Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 13 (1988)

Artikel: Non-welded structural system

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DOI: https://doi.org/10.5169/seals-13108

Non-welded Structural System

Structures métalliques non soudées

Schweißfreie Stahlkonstruktion

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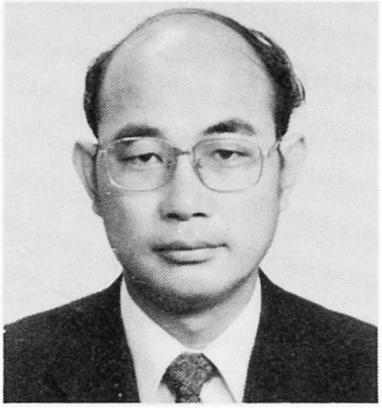

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SUMMARY
In Japan, seismic forces and wind pressures are major loads which must be considered in structural design. To cope with these loads, connections of structural members are generally required to be made as rigid connections, which are made only by welding these days. This causes restrictions and problems concerning realization of more fully automatic welding, assurance of weld qualities, reduction of construction time, etc. This paper deals with a non-welded steel structural system which eliminates the above mentioned limitations and problems and thus enables to pursuing total rationality in all such aspects of design, fabrication and construction by fully utilizing CAD and CAM.

RÉSUMÉ
Au Japon, les charges dues au vent et aux tremblements de terre sont les deux charges principales qui doivent être prises en compte dans l'étude d'une construction. Ces charges impliquent des assemblages rigides entre les éléments de la structure, qui ne peuvent étre réalisées que par soudure. Il en résulte des problèmes de soudage automatique, d'assurance de la qualité des soudures, de réduction de la durée de construction. Ce rapport aborde certains aspects des structures non soudées qui permettent de se libérer de ces contraintes et de concevoir les éléments aussi rationnellement que possible en faisant appel à tous les moyens offerts par la conception et la fabrication assistées par ordinateur.

ZUSAMMENFASSUNG
In Japan müssen bei der Berechnung die Erdbeben- und Windlasten berücksichtigt werden. Dies bedingt feste Schweißverbindungen zwischen den einzelnen Elementen, wodurch jedoch Restriktionen hinsichtlich vollautomatischer Schweißung, der Schweißqualität, der Bauzeit usw. hingenommen werden müssen. Diese Schrift befaßt sich mit nicht geschweißten Stahlkonstruktionen, so daß die erwähnten Restriktionen entfallen und volle Rationalisierung der Konstruktion, der Fertigung und der Errichtung unter Verwendung von CAD und CAM Systemen realisiert werden kann.

1. INTRODUCTION

In Japan, buildings (not including detached or semi-detached houses) constructed of structural steel amounted to 34.50-million m^2 in floor area in 1986. About 95 % of them was accounted for by comparatively small buildings not more than five-storeyed.
Welding which began to be used for steel buildings more than 20 years ago has come to be used for construction of almost all buildings including the aforesaid relatively small buildings.
Despite a great deal of research effects made until now, welding still has its restrictions and problems concerning realization of more fully automatic welding, assurance of weld qualities and dimensional accuracy of products, development of effective measures against residual stresses and strains caused by welding, reduction of construction time, etc. many of which cannot be rationally solved even by today's highly developed electronic and mechatronic technology.
This paper deals with non-welded steel structural system (as shown in Fig. 1) which eliminates limitations and problems accompanying welding and thus enables to pursue the total rationality in all such aspects as design, market distribution, fabrication and construction by utilizing CAD and CAM. This system has been developed as a subsystem to a total building system which includes exterior cladding, electrical and mechanical systems, etc.

2. OUTLINE OF CONSTRUCTION METHOD

2.1 Framing System

As shown in Fig. 1, H-shapes are used as columns and beams. Rigid frames are used in the transverse direction, and braced frames or aseismic column frames in the ridge direction.

2.2 Detail of Column-Beam Connection

Reinforcing pieces are attached to inside of column flanges in order to reinforce the column flanges by sharing tensile forces from split tees and carrying them smoothly to the panel zone.

3. CONNECTION EXPERIMENTS

The following experiments were performed to determine strength, deformation capacity, reinforcing effect and other factors relating to beam-column connection.

3.1 Split Tee Unit Test for Investigating Split Tee Form and Deformation Capacity

Strength: Table 1 gives a comparison of measured values and calculated strength (Kato formula) for yielding strength F_y and maximum strength F_u. The calculated ones generally gave good agreement with the measured ones.
Deformation capacity: No. 5 in mode a, which takes no bolt separation, shows outstanding deformation capacity up to the final strength. It appears that there is deformation capacity of about d_{FU} = 10 mm even in modes b and c, which finally takes bolt separation. (See Fig. 2.)

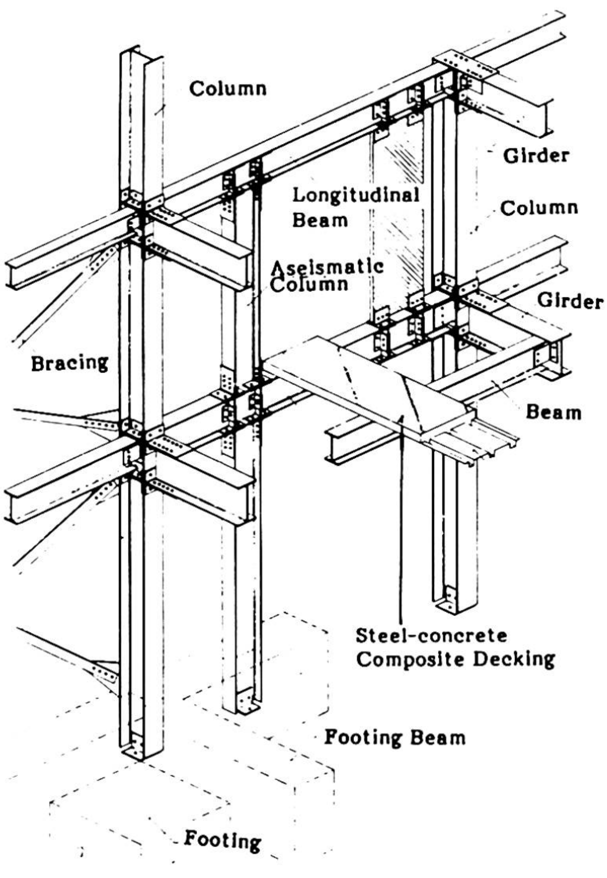
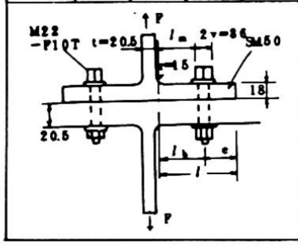


Fig. 1 Structural System

Test Specimen	Dimension (mm)				Computed Strength (Kato's Formula)			Test Results						
	l_m	l_b	e	l	Mode	T_{yt} (t)	T_{ut} (t)	T_{Ye} (t)	T_{ue} (t)	K_e (t/mm)	δ_e (mm)	δ_{Fu} (mm)	δ_B (mm)	Give-away Mode
No 1	20	38	80	118	c	88.2	97.9	92.5 (1.05)	113.4 (1.16)	116.9	0.554	6.6	3.5	Bolting torn-off by tensile force
No 2	30	48	40	88	c	68.2	75.8	74.5 (1.09)	93.0 (1.22)	147.4	0.505	11.53	4.8	"
No 3	30	48	70	118	(b→) c	81.2	90.3	83.5 (1.03)	106.2 (1.17)	197.8	0.422	9.13	4.6	"
No 4	60	78	40	118	b	44.1	61.4	54.5 (1.23)	78.2 (1.27)	54.2	1.006	23.18	4.35	"
No 5	60	78	70	148	a	44.1	66.2	57.5 (1.30)	94.8 (1.43)	50.2	1.145	39.10	5.6	"
No 6	90	108	40	148	b	29.4	51.6	36.0 (1.22)	71.9 (1.39)	22.9	1.57	41.42	4.9	"



Bolt
B = 27.27 t/bolt
B_B = 30.3 t/bolt
Flange
(Actual Strength)
σ = 4.08 t/cm²
$σ_B$ = 6.13 t/cm²

T_{Ye} (T_{Ye}/T_{yt}) T_{ue} (T_{ue}/T_{ut}) $\delta_e = T_{Ye}/K_e$

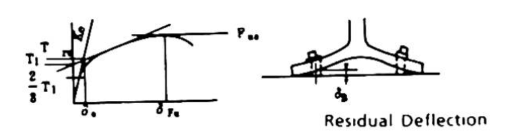


Table 1 List of Test Specimens and Test Results

3.2 Tensile Test for Reviewing Column Flange Reinforcement

Experiments were performed regarding strength when the column flange was reinforced by a plate with stiffener (Types A and B), and results were further reviewed via yielding line analysis. Thus a reinforcement design formula was obtained. (See Tables 2 to 4 and Fig. 4.)

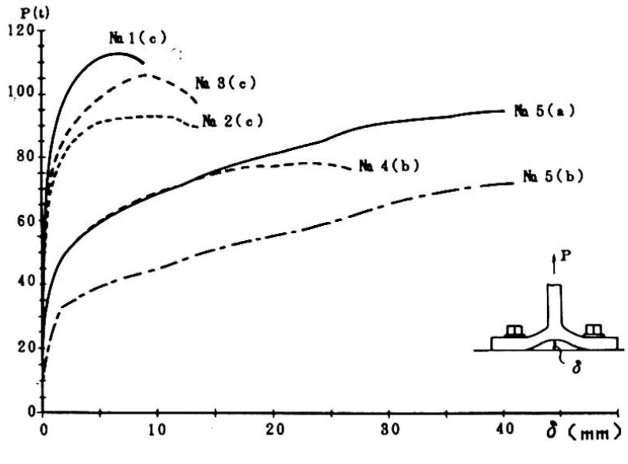


Fig. 2 Load-Displacement Relationship

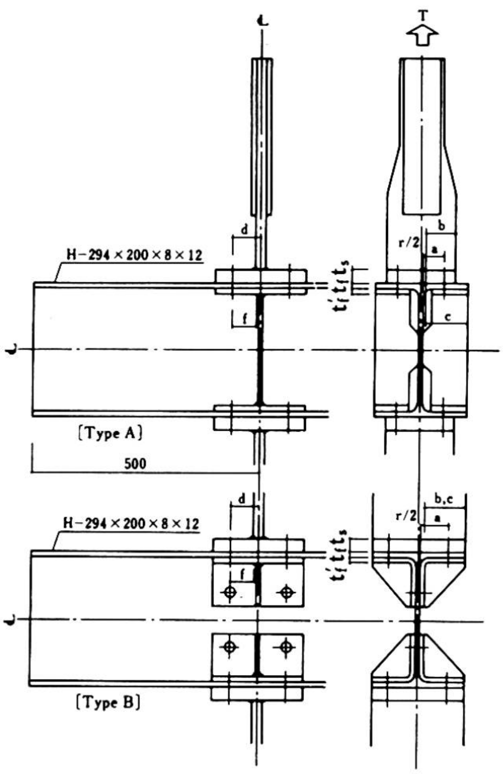


Fig. 3 Shape of Test Specimen

No	Reinforcing Type	Dimension (mm)					Bolt Size	t_f (mm)	t_f' (mm)	t_s (mm)
		a	b	c	d	f				
1	—	52	87	87	62.5	—	M22	12	—	30
2	A	52	87	87	62.5	56.5	M22	12	6	30
3	"	"	"	"	"	50.5	"	"	12	"
4	"	"	"	"	"	"	M16	"	"	"
5	"	36	62	"	"	56.5	M22	"	6	"
6	"	52	87	"	"	"	"	"	"	22
7	B	52	87	87	62.5	56.5	M22	12	6	30
8	"	"	"	"	"	50.5	"	"	12	"

t_f : Thickness of flange of column t_s : Thickness of split tee plate
t_f' : Thickness of reinforcing plate

Table 2 Dimensions of Test Specimens

No.	Measured				Analyzed (Mode)				Ratio (Measured/Analyzed)			
	$T_{Y\varepsilon}$ (ton)	$\Delta T_{Y\varepsilon}$ (ton)	Tmax (ton)	Torn-off Portion	T_Y (ton)	ΔT_Y (ton)	T_Y' (ton)	Tu (ton)	$T_{Y\varepsilon}/T_Y$	$\Delta T_{Y\varepsilon}/\Delta T_Y$	$T_{Y\varepsilon}/T_Y'$	Tmax/Tu
1	32.0	—	81.0	B	43.2(2)	—	30.2(2)	63.9(2)	0.74	—	1.06	1.27
2	42.5	10.5	96.0	B,S	50.5(2)	7.3	39.1(2)	74.3(2)	0.84	1.44	1.09	1.29
3	70.6	38.6	100.0	B,S	68.1(2)	24.9	60.2(2)	99.9(1)	1.04	1.55	1.17	1.00
4	42.7	—	67.5	B	54.5(1)	—	45.3(1)	70.2(1)	0.78	—	0.94	0.96
5	54.4	—	102.3	B	77.3(2)	—	58.3(1)	94.3(1)	0.70	—	0.93	1.08
6	43.1	11.1	85.2	B,S	50.5(2)	7.3	39.1(2)	74.3(2)	0.85	1.52	1.10	1.15
7	46.7	14.7	91.0	B	54.1(2)	10.9	43.3(2)	79.3(2)	0.86	1.35	1.08	1.15
8	69.4	37.4	110.8	B	78.8(2)	35.6	73.0(2)	105.6(1)	0.88	1.05	0.97	1.05

B : Bolt S : Stiffener

Table 3 Comparison between Measured Values

3.3 Beam-Column Connection Mock-up Test

This confirmed that beam-column connections formed through non-weld techniques had strength and deformation capacity as good or better than those formed through welding techniques. (See Table 5 and Fig. 5.)

Test Specimen		Material	σ_y (t/cm²)	σ_B (t/cm²)
H-294 x 200 x 8 x 12 (Fℓ)		SS41	3.07	4.55
PLATE	PL - 6	SS41	3.30	4.62
	PL - 12	"	2.62	4.22
BOLT	M16	F10T	10.4	11.2
	M22	"	10.8	11.5

Table 4 Mechanical Characteristics of Materials

No.	Column-Beam Connection	Cut Tee	Horizontal Stiffener	Reinforcing Plate
W	Welding	None	Welding	None
NW1	Bolting	CT-303 x 201 x 12 x 20	None	None
NW2	Bolting	CT-303 x 201 x 12 x 20	Provided	None
NW3	Bolting	CT-303 x 201 x 12 x 20	Provided	Reinforced at one side by panel
NW4	Bolting	CT-303 x 201 x 12 x 20	Clip Angle	None
NW5	Bolting	CT-303 x 201 x 12 x 20	Clip Angle	Reinforced at one side by stiffener
NW6	Bolting	CT-303 x 201 x 12 x 20	Clip Angle	Reinforced by stiffener and panel

Table 5 List of Test Specimens

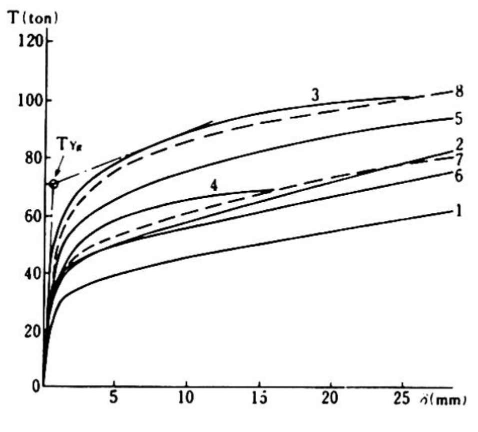


Fig. 4 Load-Deformation Curve

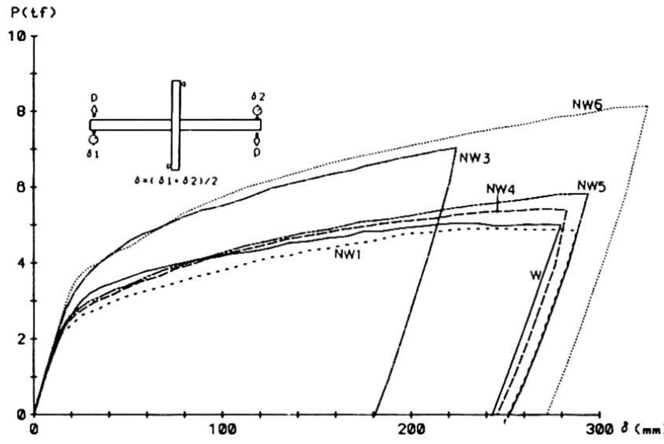


Fig. 5 Load-Displacement Relationship

4. DESIGN, FABRICATION AND CONSTRUCTION

4.1 Design

Once structural members have been determined from structural design and stress analysis, connection parts are determined automatically from combinations of beam-column members in connection design by virtue of the manualized system.
Strength of these connections are designed (retained strength design) to exceed that of beam members, and so connection strength checking is unnecessary.

These connections are also standardized, and this enables labor-saving in fabrication.

4.2 Fabrication

Shop drawings: These techniques assume the use of numerical control (NC), so shop drawings can be greatly simplified.
Fabrication at Workshop: Fabrication is performed using NC machine tools. The fabrication process is compared with conventional techniques in Fig. 7, and the new process achieves extreme reductions in processing and the number of process steps. Cut and drilled materials and parts are assembled according to fabrication drawings and fastened together with high strength bolts.

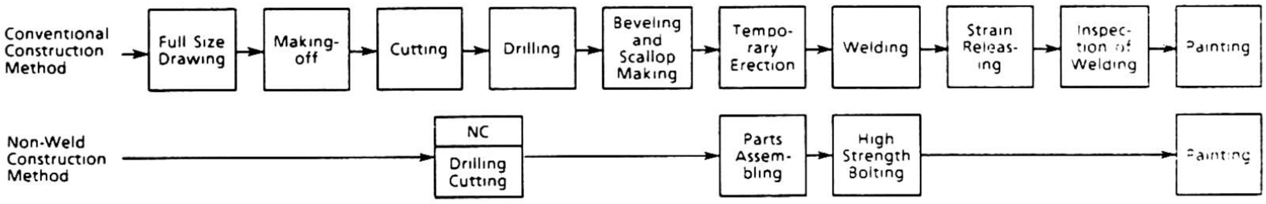


Fig. 6 Comparison of Construction Procedures

4.3 On-site Construction

In erection using these techniques, the split tee on the underside of the beam is mounted beforehand on a column, so the beam is placed on that split tee.
Because of this simple construction method for the beam-column connection, on-site construction workers can perform safe and rapid construction from a temporarily provided work space set up near the beam-column connection.
The number of high strength bolts used in these techniques is about 50 % more than that used in welding techniques, but a large number of bolts are installed beforehand at a workshop so the number of bolts installed on-site is not much different that in other techniques. In on-site erection, dimensional accuracy of materials and parts is good, so reconstruction is unnecessary and high precision construction is facilitated.

5. COMPARISON OF CONSTRUCTION COSTS

For the purpose of comparison between construction costs of buildings constructed by the conventional welding techniques and those of buildings constructed by the non-weld techniques, many types of model buildings (as shown in Table 6) were designed. Then steel costs, fabrication costs and construction costs (incl. erection and high strength bolt fastening) are estimated for all of these model buildings and compared in Table 6.

Comparison of non-weld vs. welding techniques
Steel costs: Non-weld technique steel costs may be somewhat higher. Using low cost materials such as rolled H-shapes almost eliminates the difference.
Fabrication costs: Since automatic machine tools using numerical control are employed in the former, cost become about 60 % of that of the latter.
Construction costs: With non-weld techniques, the number of high strength bolt connections increases, but many connections can be made at the workshop, so costs are almost the same as those for welding techniques. There is almost no difference in the cost comparison in the Table, but since transport costs are low and on-site construction techniques are improved, the cost of these techniques can be further reduced.

Model	Type	Construction Method	Structural System		Construction Cost				Remarks
			Span Direction	Transverse Direction	Cost of Steel	Manufacturing Cost	Erection Cost	Total	
(1) 3-story bldg Total floor area: 233 m²	B1	Weld	Rigid Frame	Bracing	39	32	29	100	Construction cost of Type B1 is taken at 100
	B1N	Non-weld	Rigid Frame	Bracing	40	22	30	92	
	R1	Weld	Rigid Frame	Rigid Frame	57	55	40	142	
	R1N	Non-weld	Rigid Frame	Rigid Frame	52	32	40	114	
(2) 4-story bldg Total floor area: 904 m²	B2	Weld	Rigid Frame	Bracing	42	31	27	100	Construction cost of Type B2 is taken at 100
	B2N	Non-weld	Rigid Frame	Bracing	45	20	28	93	
	R2	Weld	Rigid Frame	Rigid Frame	56	45	29	130	
	R2N	Non-weld	Rigid Frame	Rigid Frame	52	26	31	79	
(3) 2-story bldg Total floor area: 1,825 m²	B3	Weld	Rigid Frame	Bracing	49	25	26	100	Construction cost of Type B3 is taken at 100
	B3N	Non-weld	Rigid Frame	Bracing	50	15	27	92	
	R3	Weld	Rigid Frame	Rigid Frame	57	34	28	119	
	R3N	Non-weld	Rigid Frame	Rigid Frame	55	20	30	75	

Table 6 Comparison of Construction Costs

6. CONCLUSION

The strength, deformation capacity and reinforcing effect of connections with these techniques have been experimentally confirmed, and design formulas have been established from the obtained findings and findings obtained in current experiment and research. A complete structural system has been perfected for design, fabrication and construction. As already explained, the merits of these techniques include high economy, quality assurance and construction period reduction, and further improvements can be expected to fully enjoy these merits in the future through complete systemization, from structural design to construction.

These techniques employ high strength bolt tension connections, so there are limits on their applicability to large-scale structures, but in Japan, where there are large out-of-design forces such as earthquakes and winds, the authors have already applied the techniques to 8-storey structures, and they appear to be applicable to the majority of steel-frame structures.

At present, these techniques have been implemented in 20 cases (overall steel-frame tonnage 5,000 ton), so the advantages of these techniques have been proven in practice.

7. ACKNOWLEDGEMENTS

By taking this opportunity, the authors wish to express their cordial thanks to Dr. Toshiro Suzuki of Tokyo Institute of Technology, and Dr. Hiroshi Akiyama of The University of Tokyo, for their cooperation and advice afforded in the implementation of this study.

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