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Application of a New Seismic Retrofit Technique to an Existing Gas Supply Facility

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1. Introduction

Since the Great East Japan Earthquake, the demand for stable energy to ordinary homes, offices, factories and especially the public facilities, such as hospitals and schools, which had experienced the great disaster, has increased more than ever. Improving the seismic capacity of an existing gas supply facility established by the old seismic design standard does not only aim to ensure the safety of the persons working in the facility at the time of severe earthquake but also aims to maintain the functionality of the plant, enabling it to quickly resume its operation right after an incident. Moreover, during the reinforcement work, it is important that the plant operation will not be interrupted. This paper presents a new seismic retrofit technique that uses a reinforcing steel frame constructed on the outer side of the existing building. It protects the equipment, piping and electrical instrumentation from a severe earthquake damage.

2. Transition of the seismic design standards in Japan

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 (Table1). In the new seismic design method, magnitude of seismic force is categorized by two levels. With moderate earthquake, (ground acceleration: 80gal) which occurs several times during the service life of a building, preservation of functionality of the building is the design consideration. On the other hand, with severe earthquake, (ground acceleration: 400gal) which may only occur once during the service life of a building, safety and

Photo1 Short RC Column's shear fracture by Tokachi-oki Earthquake in 1968 [1)]

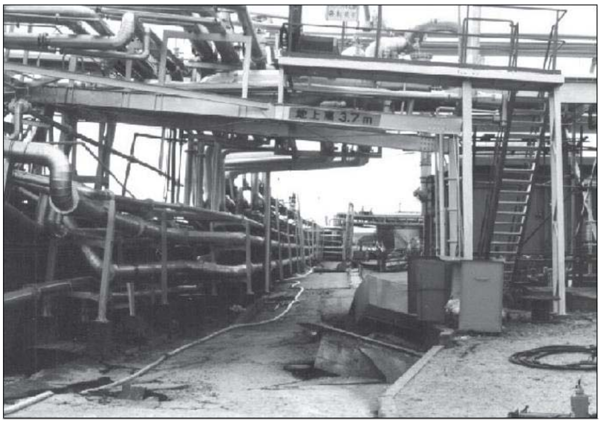

Photo2 Steel structure bent by liquefaction and lateral flow of Great Hanshin Earthquake in 1995 [2)]

Table1 Primary Earthquake in Japan and 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) **(Photo1)**	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)	1981 Revision of Building Code of Japan (Enforcement): General revision of structural design standards by introduction of new seismic design method	1981 Notification of earthquake-resistant design: Clarification of standards for earthquake resistance of towers, supporting structures, and foundations
1995 Hyogo-ken Nanbu Earthquake (M7.3) (Great Hanshin Earthquake) **(Photo2)**	1995 Establishment of Law on Promotion of Seismic Retrofitting of Buildings	
2003 Tokachi-Oki Earthquake (M8.0) 2004 Niigata-ken Chuetsu Earthquake (M6.8) 2005 West Off Fukuoka Earthquake (M7.0)	2000 Revision of Building Code of Japan (Enforcement): Adoption of performance-based design in building standards	1997 Revision of Notification of earthquake-resistant design: Consideration of giant earthquakes Consideration of ground liquefaction deformation
2007 Niigata-ken Chuetsu-Oki Earthquake (M6.8) 2011 Off the Pacific Coast of Tohoku Earthquake (M9.0) (Great East Japan Earthquake) **(Photo3 - 5)**	2007 Revision of Building Code of Japan (Enforcement) More stringent building certification examination Clarification of structural technology provisions	

protection of persons from collapse in spite of cracks in the structure is the design consideration.

In Great Hanshin Earthquake of 1995, efficacy of a new seismic design method in general building was proved. And for making the law for the promotion of seismic retrofitting, seismic retrofitting of existing facilities was carried out nationwide. In contrast, though gas supply facility in waterfront area didn't suffer serious damage such as gas leakage, the facility suffered damage by liquefaction (Photo2). Therefore, High Pressure Gas Safety Act was improved, foundation design considering ground deformation by liquefaction was regulated, and seismic performance evaluation of pipe (preventing high pressure gas leakage) came to consider about foundation settlement and horizontal displacement.

In Off the Pacific Coast of Tohoku Earthquake of 2011, Japanese industrial facility which has the advanced industrialization and computerization suffered from Tsunami for the first time. Gas Supply Facility suffered serious damage in that earthquake (Photo3.1, 3.2, 3.3). Though main equipment such as unloading arms and storage tank of LNG didn't suffer any damage(Photo4), it took a long time to recover because of electrical equipment (Photo5.1, 5.2) and small diameter pipe on independent foundation that were damaged. After this earthquake, safety shut-off software and electrical instrumentation facility protection hardware are the measures considered to protect the gas related facilities prior to arrival of Tsunami [5].

Photo 3.1 LNG terminal before the strike of the tsunami of the Great East Japan Earthquake in 2011 [5].

Photo 3.2 LNG terminal upon arrival of the tsunami of the Great East Japan Earthquake in 2011[5]

Photo 3.3 LNG terminal after the strike of the tsunami of the Great East Japan Earthquake in 2011 [5].

Photo 4 Undamaged storage tank of LNG [5]

Photo 5.1 Transformer room's door was broken by the Tsunami[5]

Photo 5.2 Flooded panel board in Transformer room[5]

3. Application of the new seismic retrofit technique

3.1. Outline of Facility

This gas supply facility is a one-story reinforced concrete Governor Station (**Photo 6**) 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. 1**, the governor station includes a governor room, which contains the equipment and piping used in depressurization; and a control room, which controls the whole governor station.

3.2. Evaluation of Seismic Capacity

A seismic evaluation was carried out based on "Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings"[4] 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, the new seismic retrofit technique (an external steel frame construction method) was finally adopted (**Fig2**). A new reinforcing structure was constructed around the existing building instead of increasing the structural member sizes as used in the conventional method of retrofitting. 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 the 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, a structure which is capable of safely supporting the existing building was adopted by securing adequate strength and stiffness. The seismic retrofitting policies are 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

Photo 6　Governor station before reinforcement work

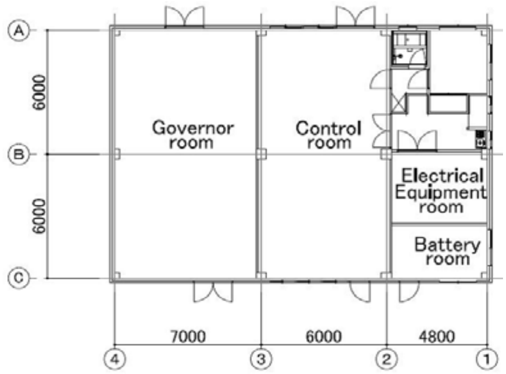

Fig.1　Building plan

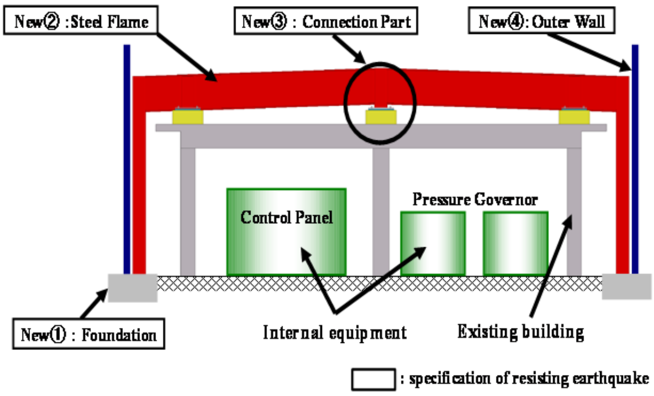

Fig.2　External steel frame construction method (earthquake-resistant)

Photo 7　Governor station after reinforcement work

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 7 and 8 show the appearance of the governor station after the reinforcement work.

3.4. Process

Table2 compares this method to reconstruction. In case of reconstruction, we examine two cases; one is the method of reconstruction on the same place on the premise of stopping equipment in a facility, and the other is the method of reconstruction to another place on the site without stopping equipment in a facility. This method has several benefits.

First, application for building permit is not necessary since a new roof will not be constructed. Second, it is not necessary to modify the existing building itself. So, it is not necessary to stop the operation of the facility temporarily since movement of equipment, piping, and electrical instrumentation cables and control panels are basically unnecessary. Photo9 shows reinforcement stage. Morever, it is not necessary to have building equipment and interior finish (firefighting equipment, air conditioner, electrical equipment, etc.) since the existing building was preserved. As a result, construction period of this method is less than half of the period to reconstruct at the same place and one third of the case of reconstruction at another place. Therefore, the project was able to be accomplished in a short term of 3 months.

Photo 8 The parts of Governor station after reinforcement work

Table2 The comparison on process between the new seismic retrofit technique (named W-defense) and reconstruction

Technique	Process	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16month
W-Defense technique	Design	■	■														
	Foundation work			■													
	Upper frame construction work (steel)				■												
	Outer wall • roof waterproof work					■											
Reconstruction (the case of reconstruction on the same place)	Design and application for building permit	■	■	■	■												
	Protective work for existing equipments			■													
	removal of existing equipments				■												
	Foundation work					■											
	Turning pipe and cable						■										
	Upper frame construction work (RC)							■	■								
	Building equipment / interior finish									■	■						
Reconstruction (the case of reconstruction to another place)	Design and application for building permit	■	■	■	■												
	Foundation work					■	■										
	Upper frame construction work (RC)							■	■								
	Instrumentation of equipments, pipes and electrical appliance									■	■						
	Manegement of existing gas installation											■	■	■	■		
	Building equipment / interior finish															■	■

4. Conclusion

Fig3 shows the characteristic of this method. Not only Gas Supply Facility's seismic performance was improved in a short period of time but also facility's image was improved by renewing the building facade. In the high tsunami risk areas, if it's possible to protect from water pressure of the tsunami by external wall made of reinforced concrete and the watertight design of the fittings, this method can resist not only earthquake but also Tsunami (Fig4). In addition, this method is named W-Defense technique, since it is capable to resist both tremors of earthquake and flood of Tsunami. Therefore, this method is the most suitable for protection of electrical equipment etc. which is indispensable for security measure of Gas Supply Facilities. Hereafter, to stabilize the supply of gas in Japan where is highly seismic country, the authors will continue to improve seismic performance of Gas Supply Facility.

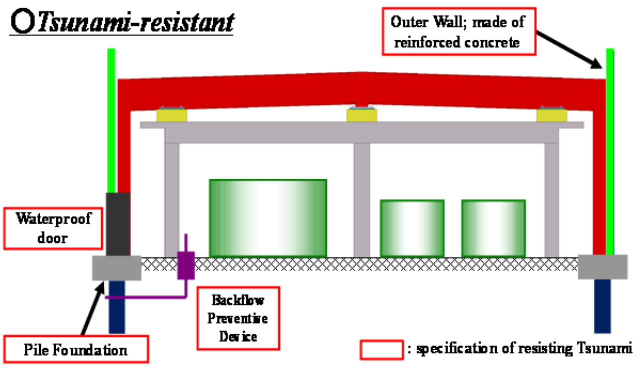

Fig.4 The new seismic retrofit technique in the high Tsunami risk areas (Tsunami-resistant)

References

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4) High Pressure Gas Safety Institute of Japan. High-Pressure Gas Facility Seismic Design Guidelines: Level 2 Seismic Performance Assessment. 2000.
5) Nuclear and Industrial Safety Agency and Gas Safety Subcommittee disaster countermeasures Working Group: Research Report of Disaster Countermeasures of City Gas Supply Based on the Great East Japan Earthquake, 2012
6) The Japan Building Disaster Prevention Association. Seismic Evaluation Standards, Guidelines for Seismic Retrofit, and Their Application Example (Reinforced Concrete Buildings). 2001.

Photo 9 At upper frame (steel) construction work

(1) It's not necessary to modify the existing structure. Also, there is no need to stop the operation of the facility temporarily since movement of equipment, piping, and electrical instrumentation cable and control panels are basically unnecessary.

(2) Although a wall is to be constructed over the steel frame so that its appearance is the same as a newly-constructed building, the application for a building permit is not necessary since a new roof will not be constructed. Therefore, immediate start of construction is possible.

(3) The first application project in Nerima city gas governor station of Tokyo Gas Corporation was able to be accomplished in a short term of 3 months upon preparation of a detailed construction scheme in cooperation with the facility operators and builders.

(4) In the high tsunami risk areas, it's possible to protect from water pressure of the tsunami by building external walls made of reinforced concrete and the watertight design of the fittings .(Nerima city gas governor station is out of the high tsunami risk areas)

Fig 3 The characteristic of the new seismic retrofit technique (an external steel frame construction method)