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Transportation and Telecommunications Infrastructure during Volcanic Eruptions on Inhabited Islands: The Cases of O-shima and Miyake-jima, Izu-Islands, Japan

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Key words: inhabited island, volcanic eruption, evacuation, shipping, telecommunications

Ⅰ Introduction

The Japanese archipelago is one of the most frequent earthquake occurrence zones in the world.[1)] There are also a large number of volcanoes in Japan, many of which are active. There are around 300 inhabited islands in Japan, of which around 15 are active volcanic islands (Nihon Rito Senta 2004). Residents of these islands face a constant risk of eruption disaster. When a large-scale volcano eruption occurs, volcanic bombs, ash, and lava flows damage the lives of those in the affected area. Especially in the case of an inhabited volcanic island, where the mountain occupies a major portion of the land and human settlements are located in limited flatlands, a volcanic eruption at the center of the island causes immediate human consequences. When a large-scale eruption occurs on a volcanic island, it may also be difficult to evacuate residents to destinations where they can avoid danger.

The transportation and telecommunications infrastructure forms the basis of economic activities and daily life not only on volcanic islands, but also across remote islands in general. After World War II, a special legislative framework to secure the sustainability of remote islands was widely recognized as necessary. The Japanese Government enacted the Remote Islands Development Act (RIDA) and other laws to promote the development of remote Japanese islands. As a result of investments under these legislative frameworks over more than 60 years, construction of essential infrastructure, such as remote-island shipping lines and airlines, and telecommunications infrastructure, such as submarine telecommunication cables and microwave radio networks, have progressed and substantially reduced the disadvantages of living on a remote island.

However, when a volcano erupts on an inhabited island, the transportation and telecommunications infrastructure is significantly damaged. On the other hand, demands for transportation and telecommunications services are increased markedly. These extreme situations may also indicate the essential role of the transportation and telecommunications infrastructure to the local society. Therefore, a close examination of these disasters can suggest the conditions for robust regional transportation and telecommunications infrastructure.[2)]

In this paper, the details of two large volcanic island eruption disasters in the Izu Islands of Tokyo, Japan are examined, with specific focus on the cases of Izu O-shima (O-shima) in 1986 and Miyake-jima in 2000. In both cases, all residents of each island were evacuated just after the eruptions. The evacuees numbered around 10,500 in O-shima and around 3,800 in Miyake-jima. No larger-scale evacuations than these can be found in the history of eruption disasters in Japan.

The Tokyo Metropolitan Government published the official records of the eruptions in O-shima (Tokyo-to 1988) and in Miyake-jima (Tokyo-to 2007). These official records, and the official histories by the transportation and telecommunications companies, were used to collect the details of these two disasters. Based on these materials, the desirable conditions for the transportation and telecommunications infrastructure on inhabited volcanic islands are discussed.

II Study area overview

1. Study area

O-shima and Miyake-jima belong to the Izu Islands, a 300 km-long island chain southeast of mainland Japan. In the central Pacific Ocean, about 800 km south of the Izu Islands, the Ogasawara Islands are the most remote from mainland Japan (Figure 1). Geologically, the Izu Islands are part of the Izu-Bonin-Mariana Arc on the boundary between the Pacific Plate and the Philippine Sea Plate. Many of the islands in this region have active and currently erupting volcanoes.

The Izu Islands consist of nine inhabited islands. Table 1 shows basic statistics on Izu

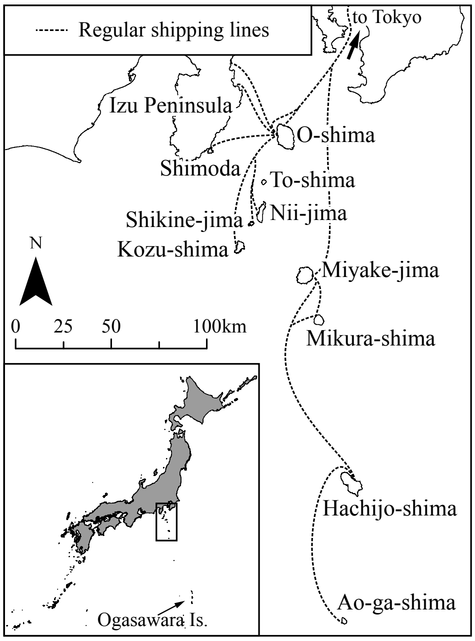

Figure 1. Regular shipping lines to the Izu Islands
(Source: Tokai Kisen 2017)

Table 1. Basic statistics of the Izu Islands (1995)

Island	Total Population (1995)	Percentage of the aged*	Household (1995)	Area (sq. km)
O-shima	9,693	22.8	4,117	91.1
To-shima	317	19.6	174	4.1
Nii-jima	2,560	27.4	923	23.9
Shikine-jima	603	26.5	253	3.9
Kozu-shima	2,276	18.4	777	18.9
Miyake-jima	3,831	24.0	1,722	55.5
Mikura-shima	275	18.2	161	20.6
Hachijo-shima	9,476	22.2	4,079	69.5
Ao-ga-shima	237	13.9	140	6.0
Total	29,268	22.7	12,346	293.4

Note:
* 65 years of age and over
Source: Nihon Rito Senta (2002)

Islands as of 1995, when the latest national population census was conducted before the evacuation of all residents from Miyake-jima. Around 30,000 residents lived on these islands, among which the three largest-populated are O-shima, Miyake-jima, and Hachijo-shima. These three islands also serve as transportation and telecommunications hubs. The portion of mainland Japan nearest to the Izu Islands is Izu Peninsula, Shizuoka Prefecture. Despite their locations, the Izu Islands are under the control of the Tokyo Metropolitan Government (Tokyo-to) due to a historic decision at the beginning of the Meiji era. At that time, the Japanese Government assigned the islands to Tokyo-fu, the largest local government in Japan, to overcome the islands' geographic difficulties (Tokyo-to Hachijo Shicho 2016; Tokyo-to Miyake Shicho 2006; Tokyo-to O-shima Shicho 2016).

O-shima is located in the northernmost portion of the Izu Islands, about 110 km from central Tokyo. O-shima has the largest area and population among the Izu Islands and is at the center of an administrative territory that includes four islands further to the south. It is also the site of the regional branch office of the Tokyo Metropolitan Government. Mihara-yama, arising in the center of O-shima, is an active volcano that has erupted repeatedly throughout history (Figure 2). The largest Mihara-yama eruption on historical record occurred in 1778. More recently, small- and medium-scale eruptions occurred in 1950, 1957, and 1974 (Tokyo-to O-shima Shicho 2016).

Miyake-jima is located around 70 km from O-shima and has the third-largest area and population in the region. Miyake-jima forms an administrative territory with Mikura-shima and is the site of the regional branch office. Oyama, at the center of Miyake-jima, is also an active volcano that has erupted repeatedly (Figure 3). In recent years, Oyama has erupted in 1940, 1962, and 1983. Lava flows were observed during each of these eruptions (Tokyo-to Miyake Shicho 2006).

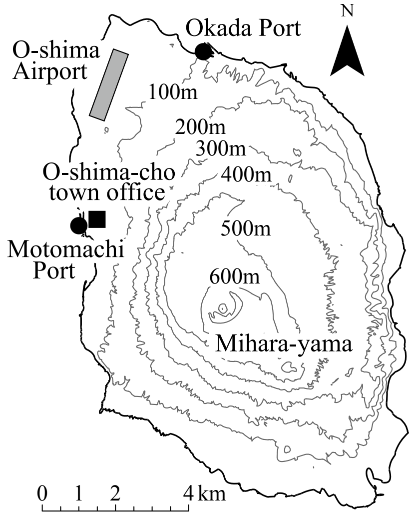

Figure 2. Map of O-shima

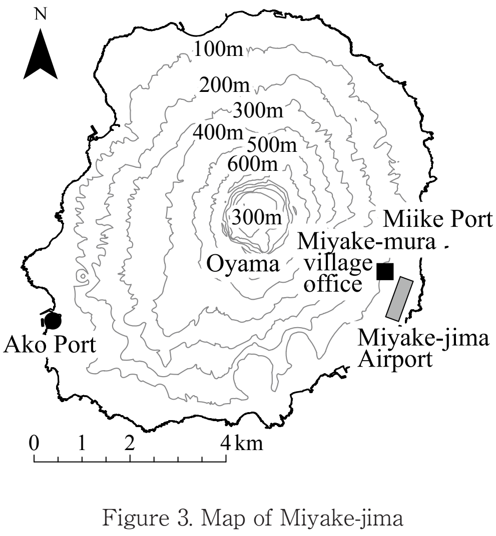

Figure 3. Map of Miyake-jima

2. Transportation infrastructure

The Izu Islands have a long history of human habitation. In the Edo era, about 150 to 350 years ago, premodern industries were developed in the islands and overseas traffic was opened via sailing ships (Tokyo-to O-shima Shicho 2016). Following the trend of modernization throughout Japan after the Meiji Restoration (1868), a Western-style shipping business was launched in the Izu Islands. From 1900 to 1907, Tokyo-wan Kisen Co. Ltd, headquartered in Tokyo, opened regular line services between Tokyo and the Izu Islands (excluding Hachijo-shima, the island furthest from mainland Japan). Postal services in the region were also begun using Tokyo-wan Kisen's regular line services. By around 1920, a regular shipping line to Hachijo-shima went into service, thus completing the marine Izu Islands' transportation network (Tokai Kisen 1970).

Subsequently, Tokai Kisen Co. Ltd, which was renamed from Tokyo-wan Kisen, reformed its shipping line operations. By around 1950, a regular line to the Izu Islands was completed and has remained relatively unchanged to the present day (Tokai Kisen 1970). Today, Tokai Kisen operates regular shipping lines between mainland Japan and the islands using passenger ships that are larger than 3,000 tons and high-speed boats. These passenger ships connect Tokyo and the islands within 6 to 10 hours and high-speed boats make the passage in 2 to 4 hours (Tokai Kisen 2017) (Figure 1).

3. Telecommunications infrastructure

Postal services to the Izu Islands started in the early 1900s, as described above. Telegraph services were also started at about the same time. In 1903, an initial submarine telegraph cable was laid between O-shima and Shimoda, the nearest point to mainland Japan. A direct submarine telegraph cable was laid between Tokyo and O-shima the following year. In 1906, submarine cables were completed between O-shima, Miyake-jima, and Hachijo-shima, and telegraph services became available throughout the Izu Islands (Nippon Denshin Denwa Kosha 1971). By 1925, radiotelegraph services had started operating in the region and became a major means of communications between Mikura-shima, Hachijo-shima, and mainland Japan (Nippon Denshin Denwa Kosha 1960). The first telephone services between the Izu Islands and mainland Japan were launched in 1934, when the local telephone network for O-shima was connected to the nationwide telephone network through the existing submarine telegraph cable (Nippon Denshin Denwa Kosha 1971).

After World War II, Nippon Telegraph and Telephone Co. (NTT) deployed telephone channels using VHF radio technology to the Izu Islands. By 1956, NTT completed a VHF telephone network that covered all of the islands (Nippon Denshin Denwa Kosha 1960). In stages during the latter half of the 1960s, NTT replaced the VHF radio channels in that region with microwave radio channels, greatly enlarging the capacity of the region's telecommunications network. NTT also constructed a submarine coaxial cable network between O-shima, Miyake-jima, and Hachijo-shima, providing telephone services to the Izu Islands (Nippon Denshin Denwa Kosha Kanto Denki Tsushin Kyoku 1968; Tokyo-to Miyake Shicho 2006).

After the O-shima eruption, NTT constructed an optical submarine cable network between mainland Japan, O-shima, Miyake-jima, and Hachijo-shima for high-speed telecommunications services (Figure 4). At the beginning of the 2000s, broadband Internet services were launched on the three islands using these optical submarine cables. However, the telecommunications routes to the other islands via the old microwave radio channels remained. Therefore, only low-speed Internet services were provided to the islands via old microwave radio channels (NTT Higashi Nippon 2005).

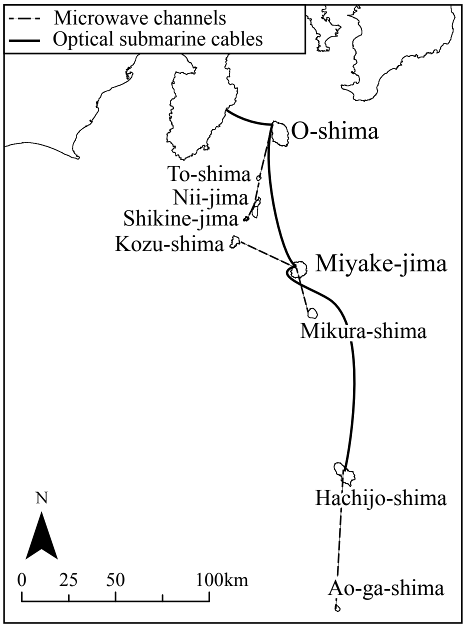

Figure 4. Telecommunications network in the Izu Islands
(Source: Tokyo-to 2007 and others)

III O-shima eruption disaster

1. Eruption and evacuation transportation of residents

At the center of O-shima, Mihara-yama is an active volcano that has repeatedly erupted. The first large-scale eruption of Mihara-yama occurred on November 15, 1986 and continued actively. On

Table 2. Number of evacuees transported from the night of November 21 to 0600 hours on November 22

Organization	No. of the evacuees	Percentage
Tokai Kisen	7,407	72.5
Japan Coast Guard	1,883	18.4
Japan Maritime Self-Defence Force	849	8.3
Others*	72	0.7
Total	10,211	100.0

Note:
* including the evacuees transported by aircrafts
Source: Tokyo-to (1988)

November 21, 1986, frequent explosions observed. Fissure eruptions began around 1600 hours, with enlarged fissures and lava flows close to several settlements. The local government of O-shima (O-shima-machi) issued an evacuation order to the residents of these settlements. However, as the eruptions became more active and emissions from several new volcanic fissures were observed in various parts of the island, the residents were unable to find safe refuge from the eruptions.

The local government finally issued an evacuation order to all island residents, when an unprecedentedly large evacuation was initiated around 2300 hours. The local government requested that the Japan Coast Guard, the Maritime Self-Defense Force, and Tokai Kisen transport evacuees. Tokai Kisen is a local private shipping company with the largest shipping capacity among these organizations. Tokai Kisen had prepared to operate evacuation ships before the evacuation order, based on their own analysis of the eruption conditions. At 1900 hours they began transporting tourists staying in the island to mainland Japan using high-speed boats. After the evacuation order was issued, the company also transported evacuees using two high-speed boats and two large passenger ships. By 0700 hours the next day, the final evacuation ship arrived at the mainland port. Including those transported by the Japan Coast Guard and other organizations, evacuation of all 10,211 island residents was completed in 12 hours, from the night of November 21 to the early morning of November 22 (Table 2). Tokai Kisen transported 7,407 evacuees.[3)] A small number of disaster-prevention staff members remained on the island (Tokyo-to 1988).

2. Electric power and telecommunications infrastructure

Tokyo Electric Power Company Inc. (Toden) supplies electric power to the Izu Islands (Table 3). Although the electric power supply to part of the island was interrupted on November 21, 1986 due to an earthquake caused by the eruption, the power supply was quickly restored. After that, no large-scale power outages occurred. When the evacuation order was issued to all residents, only three staff members of Toden remained to maintain the power plant operations. As the result of their work, the power supply to the island was maintained while residents were off the island.

When the Mihara-yama eruptions intensified,

Table 3 Electric power supply on the Izu Islands

Island	Power generation type	Max. power supply (kw)
O-shima	Diesel	15,400
To-shima	Diesel	720
Nii-jima	Diesel	7,700
Shikine-jima	Power line from Nii-jima	-
Kozu-shima	Diesel	4,500
Miyake-jima	Diesel	5,000
Mikura-shima	Diesel	600
Hachijo-shima	Diesel and geothermal	14,100
Ao-ga-shima	Diesel	640
Total		48,660

Source: Tokyo Shichoson Jichi Chosa Kai (2013)

telephone calls to O-shima increased dramatically. Because telephone traffic reached 5 to 7 times the ordinary level, NTT restricted telephone calls received on the island. However, no severe telecommunications system failures occurred because electric power was maintained. After the November 23 eruption calmed, NTT opened new telecommunications channels between the local government office, earthquake observation equipment, and branches of banking institutions. In addition, NTT reinforced the microwave telecommunications channel between O-shima and mainland Japan to respond to the large telecommunications demand during island restoration activities (Tokyo-to 1988).

IV Miyake-jima eruption disaster

1. Eruption and evacuation transportation of residents

Oyama, in the center of Miyake-jima, is an active volcano that has also erupted repeatedly. Oyama began erupting on June 27, 2000, for the first time in 17 years. After a brief quiescence, a large-scale phreatomagmatic explosion occurred on August 18. Beginning on August 29, volcanic gas was ejected in large volume from the burner at the mountaintop and cold pyroclastic flows swept down its flanks. The local government of Miyake-jima (Miyake-mura) first started evacuating schoolchildren and the elderly in need of care. However, because larger eruptions were expected to continue, the local government finally issued an evacuation order to all residents on September 2. The evacuation of 3,700 residents to mainland Japan was completed on September 4 using Tokai Kisen's regular line passenger ships. Disaster-prevention staff members from the Miyake Branch of the Tokyo Metropolitan Government, the Miyake-mura government, Toden, and NTT Higashi Nippon (NTT-East), a regional subsidiary of NTT, continued to work from a Tokai Kisen passenger ship that stayed near the island, because volcanic gas ejections continued, after which they moved to Kozu-shima and continued their work. The evacuees stayed in shelters in mainland Tokyo. The evacuation order was continued for more than five years until it was finally lifted in February 2005 (Tokyo-to 2007).[4)]

2. Electric power and telecommunications infrastructure

After the evacuation of all residents to mainland Japan, Toden maintained the power supply throughout the island. However, the ejection of volcanic gas increased significantly on September 26, 2000 and the power supply to the entire island was interrupted when all Toden staff members were evacuated. The power outage

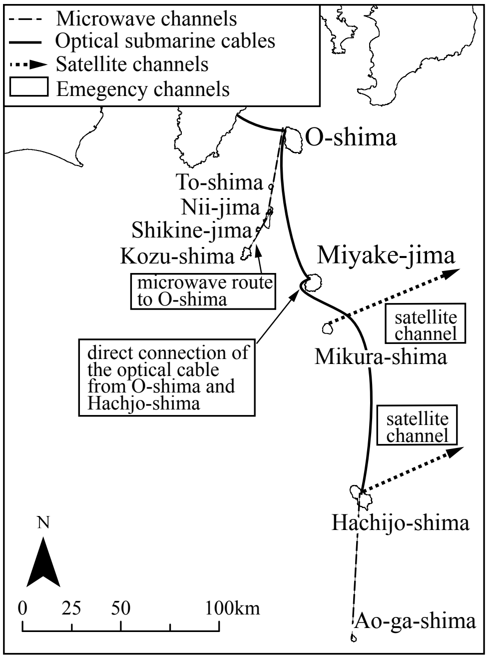

Figure 5. Emergency telecommunications network at the Miyake-jima eruption disaster
(Source: Tokyo-to 2007 and others)

continued long-term because the volcanic gas ejection did not abate. In the spring of the next year, the volcanic gas ejection decreased gradually and Toden resumed partial power supply to the island. However, the island's power supply outage continued until November 2004.

NTT-East maintained telecommunications services using its own emergency power generation after the commercial power supply outage. However, NTT-East could not keep up a power supply because the emergency generators could not be maintained. The entire telecommunications system in Miyake-jima was finally suspended on December 27, 2000.

Optical submarine cables from mainland Japan and Hachijo-shima were landed at Miyake-jima. These two cables were relayed at NTT-East's station on the coast of Miyake-jima. Microwave channels to Kozu-jima and Mikura-shima were also connected to the station. Therefore, if the relay station in Miyake-jima was suspended, almost all telecommunications services to the surrounding islands connected with the Miyake-jima relay station were cut off. NTT-East temporarily connected the two optical submarine cables without any relay equipment on the coast of Miyake-jima to avoid interruption of telecommunications services in Miyake-jima and the other islands, allowing the O-shima and Hachijo-shima stations to communicate directly. NTT-East also set up emergency portable microwave radio devices in Kozu-shima, Sikine-jima, and Nii-jima to retain telecommunications channels between these islands and O-shima. For aviation communications between Hachijo-shima and mainland Japan, an emergency satellite communication channel was opened. In addition, NTT-East brought a satellite communication car to Mikura-shima to provide a channel between the island and mainland Japan (Figure 5). Consequently, at least basic telecommunications services were maintained to all islands.

NTT DOCOMO Inc., a leading mobile phone company in Japan, interrupted its services in Miyake-jima and Mikura-shima after power supply outages because it used NTT-East's leased telecommunications lines. Thus, services in Mikuka-shima were temporally interrupted until NTT DOCOMO recovered them using an emergency satellite station in Mikura-shima (Tokyo-to 2007; NTT Higashi Nippon 2005).

V Discussion

In this section, lessons from the experiences in O-shima and Miyake-jima, and comparisons between these eruption disasters, are discussed.

1. Transportation infrastructure

The basic off-island transportation method from both O-shima and Miyake-jima was via ships. Although both islands have air routes to mainland Japan, it is difficult to operate passenger aircraft in the vicinity of a volcanic eruption. In fact, in both cases, ships transported almost all evacuees (except for a few individuals who were conveyed by helicopter). Especially in the case of the O-shima eruption, it was necessary to evacuate more than 10,000 people to mainland Japan within around 10 hours. Ultimately, 44 ships in total were used to transport evacuees. Tokai Kisen operated all of its passenger ships and high-speed boats, transporting 70.5% of evacuees.

Tokai Kisen is the only shipping company that operates in the Izu Islands, and its operation area covers the entire area. Because Tokai Kisen provides passenger services for a large number of tourists during the summer season, it owns several passenger ships with a capacity of more than 2,000 passengers, and operated three passenger ships in the O-shima evacuation. The company also owns several high-speed boats, which could travel between mainland Japan and the islands. Two high-speed boats were used to shuttle 400 evacuees per launch.

In the Miyake-jima eruption, the evacuees could use the regular ship line because there were fewer than 4,000 residents with sufficient evacuation time.

The presence of a shipping company that had thorough knowledge of the island's details and sufficient transportation capacity was a key factor in preventing large-scale human casualties in both the O-shima and Miyake-jima eruptions. At the time of the O-shima eruption, Kokai Kisen possessed four passenger ships (permitted to carry a total of around 8,600 passengers) and two high-speed boats (permitted to carry around 800 passengers). The total passenger capacity of Tokai Kisen of 9,400 passengers was almost equal to the entire population of O-shima. Therefore, Tokai Kisen could transport almost all residents on the islands by launch to its ships. More than one evacuation journey for a passenger ship was not realistic, because a single trip from O-shima to mainland Japan via passenger ship took around two hours. In fact, three passenger ships were used for evacuation and one was ordered only to be ready. If the local shipping company's transportation capacity had been insufficient, the evacuation may have required many more hours.

During a large-scale evacuation such as that of O-shima, the transport organization is required to take proper steps to respond to the situation. In addition to shipping services, Tokai Kisen operated bus services in O-shima and could grasp the overall situation on the island through local staff members of the bus service network. During the major eruption of Mihara-yama, it immediately ordered buses to be ready. Simultaneously, it started to prepare for evacuations via ship. Therefore, the first evacuation ship arrived at the port of O-shima only one hour after the eruption. Later, the bus and ship departments of Tokai Kisen managed the evacuation in cooperation. Consequently, the bus and ship transportation of the evacuees was conducted smoothly.

2. Telecommunications infrastructure

The telecommunications situation differed significantly from the transportation situation in both disaster cases.

Limited numbers of telecommunications facilities were damaged in both cases. The damage was not serious, and the telecommunications company was able to recover its operations. The telecommunications company was also able to maintain telecommunications services and respond to the greatly increased communication demands required for the evacuation of residents.

In the case of O-shima, a minimum number of electric power company operation staff members were able to maintain the commercial electric power supply, allowing the telecommunications company to ensure services.

The situation in the Miyake-jima eruption was in stark contrast to the O-shima eruption. When the commercial power supply was suspended, the telecommunications company was able to maintain operation of its telecommunications stations using its own emergency power generators. However, they were forced to give up emergency power generation. The entire telecommunications system in Miyake-jima was suspended three months after the evacuation.[5)] However, there were no severe consequences in Miyame-jima, because all residents had been evacuated from the island. The biggest challenge at that time was to secure the telecommunications lines connected to the Miyake-jima relay stations for public services to the surrounding islands. The telecommunications company was able to maintain minimal services via directly connecting the optical submarine cables, emergency microwave radio channels, and satellite channels. The mobile phone company avoided interruption of its services by using an emergency satellite communication channel. However, public telecommunications services in the southern part of the Izu Islands was necessarily reduced until full recovery of the telecommunications system in Miyaka-jima.

A primary cause of this difficulty was that the telecommunications company did not foresee the electric power outage for several months and could not respond to such conditions. However, an underling cause was also a star-shaped telecommunications network configuration that included unalterable relay points on the island. A star-shaped network necessarily loses whole-network function when a relay node is damaged. In the telecommunications network across the Izu Islands, the telecommunications company decided to place unalterable relay stations on a small island with a repeatedly active volcano. This decision underestimated the risk of volcanic eruption on the island.

Experiences with the volcanic disaster on Miyake-jima provided important lessons about robust telecommunications infrastructure configurations on the island. The telecommunications company subsequently took measures to cope with eruption risks. A new, direct optical submarine cable was laid in 2008 to duplicate the communication routes between Hachijo-shima and mainland Japan. At present, optical submarine

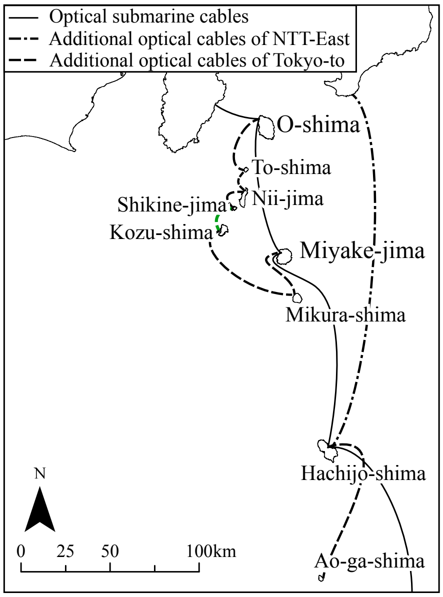

Figure 6. Additional optical submarine cables in the Izu Islands
(Source: Tokyo Metropolitan Government internal documents)

cables between Hachijo-shima and mainland Japan are part of the telecommunications route to the Ogasawara Islands, where many central Pacific Ocean meteorological and astronomical observation stations are located. Therefore, it is quite important for the whole of Japan to reduce the fragility of the telecommunications routes between Hachijo-shima and mainland Japan.

The Tokyo Metropolitan Government has recently constructed a new optical submarine network in the Izu Islands to duplicate the optical telecommunications routes and ensure telecommunications services in that region. Although the Miyake-jima eruption caused marked damage to the islands, its lessons have been used to improve the telecommunications infrastructure (Figure 6).

3. Vulnerability on an inhabited volcanic island and robustness of the transportation and telecommunications infrastructure

A number of studies based on the concept of vulnerability have been conducted in the field of disaster science. Wisner et al. (2004: 55) defined “vulnerable” people as those who “…live in or work under unsafe conditions”.[6] A volcano brings “unsafe” conditions to the residents in the adjacent areas in general. It is especially difficult to find a safe place on a small volcanic island. The residents of such islands usually experience an underlying sense of vulnerability.[7] During a large-scale eruption on a small volcanic island, the risk of human casualties must be reduced above all else. To do so, transportation infrastructure that enables swift evacuation from the island should be ensured. Ships are easier to operate on such occasions than airplanes, which are strongly affected by the weather (Shimizu 2012). Shipping is very robust in the face of eruptions on volcanic islands. During the disaster evacuations that are the focus of this paper, it was fundamental to their success that the local shipping company had sufficient transportation capacity.

On the other hand, some social factors may support the smooth transport of evacuees. None of the social fragmentation pointed out in many studies on disaster vulnerability can be found in the societies of the islands discussed here. In addition, ports and local roads on most Japanese islands are in good condition because of the Japanese Government policies mentioned above.[8] The Japanese Government has also subsidized the operation of ship lines between remote islands and mainland Japan, and has financed the construction of new ships for remote island ship lines (Nihon Rito Senta 2004). Because of this governmental support, most remote island ship lines have a large shipping capacity, despite their low profitability. This national policy led to Tokai Kisen possessing a large transportation capacity relative to the total population in the region.

By contrast, there was a lack of robustness in the telecommunications network in the region. When the Miyake-jima eruption occurred, the entire telecommunications system on Miyake-jima was suspended because of an electricity power supply outage, and the telecommunications services on all the southern Izu Islands faced the risk of disruption. The effect of a local obstruction to the telecommunications system tends to extend to the entire network, unlike the transportation system, which has high operational flexibility. There is no other means to ensure the robustness of a telecommunications system than multiple routing. Before the Miyake-jima disaster, the telecommunications company's investment in network improvement had been delayed because the risks were not recognized. This delay caused the telecommunications crisis in the region during the Miyake-jima eruption.

As these disasters show, the social vulnerability of the Japanese volcanic islands is rather low, and the robustness of the transportation infrastructure has been ensured. However, weaknesses in the telecommunications infrastructure were not remedied until recently.

VI Conclusions

In this paper, experiences with two large, recent volcanic eruptions on inhabited Japanese islands were examined to determine the conditions for a robust transportation and telecommunications infrastructure. The eruption disasters on Izu O-shima in 1986 and Miyake-jima in 2000 were examined. In both cases, all residents were evacuated from the islands immediately after the eruptions. There were around 10,000 evacuees from the O-shima eruption and around 4,000 from the Miyake-jima eruption. No similar large-scale evacuations can be found in the history of eruption disasters in Japan. The official records from these two eruption disasters were analyzed to identify robust transportation and telecommunications infrastructure conditions in the event of volcanic eruption on an inhabited island.

The results show: 1) In the case of the O-shima eruption, more than 10,000 residents could be evacuated within around 10 hours, primarily via ships owned by Tokai Kisen, a local commercial shipping company. The presence of a local shipping company with thorough knowledge of the island's details and a capacity to transport a large number of passengers was a key factor in preventing large-scale human casualties; 2) In the case of the Miyake-jima eruption, the entire telecommunications system for the island was suspended by a long-term power failure. Public telecommunications services in the southern Izu Islands were largely reduced due to the telecommunications interruption on Miyake-jima. An underling cause of this problem was a star-shaped telecommunications network configuration that included unalterable relay points on an island with an active volcano. In the Izu Islands, this telecommunications network's weakness has recently been reduced by duplicating the telecommunications routes. Experiences with these inhabited island volcanic eruption disasters have been used to make infrastructure improvements.

In general, social vulnerability on Japanese volcanic islands is rather low and transportation infrastructure is robust. However, fragility remained in the telecommunications infrastructure until recently.

Acknowledgments

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Notes

1) The Great East Japan Earthquake occurred and caused great damage to eastern Japan in 2011.
2) Telecommunications conditions in disaster areas have been studied by Marchetti (2010). However, these studies focused to disasters caused by tropical cyclones and earthquakes. Few studies mention volcanic disasters.
3) Mochizuki et al. (1987) studied the challenges related to accepting the O-shima evacuees by the municipalities in the Tokyo Metropolitan Area.
4) Takagi and Seto (2014) discussed the impacts of the long-term evacuation on Miyake-jima industries.
5) Kwasinski (2010) examined the challenges of electric power supply for continuous telecommunications operations. However, that study did not discuss volcanic disasters.
6) A range of opinions about the scope of "vulnerability" can be found across research fields. Many anthropologists claim that the concept of vulnerability should be applied to people and society (Wisner et al. 2004; Watts and Bohle 1993). However, researchers in civil engineering and architecture tend to widen the scope of vulnerability to buildings and infrastructure (Ieda 2011; Ieda and Park 2012).
7) Wisner et al. (2004) analyzed the eruption of Montserrat, which is a small island in the Lesser Antilles in the Caribbean. The size of Montserrat, with an area of 102 km^2 and a total population of about 12,500, is almost same as that of O-shima.
8) The RIDA has contributed to the budgets for public works in remote islands, such as ports, airports, roads, electricity and water supply. Since the RIDA was enacted about 60 years ago, two-thirds of the total budget for public works has been invested in transportation infrastructure.

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(J) written in Japanese

(J/E) written in Japanese and English

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