EICA Report of the Great East Japan Earthquake Investigation

(Flags at half-staff at Sen-En Sewage Treatment Plant)

April 2012

GREAT EAST JAPAN EARTHQUAKE INVESTIGATION COMMITTEE
THE SOCIETY OF ENVIRONMENTAL INSTRUMENTATION, CONTROL AND AUTOMATION (EICA)

INDEX

STP : Sewage Treatment Plant

Introduction

The Society of Environmental Instrumentation, Control and Automation (EICA) is an association that has conducted research on electrical and instrumentation of water supply and sewerage systems, waste disposal treatment and prevention of air pollution. It had been established for 22 years as of 2012.

From the time of establishment, social conditions involved in these research areas have changed dramatically. Social infrastructure of water supply facilities, sewerage facilities, waste disposal treatment facilities were still underdeveloped in many areas, and construction and operation of these had been rushed. Also there were still many problems to face on the air pollution prevention facilities, both from fixed emission sources and mobile emission sources.

At that stage, it had to aim for the fulfillment of power supply, process instrumentation control, network management and many areas that are related to electrical and instrumentation systems in order to meet the basic function of infrastructure. It was called the era of construction.

Then, by using the maintenance of hardware aspects such as construction facilities and the software aspects such as the legal system and operation management for each issue, with the cooperation and effort of the government and academia, certain progress was seen that came with the prospect of solving a fundamental challenge.

However, because of the Great East Japan Earthquake on March 11, 2011, Sewage Treatment Plant (STP) had been forced to conduct reviews.

STPs that were built near the coast have suffered unprecedented damage by the tsunami and have been entirely destroyed.

There are cross section forms of earthquake. From the electrical and instrumentation point of view, there are 3 characteristic points.

Damage caused by tsunami

Even though the damages because of the seismic motion were small, the damages that were caused by the external force of the tsunami, and sea water infiltration were more significant. As a result, electrical and instrumentation facilities suffered severe damage and required long term recovery.

Power Loss

The power loss at Fukushima No. 1 nuclear power plant had reached the fatal condition of melting reactor cores. The collapse of power company transmission line towers and the damage of emergency generators caused AC power loss in STPs in the area that was hit by the tsunami and lead to the grave situation of losing the pumping function.

Lifesaving

Regardless of the tsunami, the staff of the STP, staff of operation management company, and the construction officers were safely evacuated to the administration building at STP. Immediately after the earthquake, when there were information conflicts, despite the loss of external power supply and equipment damage, the result of daily disaster training, saving of emergency power supply, the certainty of information collection and information transfer had been evaluated. But in one of the STPs, there was one woman from the management operation company who died in the locker room. That means the issues of disaster training and information transfer that should already be resolved have still been neglected.

Some lessons were also learned in the recovery phase.

Water soaked

Electrical and mechanical facilities were tremendously damaged. Being soaked by water for a time has caused minor damage to building and civil engineering structures, but electrical and mechanical facilities were seriously damaged, especially facilities that would breakdown when flooded even for a short amount of time. It has required significant cost and time to recover.

Power loss

Long term power loss has become a bottleneck problem to recover activated sludge treatment processes that requires much more amount of power, and produces much more amount of sludge. Because of the large amount of power and treated sludge needed, if the supplied power from power company is not enough, even though the building and civil engineering structures, and electrical and mechanical facilities can be recovered, activated sludge treatment processes still cannot be reopened. Because of that problem, the difficult situation has persisted.

Quick recovery

In the areas that are far away from the coastline and were not influenced by the tsunami, the water purification facilities and sewage water pumping stations were safe. After the power was restored, early stage of water purification facilities and sewage pumping stations had been achieved. In connection with this, with the hard work of STP staff members, broken equipment and sewer pipe lines had progressed partially. As a result, toilets and kitchens became usable without any restriction.

Many reports related to Great East Japan Earthquake have already been published, and the whole picture is still being disclosed. Full scale discussions about the reconstruction plans have begun. However, there are very few report documents related to electric and instrumentation system of devastated STPs. In response to this, EICA has formed a research committee for the Great East Japan Earthquake Investigation on July 2011. The research objects are four large scale STPs that are located in Miyagi prefecture which got tremendous damage from the tsunami. Those STPs' electricity and instrumentation recovery and reconstruction were investigated by the committee on November with the cooperation of Sendai City and Miyagi Prefecture Local Government.

On it, analysis of the damage from the impact of the tsunami was conducted, which includes identifying the similarity & differences between affected STP facilities.

We will propose the countermeasure of electricity and instrumentation facilities of STPs across the country in the area that was affected by the damage of Great East Japan Earthquake and tsunami.

The content of this report provides Introduction, research overview in Chapter 1 (photo only), Facilities overview of Ishinomaki Tobu STP (25,300 m^3/d) in Chapter 2 (photo only), Sen.-En STP (222,000 m^3/d) in Chapter 3 (photo only), Minami Gamo STP (398,900 m^3/d) in Chapter 4, Kennan STP (125,000 m^3/d) in Chapter 5 (photo only), Conclusion in Chapter 6, Proposals in Chapter 7.

Using this report, we are trying to help the reinforcement of electrical and instrumentation systems of STPs that may be affected by tsunamis in the near future.

Chapter 1 Investigation Committee

1. Establishment of Committee

In the occurrence of the Great East Japan Earthquake, in order to uphold the responsibility of the association, EICA Great East Japan Earthquake Investigation Committee was established mainly by the members of the association in July, 2011.

Photo. 1. 1 Survey conducted at the emergency generator room in Ken-nan STP (Photo taken in Nov. 2011)

2. Member of Committee

Chairperson :

Dr. Hiroaki Tanaka
(EICA Chairman & Professor of Kyoto University)

Vice Chairperson :

Takuji Nakazato (EICA Vice-chairman)
Kunio Waseda (EICA Vice-chairman)

Member :

Manabu Katayama
Akio Sato
Shigeo Sato
Takeshi Sato
Takaaki Shinoda
Katsumi Shimamura
Yasuaki Tago
Kunio Tamura
Shire Toyoshisa
Masajiro Nakada
Hiromitu Moridera
Akihiro Yamada

Chapter 2 Ishinomaki-Tobu STP (Photograph only) (25,300 m^3/d)

Photo. 2. 1 Aerial photo of Ishinomaki Tobu STP

Photo. 2. 2 The moment when the tsunami hit (Photo taken by staff member at the sewage treatment plant in Mar. 11, 2011)
Inundated up to GL (Ground Level) 6 m (above the 2nd floor level of the 1st sedimentation tank)

Photo. 2. 3 Interior of the administration building on the 1st floor (Photo taken by staff member at the STP in Mar., 2011)
The ceilings, etc. were inundated and destroyed.

Photo. 2. 4 Upper part of the indoor biological reactor tank on the 2nd floor (Photo taken in Nov. 2011)
No significant damage to the building structure was found.

Photo. 2. 5 Equipment carry-in entrance on the 2nd floor (Photo taken in Nov. 2011)
The backfilled section of the equipment carry-in entrance was destroyed by Tsunami.

Photo. 2. 6 Upper part of the outdoor biological reactor tank on the 2nd floor of the building (Photo taken by staff member at the sewage treatment plant in Mar. 2011)

Photo. 2. 7 Local control panel of the sewage pump on the 1st floor (Photo taken by staff member at the STP in Mar. 2011)

Photo. 2. 8 The destroyed NTT (Nippon Telegraph and Telephone Corporation) service leading-in pole (Photo taken by staff member at the STP in Mar. 2011)

The power receiving wire pole was destroyed by the Tsunami.

Above : Immediately after the Tsunami. Submerged in water because it was installed on the basement floor. (Photo taken by staff member at the STP in Mar. 2011)
Below : Under restoration work after water was drained (Photo taken in Nov. 2011)

Photo. 2. 9 Grit chamber on the basement floor

Photo. 2. 10 Electrical room in the dehydrator building area (Photo taken by staff member at the STP in Mar. 2011)

Inundated because it was installed on the 1st floor

Photo. 2. 11 Submerged sludge-treatment monitoring room on the 1st floor (Photo taken by staff member at the STP in Mar. 2011)

Inundated up to ceiling level by the Tsunami

Chapter 3 Sen-En STP (Photograph only) (222,000 m³/d)

Photo. 3. 1 Aerial photo of Sen-En STP

Photo. 3. 2 Tsunami upon hitting the area (Photo taken by staff member at the STP in Mar. 11 2011)
The tsunami height was GL 1.3 m on the water-treatment side and GL 2.8 m on the sludge-treatment side.

Photo. 3. 3 Toppled digestion gas tank (Photo taken by staff member at the STP in Mar. 2011)
The gas tank was toppled due to the buoyant force of the sea water.

Photo. 3. 4 Damaged blower equipment (Photo taken by staff member at the STP in Mar. 2011)
Lifted and destroyed due to the buoyant force applied to the air header pipe

Photo. 3. 5 Temporary storage yard for the disassembled digestion tank (Photo taken in Nov. 2011)
The tank, which was destroyed by Tsunami, was disassembled and placed temporarily in this yard.

Photo. 3. 6 The water treatment facilities (Photo taken in Nov. 2011)
The section covered with the blue sheet is the temporary storage yard for the sludge of tsunami.

Photo. 3. 7 The temporary dehydrator (Photo taken in Nov. 2011)
Sludge brought about by the tsunami is treated using the temporary dehydrator.

Photo. 3. 8 Caved-in road within the facilities because of ground liquefaction (Photo taken in Nov. 2011)

Photo. 3. 9 Tsunami trace on the electrical room entrance on the 1st floor of the sludge treatment building (Photo taken in Nov. 2011)
The water level can be estimated by the flood trace.

Photo. 3. 10 Tsunami trace in the electrical room on the 1st floor of the sludge treatment building (Photo taken in Nov. 2011)
The water level can be estimated by the flood trace.

Photo. 3. 11 Simple aeration (Photo taken in Nov. 2011)
Simple aeration, that means aeration without return sludge, was performed temporarily

Photo. 3. 12 The disinfection tank (Photo taken in Nov. 2011)
Disinfection was performed strictly for sanitation.

Photo. 3. 13 Centrifugal dehydrator installed on the high frame (Photo taken in Nov. 2011)
Not inundated because installed at elevation, but auxiliary equipments were broken

Chapter 4 Minami Gamo STP (398,900 m^3/d)

1. Facility overview of Minami Gamo STP

1.1 Location

Minami Gamo STP is located at the right side bank of the estuarine of Nanakitada River in Sendai city. The plant is facing the Pacific Ocean and Teizan canal cuts across the plant field. (**Photo. 4. 1**)

Photo. 4. 1 Aerial photo of Minami Gamo STP Tsunami came from southeast direction.

Topographically, the Plant is located in the lowland area. Therefore the sewage flows by gravity to STP, and to the Pacific Ocean.

1.2 Public sewerage area

Minami Gamo treatment area (Approximately 60% of treatment area in Sendai City.)

1.3 Population of the treatment area

716,192 people

1.4 Treatment method

Standard activated sludge method (anaerobic-aerobic method) and chlorination.

1.5 Treatment capacity

Maximum treating amount : 398,900 m^3/d

1.6 Installation timeline

1964 : Basic treatment facility by sedimentation method started to operate.

1979 : Complete treatment facility started to operate

1.7 Major Facilities Construction Company (under construction)

Settling basin : Hitachi Kiden Kogyo, Ltd.

Primary and final sedimentation tank : Hitachi Plant Construction and Services Co., Ltd.

Aeration facility : Sanki Kogyo Co., Ltd.

Sludge treatment prosess : Tsukishima Kikai Co., Ltd.

Incineration facility : Kubota Co., Ltd.

Electric/Instrumentation : Hitachi Co., Ltd.

2. Overview of Electrical Facilities

2.1 High voltage power receiving facility

66 kV/50 Hz/1
line/aerial cable/Gas Isolated System

2.2 Substation facilities (Main transformer)

10,000 kVA/66 kV/6.6 kV/1
Unit of Oil-immersed type

7,500 kVA/66 kV/6.6 kV/1
Unit of Oil-immersed type

2.3 Power distribution facility (6.6 kV power distribution panel, low voltage power distribution panel, transformer panel)

Extra high voltage electrical room, water treatment facilities electrical room, sludge treatment facilities electrical room

Approximately 180 panels

2.4 Emergency generators

3,500 kVA/66 kV/50 Hz/2
Units of diesel engine

2.5 Control operating facility

Control center board, relay panel, junction terminal panel, operation panel in the field

Approximately 600 panels

3. Overview of Instrumentation Facilities

3.1 Monitoring and Controlling Facilities

(1) Water treatment system

3 CRT monitoring equipment units, graphical panel monitoring equipment, 1 server unit (dual system), 8 controller units,

(2) Sludge treatment and incineration system

5 CRT monitoring equipment units, graphical panel monitoring equipment, 2 server units (dual system), 12 controller units,

3.2 Instrumentation

Approximately 210 units

4. Damage and restoration of the electrical facilities

4.1 Damage situation

The Great East Japan Earthquake that occurred at 14 : 46 on March 11, 2011 had stopped the power transmission system from Tohoku Power Company. Then, an attempt to start two emergency generators was automatically made. Although one of the 2 units had broken down due to the cooling pipe damage, the other unit was started and electricity was generated. It had supplied electricity until the system was flooded by the Tsunami.

The damage due to the earthquake was rather small, but the Tsunami that came in 30–40 minutes after the earthquake damaged most of the electrical and mechanical facilities on the 1st floor and the basement. Then the function of STP was stopped. (**Photo. 4. 2**)

Photo. 4. 2 Tsunami attack (Photograph taken in Mar 2011) (Provided by Sendai city)

The tsunami wave reached 10.5 m from ground level (G. L), (Tokyo bay Point average level (TP) +12.85 m) at its peak near the closest area to the coast, and G. L. 4 m (TP+6.9 m) around the area just across the Teizan canal. (**Fig. 4. 1**)

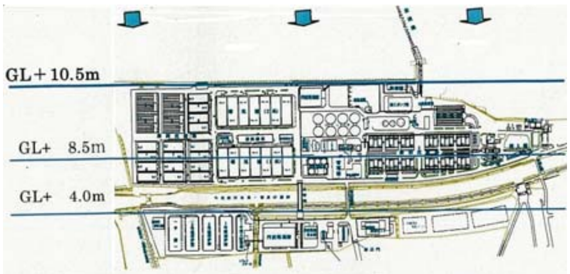

Fig. 4. 1 Flood level (Provided by the STP)

The electrical towers on the STP side were safe from the earthquake and tsunami. However the primary transmission line had lost power because several transmission towers outside of the STP had collapsed. Due to this, high voltage power could not be used until December 2011, so the other high voltage service was used as emergency power supply. Prolonged restoration of the transmission line of Tohoku Power Company had serious effects on the recovery of the STP. (**Photo. 4. 3**)

The water treatment plants built on the ocean side

Photo. 4. 3 Electrical towers. (Photograph taken in April 2011) The electrical tower withstood the Tsunami attack. It did not collapse and was not damaged.

of the STP were largely damaged by the Tsunami. The wall of the main pump building was bent, and the walls of the air blower building were destroyed and cracked open by the impact of the Tsunami. The distribution panels and operator control panels placed in the building were mostly flooded and lost their function due to the impact. (**Photo. 4. 4**, **Photo. 4. 5**)

Photo. 4. 4 Wall of the main pump building. Tsunami came and struck the building from the right side in the photo and bent the wall

Photo. 4. 5 Inner part of the air blower building. Air blower and electric motors were covered with the rubble that entered from the destroyed wall

Meanwhile, the equipment installed outside, on the 1st floor, and on the basement in the administration building and the sludge treatment and incineration facility located on the west side of the Teizan canal were flooded, but the water level was rather low. The equipment on the 2nd or higher floors were less damaged.

Main mechanical facilities such as dehydrators installed on the 2nd or higher floors were not directly damaged, but operation of some equipment were suspended due to the submergence of auxiliary machines on the 1st floor. The wall of the housing for the high voltage power was largely damaged by collision of drift wood, this may be because of structural weakness, the distribution panels inside had collapsed due to the impact and submerged and broke down. (**Photo. 4. 6**)

Photo. 4. 6 Housing for the high voltage power
Largely damaged wall because of drift wood.

The cable duct and cooling pipe of the emergency generator were partially damaged by the earthquake, but there was no damage and no flood in the building. This is because the tsunami height was low in this area, the structure of the building was firm, secured with the sound insulation and elimination of vibration, and the housing adopted an airtight structured door and no windows. (**Photo. 4. 7**)

The Direct Current (DC) power unit was not directly damaged by the earthquake nor the tsunami. However, the long term blackout caused over discharge of the storage battery.

4. 2 Recovery situation of the electrical facilities

Based on the Business Continuity Plan (BCP) for Minami Gamo STP, recovery of the temporary electrical facilities were conducted along with securing the effluent flow channel and sedimentation facility, and recovering the sludge treatment facility.

Photo. 4. 7 Housing of the emergency generator facility (Photograph taken in Apr.2011)
Major damage could not be seen on this building.

(1) Right after the disaster

Maximizing the usage of gravity flow, influent → primary sedimentation tank → bypass gate → effluent, the basic process and effluent had been carried out without electric power.

(2) Temporary power generator

A temporary dehydrator was installed in the middle of April 2011. According to the plan, power was supplied temporarily with a portable type of diesel engine generator.

(3) Backup receiving power unit

It started to receive electrical power (6.6 kV/1.998 kW/1 line) from Tohoku Power Company as backup power supply from the middle of May 2011. In accordance with the restoration of the mechanical facilities such as automatic settling basins, sedimentation tanks, sludge pumps, and centrifugal dehydrators, the power had been fed sequentially and sludge treatment was reopened. (**Photo. 4. 8**)

(4) High Voltage power receiving facility

Tohoku Electric Power is planning to recover the

Photo. 4. 8 Temporary receiving power unit 6.6 kV installed on the primary sedimentation tank. (Photograph taken in May 2011)

Table 4. 1 Recovery situation of damaged electric/instrumentation at Minami Gamo STP
(By EICA analysis of sewage treatment plant questionnaire)

Item		Damage by earthquake	Damage by the Tsunami	Extent of damage	Estimated recovery time	
					Temporary	Permanent
water treatment	Power receiving equipment	None	Damaged	116 panels	May 2011	Mar 2015
	Power transforming equipment	None	Damaged	20 panels	May 2011	Mar 2015
	Power distributing equipment	None	Damaged	152 panels		Mar 2015
	Central supervision facilities	None	Damaged	53 units		Mar 2015
	Field operating board	None	Damaged	290 panels	May 2011	Mar 2015
	Field instrumentation (Number of sensors and panels)	None	Damaged	151 units	May 2011	Mar 2015
sludge treatment	Power receiving equipment	None	Damaged	30 panels	May 2011	Jun 2012
	Power transforming equipment	None	Damaged	6 panels		Jun 2012
	Power distributing equipment	None	Damaged	24 panels		Jun 2012
	Central monitoring room	Damaged	Damaged	19 units		Jun 2012
	Field operating board	Damaged	Damaged	150 panels	May 2011	Jun 2012
	Field instrumentation (Number of sensors and panels)	None	Damaged	60 units	May 2011	Jun 2012
Common facilities	Power receiving equipment	None	Damaged	12 panels		Jun 2012
	Power transforming equipment	None	Damaged	2 panels		Jun 2012
	Power distributing equipment	None	None	None		
	Central monitoring room	None	Damaged	6 units		Mar 2015
	Emergency generator	Damaged	None	2 units		Jun 2012
	DC power supply	None	None	2 units	May 2011	Jun 2012
	Field operating panel	None	Damaged	2 panels		Jun 2012
	Field instrumentation (number of sensor and board)	None	Damaged	2 units		Jun 2012
	Inside transmission and communication equipment	None	None	None		
	Outside transmission and communication equipment	None	None	None		
	Others	None	None	None		

Note) Facilities are classified as below.
Power receiving equipment : High and low voltage panel, DC panel, UPS
Transforming equipment : Transformer, transformer panel
Distributing equipment : Motor control center panel, relay panel, junction terminal panel
Central monitoring room : Instrumentation panel, monitor and control equipment, ITV system
Field operating panel : Operating panel in field
Field instrumentation : Measurement instrumentation, transmitter

power supply in June 2012 as originally scheduled. New electrical substation has been ordered and under construction.

4. 3 Policy for restoration of electric facility

Minami Gamo STP can do primary treatment and effluent by gravity flow without using pumps because of the geographical condition. This condition also avoids limitation of using sewage and overflow in the city. By exploiting this advantage, the recovery plan will be continued while maintaining this primary treatment that can be used in case of emergency. According to this policy, primary sedimentation tanks will be reconstructed in their former level, biological reactor (aeration tank) and final sedimentation tanks will be reconstructed on the 2nd floor in order to avoid tsunami disaster, Main electrical facilities will be installed on the 2nd or higher floor. For securing the power during emergency situations, solar cell facility and small-scale hydropower generator will be promoted to establish an STP that is less vulnerable to tsunami disaster.

5. Damage and recovery of the monitoring control equipment

5. 1 Damage situation of the instrumentation

Main devices of monitoring control equipments such as CRT monitoring device and servers weren't damaged because they were installed in the central monitoring room on the 2nd or higher floors. However 8 controller units for the water treatment system and 2 controller units for the sludge treatment had broken down because of the flood.

The instrumentation such as sensors and transmission equipment panel, instrumentation switch panels that were installed outside on the 1st and basement had all broken down due to the flood.

5. 2 Recovery situation of the monitoring control equipment

(1) Monitoring control equipment

For emergency recovery of existing centrifugal dehydrator, 2 controller units were installed temporarily, and additionally the undamaged auxiliary relay panels and control panels were used. This enabled the operation of the facility. (**Photo. 4. 9**)

Photo. 4. 9 Temporary sludge treatment controller (Photograph taken in May 2011)
It is installed in the electric room on the 4th floor of sludge treatment building.

However, during the investigation period (Nov. 2011), almost all water treatment and sludge treatment were suspended because the electricity and mechanical facilities in the sewage treatment plant weren't recovered yet.

(2) Instrumentation equipment

Since the sewage flows by gravity without pumping and also water level gauge of pump well and pressure gauge for control were unnecessary, inflow meter for monitoring (ultrasonic wave pulse Doppler method) was preferentially recovered temporarily. (**Photo. 4. 10**)

Photo. 4. 10 Temporary inflow meter (Photograph taken in April 2011)
It is installed temporarily at the inlet of the STP.

5. 3 Recovery policy of monitoring controlling equipment

For countermeasure to prevent the monitoring control system from shutting down, the CRT monitoring control equipment and controller will be installed on the 2nd or higher floors to minimize the flood damage in case of a Tsunami.

6. Task of restoration

The biggest feature point of Minami Gamo STP is that basic sedimentation treatment and effluent can be carried out without using power if the bypass route from primary sedimentation tank to the emergency effluent gate is used.

On March 12, 2011, the following day of the disaster, the old effluent channel gate (normally closed) was opened manually and malfunctioned emergency effluent gate was destroyed on March 17, 2011 to secure the effluent function.

On March 18, 2011, rubble in the STP was removed and water in the primary sedimentation tank was drained. Solid chlorination disinfection had begun right after (**Photo. 4. 11**) and about one month later, on April 14, 2011, injection of sodium hypochlorite had begun. (**Photo. 4. 12**) After that, sewage could be

Photo. 4. 11 Disinfection with solid chlorine

Photo. 4. 12 Injection of hypochlorous acid in temporary facility

Table 4. 2 Comparative review of sewage treatment methods between primary treatment and complete treatment restoration for Minami Gamo STP

Treatment method	catalytic oxidation	Rapid filtration + Feeding coagulant	Standard activated sludge, membrane separation activated sludge, carrier, batch type activated sludge	Modified aeration
Capability with existing facility	○ Use pre-aeration tank	○ Use pre-aeration tank	× Unable to secure necessary capacity of tank	× Unable to secure necessary capacity of tank
Securing BOD less than 60 mg/L	○ BOD approximately 40 mg/L	○	—	—
Maintenance cost	○ Less chemical cost Less sludge generation	△ More chemical cost More sludge generation	—	—

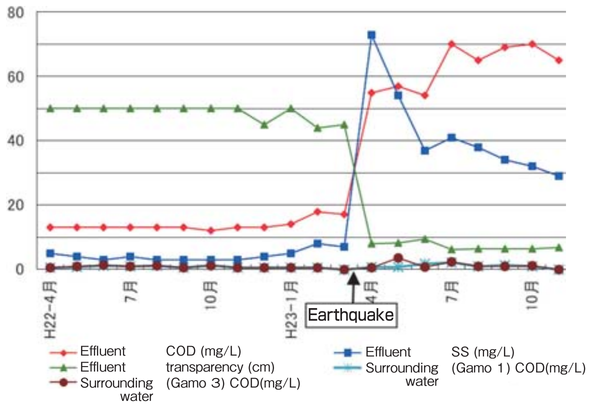

Fig. 4. 2 Influence on the effluent water by the earthquake disaster (x axis is month, y axis is mg/l)

treated by primary treatment. Sodium hypochlorite for disinfection was injected and effluent discharge to the Pacific Ocean had been done.

The effluent water quality during this treatment is shown in the **Fig. 4. 2**. The level of COD and SS largely went down right after the disaster, but improvement of SS was seen after the primary treatment had begun. Furthermore, water quality deterioration at the environmental standard place was not observed. The major reason being considered for this is the diluting effect by effluent to the Pacific Ocean.

Restoration of the treatment facility is anticipated to be completed in 5 years. Therefore the sewage treatment method should be shifted from primary treatment to biological treatment and disinfection in 3–6 months. Usage of "Catalytic oxidation method" has been promoted after a comparative review of the treatment methods as in the **Table 4. 2**.

The sludge treatment resumed sludge extraction from the primary sedimentation tank and also sludge treatment in the temporary dehydrator housing. (**Photo. 4. 13**) After the introduction of the backup high voltage substation facility in middle of May 2011,

Photo. 4. 13 Temporary dehydrator housing. (Photograph taken in May 2011)
Temporary tent house was set up and equipment was installed inside.

treatment of generated sludge resumed with existing centrifugal dehydrators through the temporary sludge pump.

Dehydrated sludge could not be incinerated because of power shortage ; therefore the sludge was conveyed by truck to land-fill site and partly conveyed out and treated in Miyagi Prefecture.

References :

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2) Sendai city STP damage resulting from the Great East Japan Earthquake.
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3) Report for recovery policy of Sendai city Minami Gamo STP
Sendai city Minami Gamo STP recovery policy committee, (Sep. 2011)

4) Sewerage recovery strategy for continuance of STP utilization and retention of hygienic environment — effective utilization of [Sendai city Sewerage network]—
Sendai city Construction Bureau, (Apr. 2011)

Chapter 5 Ken-nan STP (Photograph only) (125,000 m³/d)

Photo. 5. 1 Aerial photo of Ken-nan STP

Photo. 5. 2 The destroyed upper part of the water treatment facilities (Photo taken in Apr. 2011)
The facilities was directly hit by the Tsunami

Photo. 5. 3 Damaged electrical room (Photo taken in Apr. 2011)
Electrical equipment was inundated or destroyed by the Tsunami

Photo. 5. 4 Restoration status of destroyed upper part of water treatment facilities (Photo taken in Dec. 2011)
Treatment by standard activated sludge process was partially restarted

Photo. 5. 5 Restoration status of local electrical room (Photo taken in Dec. 2011)
Restoration of the sand-filtration system

Photo. 5. 6 The destroyed pH meters for Aeration Tank No. 1 and 2 (Photo taken in Apr. 2011)
Mounting pole destroyed by the Tsunami

Photo. 5. 7 Restoration status of supplied-sludge density meter for No. 3 dehydrator (Photo taken in Oct. 2011)
The equipment in the No. 1 dehydrator building was the first to be restored.

Chapter 6 Conclusion

1. Damage Characteristics

Damage conditions at each STP are summarized in **Table 6. 1**. There were various forms of disaster from the earthquake. In general, the earthquake itself caused little destruction or damage, but the destruction from the impact of tsunami as well as flood damage it caused has been immense. Conversely, in buildings where water-proofing and anti-inundation measures such as water-tight doors/gates were in place, a certain level of efficacy has been noted.

Common forms of damages at each sewage treatment plant are as follows :

1. 1 Power distribution Feeds/Connection Points from Power Companies

All of the STPs had slight earthquake damage ; however, there were some cases where incoming service poles, leading from the power company to the plant, were knocked down by the tsunami. There were no collapsed incoming transmission towers or switch towers at Minami Gamo STP, but there were collapsed distribution transmission towers from Tohoku Electric Company, which led to serious power outages. Hence, recovery is taking a long time. However, at Sen-En STP, the distribution transmission towers and incoming service poles were not knocked down and power transmission from Tohoku Electric Company was restored within two weeks which lead to the STP's speedy recovery.

1. 2 Substation Facilities

Damages from the earthquake were minor except for damages to some open-structure type disconnectors at Sen-En STP. Conversely, local electrical rooms situated on the 1st floor of each STP were destroyed by the impact of the tsunami. Tohoku Electric Company restored power at Ken-nan STP by the end of March 2011. The speedy recovery can be linked to immediate resumption of supply needed to power the 2nd floor local electric rooms, which were not inundated by the tsunami. On the other hand, there was no flood damage to the 2nd floor local electric rooms at Ishinomaki Tobu STP, but its recovery was delayed because Tohoku Electric Company was not able restore power until June 2011.

1. 3 Emergency Generator

There was damage to wiring ducts at Minami Gamo STP caused by the earthquake. Also, due to damages to cooling-water pipes, there were some burns to machineries. However, 1 in 2 machines started up normally and succeeded in producing power. On the other hand, other STPs were not damaged by the earthquake, but since power generation facilities were located on the first floor, the facilities sustained some flood damage. Even when flood damage was avoided, auxiliary systems needed to run the facilities, such as fuel transfer pumps, etc., were flooded and these units lapsed into non-power generation mode.

1. 4 Water Treatment Facilities

Though cases of power line sections being cut by earthquake-caused ground subsidence have been observed, there were no damage reports of toppled electrical panels. Panels that were set up on the 1st floor level or basement − where they sustained a lot of tsunami flood damage − were catastrophically damaged.

1. 5 Sludge Treatment Facilities

There was no substantial damage or collapse panel due to the earthquake. However, panels at each STP that were installed on the 1st floor or basement − where they sustained a lot of tsunami flood damage − were catastrophically damaged. In many cases, sludge dehydrators installed on the 2nd floor were not affected by the flood. However, since auxiliary systems needed for the facilities to run were installed on the 1st floor, or basement, these systems were flooded and disabled.

1. 6 DC Power Supply Systems/Uninterruptible Power Supply (UPS)

There was no damage due to panel collapse ; however there were many cases where prolonged power outages led to excessive discharging of lead storage batteries resulting to complete damage with no hope of recovery. In addition, there were power supply units in several of the electrical rooms on the 1st floor of Sen-En STP that escaped flood damage because of being situated in highly watertight electrical rooms.

1. 7 Instrumentation

There were instruments that were destroyed by the impact of the tsunami or by flooding/insulation failure. Instruments set up inside buildings and in piping galleries did not appear to be damaged, but could not be used because of insulation failure caused by the flood.

1. 8 Central Monitoring Equipment

Though there were some STPs where Liquid Crystal Display (LCD) monitors fell over due to the earthquake, there was no damage from panels collapsing, etc. Also, since the central monitoring room for each STP was set up on the 2nd floor or higher floors, there was no damage from flooding. However, the sludge treatment monitoring and control rooms at Ken-nan STP, and at Ishinomaki Tobu STP, were on the 1st floor and were thus flooded by the tsunami. In addition, control panels that were set up on the 1st floor of these buildings were damaged by flooding and the impact of the tsunami and said equipment was unable to perform monitoring and control operations.

1. 9 Equipment Operation and Operation Control Panels

Panels, such as motor control centers, auxiliary relay panels, on-site control panels, control panels, etc., that were set up outdoors, on the 1st floor, or basement were affected by the flood damage/insulation failure or impact from the tsunami. Even if the panel itself avoided being flooded, instances of insulation failure due to flooding at connection points, such as junction boxes, etc. were observed.

1. 10 Off-site Pump Stations (Remote Monitoring Equipment)

There was no damage due to collapsing panels, but NTT telephone service poles collapsed at each STP due to the tsunami and dedicated network lines between pump stations were cut, thus making them inoperative.

1. 11 Communication Equipment (Disaster Management Radio Communications)

There were STPs where disaster management radio communications functioned normally and STPs where breakdowns at the disaster management authority led to disconnections in mid-operation. Since this was the designated means of communication to secure correspondence on which lives depended, where normal functionality was not present, earthquake information and tsunami information was obtained by means of digital TV of cellular phones, e-mail, etc. on public communication networks.

1. 12 Other Information

Directly following the earthquake, those staff members associated with sewage facilities acted calmly and appropriately, basing their actions on the Disaster Management Manuals or the Business Continuity Plans (BCP) enacted at each STP. It is thought that this was a result of precise information gathering/transmission due to regular disaster training. Meanwhile, when power was restored to emergency generators, there were cases where standardized visual checks of local electric rooms and transformer facilities − which were located a long distance away from administrative buildings − were performed. Learning from this experience, it is concluded that in situations where leaving the administrative buildings is extremely dangerous, as was the case with this tsunami, a review of power distribution plans and of the process manual for the restoration of electrical equipment is needed.

2. Challenges

As for the damages, it has been recognized that the distinct feature of this disaster is that there was far more damage, such as flooding and collapsing of electrical and instrumentation facilities, caused by the tsunami than the earthquake. Thus, not only are earthquake-proof countermeasures necessary for electrical and instrumentation facilities, but it is also important for earthquake and tsunami countermeasures that involves building a highly reliable system that includes external factors such as the loss of distribution power lines. Challenges for earthquake-proof and tsunami-proof countermeasures are as follows :

2. 1 Reconsideration of Equipment Locations, Installation Methods, Wiring and Plumbing

Besides earthquake-proof countermeasures for breaking cables and collapsing electric panels, in order to prevent flood and tsunami impact damage, important measures include : Installing equipment where it will not be hit directly by a tsunami, installing countermeasures to prevent indoor flooding, or in the unlikely event that there is flooding, installing countermeasures so that the damage is decreased to minimum.

2. 2 Reducing External Power Source Dependency Rates & Fallback Procedures When Power is Lost

The treatment methods and operational equipment for each STP in the recovery stage are summarized in **Table 6. 2**. Simply, whether it is full recovery or temporary repairs, the geographic location and the installation emplacement of each STP varies so that the required equipment and treatment method for each recovery stage (step-by-step) also differs. These are also the factors that decide the amount of power required for recovery or temporary repairs. Thus, it is necessary to conduct a thorough preliminary investigation in order to address thoughts like, "even if it is broken, how can functions recover quickly," or "even if it is broken, partial functionality will be maintained and fallback procedures will come into effect," and to see how much power will be used for recovery and emergency procedures as well as which disinfection treatments to perform.

In the case of power loss due to collapsed distribution power lines, it is important to study the implementation of independent sources of energy, such as renewable energy and storage batteries, in order to independently supply the minimal power needed for emergency procedures like sewage pumping, sedimentation and simplified disinfection.

2. 3 Increasing System Reliability as a Whole & Fallback Procedures/Reducing Operation failure period

Due to external factors associated with tsunami flood damage, it is necessary to look at things from the viewpoint of maintaining the reliability of electrical equipment as a whole; even if certain equipment in local electrical rooms is damaged, back-up power can be sent from other local electrical rooms. And, even if some damage is sustained, in locations that are far removed from the damaged area, it is important to build system configurations where fallback procedures are possible, thus making sure that the entire system is not affected

2. 4 Information Sharing, Plans for Cooperation Between Municipalities

For speedy recovery and backup to occur between municipalities during a disaster, there must be quick and accurate information collection, even when there is confusion directly following an earthquake. The necessary information concerning disaster conditions, emergency measures, emergency repairs, temporary equipment procurement plans, etc. need to be collected quickly and smoothly, by means of various forms of communication that are resistant to disasters. There is also a need to construct plans for information sharing.

3. Countermeasures

The earthquake and tsunami countermeasures for electrical and instrumentation equipment, which we touched upon above, will be described below.

3. 1 Power distribution Feeds/Incoming Connection Points

In order to prevent toppling of transmission towers or service poles from tsunami impact, it is desirable to have power lines from the power company buried underground.

3. 2 Substations

(Grid Connection)

Figure 6. 1 shows backup power distribution for essential services and grid connection of renewable energy.

Since ensuring power is difficult during a disaster, it is recommended that we reduce dependence on external power sources through the introduction of renewable energy. Specifically, connecting renewable energy sources like solar cell power to the pumping motor and using large scale storage batteries for grid independent operation in an emergency are useful. Even in such cases, earthquake and tsunami impact/flooding countermeasures are needed. Sufficient research must be put into the location of facilities and plumbing/wiring.

(Power Distribution Equipment)

For this disaster, the complete loss of power from major electrical equipment needed for facility operations, due to electrical breakdowns and damage caused by flooding and tsunami impact, was a distinguishing characteristic. Thus, as far as loads needed for recovery and minimum loads on electrical equipment needed for initial treatment are concerned, even when power supplies to major electrical equipment are lost, if power can be supplied by connecting to alternate

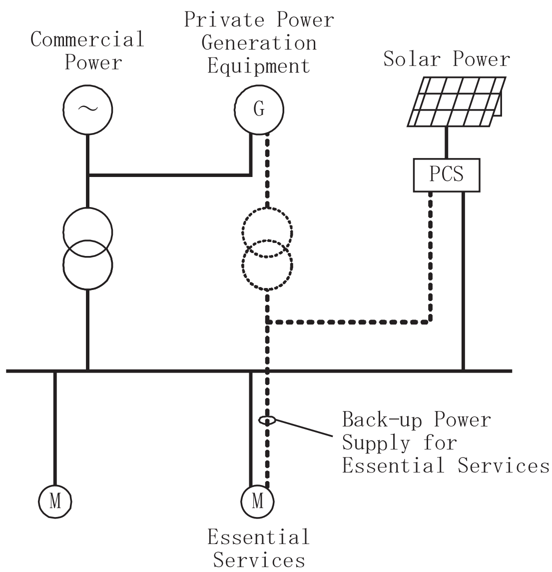

Fig. 6. 1 Conceptual Diagram of Renewable Energy and Power Grid Connection

substations and district electrical rooms, then these flexible power distribution routes become viable.

3. 3 Emergency Generator

Inspecting the deployment of flooding countermeasures for emergency generator, including auxiliaries, is important. It is desirable to have all equipment, including auxiliaries, on the 2nd floor or above. We must also pay attention to wiring/piping between fuel tanks and fuel pumps in particular. When installing equipment on the first floor is unavoidable, it is important to use flood-proof doors as a method for mitigating flood damage.

Also, there is a need to ensure that the estimated capacity of fuel tanks for emergency generator is sufficient for long-term power stoppages. Ensuring the required fuel capacity for running 24–48 hours, as suggested by the Japan Ministry of Land, Infrastructure, Transport and Tourism's Sewage Works Earthquake/Tsunami Countermeasures Technical Investigation Committee, is a given, but if transportation corridors are cut off, we can assume that there will be difficulties associated with ensuring that additional fuel will arrive. Hence, running in conjunction with independent power sources becomes viable. In addition, "dual-fuel" emergency generator that can switch between liquid fuel and gas fuel is feasible.

3. 4 Water Treatment Facilities

Preventing flood damage from a tsunami is critical and it is important to install control panels on upper floors or to install flood-proof doors as a method for mitigating damage. In addition, using a submersible pump for the main pump and taking water-proofing precautions for power sources and control cable terminal is important. When installation in the underground is unavoidable, steps must be taken based on the assumption that equipment will be submerged.

3. 5 Sludge Treatment Facilities

To prevent flood damage caused by a tsunami, installing sludge dehydrators, including auxiliaries, on the 2nd floor or above is desirable ; however, when installed on the 1st floor, methods to mitigate flood damage, such as flood-proof doors, are important. When installation in the underground is unavoidable, steps must be taken based on the assumption that equipment will be submerged.

3. 6 DC Power Supply Systems/Uninterruptible Power Supply (UPS)

Preventing flood damage from a tsunami is critical and it is important to install Power Supply Systems on upper floors or to install flood-proof doors as a method for mitigating damage. Also, when alternating current power supplies fail, including emergency generators, in order to stop the discharging of electricity from storage batteries before they become depleted and damaged, it is important to shut down batteries automatically through the use of an over-discharge alarm.

3. 7 Instrumentation Facilities

During this disaster, instrumentation facilities installed outside were destroyed or flooded by the tsunami and thus became useless. However, there were some equipment, which were installed inside buildings or piping galleries, that remained unharmed. Thus, countermeasure precedents, such as using water-proof/flood-proof converters or installing converters on the 2nd floor or above, should be considered. Moreover, sampling of instrumentation equipment needed at the recovery stage and back-up equipment procurement are also important.

3. 8 Central Monitoring and Control Equipment

During this disaster, central monitoring and control equipment installed on the 2nd floor did not get severely damaged but the controllers installed in local electric rooms on the 1st floor received flood damage. If a local electric room gets damaged, the central monitoring and control equipment will not be able to fulfill its role. So, it is thought that there is a need to put these rooms in locations that are safe from disaster or to examine regional electric room back-ups, decentralization, etc. Methods for installing controllers on upper floors, or for making the primary equipment's controls redundant between different controllers, are to be considered.

3. 9 Equipment Operation Panels

To prevent flood damage caused by a tsunami plans to mitigate damage through the installation of equipment operation panels on second floors or through the installation of flood-proof doors are important. Also, water-proofing countermeasures for power sources/control cable terminal is critical.

Since there are a lot of cases of on-site control panels being installed outdoors or on lower floors, there is a need for drastic countermeasures. As an alternative to conventional on-site control panels, replacement by close-range wireless equipment, for example Tablets or Exclusive PHS (Personal Handy-phone System) is effective.

3. 10 Off-site Pump Station Remote Monitoring Equipment

Poles of NTT collapsed and dedicated network lines were cut by the tsunami, thus rendering monitoring equipment inoperative. So, it is necessary to install network lines underground in order to avoid this in the future.

Also, in cases where a facility is damaged temporarily by a disaster, it becomes important to have independent operational control of off-site pump stations based on the assumption of network troubles. It is also important to make networks highly reliable. Remote monitoring is effective only when network communications can be established without any problems, so establishing a stable network between the disaster control center, the STP, and off-site pump stations using the most reliable private network lines − fiber optic cables installed in the sewage pipes − is recommended.

Also, automatic operation of manhole pump stations is possible when there is network trouble. In order to continue remote monitoring at off-site pump stations from the STP, it is valid to use communication line back-up plans that incorporate both commercial dedicated lines and private lines, such as analog 3.4kHz dedicated lines/private lines or digital dedicated lines/private lines.

3. 11 Emergency Communication Facilities

In this disaster, there were cases where, due to damaged public emergency radio stations, the designated means of communication for securing the correspondence on which lives depended was lost. Also, there were many cases where commercial communications were unable to connect because of congested cellular phone line traffic. Therefore, communication gathering necessary for evacuation and grasping of the situation was delayed and this hindered precise gauging of the height of the tsunami and relaying of the urgency of evacuation procedures to the public. Back-up communication lines are critical when both private communications and commercial communications fail. Thus, it is necessary to set up independent communication lines in order that we are not dependent upon commercial communications. This can be achieved through satellite phones or through connecting STPs and disaster control centers with private lines by utilizing a dedicated communication network with fiber-optic cables laid in sewage pipe-line grids. Also, within STPs themselves, it is recommended to prepare private communication equipment such as PHS.

3. 12 Disaster Information Ascertainment System

Amid the chaos directly following this disaster, we propose a Disaster Information Ascertainment System that aims to collect information quickly and accurately. In order to grasp disaster conditions quickly and accurately, everyone sends critical data like safety status, power status, main pump conditions, off-site pump station conditions, etc. to a Cloud Data Center where it can be assembled into a database. We also suggest having a standardized format for reporting emergency operations, emergency repairs, and procurement plans for temporary equipment, etc. which covers conditions of major facilities and conditions of major equipment during each recovery stage. Last but not least, we propose constructing a plan to communicate quickly and reliably with the disaster control center by utilizing disaster proof platforms such as satellite phones and sewage pipe fiber-optic networks.

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Table 6. 1 Summary of the Damage Situation of Respective STPs

		Ishinomaki Tobu STP	Sen-En STP	Minami Gamo STP	Kennan STP	Remarks
Power receiving point	Earthquake damage	No damage	No damage	No damage	No damage	
	Tsunami damage	The leading-in poles were destroyed. (tsunami)	No damage (Because located at elevation)	The power transmission lines of the power company were destroyed. (tsunami)	The leading-in poles were destroyed. (tsunami)	
Power receiving and transforming equipment	Earthquake damage	No damage	The disconnecting switches were damaged. (open structure)	No damage	No damage	
	Tsunami damage	Inundated, tsunami (1st floor)	Inundated, tsunami (1st floor)	Inundated, tsunami (1st floor)	Inundated, tsunami (The electric room on the 2nd floor is undamaged.)	
Emergency generator	Earthquake damage	No damage	No damage	One set was broken due to the earthquake. (Although it started, it later failed because the cooling water pipe was broken and the control power supply was lost.)	No damage	
	Tsunami damage	The auxiliary machine was damaged.	Inundated, tsunami (1st floor)	No damage	Inundated, tsunami (1st floor)	
Water treatment facilities	Earthquake damage	Damaged. (in-house transmission/ communication equipment)	No damage	No damage The printers on the desks were moved slightly.	No damage	Some electric cables were damaged.
	Tsunami damage	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	
Sludge treatment facilities	Earthquake damage	No damage	No damage	Damaged. (The LCD monitors were toppled and destroyed. The anchor seat for the power supply board for operation was deformed.)	No damage	
	Tsunami damage	Inundated, tsunami (1st floor)	Inundated, tsunami (1st floor) (The dehydrator was on the 2nd floor, but the auxiliary machine on the 1st floor was inundated.)	Inundated, tsunami (1st floor) (The dehydrator was on the 2nd floor, but the auxiliary machine on the 1st floor was inundated.)	Inundated, tsunami (1st floor) (The dehydrator was on the 2nd floor, but the auxiliary machine on the 1st floor was inundated.)	
Common facilities	Earthquake damage	No damage	No damage	No damage	No damage	
	Tsunami damage	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	
DC power source/uninterruptible power system	Earthquake damage	No damage	No damage	No damage	No damage	The storage battery was damaged (over discharge) (excluding the Sen-En Purification Center).
	Tsunami damage	No damage	Only the 1st floor in sludge building was inundated. Other rooms (watertight doors) on the 1st and 2nd floors were undamaged.	No damage	Inundated, tsunami (1st floor)	
Instrumentation facilities	Earthquake damage	No damage	No damage	No damage	No damage	
	Tsunami damage	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	Inundated, tsunami (outdoor, 1st floor, basement)	
Central monitoring facilities	Earthquake damage	No damage	No damage	No damage The printers on the desks were moved slightly.	No damage	
	Tsunami damage	No damage (installed on the 3rd floor). However, the central sludge treatment facilities on the 1st floor were damaged.	No damage (installed on the 2nd floor)	No damage (installed on the 2nd floor)	No damage (installed on the 2nd floor)	
Control device Control panel Operation system	Earthquake damage	No damage	No damage	No damage	No damage	
	Tsunami damage	Inundated, tsunami (1st floor)	Inundated, tsunami (1st floor)	Inundated, tsunami (1st floor)	Inundated, tsunami (1st floor, basement)	
Outside pump station	Earthquake damage	No damage	The power receiving cables were damaged. (The hand hole sagged.)	——	The cables were damaged due to the subsidence.	The storage battery was damaged (over discharge).
	Tsunami damage	* Several of the 14 stations were inundated. * The circuit was cut off (The service line poles for the NTT circuit were destroyed.) * Some pump stations were submerged.	* The trunk flow meters were submerged (in about 18 places). * The circuit was cut off (The service line poles for the NTT circuit were destroyed.)	——	The circuit was cut off (The service line poles for the NTT circuit were destroyed.)	
Communication equipment (wireless accident prevention system)		——	The line was cut off during communication.	Normal	It could not be used because the power supply was lost.	
Unaccounted-for water (immediately after the disaster)		30,000 to 40,000 $m^{4/day}$	Instrumentation functioned only in the Shiogama Pumping Station. Usually it increased to 25,000 ® 30,000 m^3/day.	Unclear	Unclear	
Unaccounted-for water (as of Nov. 2011)		10,000 $m^{4/day}$	Increased by about 10 to 20%.	Unclear	About 10,000 m^3/day	

Table 6. 2 Summary of the Restoration Process in Respective STPs

		Ishinomaki Tobu STP	Sen-En STP	Minami Gamo STP	Kennan STP	Remarks
Power receiving equipment		Temporary power generator/power receiving	Temporary power generator/power receiving	Temporary power generator/power receiving	Temporary power generator/permanent power receiving	
Restoration stage * The items in parentheses are equipment to which electrical power is supplied.	Step 1	Primary sedimentation＋Simple disinfection by solid chlorine (Temporary submerged pump)	For in-house treatment : primary sedimentation＋simple disinfection (screen, temporary submerged pump, temporary simple disinfection equipment) For wastewater not treated sufficiently : Wastewater is settled in the sedimentation tank installed temporarily in the green park, disinfected simply and then discharged.	Primary sedimentation＋Simple disinfection by solid chlorine	Temporary sedimentation tank＋simple disinfection by solid chlorine (temporary submerged pump, temporary simple disinfection equipment)	
	Step 2	Primary sedimentation＋Simple disinfection by solid chlorine (Main pump＋gate, screen, sludge removal equipment)	Primary sedimentation＋simple disinfection (screen, main pump＋permanent sodium hypochlorite injection equipment)	Primary sedimentation＋disinfection (temporary sodium hypochlorite injection equipment) Sludge removal＋temporary sludge dehydration Temporary power receiving	Temporary sedimentation tank＋simple disinfection by solid chlorine (screen, main pump. Temporary filter, temporary disinfection equipment)	
	Step 3	Primary sedimentation＋contact aeration process＋disinfection (main pump, temporary biological treatment facilities, sludge removal pump, permanent sodium hypochlorite injection equipment)	Primary sedimentation＋simple aeration＋simple disinfection (screen, main pump, simple aeration equipment, permanent sodium hypochlorite injection equipment)	Primary sedimentation＋disinfection (sodium hypochlorite injection equipment) ＋contact aeration process＋sludge removal＋existing centrifugal dehydrator	Temporary sedimentation tank＋simple aeration＋simple disinfection by sodium hypochlorite (screen, main pump, temporary filter, simple aeration equipment, temporary disinfection equipment)	
	Step 4	Permanent restoration (Main pump, sludge removal pump, sodium hypochlorite injection equipment, pure oxygen generator, electrical equipment for sludge treatment)	Permanent restoration (Power receiving and transforming equipment, screen, main pump, sodium hypochlorite injection equipment, blower)	Permanent restoration (Power receiving and transforming equipment, screen, main pump, sodium hypochlorite injection equipment, air blower)	Permanent restoration (Power receiving and transforming equipment, screen, main pump, sodium hypochlorite injection equipment, blower)	
Sludge treatment * The items in parentheses are the equipment to which power is supplied.		Operation of sludge treatment was permanently restored.	Permanent dehydrator, temporary auxiliary machine ® carried outside the facilities (sludge removal/chemical injection pumps, centrifugal/belt dehydrator	1. Temporary dehydrator ® carried outside the facilities (collector, temporary dehydrator, chemical injection pump) 2. The existing centrifugal dehydrator was restored → carried outside the facilities (collector, dehydrator)	Some dehydrators were permanently restored. → carried outside the facilities (sludge removal pump, dehydrator)	
Recycled water		The sand filter was permanently restored. For the pump-shaft seal water, influent was filtered simply and used.	Industrial water is purchased.	No damage	Part of the sand filter was permanently restored.	
Instrumentation equipment		The water-level meters (influent ditch, pump well) and influent flow meters were restored. All the other instrumentation equipment was permanently restored.	The following were set up temporarily : pump well water level for the main pump, discharge tank water level. Sludge facilities : sludge storage tank liquid level, temporary chemical injection tank liquid level.	The influent flow meter was restored preferentially.	They restored the water level of the influent ditch and pump well, which is necessary for the operation of the main pump.	
Central monitoring facilities		The central facilities were undamaged. The central facilities of sludge treatment were permanently restored.		Some damaged devices were replaced with new ones.	Some functions were restored by using the simple monitoring device.	
Others				Sludge removal is performed by the telescopic gate. (No power is required.)	Power is supplied to the respective buildings via the electrical room on the 2nd floor, which was undamaged.	

Chapter 7 Proposal

EICA has conducted hearings and surveys about the tsunami disaster areas in Tohoku (northeast) Japan. Proposals from results and findings of the hearings and surveys will be covered in the following paragraphs.

1. Securing information sharing and transmission methods

In times of emergency, effective collection and sharing of disaster information is important. Therefore, there is a need to implement fiber-optic wire transmission network installed in sewer pipe and cloud sharing information databases for sewage treatment facilities.

2. Implementation of Business Continuity Plan (BCP)

Implementing BCP and emergency manual protocol allows problems of not only the times of disaster but also current situation and solutions to be identified easily. As for fallback operation of electrical and instrumentation systems, it will be effective to review BCP and document for such procedures.

3. Fallback operation of electrical and instrumentation system

During early stages of Great East Japan Earthquake disaster recovery, many electrical rooms were affected by the tsunami. Such rooms was backed up by separately located electrical rooms via temporary installed cables, where demand power was provided. At affected STPs, only the primary sedimentation treatment process was operated as tempory sewage treatment process, reducing the overall operation of STP. Therefore, there is a need for fallback operation of electrical and instrumentation systems to be developed.

4. Securing Power Supply

Usage of independent power supply such as solar cell and emergency generator should be encouraged, so as to reduce external power reliance. In times of emergency, it is important to secure the minimal power supply with independent power supply during long periods of blackouts. And as final power supply, it is important to install large scale storage batteries to make it certain.

5. Shifting of important electrical and instrumentation systems to the 2nd floor

According to surveys conducted, installations that were located on the 2nd level were apparently not affected by the tsunami. Therefore, it is important to shift installations such as central monitoring system, water treatment process and sewage treatment process monitoring systems, power supply systems, emergency power supply systems, etc to the 2nd floor to counter disasters such as tsunami, high tides and flooding. In addition, development of technical implementation methods of such installations on the 2nd floor is needed.

6. Water-proofing installations for electrical and instrumentation systems

Cases of installations with flood doors, situated on the 1st floor, were discovered to be able to reduce the effects of flooding. Installations which are unable to be installed on the 2nd floor should be provided with flood walls, flood doors, etc. For such installations, wiring shaft and pipe shaft should be tightly closed to prevent inundation. Thus, there is a need to develop methods of reducing the effects of floods on electrical and instrumentation systems.

7. Power lines, signal lines, etc installed underground

Utility poles supporting power lines, signal lines were destroyed by the tsunami, resulting in power disruptions and information disconnection. Therefore, it is important to install the cables underground.

8. Prevention of over discharge of lead storage battery

During disaster, there were many cases where lead storage batteries of emergency power supply over discharge and resulted in damages. Therefore, it is important to install warning devices where warning is given when storage batteries over discharge. In addition, storage batteries should automatically shut down just before or during times of over discharge.

9. Water-proofing of emergency generator system

Many emergency generator systems were damaged by the tsunami. Hence, it is important to waterproof not only generator itself but also auxiliary units, for example fuel supply pumps. In addition, such units should be earthquake proof as well.

10. Prevention of buoyancy damage by tsunami

During disaster, at each STPs, huge digestion gas tanks were damaged by buoyancy and washed away by the tsunami. In addition, air pipes and respective machines in pipe corridors were also damaged by buoyancy of tsunami. Therefore, it is needed to install suitable measures to prevent the damage of machines by buoyancy. Technical review of protecting such buoyancy phenomenon by tsunami is needed as well.

11. Ensuring safety of staff after earthquake

It is important consider ensuring safety of STP's staff. Fortunately, most of the people involved with the STPs survived the tsunami by finding shelter in the roof of the administration building. After earthquake and blackout, when emergency generator starts, staff should check local electric rooms in order to confirm normal operation. But in the case of Great East Japan Earthquake, on their way to check the electric rooms, the tsunami hit the STPs. Consequently, it is found that there is a need to revise the manual of emergency power supply procedure. In addition, alarm system and sound system are needed to be installed so as to effectively direct people concerned to safe evacuation zones.

12. Earthquake Procedure

Even though damage from this earthquake was not serious, procedures to handle earthquake disaster situation is still important. During Great East Japan Earthquake, collapse of shelves, chairs, Liquid Cristal Display (LCD) monitors disrupted monitoring operations in central control rooms of many STPs. Therefore, it is needed to ensure and implement measures where shelves, chairs, LCD monitors, etc are firmly rooted.

Afterword

First, a heartfelt thanks to all personnel from Miyagi Prefectural Government and Sendai City Government for the support given us during the disaster assessment held at the end of 2011. We have managed to complete this report with help in a questionnaire about the disaster and the condition of restorations, hearings, and STP investigation. To those who have done a tremendous job in rehabilitating the devastated sewage STPs to restore a decent level of operation, we pay our highest respect for all your hard work.

By going through this investigative research, we found that disaster can come in various ways. Throughout the history of Japan sewerage works, we have experienced various kinds of disasters such as land liquefaction during Niigata Earthquake (1964), an earthquake directly above the epicenter like Great Hanshin Awaji Earthquake (1995), and Niigata-Chuetsu Earthquake (2004) which caused the uplifting of sewage manhole. Crisis comes one after another. Now, for the first time, we have suffered the impact of a tsunami on STPs during Great Eastern Japan Earthquake.

The investigation was focused on electrical and instrumentation control systems of 4 large scale STPs in Tohoku district. We visited the sites and found out that various types of damages had occurred at each STP. Minami Gamo STP was directly hit by the tsunami while the Sen-En STP was swooped by sludge mixed with water from the nearby Sendai Bay. Because of this, different countermeasures had to be applied on each restoration work. For example, **Photo. 1** shows a damaged site where an inventive approach was needed to improve the conditions. They were able to make a temporary monitoring control system of the dehydrator in a short amount of time. **Photo. 2** shows a temporary sedimentation pond which was designed based on the experience from Niigata-Chuetsu Earthquake.

The fact that even the slightest difference in location can result in a totally different impact from a hit of Tsunami should be a crucial hint for disaster prevention in the future.

Throughout our investigation we have found a number of common grounds among all disaster cases. First is the occurrence of severe power shortage. Next is the fact that restoration work was oftentimes harder than expected. Third, most people who escaped into the administrative building were saved. Finally, machines such as dehydrators and central monitoring system which are usually located on the 2nd floor were hardly affected by the tsunami.

EICA has conducted the research based on the conditions described above, supporting rehabilitation works in electrical and instrumentation fields while learning to prevent the same effects of disasters from happening again.

Because of the catastrophe from Great Eastern Japan Earthquake which was caused mainly by the

Photo. 1 A temporary monitoring control system of dehydrator which consists of a notebook PC and instrumentation attached to card box. (Date Taken : October 2011 at Sen-En STP)

Photo. 2 A temporary sedimentation pond and discharge pump was installed near the watershed of the Kyuukitakamigawa River to treat sewage water right after the earthquake. (Date Taken : May 2011 at near Ishinomaki Tobu STP)

massive tsunami, most of the research and investigation were focused on it. However, the tsunami was not the only disaster that accompanied earthquakes. Lack of awareness on other prevention methods such as in ground shake prevention could be fatal. Moreover, the possibility of multiple impacts like land liquefaction, catastrophic fires and massive blackouts that happen in major cities should also be considered.

Regardless of the kind of disaster, information collection and resources for countermeasures against disaster should be arranged and prepared, putting the highest priority on saving human lives.

Torahiko Terada (1878～1935), a well-known physicist in Japan once wrote, "The meteorology and geophysical location of Japan is largely affected by the extremely unique environment surrounding it. As a result, one shall never forget that we are bound to the threat of catastrophe every single day."