Trends in big bridge engineering (part 2: fabrication)

VIIIb

Trends in Big Bridge Engineering (Part 2: Fabrication)

Evolution dans la construction de grands ponts (2e partie: fabrication)

Tendenzen im Grossbrückenbau (2. Teil: Fabrikation)

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SUMMARY
HT80 steel with satisfactory weldability and toughness due to low Ceq. was used for the Osaka Port Bridge. Fracture mechanics concept was applied to the evaluation of the toughness of steel for bridge use. The establishment of the welding procedure and the quality control system was important in using high strength steels, such as HT70 and 80. The quality system, where full size drilling without reaming is made at the fabrication stage, has been established.

RESUME
L'acier à haute résistance HT80 choisi pour le Pont d'Osaka présentait des qualités de soudage et de résilience satisfaisantes, dues à un bas Ceq (équivalent carbone). Le concept de la mécanique de la rupture a permis d'évaluer le degré de résistance désiré dans un acier destiné à être utilisé dans la construction de ponts. L'utilisation d'aciers à haute résistance tels que HT70 et 80, rend le choix d'une méthode de soudage et du contrôle de qualité extrêmement important. Le contrôle de qualité a conduit à un percement au diamètre nominal sans alésage, à l'atelier.

ZUSAMMENFASSUNG
Für die Osaka Hafenbrücke wurde ein HT80 Stahl gewählt, der wegen seines niedrigen Kohlenstoffäquivalentes befriedigende Schweissbarkeit und Zähigkeit aufweist. Zur Festlegung der für den Brückenbaustahl erforderlichen Zähigkeit wurden bruchmechanische Konzepte herangezogen. Beim Einsatz hochfester Stähle wie HT70 und 80 kommt der Festlegung des Schweissverfahrens und der Prüfverfahren grösste Bedeutung zu. Die festgelegte Herstellungsgenauigkeit erlaubte ein volles Ausbohren der Löcher in der Werkstatt ohne nachträgliches Aufreiben.

1. INTRODUCTION

The high strength steels with minumum ultimate tensile strengths of 70 and 80 kg/mm2 (HT70 and 80) have already been used with increase of the size of bridges. On using high strength steels, one should bear in mind that it is important to clarify required performance in strength, toughness and weldability and select one with a suitable combination of these properties. In Japan, in order to evaluate the steels used for the Osaka Port Bridge, fracture mechanics concept for strength and toughness, and carbon equivalent (Ceq) for weldability were employed. In this paper, the specifications and the fabrication standards for high strength steels in Japan are discussed with reference to the application to big bridges.

2. APPLICATION OF HIGH STRENGTH STEELS TO BIG BRIDGES

The high strength steels frequently used for bridges, their specifications, and also how steel selection was made in Japan are described in this chapter.

2.1 Kinds of High Strength Steels

The high strength steels being used for bridges can be devided according to ultimate tensile strength into three classes ; 60, 70 and 80 kg/mm^2. The former has been used for more than 20 years and are standardized in The Japan Industrial Standard (JIS) as shown in Table 1. HT80 has been used for spherical storage tanks since 1960. As for bridges, it was first used in 1964. It was the case of the Osaka Port Bridge when a large quantity of HT70 and 80 was at first used in Japan. Table 2 shows the specification for the steels used for the Osaka Port Bridge.

TABLE 1 SPECIFICATION OF SM58 (JIS)

STEEL	CHEMICAL ANALYSIS						MECHANICAL PROPERTY											
	CHEMICAL COMPOSITON (%)					1)	TENSION TEST						BEND TEST		IMPACT TEST		
	C	Si	Mn	P	S	Ceq	THICKNESS t (mm)	YIELD POINT OR PROOF STRESS (kg/mm²)	TENSILE STRENGTH (kg/mm²)	ELONGATION THICKNESS t (mm)	ELONGATION GAUGE LENGTH (mm)	ELONGATION (%)	BENDING ANGLE	INSIDE RADIUS	TEST TEMPERATURE (°C)	CHARPY ABSORPTION ENERGY (kg·m)	TEST PIECE
SM58	0.18 Max.	0.55 Max.	1.50 Max.	0.040 Max.	0.040 Max.	0.44 Max.	6≦t≦16	47 min.	50 to 73	6≦t≦16	50	19min.	180°	1.5t	-5	4.8 min.	ALONG ROLLING DIRECTION
							16<t≦40	46 min.		16<t	50	26min.					
							40<t≦50	44 min.		20<t	50	20min.					

REMARK 1) CARBON EQUIVALENT (Ceq(%)) = $C + \frac{Mn}{6} + \frac{Si}{24} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14}$

TABLE 2 SPECIFICATION OF HIGH TENSILE STRENGTH STEEL FOR OSAKA PORT BRIDGE

STEEL	THICKNESS (mm)	CHEMICAL COMPOSITION								TENSILE PROPERTY			NOTCH TOUGHNESS
		C	Si	Mn	P	S	V	B	Ceq	Y.P. (kg/mm²)	T.S (kg/mm²)	EL (%) Gl=50mm	
HT70	6≦t≦50	0.14 max	0.55 max	1.50 max	0.030 max	0.030 max	—	—	0.49 max	63 min	70~85	6<t≦16 17%min t>16 23%min	vE-15≧4.8kg.m vTrE≦-35°C
	50<t≦100	0.17 max	DO	DO	DO	DO	—	—	0.53 max	60 min.	68~73	t>20 17%min.	
HT80	6≦t≦50	0.14 max.	DO	DO	DO	DO	—	—	0.53 max	70 min	80~95	6<t≦16 16%min t>16 22%min.	DO
	50<t≦100	0.17 max.	DO	DO	DO	DO	—	—	0.57 max	68 min.	78~93	t>20 16% min	

2.2 Required Performance of HT70 and HT80

There are basically two properties required for high tensile strength steels. One is the mechanical properties on which design is based and the other is the workmanship. One should pay special attention to toughness and weldability with increasing strength. In order to ensure the toughness and the weldability, the specification of the chemical compositions is a very significant subject. In case of the Osaka Port Bridge, the specification was set up by investigating test steels prepared by six Japanese steel makers.

(1) Toughness

The design temperature the bridge might be exposed was assumed to be -15°C which was lower than -7.5°C, the lowest temperature record in the past in this district. The steels were thus specified not to be fractured in a brittle manner at this temperature. To confirm this, wide plate tension test with through the thickness center notch was carried out. Based on the correlation between the results of the wide plate tension test and of 2 mm V-notch Chapy impact test shown in Figs. 1 and 2, the production tests of the steels and welding procedure were done with Charpy impact test. As for specifing required toughness, the crack initiation temperature on wide plate tension test was determined to be -60°C by taking account of the increase of the brittle fracture initiation temperature due to residual stresses in the weldments and errors in the shop fabrication, and missdetection of defects. From the results of Charpy impact test at this temperature, the required toughness was specified.

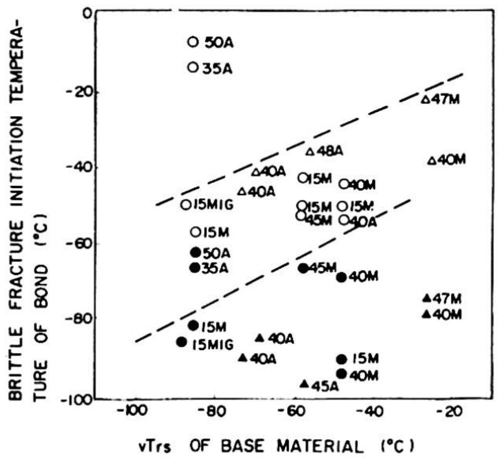


FIG. 1 RELATION BETWEEN THE BRITTLE FRACTURE INITATION TEMPERATURE (n=2.0) AND vTrs OF BASE MATERIAL

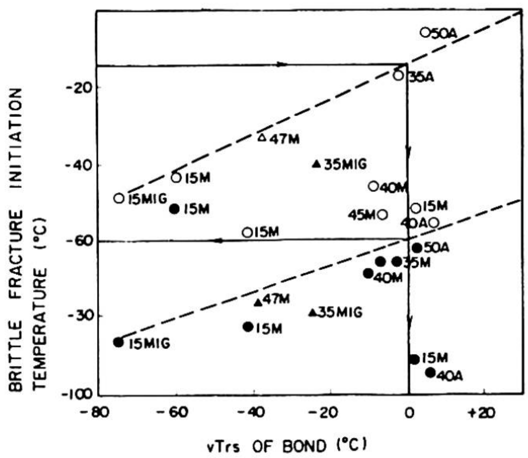


FIG. 2 RELATION BETWEEN THE BRITTLE FRACTURE TEMPERATURE (n=2.0) AND vTrs OF BOND.

NOTATION

BRITTLE FRACTURE INITIATION TEMPERATURE=[Ti]C=40 (HEAT INPUT 50 KJ/cm max.)+RESIDUAL STRESS+ERROR IN FABRICATION+SIZE EFFECT (STANDARD THICKNESS=50mm)

(NOTE) THE MARKS IN THE FIGURE SHOW HEAT INPUT AND WELDING PROCESS.

Ex. 15M ..... HEAT INPUT 15 KJ/cm SMAW
45A ..... HEAT INPUT 45 KJ/cm SAW
15MIG ..... HEAT INPUT 15 KJ/cm MAG WELDING

HT 80
○ THROUGH THICKNESS CRACK
● SURFACE CRACK

HT 70
△ THROUGH THICKNESS CRACK
▲ SURFACE CRACK

(2) Weldability

For the prevention of cold cracking in welds, it is necessary to decrease Ceq values of steels.

On the other hand, as HT70 and 80 are quenched and tempered steels, a decrease in Ceq. value may lead to the loss of hardenability. Especially in thicker steels, this tendency becomes more pronounced in the middle part of the thickness. It is well recongnized that the loss in hardenability results in the deterioration of the toughness and also in the aggravation of the softening phenomenon in the welded joints. From these facts, the decrease of Ceq. values has to be limited in order to obtain steels with enough strength and toughness. It is therefore necessary for specifying the Ceq. range to reflect the preheat temperature, applicable for the practical fabrication and not injurious to the performance of base materials and their welded joints.
An investigation was made on the relation of Ceq. to mechanical properties of the steels, and the critical preheat temperature for weld cracking. For HT80 with thickness of 50 mm, it was concluded that the necessary preheat temperature and Ceq. were 100°C and in the range from 0.47 to 0.53%, respectively.
As Fig.3 shows, with increasing the carbon content, both the required preheat temperature and the transition temperature (vTrs) of the weld bond zone rise. It is therefore desirable for the carbon content to be less than 0.13% for the thickness less than 50 mm and to be less than 0.14% for the thickness over 50 mm. However, the specification was established, as shown in Table 2, with the wider range for the enough hardenability of the steels.

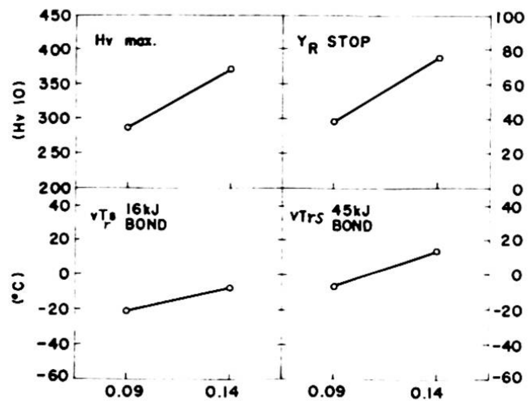


FIG. 3 EFFECT OF CARBON

(3) Lamellar tearing test and restraint weld cracking test

It sometimes happens that the welding of thick plates is troubled with lamellar tearing. It was therefore important to clarify whether or not the steels specified in Table 2 were safe against the initiation of lamellar tearing. The modified Cranfield cracking test and restraint weld cracking test shown in Figs. 4 and 5, were carried out. The former test is the case where free angular distortion was allowed and the latter is the case where it was not allowed. No lamellar tear cracks were found. Thus, it was confirmed that any cracking could be prevented by the preheating up to 125°C.

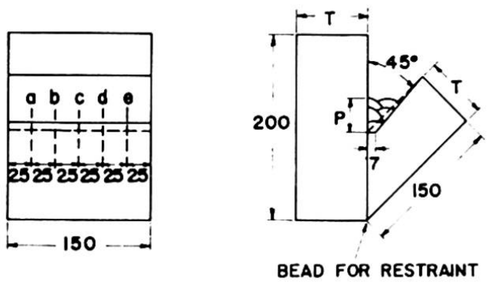


FIG 4 LAMELLAR TEARING TEST SPECIMEN

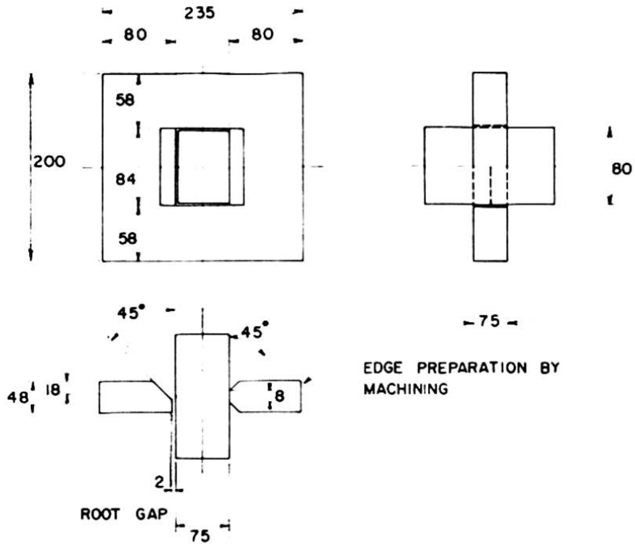


FIG. 5 DETAILS OF RESTRAINT CRACK TEST SPECIMEN

3. FUTURER SUBJECTS IN THE USE OF HIGH STRENGTH STEELS

3.1 Future project

One of the biggest projects concerning bridge construction in the next decade in Japan, is the Honshu Shikoku Bridge project. The steel specification in this project is recommended as shown in Table 3 by the Honshu Shikoku Bridge Committee of the Japan Society of Civil Engineers refered to the specification used for the Osaka Port Bridge construction.
Some of the bridges have both highways and railways, so it is necessary to clarify the fatigue strength. In 1971, HT80 was used for a railway bridge in Japan. According to its experience, it was pointed out that, even under compressive stress condition, a fatigue crack initiation could occur due to residual stresses. At present, fatigue tests by the Honshu Shikoku Bridge Authority have been carried out using the model truss panel construction.

TABLE 3 SPECIFICATION OF HT70 AND HT80 FOR HONSYU-SHIKOKU BRIDES

STEEL	THICKNESS t (mm)	CHEMICAL COMPOSITION (%)					CARBON EQUIVALENT		MECHANICAL PROPERTY										
									TENSION TEST						BEND TEST		CHARPY V NOTCH TEST		
												ELONGATION							
		C	Si	Mn	P	S	THICKNESS t (mm)	(%)	THICKNESS t (mm)	YIELD POINT OR 0.2% PROOF STRESS (kg/mm²)	TENSILE STRENGTH (kg/mm²)	THICKNESS t (mm)	GAUGE LENGTH (mm)	(%)	BENDING ANGLE (°)	INSIDE RADIUS	TEST TEMPERATURE (°C)	ABSORBTION ENERGY (kg·m)	TEST PIECE
HT70	8≦t≦75	0.14 max	0.15~0.55	0.60~1.50	0.015 max.	0.015 max.	8≦t≦50	0.49 max.	8≦t≦50	60min.	70~85	8≦t≦16	50	17min.	180	t<32 1.5t; t≧32 2.0t	-35	4.8min.	ALONG ROLLING DIRECTION
												16<t≦25	50	23min.					
							50<t≦75	0.51 max.	50<t≦75	58 min.	68~83	25<t≦75	50	17min.					
HT80	8≦t≦75	0.14 max.	0.15~0.55	0.60~1.50	0.015 max.	0.015 max.	8≦t≦50	0.53 max.	8≦t≦50	70min.	80~90	8≦t≦16	50	16min.	180	t<32 1.5t; t≧32 2.0	-40	4.8min.	
												16<t≦25	50	22min.					
							50<t≦75	0.55 max.	50<t≦75	68min.	78~93	25<t≦75	50	16min.					

3.2 Approach toward new high tensile steels

As a new steel for future big bridges, an approach toward HT100 (Tensile strength$\geqq$ 100 kg/mm^2) can be conceivable. Some of steel makers have already made a couple of HT100 trial steels of which thickness are up to 100 mm and their weldability have also been investigated. According to the results obtained so far, one of them has comparable weldability to that of HT80. An example of typical chemical compositions and mechanical properties of HT100 is shown in Table 4.
In addition, other quenched and tempered steels, weldable under high heat input and/or low preheat temperature are available for the purpose of enhancing the productivity in welding.

TABLE 4 PROPERTIES OF HT 100 (ONE EXAMPLE)

STEEL	CHEMICAL ANALYSIS													TENSILE PROPERTY						CHARPY ABSORPTION ENERGY vE-15 (kg·m)
	PROCESS	CHEMICAL COMPOSITION (%)											Ceq (%)	LOCATION OF TEST SPECIMENS		YIELD POINT (kg/mm²)	TENSILE STRENGTH (kg/mm²)	ELONGATION (%)	REDUCTION OF AREA (%)	
		C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	B								
HT100 (50mm)	LADLE	0.09	0.28	0.92	0.009	0.005	0.26	1.85	0.56	0.55	0.06	0.0012	0.555	L	1/4 t	92.1	98.0	23.0 (Gl=50)	69.0	16.3
															1/2 t	89.4	96.2	23.0 (Gl=50)	68.1	18.1
	CHECK	0.09	0.28	0.90	0.009	0.006	0.25	1.88	0.50	0.52	0.073	0.0010	0.534	C	1/4 t	92.5	97.6	22.0 (Gl=50)	63.5	6.9
															1/2 t	89.0	96.2	22.0 (Gl=50)	64.0	6.3
														Z		89.0	95.9	19.6 (Gl=14)	49.2	–

3.3 Future subjects in the use of atmospheric corrosion-resistant steels

In the United States, the use of unpainted atmospheric corrosion-resistant steels like ASTM A588 material is recently increasing, although it is not so often for bridges in Japan.
The reason why the application of unpainted atmospheric corrosion-resistant steels is not widely used is attributable to the fact that the amount of alloying addition is restricted due to the limitation arising from their weldability. Therefore, it is important to develop the highly atmospheric corrosion-resistant steels and to establish their welding procedure techniques. In addition, if a chemical surface treatment method, which is inexpensive and stable, is developed, the practical use of the unpainted steels will be more prevailed.

4. FABRICATION

4.1 Subjects on the Fabrication of HT70 and HT80

In the fabrication of the Osaka Port Bridge for which HT70 and 80 were used, the fundamental studies on the following subjects were conducted prior to the establishment of the fabrication standard.

(1) Effects of thickness, restraint intensity, preheat temperature, welding process and welding materials on cracking

(2) Influences of angular distortion, missalignment in welded joint on joint strength and fracture strength

(3) Relationship between welding process and welding materials

(4) Relationship between welding conditions and depth of fusion in partial penetration welding

(5) Correlation between tack welding and cracking mechanism in main welds

(6) Relationship between the assembly and welding sequence and welding distortion

(7) Problem of hardening on gas cut surface

4.2 Fundamental Tests on the Fabrication of HT70 and HT80

In the fabrication of the Osaka Port Bridge, following various procedure tests were carried out to clarify the items shown above.

(1) Cracking test using small size test specimens

Relationship between the crack length in welds made by various processes and the amount of angular distortion was investigated by means of y-slit type cracking test on thick HT80 plate, which was subject to various restraint conditions and preheat temperatures.
It was concluded from the test results that so-called "Lamellar Tearing" could not occur in SAW and MAG welds, and by the preheating up to 125°C, any cracking could be prevented within the amount of angular distortion which could be occured in an actual fabrication.

(2) Investigation on the influence of angular distortion and missalignment

Using wide butt-jointed test specimens, the following influences were investigated on HT80 with the thickness of 38-50 mm; (1) the influences of angular distortion and missalignment occured in actual fabrication on the tensile strength of welded joints ; 2, the influences of initial deformation of welded joints which is press-reformed on the Charpy impact values. Test results showed that there was a tendency to decrease the tensile strength by the increase of angular distortion and missalignment, and the fracture toughness of the welded joints by press reform.

(3) Confirmation tests of fabrication procedures using pilot members

The pilot members for the Osaka Port Bridge were made using HT80 for the investigation of fabrication procedure. These test members have the same size and thickness for the chord member and the tower. Measurements of the fabrication accuracy, the residual stresses, impact test, tension test, etc. were carried out. For the inspection of the depth of fusion and the cracking on the corner joints with partial penetration, the reliability of ultrasonic inspection was checked by the macroscopic examination. From the test result, ultrasonic inspection was proved to be reliably used for actual works.
Test results revealed that, even though the welding materials for 60 kg/mm^2 class steel was used for the HT80 corner joints, the strength of 70 kg/mm^2 class could be attainable, and CO_2 welding was appropriate for the tack welding of HT80 because of its low hydrogen content.

(4) Gas cutting procedure test

On thick section HT70 and 80, the roughness of gas cut surfaces and the hardenability of the heat affected zones were investigated. Test results showed that usual cutting conditions were proved to be applicable, because the gas cut surface roughness could meet the requirement and also the hardness was within the permissible levels as shown in the following.

HT70 : Hv (10 kg) $\leqq$ 390
HT80 : Hv (10 kg) $\leqq$ 410

4.3 Fabrication of the Osaka Port Bridge

The total weight of the Osaka Port Bridge was 34,910 tons, 5,272 tons of which was made of HT70 and 80.
For the fabrication, the various test results mentioned in 4.2 were summerized into a standard for the fabrication of steel bridges using HT70 and 80.

(1) Configuration of corner joints in chord members

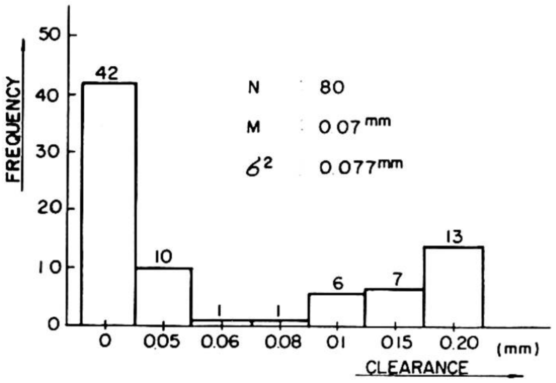
Corner joints of thick section members such as chord members and tower members of the Osaka Port Bridge were decided to be welded with partial penetration type groove welds by taking account of design considerations, the fabrication accuracy, and the weldability. The designed throat thickness of the single beveled joint was decided to be $\sqrt{2T} + 3$ mm (T signifies the thickness of the thicker plate).

(2) Full size drilling method for chord members

Although in the foreign specifications, reaming is sometimes specified to be conducted at the stage of shop assembling after making small size drilling during member processing. In Japan, the procedure without reaming at the stage of shop assembling has been employed as full size drilling method for ordinal steel bridges. To do this, the amount of weld shrinkage statistically obtained is included as an extra size, when the marking is carried out. The full size drilling is done with a template with steel hardened bush. In the fabrication of the Osaka Port Bridge, this drilling method was extensively used and the result was satisfactory.

(3) Milling of metal touch compression joints of lower chord members

Compression joints of lower chord members near the center support of the Osaka Port Bridge was designed to have metal-touch structural joints. It was decided that the milling accuracy of the member's edge surface was less than 10 S (10μ) and the clearance at the stage of the shop assembling was narrow enough to refuse the clearance gauge of 0.2 mm (Fig. 6).



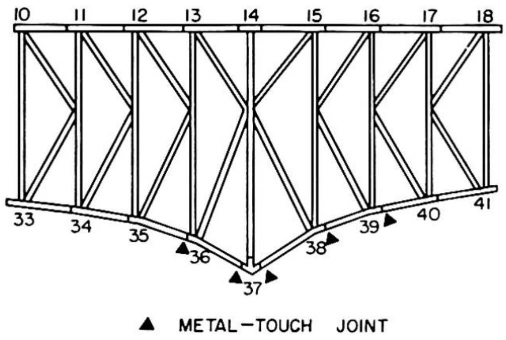


FIG. 6 DISTRIBUTION OF CLERANCE IN METAL-TOUCH JOINTS (OSAKA PORT BRIDGE)

(4) Assembling by panel assembling method

For assembling chord members and tower columns, a panel assembling method conventionally used in ordinal bridges, was applied. Longitudinal stiffeners attached to flanges and webs were welded by an automatic process in a panel state prior to assembling to a box shape (Fig. 7).

(5) Welding procedures for HT70 and HT80

a) Weather survey : It was decided that, as for HT70 and 80, an in-door welding procedure was basically employed. The measurements of temperature, humidity and the partial pressure of water vapor was carried out four times in a day and the procedure control was made with these data.

b) Welding materials for dissimilar joints : The materials appropriate for higher strength materials were used in the welding of butt joints where the two of HT70, HT80 or other steels were combined. On the other hand, 60 kg/mm^2 class materials were used for the welding of fillet and corner joints of HT70 and 80. In this case, the preheating was conducted in a same manner done in cases of HT70 and 80, respectively.

c) Drying of welding materials : The welding electrodes for shielded metal arc welding and flux for SAW welding were used under the controled humidity as specified following,

Electrode ; drying temperature : 380-450°C
drying time : 45-75 min.
holding temperature: 120°C

Flux; drying temperature : 250-300°C
drying time : 60 min.
holding temperature: 120°C

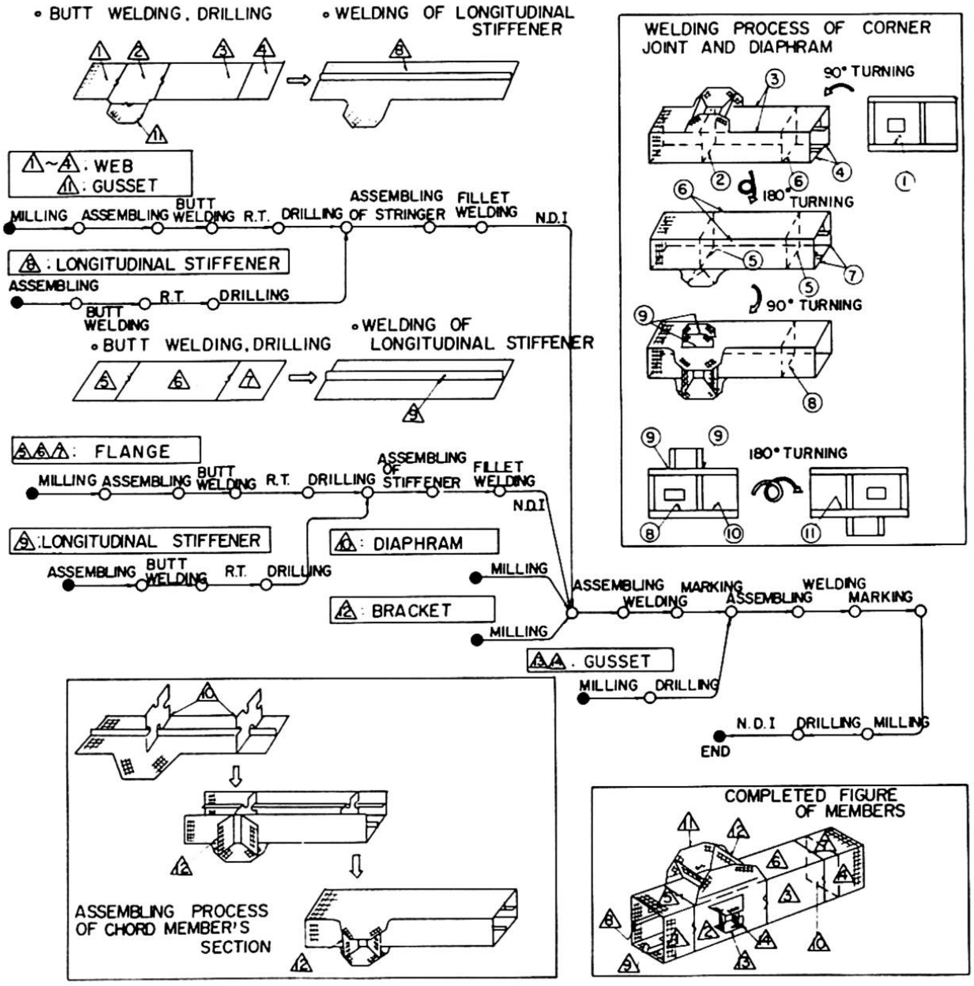


FIG 7 FLOW CHART OF PANEL ASSEMBLING METHOD OF CHORD MEMBERS
(OSAKA PORT BRIDGE)

d) Control of preheat temperatures : The preheat temperatures were determined with reference to the various procedure test results and the recommended data by steel makers. The preheating was carried out by electric strip heaters with self control devices and fixed type heating devices (Fig. 8 and Table 5). For ensuring toughness, the upper limits of heat input and interpass temperature for various steels and thicknesses were specified.

e) Tack welding : For the tack welding of HT70 and 80, low hydrogen type electrodes were used and the welding was made with the preheat temperatures higher than those in main welding by 30 - 50°C. To the tack welding of the corner joints of HT70 and 80, however, CO_2 semi-automatic welding method was applied to minimize diffusible hydrogen.

f) Symmetric preheating and welding : In order to minimize the weld deformation, symmetric preheating and welding were carried out for HT70 and 80 weldments.

(6) Reforming

Reduction of deformation in HT70 and 80 weldments was basically done by press reforming. However, to places where press reforming are not applicable, correction by gas burner heating without water cooling was used under the condition of the maximum temperature of 750°C.

TABLE - 5 MINIMUM PREHEAT AND INTERPASS TEMPERATURE (UNIT °C)

WELDING PROCESS	WELDS								TACK WELD	
	SMAW	MAG & SAW	SMAW	MAG & SAW	SMAW	MAG	SAW		SMAW	MAG
WELDED PLATES	SM50		SM58		HT70, HT80				HT70, HT80	
THICKNESS OF PLATES / TYPE OF WELDS	GROOVE WELD FILLET WELD CORNER WELD		GROOVE WELD FILLET WELD CORNER WELD		GROOVE WELD FILLET WELD CORNER WELD		GROOVE WELD	FILLET WELD	GROOVE & FILLET WELD	CORNER WELD
t ≦ 25 mm	—	—	40	—						
25mm< t ≦ 38mm	40 *	—	80	40 *	100	80	100	80	120	100
38mm< t ≦ 50mm	80	Corner 40 *	80	60	100	80	100	80	120	100
t > 50mm	100	80	100	80	120	100	150	100	150	120

NOTICIES : 1. MAXIMUM PREHEAT TEMPERATURE AND INTERPASS TEMPERATURE FOR HT70 & HT80 SHALL BE LIMITED UNDER 200°C (t ≦ 50mm) AND 230°C (t > 50mm)

2. SIGN * MEANS SUCH CONDITION HEATED BY GAS BURNER LIGHTLY

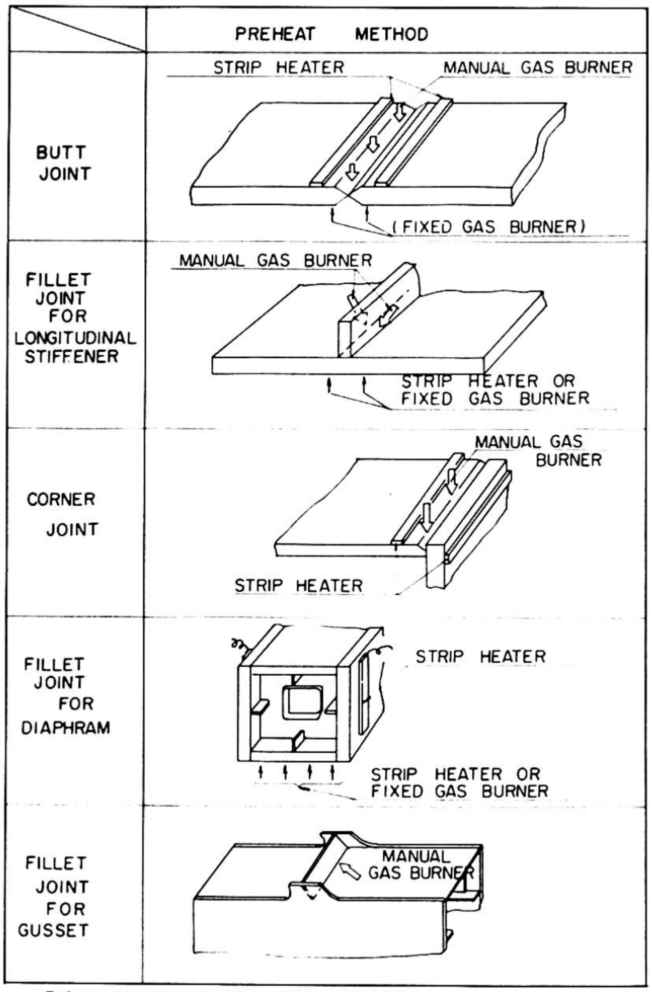


FIG 8 STANDARD PREHEAT METHOD

(7) Non destructive inspections

a) Radiographic test was applied to butt joints.

b) Magnetic or penetrant tests were applied to the fillet joints of HT70 and 80.

c) Ultrasonic inspection was applied to the corner joints of chord members and tower columns.

d) As for the butt and corner joints of HT70 and 80, macroscopic examination and mechanical test by means of end tab were also made.

(3) Fabrication accuracy

In the fabrication of the Osaka Port Bridge, the accuracy in the shop fabrication was specified in details to avoid troubles during its erection (Table 6, Fig. 9).

TABLE 6 TOLERANCE FOR TRUSS BRIDGE (UNIT : MM)

TOLERANCE FOR MEMBERS			TOLERANCE FOR SHOP ASSEMBLY	
TERMS		TOLERANCE	TERMS	TOLERANCE
LENGTH		$\Delta l \leq \pm 2$	PANEL LENGTH	$\Delta l \leq 2.5$
STRAIGHTNESS OF MEMBER		$\delta \leq \frac{l}{2000}$	TOTAL LENGTH	$\Delta l \leq \pm 2 \times N$ (N: NUMBER OF PANEL) And $\lvert \Delta l_1 - \Delta l_2 \rvert \leq 9$; Δl_1: RIGHT MAIN TRUSS; Δl_2: LEFT MAIN TRUSS
TORSION		$\delta \leq \frac{h}{500}$ And $\delta \leq 3$	HEIGHT OF TRUSS	$\Delta l \leq \pm 2 \times N$ (N: NUMBER OF PANEL) And $\Delta l \leq \pm 10$
SIZE OF SECTION	BOX TYPE	$B \leq \pm 2$, $H \leq \pm 2$, $\lvert l_1 - l_2 \rvert \leq 3$	DISTANCE BITWEEN CENTER TO CENTER OF TRUSS	$\Delta W \leq \pm 3$ (ON SUPPORT POINT); $\Delta W \leq \pm 5$ (OTHERS)
	I - TYPE	$H \leq \pm 2$, $-1 \leq B \leq 2$	CAMBER	$\delta \leq \pm 8$ (FOR 4-PANELS); $\delta \leq \pm 10$ (FOR 5-PANELS)
ANGLE OF FLANGE & WEB		$\frac{d}{(b/2)} < \frac{1}{100}$	STRAIGHTNESS OF GIRDER	$\delta \leq \pm 8$
DEFORMATION OF WEB		$H \leq 1m$: $\delta \leq \frac{1}{3} t$; $1 < H < 4$: $\delta \leq \frac{1}{2} t$; $H \geq 4$: $\delta \leq \frac{2}{3} t$	DIAGONAL LENGTH OF TRUSS SECTION	$\lvert d_1 - d_2 \rvert < 10$; d_1, d_2 : DIAGONAL LENGTH OF TRUSS SECTION
ANGLE DEFORMATION OF BASE PLATE	MEMBER ON SPAN END	NORMAL: $\delta \leq l/1000$; TRANS VERSE $\delta \leq B/1500$	CLEARANCE OF FIELD JOINT	ORDINARY JOINT : $\delta \leq 2$; METAL-TOUCH JOINT : $\delta \leq 0.2$
	MEMBER ON SUPPORT POINT	NORMAL $\delta \leq l/1000$; TRANS VERSE $\delta \leq B/3000$	MISS ALIGNMENT OF BUTT JOINT	$\delta \leq 2$

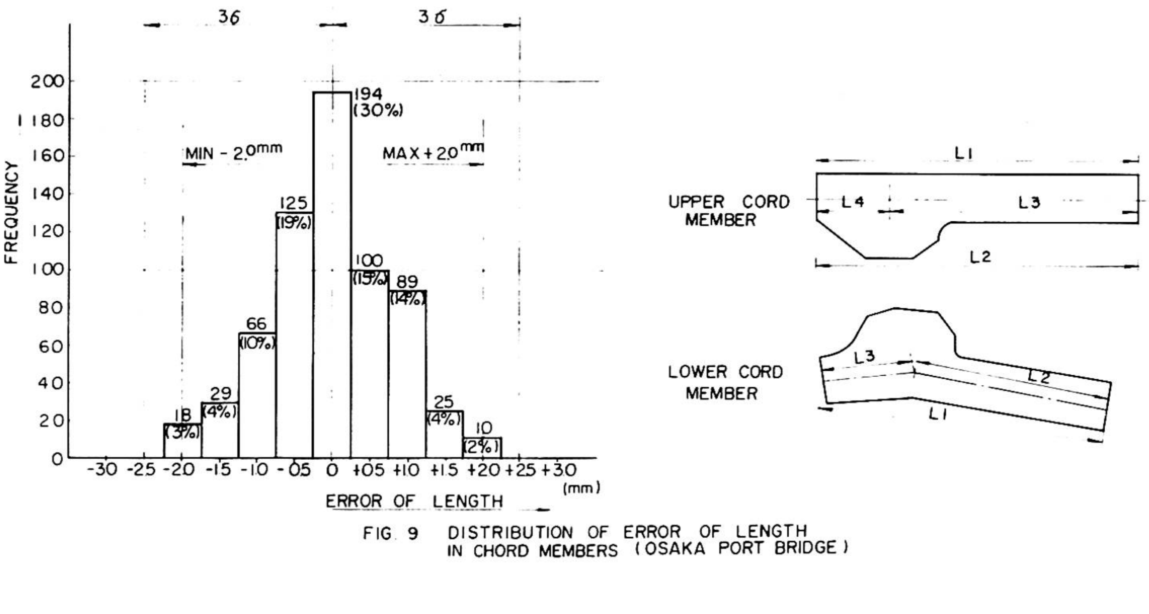


FIG. 9 DISTRIBUTION OF ERROR OF LENGTH IN CHORD MEMBERS (OSAKA PORT BRIDGE)

4.4 Future Subjects in the Fabrication of Steel Bridges

(1) Shapes of cross sections of members and the productivity of welding

As the cross sectional shape of the members used in the Osaka Port Bridge, the simple square section of two web-flange was employed from the stand-point of simplicity and productivity of welding and erection, although other sections including members with cruciform middle web-flange and single middle web-flange types were considered. From the view-point of the productivity, it is desirable for the shape of the member section of high strength steel to increase the height of web, the width of flange and also thickness with increasing the rigidity of section, and to minimize the number of longitudinal stiffeners.

(2) Fatigue strength of HT80

It is effective for improving the fatigue strength of bridges to have good appearance beads and to finish welded beads. As for future subjects to be studied, the improvement of welding materials or the employment of Toe Melting method are still left.

(3) Simplification of joint design

Up to now, a high tensile strength bolt (HTB) joint is widely used in the field joint of steel bridges. In order to simplify joint design, it may be worthwhile studying whether metal-touch can be applied to compression joints, or the joint of HTB combined with welding used in steel-deck-plate joints can be used extensively.

(4) Coating system in inland sea bridges

As discussed in 3.3, there are unsolved aspects concerning the effect of salt glanule in a sea on atmospheric corrosion-resistant steels.
It is therefore desirable to investigate them and also carry out the finishing coating in shops as much as possible, because usually the painting of inland sea bridges is specified to use heavy coating due to the maintenance.

(5) Establishment of fabrication accuracy for big bridges

In the determination of the fabrication accuracy, the accuracy in fabrication processes in every stage should be statistically known and the use of cumulative error concept, in which Propagation law of error is utilized, should be promoted to streamline the fabrication and shop assembling procedure and the control of accuracy.

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