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Examples of Evaluation and Improvement in Seismic Capacity for Existing Plant Facilities†

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Abstract:

The main purpose of improving the seismic capacity of an existing plant facility is not only to ensure the safety of the persons working in the facility at the time of the severe earthquake. It is also aimed to maintain the functionality of the plant, enabling it to quickly restart its operation after an incident. Moreover, during the reinforcement works, it is important that plant operation is not disturbed. This paper undertakes the said considerations in the following examples: (1) LNG unloading facility (Supporting structure: steel framing); Structural steel framing is reinforced by additional steel section to withstand seismic response based on Level 2 seismic motion. (2) City gas governor station (RC building); RC framing is reinforced by additional outer structural steel framing to reduce its seismic load. (3) Waste incineration plant facility (RC building with structural steel framing for roofing and siding); Combined steel and RC framing is reinforced by additional earthquake-resistance RC wall and steel bracing respectively, to satisfy the specified criteria for existing building.

1. Introduction

In Japan, the standards for the earthquake resistance of plant facilities have evolved in response to past earthquake disasters. In 1981, a new seismic design method was introduced in the Building Code of Japan. The Ministry of Economy, Trade and Industry's Notification of earthquake-resistant design was enacted in the High Pressure Gas Safety Law. This established the current framework of standards for earthquake resistance, which assumes a large earthquake as that of the Great Kanto Earthquake of 1923. In 1995, the Law on Promotion of Seismic Retrofitting of Buildings was enacted in response to the Great Hanshin Earthquake (Kobe Earthquake) of 1995. As a result, seismic retrofitting of existing facilities constructed under the old design method was carried out nationwide. **Table 1** shows the transition of seismic design standards.

The main purpose of improving the seismic capacity of existing plant facilities is not only, as in general structures, prevention of damage to the structural skeleton premised on protection of human life, and maintenance of the functions of the plant facilities as a whole, including equipment, piping, and electrical instrumentation. It is also necessary to consider the continuity of plant operation during construction. **Table 2** shows examples of seismic retrofitting projects carried out by JFE Engineering in recent years. From these examples, this paper presents the following: (1) a liquefied natural gas (LNG) unloading facility; (2) a city gas governor station; and (3) a waste incineration plant facility.

2. LNG Unloading Facility (Unloading Arms for Receiving LNG)

2.1 Outline of Facility

This facility is comprised of unloading arms (16B × 60' DCMA-FP Type, Manufactured by Niigata Loading Systems, Ltd.; Start of commercial operation in 1984)

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Table 1 Transition of the seismic design standards

Earthquake (Magnitude)	Building-related laws and ordinances	High pressure gas-related laws and ordinances
1923 Taisho Kanto Earthquake (M7.9) (Great Kanto Earthquake)	1924 Revision of Urban Building Law: Calculation of earthquake resistance made mandatory (Horizontal seismic coefficient 0.1)	
1948 Fukui Earthquake (M7.1)	1950 Building Code of Japan (Establishment): Horizontal seismic coefficient 0.2	1951 Establishment of High Pressure Gas Control Act
1964 Niigata Earthquake (M7.5) 1968 Tokachi-Oki Earthquake (M7.9)	1971 Enforcement of revisions of Building Code of Japan: Strengthening of shear reinforcement of RC columns, etc.	
1978 Miyagi-ken-Oki Earthquake (M7.4) 1993 Kushiro-Oki Earthquake (M7.5) 1994 Sanriku-Haruka-Oki Earthquake (M7.6) 1995 Hyogo-ken Nanbu Earthquake (M7.3) (Great Hanshin Earthquake) 2003 Tokachi-Oki Earthquake (M8.0) 2004 Niigata-ken Chuetsu Earthquake (M6.8) 2005 West Off Fukuoka Earthquake (M7.0) 2007 Niigata-ken Chuetsu-Oki Earthquake (M6.8) 2011 Off the Pacific Coast of Tohoku Earthquake (M9.0) (Great East Japan Earthquake)	1981 Revision of Building Code of Japan (Enforcement): General revision of structural design standards by introduction of new seismic design method 1995 Establishment of Law on Promotion of Seismic Retrofitting of Buildings 2000 Revision of Building Code of Japan (Enforcement): Adoption of performance-based design in building standards 2007 Revision of Building Code of Japan (Enforcement) More stringent building certification examination Clarification of structural technology provisions	1981 Notification of earthquake-resistant design: Clarification of standards for earthquake resistance of towers, supporting structures, and foundations 1997 Revision of Notification of earthquake-resistant design: Consideration of giant earthquakes Consideration of ground liquefaction deformation

Table 2 Examples of seismic evaluation and seismic reinforcement project

Object field	Object facility	Object structure	Related law		Year of construction		Structural type			Method of seismic reinforcement
			Building Code of Japan	High Pressure Gas Safety Law	To 1980	From 1981	S	RC	CB	
Energy	LNG unloading terminal	Management building	Conforms			New seismic design		Adopted		· Increased thickness of bearing walls, close windows in bearing walls · Addition of structural slits
		Unloading arm equipment for receiving LNG		Conforms	Old seismic design		Adopted			· Reinforcement of columns, beams, and earthquake-resisting braces
	City gas governor station	Governor station	Conforms		Old seismic design		Adopted	Adopted	Adopted	· Increased thickness of bearing walls, close windows in bearing walls · Addition of structural slits, reinforcement of steel frame beams
		Governor station	Conforms		Old seismic design			Adopted		· Reinforcement by external steel frame
	Gas pipe bridge	Bridge pier		Conforms		New seismic design	Adopted	Adopted		· Reinforcement of earthquake-resisting braces
	Nuclear power plant	Exhaust stack	Conforms		Old seismic design		Adopted			· Construction of new supporting steel tower · Introduction of response control structure using oil dampers[1)]
Urban environment	Waste incineration plant facility	Recycling building	Conforms		Old seismic design		Adopted			· Reinforcement of columns, addition of earthquake-resisting braces · Reinforcement of roof trusses
		Waste incineration building	Conforms		Old seismic design		Adopted	Adopted		· Increase in number of earthquake-resisting walls, addition of earthquake-resisting braces · Reinforcement of roof braces
Industrial machinery	Livestock feed base	Feed blending plant	Conforms			New seismic design	Adopted			· Reinforcement of columns and beams · Addition of earthquake-resisting braces, reinforcement of earthquake-resisting braces
		Feed silo	Conforms		Old seismic design		Adopted			· Reinforcement of silo container

▭ Introduced in this paper. LNG: Liquefied natural gas
S: Steel structure RC: Reinforced concrete structure CB: Concrete block structure

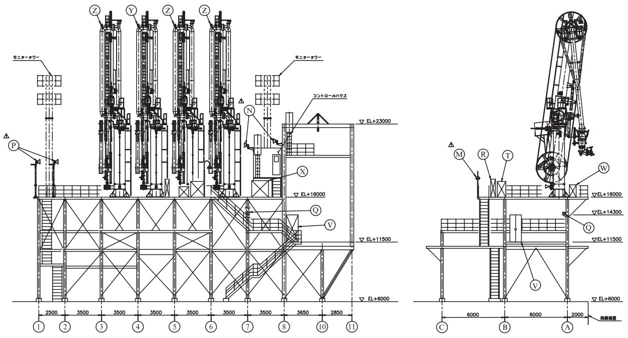

Fig. 1 Existing unloading arms for liquefied natural gas (LNG)

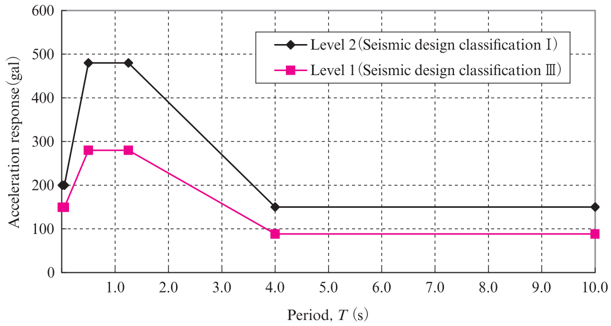

Fig. 2 Acceleration response spectra based on guideline

for receiving LNG from tankers and their supporting structure (**Fig. 1**). This was constructed on the marine berth of Niigata LNG Terminal of Nihonkai LNG Co., Ltd., which is located at the northern edge of Niigata East Port. LNG received by this facility is stored in land-based tanks and is shipped in response to the demand of the customers.

2.2 Evaluation of Seismic Capacity

Under the commission of Nihonkai LNG Co., Ltd., an evaluation of the seismic capacity of the piping from the marine unloading equipment to the land-based receiving equipment and its supporting structure was performed based on the existing "Seismic Design Standard for High Pressure Gas Facilities"[2,3]. As part of this work, a lateral soil movement analysis of the bearing ground (seawall part) of the land-based supporting structure was also carried out. These were done in order to have a comprehensive evaluation of the seismic capacity of the whole system (i.e. piping equipment, its structures and foundations) and a rational seismic capacity improvement plan.

In this project, for the unloading arms described in the previous section, an evaluation of seismic capacity for Level 1 seismic motion was carried out based on the above-mentioned "Seismic Design Sandard for High Pressure Gas Facilities." The results confirmed that the section force of some structural members exceeded their allowable strength. Although exceeding allowable strength as such is not linked to serious structural damage such as collapse of the structure, it was assumed that the function of these facilities as unloading arms could not be maintained if a Level 1 earthquake occurrs.

Accordingly, in order to improve the performance in earthquake-resistance of the equipment and its supporting structure as a whole, a study was carried out by raising the evaluated seismic motion to Level 2 with the assumption of changing into a new type of unloading arm with high earthquake-resistance capacity.

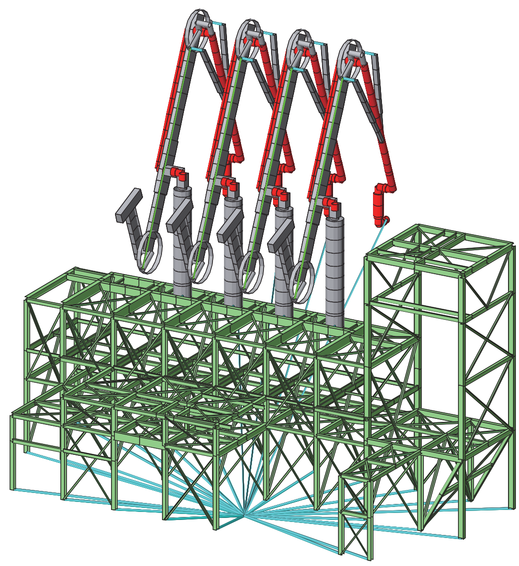

Fig. 3 Overall view of structural model including unloading arm

2.3 Adopted Seismic Motion and Structural Model

Based on "Seismic Design Standard for High Pressure Gas Facilities,"[3] ground surface acceleration equivalent to Level 2 seismic motion (Importance classification I) in the acceleration response spectra of seismic motion, was set as the standard ground surface acceleration (200 Gals) corrected to the standard's alternative assessment method. Therefore, the acceleration response spectrum (Level 2) shown in **Fig. 2** was assumed. The entire structural model was constructed as beam elements, under a condition in which the new-type unloading arm (16B × 60' RCMA-S Type, Supporting horizontal response of 2.0 G (2 000 Gals), Manufactured by Niigata Loading Systems, Ltd.) is mounted on the support frame. The legs of the supporting frame were modeled as a spring-mass model considering the weight and stiffness of the foundation piles. An overall view of the structural model is shown in **Fig. 3**. The mode synthesis method was assumed because elastic response is the basis of seismic response analysis.

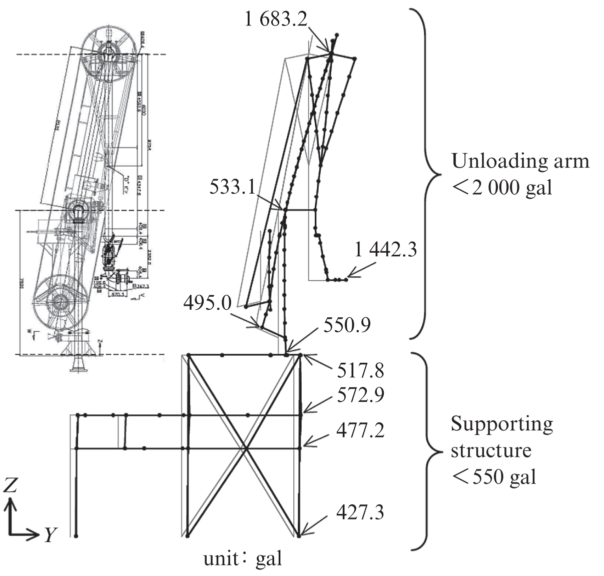

Fig. 4 Maximum acceleration response of structural model

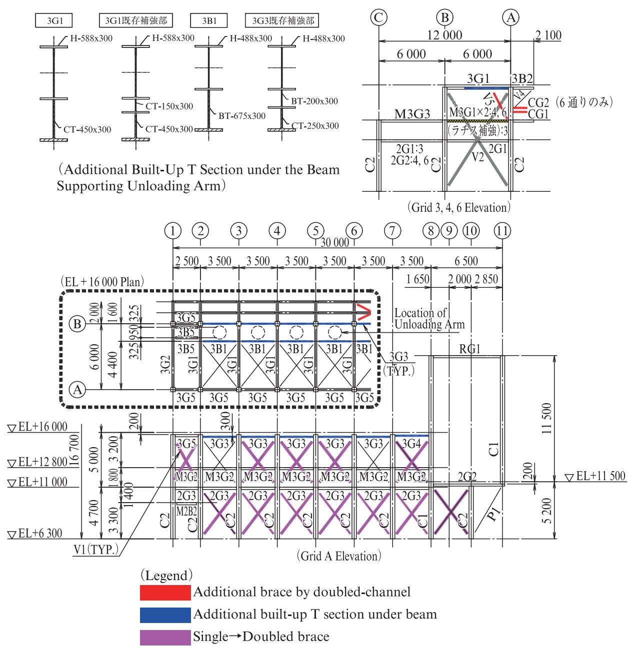

Fig. 5 Reinforcement work of supporting structure for K_{MH}=0.55

2.4 Response of Unloading Arms

Figure 4 shows the *Y* direction (vertical berthing line) as representative of the maximum horizontal response acceleration of the respective parts of the new-type unloading arm and its supporting structure. Although the response acceleration of the entire structure increased due to the higher seismic motion level, the response acceleration in the strength evaluation of the unloading arm was held within 2.0 G (2 000 Gals), confirming that the unloading arm itself has no strength-related problems under Level 2 earthquake motion.

2.5 Response of Supporting Structure and Outline of Reinforcement Work

Due to the structural complexity of the supporting structure of the unloading arm, response was set at 550 Gals, which is a level that roughly envelopes the maximum horizontal response by direction and by story based on the results of the seismic response analysis in the above Section 2.4. Also, static seismic intensity (K_{MH}) to be used in the new design of the supporting structure was assumed to be 0.55 (0.3 in the previous design) for both directions.

An outline of the reinforcement work for the supporting structure based on the results of the stress analysis using the above-mentioned seismic force is shown in **Fig. 5**. In order to carry out the reinforcement work while the equipment was in operation, the reinforcement was designed in a way in which the necessary reinforcement in the cross section was added without replacing the members with inadequate strength, considering stability under stationary load. In particular, due to the increase in the overturning moment of the unloading arms, it was necessary to reinforce the beams that are directly supporting this force by the addition of a comparatively large section (built-up T-section) under H-section beams. Moreover, since the design seismic intensity of the total supporting structure increased, it was also necessary to reinforce virtually all of the vertical frames (e.g. installation of double steel angles at existing single angles). The final weight of the reinforcing steel is approximately 20 tons. The pedestals were also reinforced by expansion of base plates, among others. It should be noted that the allowable stress ratio in the section performance evaluation was 1.0 or less.

3. City Gas Governor Station (Control Building)

3.1 Outline of Facility

This facility is a one-story reinforced concrete building (see **Photo 1**) which was constructed in 1950s and is located in a city gas governor station owned by Tokyo Gas Co., Ltd. City gas governor station control building is a facility that reduces the pressure of gas transported from LNG unloading terminals via the high pressure and medium pressure gas pipeline networks and then sends the gas to end-users. As shown in **Fig. 6**, the governor station includes a governor room, which contains the equipment and piping used in depressurization; and a control room, which controls the governor station as a whole.

3.2 Evaluation of Seismic Capacity

A seismic evaluation was carried out based on “Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings”[4] under the commission of Tokyo

Photo 1　Governor station before reinforcement work

Photo 2　Governor station after reinforcement work (Outer wall)

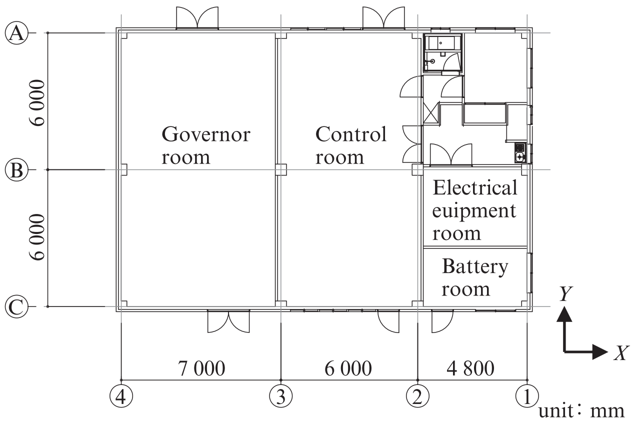

Fig.6　Building plan (Before reinforcement work)

Photo 3　Governor station after reinforcement work (Roof)

Gas Co., Ltd. As a result, although the bearing walls were arranged in a well-balanced manner in the Y direction, seismic performance was found to be inadequate in the X direction, which has many openings. Brittle damage was predicted in some columns for this direction.

3.3 Seismic Retrofitting

Seismic retrofit techniques were studied, including drastic measures such as reconstruction of the facility. However, due to various factors such as the need to avoid serious impact on continuous operation of the facility and the need to prevent noise in the neighboring residential area which will pose as a problem when external walls are demolished, an external steel frame construction method was finally adopted. In this method, a new reinforcing structure was constructed on the outer side of the existing building.

The external steel frame construction method has a number of advantages. For one, it is not necessary to modify the existing building itself. Also, it is not necessary to stop operation of the facility temporarily since movement of equipment, piping, and electrical instrumentation cables and control panels are basically unnecessary.

In the design of the steel frame, the possibility of future deterioration of the concrete of the existing building was also considered. A structure which is capable of safely supporting all horizontal forces that occur in the existing building during an earthquake was adopted by securing adequate strength and stiffness. The seismic retrofitting policy was as follows:

· The steel frame shall secure sufficient stiffness to prevent lateral deformation of the existing reinforced concrete (RC) building, and the allowable story drift shall be 1/1 000 or less.
· The steel frame shall be connected to the existing RC building so as to be able to withstand vertical earthquake motion.
· The foundation of the steel frame shall have the minimum foundation area as a pile foundation in order to avoid interference with the existing underground facilities.
· Structural slits shall be installed in existing columns adjoining openings where there is a danger of brittle fracture during large earthquakes.

Photos 2 and **3** show the appearance of the governor station after the reinforcement work. Although a wall was constructed over the steel frame so that its appearance is the same as a newly-constructed building, application for a building permit was not necessary since a new roof was not constructed. This enabled an early start of the work and shortened project period.

4. Waste Incineration Plant Facility (Incinerator Building)

4.1 Outline of Facility and Results of Site Investigation

Among existing waste incineration facilities, there are many examples in which the facility is modernized with state-of-the-art plant equipment for high combustion efficiency, high power generating efficiency, and clean off-gas treatment. In addition, seismic retrofitting is also carried out to improve the seismic performance of the facility as a whole. As an example, **Fig. 7** shows the building section of an existing facility in Higashimurayama City, which is located in the Tokyo Metropolitan area. The facility has a rectangular plan shape with the dimension of 20.0 m × 55.6 m, and consists of a steel frame structure (S structure) with a height of 24.0 m and reinforced concrete structure (RC structure). The facility is comprised of three spaces, namely platform, waste pit, and incinerator and flue-gas treatment area.

The results of the site investigation are shown in **Table 3**. The dimensions of the structural members were measured, a physical test of the concrete was performed, and non-destructive inspection of welded joints was carried out for penetration welds of the steel frame. This investigation confirmed that the actual plant conformed with the design drawings and the materials of the steel frame and concrete were sound.

4.2 Evaluation of Seismic Capacity

The seismic evaluation was carried out in accordance with the “Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings”[4] and “Standard for Seismic Evaluation of Existing Steel Frame Buildings”[5]. The targeted seismic capacity index (Is) was 0.6 or higher.

Because the evaluation methods for the RC structure and the S structure are different, an analytical model divided by structural type was used. A 3D analysis which reproduced the actual structural form was performed to enable consideration of earthquake-resistant elements (e.g. earthquake-resisting walls and braces) and uneven distribution of load.

Results of the seismic evaluation (see **Fig. 8**) shows the members with inadequate strength. These results confirmed that seismic retrofitting was necessary in both the RC and S structures.

4.3 Seismic Retrofitting

Figures 9 and **10** show examples of the seismic retrofit in the RC and S structures, respectively. The strength of the RC structure was improved by adding earthquake-resisting walls and increasing the thickness

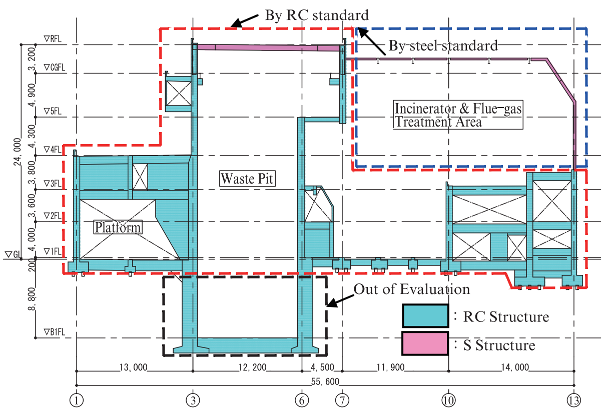

Fig. 7 Building section (Structural division and evaluation scope)

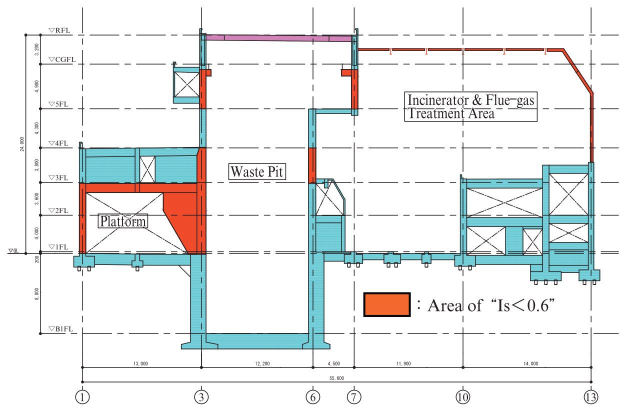

Fig. 8 Results of seismic capacity index, Is

Table 3 Results of site investigation and material test

Site investigation item	Purpose of inspection	Judgment standard	Investigation result	Judgment
Dimensions of members	Compare existing drawings and actual condition.	Actual condition conforms to drawings.	No nonconformities.	Good
Cracks	Detect crack occurrence.	Crack width 0.3 mm or less.	Crack width 0.3 mm or less.	Good
Concrete compressive strength	Detect current condition of concrete strength.	Design strength, Fc = 21 N/mm^2 or higher.	Average Fc = 30.6 N/mm^2.	Good
Concrete neutralization	Check for corrosion of steel reinforcing bars.	Protective concrete cover thickness of 30 mm or less.	Average neutralization depth of 10 mm.	Good
Ultrasonic testing for welding	Check for internal defects in penetration welds.	Conforms to inspection standard.	Conforms to inspection standard.	Good
Uneven settlement	Check for uneven settlement of building.	No settlement cracks.	No settlement cracks.	Good

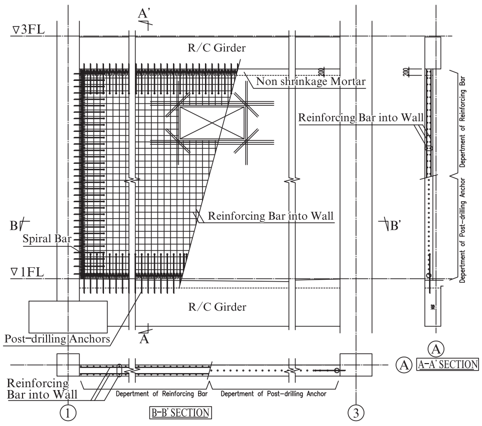

Fig. 9 Example of seismic retrofit in reinforced concrete (RC) structure (Additional bearing wall)

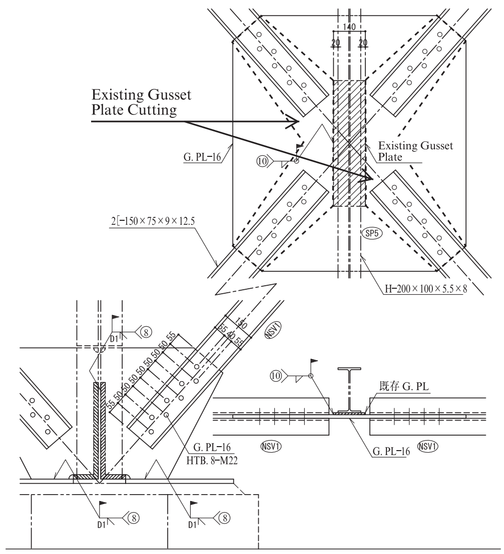

Fig. 10 Example of seismic retrofit in steel structure (Additional bracing)

of the existing earthquake-resisting walls. On the other hand, the Is value of S structure was improved by adding earthquake-resisting braces. In this case, inadequate strength was confirmed at the waste pit wall, an RC structure. However, since the retrofitting work for this structure would have a serious effect on continuous operation of the facility, it was necessary to reduce the lateral seismic force acting on this area. An evaluation showed that lateral force could be transferred to the adjoining Incinerator & Flue-gas Treatment room by reinforcement using horizontal braces, an S structure, on the roof surface. As a result, minimizing the effect on operation became possible. In this evaluation, a horizontal load-carrying capacity calculation for a total model unifying the S structure and RC structure parts was adopted.

The seismic capacity index (Is) before and after seismic reinforcement is shown in **Table 4**, and the horizontal load-carrying capacity ratio before and after reinforcement is shown in **Table 5**. After seismic reinforcement, both the seismic capacity index and the horizontal load-carrying capacity ratio cleared the target values for all floors, thereby securing the required seismic capacity.

Table 4 Seismic capacity-proof index, Is

Structural type	Floor	*X* Direction		*Y* Direction	
		Before seismic reinforcement	After seismic reinforcement	Before seismic reinforcement	After seismic reinforcement
RC	CGFL	1.82	1.80	2.01	1.99
	5FL	0.57	0.60	1.03	1.02
	4FL	0.69	0.71	0.64	0.63
	3FL	1.03	0.93	0.87	0.60
	2FL	0.54	1.24	0.46	0.77
	1FL	0.39	0.84	0.37	0.76
S	CGFL	0.26	0.67	0.35	0.82
	5FL	0.22	0.68	0.35	0.72

Table 5 Horizontal load-carrying capacity ratio

Floor	*X* Direction	*Y* Direction
	After seismic reinforcement	After seismic reinforcement
CGFL	1.34	1.14
5FL	1.15	1.21
4FL	1.07	1.06
3FL	1.97	1.08
2FL	1.25	1.60
1FL	1.84	1.60

5. Conclusion

This paper focused on the content of studies of structural parts in which the main emphasis was on seismic reinforcement. However, it goes without saying that close cooperation with related engineers, such as those responsible for equipment, piping and electrical instrumentation engineering, including those responsible for planning the retrofitting work, was indispensable for rational and smooth execution of this work.

Since plant facilities form the basis for both social life and industry, there has been a heightened necessity to put seismic retrofitting in business continuity plans (BCP) since the Great East Japan Earthquake of 2011. In the future, the authors will continue to propose seismic capacity improvements which address not only the prevention of damage of the structural skeleton, but also the long-term perspective of stable operation after disasters.

The authors would like to take this opportunity to express their appreciation to Nihonkai LNG Co., Ltd., Tokyo Gas Co. Ltd., and Higashimurayama City for their guidance and cooperation in carrying out the seismic capacity improvement projects presented in this paper.

References

1) Aizawa, S.; Yamagata, Y.; Katou, N. Design and Construction for Seismic-upgrading of Existing Stacks of Unit 3, 4, and 5 at Hamaoka Nuclear Power Station. JFE Giho. 2010, no. 25, p. 60–65.
2) High Pressure Gas Safety Institute of Japan. High-Pressure Gas Facility Seismic Design Guidelines: Level 1 Seismic Performance Assessment. 1997.
3) High Pressure Gas Safety Institute of Japan. High-Pressure Gas Facility Seismic Design Guidelines: Level 2 Seismic Performance Assessment. 2000.
4) The Japan Building Disaster Prevention Association. Seismic Evaluation Standards, Guidelines for Seismic Retrofit, and Their Application Example (Reinforced Concrete Buildings). 2001.
5) The Japan Building Disaster Prevention Association. Seismic Evaluation Standards, Guidelines for Seismic Retrofit, and Their Application Example (Steel Buildings). 1996.