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Influence of Details of Column Bases on Structural Behaviour

Influence des socles de colonne sur le comportement structural

Einfluß der Stützenfussplatte auf das strukturelle Verhalten

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SUMMARY
There are three types of column bases, which have been used conventionally in steel structures, namely exposed type, encased type and embedded type. In this paper, their mechanical performances will be discussed respectively. In addition, a new type column base with brackets will be introduced. It will also be shown that this new type column base has a sufficiently high degree of fixity and that its restoring force characteristics are of stable hysteretic form. Further, the relation between the column base fixity and the frame deformation will be discussed.

RÉSUMÉ
Trois types de socles de colonne sont utilisés dans les structures en acier: embase nue, embase fermée et embase encastrée. Les caractéristiques mécaniques de chacune sont exposées dans ce rapport. En outre, un nouveau type d'embase de colonne à cornières est présenté. Ce nouveau type d'embase présente un haut degré de rigidité et les caractéristiques de sa contrainte spécifique présentent une hystéresis stable. La relation entre la rigidité de l'embase et la déformation de la structure est abordée.

ZUSAMMENFASSUNG
In Stahlstrukturen werden normalerweise drei Arten von Stützenfussplatten verwendet, der freiliegende Typ, der geschlossene Typ und der eingebettete Typ. In dieser Schrift wird das Tragverhallen dieser Ausführungen verdeutlicht. Zusätzlich wird eine neue Stützenfussplatte mit Konsolen vorgestellt. Es ist auch ersichtlich, daß dieser neue Typ der Stützenfussplatte einen ausreichenden Einspanngrad sowie stabile Kraftkennlinien aufweist. Weiter wird der Zusammenhang zwischen dem Einspanngrad des Stützenfusses und der Verformbarkeit des Rahmens diskutiert.

1. INTRODUCTION

The column bases in a steel structure play a very important role in connecting the columns to the foundation. In Japan, steel structures, when a large lateral load is applied at the time of an earthquake, storm or the like, often collapse owing to the inadequate design and/or construction of their column bases. Column bases are composed of steel and concrete, which are foreign to each other. Unlike the connections in superstructures, the studies involving column bases had drawn little attention until quite recently when the importance of the subject began to be recognized and more papers are now being published. The Japanese seismic design standards regulate that the story deflection shall not exceed 1/200 of the story height as shown in Fig. 1. However, where the column base fixity is poor, the column member sections should be increased to satisfy this requirement. Dr. Akiyama states that in the case of a multi-story building wherein all stories have the perfect elasto-plastic type restoring force characteristics except one story that has a mixture of different restoring force characteristics (e.g. perfect elasto-plastic type and slip type), the damage would be concentrated in that one story. He also asserts that in case the second story and upward stories have the perfect elasto-plastic type restoring force characteristics and only the first story has a different type of restoring force characteristics (e.g. slip type), the damage would be concentrated in that first story [1]. Thus, the mechanical performance, such as rotation rigidity and restoring force characteristics, of the column bases greatly affects the entire structure's resistance against earthquakes. Therefore, it is very important to clarify the mechanical performance of this part of the structure. Conventionally, three types of column bases have been in use, namely 1) exposed type, 2) encased type and 3) embedded type as shown in Fig. 1. On the other hand, recently in Japan cold-formed square steel tubes are widely used as columns, but the mechanical performances of these columns in combination with column bases of different types had not been clarified sufficiently. It was under these circumstances that the authors of this paper in collaboration with their colleagues have experimentally clarified the mechanical behaviours of the column bases. As the result, it was found that the behaviours of the conventional type column bases were not satisfactory from the view point of both design and construction. Therefore, an effort was made to improve the conventional type column bases, resulting in the introduction of a new type of column base, namely 4) column base with brackets, as shown in Fig. 2. This new type column base consists of a pair of H-section steel brackets welded to the adjoining faces of the tubular column. The base and the bracket ends are fixed by the anchor bolts welded to the standardized anchor frame as shown in Fig. 3. The bracket portion is then buried in the concrete floor of the building. This type of column base has been employed in mass production housing construction and its installation method is now systematized. Lateral force was applied to full-size models of this type of column base to clarify their mechanical behaviours. Further, assuming three different structural frames, the relationship between the rigidity of column bases in the frames and the moment distributions of the frames and that between the rigidity of column bases and the horizontal deflections were clarified and the design method of this type of column base is discussed.

2. MECHANICAL BEHAVIOUR OF STEEL COLUMN BASES

Firstly, the results of the study made of the mechanical performances of the three conventional type column bases, as shown in Table 1, will be described, and thereafter the new type column base will be described.

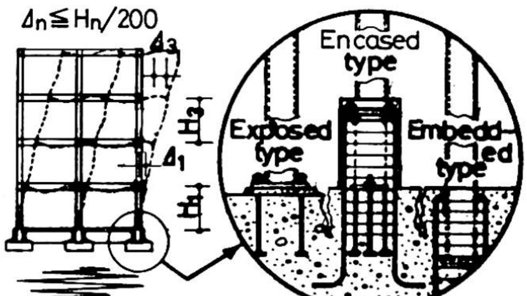
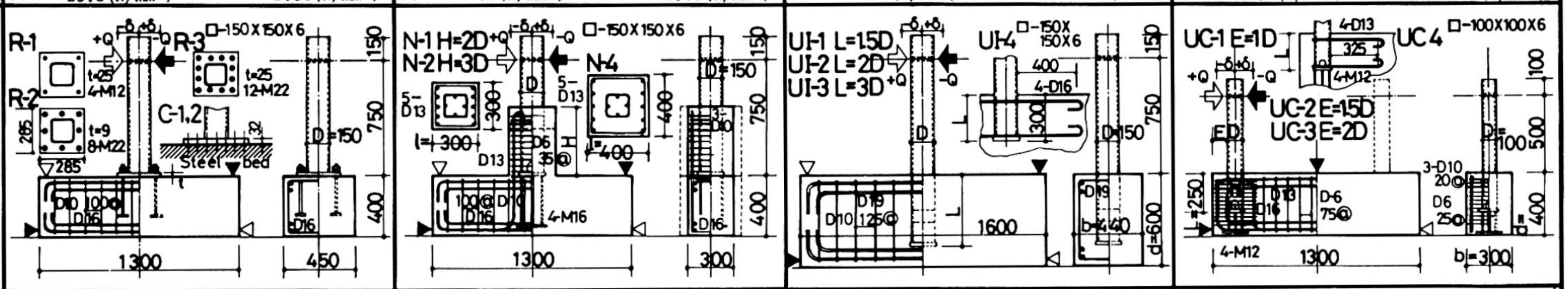


Fig.1 Three conventional type column bases

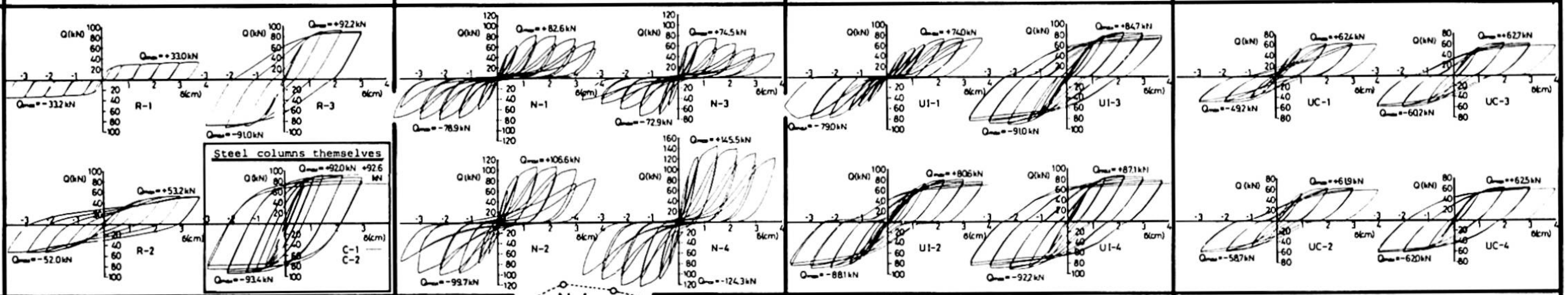
Table 1 Mechanical characteristics of three conventinal type column bases

	Exposed Type (R Type)	Encased Type (N Type)[2]	Embedded Type (U Type): Interior Column (UI Type)[3]	Embedded Type (U Type): Exterior (Corner) Column (UC Type)[4]
Test Program	B.Pl A.Bt R-1 25(t) 4-M12 R-2 9 8-M22 R-3 25 12-M22 C-1,2 32 34-M24 Column □-150x150x6.0 B.Pl 285x285	L/D l/D Hoop N-1 2 2 35@ N-2 3 2 35@ N-3 3 2 No N-4 3 2.67 35@ Column □-150x150x6.0 B.Pl 160x160x19 A.Bt 4-M16 Chord Rein. 10-D13 Top Hoop 3-D10 25@	L/D UI-1 1.5 UI-2 2.0 UI-3 3.0 UI-4 2.0 Anchor Rein. 4-D16 Column □-150x150x6.0 Foundation bxd=440x600 Reinforcement 8-D19	E/D UC-1 1.0 UC-2 1.5 UC-3 2.0 UC-4 1.0 A.R.4-D13 Column □-100x100x6.0 Foundation bxd=300x400 A.Bt 4-M12 L=2.5D Chord Rein. 4-D16 | Hoop Top Hoop 3-D10 20@ | D6 25@
Mechanical Properties of Steel	σy σmax El. (N/mm²) (%) C. 348 421 35 B.Pl 350 465 33 A.Bt M12 376 522 31 A.Bt M22 320 470 30 σy σmax El. (N/mm²) (%) D10 371 518 21 D16 419 572 21	σy σmax El. (N/mm²) (%) C. 348 421 35 B.Pl 300 461 33 A.Bt M16 322 439 31 σy σmax El. (N/mm²) (%) D 6 305 445 25 D10 371 518 21 D13 375 560 21 D16 419 572 21	σy σmax El. (N/mm²) (%) C. 351 406 33 B.Pl 300 461 33 σy σmax El. (N/mm²) (%) D10 517 713 16 D16 517 743 14 D19 379 563 19	σy σmax El. (N/mm²) (%) C. 407 465 23 B.Pl 325 450 34 A.Bt 312 440 32 σy σmax El. (N/mm²) (%) D 6 361 485 22 D10 377 512 25 D13 367 534 22 D16 383 563 22
P.Con.	σc 25.5 (N/mm²) σt 2.38 (N/mm²)	σc 24.2 (N/mm²) σt 2.35 (N/mm²)	σc 29.5 (N/mm²) σt 2.77 (N/mm²)	σc 30.1 (N/mm²) σt 2.45 (N/mm²)

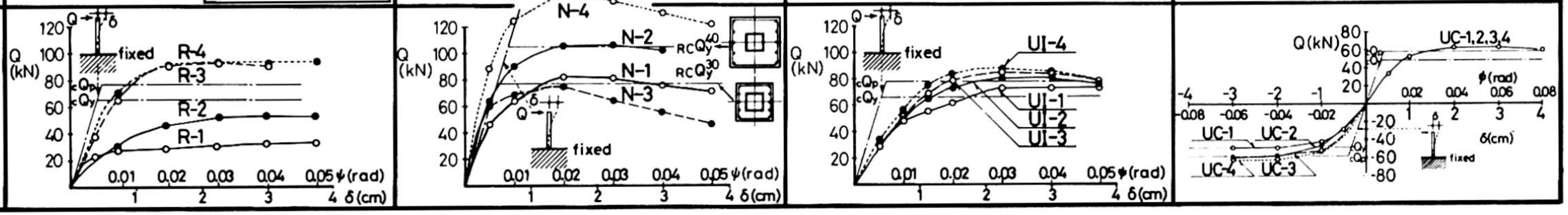
Specimens



Q-δ Curves



Envelope Curves of Q-δ Curves



2.1 Exposed Type Column Base (R Type)

This column base is composed of a base plate welded to the column bottom and anchor bolts. The initial rigidity is well in accord with the test result if the modulus of elasticity of the anchor bolt including the threaded connection of the anchor bolt and nut is assumed to be E/2. (E: Elastic modulus) When the anchor bolts yield, the restoring force characteristics will be of the slip type (R-1), and when the base plate yields the spindle shaped restoring force characteristics will be obtained. (R-2) If large rotation rigidity is to be obtained and a fully plastic load of the column is to be transmitted, this type of column base must have large anchor bolt sections and the base plate must be considerably thicker and the installation work will become difficult. (R-3)

2.2 Encased Type Column Base (N Type) [2]

This type of column base consists of a steel column base of a relatively small flexural rigidity enclosed by reinforced concrete to secure the required strength and rigidity, both of which increase as the concrete cover thickness and/or the encasement height increases. In this case, the uppermost hoop reinforcement of the encasement must be properly laid out. When the encasement height is approximately 3 times the column depth (D) and if sufficient care is given to its detail, its fixity can be considered to be perfect. (N-2,3,4) However, the restoring force characteristics of this column base type, if the concrete cover is of ordinary thickness, will be of the slip mode. (N-1,2,3,4) Further, the column base volume increased by the encasement concrete sometimes interferes with design flexibility.

2.3 Embedded Type Column Base (U Type) [3],[4]

The initial rigidity of this type column base is 50% to 70% of that of the steel column itself which is assumed to have been fixed to the foundation beam top. The mechanical properties are different between the interior column and the side column (or corner column) whose concrete cover is thin (UC-1). In the case of the former, even in the absence of any special reinforcement, the restoring force shows spindle shaped characteristics if the depth of embedment is sufficient (normally approx. 2.5D). (UI-2,3) In the case of the latter, it is necessary to reinforce the concrete top and the base plate level. The column, then shows the mechanical behaviours of an interior column if it is reinforced sufficiently by hoops and an end distance of at least 2D is provided. (UC-3) Efficient methods of reinforcement in this case are the use of welded anchor bars (UC-4) or U-shape bars. In the case of this column base type, difficulties are often encountered in concrete placement for the foundation beam when the embedment depth is great.

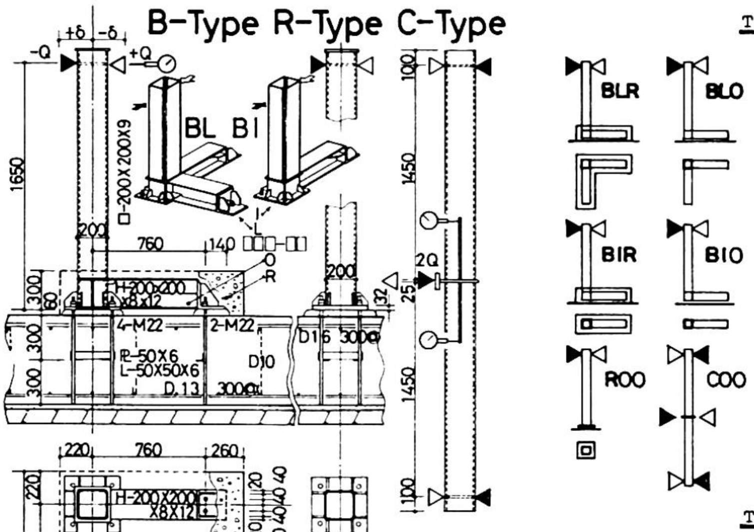
2.4 Bracket Type Column Base (B Type)

2.4.1 Experiment Program

As mentioned before, this type column base is shown in Figs. 2 and 3. Upon this type of column base model, monotonic and repeated loads were applied by a hydraulic jack through a hinged attachment at a conceived inflection point. The experimental factors were the presence or absence of brackets (L, I) placed at right angles with the loading direction and the presence or absence of encasement concrete (R, O). In addition, two exposed type specimens without brackets (RO) and two beam type specimens (CO) were planned, of which the beam type specimens were intended for examination of the mechanical performance of the steel column itself. The results of the elemental material tests are shown in Table 3.

2.4.2 Results of Experiments and Discussions

The relationships between the load (Q) applied on the column and its horizontal



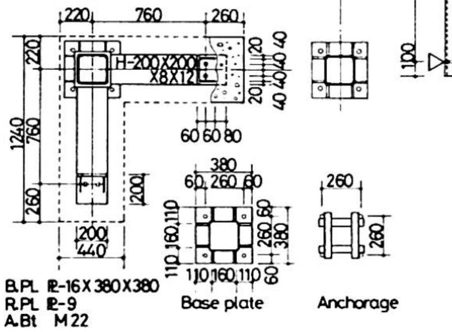


Fig.2 Test specimens

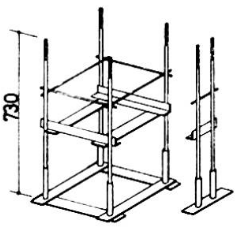


Fig.3 Anchor frames

Table 2 Test program and test results

*1 M : Monotonic load
R : Repeated load
*2 Measured at 40 kN

Type	M*1 or R	Sym	Specimen Symbol	Displacement*2 + (cm)	Displacement*2 - (cm)	K ($\times10^5$ kNcm/rad) (+)	K ($\times10^5$ kNcm/rad) (-)	$+Q_{max}$ (kN)	$-Q_{max}$ (kN)
B	+M	A	BLR-M1	0.723	—	—	—	147	—
	-M	B	BLR-M2	0.751	-0.825	—	—	149	-142
	R	C	BLR-R	0.701	-0.834	—	—	153	-146
				0.725	-0.830	72.8	40.5		
	+M	D	BLO-M1	0.860	-0.955	—	—	150	-147
	-M	E	BLO-M2	—	-0.956	—	—	—	-148
	R	F	BLO-R	0.921	-1.040	—	—	148	-142
				0.891	-0.984	32.2	24.6		
	+M	G	BIR-M1	0.700	—	—	—	152	—
	-M	H	BIR-M2	—	-0.750	—	—	—	-152
	R	I	BIR-R	0.757	-0.826	—	—	147	-141
				0.729	-0.788	70.7	49.3		
	+M	J	BIO-M1	0.874	-0.971	—	—	147	-145
	-M	K	BIO-M2	—	-0.948	—	—	—	-136
	R	L	BIO-R	0.862	-0.960	—	—	144	-139
				0.868	-0.960	34.9	26.2		
R	M	M	ROO-M	—	—	—	—	58.0	—
	R	N	ROO-R	—	—	—	—	56.2	-54.0
				—	—	9.29	12.7		
C	M	O	COO-M	0.539	—	—	—	148	—
	R	P	COO-R	0.541	0.544	—	—	142	-142
				0.540	0.544	—	—		

Table 3 Mechanical properties of steel and concrete

Steel	σ_y (N/mm²)	σ_{max} (N/mm²)	E ($\times10^5$ N/mm²)	El. (%)
□-200x200x9	395	446	1.87	38
H-200x200x8x12	301	486	2.11	38
B.PL	322	493	2.05	24
A·Bt (M22)	340	540	2.10	26
D16	546	761	2.15	10
D13	499	713	2.10	13
D10	351	494	2.13	12

Concrete		σ_c (N/mm²)	σ_t (N/mm²)	E_c ($\times10^4$ N/mm²)
Concrete	Foundation	21.5	1.86	1.98
	Encasement	22.3	1.74	2.05
Mortal	—	44.6	5.19	—

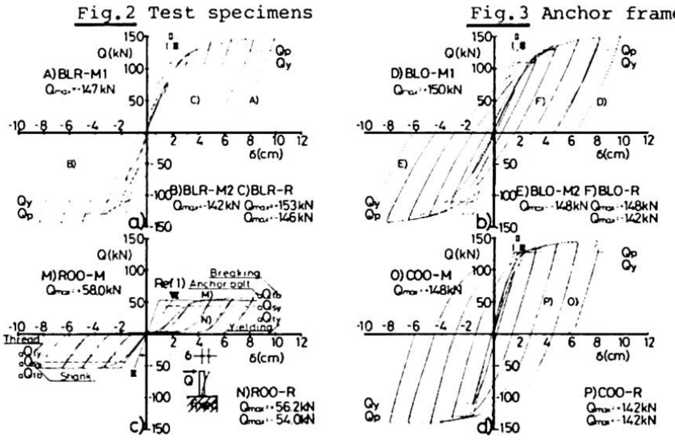


Fig.4 Q-δ curves

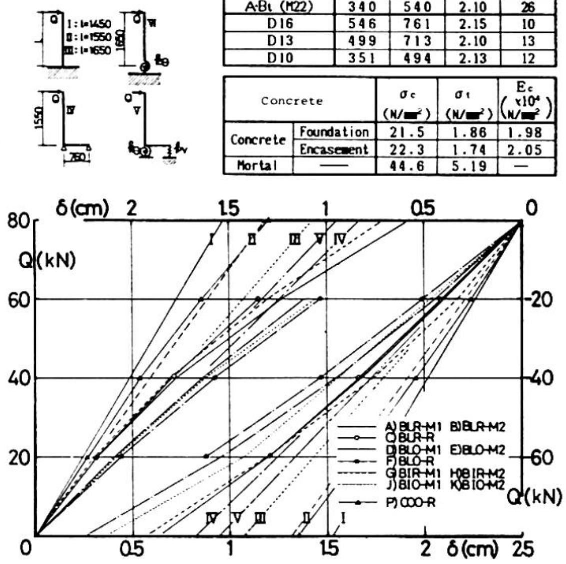


Fig.5 Initial Q-δ curves

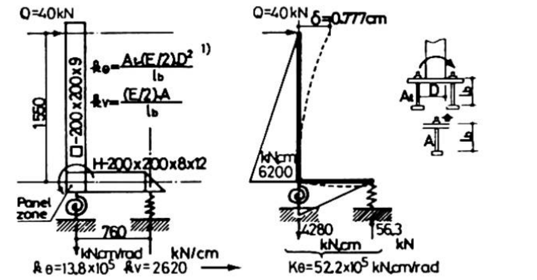


Fig.6 Structural analysis model

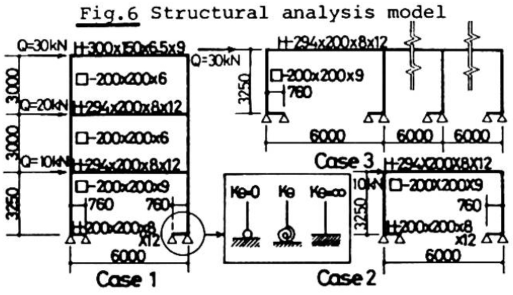


Fig.7 Three model frames conceived for structural analysis

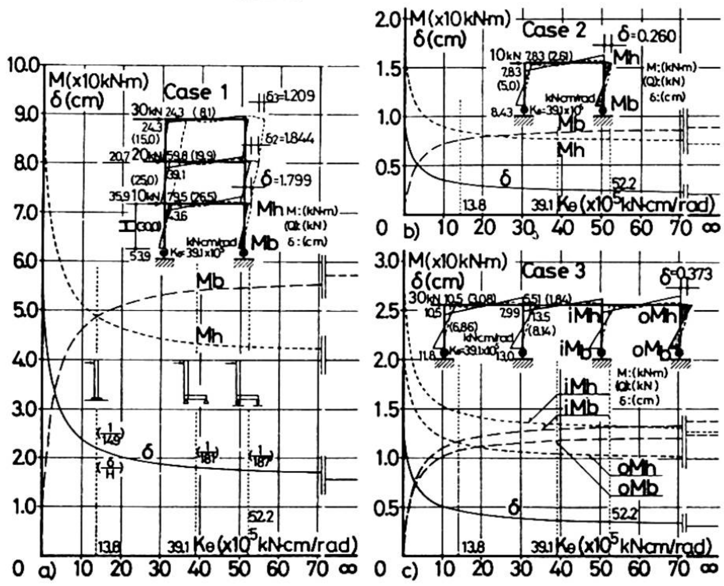


Fig.8 Moment and deflection of 1st story of analysis frames

deflection (δ) are shown in Fig. 4. Fig. 4-d) shows the Q-δ curves of the steel column itself. All bracket type (BL, BI) specimens showed stabilized spindle shaped loops as shown in Fig. 4 a) and b). The initial Q-δ relationships are shown in Fig. 5, and the deflections at Q = ±40 kN and the equivalent spring constants of the column base including bracket obtained from the values of such deflections are shown in Table 2. The rotation rigidity of the column base covered with concrete was approximately two times that of the column base without concrete cover. The rotation rigidity of the exposed type column base without brackets was considerably small. The calculated values I, II and III in Figs. 4 and 5 represent Q-δ relationships of the steel column itself, and the value VI represents those where the column base and the bracket ends were assumed to have been supported with pins. The calculated value V was obtained by computer analysis through replacement of the bending moment rotation rigidity of the column base with an equivalent rotation spring in accordance with the Akiyama Method [1] and through evaluation of the bracket end expansion and contraction rigidity in terms of an equivalent expansion and contraction spring, and also with consideration of the effect of the shear deformation of the panel zone, as shown in Fig. 6. From the calculated values IV and V through the replacement of the column base including bracket with an equivalent rotation spring, ${}_{IV}K_{\theta}$ = 39.1 x 10^5kN.cm/rad and ${}_{V}k_{\theta}$ = 52.2 x 10^5kN.cm/rad will be obtained respectively. In the absence of a concrete cover, the rigidity by the calculated value V tends to be over-estimated, however in the presence of a concrete cover, it will be close to the value V and sufficiently safe if the design is based on the assumption of the value IV.
The relationship between the column base rotation rigidity and the column head and column base moment of the first story and also that between the column base rigidity and story deflection of the first story when a hypothetic lateral force is applied to the three model frames conceived as shown in Fig. 7 are respectively shown in Fig. 8. From these figures, it is shown that the column base with brackets may be regarded as perfect fixity. This type of column base is widely used in prefabricated house construction in Japan as it allows efficient installation with high degrees of fixity and stable restoring force characteristics.

3. CONCLUSION

The experiments and discussions performed have clarified the mechanical behaviours of the conventional type column bases. It was also shown from the behaviours of the structures and their components that the column base with brackets excels in rotation rigidity and restoring force characteristics as well as reliability from the standpoint of field application.

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