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THE ASEISMIC BEHAVIOR OF STEEL COLUMN-BASE

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SUMMARY

In the aseismic steel frame structure, the effectiveness of a column-base is determined by its strength capacity and fixity. An evaluation formula for the column-base introduced in this paper, is based on the experimental results that have been performed to investigate the behaviour of the components. Furthermore, to verify the validity of this evaluation formula, some analytical simulations have been performed.

INTRODUCTION

As an earthquake resistant structures, the column-base also plays a very significant function from the standpoint of structural mechanics. This is because the earthquake ground motion is induced as an inertia force in the super-structure through the column-base, and the motion energy of super-structure is simultaneously dispersed to soil through the column-base. In this process, the column-base is the passing point of forces, therefore, its failure will result in the collapse of structural framing.

To prevent the disastrous collapse, the column-base should be a moment-carrying connection just like the beam-to-column connection. However, this research is still in the frontier stage. The peculiar point of this research comes from the composite mechanism between the elements of steel and concrete. Moreover the environment of construction strongly influences the actual characteristics.

This exposed steel column-base system is composed of a stiff base plate against out-of-plane bending, which is rigidly welded to column, and anchor bolts, which are embedded in concrete foundation. Both elements are tightly connected by means of post tensioning (Fig.1).

The first author has performed experimental research on the column-bases with this type of connection system focusing on their force transmission mechanism. Based on these results, the design formula for this type of column-base was proposed (Ref.1).

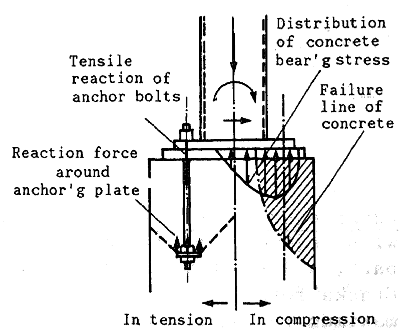


Fig.1 Steel Column-Base Figure

COLUMN-BASE FORCE TRANSMISSION MECHANISM

Along with the axial compression, the column-base must withstand a bending moment, and a shear force which are caused simultaneously by the external disturbances.

Consider a case where the axial force is constant, and the bending moment increases gradually. When the moment is sufficiently small, the entire base plate is subjected to the compressive stress of concrete (bearing stress). As the moment gradually increases, the bearing stress of concrete shifts to the compressive side, and the anchor bolts begin to go into tension. As the moment increases further, the bearing stress distribution becomes parabolic with the maximum stress directly under the compression flange of the column. In this process, the distribution of the bearing stress is related to the base plate stiffness against out-of-plane bending, and that the maximum stress tends to shift outward as the stiffness increases.

Meanwhile, as the anchor bolts go into tension, the separation between the anchor bolts and the concrete progresses towards the lower portion. Ultimately, the anchor bolts and the anchoring plates act as an anchoring mechanism become unbonded. In this way, the axial force and bending moment acting on the column-base are balanced by bearing stress on concrete and tension in anchor bolts.

COMPREHENSIVE EXPERIMENT

The test specimen is a full size column-base with cast steel base plate which is set on a pedestal of a reinforced concrete foundation beam of adequate capacity (Fig.2). One-half of the anchor bolt length is embedded in the foundation beam to prevent cone failure of concrete. The concrete pedestal is adequately reinforced for force transmission even under the ultimate strength state of the column-base. The steel column is of adequate plate thickness to prevent yielding at the ultimate state of the column-base.

A transverse horizontal load was applied, with consideration to the inflection point. The test speciments are listed in Table-1. The paramenters are the sizes of the base plate, column axial load, and yield ratio of the anchor bolt.

Table-1 Test Specimens

Specimen	HIBASE	Anchor bolt (σ_y/σ_u)	Column load (tf)
B-2-O B-2-4 B-2-7 B-2-M	BOX 200x200	4-M30 (0.95)	0 50 100 -8 ~ 100
B-3-4	BOX 300x300	4-M42 (0.93)	100
B-2-OS	BOX 200x200	4-M30 (0.66)	0

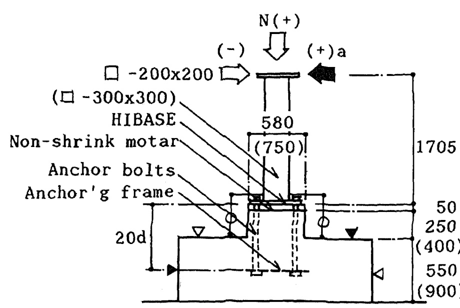


Fig.2 Test Specimen Configuration

Experimental Results   The column-base hysteresis curve is an inelastic type with less energy absorption until the yielding of anchor bolt in the threaded part, and thereafter it shifts into slip-type hysteresis loop (Fig.3). Cracks formed on the compression side of the concrete pedestal before the maximum force, but no reduction in column-base strength occurred. The horizontal displacement of the base plate due to shear force was mostly unnoticed for all test speciments. Therefore no strength reduction occurred.

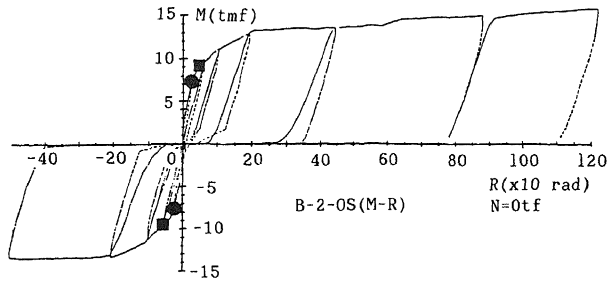


Fig.3 Restoring Hysteresis (anchor bolt with low yield ratio)

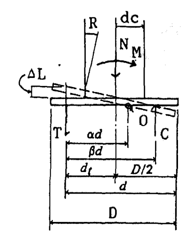
<u>Evaluation of Fixity Against Rotation</u> The following assumptions are made for evaluating the fixity against rotation (K= :K-value) (fig.4).

1) Base plate is rigid and the deformation is negligible.
2) Tensile force acts on anchor bolt, and its elongation is expressed by (dL).
3) The compressive reaction acts at a distance (d) from tensile anchor bolt.
4) The elongation of anchor bolt and the concrete deformation causes the rotation of the column-base with the center of rotation at point O. The location of point O is (a*d) from tensile anchor bolt.

$$K = \frac{1}{L}\cdot(1+\kappa)\cdot E\cdot\Sigma A_b\alpha\beta d^2 + \frac{N}{TL}\cdot(\beta d - dt)\left\{(1+\kappa)\cdot E\cdot\Sigma A_b\cdot\alpha d\right\} \qquad \cdots\cdots \quad (1)$$

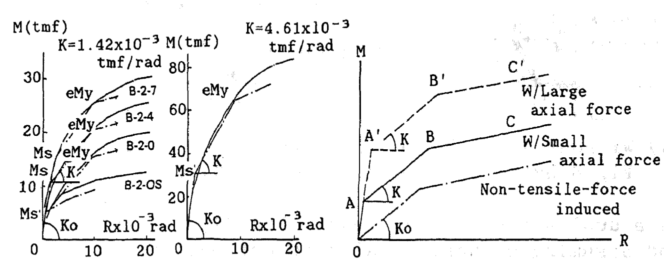
where L: Length of non-threaded part of anchor bolt
A_b: Sum of cross-section areas of non-threaded part of anchor bolts on the tension side.
κ: $(= K_c/K_b)$

The second part of formula (1) shows the effect of column axial force. The K-value becomes greater, provided that the axial force is applied (Fig.4). Next, in the state from the separation of bolt to the yielding of the threaded part, K-values are almost the same whether the column axial force is present or not. The second part of formula (1) has almost no effect in this case.



T:Tensile force of anchor bolt
C:Center of compression force
O:Center of rotation

Fig.4 Diagram of Model



(a) B-2 (b) B-3-4 (c) Idealization of M-R Curve

Fig.5 Idealization of Fixity against Rotation

Also, since K = 0 in the first part of formula (1) after the separation, the K-value at that stage: K_0, can be obtained by formula (2).

$$K_0 = \frac{1}{L}E\Sigma A_b\alpha\beta d^2 \qquad \cdots\cdots \quad (2)$$

The M-R relationship is idealizes as a tri-linear curve, which is defined by the separation of anchor bolt(Point-A) and the yielding of the threaded part of anchor bolt(Point-B). Also, the K-value is noticeably large until the separation, which confirms the effect of column axial load. In a practical design, this can be idealized using a tri-linear curve (Fig.5). From the standpoint of practical design, the simplified formula is proposed as follows:

$$K = \left(1 + 0.4\frac{N}{T}\right)\frac{0.5EnA_b}{L}(d_t + d_c)^2 \qquad \cdots\cdots \quad (3)$$

$d_t = \alpha d \qquad d_c = 0.7d_t \qquad En = 0.85E \qquad \beta d = d_t + d_c$

Evaluation of Ultimate Bending Moment   The bending strength of column-base depends on the quality of the anchor bolt material, and the deformability varies with the yield ratio of anchor bolts. An evaluation formula is developed from the force balance requirement.

Table-2 Ultimate Bending Moment

Stress condition		N	M_u
A	F_c, D	$N_u \geqslant N > N_u \frac{X_1}{D}$	$M_u = \frac{ND}{2}\left\{1-\left(\frac{N}{N_u}\right)\right\}$
B	F_c, X_1	$N_u \frac{X_1}{D} \geqslant N > N_u \frac{X_1}{D} - T_u$	$M_u = -N d_t + N_u \frac{X_1^2}{2D}$
C_1	F_c, T_u	$N_u \frac{X_1}{D} - T_u \geqslant N > \frac{N_u}{4} - T_u$	$M_u = T_u d_t + \frac{(N+T_u)D}{2}\left\{1-\left(\frac{N+T_u}{N_u}\right)\right\}$
C_2	σ_c, T_u, X	$\frac{N_u}{4} - T_u \geqslant N > -T_u$	$M_u = T_u d_t - \frac{(N+T_u)D}{2}\left\{1-\left(\frac{N+T_u}{N_u/2}\right)\right\}$
D	T_u	$-T_u \geqslant N \geqslant -2T_u$	$M_u = (N+2T_u) d_t$

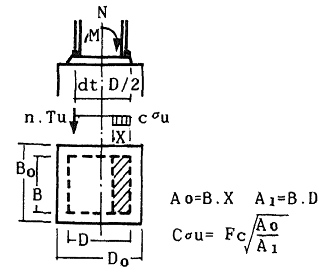


Fig.6

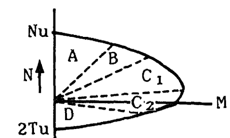
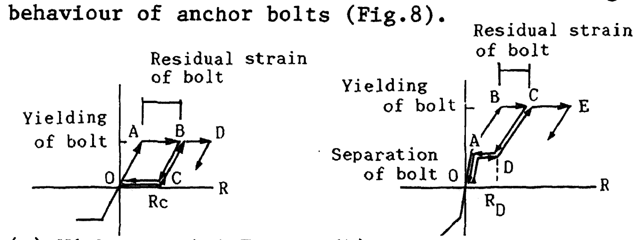


Fig.7 M-N Condition

EFFECT OF COLUMN-BASE HYSTERESIS CHARACTERISTIC
ON THE BEHAVIOUR OF SUPERSTRUCTURE

Hysteresis Model of Column-Base   The experimental results of column-base are expressed as the hysteresis model which is largely dependent on the elongation behaviour of anchor bolts (Fig.8).



(a) Without Axial Force (b) With Axial Force
Fig.8 Hysteresis Loop of Column-Base

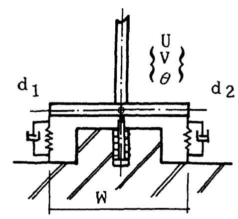
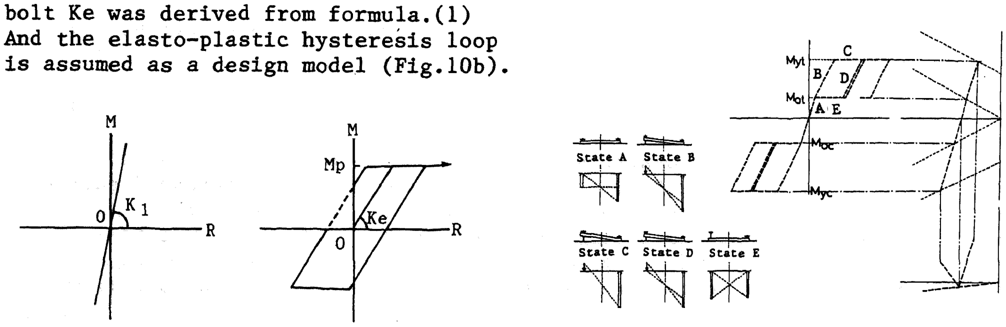


Fig.9 Dual Slip-bilinear Model

As a dual slip-bilinear model (Fig.9), a stiff base plate was used as the model, and assuming no horizontal deformation, it was matched with the results of an experiment (Fig.10c). The fixity against rotation Kf for the fixed model (Fig .10a) corresponds to the initial stiffness of the dual slip-bilinear model. Also, fixity against rotation due to anchor bolt Ke was derived from formula.(1)
And the elasto-plastic hysteresis loop is assumed as a design model (Fig.10b).



(a) Fixed model (b) Design model (c) Analysis model(Dual slip-bilinear)
Fig.10 Idealization of Column Base Hysteresis Loop

Model for structural framing   In order to investigate the effect of structural fundamental period, seismic response analyses were performed on three kinds of framing model (Fig.11). The design method was in accordance with the Japaneses seismic design code. With regard to the degree of column-base fixity, the formula (3) was taken into account, and stress computation based on the point of inflection of column was performed.

Elasto-plastic type hinges can be developed at the both ends of columns and beams in this analysis. The characteristics of column-base are shown in Table-3.

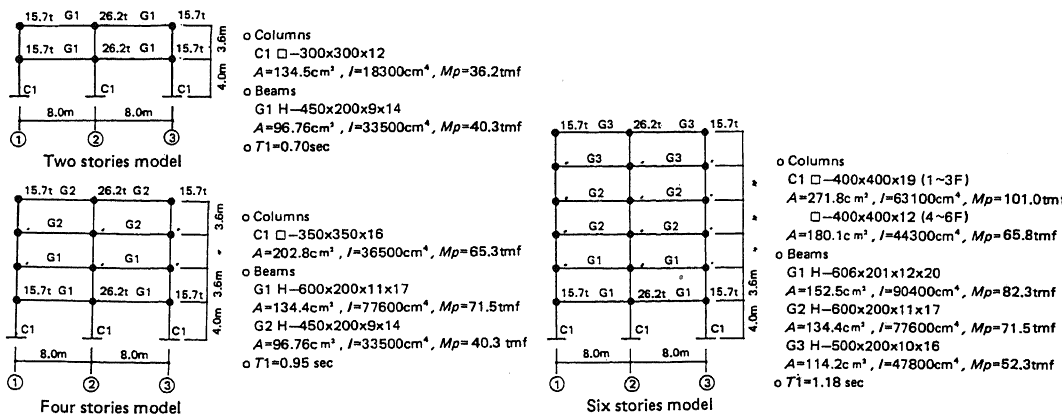


Fig.11 Model of Structural Framing

The seismic waves applied were El Centro (NS) and Taft (EW). Maximum acceleration was arranged to 300 gal, and 450 gal for investigating the effect of the plastic state of framing (Fig.12).

Table-3 Characteristics of Column-Base

Frame model	K 10^{-3} tmf/rad	$_BM_P$ (tmf) ext. col	$_BM_P$ (tmf) int. col	$_CM_P$ (tmf)
2-stories	4.61	38.5	41.2	36.2
4-stories	6.49	57.0	63.0	65.3
6-stories	9.77	81.0	88.0	101.0

$_BM_P$: Plastic moment of col. base (table 4.5)
$_CM_P$: ditto col.
K : Eq. 4-8

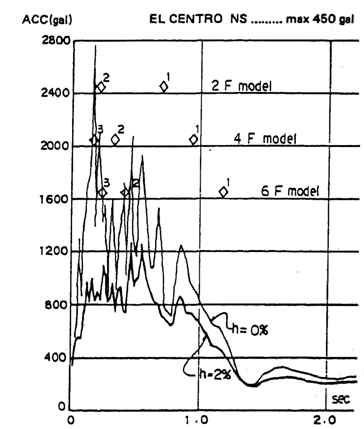


Fig.12 Max.Response Spectrum; Acceleration

Analytical Results   Frame analysis assuming fixed column-base will result in an underestimation of the storey drift and of the accumulation of plastic energy for column top or beam of the storey directly above. The response column base hysteresis curves for the two storey model were most significantly affected by the hysteresis of the column-base.

In an analysis based on elasto-plastic type of column base, by using K-value obtained from formula (3) for the column-base rotational fixity, the forces in the storey directly above can be properly evaluated due to the lower column inflection point. As a result, the design is equivalent to that of seismic response spectrum analyses based on the column-base with slip type hysteresis characteristics.

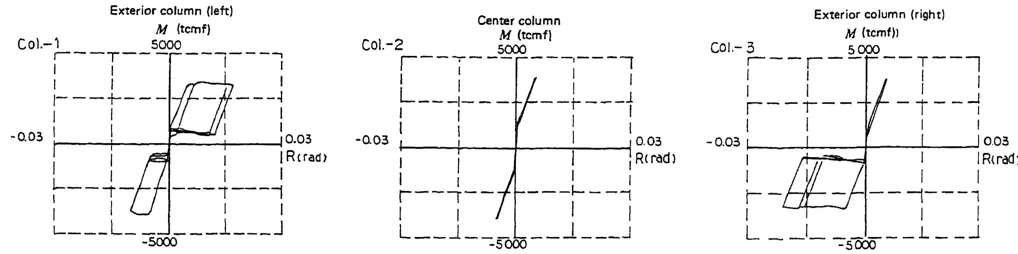


Fig. 13 Response Hysteresis of Column Base

In the fixed model, the plastic energy absorption of the first storey column base had a tendency to increase, but in the design model and the analysis model, the values of the second storey beam or the 1st storey column top increased (Fig.14).

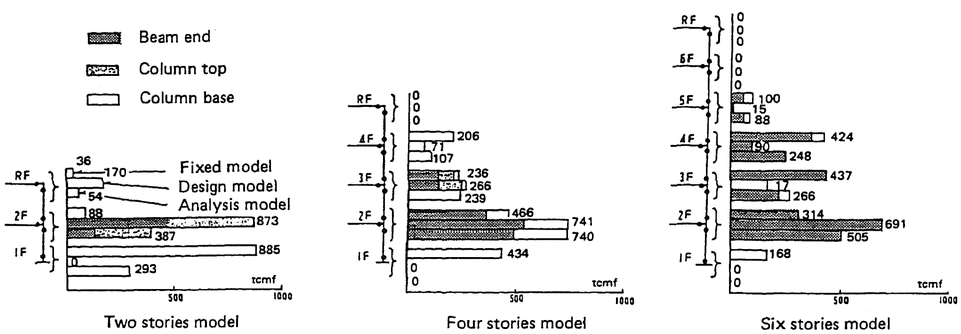


Fig.14 Accumulation of Plastic Energy

CONCLUSION

The superior points of the proposed steel column-base system are to ensure the sufficient fixity and deformability by means of the full moment-carrying. The simplified plastic mechanism contributes to less deviation of the characteristics of the column-base.

The physical property of this column-base system was certified by the results of the experimental research. Based on these results, some practical design formulae were proposed to evaluate the fixity and the ultimate strength.

Some seismic response analyses were conducted to ensure the correctness of the proposed design procedure. From these results, an important suggestion is made as to the strength of the column top and beam in the storey directly above the column-base.

REFERENCES

1. Sato,K. "A Research on the Aseismic Behaviour of Steel Column Base Evaluating its Strength Capacity and Fixity" Pacific Structural Steel Conference August 1986 Auckland New Zealand.