<Reference>
October 7, 2013
Tokyo Electric Power Company

Seismic Safety Evaluation of Fukushima Daiichi NPS Units 1 and 2 Exhaust Stack Having Damaged Components

TEPCO 東京電力

Overview of the Units 1 and 2 exhaust stack

- This exhaust stack is a shared, steel-tower support type exhaust stack, which has its stack shaft (120 m in height and 3.2 m in inner diameter) supported by a square steel tower formed of steel pipes.
- The steel tower part is mainly composed of principal posts, diagonal bracings, and horizontal bracings.

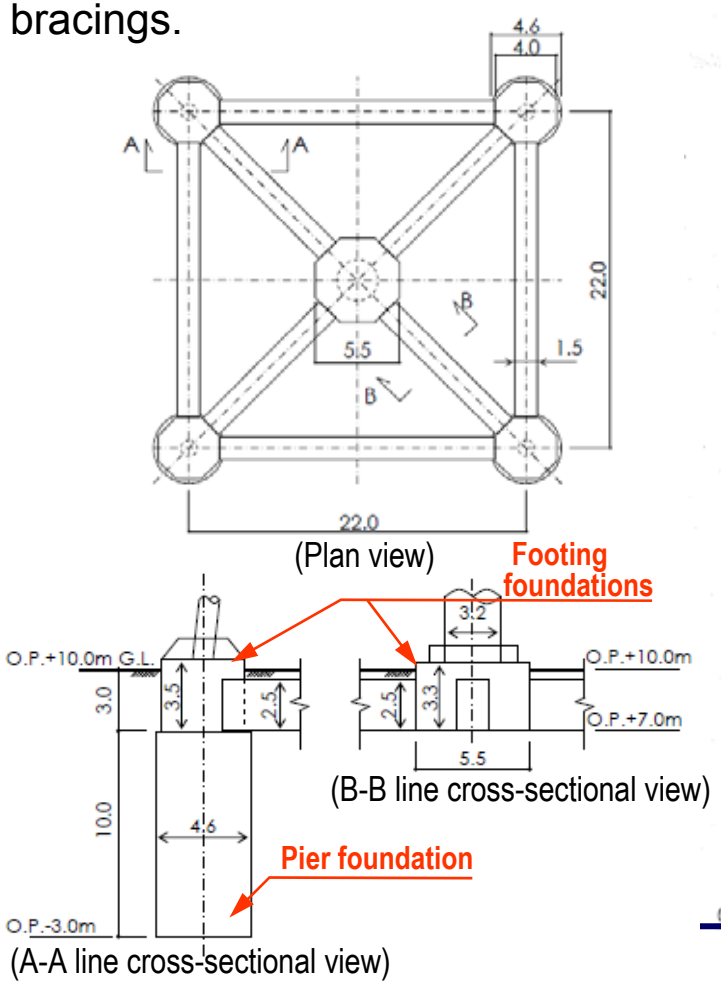
Stack shaft
- Height above the ground: 120 m
- Inner diameter: 3.2 m

Steel tower
- Height: 111 m
- Width: From 5.4 m (at the top) to 22.0 m (at the bottom)

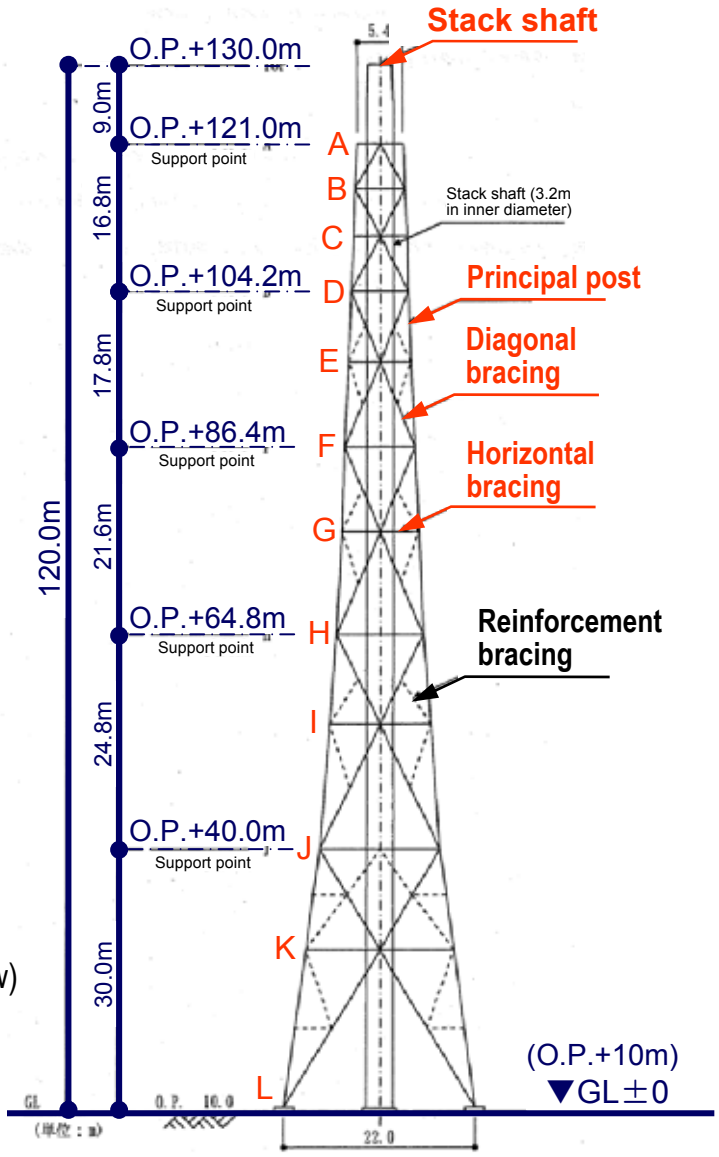
Foundations
- Footing foundation for the stack shaft part
- Footing foundation plus pier foundation for the steel tower part, with the pier foundation being 4.6 m in diameter and approx. 10 m in length

* A pier foundation is …

a columnar foundation that functions to transfer the weight of a construction to the ground.



Schematic illustration of the foundation part



Schematic illustration of the above-ground part

Inspection of Units 1 and 2 Exhaust Stack

Outline of the inspection

Inspection method

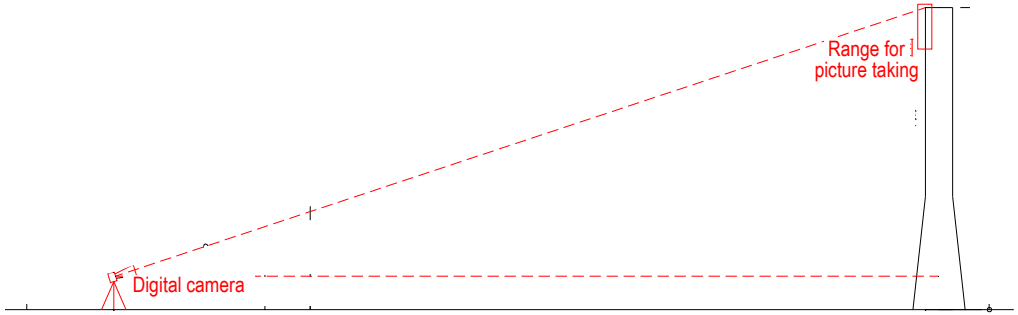
1. Site investigation
   Taking photos of the exhaust stack from various directions with a telescopic camera.
2. Image analysis
   Applying image processing to the thus taken photos to evaluate all of the components with respect to the posts, bracings, joint sections, stack shaft and post bases.

Equipment used in the inspection

Digital single-lens reflex camera (with a tripod)
Telescopic lenses (75 to 200 mm and 200 to 400mm)

Periods

Site investigation: August 26 to 29, 2013
Image analysis: September 9 to 26, 2013



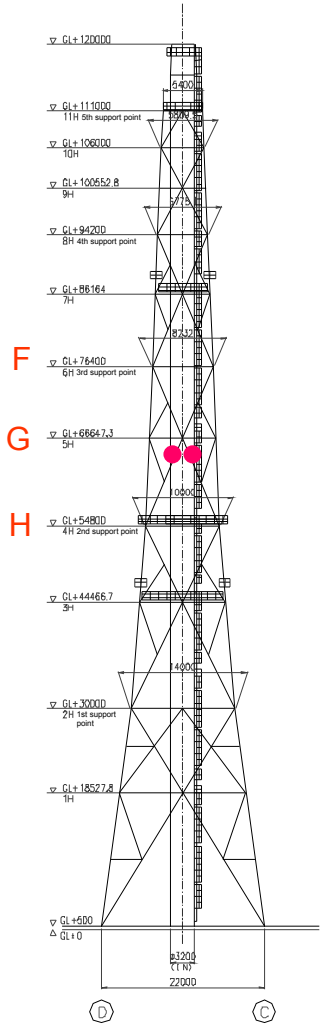
How the pictures were taken

A scene of the picture taking

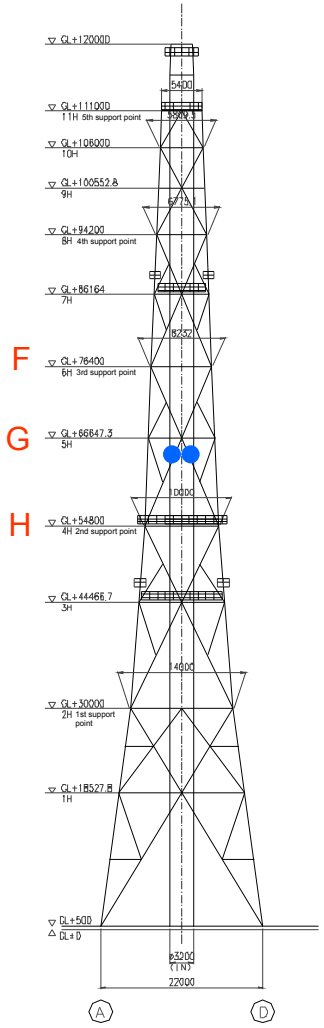
Inspection results [1]

- Breakage: 5 locations (2 on the north side, 2 on the south side, and 1 on the west side)
- Deformation: 3 locations (2 on the east side and 1 on the south side)

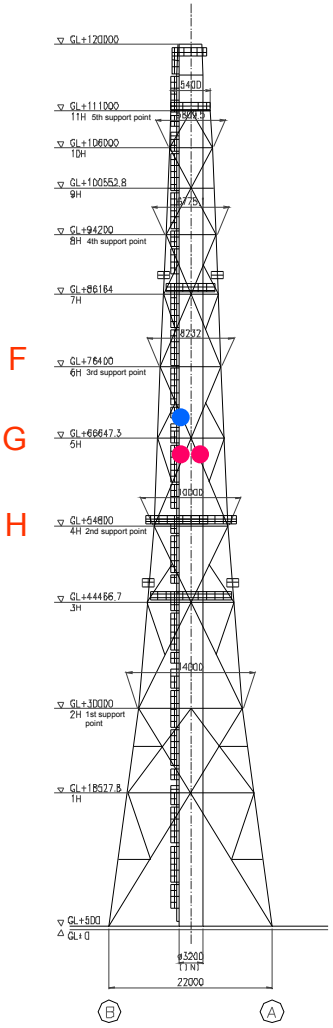
All of the above locations are found at the joint sections of the diagonal bracings near 66 m above ground (O.P. +76 m).



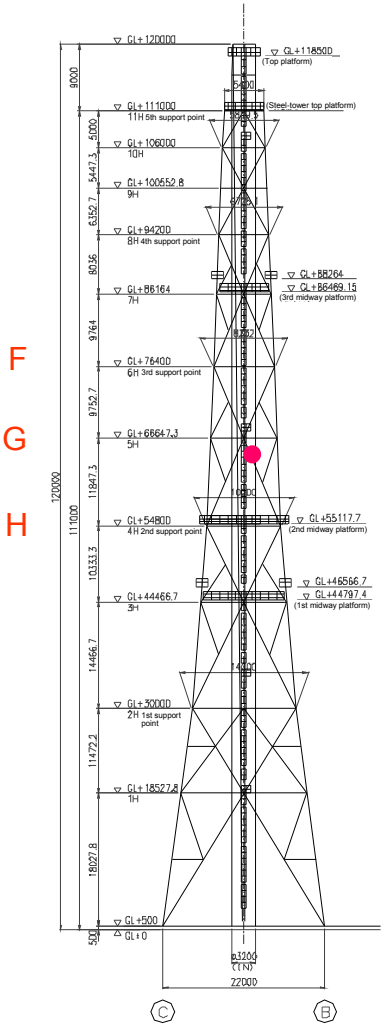
North-side elevation view



East-side elevation view

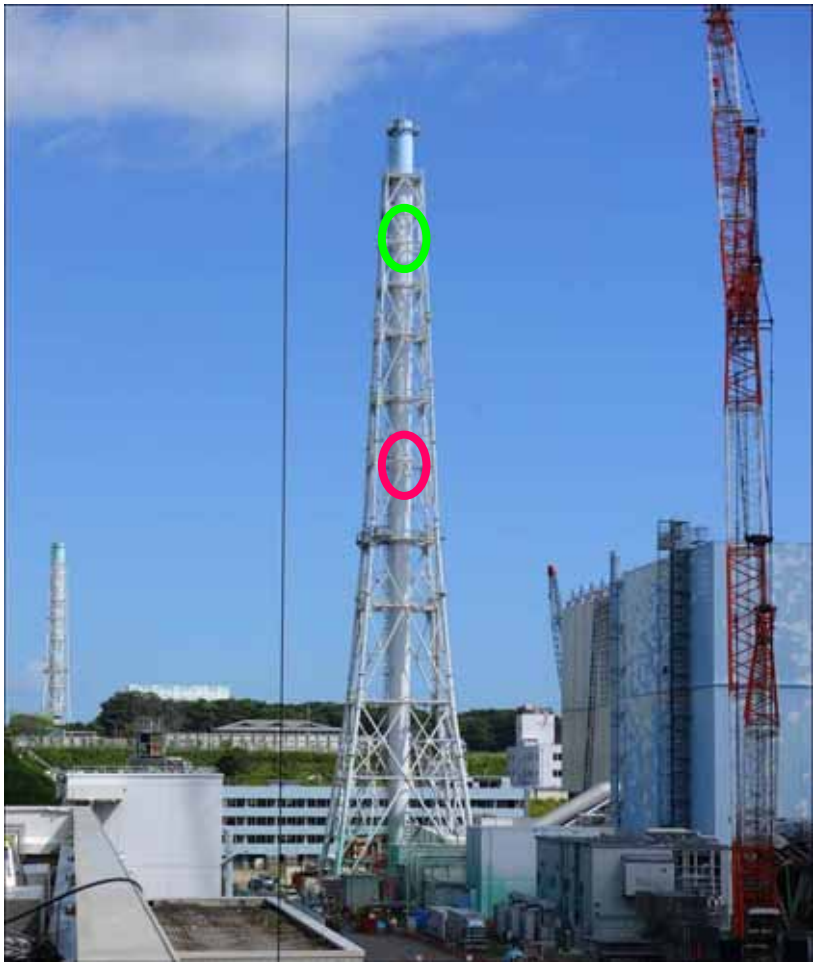


South-side elevation view



West-side elevation view

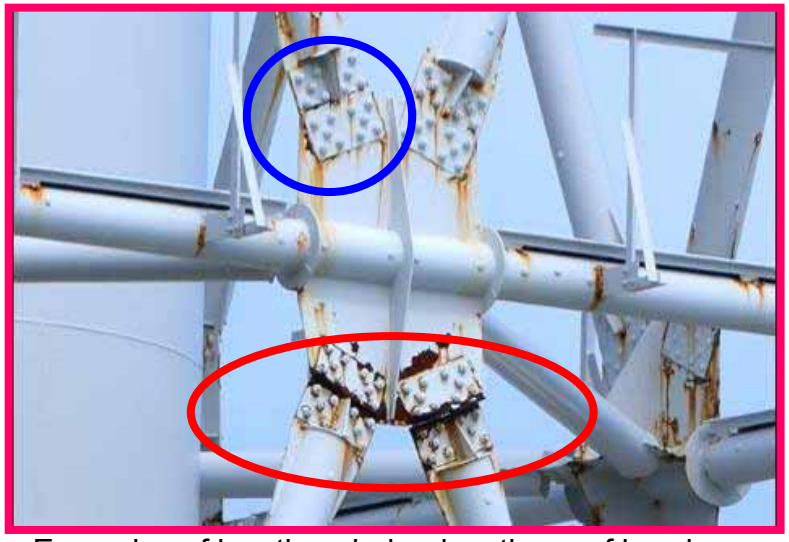
Inspection results [2]



Full view of the stack photographed from its south side

- Example of a sound location
- Example of a location of breakage
- Example of a location of deformation

Example of a location judged sound

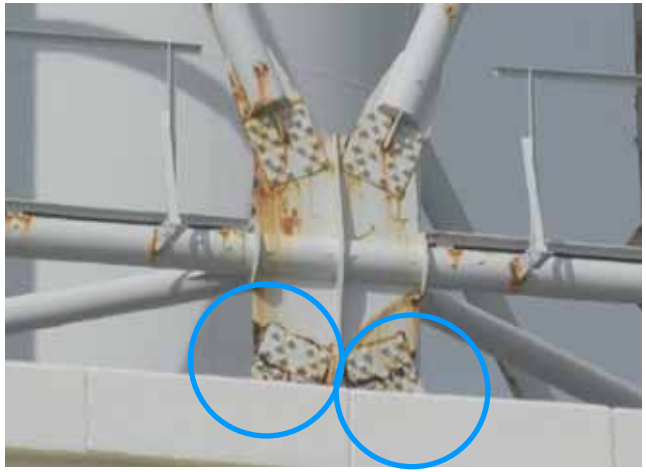


Examples of locations judged as those of breakage and of deformation

Inspection results [3] (Locations of leakage or deformation)

- Breakage: 5 locations (2 on the north side, 2 on the south side, and 1 on the west side)
- Deformation: 3 locations (2 on the east side and 1 on the south side)

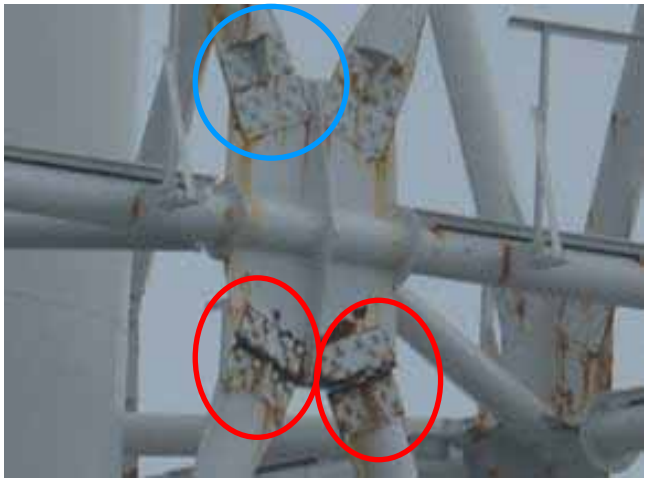
These locations are all found at the joint sections of the diagonal bracings near 66 m above ground (O.P.+76 m).

	North side	East side
Outer side		
Inner side		
Notes	Breakage is found at 2 locations in the lower side of the joint section 66 m above ground.	Deformation is found at 2 locations in the lower side of the joint section 66 m above ground.

Inspection results [4] (Locations of breakage or deformation)

- Breakage: 5 locations (2 on the north side, 2 on the south side, and 1 on the west side)
- Deformation: 3 locations (2 on the east side and 1 on the south side)

These locations all belong to the joint sections of diagonal bracings near 66m above ground (O.P.+76m).

	South side	West side
Outer side		
Inner side		* It was difficult to take photos of the inner side of the west side, so we took this photo from a different angle. 
Notes	Breakage is found at 2 locations in the lower side and deformation at 1 location in the upper side of the joint section 66 m above ground.	Breakage is found at 1 location in the lower side of the joint section 66 m above ground.

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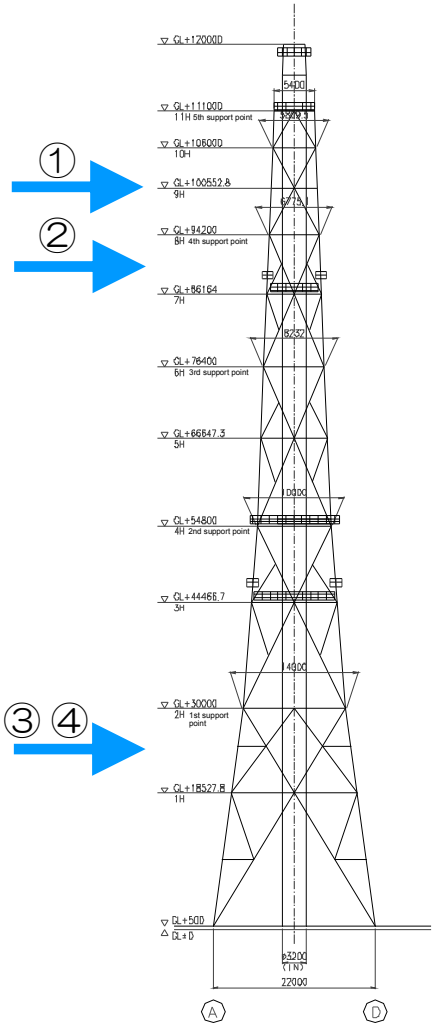
Inspection results [5] (Examples of locations judged sound)

① South side (around 100 m above ground)
A joint section

② East side (around 82-94 m above ground)
Stack shaft of the exhaust stack

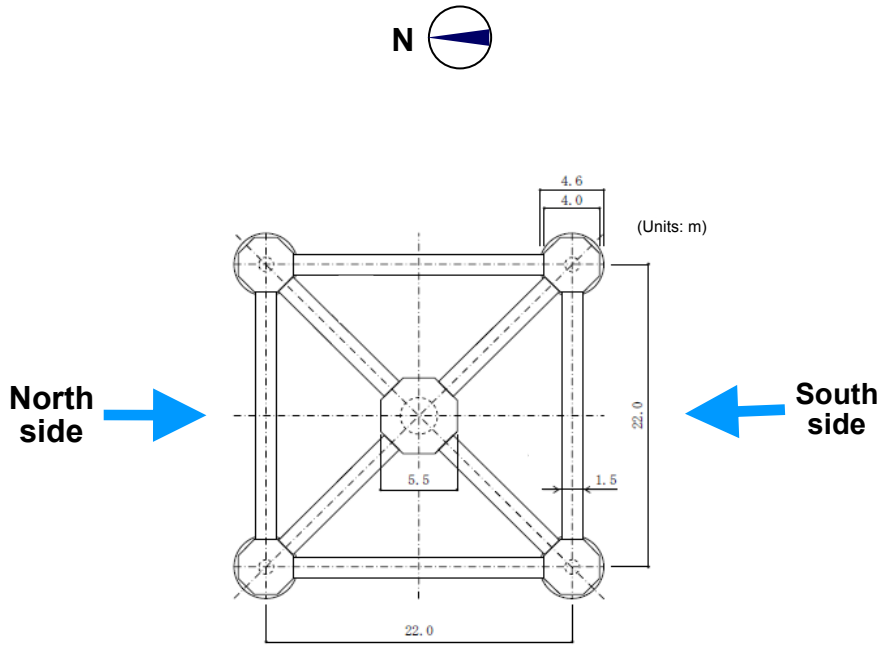
③ North side (around 19-30 m above ground)
A principal post and diagonal bracings

④ East side (around 19-30 m above ground)
Stack shaft of the exhaust stack



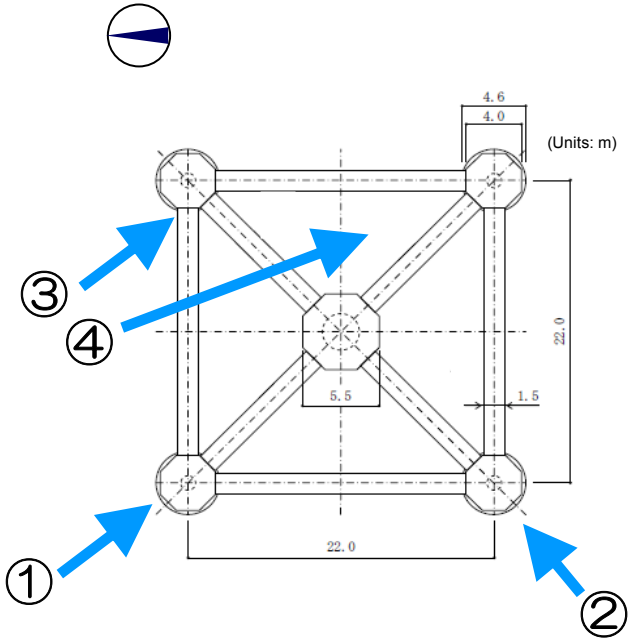
Photographed locations
(Provided above for reference is the east-side elevation view.)

Inspection results [6] (Between levels G and H of the steel tower)



Inspection results [7] (Post base section)

With respect to the post base part, neither the steel tower nor the concrete foundation was found to be in a bad condition.



Photographed locations

* The post base section's southeast side ④ is a high radiation dose spot, and was photographed from a road.

Summary of the inspection results

- Breakage was found at 5 locations between levels G and H of the steel tower.
- Deformation was found at 2 locations between levels G and H, and at 1 location between levels F and G, of the steel tower.
- With respect to the post base part, neither the steel tower nor the concrete foundation was in a bad condition.

Seismic Safety Evaluation of the Units 1 and 2 Exhaust Stack

Outline of analysis

Taking the obtained inspection results into consideration, we conducted earthquake response analysis using an analytical model from which a total of 9 diagonal bracings (1 bracing between levels F and G and 8 bracings between levels G and H) were excluded.

Note that, although there are 7 diagonal bracings found broken or deformed between levels G and H, all of the 8 diagonal bracings between these levels were excluded from the analytical model in the analysis conducted this time to make the analysis conservative.

- Model earthquakes
  Basic earthquake ground motion Ss-1 (450 Gal in the horizontal and 300 Gal in the vertical directions)
  Basic earthquake ground motion Ss-2 (600 Gal in the horizontal and 400 Gal in the vertical directions)
  Basic earthquake ground motion Ss-3 (450 Gal in the horizontal and 300 Gal in the vertical directions)
- Analytical model
  Three-dimensional frame model
- Analytical approach
  Linear time history response analysis
- Parts to be evaluated
  Steel tower (principal posts, diagonal bracings, and horizontal bracings), stack shaft, and foundation part

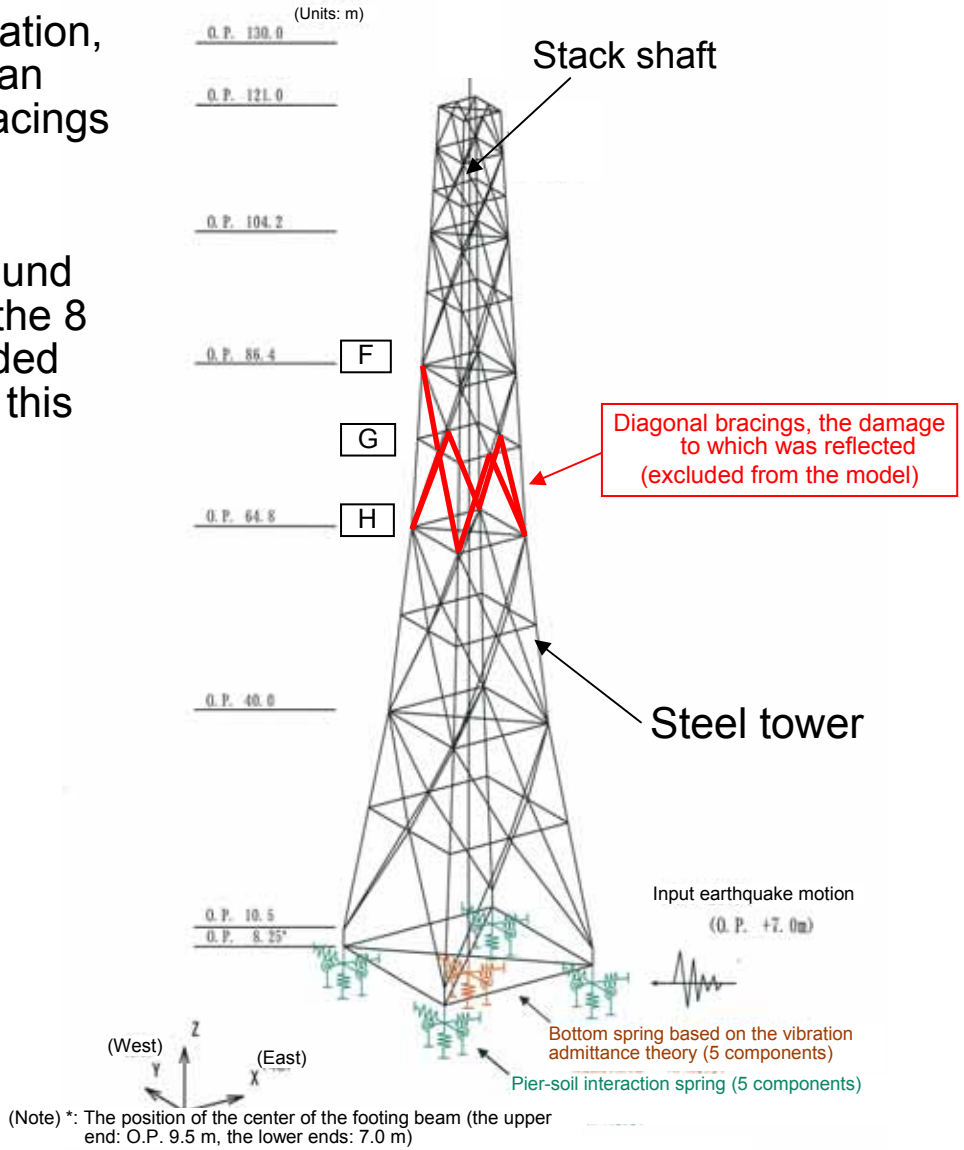
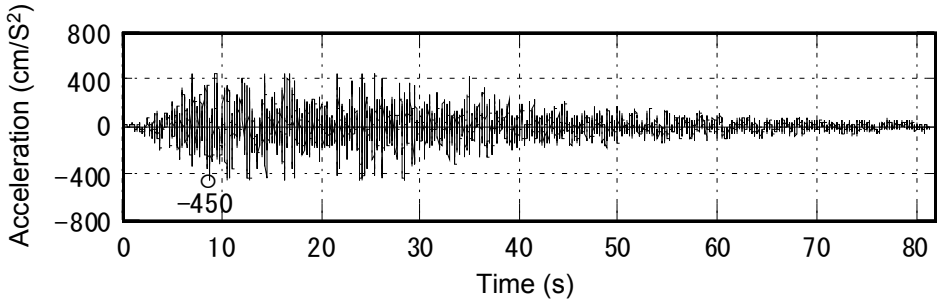
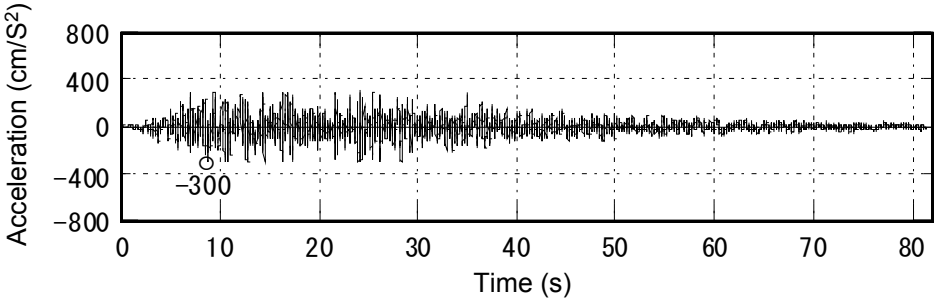


Illustration of the analytical model

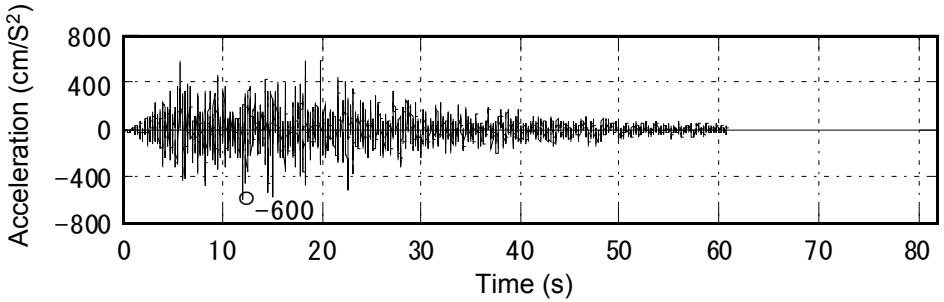
Acceleration time history waveforms (Ss-1 to Ss-3)



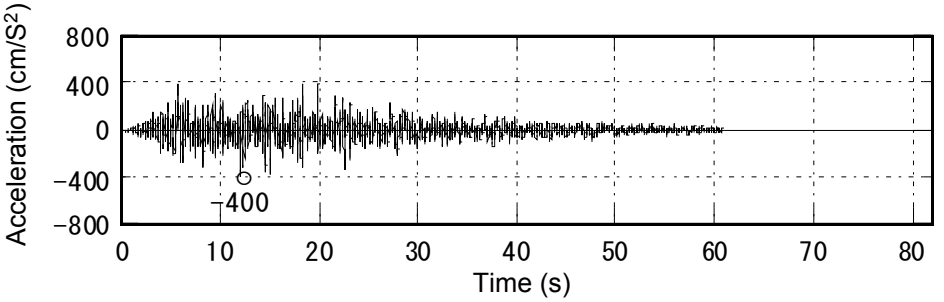
Acceleration time history waveform (Ss-1H)



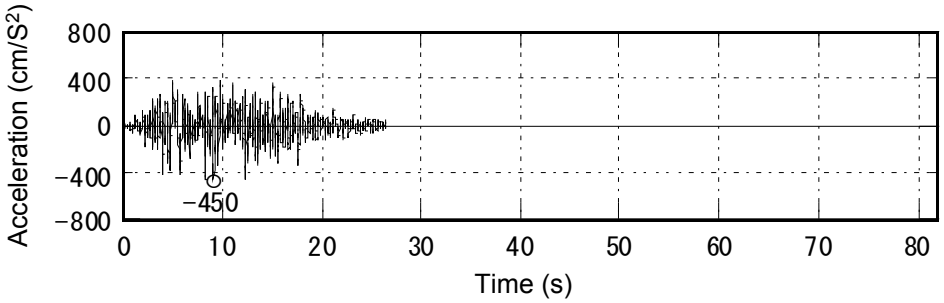
Acceleration time history waveform (Ss-1V)



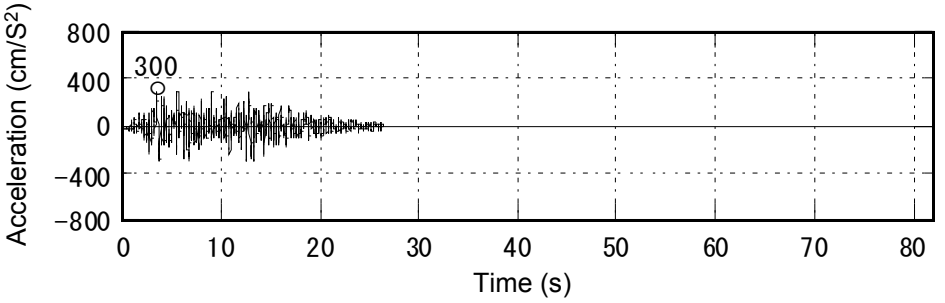
Acceleration time history waveform (Ss-2H)



Acceleration time history waveform (Ss-2V)



Acceleration time history waveform (Ss-3H)



Acceleration time history waveform (Ss-3V)

Evaluation results [1] (Steel tower part and stack shaft part)

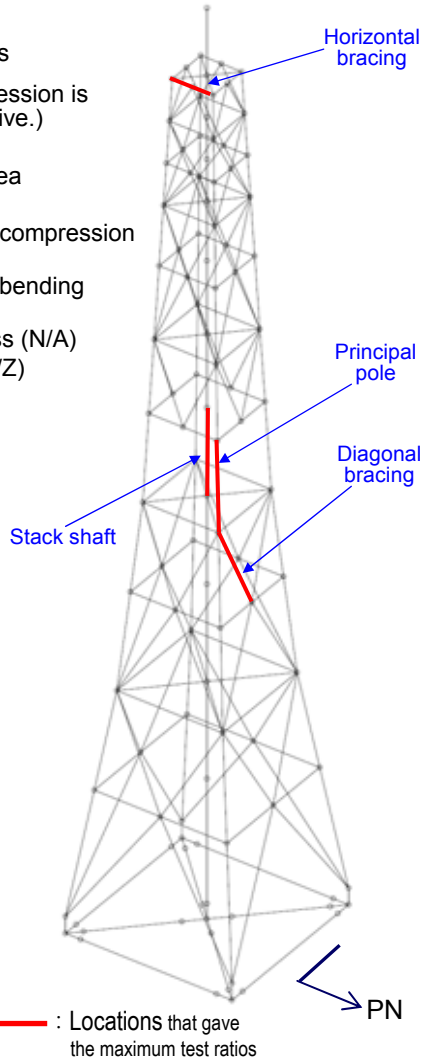
The following table shows, with respect to each component category, evaluation results for a section that gave the highest test ratio among all of the sections of the component category.

Location	Component category	N (kN)	M (kNm)	A ($\times 10^2$ mm^2)	Z ($\times 10^3$ mm^3)
Steel tower	Principal post	2,726	276	213.8	2,526.5
	Diagonal bracing	844	—	54.1	—
	Horizontal bracing	127	—	38.4	—
Stack shaft		1,097	10,241	807.3	64,662.6

Description of characters

N	Axial force (compression is defined to be positive.)
M	Bending moment
A	Cross-sectional area
Z	Section modulus
$_sf_c$	Tolerance against compression stress
$_sf_b$	Tolerance against bending stress
$_s\sigma_c$	Compression stress (N/A)
$_s\sigma_b$	Bending stress (M/Z)

Location	Component category	σ_c (N/mm^2)	σ_b (N/mm^2)	$_sf_c$ (N/mm^2)	$_sf_b$ (N/mm^2)	Check ratio $\frac{_s\sigma_c}{_sf_c}+\frac{_s\sigma_b}{_sf_b}$	Judgment	
Steel tower	Principal post	127.5	109.2	228.2	258.5	**0.981***	≦1	OK
	Diagonal bracing	156.1	—	227.4	—	**0.687**	≦1	OK
	Horizontal bracing	33.1	—	224.8	—	**0.148**	≦1	OK
Stack shaft		13.6	158.4	214.5	224.5	**0.769**	≦1	OK



Sections covered in the stress evaluation

* The check ratio of 0.981 is an indicator against the elastic limit, and the safety margin under the full-plastic moment is approximately 1.3 times.

[Recommendation for the Plastic Design of Steel Structures (Architectural Institute of Japan)]

The "fully-plastic moment" is a moment with which the entire cross section of a component member becomes plastic (reaches a yielding state).

Note that plasticization of the entire cross section of a post or bracing does not necessarily result in immediate collapse of the exhaust stack.

Recommendation for the Plastic Design of Steel Structures: A design approach intended to ensure that a structure would not collapse in the event of an extremely rare incident such as an earthquake, with the plastic behavior of the structure taken into consideration.

Evaluation results [2] (Foundation part)

The following tables show the examination results of the bearing capacities of the foundation part.

Examination of the vertical bearing capacity, etc. (Steel tower part)

Examination items	Stress	Evaluation reference value (Resisting force)	Check ratio (Stress/Evaluation reference value)	Judgment	
Examination of total pull-out capacity (kN/post)	522 (Maximum pull-out capacity)	3,911 (Weight of pier foundation)	**0.134**	**≦1**	**OK**
Examination of the bearing capacity (kN/m^2)	1,111 (Maximum compression force)	3,923 (Short-time allowable vertical bearing capacity)	**0.284**	**≦1**	**OK**

Examination of the vertical bearing capacity, etc. (Exhaust stack part)

Examination items	Stress	Evaluation reference value (Resisting force)	Check ratio (Stress/Evaluation reference value)	Judgment	
Examination of total pull-out capacity (kN/post)	No pull-out capacity occurs	—	**—**	**—**	**OK**
Examination of the bearing capacity (kN/m^2)	308 (Maximum compression force)	3,923 (Short-time allowable vertical bearing capacity)	**0.079**	**≦1**	**OK**

Summary of the evaluation results

- The results obtained by inputting the basic earthquake ground motion Ss (equivalent to the Tohoku-Chihou Taiheiyou-Oki Earthquake) with the damages to the exhaust stack taken into consideration indicate that the exhaust stack is sound.

→ The exhaust stack, composed of the stack shaft and the steel tower, is not expected to collapse in the event of recurrence of an earthquake equivalent to the Tohoku-Chihou Taiheiyou-Oki Earthquake (with a seismic intensity of 6 upper).

Next actions

1. Temporary measures to ensure human safety and facility protection against falling objects from the stack

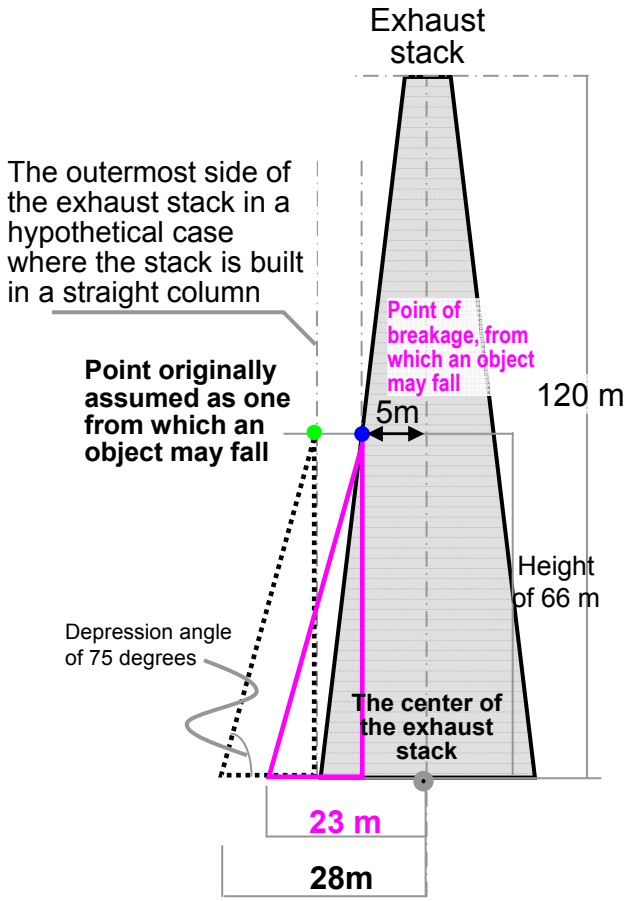
- The area within approx. 23 m from the center of the exhaust stack will be set as a restricted area according to the actual situations.
- Protective measures against falling objects will be implemented on paths for patrollers and important facilities within the restricted area.
- While work (such as temporary assembly) within the restricted area will not be permitted, brief activities such as investigation will be permitted under the presence of a dedicated observer.
- The road on the west of the exhaust stack will be limited to vehicles and closed to people. The road in front of the large carry-in entrance will be limited to use under the presence of a dedicated observer.

2. Short-term considerations

- Analytical evaluation of the exhaust stack using observation records on the Tohoku-Chihou Taiheiyou-Oki Earthquake will be conducted.
- The cause of damages in the component members will be continuously studied.
- In our radiation dose measurement, first priority will be given to locations at and around the exhaust stack so that the conditions for future actions such as disassembly and reinforcement can be prepared.

3. Mid-term considerations and actions

- Construction methods and schedule will be considered for future actions such as disassembly and reinforcement.
- Studies will be conducted about the basic earthquake ground motions in compliance with the new regulatory standards.



Reference used for calculation of the area within which an object may fall: “Guidelines for Public Disaster Countermeasures in Construction Work - For Civil Engineering Works” from the Ministry of Land, Infrastructure, Transport and Tourism