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RESTORATIONS AND SYSTEM INTERACTIONS OF LIFELINES IN THE GREAT EAST JAPAN EARTHQUAKE DISASTER, 2011

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ABSTRACT: In the Great East Japan Earthquake Disaster, lifeline systems were severely damaged by ground shaking, liquefaction and tsunami. In this paper, restoration processes of lifelines including electric power supply, water supply, city gas supply systems and telecommunication systems are compiled on the basis of published data and press releases by the service providers and/or supervisory authorities. The scale and the duration of lifeline disruptions are compared with the Great Hanshin-Awaji Earthquake Disaster.

Key Words: Great East Japan Earthquake Disaster, lifeline systems, restoration processes

INTRODUCTION

Lifeline systems were severely damaged by ground shaking, liquefaction and tsunami caused by the 2011 off the Pacific Coast of Tohoku Earthquake, Japan (Mw=9.0). In this paper, restoration processes of lifelines including electric power supply, water supply, city gas supply systems and telecommunication systems are compiled on the basis of published data and press releases by the service providers and/or supervisory authorities. The scale and the duration of lifeline disruptions are compared with the Great Hanshin-Awaji Earthquake Disaster.

ELECTRIC POWER SUPPLY SYSTEMS

The initial outage of electric power supply was 8.91 million households. In the area provided by Tokyo Electric Power Company, 4.05 million households suffered power outage. However, the restoration was rapid; almost all the customers in Tokyo, Kanagawa, Gunma, Yamanashi and Shizuoka prefectures were restored by the next day of the earthquake. The completion of functional recovery was on March 13th in Saitama prefecture, March 14th in Tochigi and Chiba prefectures, and March 19th in Ibaraki prefecture.

In the area of Tohoku Electric Power Co., Inc., 4.86 million households in six prefectures (Aomori, Iwate, Akita, Miyagi, Yamagata and Fukushima) suffered power outage. Figures 1 and 2 show the restoration processes of electric power supply in each prefecture. The 90% and 95% levels of restoration (percent number of households restored divided by the initial outage) took six days and ten

days, respectively (four days and seven days including Tokyo Electric Power Company). Relatively rapid restoration was accomplished at the early stage as a result of rerouting operations and prompt recovery works of hierarchically higher facilities such as transmission lines and substations. The aftershock on April 7th (M=7.2) affected 4 million households and that on April 11th (M=7.0) affected about 200 thousand households in Fukushima prefecture again, but the restoration was very rapid.

The restoration in the tsunami-devastated area was extremely lengthy process. Figure 3 shows the number of household without electric power during about a month after March 21st. The causes are categorized into six: (1) public infrastructures and dwelling houses washed away by tsunami, (2) areas blocked by tsunami debris, (3) equipments inundated by tsunami and/or damaged by ground shaking, (4) no safety confirmation mainly due to absence of users, (5) ready to be restored but not yet, (6) no entry zones around the Fukushima Daiichi Nuclear Power Plant. Note that these categories had been recomposed during the period of time.

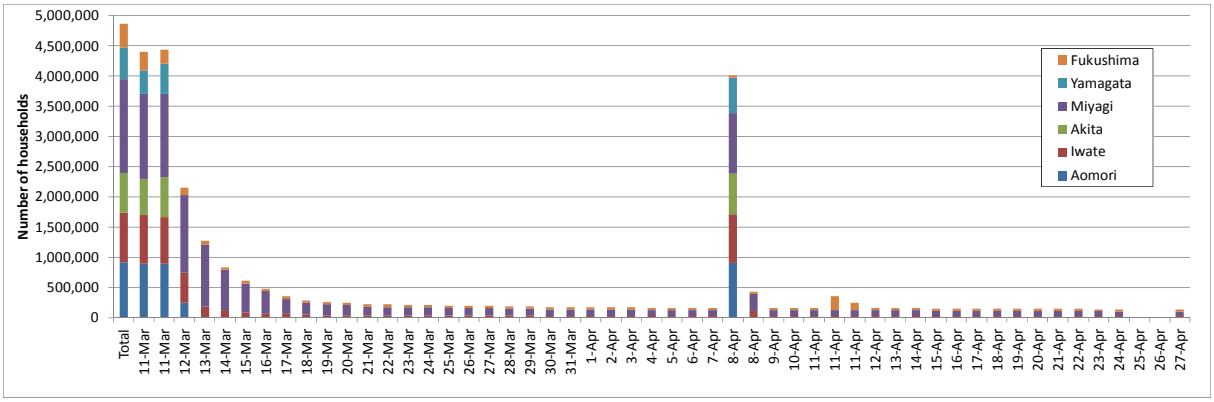

Fig. 1 Number of households without electric power supply (Tohoku Electric Power Co., Inc.)

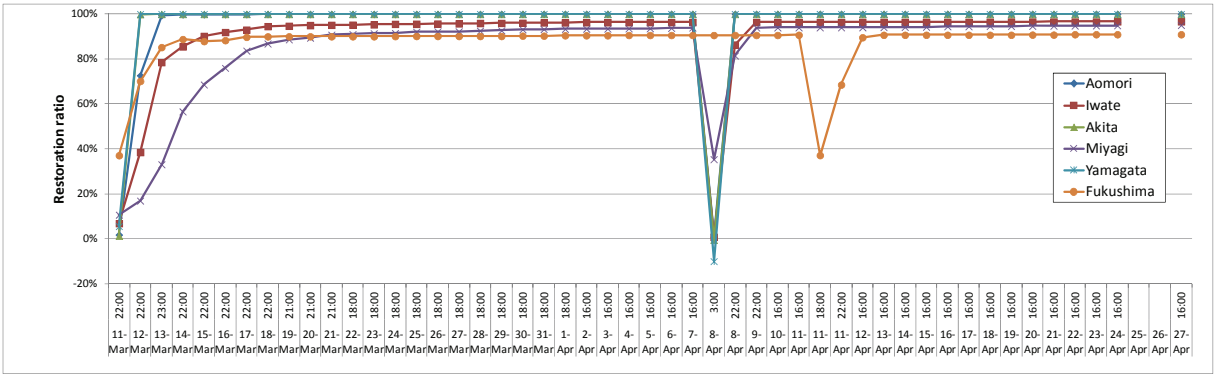

Fig. 2 Restoration curves of electric power supply function in affected prefectures (Tohoku Electric Power Co., Inc.)

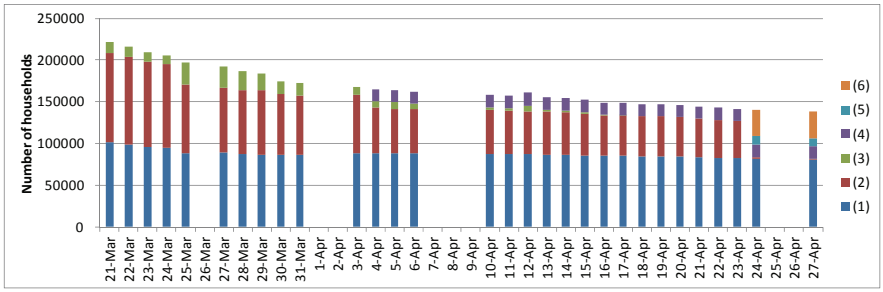

Fig. 3 Number of households without electric power categorized into six causes (Tohoku Electric Power Company Inc.)

WATER SUPPLY SYSTEMS

Water supply was disrupted at about 2.2 million households after the earthquake. Figures 4 and 5 show the restoration processes of water supply in each prefecture. Iwate, Miyagi and Fukushima prefectures have been most affected. The 90% and 95% restoration were achieved in 36 days and 41 days, respectively. Two major aftershocks on April 7th and 11th also drew back the restoration progress especially in Miyagi and Fukushima prefectures.

In Miyagi Prefecture, The Sennan-Senen regional water supply system takes water from Shichkasyuku Dam and Shiroishi River, and transmits to 17 municipalities in the central-south Miyagi prefecture. The Ohsaki regional water supply system takes water from Naruse River and Yoshida River, and transmits to 10 municipalities in central-nourth Miyagi prefecture. Large-diameter welded steel transmission pipelines of these trans-municipal water supply systems suffered major damage (16 and 51 breaks, respectively), which significantly hindered recovery work during a few weeks. The configurations of these water transmission networks are basically tree-like structures. Because of poor redundancy of tree networks, the downstream areas of the most upstream location of pipe failures lose water supply. Recovery works of the failed pipes had to be conducted from the upper part in order to restore connection between water sources to users. Therefore, remote areas from the water source experienced longer disruption of water. According to Miyagi Prefectural Government, two independent lines, serving high- and low-elevation areas, are planned to be connected and looped to enhance redundancy and improve reliability in case of disaster.

In Iwate Prefecture, restoration ratio as of ten days after the earthquake reached 50%, but the restored customers were limited to those in inland regions or northern coastal regions where tsunami disaster was relatively slight. Slow progresses of restoration thereafter reveal that recovery works in the tsunami devastated coastal regions were significantly hindered.

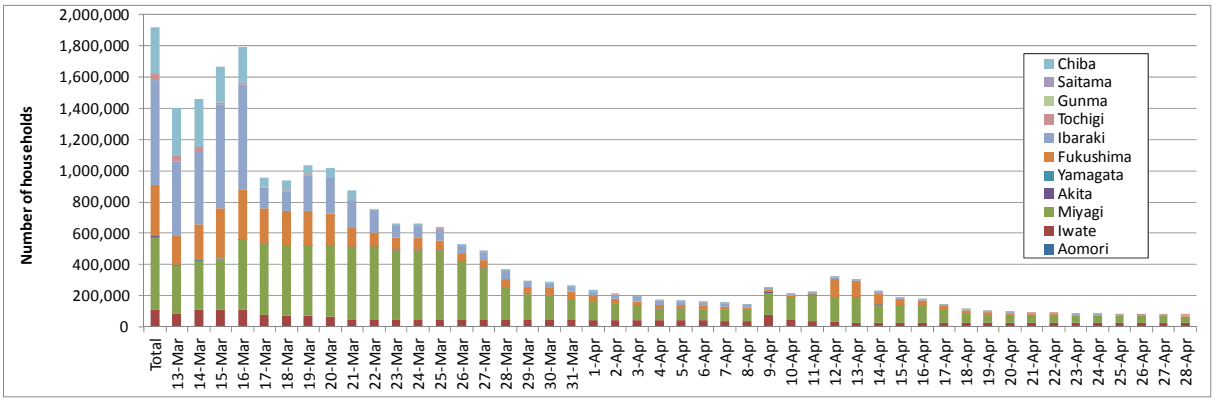

Fig. 4 Number of households without water supply

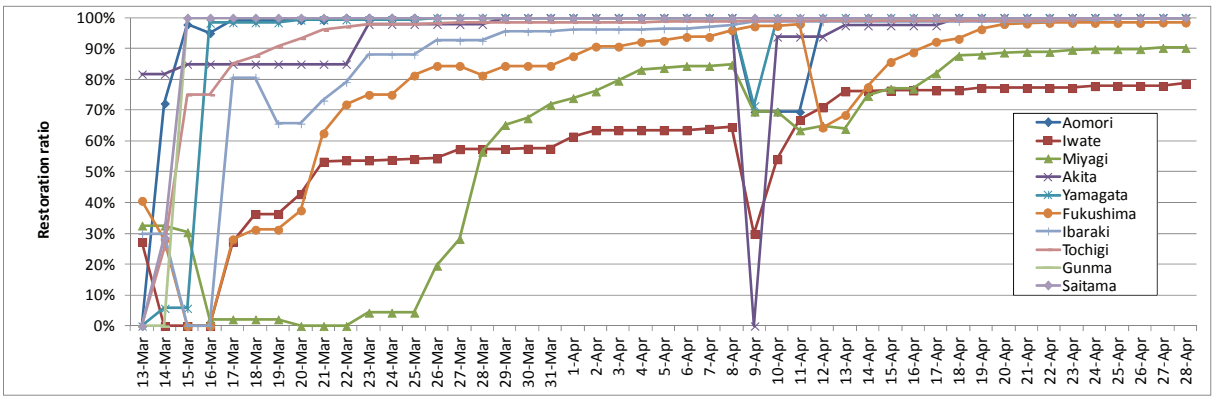

Fig. 5 Restoration curves of water supply function in affected prefectures

CITY GAS SUPPLY SYSTEMS

The service areas of city gas supply are limited to urbanized regions in Tohoku. In Tohoku and Kanto regions, 16 city gas suppliers sustained suffered damage and the initial outage was 459 thousand households in total. Figures 6 and 7 show the restoration processes of city gas supply in each prefecture. The 90% and 95% restoration were achieved in 35 days and 36 days, respectively. In Saitama, Kanagawa, Aomori and Ibaraki prefectures, restoration processes were relatively rapid; temporary restorations were achieved on March 12th, 13th, 16th and 24th, respectively. However, this accounts for only 10.3% on the number of customers basis. In Chiba prefecture, pipelines of Keiyo Gas Corp. suffered severe damage in Urayasu City due to liquefaction, and temporary restoration was completed on March 30th. In Iwate, Fukushima and Miyagi prefectures, completion days were April 11th, 15th and 25th, respectively.

The most affected supplier was the Gas Bureau of City of Sendai. The Minato LNG plant was devastated by tsunami, which was the main cause of the city gas outage at 359 thousand households (78.2% of the total outage). Fortunately, long-distance high-pressure pipeline network transmitting natural gas from Niigata Prefecture to Sendai performed well. Transmission of natural gas was shut off immediately after the earthquake at Shiroishi junction valve station. However, after completing safety inspection along the transmission line to Sendai including 15 valve stations the network system restarted its operation on March 23th, contributing to rapid recovery thereafter. Thanks to this operation, two disaster base hospitals in Sendai City were prioritized and immediately restored. Without the natural gas supply via high-pressure pipeline, recovery of city gas supply in Sendai City could have been much later.

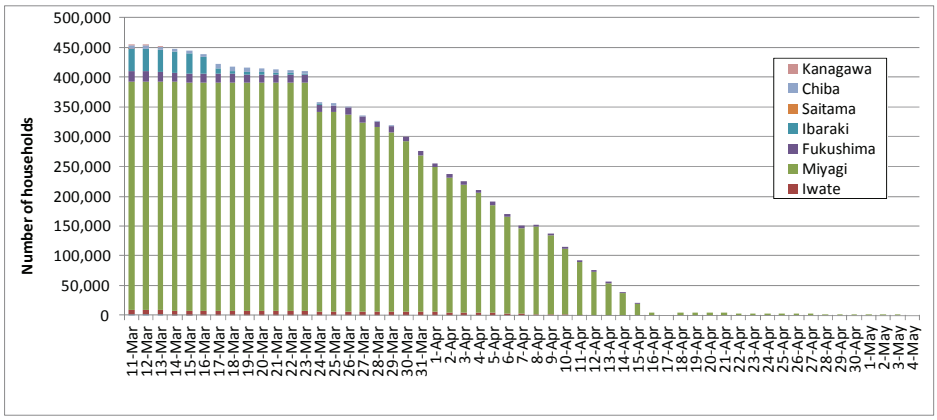

Fig. 6 Number of households without city gas supply

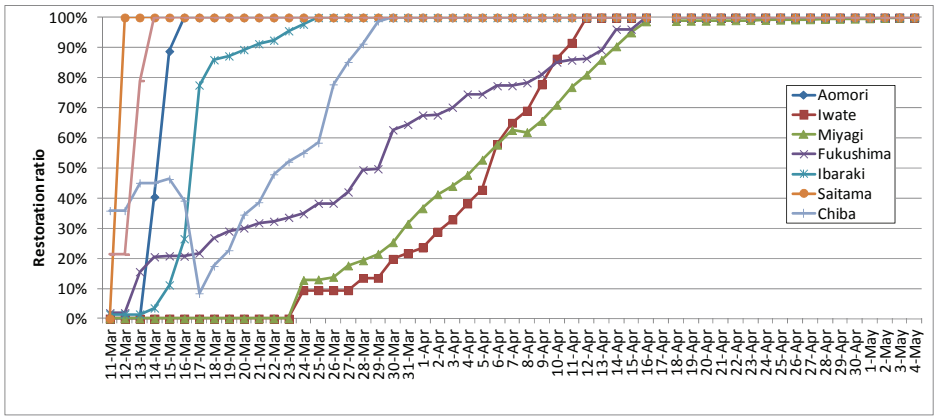

Fig. 7 Restoration curves of city gas supply function in affected prefectures

Figure 8 shows the restoration processes of telephone and telecommunication lines. Affected telephone and telecommunication lines peaked on March 13, i.e., two days after the earthquake, because of exhausted back up generators and batteries. About 1.52 million lines were out of service. The 90% and 95% restoration took 14 days and 25 days, respectively. About 70,000 lines were affected again on April 8th mainly due to power loss caused by the major aftershock on April 7th.

As for cellular phones, more than 13,000 base stations of three major service providers lost functions. Figures 9 and 10 shows the restoration processes of base stations of three major cellular phone companies. The 90% and 95% restoration were achieved in 19 days and 46 days, respectively. The rapid recovery of base stations at the early stage is congruent with that of electric power supply, which is a typical aspect of lifeline system interactions. Many base stations for cellular phones were damaged mainly because electric power supply units were inundated and/or washed away by tsunami, significantly hindering progress of recovery.

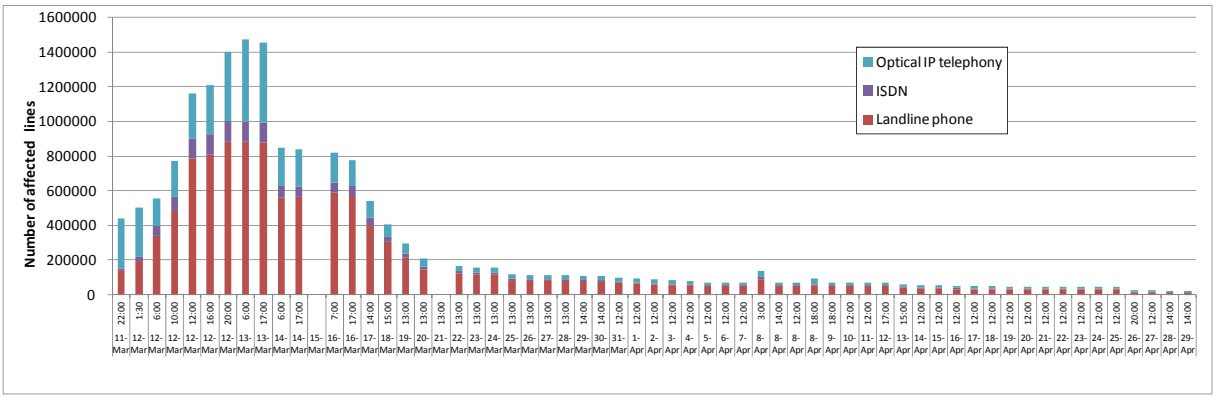

Fig. 8 Number of affected telephone lines (NTT East Corp.)

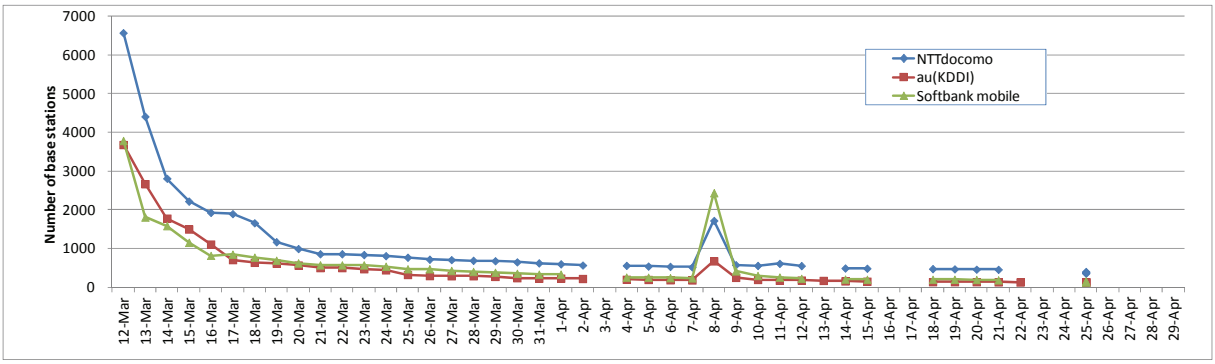

Fig. 9 Number of affected base stations for mobile phones of three providers

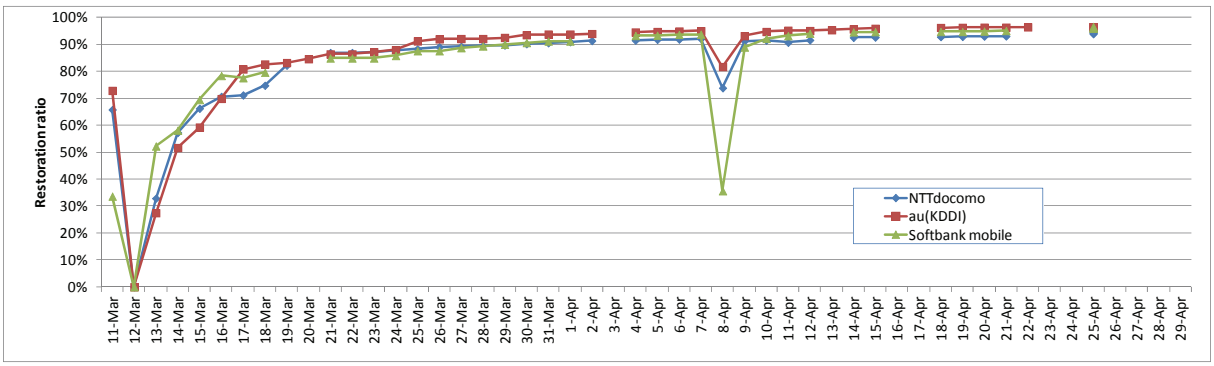

Fig. 10 Restoration curves of base stations for mobile phones of three providers

COMPARISON WITH THE GREAT HANSHIN-AWAJI EARTHQUAKE DISASTER

Figures 11 and 12 compare the number of households without utility lifelines (*E*: electric power, *W*: water and *G*: city gas) and associated restoration curves in the Great Eastern Japan Earthquake Disaster (GEJED) and Great Hanshin-Awaji Earthquake Disaster (GHAED). As for electric power in the Great East Japan Earthquake disaster, Tokyo Electric Power Company is excluded from the data. Ratios of initial outage (GEJED/GHAED) are 1.9 (3.4 if Tokyo Electric Power Company is included), 1.7 and 0.54 for *E*, *W* and *G*, respectively. The fact that spatial extents of initial damages are in the order of *E*, *W* and *G* is common to the two disasters. Also common is the fact that rapidness of functional recoveries are in the order of *E*, *W* and *G*. Moreover restoration curves are incidentally similar. However, it should be noted that the restoration of tsunami-devastated areas has been extremely lengthy process and still in progress in association with regional disaster recovery plans.

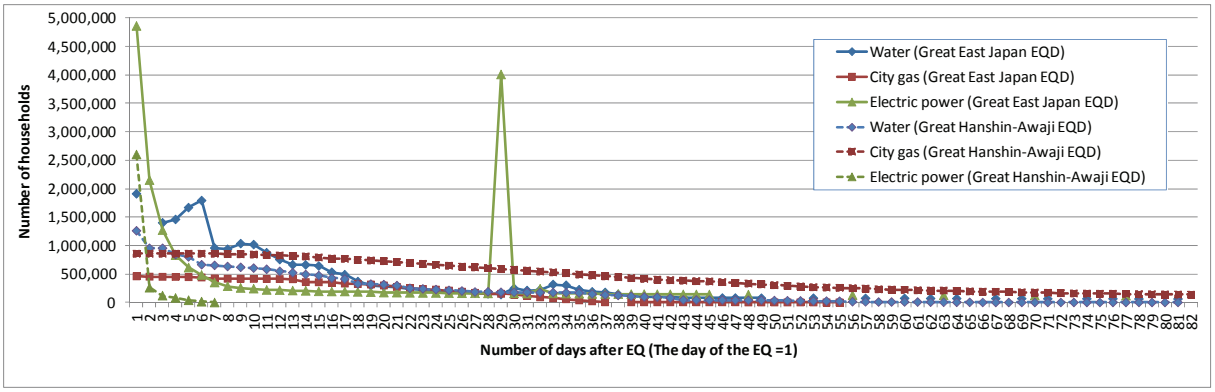

Fig. 11 Comparison of number of households without lifeline functions (Great Eastern Japan EQD and Great Hanshin-Awaji EQD)

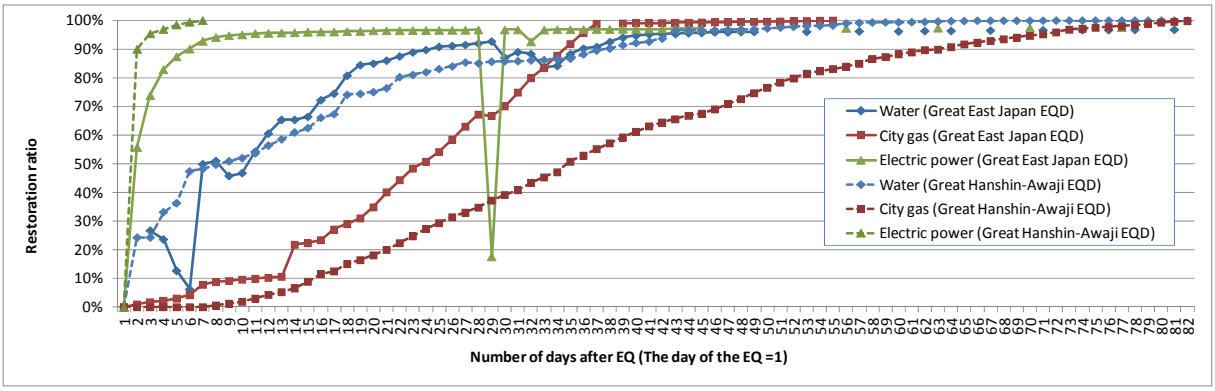

Fig. 12 Comparison of restoration curves (Great Eastern Japan EQD and Great Hanshin-Awaji EQD)

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