*RESTORING FORCE CHARACTERISTICS OF ANCHOR-BOLT-YIELD-TYPE EXPOSED COLUMN BASE SUBJECTED TO AXIAL FORCE AND BENDING MOMENT

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ABSTRACT :

An anchor-bolt-yield-type column base shows slip-type restoring force characteristics. A column base subjected to constant axial and cyclic horizontal forces shows more complicated characteristics. An experimental study was carried out on column bases under constant axial force and cyclic bending.

KEYWORDS: exposed column base, anchor-bolt-yield-type, axial force, restoring force characteristics, loading test

1. INTRODUCTION

Anchor-bolt-yield-type exposed column bases are generally used in steel buildings. The restoring force characteristics of these column bases show slip-type behavior[Akiyama 1985]. Many researchers have already conducted experimental and analytical studies on cyclic curves of slip-type column bases. Column bases with multi-rows of anchor bolts have been employed to obtain the strength and stiffness of column bases up to anchor-bolt yielding [Yamanishi 2005, 2006]. The authors have proposed models for determining restoring force characteristics of column bases with multi-rows of anchor bolts. Response analyses of tall buildings with slip-type column bases subjected to earthquake ground motion have shown that slip-type cyclic characteristics are useful for reducing residual horizontal deformation after ground motion has stopped [Kawano 2005]. A bi-linear-type cyclic curve was applied to the restoring force characteristics of the column base in the response analysis and more accurate curves of restoring force characteristics were shown to be needed for more accurate response analysis results.
Some researchers have proposed a model for determining slip-type restoring force characteristics of a column base subjected to axial force [Tanuma 1998]. However, these models have focused on column-bases under axial compression and their applicability to column bases under axial tension was not examined sufficiently.
The objective of this study was to formulate models for determining restoring force characteristics for anchor-bolt-yield-type column bases subjected to both axial tension and axial compression, to be used in structural analysis. The proposed models are shown to be more effective than those dealing with simply resisting moments of anchor bolts.
An anchor-bolt-yield-type column base shows slip-type restoring force characteristics. A column base subjected to constant axial and cyclic horizontal forces shows more complicated characteristics. An experimental study was carried out on column bases under constant axial force and cyclic bending.

2. EXPERIMENT

Experiments were carried out on cantilever columns with exposed column bases subjected to combined constant axial force and cyclic horizontal forces. Axial force was the experimental parameter.

2.1 Specimen

Table 1 shows the specimens' material properties and dimensions, and Figure 1 shows their shape. Since the experiments focused on the elastic-plastic deformation behavior of the anchor bolts, the base plate, column and foundation were maintained in the elastic range. A steel foundation (BH-400x400x32x36) was employed instead of a concrete one and failures of base mortar and foundation concrete were ignored. Three types of axial forces were employed: compression of 125 kN (Comp), tension of 57 kN (Ten I) and tension of 117 kN (Ten II). A column (Box-200x200x12) and a base plate (PL-400x400x50) with four anchor bolts were used. The base plate was fillet welded to the column. M16 rolled thread anchor bolts to Japan Society of Steel Construction standard were employed. Each was subjected to thirty percent yield tension (15kN) as the initial axial force.

2.2 Loading apparatus and method

Figures 2 and 3 show the loading apparatus and the axial forces applied to each specimen. Both vertical and horizontal loadings were introduced from the yoke of the column head by two oil jacks. The cyclic horizontal loadings were controlled by the rotation of the base plate. The axial forces were applied under the following conditions. 1) Under axial compression, the base plate was always in contact with the foundation so the foundation resisted the compression. Thus, the resistant mechanism was the same irrespective of the magnitude of the compression. 2) Under axial tension, one row or two rows of anchor bolts resisted the axial tension. For 57 kN one row of anchor bolts resisted the axial tension and for 117 kN two rows of anchor bolts resisted the axial tension.

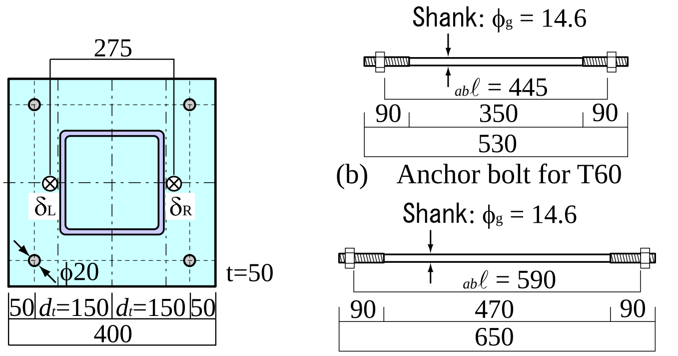
2.3 Measurement

Figures 4 show the measurement points. Base-plate displacements were measured to obtain their rotations. Both vertical and horizontal loads were measured by load cells. The axial loads in the anchor bolts were measured by center-hole-type load cells.

Table 1 Material properties

		Material	E (N/mm^2)	σ_y (N/mm^2)	Main dimension (mm)
Column		STKR400	205,000	414	Box-200x200x12
Base plate		SS400	205,000	274	PL-400x400x50
Achor bolt	: C60, T30	ABR400	205,000	315	ϕ_g = 14.6, $_{ab}l$ = 590
	: T60	ABR400	205,000	294	ϕ_g = 14.6, $_{ab}l$ = 629

E : Young's modulus
σ_y : Yield stress
ϕ_g : Diameter of shank
$_{ab}\ell$: Effective length



(a) Base plate (b) Anchor bolt for T60 (c) Anchor bolt for C60 and T30

Figure 1 Specimen

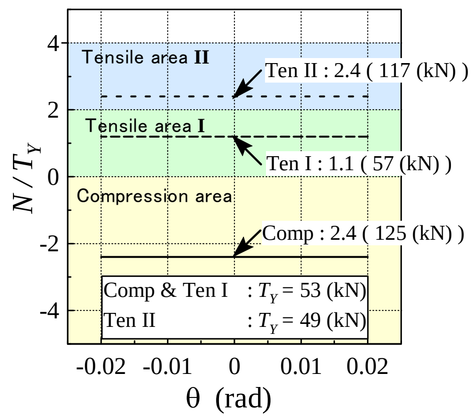


Figure 3 Axial force of each specimen

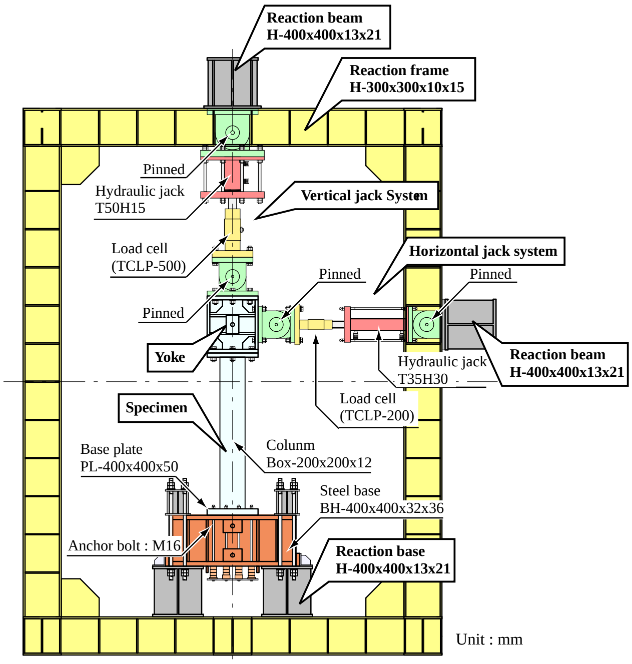


Figure 2 Apparatus

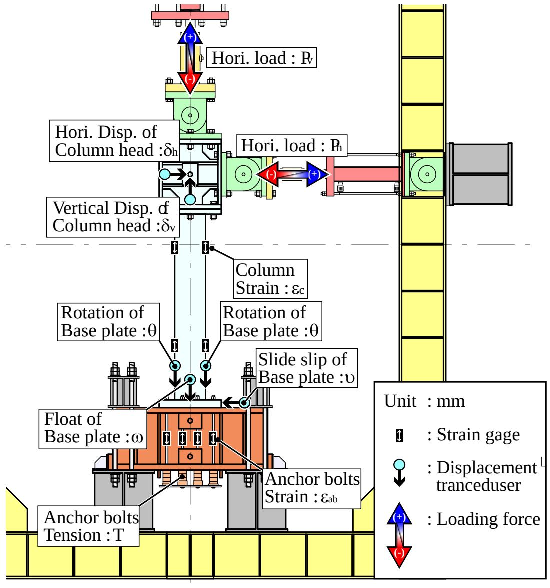


Figure 4 Measurement points

3. Resisting mechanism and models of restoring force characteristics

Figure 5 shows three types of resisting mechanisms of the exposed column bases subjected to constant compression or tension. Additional bending resistance, yield bending strength, elastic rotational stiffness and model of restoring force characteristics of the column base are obtained from these mechanisms.

3.1 Assumption

Models of restoring force characteristics are based on the following assumptions.

1) The anchor bolts are the only yielding elements in the column base.
2) For the base plate in contact with the foundation, the position of compressive reaction of the foundation is at the edge of the base plate and the anchor bolts on the tension side resist bending moment.
3) A coefficient of reduction R in elastic rotational stiffness is employed for elastic deformation of base plate and foundation.
4) When the base plate is in contact with the foundation, friction between base plate and foundation resists shearing force, but when it is separated, the anchor bolts resist the shearing force. Figure 6 shows no reduction in anchor bolt yield strength due to shearing stress under either condition, i.e., condition A is base plate separated from nut and condition B is anchor bolt behaving elastically.
5) The perfectly elastic-plastic model is used to define the material properties of the anchor bolts.

3.2 Resisting mechanism A

Resisting mechanism A occurs when the base plate is in contact with the foundation. The friction generated between base plate and foundation resists the shearing force. This mechanism occurs in compression and tension I ($N<2T_y$). Additional bending resistance M_{An}, yield bending strength M_{AY} and elastic rotational stiffness $K_{A\,BS}$ are given by the following equations.

$$M_{A\,n} = -N \cdot d_c \tag{1.a}$$

$$M_{AY} = n \cdot {}_{ab}A \cdot {}_{ab}\sigma_y \cdot (d_c + d_t) - N \cdot d_c \quad (1.b)$$

$$K_{ABS} = \frac{E \cdot n \cdot {}_{ab}A \cdot (d_c + d_t)^2}{R \cdot {}_{ab}l} \quad (1.c)$$

where n is the number of anchor bolts on the tension side, ${}_{ab}A$ is the gross area of the anchor bolts, ${}_{ab}\sigma_y$ is the yield stress of the anchor bolt, d_t is the distance from the center of the column cross-section to the line of the tensile anchor bolts, d_c is the distance from the edge of the base plate to the center of the column cross-section, N is the axial force, E is Young's modulus and ${}_{ab}l$ is the effective length of the anchor bolt.

3.3 Resisting mechanism B

Resisting mechanism B occurs when the base plate is separated from the foundation and the base plate on the compression side is separated from the nuts. In this case, the anchor bolts resist the shearing force. Resisting mechanism B occurs in tension I (0<N<2Ty). Additional bending resistance M_{Bn} is given by the following equation.

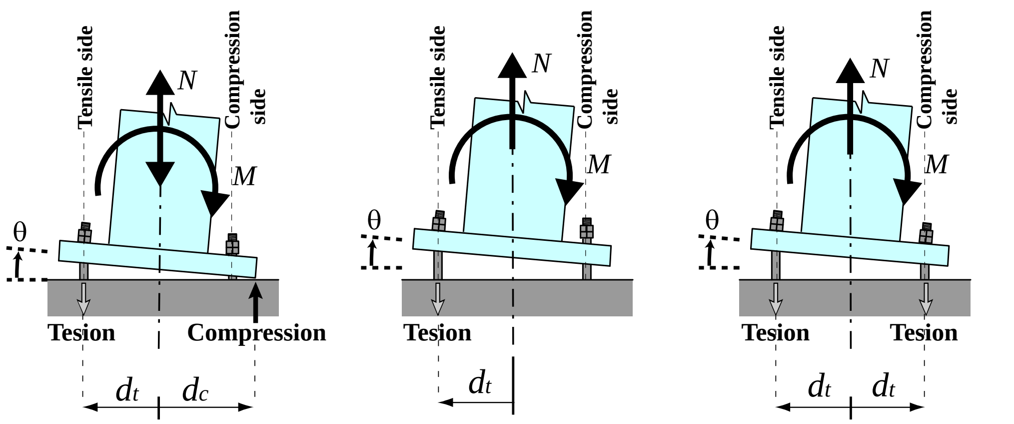
$$M_{Bn} = N \cdot d_t \quad (2)$$

3.4 Resisting mechanism C

Resisting mechanism C occurs when the base plate is separated from the base plate and the nuts of all anchor bolts are in contact with the base plate. Non-yielding anchor bolts resist the shearing force. The resisting mechanism occurs in tension I and II (0<N<4Ty). Yield bending strength M_{CY} and elastic rotational stiffness K_{CBS} are given by the following equations.

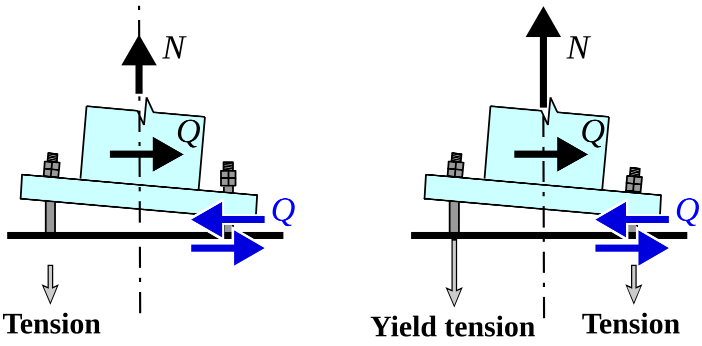
$$M_{CY} = n \cdot {}_{ab}A \cdot {}_{ab}\sigma_y \cdot (2d_t) - N \cdot d_t \quad (3.a)$$

$$K_{CBS} = \frac{E \cdot n \cdot {}_{ab}A \cdot 2 \cdot d_t^2}{R \cdot {}_{ab}l} \quad (3.b)$$



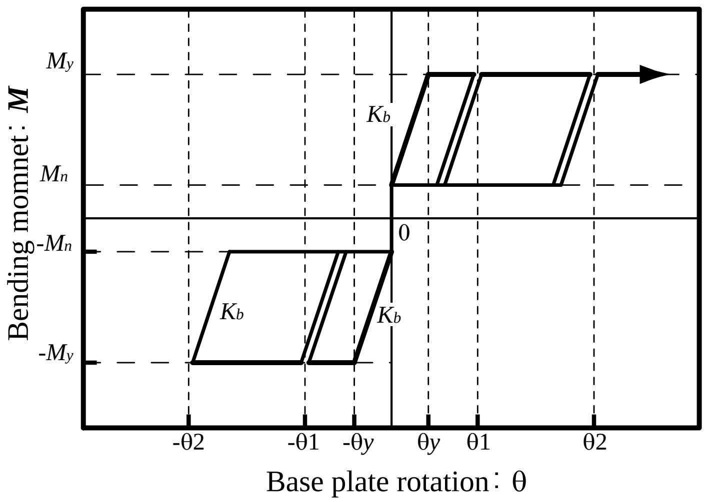
(a) Resisting Mechanism A (b) Resisting Mechanism B (c) Resisting Mechanism C

Figure 5 Resisting mechanism under bending moment and constant axial-force

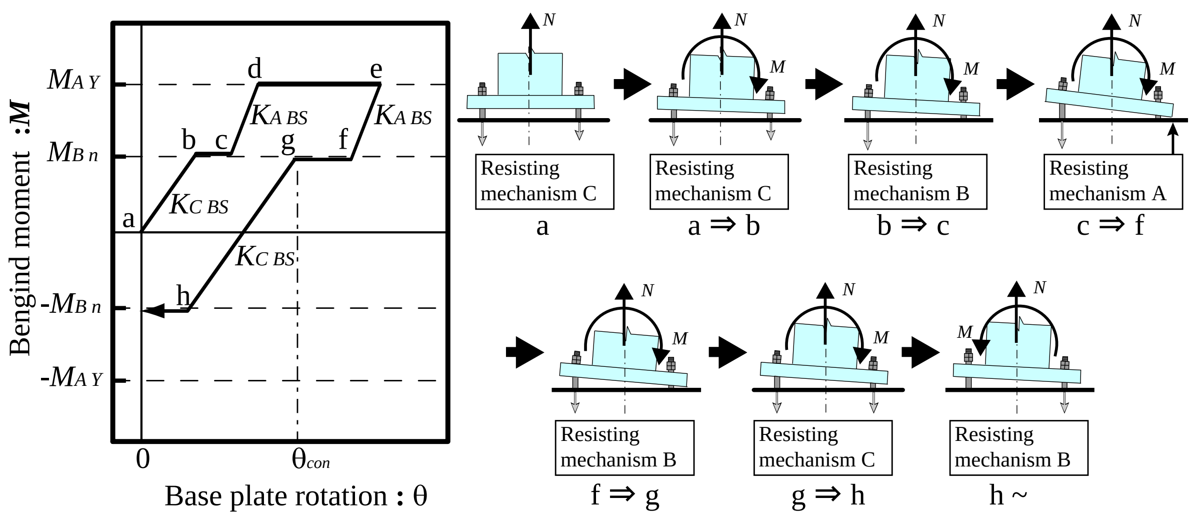


(a) Condition A (b) Condition B

Figure 6 Resisting mechanism under shearing force and constant axial-force

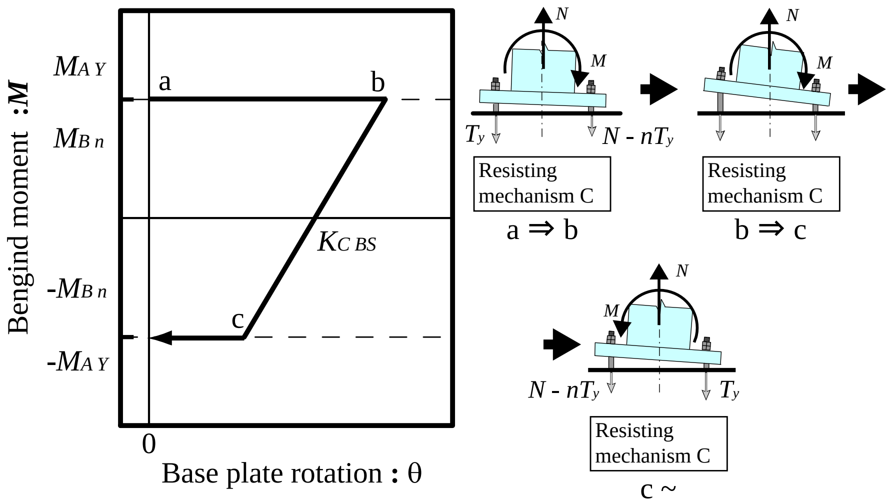


(a) Axial compression



(b) Axial tension I

Figure 7 (a), (b) Resisting mechanisms under bending moment and constant axial-force



(c) Axial tension II

Figure 7 (c) Resisting mechanisms under bending moment and constant axial-force

4. RESULTS AND DISCUSSIONS

Figures 8, 9 and 10 show experimental results and the models of restoring force characteristics are added in Figure 8(a), 9(a) and 10(a).

4.1 Axial compression (Comp)

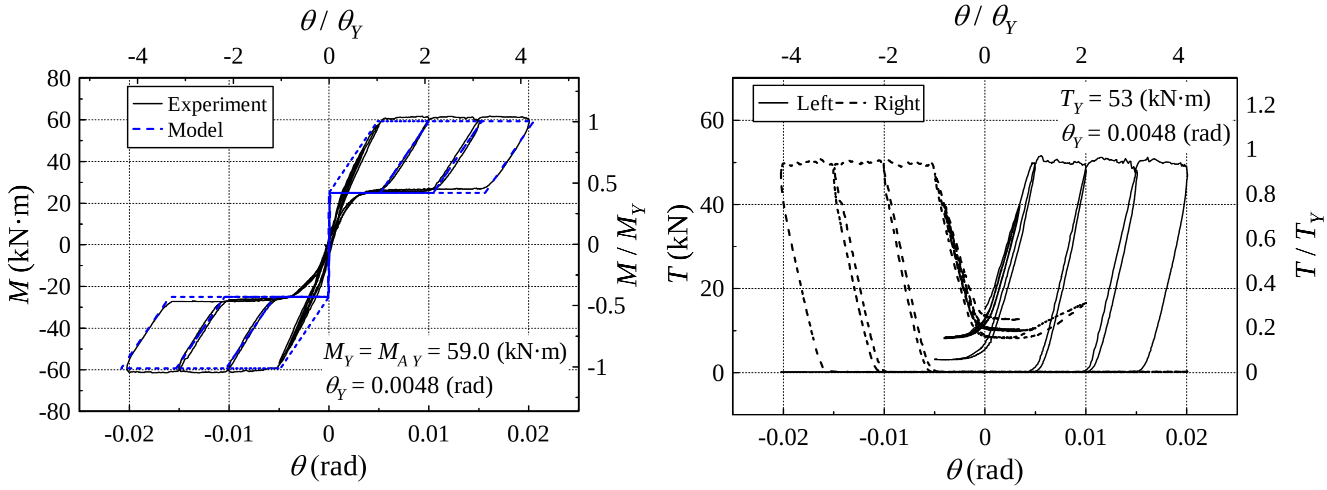
The cyclic curves for axial compression were slip-type and in good agreement with the model of restoring force characteristics, as shown in Figure 8(a). The anchor bolts on the compression side did not resist bending moment and slip phenomena occurred on the tension side, as shown in Figure 8(b).

4.2 Axial tension I (Ten I)

The cyclic curves for axial tension I were slip-type and showed non-symmetric behavior, and were in good agreement with the model of restoring force characteristics, as shown in Figure 9(a). Additional bending resistance occurred and the cyclic curves were similar to those for axial compression. However, the yield bending strength was less than that for axial compression. The direction of rotation was in reverse to the additional bending resistance, because the nut of the anchor bolt on the tension side was in contact with the base plate. However, Figure 9(b) shows that the nuts of the compressive anchor bolts were in contact with the base plate and resisting mechanism C occurred until the direction of rotation was in reverse to the bending resistance. In negative unloading, plastic elongations of the anchor bolts on both sides were equal and these phenomena did not occur.

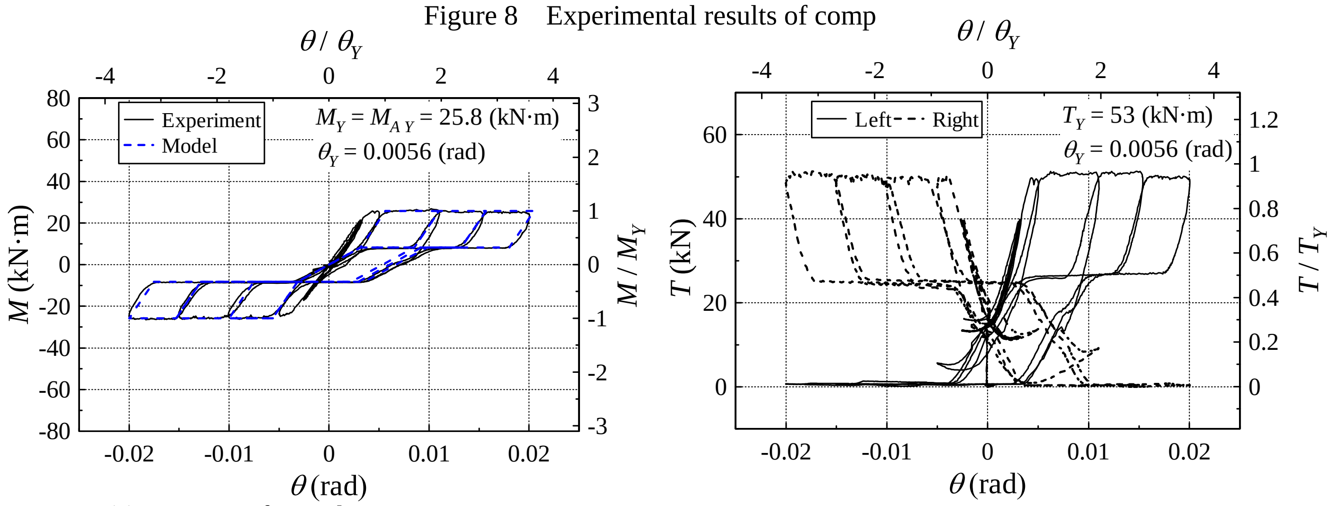
4.3 Axial tension II (Ten II)

The cyclic curves for axial tension II showed perfectly elastic-plastic behavior and were in good agreement with the model of restoring force characteristics, as shown in Figure 10(a). Yield bending strength decreased due to axial tension, and in the final cycle, bending resistance increased due to strain hardening of the anchor bolts. Figure 10(b) shows that all the anchor bolts always resisted axial tension.



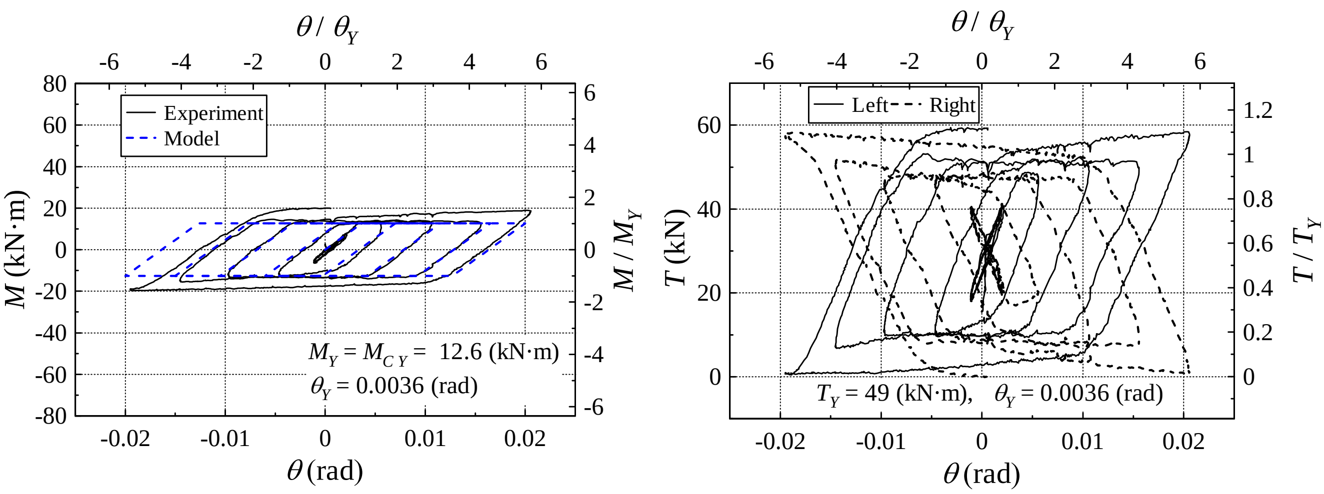
(a) Restoring force characteristics (b) Anchor-bolts tension, T vs. Base plate rotation relation

Figure 8 Experimental results of comp



(a) Restoring force characteristics (b) Anchor-bolts tension, T vs. Base plate rotation relation

Figure 9 Experimental results of ten I



(a) Restoring force characteristics (b) Anchor-bolts tension, T vs. Base plate rotation relation

Figure 10 Experimental results of ten II

5. CONCLUDING REMARKS

An experimental study was carried out on exposed column bases subjected to constant axial force and cyclic horizontal loadings. The following conclusions were obtained:

1) Three types of resisting mechanisms of the column base under a constant axial force were classified to evaluate the yield strength and the elastic rotational stiffness.
2) For axial tension N=0.3Ny, the restoring force characteristics of the column base showed all types of resisting mechanisms.
3) Under axial tension N=0.6Ny, the restoring force characteristics showed perfectly elastic-plastic curves without slip behavior.

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