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Seminar VII

Developments in the Construction of Steel Structures

Développements dans l'exécution de constructions métalliques

Fortschritte in der Ausführung von Stahltragwerken

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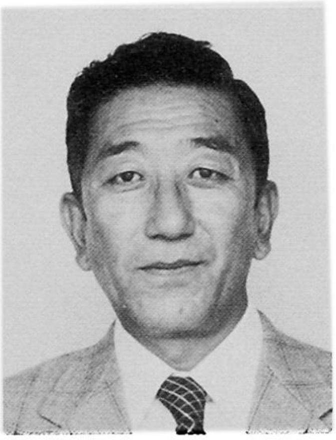

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SUMMARY
Development in steel construction is being supported by various technologies: design process, steel quality, welding technique, quality control in fabrication and method of erection. In this paper, experiences of quality control of high strength steel in manufacturing and advanced column-to-beam connections are reported.

RESUME
Les développements dans l'exécution de constructions métalliques sont dus à diverses technologies: méthodes de calcul, qualités d'acier, technique de soudage, contrôle de la qualité dans la fabrication et méthodes de montage. Le rapport mentionne des expériences du contrôle de la qualité d'aciers à haute résistance lors de la fabrication, ainsi que de nouvelles liaisons poutre-colonne.

ZUSAMMENFASSUNG
Die Fortschritte in der Ausführung von Stahltragwerken werden von verschiedenen Technologien gestützt: Entwurfsprozess, Stahlqualität, Schweisstechnik, Qualitätskontrolle in Fabrikation und Montagemethoden. Dieses Referat berichtet über Erfahrungen der Qualitätskontrolle des Stahles von hoher Festigkeit in der Fabrikation und der modernen Säule-Balken-Verbindung.

1. INTRODUCTION

Iron and steel for structural use have bee developed as shown in Fig.1 from cast iron up to quenched-and-tempered high strength steel during two centuries. In Fig.2 amount of crude steel production in U.S.A., Europe(sum.of U.K., France and West Germany) and Japan are shown. Production of Steel was increased remarkablly after the second World War in Europe and Japan. In the figure, names of suspension bridges, truss bridges and arch bridges are shown together in the order of span length and year completed. Author picked up the bridges as the one sample of steel structure in the figure. The center span length of bridge reached 1280m in 1937. However, it is a interesting fact that span lengths of bridges after the second World War have the same tendency as the increasing of product of crude steel in these three regions. Tendency of increasing of steel product in Europe and Japan are behind ten or twenty years that in U.S.A., and so are bridge span lengths.

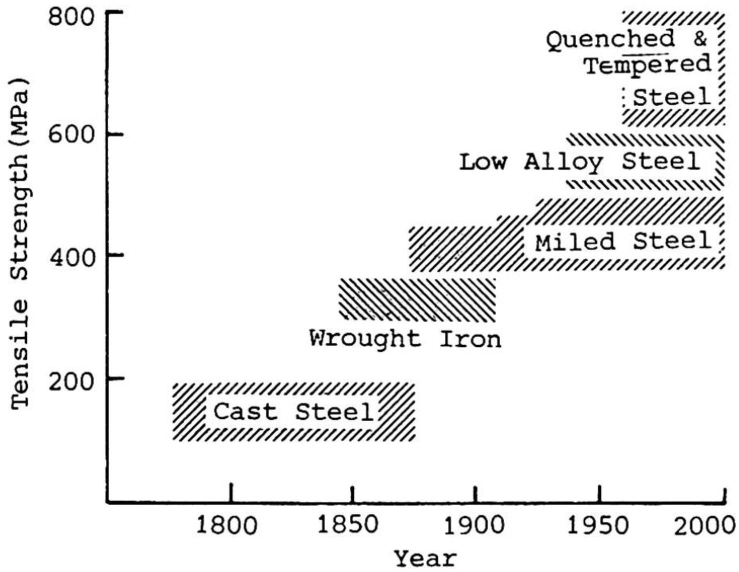


Fig.1 Vicissitude of Structural Steel

In recent years product of steel are hovering round according to the economic situation in the world. Nowadays, big bridge projects like the

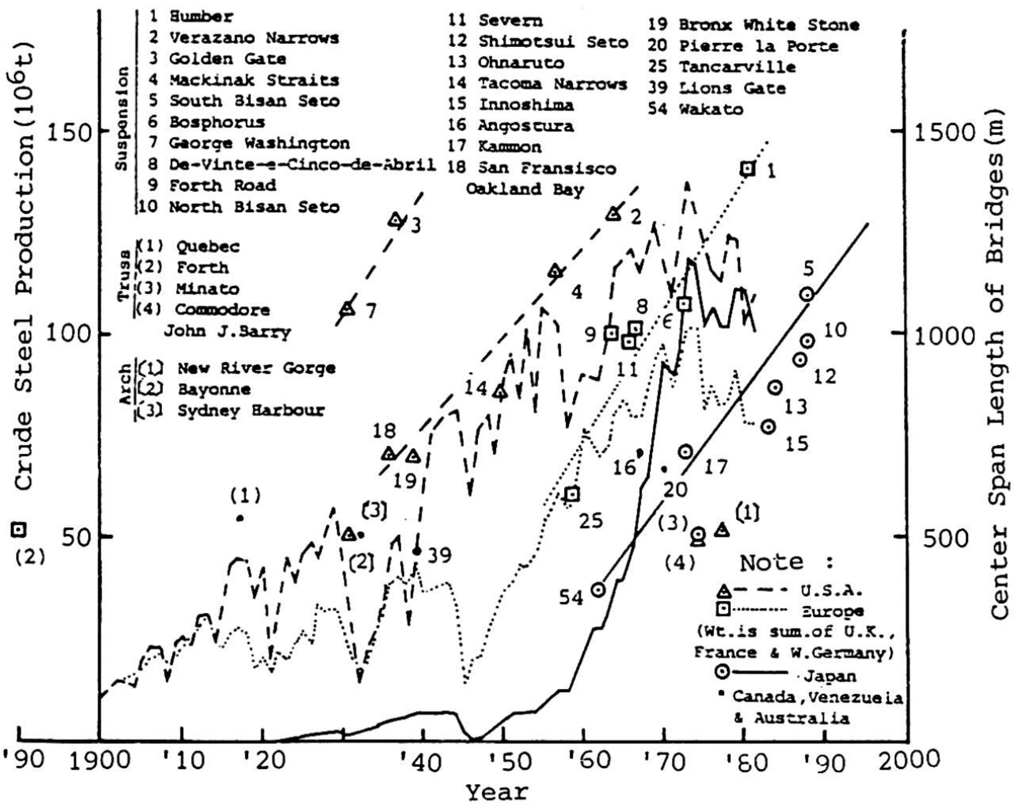


Fig.2 Crude Steel Production and Span Length of Bridges

Akashi-kaikyo Bridge - Japan, 1780m, Great Belt Bridge - Denmark,1416m, Messina Straight Bridge - Italy, 3000m, are postponed also.

Fig.3 shows the increased adoption and development of steel-frame buildings in Japan in the last twenty years. It was in the latter half of the 1960s that steel-frame structures overtook reinforced concrete structures in terms of floor area. Two reasons for this phenomenon are conceivable. One is the natural environment of Japan since it is an earthquake country and lies in the path of typhoons so that steel-frame construction is suited for meeting severe mechanical requirements. The second reason for the marked increase in steel-frame construction is the emergence of a number of a structural forms more readily meeting the need for improved productivity as a result of increased technical information exchanges and joint research and development between various engineering field. In the field of bridge construction, total cost of construction of steel superstructure is about 50% over the prestressed concrete bridges in recent five years in Japan(Fig.4).

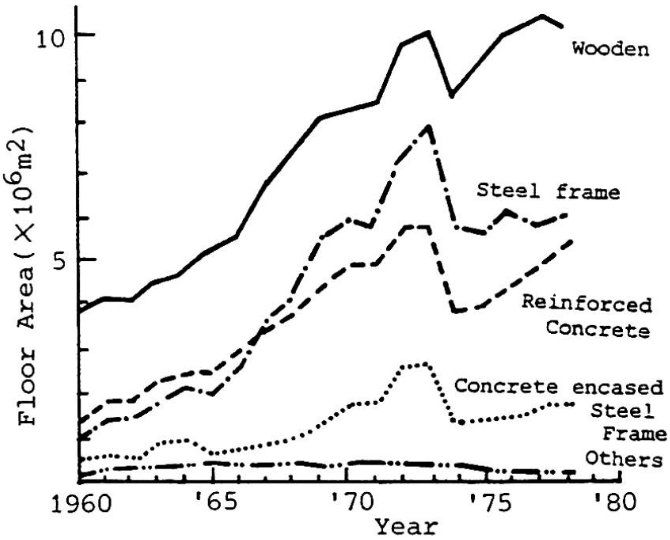


Fig.3 Building Floor Area Constructed in Each Year Classified by the Structural Material

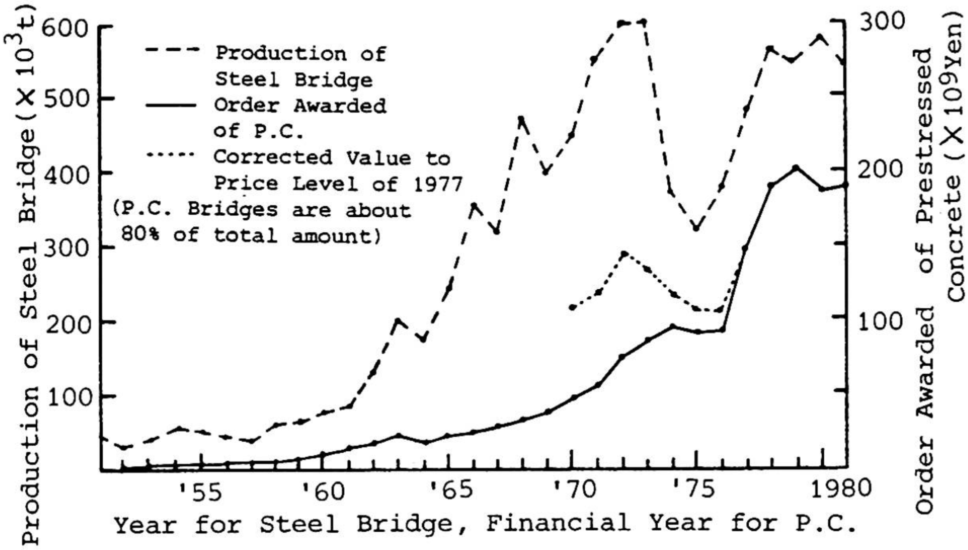


Fig.4 Production of Steel and P.C.Bridges

Development of steel construction is being supported by technologies in various fields such as the progress of design process, steel quality, welding technique, quality control in fabrication and method of erection (Fig.5and 6).

On some steel constructions investigations or problems in some construction stage are given in following examples.

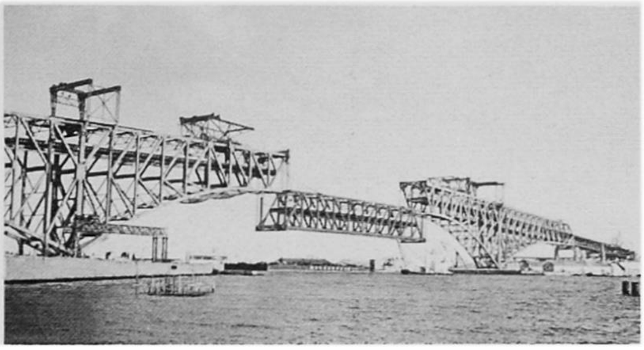


Fig.5 Osaka Port Bridge(1973)
Suspended Span 186m, 4500t

Fig.6 Izuni Otsu Bridge(1976)
Span 172.572m, 3000t

2.APPLICATION OF HIGH-STRENGTH STEEL ON LONG SPAN BRIDGES

Carquinez-Strait Bridge is well Known as the application of Quenched-and-tempered 800MPa class steel which was completed in 1958. De-Vinte e Cinko de Abril Bridge, completed in 1967 over the River Tejo in Lisbon Portugal, is also famous as the long spanned suspension bridge in Europe. This bridge is expected to be able to carry the railway in the second stage of construction, and quenched-and-tempered 800Mpa class steel was used for the stiffening truss members.

Application of quenched-and-tempered high strength steel was started since 1961 in Japan, but at that time of 600MPa class, and standard design specification of bridges made of this class steel was set in 1967 for highway bridge and in 1974 for railway bridge. For highway bridges 600MPa class steel is used widely in Japan nowadays.

700MPa and 800MPa class steels were applied for the first time for the huge bridge - Osaka Port Bridge, cantilever truss with 510m center span length in 1974(1) (See Fig.5). These steels had high weldabity and were newly produced for the construction of this bridge. Before the construction of this bridge, application of 800MPa class steel was tried for a highway plate girder in 1964, and for railway trial application was done in 1971 for center girder of a through type plate girder bridge with three main girder (2) .

Honshu-Shikoku bridge has three route and the total length over the sea is about 30km. It is composed of eleven suspension bridges and other long span cable stayed bridges etc. Then, one harf of the whole project is under construction now. In these bridges four suspension bridges which have the center span length 876m, 940m(Fig.7), 990m and 1100m and two cable stayed bridges(Fig. 8) which have the center span length 420m are highway-railway combined bridge.

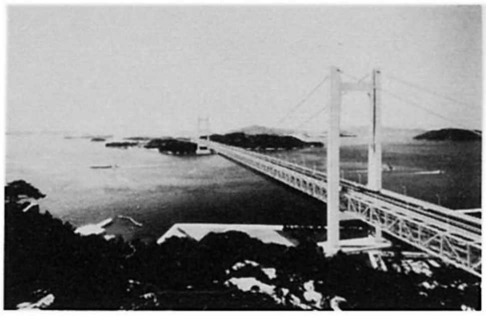


Fig.7 Shimotsui Seto Bridge
Center Span 940m

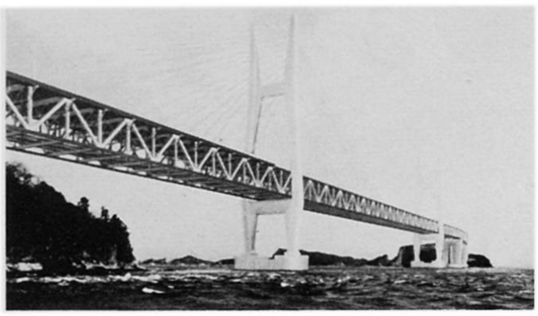


Fig.8 Iwagurojima Bridge
Center Span 420m

The type of suspended structures of these bridges are truss type with box-section members. The dimension of them are large as shown in Fig.9 and quenched-and-tempered 700MPa class and 600MPa class high strength steels are applied. Because of the railway carrying bridges, careful attention must be paid for effect of load repetition in designing and manufacturing of these bridges.

Abreasting with the establishment of fatigue design code [3], many fatigue tests were conducted to certify the fatigue strength with large size specimens [4], [5]. Based on these results design code was revised 1982 [6], and relation between the imperfection of root of weld in the corner welding and fatigue strength was clarified as shown in Fig.10. For the corner weld of box section as shown in Fig.9, partially penetrated groove weld and fillet weld are used and the welding is only one side weld from the outside of box ~~seotion~~ section.

Discontinuity of root of weld - blow holes, slag inclusion, drooping of weld metal and irregularity of root line - must be controled in every respect of above mentioned conditions. In the fatigue design initial size of imperfection at the root of weld was estimated as ai=1.0mm.

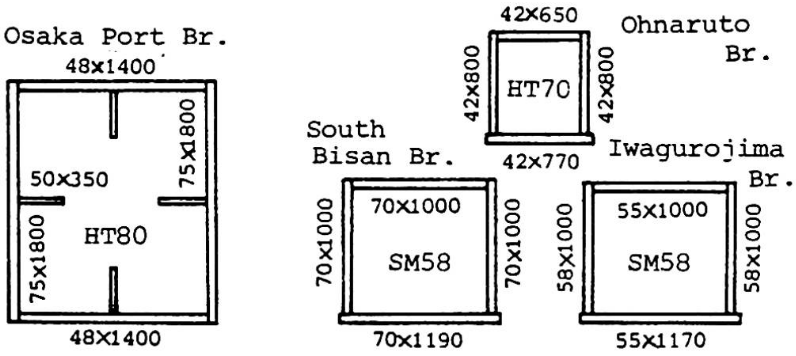


Fig.9 Maximum Section of Chord Member

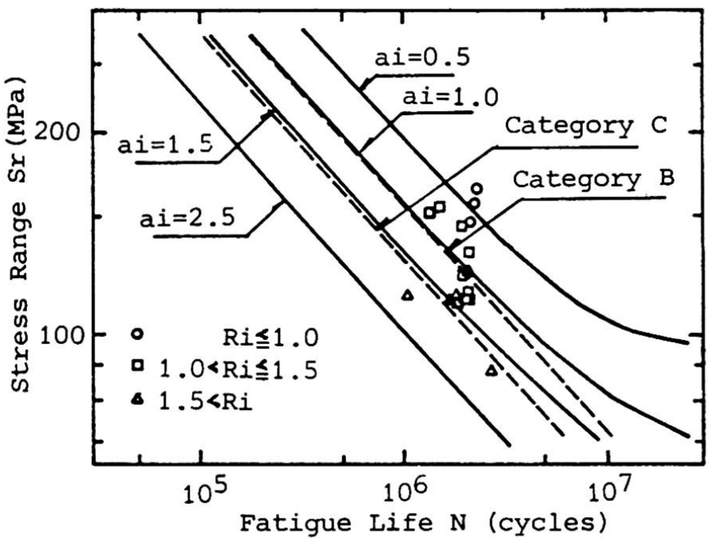


Fig.10 Predicted Sr-Np Curves and Test Results

To keep the quality of welding reliable, many procedure test has been conducted with small L type specimens, specimens of full size section with medium length and full length of chord member which had the length of 20m. From the results of these tests quality control points and standard process of workmanship were established in every stage of fabrication . Main control points are cleaning of surface for weld, keeping the root opening less than 0.5mm(Fig.11), putting the sealing bead at the root and selection of proper welding conditions. Some solutions for them are as follows:

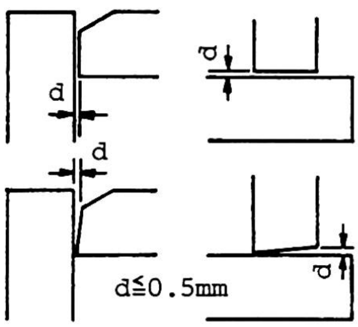


Fig.11 Tolerance of Root Opening

1) Plates used must be flat. In the standard of Honshu-Shikoku Bridge Authority(HBS G 3103), flatness of steel Plate is specified as less than 2mm measured in 1 meter span for 600MPa class steel over 50mm thickness and for 700MPa and 800Mpa class steel over 32mm thickness.Flatness of plates with the thickness less than these values is supposed to follow in the tolerance specified in JIS.

However, before and after the cutting and welding the plates correction of small waving are conducted for every plate.

2) Plates must be cut straight and to be square in its edges. After cutting plate edges are finished with automatical running belt grinder or machined. No drag lines due to flame cutting must be remained.

3) After the tack weld, sealing beads must be put between the tack welds in full length by semi-automatic CO_2 welding or MAG. Size of these welding must be nearly 4~5mm because they can be remelted by the corner welding conducted submerge arc welding.

4) Examples of welding condition in the Ohnaruto Bridge using 600MPa and 700 MPa class steels are shown in Table 1.

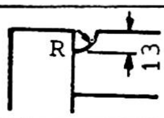
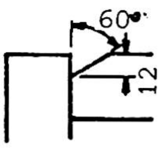
	Shapes of Groove	Kind of Weld	Welding Condition of 1st pass: Current (A)	Voltave (V)	Velocity (cm/min)	Welding Material
A		Single S.A.W.	600	30	30	Wire: dia. 4.0 ~4.8mm
B		Single S.A.W.	750	32	26	
C		Tandem S.A.W.	Front 700 ~750	Front 30 ~33	HT 70: 60	Flux: Fused Type
			Rear 550 ~ 620	Rear 32 ~38	SM 58: 55 ~40	

Table.1 Welding Condition

5) Weld lines must be preheated by electric heater up to proper temperature symmetrically preventing the irregular deformation of members. State of the welding is shown in Fig.12.

6) For the check of soundness of these welding ultra sonic wave testing system was newly developed. This equipment runs automatically, and its velocity is 30~50cm/min. Fig.13 shows the system of A.U.T. and state of the testing is shown in Fig.14.

To satisfy the required quality of welding and reap the full advantage of high strength steel, quality control over the workmanship is being conducted not only in the process above mentioned but in every stage of fabrication.

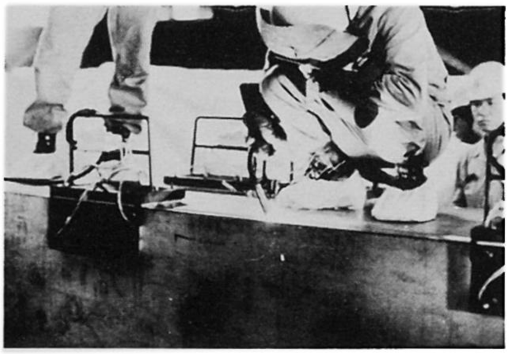
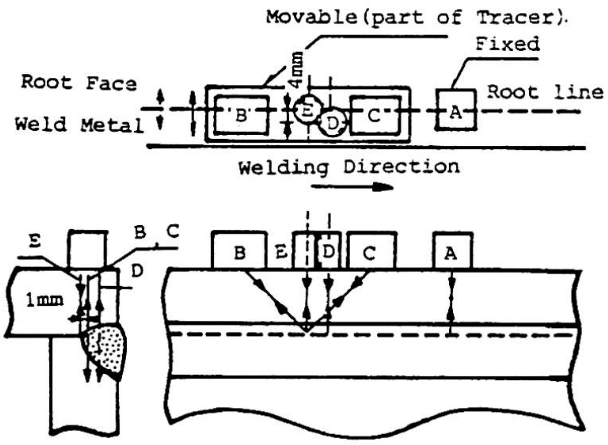


Fig.12 State of the Welding for Sealing



A : Line Focus Type.
Check for Deapth of Penetration
B, C: Point Focus Type.
Check for imperfection of weld root
D : Point Focus Type.
Check for pipe shaped blow hole and imperfection in the weld metal
E : Point Focus Type.
Sensor for root tracer

fig.13 A.U.T.System

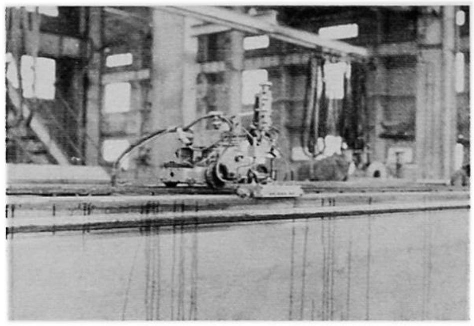


Fig.14 Inspection by U.T

3. ADVANCED COLUMN-TO-BEAM CONNECTION OF STEEL FRAMEWORK

High earthquake resistance and high wind resistance are prerequisites for building in Japan. Meanwhile, whatever such special requirements there may be, a world-wide trend exists aiming for economical buildings erected in short periods of time while maintaining specific levels of quality. For this purpose, structural steel which is comparatively expensive must be used effectively in building production achieving the goal of improvement in safety, ease of work execution and economy of the building as a whole.

In order to increase earthquake resistance and wind resistance performances of frameworks of high-rise buildings as in Japan, it will be effective to utilize wall. However, such performances can also be attained by rigid connection between columns and beams [7] .

The steel framework is to be constructed by connecting the columns and beams successively, therefore "connecting" is the basic means for the production of steel framework. Meanwhile the internal stresses of frame are transmitted via the connection. It means that the connection is the most important element of the steel framework, that could control the safety of the whole structural system. As mentioned above, the connection between column and beam holds the key for the solution of the productivity and the safety of the structural steel framework.

The types of rigid connections between columns and beams normally used in Japan are shown in Fig.15. As indicated in (a), (b) and (c) of Fig.15, the method of welding beam ends to columns is mechanically effective for rigid connections.

However, this method requires a high technical skill including control to secure the reliability of welding.

In case of the field welding, the quality control of welding is vital, where manual arc welding, non-gas shielded arc welding and semi-automatic gas shielded arc welding are used almost exclusively for column-to-beam connection. Meanwhile narrow-gap automatic welding is used at times for the column-to-column field connection where the plate of column is relatively thick. To confirm the soundness of these welding, standard of ultrasonic manual testing for structural joint was prepared by Architectural Institute of Japan in 1973 [8].

There was another problem of lamellar tearing for structural steel at the welded T-joint connecting beam flange plate to column several years ago. But it is under control by the development of anti-lamellar tearing steel [9] and carefully controled preciseness of steel fabrication.

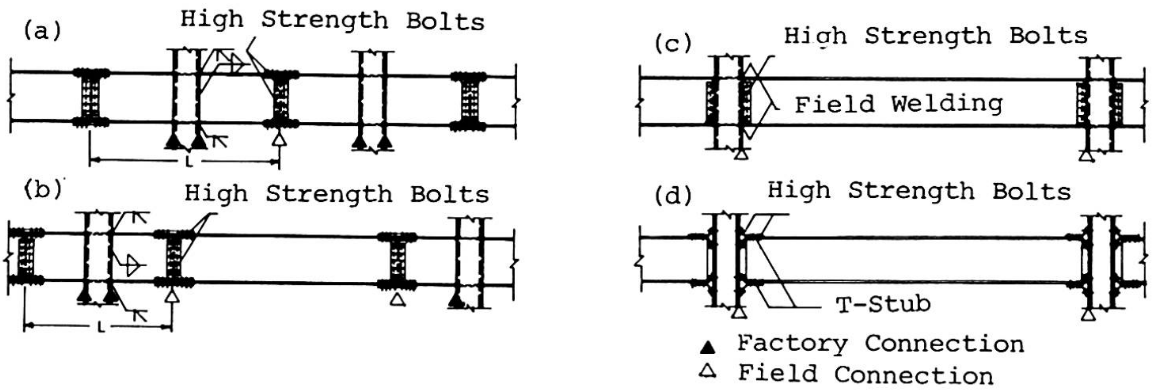


Fig.15 Four Types of Beam-to-Column Rigid Connections [10]

The rigid connection detail shown as (d) was newly developed putting a great improvements into the existing Split-Tee connection and called HISPLIT. This system is a method of simplifying the constitution of the beam-to-column connection while maintaining mechanical performance. The method is to assemble joints by simple tightening of bolts at the jobsite using connection parts mass-produced at the factory. It could be said that the function of the connection is concentrated into this connection parts(Fig.16). Since its development in 1973, this system has been used not only in Japan, but also in the U.S.A., Germany and the Near and Middle East.The connection part is made of cast steel or is stamp-forged. The configuration of the connection part minimizes the lever action occured in the Split-Tee connection system and at the same time allows the internal stresses to be transferred smoothly. Bending moment and shear force must be trnsferred from beam to column through the T-stub web alone. According to the von Mises'yield criterion, the yield stress of the T-stub web when bending moment M and shear force Q act simultaneously can be expressed as,

$$\sigma_y = \sqrt{\sigma^2 + 3\tau^2} = \sqrt{\left(\frac{M}{dA_w}\right)^2 + 3\left(\frac{1.5Q}{2A_w}\right)^2}$$

in which, d = distance between the centers of two T-stub webs
A_w = cross area of T-stub web

The yield strength of the T-stub web based on the formula shown above usually comes about twice as high as the full strength of beam members, even if the local bending in the T-stub web is considered. When the shear arm ratio M/Qd is less than 2, however, we must examine the effect of local bending which may reduce the strength of the connection.

The mechanical properties and shape of T-stub are shown in Table 2 and Fig.17 respectively.

A great amount of the fundamental experiments were carried out during this technology development and moreover the full-size strength tests of this con-netion system were conducted to confirm the safety.

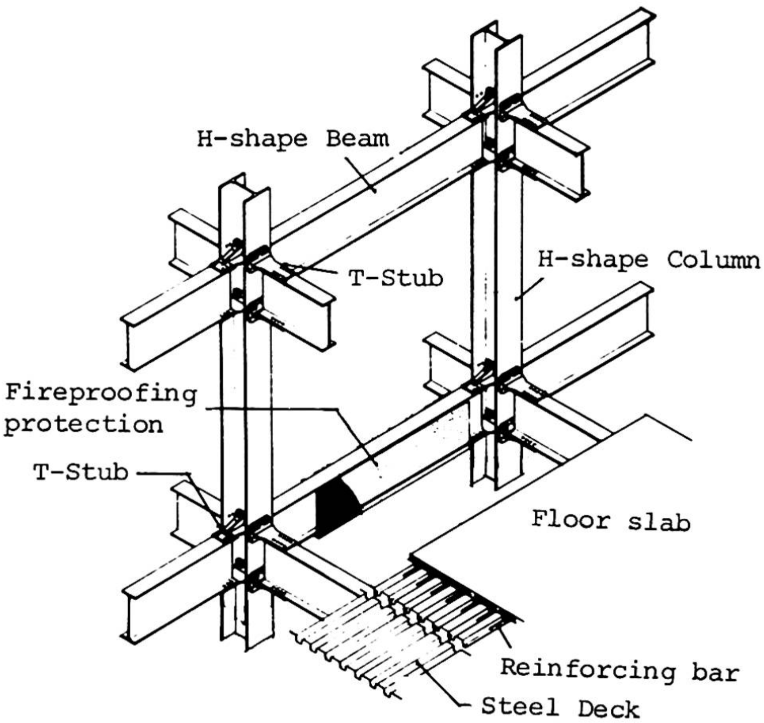


Fig.16 Sketch of Steel framework

Tensile strength	Not less than 490MPa
Yield Point	Not less than 280MPa
Elongation(%)	Not less than 23
Impact value	Not less than $28N\cdot m/cm^2$
Bending 180°	Good

Table 2 Mechanical Properties of T-Stub

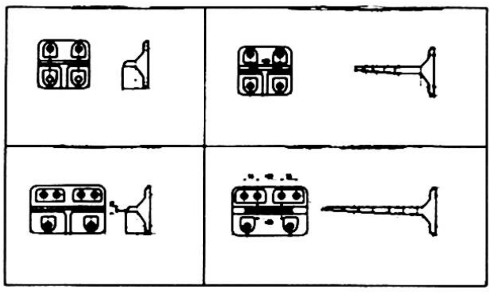


Fig.17 Example of T-Stub

As the practical example of this system, the Akasaka Prince Hotel that was completed in May 1983 is summarized here[12] (Table 3 and Fig.18,19). This hotel is located at Akasaka that is in the center portion of metropolitan Tokyo. The most attractive feature of this hotel is the V-shaped building plan consisting of two wings and this plan is reflected conspicuously in the exterior elevation which is the essence of modern architecture(Fig.20). Meanwhile,the unusual shape of this plan posed some perplexing problems which the structural engineer had to deal with. Two of the problems are described briefly below.

To design a structural system enabling control to minimize stresses and deflections of the building structure against earthquake and wind forces in all directions --- to ensure high degrees of safety during earthquake and storms and not to spoil residential comfort even under such circumstances.

To develop a construction method for the steel framework to simplify the connections of this complicated structural framing in three directions --- to raise productivity of fabrication at the factory, to simplify erection at the jobsite and to ensure a high degree of quality control with minimum efforts. The solutions arrived at are descrived below.

The structural system employed in this building is a combination of a rigid steel framework (4.0m bay x 4.0m bay) and precast concrete shear walls (slitted shear walls) located at the central core portion and at the end of each wing to minimize the torsional deflection of the building. The slitted shear

Architect:	Kenzo Tange + URTEC
Structural Engineer:	Architectural Design Division, Kajima Corporation
Contractor:	Kajima Corporation
Construction Period:	Approx, 3 years
General Description of the Building	
Typical Floor Area:	1,485m^2
Total Floor Area:	67,485m^2
Number of Guest Room:	761
Stories:	39 stories above ground, 2 stories underground
Building Height:	139.8m above ground level
Typical Story Height:	3.2m
Structural System:	
2nd Basement Flr.:	Reinforced concrete structure
1st Basement Flr. - 2nd Flr.:	Reinforced concrete encased steel structure
3rd Flr. and above:	Steel structure by HISPLIT System
Exterior Finish:	Aluminum curtain wall with mirror glass
Structural Materials:	
Concrete:	Approx. 25,000m^3
Reinforcing Steel:	Approx. 2,800ton
Structural Steel:	Approx. 8,500ton
T-Stub:	Approx. 500ton

Table 3 The summary of the Akasaka Prince Hotel

walls mentioned above, in the case of this building, bear 30 to 50% of holizontal forces due to earthquakes and storms. The safety of this structural system against earthquakes or storms was studied and comfirmed in detail by means of a three-dimensional elastoplastic analysis program developed for this project [12].

Steel fabrication at the factory was reduced to a minimum using the simplified connection details, and at the same time erection speed at the jobsite was raised drastically.

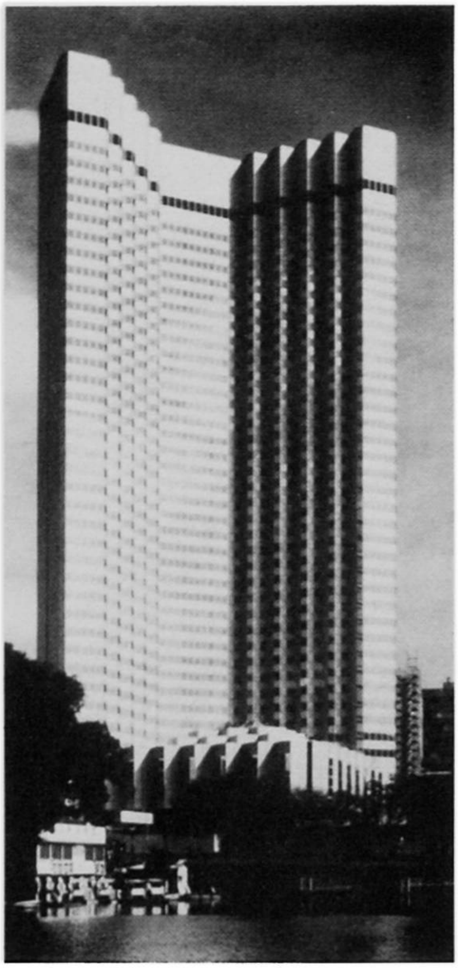


Fig.18 The Akasaka Prince Hotel

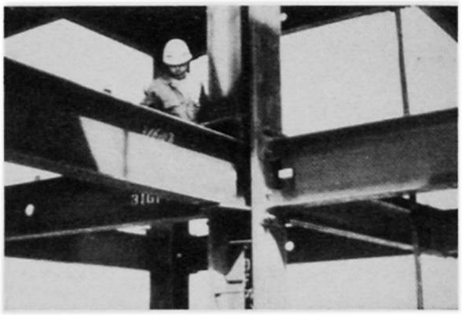


Fig.19 Detail of Column-to Beam Connection

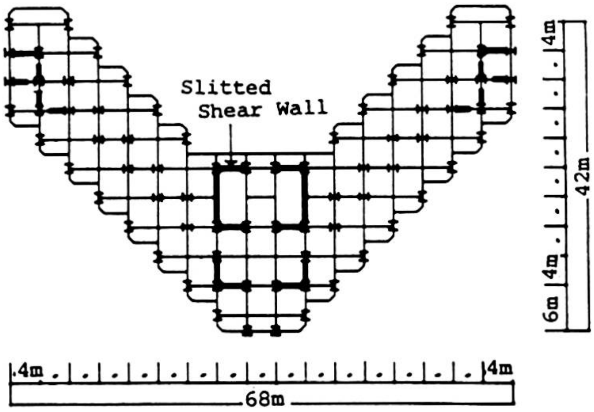


Fig.20 Typical Framing Plan

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