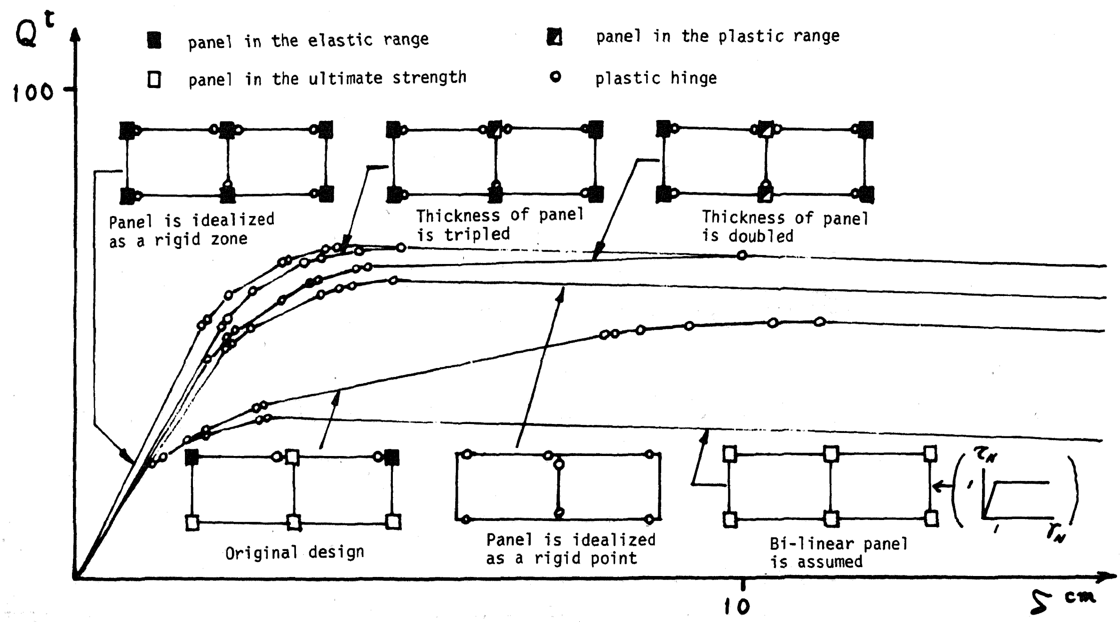



Fig.8 Result of Analysis of Story Frame Model