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Fabrication and erection of Tokyo Gate bridge

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ABSTRACT: Tokyo Gate bridge was planned to mitigate traffic congestion on coastal roads around Tokyo Port and to provide access to a future logistics hub. In engineering, there were two major restrictions; airspace above the bridge due to proximity to Haneda Airport and seaway clearance beneath the bridge for vessel passage. These constrains resulted in selection of a composite structure with steel truss members and a steel box girder in lieu of a cable-stayed or a suspension structure. In order to save construction cost, several significant measures were adopted. They include use of newly developed SBHS (Steels for Bridge High Performance Structure) and large block erection using three heavy duty floating cranes.

1 FACTS AND CHALLENGES

The bridge is located just outside of the Tokyo Port, which is one of the busiest ports in the world and which has future expansion plan including new container terminals. The bridge is expected to improve traffic and to mitigate approaching routes congestion. It is located near Haneda International Airport. Under the bridge there is Tokyo Port's Seaway #3 for the vessel traffic. Therefore the bridge has the following challenges.
-Overall structure's height shall not exceed 98.1 meter in order to assure clearance for incoming and outgoing air traffic to and from the airport.
-For 300 meter seaway, under bridge clearance shall be at least 54.6 meter for 60000 ton class vessels and the world's largest cruise ships such as the Queen Elizabeth II.

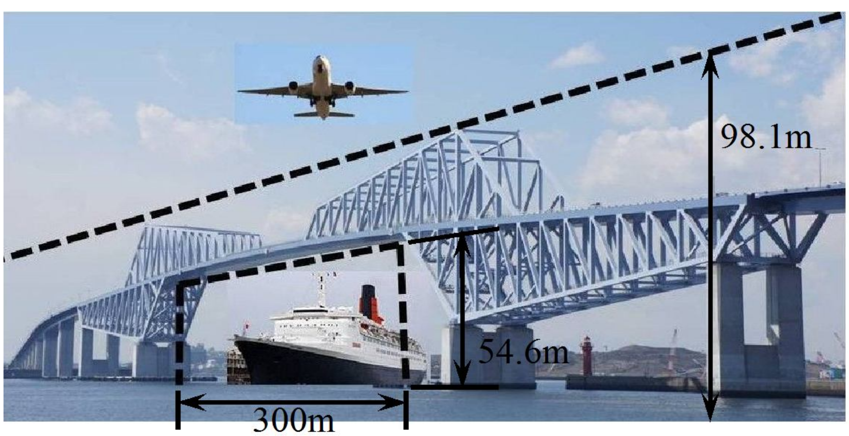
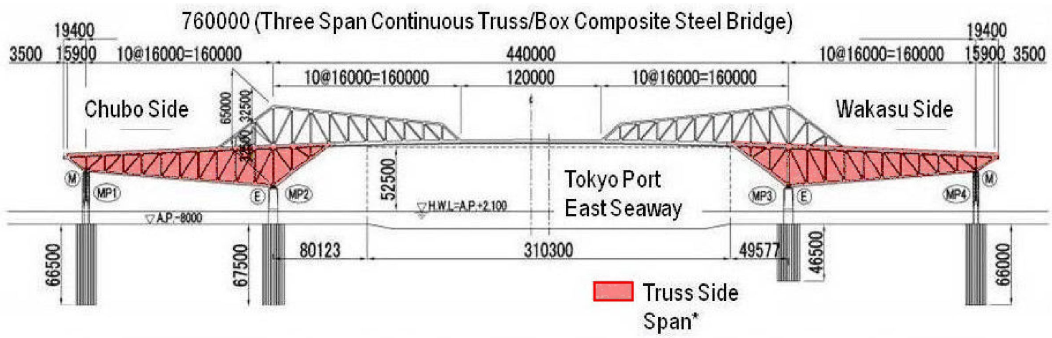


Figure 1. Geometrical Restriction of the Bridge

In order to achieve the above challenging requirement, the bridge type was elected to be of a composite structure with steel truss members and a steel box girder in lieu of a cable-stayed or a suspension structure.
General information of the bridge is shown in the following figure.



Type	Three Span Continuous Truss/Box Composite Steel Bridge
Bridge Length	792.0m
Spans	160.0+440.0+160.0m
Width	21.0m (Truss chord member center-to-center 22.3m)
Effective Width	18.5m (Motor way 15.5m+Pedestrian Walkway 3.0m)
Block Erection Portion	6,800 tons 232.0m long each (Lifting weight 7,400 tons each)

Figure 2. General Information of Tokyo Gate bridge

2 THE BRIDGE'S KEY FUTURES FOR ENGINEERING AND CONSTRUCTION

The following are the key futures of design, fabrication and erection of the bridge.

i. Use of Newly developed High Performance Steel for Bridge-SBHS Steel
ii. All Welded Joints for Main Truss Members
iii. Orthotropic Bridge Deck
iv. Eliminating shop trial assembly, the side span truss bridge sections were fabricated at shop and assembled in the yard close to the erection point as erection blocks.
v. Erection of the two large blocks with well synchronized performance of 3 heavy duty floating cranes
vi. Among those above, this paper will be focused on "Fabrication using newly developed SBHS steel" and "Erection of the large blocks with 3 heavy duty floating cranes".

3 FABRICATION USING SBHS STEEL

3.1 *Outline of SBHS Steel*

The project used significant amount of newly developed SBHS Steel : Steels for Bridge High Performance Structure, with high tensile strength as 570 N/mm2 or above (to be called SBHS steel in this paper).
The location of SBHS steel application and the amount used are shown in the following figure. We were able to save 600 tons (3%) of steel usage comparing to regular JIS SM570 steel (Ts=570 N/mm2 or above : to be called 570 N steel in this paper).

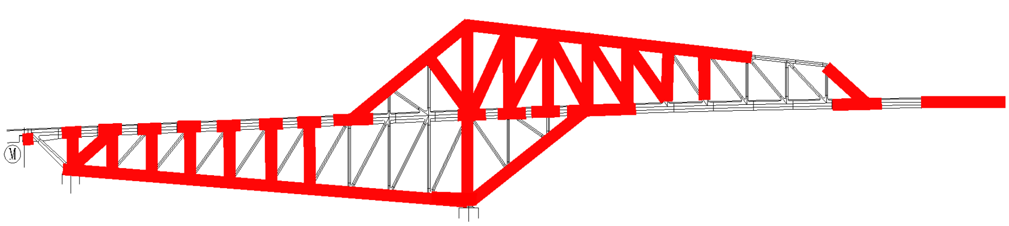


Figure 3. Members where SBHS steel was used

Table 1. SBHS500 Steel

Total Steel Weight : Approximately	20,500 tons
SBHS Steel Included : Approximately	10,300 tons (51%)

SBHS steel features high-performance, high-tensile strength that was developed through a joint project carried out by industry and academia for the purpose of reducing steel bridges' construction costs in Japan.
The specifications for the material grade of SBHS-SBHS500 that was used for the bridge are shown in the following table.

Table 2. Specifications of SBHS500 steel

Chemical composition		C	Si	Mn	P	S	N
		(%)	(%)	(%)	(%)	(%)	(%)
		0.11max.	0.55max.	2.00max.	0.020max.	0.006max.	0.006max.
Mechanical properties	YP	TS	Elongation		Toughness		
			Thickness range	Elongation	Temperature	Energy	Direction
	(N/mm2)	(N/mm2)	(mm)	(%)	(°C)	(Joule)	
	500min,	570~720	6 up to 16	19min.	-5	100min.	Transversal to roll direction
			Over16 up to 20	26min.	-5	100min.	Transversal to roll direction
			Over 20	20min.	-5	100min.	Transversal to roll direction

It has the following advantages;

i. Higher yield strength than conventional steel (constant yield strength irrespective of sheet thickness)
ii. Greater ease of fabrication and welding than conventional 570 N steel, eliminating preheating in some cases, and enabling reducing preheating temperature.
iii. Charpy test conducted perpendicular to rolling direction; Toughness is high at any plate rolling direction.
iv. Improves ease of welding and cold fabrication, etc.; improves formability in manufacturing

SBHS steel is produced by high-tech thermal process controlling and by adding synthetic element so that it has higher precipitation strength and finer crystalline structure.
As a result, SBHS steel is low carbon alloy and yet it has high strength and high toughness.
It also has as good workability as JIS SM 490Y class steel (Ts=490 N/mm2 or above : to be called 490 N steel in this paper).

3.2 *Tests to Confirm Workability for SBHS Steel*

Prior to fabrication work, a series of tests were conducted in order to confirm those advantages of SBHS steel for thermal cutting, cold bending, heat straightening, preheating and weldability.

3.2.1 *Thermal cutting*

Thermal cutting was performed using the same work parameters as 490N steel and no problem such as rough cut surface , sticky slag or edge melting was observed.

3.2.2 *Cold-bending*

After bending with radius=5 times of thickness, the Charpy V-notch value (vE-5) still exceeded 200J for both longitudinal and transverse directions, while SBHS specifications requires that after bending with radius=7xt, the Charpy V-notch value (vE-5) shall be 100 J min.

Table 3. Charpy Test Result

Treatment			Strain Aging
Impact Test Specimen Sampling Location			thickness/4
	Direction	vE-5 average	vTrs
		Joule	°C
	Longitudinal	273	-45
	Transversal	298	-40

3.2.3 *Heat straightening*

After liner heating 1000°C and either air-cooling or water-cooling, the tensile strength and Charpy V-notch toughness value still exceeded requirement.

Table 4. Heat Straightening Methods for Comparison

Method#	Heat Temperature	Cooling	Gas	Height of Torch	Water Applied
1	900°C	Air	O2* and C2H2**	14mm	None
2	900°C	Water	O2* and C2H2**	14mm	6 liter per minute
3	1000°C	Air	O2* and C2H2**	14mm	None
4	1000°C	Water	O2* and C2H2**	14mm	6 liter per minute

*Pressure 5kg/cm2 Flow Rate 50 liter per minute
**Pressure 0.5kg/cm2 Flow Rate 20 liter per minute

Table 5. Heat Straightening Method Comparison Result

Method#	Transversal Direction Mechanical Test			1mm under Surface Impact Test Result	
	Yield Point	Tensile Strength	Elongation	Direction	vE-5
	(N/mm2)	(N/mm2)	(%)		(Joule Average)
1	534	637	30	Longitudinal	30.1
1	ditto	ditto	ditto	Transverse	29.3
2	536	637	28	Longitudinal	29.9
2	ditto	ditto	ditto	Transverse	29.5
3	529	633	29	Longitudinal	28.7
3	ditto	ditto	ditto	Transverse	29.5
4	538	637	29	Longitudinal	29.9
4	ditto	ditto	ditto	Transverse	28.9

3.2.4 *Preheating*

Y-groove weld cracking tests were performed on GMAW welding and SMAW welding with no preheating (room temperature 6°C) and no crack was detected.

Table 6. Welding Procedure Test with No Preheating

Welding Process	SMAW
Welding Consumable	L-62CF
Diameter	4mm
Preheating	None (Room Temperature 20°C)
Humidity	60%
Parameter	170Amp-25Volt-15cm/minute
Heat Input	1.7 K.Joule/mm
Drying Consumable	400°C for 1 hour Stored at 110°C No Moisture Absorption
Result	NO CRACK DETECTED

Welding Process	GMAW
Welding Consumable	YM-60C
Diameter	1.2mm
Preheating	None (Room Temperature 20°C)
Humidity	60%
Parameter	280Amp-30Volt-30cm/minute
Heat Input	1.7 K.Joule/mm
Drying Consumable	CO2 25liter/minute
Result	NO CRACK DETECTED

3.2.5 *Weldability*

Welding procedure tests with two processes were conducted. One was by CO2-GMAW with heat input under 5KJ and interpass temp under 250 ^{o}C. Another one was SAW double electrodes in tandem with heat input under 10 kJ and interpass temperature under 300 ^{o}C. Both welding processes were proven to be satisfactory with the tensile strength and Charpy toughness exceeding requirement.

3.2.6 *Summary of the procedure test results*

While conventional 570N steel tends to have more restricting factors that 490 N steel for cutting because of more alloy ingredients, SBHS steel is as easy to cut as regular 490 N steel. SBHS steel can be bent to 5 x thickness radius and it is equal to regular 490 N steel. Heat straightening up to 1000°C and water cooling still resulted in all sound steel mechanical properties. All the welding procedure tests with minimum heat input and no preheating caused no cracking on Y-groove weld cracking tests. These results proved that we do not need preheating. Both SAW welding with heat input 100 KJ/cm and CO_2-GMAW welding inter-pass temperature over 230 °C(specified for JIS 570 N steel) produced sound and acceptable mechanical properties. Supported by the above procedure test results, the fabrication was performed with NO preheating.

Figure 4. Fabrication Photo

The fabricated members were then transported to the assembly yard near erection point to complete erection block assembly.

Figure 5. Yard Assembly and Completing Erection Block at Ariake Yard

4 ERECTION

4.1 *General*

Side span unit weighs approximately 6800 tons and including lifting assembly the overall erection block ended up with 7400 tons. It takes three heaviest duty floating cranes in Japan working together in synchronized way to lift and install the block. In Japan, such a three-FC operation has been done 3 times in the past and this was the fourth. The last time it was done was 16 years ago. The three floating cranes assigned for this erection are Kasho with 4100 ton capacity, Musashi with 3700 ton capacity and Yoshida 50 with 3700 ton capacity. The scheduling process started two years before erection time so that we could be sure that those high demand floating cranes are available on the erection day.

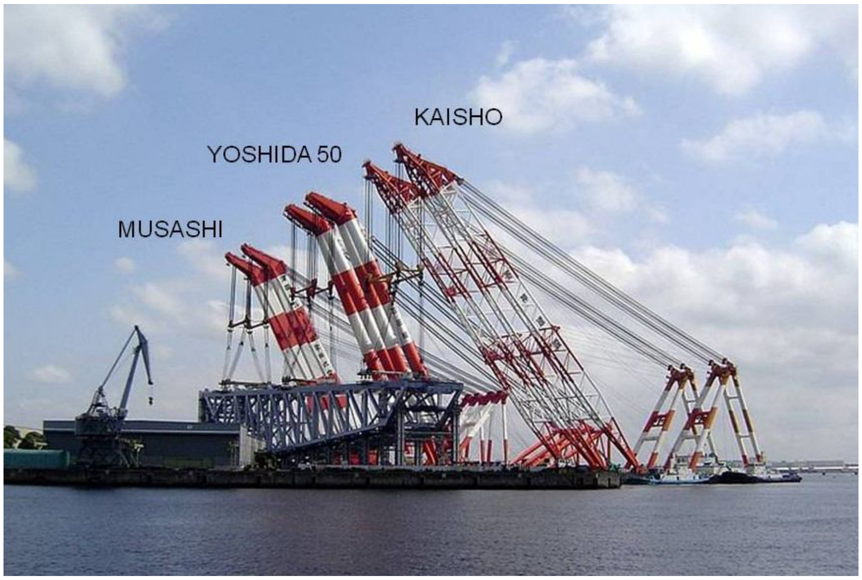


Figure 6. Three Heaviest Duty Floating Cranes for Erection

4.2 *Challenges*

The location being so close to the airport, floating crane jibs have to be below required elevation. It had to be closely monitored and controlled all the time.
Vessel seaway was restricted for the operation during narrow window of time. The floating crane location (coordinates) had to be closely monitored and controlled .
Lifting load had to be distributed among the three floating cranes as designed.
In order to deal with these challenges, the Three FC Lifting Control System was developed.

4.3 *Three FC Lifting Control System*

The system was developed in order to monitor real time for lifting load, elevation and location (coordinates) of each floating cranes.
As a part of the system operation, GPS devices were installed at the jib top and back stay of each floating crane. The acceleration meter was installed in the middle of the erection block.
Each floating crane control is linked by wireless LAN and the real time joint operation was monitored and controlled. Lifting load, jib inclination angle and jib top elevation are closely related to FC's lifting performance. Therefore they had to be closely monitored and controlled.

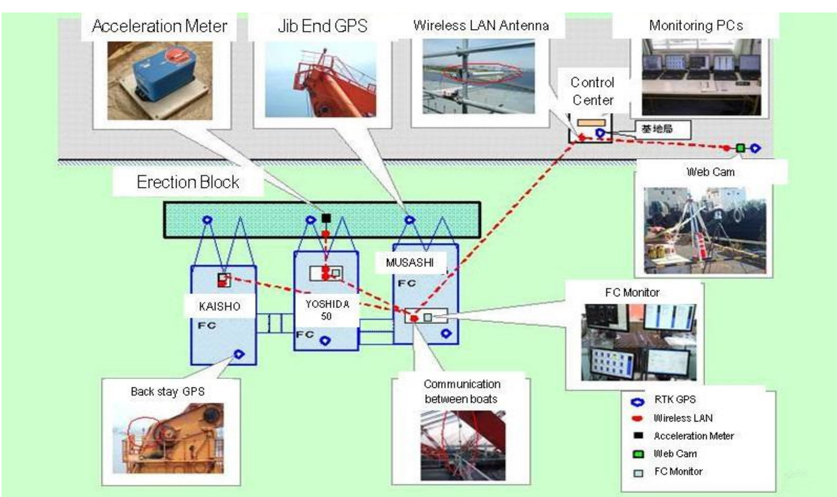


Figure 7. Three FC Lifting Control System

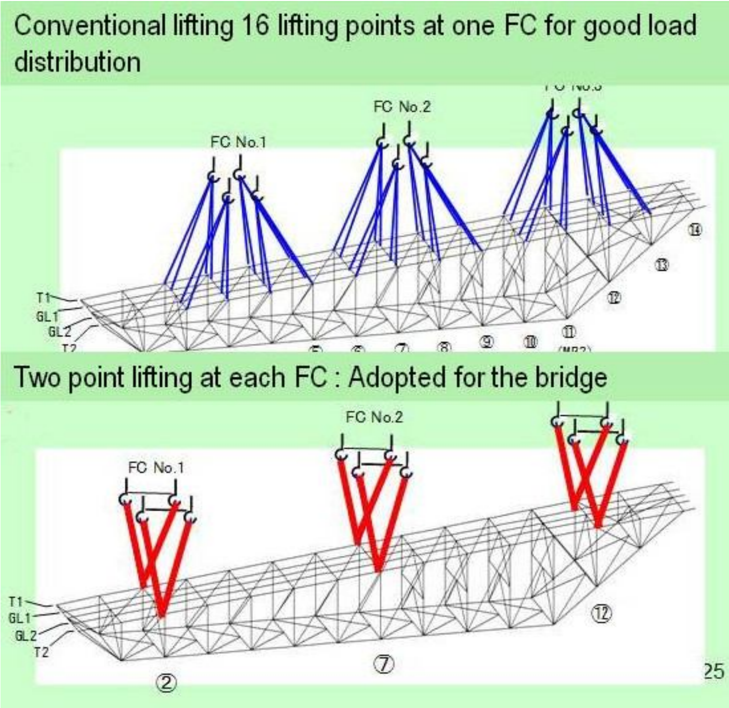


Figure 8. Lifting points

4.3.1 *Lifting load control*

Usually, in one floating crane four-hook-operation, lifting points would be either 8 or 16 for even load distribution. In this project the three floating cranes have to work together, each floating crane was set to have two lifting points in order to simplify the control work. The lifting load was closely monitored for each loading by hook as well as total four hooks. The actual lifting loads had to be within plus or minus 10% of the designed loads. If the actual load is out of this range, the operation had to be stopped for re-adjustment.

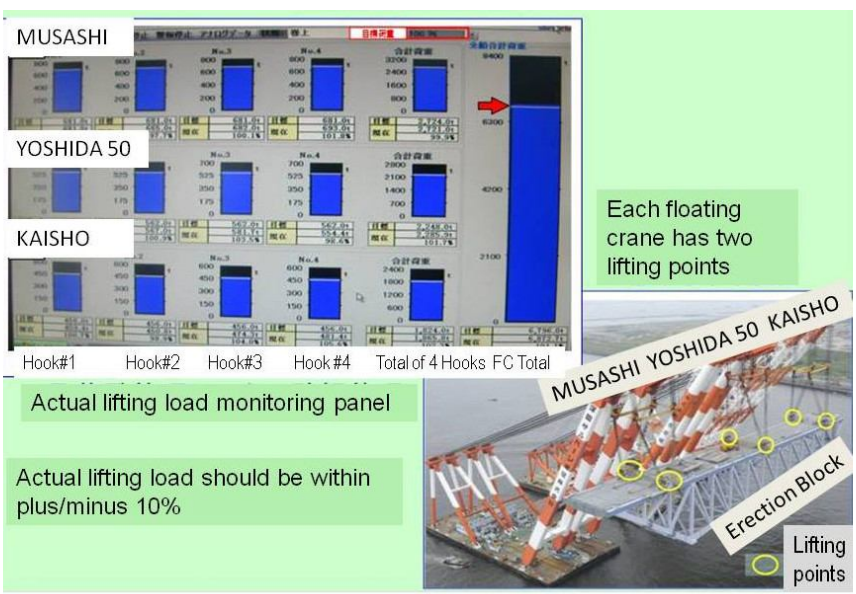


Figure 9. Lifting load monitoring

4.3.2 *Elevation control*

Elevation coordinates as well as latitude and longitude were monitored and controlled closely in order to confirm that the operation would not interfere with airway traffic. The information of the coordinates was obtained from GPS devices installed at jib tops.

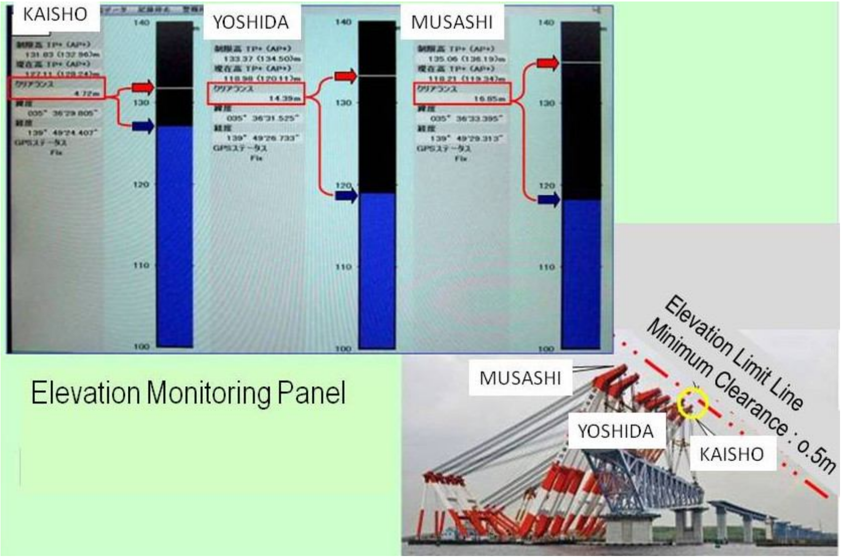


Figure 10. Elevation Control

4.3.3 *Location control*

During lifting off the ground and erection operation, the three floating cranes travel over 100 meter going back and forth. If the relative locations among the three cranes change, loading should be changed. So the locations were closely monitored and controlled by GPS devices. At the same time using the acceleration meter installed in the middle of the erection block, inclination of the erection block was carefully monitored as well and controlled.

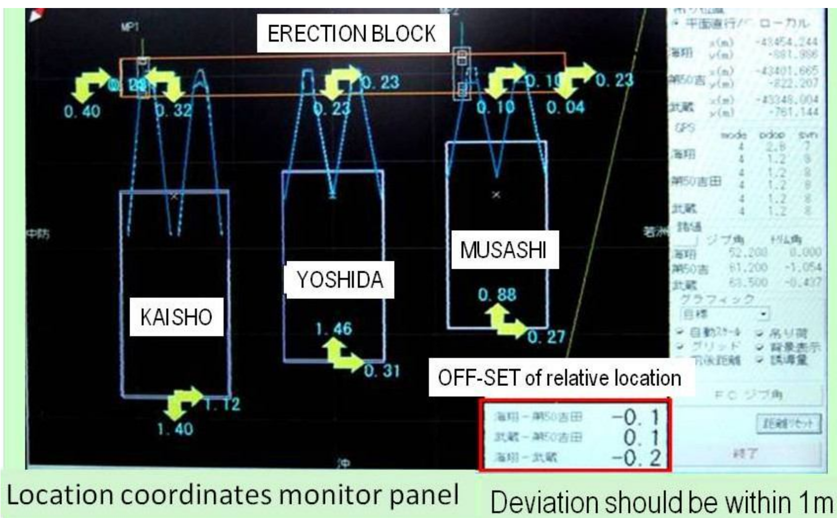


Figure 11. Location control

4.4 *Completing Erection*

Because of the well planned and careful control as mentioned above the two blocks, -Chubo side block and Wakasu side block, were successfully erected on September 15, 2009 and September 28, 2009 respectively. During the erection operation, we had Typhoon hit and we had to move back those floating cranes and wait but the erection was done within the timeframe we planned.

Figure 12. Lifting up erection block off assembly yard

Figure 13. Erection of the block

Figure 14. Completion of two block erection

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