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The full-scale experiment of "composite-type exposed column bases" for steel buildings

Y. Yanagita[(1)], Y.Arai[(2)], M.Terauchi[(3)],Y.Ishinabe[(4)]

[(1)] *Manager, Institute of Technology, Asunaro Aoki Construction Co., Ltd., yoshinobu.yanagida@aaconst.co.jp*
[(2)] *Research Engineer, Institute of Technology, Asunaro Aoki Construction Co., Ltd., yuichiro.arai@aaconst.co.jp*
[(3)] *Research Engineer, Institute of Technology, Asunaro Aoki Construction Co., Ltd.,masaki.terauchi@aaconst.co.jp*
[(4)] *Associate Prof., Junior College., Nihon Univ., ishinabe.yuichiro@nihon-u.ac.jp*

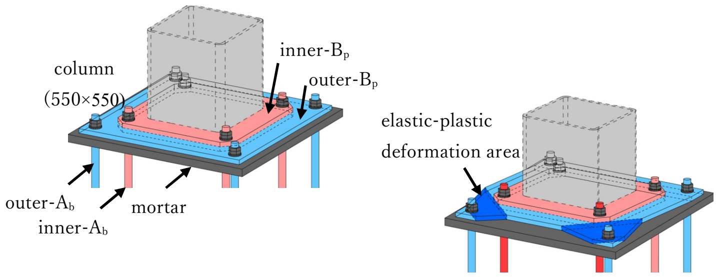
Abstract

In steel frame structures having exposed column bases, the column base yield types are roughly classified into anchor bolt yield type and base plate yield type. The anchor bolt yield type can configure bending strength and bending stiffness widely, and is superior in rotational capacity. However, the restoring force characteristic is slip-type, and energy absorption capacity is inferior. Therefore, the damage to the upper beam in the first story tends to be concentrated. The base plate yield type is rarely used in contrast to the widely used anchor bolt yield type. The main reason is that it is difficult to evaluate bending strength and bending stiffness, and it is difficult to achieve plastic deformation with the maintenance of the elasticity of anchor bolts. On the other hand, the restoring force characteristic is maximum point-orientation type and has excellent energy absorbing ability. The base plate yield type has the effect of alleviating the damage concentration of the upper beam in the first story and dispersing the damage. Avoiding damage concentration is one of the challenges in seismic design. The practical realization of the base plate yield type will provide an advantage in seismic design.

As the solution to achieve the yield mechanism of the base plate, we tried the combination with the anchor bolt yield type. At this time, the two types of seismic elements were arranged in parallel. By arranging them in parallel, it is possible to evaluate bending strength and bending stiffness by simple accumulation, and the disadvantages of each element are complemented by the advantages. In order to make the yield mechanism of the base plate effective, it is important for the base plate to yield almost simultaneously with the anchor bolt with relative displacement. The exposed column base meeting these requirements is called a composite-type exposed column base. As shown in Fig 1, the composite-type exposed column base is composed of two types of anchor bolts and a base plate. Fig 2 shows an outline of a hysteresis curve obtained by simply combining the two restoring force characteristics. After the yielding of inner anchor bolts, its resistance disappears, but the resistance due to the bending deformation of the base plate always acts. Therefore, the composite-type exposed column bases are effective for repeated loads.

In this paper, the full-scale experiment of the composite-type exposed column base is detailed, and the cumulative efficiency of bending strength and bending stiffness is evaluated the comparison between the experiment and the calculation.

Keywords: Composite-type, Cumulative performance, Base plate yield type, Cyclic loading



A_b : anchor-bolt , B_p : base-plate

Fig.1 Member configuration of composite-type exposed column base

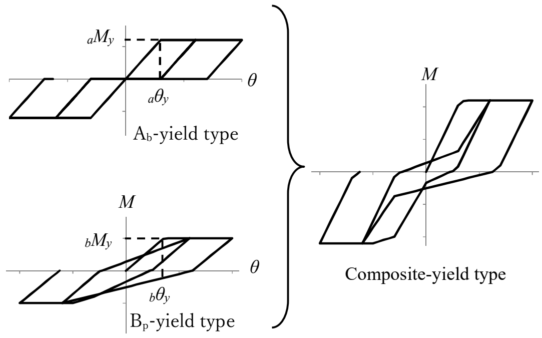


Fig.2 Overview of restoring force characteristics

1. Introduction

In a steel-frame building, the column base is an important part for joining the upper structure and the lower (foundation) structure to each other, regardless of the type of structure. The column base type structure which is widely used is an exposed type column base. Regarding a moment resisting frame structure, the exposed column base which constitutes a plastic hinge on a column base is classified broadly into 2 yield types (anchor bolt yield type and base plate yield type). These yield types have a large effect on factors such as the inter-story deformation angle and the damage distribution. The anchor bolt yield type (A_b yield type) is a yield type that has been used for many years, and its behavioral characteristics have already been clarified [1), 2), etc]. The restoration force characteristics of the A_b yield type are generally referred to as slip type characteristics, and in the slipping state accompanying the development of plasticization, the restoration force does not absorb energy. Consequently, the frame that uses the A_b yield type column base has been pointed out owing to the fact that damage is concentrated in the beams at the top of the 1st story. Due to the history of research[3), 4), 5), etc], carried out on the base plate yield type (B_p yield type), the behavioral characteristics of this type have been clarified. However, it is virtually unused mainly because bending strength and bending stiffness are difficult to be evaluated readily. On the other hand, because the restoring force characteristics are maximum point orientation type, and have excellent energy absorption performance, the B_p yield type is effective as a column base for avoiding the concentration of damage for upper beams on the 1st story. Therefore, improvement of usability of the B_p yield type is held up as an issue. Concerning the history of research on bending strength and bending stiffness of the B_p yield type, some proposal formulae[3), 4), 5), etc], are indicated. Among the references in this paper, the test types shown in Reference 5 are to be used as those that are characterized by simplicity and applicability. The bending strength and bending stiffness of the B_p yield type are determined by the width and plate thickness of the base plate. Because of the shape of a general base plate, its range of dimensions is limited. Consequently, it is extremely difficult to set the same bending strength and bending stiffness as those of the A_b yield type. Also, in consideration of the fact that the bending strength and bending stiffness are low when compared to the A_b yield type, it is not very realistic to use the B_p yield type individually. Accordingly, the authors tried using B_p in combination with A_b yield type which had already been employed conventionally. As the method of combined use, the B_p yield type and the A_b yield type were arranged so that they were in parallel with each other. It was considered that the bending stiffness and the bending strength exist independent of each other, and that the evaluation can be performed by obtaining the sum of both yield types. Also, by installing the yield types in parallel with each other, the merits of both types will compensate the demerits of each other. For this reason, the exposed column base consisting of the A_b yield type and the B_p yield type arranged in parallel is called a composite exposed column base. Figure 1 shows the relationship between the column base bending strength and bending stiffness which conceptually indicates the characteristics of the composite type exposed column base, and the energy absorption capacity. The figure below indicates that 1.0(Fix) is the embedded type column base, and origin point 0 is the pin column base.

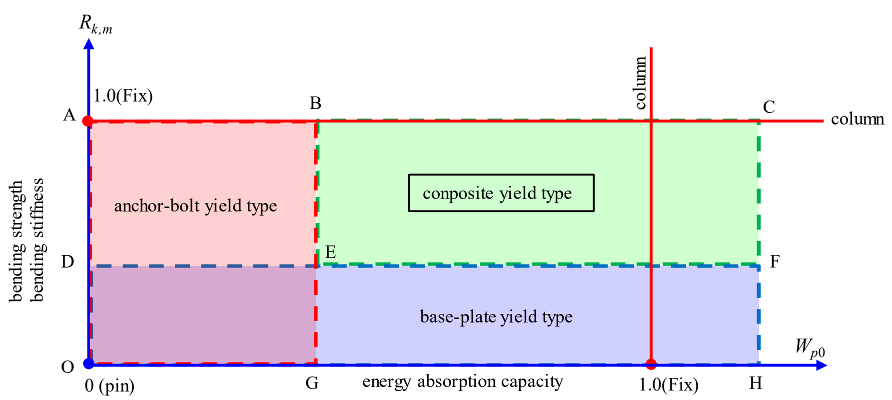


Fig. 1 Conceptual diagram of energy absorption by the exposed type column base

The horizontal axis indicates the ratio of the earthquake energy absorption amount with respect to the 1st story column, and the vertical axis indicates the ratio of the exposed type column base with respect to the bending stiffness and the bending strength of the 1st story column. The A_b yield type is shown in the OABG region, and the B_p yield type is shown in the ODFH region. It can be understood conceptually that the merits and demerits of both of these regions are in a contrasting relationship. The existence of the BCFE region means that it is difficult to be achieved using individual column bases. The composite-type exposed column base can realize the OACH region as a result of simple addition of both types, and includes the BCFE region. From Fig. 1, it can be seen that the bending strength and bending stiffness of the composite-type column base can be set widely, and also that the column base will become an exposed type column base that has excellent deformation performance and energy absorption capacity. The composite-type exposed column base consists of 2 known earthquake resisting elements arranged in parallel, and the behavioral characteristics of each element have been clarified from historical study [6)-9)]. This paper verifies the yield mechanism by means of a full-scale test that assumes commercialization, and also verifies the additivity of the bending strength and bending stiffness in a comparison with the calculated value.

2. Component elements of composite-type exposed column base

Figure 2 shows an outline of the configuration of a composite-type exposed column base, and Fig. 3 shows the deformation state under an earthquake. Figure 4 is an outline drawing showing the fabrication of the base plate. The inner anchor bolts (inner A_b) and the inner base plates (inner B_p) constitute the conventional exposed type column base. However, as shown in Fig. 3, the corners of the inner B_p are chamfered in order to induce the assumed yield line. The outer B_p are unified with the inner B_p by welding (Fig. 4). The elastoplastic deformation region (indicated by the oblique lines in the figure) functions as the B_p yield type. The outer A_b performs the role of a fixed function that causes the outer B_p to generate a relative displacement.

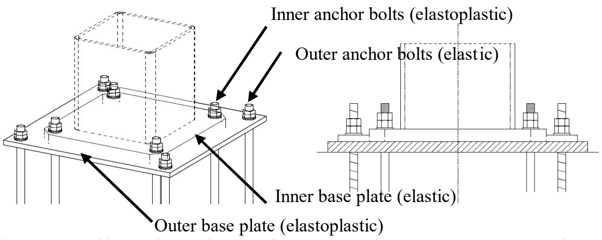


Fig.2 Outline drawing of composite-type exposed column base

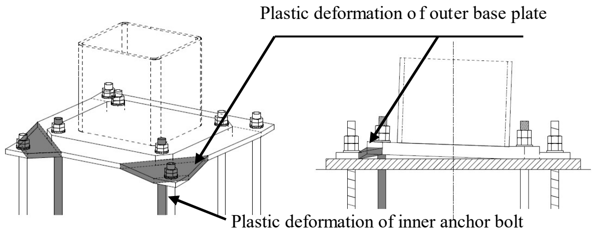


Fig.3 Deformation of composite-type exposed column base during an earthquake

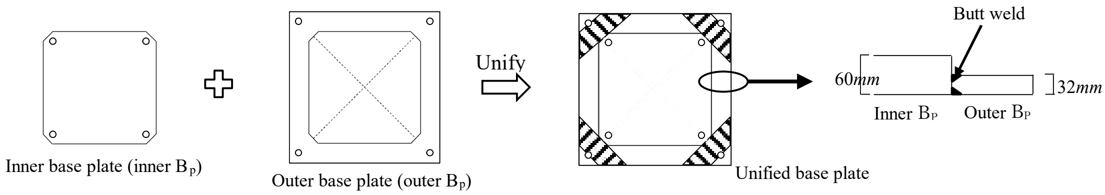


Fig.4 Outline drawing showing manufacture of base plate

3. Design of experiment

3.1 Experiment policy

The test involves fabricating a full-scale test specimen where the foundation concrete has been laid, in order to verify the aseismic performance. It can be seen that, along with the deformation of outer B_p from the former test 6), a prying force (Fig. 5) is generated at the corners. If the prying force causes the mortar at the corners of the base plate to collapse, there will be a risk of the column base rapidly losing its strength.

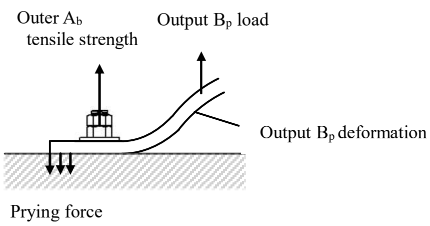


Fig.5 Mechanism of prying force

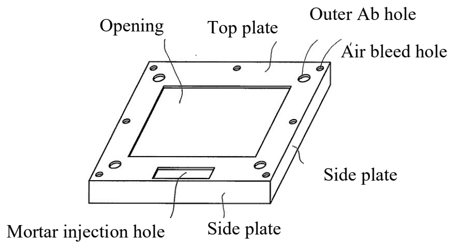


Fig.6 Base mortar reinforcing cover

For this reason, a base mortar reinforcing cover was installed(Fig. 6) to prevent reduction of bending strength during the test. Note that the base mortar reinforcing cover also functions as formwork. The member length of the column was decided upon based on the assumption that the point of contraflexure of the 1st story column that generally possesses an exposed type column base is about 1/3rd of the story height. Two test specimens were prepared. These consist of a test specimen in which no axial force is not loaded (N0 test specimen) and a test specimen in which axial force is loaded (N2640 test specimen). A horizontal force is applied until the column slope angle becomes about 1/30th. In addition, as a simulation of the case where a major earthquake results in damage to the column base, and after the plasticized inner A_b is retightened, the restoration characteristics are verified.

1) Anchor bolt yield type [1)]

Yield bending strength
$$ {}_{a}M_{y} = n_t \cdot {}_{b}a \cdot {}_{a}\sigma_y \left(d_c + d_t\right) + N d_c \quad (1)$$

Bending stiffness
$$ {}_{a}K_{r} = \frac{E \cdot n_t \cdot {}_{b}a \left(d_c + d_t\right)^2}{R \ell_b} \quad (2)$$

Where,

n_t : Number of anchor bolts on the tensile side, Number of anchor bolts arranged on one side of the cross-sectional neutral axis
${}_{b}a$: inner anchor bolt cross-sectional area
${}_{a}\sigma_y$: inner anchor bolt yield stress
E : Young's modulus of steel
ℓ_b : Effective length of anchor bolt
R : Coefficient that depends upon the stiffness of the base plate(=2)

T_a : Net tensile force on anchor bolt
C : Net compressive force from the concrete
d_t : Distance from the centroid of the column cross-section, to the centroid of the group of anchor bolts on the tensile side concerning bending
d_c : Distance from the outermost edge of the compression side of the column cross-section on the compression side, to the centroid of the cross-section of the column
M : Column base moment N : Column axial force

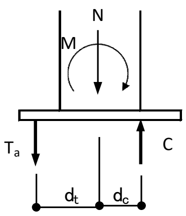


Fig.7 Load resisting mechanism

2) Base plate yield type [5)]

Yield bending strength
$$ {}_{b}M_{y} = \frac{\sigma_y \cdot b \cdot B_o \cdot t^2}{d \cdot c_m} \quad (3)$$

Bending stiffness
$$ {}_{b}K_{r} = \frac{E \cdot b \cdot B_o^2 \cdot t}{150 d \cdot c_m} \quad (4)$$

Where,

b : Average length of assumed yield line
B_o : Width of outer base plate
t_o : Thickness of the outer base plate
${}_{b}\sigma_{yo}$: Yield response of the outer base plate
c_m : Base plate shape coefficient =2.3
E : Young's modulus of steel
d : Width of elastoplastic plate

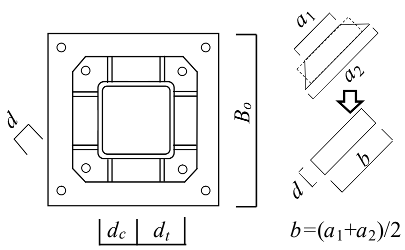


Fig.8 Symbols representing dimensions of each part

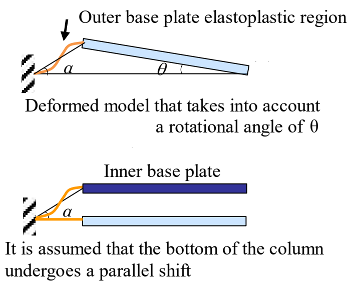


Fig.9 Base plate deformation model

Next, the situation concerning the deformation situation of each member is verified after completion of the test. Finally, the additivity of the column base bending strength and bending stiffness are verified from the test results. Note that in order to calculate the bending strength and bending stiffness from the A_b yield type and the B_p yield type, formulae 1 to 4 were used by reference must be made to References 1 and 5. Figures 7 to 9 are explanatory diagrams.

3.2 Outline of the test specimen

Table 1 shows the specifications of the test specimen, and Fig. 10 shows an outline drawing of the test specimen. For the inner A_b, anchor bolts intended for building construction with certified elongation performance were used. For outer A_b, a certain degree of strength is required, so high-strength deformed bars were used. For the inner B_p, it is necessary to prevent plasticization, so a thickness of about twice that of outer B_p was set. It was assumed that that the columns were side columns, so a T-shaped foundation was adopted. An confirmation of the foundation column was carried out aiming at preventing cone-type failure due to outer A_b, and then the distance from outer B_b was set to 50 mm. The foundation was fixed securely to the reaction floor with PC steel rods. The material test results are shown in Table 2, and the compressive strength of concrete and non-shrinkage mortar are shown in Table 3.

Table.1 The specifications of the test specimen

Name of test body member	Shape of member	Material
Column cross-section	550×550×22	BCR295
Column type cross-section	1250×1250	Normal concrete
Inner base plate	850×850×60	TMCP325B
Output base plate	1150×1150×32	SN400B
Inner anchor bolt	M42 , ℓ=931*mm*	ABR490
Outer anchor bolt	D38 , ℓ=903*mm*	SD490
Rib plate	1250×1250	SM490A

※ Anchor bolt length l indicates the effective length

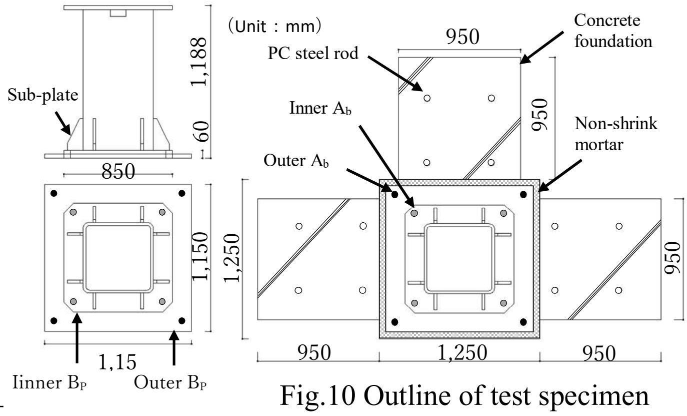


Fig.10 Outline of test specimen

Table.2 Material test results

Member name	Steel type	Yield point (N/mm²)	Tensile strength (N/mm²)	Elongation (%)	Testpiece
Inner B_p	TMCP325B	374.7	509.4	40	No. 4
Outer B_p	SN400B	266.7	424.4	35	No. 1A
Inner A_b	ABR490	338.6	537.5	35	No. 14A
Outer A_b	SD490	532.1	704.2	18	No. 14A
Column	BCR295	347.9	506.5	45	No. 5

※B_p=Base plate , A_b=Anchor bolt

Table.3 Compressive strength of concrete and non-shrinkage mortar

Name of member	Age of member	Compressive strength (N/mm²)	Young's modulus (×10⁴N/mm²)	Poisson's ratio
Concrete	13 days	36.6	2.33	0.21
Mortar	69 days	73.4	3.23	0.25

3.3 Loading and measurement plan

Figure.11 shows the setup situation. A horizontal load is applied to the test specimen by positive-negative alternate cyclic loading. The load application cycle is shown in Table 4. A perpendicular jack maintains the test specimen parallel at all times. Figure.12 shows the method of calculating the column base moment, and also an outline of the measurement positions of the column slope angle R and column base rotation angle θ. Strain gauges are installed on the anchor bolts, base plate, and the column (Fig. 13). The strain gauge on the outer B_p was installed on the assumed yield line.

Table.4 Stress application cycle

	Number of cycles	*N*0 (no axial force)	*N*2640 (with axial force)
Positive-negative alternate repeated loading	1	Elastic range verification Horizontal load 240*kN*	
	2	Short-term allowable bearing strength Horizontal load 480*kN*	
			Introduction of axial force=2640*kN*
			Column member angle *R*=1/133 *rad*
		Column member angle *R*=1/100	*R*=1/100 *rad*
		R=1/67*rad*	*R*=1/67 *rad*
		R=1/50 *rad*	*R*=1/50 *rad*
		R=1/40 *rad*	*R*=1/40 *rad*
	3	*R*=1/33 *rad*	*R*=1/33 *rad*
	Tightening up inner anchor bolt, repair		
	2	*R*=1/33 *rad*	*R*=1/33 *rad*
	1	*R*=1/25 *rad*	*R*=1/25 *rad*

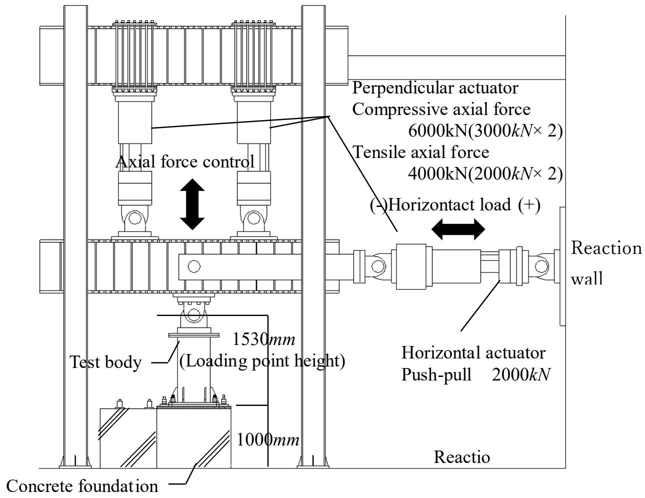
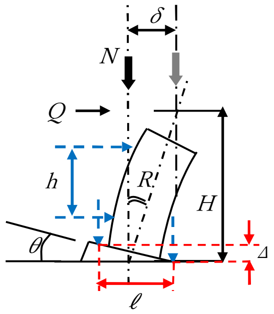


Fig.11 Stress application device



Column base moment $M = QH + P\delta$
Column slope angle $R = \delta / h$
Column base rotation angle $\theta = \Delta / \ell$

N : Axis force, Q : Horizontal force
R : Column slope angle, θ : Column base rotation angle
δ : Horizontal displacement, H : Loding point height
h、ℓ : Distance between measurements
- - → : Mounting position of high sensitivity displacement gauge

Fig.12 Column slope angle and column base rotation angle

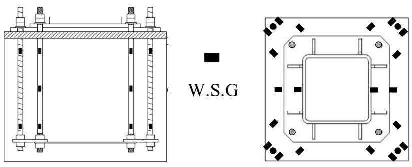


Fig.13 Strain gauge position

4. Experimental Results

4.1 Summary

First, at a column slope angle of roughly 1/100 rad, the inner A_b yielded, and soon after that, outer B_p yielded. It was confirmed that as the rotation of the column base increases, outer B_p deforms as shown in Photo. 1. When the column slope angle reached roughly 1/40, local bending deformation started to occur at outer A_b. Subsequently, outer A_b exhibited a fixed function, without inner B_p or A_b yielding, even when large deformation occurred. Also, cone-type failure of the foundation due to outer A_b did not occur.

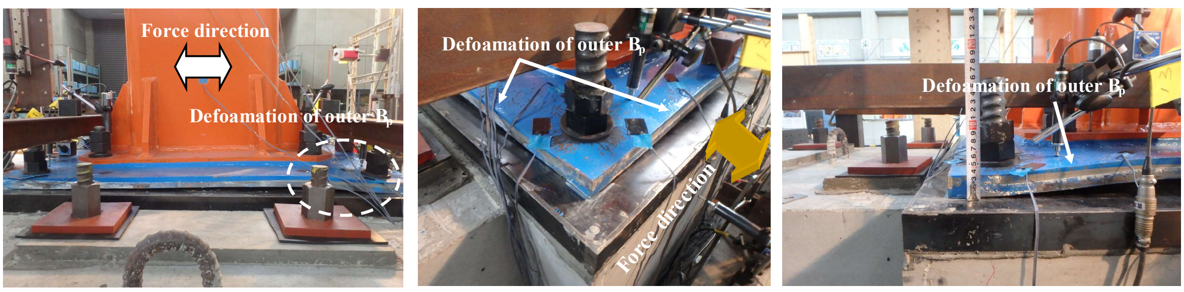


Photo.1 Deformation of outer base plate

4.2 Restoring force characteristics (before repair)

Figure 14 shows the relationship between the column base bending moment (M_b) prior to repair, which was acquired from the results of the test, and the column slope angle(R). The P-δ effect has been removed. In the diagram, the yield points corresponding to the strain values of one of the strain gauges installed on inner A_b

and outer B_p are plotted. The dashed line in the figure is the calculated value of the yield bending strength of anchor bolt yield element(${}_aM_y$), and the solid line is the calculated value of the yield bending strength of the composite-type exposed column base(${}_aM_y+{}_bM_y$). In both, cases it can be seen that A_b yielded from the positional relationship between the plotted yield points, and a short time later outer B_p yielded. Note that regarding the positive direction of the N0 test specimen, it can be seen that the yield of outer B_p has been slightly delayed. This is due to the fact that the bottom surface of the foundation has shifted in the horizontal direction. Except in this case, it can be estimated that both test specimens yield at roughly simulataneous. The fact that inner A_b and outer B_p yielded roughly simulataneous indicates the both are subjected to stress. Also, it can be seen that in the comparison between the column base moment when inner A_b yields, and the calculated value ${}_aM_y$, there is a large difference, so it is clear that another element is carrying the load imposed by the bending moment and the bending rigidity. In other words, it indicates that outer B_p contributed to the improvement of the bending strength and bending stiffness of the column base. While the restoration force characteristics are affected by slip caused by inner A_b, a tendency to aim for the maximum point can be seen, and overall, slip type elements are strongly reflected. This is because the percentage of bending strength of anchor bolt element with respect to the overall yield bending strength was large (roughly 60%).Figure 15 shows the relationship between the column base moment (M_b) and the column base rotation angle (θ_b) in the range that includes the yield point of inner A_b.

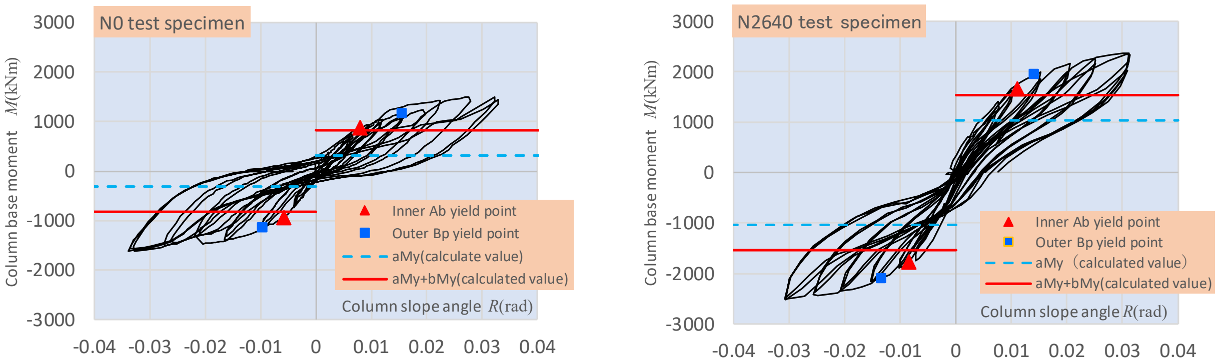


Fig.14 Relationship between column base moment M and column slope angle R

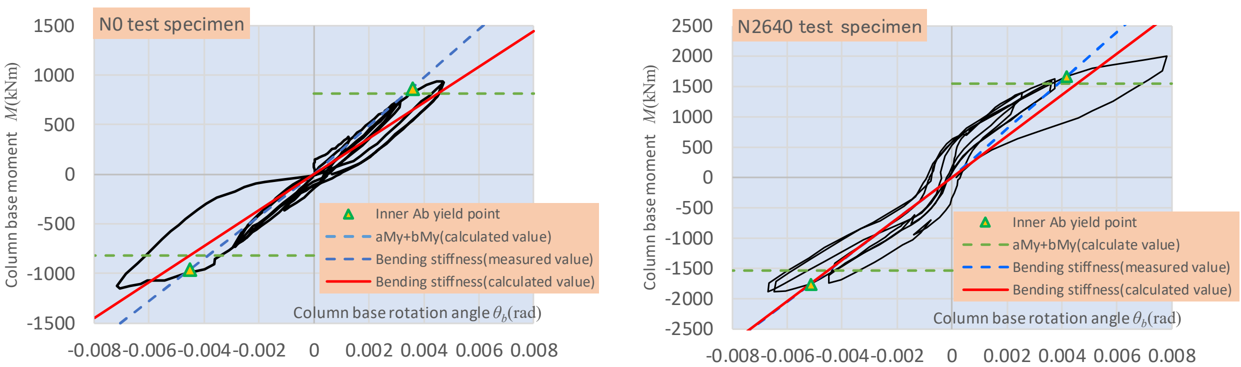


Fig.15 Relationship between column base moment M and column base roatation angle θ_b
(till inner A_b yield cycle)

The figure shows the test values and the calculated values of the bending stiffness. Note that the bending stiffness indicated on the N2640 test specimen takes into account the effective of the axial force (Fig. 16). For both test specimens, it can be seen that the test values and calculated values correspond well with each other. Table 5 shows the test values and calculated values of the yield strength and the bending stiffness. It was found that for both test specimens the test values were higher than the calculated values, and it can be estimated that the calculated values corresponding well with the test values. From these results, it is clear that both bending strength and bending stiffness values have been individually added.

Table.5 Measured values of column base elastic bending stiffness and yield bending strength

Test body	Stress application direction	Axial force (kN)	Elastic bending stiffness (×10^5 kN・m/rad)		Measured value/Calculated value	Yield bending strength (kN・m)		Measured value/Calculated value
			Calculated value	Measured value		Calculated value	Measured value	
N0	+	0	1.80	2.43	1.35	816.3	868	1.06
	−			2.12	1.18		-957	1.17
N2640	+	0	1.80	2.24	1.24			
	−			2.20	1.22			
	+	2640	3.40	3.97	1.17	1542	1666	1.08
	−			3.43	1.01		-1765	1.14

* The elastic bending stiffness (measured value) was calculated from the column base angle and the base column moment as the initial stiffness.

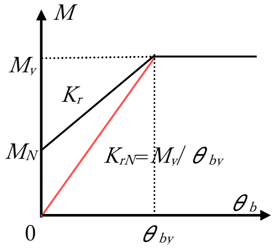


Fig.16 Column base bending stiffness

4.3 Calculaction of axial force in anchor bolts acting and column base moment

In this section, the additivity of the column base bending moment is verified from acting axial force in the inner A_b and outer A_b. The acting axial force is calculated using the material test results of the anchor bolts (axial cross-sectional area, strain value, Young's modulus). The column base bending moment load carried by inner A_b and outer A_b from the acting axial force is required based on the load-resistance mechanism shown in Fig. 17 by using the following formulae. The additivity of the bending strength is by comparing the sum of two calculated values with the test value. The acting axial force on the anchor bolts uses the axial force corresponding to the occurrence of the maximum bending moment during each cycle. Note that the average value on the strain gauge installed on the topmost point was used as the strain value for the anchor bolt .

$$ {}_aM_y = n_{ti} \cdot T_a(d_c + d_t) \tag{5} $$

$$ {}_bM_y = n_{to} \cdot T_b(d_c + d_s) \tag{6} $$

Where,

T_a : Inner A_b acting axial force, n_{io} : Number of inner A_b
T_b : Outer A_b acting axial force, n_{to} : Number of outer A_b
d_t : Distance from the centroid of the column cross-sectional to the centroid of the inner A_b group on the tensile side
d_c : Distance from outermost edge of the column cross-section on the compression side to the center of the diagram of the column cross-section
d_s : Distance from the centroid of the column cross-sectional to the centroid of the outer A_b group on the tensile side$M$: Column base moment , N : Column axial force

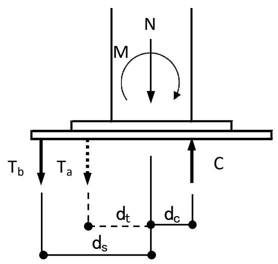


Fig.17 Load-resisting mechanism

Figure 18 shows the relationship between the axial force (T) and the column slope angle (R) calculated from the strain values of inner A_b and outer A_b in the maximum bending moment of the column base, for each cycle. Concerning inner A_b, it can be seen that for the cases of both the N0 and N2640 test specimens, after the yield axis force indicated by the calculate values has been reached, only the deformation progresses, and in the region of strain hardening, the axial force has risen again. On the other hand, it can be seen that the acting axial force of outer A_b increases roughly in direct proportion to the column slope angle. This trend is unrelated to the plasticization of inner A_b. The increase of the axial force acting on outer A_b, along with the deformation of the column base, indicates that because outer A_b exhibited a fixed function, the bending resistance that occurs at outer B_p is transmitted to outer A_b as an axial force.

Next, The column base bending moment is obtained by multiplying the acting axial force of the anchor bolt by the distance from to the rotation axis(column outer surface)shown in Fig18. The M-R relationship

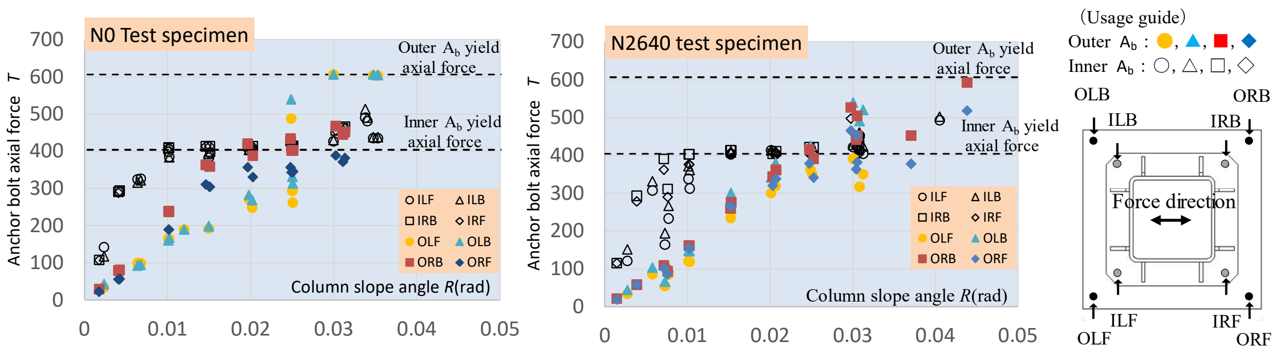


Fig.18 Relationship between anchor bolt acting axial force *T* and column slope *R*

obtained by simple cumulative[$_aM_y+_bM_y$] of the column base bending moment is shown in Fig. 19 as a contrast between the calculated value and the test values. The solid line in the figure indicates the maximum bending moments that are joined together, for each cycle. Note that in this paper, the curve that joins the maximum bending moments together approximates a skeleton curve, so it is called an approximate skeleton curve. The calculated value is somewhat smaller than the test value. One conceivable reason for the difference in the test value is the shift of the rotation axis. In calculating the column base moment, the rotation axis is set to the outer edge of the column. In actual behavior, however, because the stiffness of the inner base plate is high, it is quite conceivable that the rotation axis has shifted outward from the outermost edge of the column. It can be said that by taking the above into consideration, the calculated value is close to the test value. Regarding the composite-type exposed column base, it can be judged from the above that the column base bending moment occurred as a result of simple addition of anchor bolt yield type and base plate yield type.

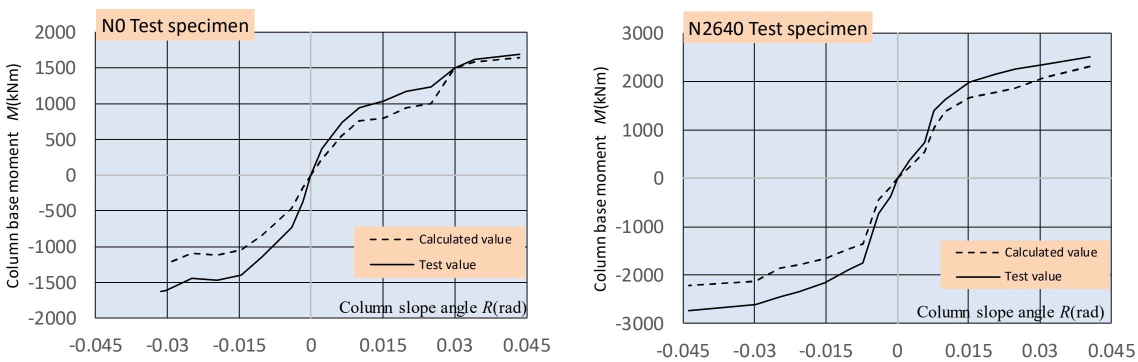


Fig.19 Approximate skeleton curve

4.4 *M-θ* relationship after repair

Figure 20 shows the relationship between *M* and *R* after repair. It can be seen that immediately after inner A_b has been retightened, the bending stiffness has recovered. Subsequently, the same history characteristics as those existing prior to repair are retained, and energy is absorbed. Compared to the *M-R* relationship that existed prior to repair, inner A_b after repair is adequately plasticized, and the maximum point orientation type characteristics are indicated. On the other hand, the reason why the effect of slippage can be seen is because in addition to the plasticization of inner A_b, a gap has formed between the nut and outer B_p along with localized bending deformation of outer A_b. It can be seen that the bending strength has not decreased, but rather has increased, even under large deformation.

Next, Fig. 21 shows the strain values of inner A_b before and after repair. The legend abbreviation conform to Fig. 18. For both test specimen N0 and test specimen N2640, inner A_b has reached yield strain from roughly where the column slope angle exceeded R = 1/100 rad. Subsequently, the strain increased from 1.5% to about 2.0% at a column slope angle of R = 1/33 rad.

The strain value at the point in the column slope angle R = 1/33 rad after repair is indicated by the filled symbol. However, it can be seen that even after the bolts have been tightened up, the strain on the axis has increased, so inner A_b exhibited adequate plastic deformation performance. It is conceivable that the N0 test specimen is not subjected to axial force, so the outer B_p rotation deformation increases. Consequently, the elongation of inner A_b also increases, and the strain increases as well.

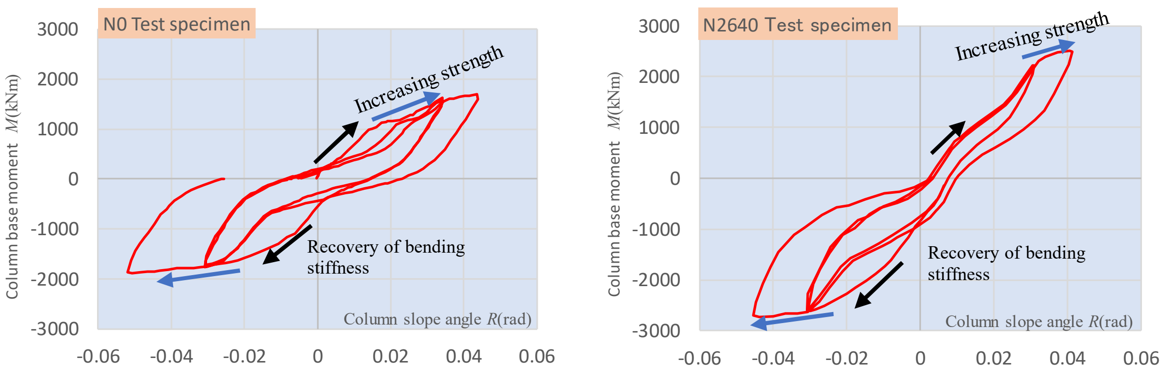


Fig.20 Relationship between M and R after repair

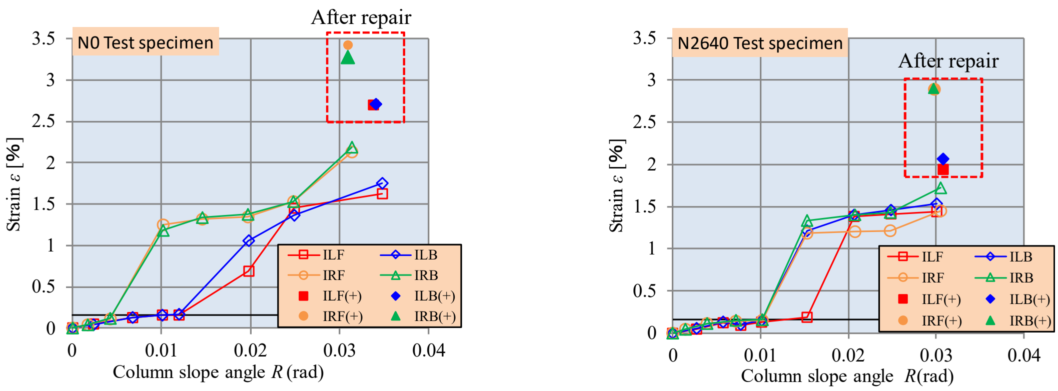


Fig.21 Relationship between ε and R after repair

4.5 Increased yield strength after yield

It can be seen from Fig. 14 that the composite type exposed column base has characteristics that prevent the bending strength from decrading, but rather enable it to rise, even when there is large deformation (column slope angle). It is considered that this is due to the effect of the mutual counter-direction relationship (Fig. 22) between the rotation axis of the bending moment due to inner A_b and the rotation axis of the bending moment due to outer B_p. Along with the rotation of the column base, a bending moment resulting from relative displacement appears at B_p. It is thought that as the relative displacement increases, the tensile force acting on outer-B_p gradually increases. The increase in strength is thought to be due to the fact that as the deformation becomes larger, the tensile force that acts on outer B_p increases. The ratio of maximum strength M_u with respect to the yield bending strength M_y is defined as strength increasing ratio S_a. It can be seen that when the column slope angle is 1/25 rad, the strength increasing ratio in this test rises to roughly 1.4. In the design, it is important that outer A_b does not yield to the increase in axial force during large deformation. Note, however, that it is necessary to be aware of the importance of carrying out a design which takes into consideration the strength rising rate with respect to outer A_b.

$$S_a = M_u / M_y \fallingdotseq 1.4 \tag{7}$$

In the case of an exposed type column base of the anchor bolt yield type, it can be seen that as the deformation become large, the strength decreases due to the P-δ effect (Fig. 23). In contrast to this, the strength of the composite-type exposed column base increases as a result of the tensile force generated at outer B_p. The strength increasing cancels the negative stiffness effect due to the *P*-*δ* effect. Figure 24 shows approximate skeleton curves before and after removal of the *P*-*δ* effect. It can be seen that the decreasing of the column base bending moment is not visible. The composite-type exposed column base can be said to be an exposed type column base that has characteristics that compensate for the *P*-*δ* effect.

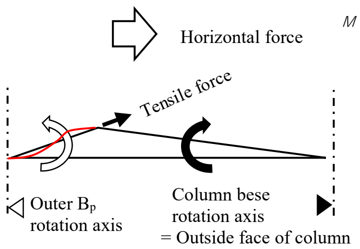


Fig.22 Outer B_p and column base rotation axis

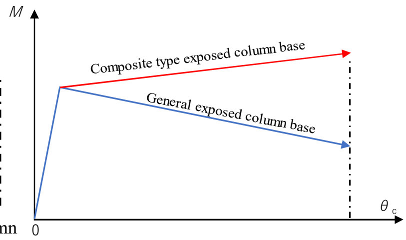


Fig.23 *P*-*δ* suppression effect

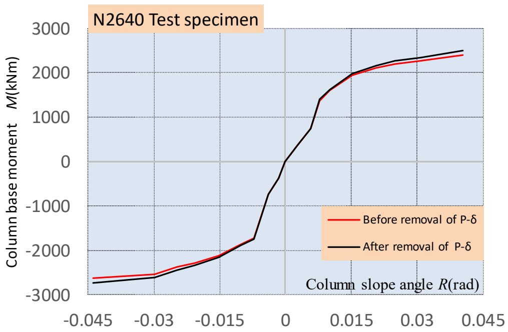


Fig.24 approximate skeleton curves before and after removal of the *P*-*δ* effect

5. The condition after the experiment

Photo. 2 shows the condition regarding the base mortar and the base plate before and after the test. It was confirmed that the base mortar at the bottom had no gaps, and also there was no significant damage.It was found that the mortar at the corners where stress is concentrated had incurred major damage, and cracked. However, no reduction of stiffness or strength in Fig. 14 and 20 was found, so it can be said that the base mortar reinforcing cover performs an important role in protecting the mortar.

It can be seen that outer A_b is deformed in the direction of the outer side. This indicates that, as shown in Fig. 22, the rotation axis of the column base and also the rotation axis of the base plate have mutually opposite directions. Also, it was confirmed that the deformation of outer B_p was roughly the same as th at shown in Fig. 3.

Photo.2 Situation regarding the base mortar and the baseplate after the the test

6. Conclusion

In this paper, the following knowledge was acquired from the results of performing a full-scale test of a composite-type exposed column base consisting of an anchor bolt yield type and a base plate yield type installed parallel to each other.

(1) This test indicates that the bending strength and bending stiffness can be evaluated by performing simple addition of A_b yield type and B_p yield type by comparison with the calculated value.

(2) The axial force was calculated from the magnitude of the strain acting on the anchor bolt, and it was found that the column base moment based on the load-resistance mechanism was roughly equal to the yield bending strength of the test value. Consequently, the bending resistance can be evaluated by simple addition of both types.

(3) The restoring force characteristics differ from a slip type in that after inner A_b yields, the test specimen tends to be oriented at the maximum point, while being affected by the slip type. Also, the reason why the effect of slippage is visible in the case of large deformation when A_b has adequately plasticized, is due to the fact that there are gaps between the nut and outer B_p, along with localized deformation at outer A_b.

(4) It was confirmed that after inner A_b had been repaired by tightening up, the bending stiffness recovered, and also the restoring force characteristics had the same tendency as that which existed prior to repair. In addition, the bending stiffness does not decrease, but rather increases once a certain inclination is reached.

(5) After inner A_b yielded, the strength rising ratio under the 1/25 column slope angle was approximately 1.4.

(6) Local bending deformation occurred at outer A_b. However, even when the column slope angle was 1/25, a fixed function was exhibited without the occurrence of axial yielding.

(7) From the condition after the test, it was confirmed that the deformation at outer B_p was the same as that indicated in Fig. 3. Also, cone-type failure at the foundation concrete due to outer A_b did not occur.

(8) The base mortar reinforced cover was found to have a role in protecting the mortar.

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