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INITIAL SURVEY RESULTS: 2011 TOHOKU PACIFIC EARTHQUAKE

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(*CUEE Newsletter No.11*—2011 Tohoku Pacific Earthquake)

Strong Motion Characteristics and Aftershock Observations

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The massive earthquake that hit the Pacific coast of the Tohoku region on March 11, 2011, with an extremely large magnitude of 9.0, shook wide areas within the Tohoku and Kanto regions. This paper reports on observed characteristics of its strong motion records as well as on findings related to observation of its aftershocks.

Figure 1 shows velocity waveforms recorded at strong motion observation stations along the Pacific coast of the Tohoku region. The figure shows that the fault rupture occurred over a distance of up to 500 kilometers north-south, emanating seismic waves over a long period, thereby causing large-amplitude portions to persist for a long time. In particular, two distinct wave packets originated offshore from Miyagi Prefecture. Another distinct phase subsequently propagated offshore from Ibaraki Prefecture. It is believed that these phases reflect a complex slip on the fault plane (National Research Institute for Earth Science and Disaster Prevention, 2011, among others).

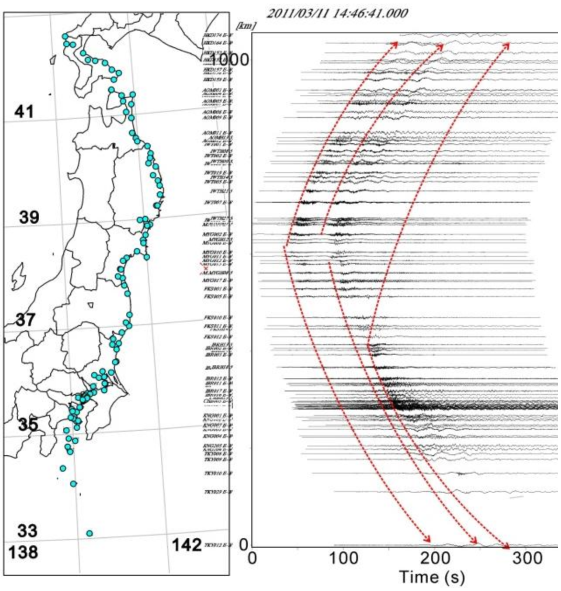

Figure 1: Strong motion records of main shock (velocity, east-west)

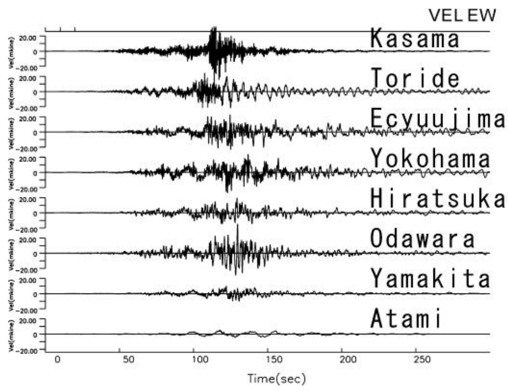

Figure 2: Velocity records for Tokyo Metropolitan Area

As such long-lasting seismic waves traveled through the Tokyo Metropolitan Area, their long-period components became conspicuously predominant. This is because of the thick sedimentary layers of the Kanto plain. Even within the Kanto plain, seismic motions assumed different characteristics at different locations, as Figure 2 shows. These long-period ground motions shook skyscrapers in the Tokyo area to an extent visible to an outside observer.

The maximum intensity of 7 (on the Japanese seismic intensity scale of 0 to 7) was observed at more than one location during the March 11 quake. One such is Tsukidate in Miyagi Prefecture, where a peak ground acceleration of 2.7G was recorded. As Figure 3 shows, an acceleration of far larger than 2G was recorded briefly at the beginning of the second wave packet. But there was no major damage involving collapsed buildings in the neighborhood of the Tsukidate strong motion station. Also shown in Figure 3 are acceleration time histories of the Hyogoken-nanbu Earthquake that hit the city of Kobe and its vicinity in 1995 (recorded at Kobe) and the Chuetsu Earthquake of 2004 (recorded at Kawaguchi town, Niigata Prefecture), both of which marked an intensity of almost 7. It becomes notably clear how strong and how long the March 11 jolt was when compared with these earlier records. Figure 3 also presents a comparison of velocity response spectra of these three major quakes, underscoring the fact that short-period components of around 0.2 second were conspicuously predominant at Tsukidate. Periodic components of approximately 1 second were greater in the Hyogoken-nanbu Earthquake. These differences in periodic components likely explain why the March 11 quake did not cause great damage in the Tsukidate neighborhood (Sakai, 2001, and other recent reports).

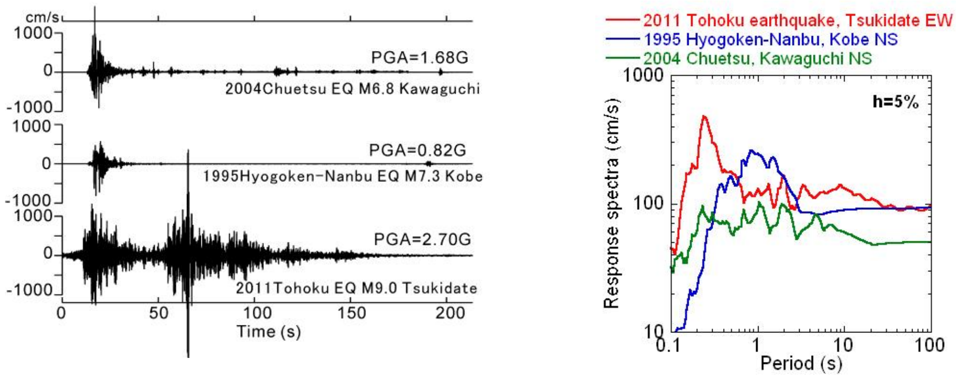

Figure 3: Acceleration time histories of past strong motions and a comparison of velocity response spectra

To gain a better understanding of what caused those short-period seismic ground motions, we continued to observe aftershocks in the neighborhood of the Tsukidate station. As the photo in Figure 4 shows, the strong motion station is located at the edge of a cut. Also shown here are spectral ratios of S-waves for firm soils obtained from aftershock records at sites above and within the cut. The site within the cut, where shallow, surface soils have been removed, shows a rather flat spectral ratio. Above the cut, by contrast, short-period components were predominant just as in the main shock. Normally, nonlinear soil response gives rise to certain differences between a main shock and any aftershocks, but it is believed that at the Tsukidate strong motion station, short-period components were greater under the influence of shallow soils.

As we have seen, broadband ground motions, extending from short-period to long-period motions, were observed at many locations during the Tohoku Pacific Earthquake. Further technical studies are being made of the earthquake, from such aspects as fault rupture process, propagation of long-period seismic motion, amplification in shallow soils and non-linear soil response, in order to shed light on these complex and varied strong motion records.

The strong motion records used in this paper are from the K-NET and KiK-net strong motion stations. I gratefully acknowledge their having been made available.

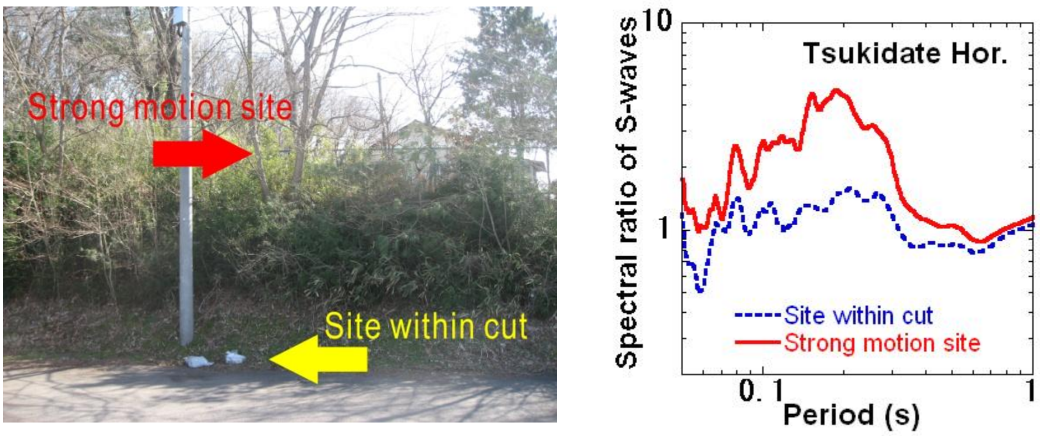

Figure 4: Tsukidate strong motion site and its neighborhood, and spectral ratios of aftershocks for firm soils

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Damage to Geotechnical Structures

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The 2011 Tohoku Pacific Earthquake of March 11 caused extensive damage due to soil liquefaction, triggering major deformation and eventual collapse of levees, roads, railways and landfills—as well as settlement of reclaimed land. This report focuses on damage to levees and seeks to offer an overview of how they were affected.

Levees suffered damage from earthquake-induced liquefaction in wide areas along the Pacific coast in the Tohoku and Kanto regions of northeastern Japan. Figure 1 shows locations at which emergency repair work was carried out at levees along major rivers under direct management of the central government. In the Tohoku region, damage was especially conspicuous in the Osaki plain (an alluvial plain formed by flooding of the Naruse and Eai rivers) in northern Miyagi Prefecture. In the Kanto region, the lower reaches of the Kuji, Naka and Tone rivers were all notably affected.

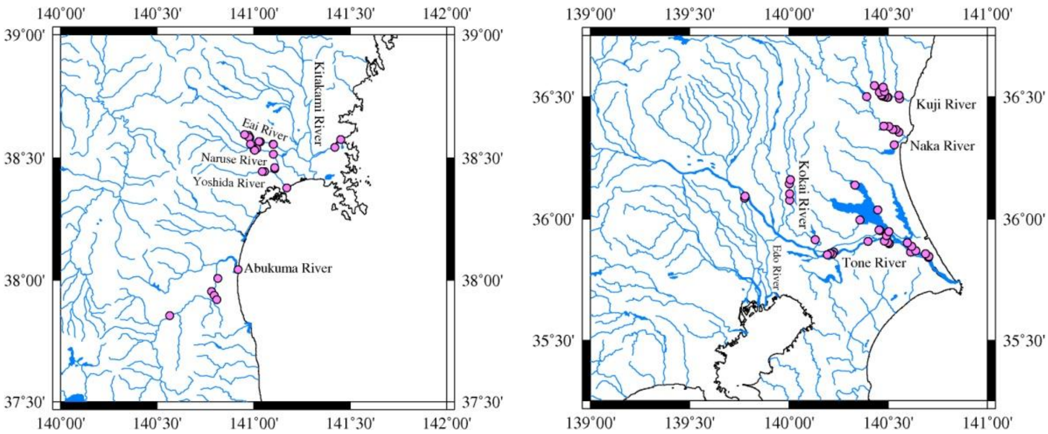

Figure 1: Sites where emergency levee repairs have been carried out along rivers managed directly by the central government (Left map: Tohoku region; right map: Kanto region)

River levees may be damaged by liquefaction in two ways: one pattern involves liquefaction at the foundational level, while the other results from liquefaction of the lower portion of the levee itself. The former is a typical form of earthquake-induced damage to levees, which occurs when foundation ground has liquefied to such an extent it can no longer support the levee, causing settlement or resulting in longitudinal cracks. Photo 1 shows one such example. A levee along the Eai River, which was built on land reclaimed from a former river channel, settled due to liquefaction. At the same time, several broad longitudinal crevices more than 2 meters deep were formed. Along the former river channel, which stretches from the site depicted in the photo to the Shin-Eai River to the south, sand boiling and resultant uneven settlement of houses were observed in many places. Emergency repairs removed paving and brought in provisional fill, with the slopes protected by articulated concrete mats. When the author visited the area for the second time after the earthquake, the emergency repair work dating to April 4, 2011, had already been completed.

The second common pattern of damage normally occurs where a foundation consists of clay or other types of soft soil that do not liquefy, yet where such ground has subsided considerably over time as a result of levee construction, leaving the lower level of the levee exposed to liquefaction. This pattern has only rarely been reported in past earthquakes, but occurred in several different places in the course of this year's March earthquake. Photo 2 shows an example. The levee built to protect reclaimed land settled more than 1 meter, producing a number of wide, longitudinal cracks. The site's clay foundation was approximately 10 meters deep and apparently did not liquefy. The main cause of damage, therefore, must have been liquefaction of the levee itself.

Photo 1: Levee along the Eai River having subsided due to liquefaction of its foundation (At Furukawa-Fukunuma in Osaki City, Miyagi Prefecture: Right Levee at River Kilometer 26.8). Left: before repairs (view from opposite bank, March 14, 2011); Right: after restoration (April 22, 2011)

Damage of this sort due to liquefaction of the levee body was relatively conspicuous in the March earthquake. This suggests that to mitigate levee damage caused by liquefaction due to earthquake, measures to counter liquefaction of the levee, such as off-drainage of water from the levee in conjunction with control of water seepage in time of flood, should be carried out in addition to measures to counter liquefaction of foundations.

Photo 2: Levee along the Hinuma River having subsided due to its liquefaction. (At Shimoishizaki in Ibaraki town, Ibaraki Prefecture: Left Levee at River Kilometer 8.) Left view: damaged area of section under prefectural management; right view: repairs undertaken by central government. (Both April 13, 2011.)

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Damage to Local Buildings from Tohoku Pacific Earthquake

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Having carried out field surveys of damage to various types of buildings following the 2011 Tohoku Pacific Earthquake, with particular attention to local schools, this author received the impression that the number of such structures severely damaged by seismic ground motion per se was surprisingly small given the scale of the earthquake. Nevertheless, overall damage was considerable and we here report some preliminary findings.

Photos 1 to 3 show examples of damage to a school gymnasium. Photo 1 exhibits damage to a column base, where anchor bolts connecting the column to its foundation extended and ruptured. These had apparently been designed as pin connections. However, when a building is deformed by seismic force, any column base will rotate significantly, exerting a strong pull-out force on its component anchor bolts. Even if such bolts are assumed to perform as part of a pin joint assembly, some degree of bending will apply, resulting in plastic deformation. At points where bracing is connected, the bolts also receive strong pull-out and shearing forces from brace elements.

This type of damage has been seen in major earthquakes in the past. But even after the major Japanese seismic standards revision of 1981, cases have been observed in which insufficient attention was paid, in the design and building of column bases, to the external force that is likely to affect column bases or to the deformation capacity of the anchor bolts. Photo 2 depicts a sheared seismic brace. At this gymnasium, no glass was broken, yet even before the structure had undergone major deformation, turnbuckles were loosened and came apart.

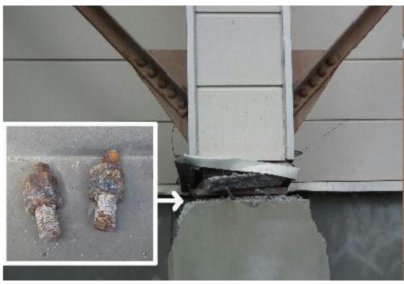

Photo 1: Column base damage at a school gymnasium

Photo 2: Broken brace element from the same gym

Photo 3: Fallen ceiling panel at an adjacent building

Thus, some of the observed damage involved issues with seismic elements or connector capacity, as seen here. These examples come as a strong reminder of the importance of fundamentals. Any building needs to be designed in ways that ensure quake-induced damage will occur mostly in places where repair and replacement are easy to implement. Similarly, new design methods to render seismic elements and connectors easier to understand must be promoted, so that each and every component possesses sufficient seismic capacity.

Photo 3 shows a fallen ceiling panel at a building adjacent to the same gym. In many other gymnasia, ceiling panels also fell down. In addition, a number of reports have also been filed on damage to nonstructural elements, such as displacement of non-bearing outer walls.

Photo 4 shows a classroom building where a column has suffered shear rupture. Damage to school facilities was by and large seen in cases dating to the pre-1981 revision of standards, and where the needed retrofitting had not yet been carried out.

In areas hit by the tsunami, on the other hand, whole communities were destroyed. A number of reinforced concrete structures appear to have held firm, but the tsunami swept timber-framed structures away and often gutted steel-frame units. In coastal areas directly hit by the force of the tsunami, steel frames were seen bent as if they were soft materials (Photo 5), proof, if needed, of the unimaginable magnitude of this tsunami.

Furthermore, soil liquefaction caused damage at reclaimed sites, as exemplified by the tilted residence depicted in Photo 6. Frequently, ground settlement also occurred, underscoring a need to improve subgrade support for structures in numerous areas.

Photo 4: Damage to reinforced-concrete school facility

Photo 5: Steel frame structure gutted and deformed by tsunami

Photo 6: House tilted due to soil liquefaction

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Damage to Civil Engineering Structures

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This report is an overview of damage to civil engineering structures in the Tohoku Pacific Earthquake of March 11, 2011, focusing on transport structures relating to roads and railways. To sum up, damage to such structures from seismic ground motion per se was minor, despite the force of magnitude 9.0. The huge quake-induced tsunami, on the other hand, wreaked enormous and significant damage.

In road bridges measures to prevent collapse were generally effective and anti-seismic reinforcement of piers performed well. Railway bridges supporting the Tohoku Shinkansen Line, as well as other trunk lines, also performed well in terms of seismic bracing. Structural damage on such lines was minor, except for downed utility poles. Local railway lines along the coast, however, suffered severe damage owing to delay in application of measures to counter girder unseating and reinforce piers.

Let us cite a few specific examples in coastal districts. Several bridges under central government management collapsed—all of these belonged to coastal segments and were hit by the tsunami. Other bridges, even though impacted by the tsunami, escaped damage where this impact was less severe. The Shishiori Viaduct at Kesennuma, Miyagi Prefecture, for example—although its piers were completely submerged—suffered no apparent damage (Photos 1 and 2). The structure's main girders are interconnected and its piers reinforced by the wrapping method.

Photo 1: Intact piers of Shishiori Viaduct at Kesennuma, shown post-submersion

Photo 2: Main girders interconnected and piers reinforced by wrapping method

The Numata Bridge crossing a railway at Rikuzentakata, Iwate Prefecture, however, lost all three main girders, which were simple post-tensioned, pre-stressed concrete T-shaped girders (Photos 3 to 6). As Photo 5 shows, the bridge's unseating prevention devices remain nearly intact. As recorded in Photo 6, anchor bars connecting the pier-supported main girders remained unbent. These observations suggest that the tsunami first pushed these girders up off their respective piers before sweeping them away.

Meanwhile, railway bridges along local lines in coastal districts suffered severe damage. Several bridges on the JR Kesennuma Line were destroyed, involving some girder displacement and pier collapse. Girder displacement and fall were apparently caused by the tsunami (Photo 7). Pier displacement in Photo 8 was likely triggered as tsunami waters scoured the riverbed; however, the broken pier in Photo 9 suggests insufficient seismic strengthening.

Photo 3: Numata Bridge at Rikuzentakata having lost all three main girders

Photo 4: Fallen girders at Numata Bridge

Photo 5: Unseating prevention systems in Numata Bridge nearly intact

Photo 6: Anchor bars remain upright in Numata Bridge

Photo 7: Fallen girder at the Sodeo-gawa Bridge (JR Kesennuma Line)

Photo 8: Collapsed piers of Tsuya-gawa Bridge (JR Kesennuma Line)

Photo 9: Broken pier of Tsuya-gawa Bridge (JR Kesennuma Line)

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Tsunami Damage and Assessment of Inundation Areas

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The huge tsunami triggered by the March 11, 2011, earthquake wreaked havoc along the Pacific coast of northeastern Japan. Of the confirmed death toll of 13,135 (one month later, as of April 11) a total of 12,143 people, or 92.5 percent, were drowned, according to the National Police Agency, an indication that the tsunami was the cause of the vast majority of fatalities. The 2011 Tohoku Earthquake Tsunami Joint Study Group (2011) has determined that the tsunami's maximum run-up height surpassed 40 meters. The run-up height reached 10 meters or more over a wide area stretching more than 300 kilometers along the Pacific coast, southward from lower Aomori Prefecture to Fukushima Prefecture (Figure 1). In the 1896 Meiji Sanriku Earthquake, which triggered one of the largest tsunami ever recorded, waters surged to 10 meters or more in areas stretching some 150 kilometers (only from Iwate Prefecture to northern Miyagi Prefecture). The affected area was thus significantly greater this time around.

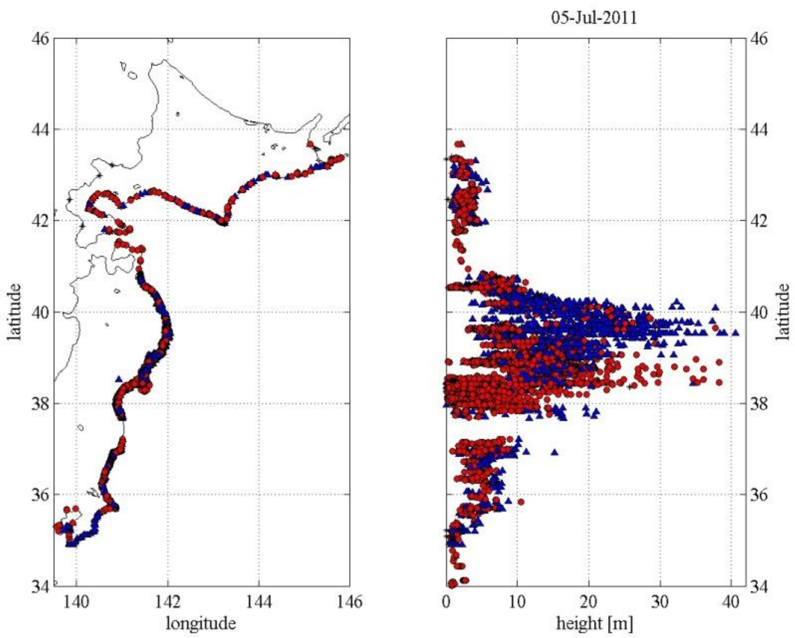

Figure 1: Distribution of tsunami run-up and inundation heights (The 2011 Tohoku Earthquake Tsunami Joint Study Group [2011]). Blue triangles indicate run-up heights; red circles show inundation heights.

The March 2011 tsunami's inundation areas were also large, extending 561 square kilometers in total—including 58 square kilometers in Iwate Prefecture, 327 square kilometers in Miyagi Prefecture and 112 square kilometers in Fukushima Prefecture, according to estimates by the Geospatial Information Authority of Japan (GSI, 2011), as based on aerial photos and other data. The overall inundation area almost matches the combined area of Tokyo's 23 wards (about 620 square kilometers). A field survey by the City Bureau of the Ministry of Land, Infrastructure, Transport and Tourism (2011) reports that across 160 square kilometers of the area inundated, a number of buildings suffered moderate to severe damage. The tsunami left a total of some 120,000 buildings severely damaged, while approximately 80,000 underwent moderate damage.

To grasp the extent of damage is important for compiling reconstruction plans. However, in cases where the damaged areas are extensive as in the March disaster of this year, time and labor are required to assess affected areas by way of aerial photos and/or field surveys. Therefore, in order to expedite the process, the authors are studying a method of determining areas affected by the tsunami through an automatic processing of high-resolution satellite images, such as have been recently made available.

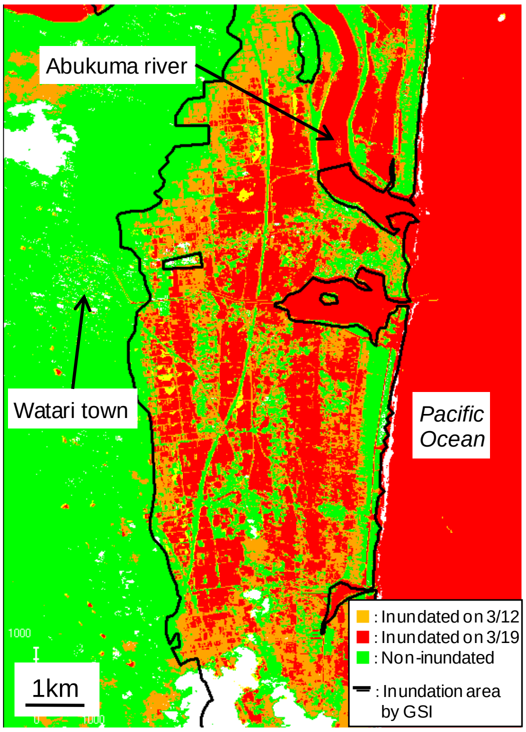

Figure 2: Tsunami inundation areas estimated from high-resolution satellite images on two separate occasions a week apart.

Here, the authors use images captured by the FORMOSAT-2 satellite (with a spatial resolution of 2 meters) to estimate the extent of tsunami inundation. Images from March 12, the day after the earthquake and tsunami, and then from March 19, were used to calculate a Normalized Difference Water Index (NDWI) for the purpose of study. The index is obtained from blue-band and near-infrared-band pixel values. The greater the index, the more likely it is that the area was submerged.

The map in Figure 2 depicts the coastal area of Watari town in the Sendai plain, in Miyagi Prefecture; inundation areas estimated from the images captured on March 12 and 19 are superimposed. Areas estimated submerged on either March 12 and 19 are shown in orange and in red, respectively. The green area shows non-inundated land, and white indicates cloud cover on one of these days.

Solid lines in the same figure refer to inundation areas estimated by the GSI through interpretation of aerial photos and other miscellaneous types of data. These lines suggest that the tsunami produced flooding as far inland as 5 kilometers from the coast. Estimates based on satellite images almost match GSI results, and this correlation strongly suggests that the NDWI is indeed effective in estimating inundated areas. The map in Figure 2 also shows that the inundated areas as of March 19 (approximately one week after the tsunami) still remained much the same as on March 12, indicating that the waters had scarcely receded. In this way, satellite images from different dates can be used to trace submersion rates over time.

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Livability of Post-quake Shelters and Temporary Dwellings

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This article looks into the issue of resident comfort at shelters and temporary housing for disaster victims. While some may believe the livability of such accommodation to be of little importance—since victims remain there only for a limited period—that is certainly not the case.

For grief-stricken individuals having lost so much to a disaster, their new residential environment, which temporarily forms the basis of their lives, is deeply significant. Homes are not just a roof over their heads. They provide a base from which to establish their "territory" and to ensure the safety and privacy of each family; it is from here they go out to work, attend school, or shop, and then return. Our lives pertain to all such places. It is for this reason that temporary houses built without good access can scarcely be called "home." It is only natural that disaster victims so often shun removal to temporary housing, leaving many units vacant.

After the massive Tohoku Pacific Earthquake and tsunami of March 11, I visited a shelter at Ofunato, Iwate Prefecture, in late April to see how tents donated from overseas had been set up inside a school gymnasium in a way calculated to ensure family privacy (Photo 1). But many elderly households preferred to maintain ties and communication with those around them; for this, low partitions were judged better than tents, indicating differences in the level of privacy that people desire and request.

Photo 1: Tents set up at a gym in Ofunato Junior High School, Iwate Prefecture

A temporary housing complex opened only last July at Tono, in the same prefecture, is built of laminated timber panels made of trees culled from managed local forests. Rows of temporary houses arranged in parallel usually have entrances to the north, as a measure to ensure equality of sunlight exposure. But at this complex, pairs of rows are built with entrances facing across a wooden deck (Photo 2). This design aims to increase opportunities for residents to meet and talk with one another.

Another temporary housing complex in Heita, Kamaishi City, has some blocks with wooden decks and some without (Photo 3). A simple comparison suggests that those with decks would be more commodious. As the season turns to winter, it will be instructive to see how the deck design will affect exchanges among residents.

Photo 2: Temporary housing complex at Tono, Iwate Prefecture, comprises two rows of homes with entrances facing across a wooden deck; connecting arcades at right.

Photo 3: Some blocks of temporary homes in Heita, Kamaishi, Iwate Prefecture, feature wooden decks, while others do not. The resulting impression of the spaces in between is starkly different.

Photo 4: A complex of temporary wooden homes in Rikuzentakata, Iwate Prefecture, harmonizes with the landscape.

Photo 5: Vehicles parked at home entrances in Taro, Miyako City, Iwate Prefecture

A timber-framed housing complex set up in an auto-camping site in Rikuzentakata harmonizes with the surrounding greenery (Photo 4). Such scenery makes it hard to believe that these houses are only temporary.

At a temporary housing complex in Taro, Miyako City, residents park their cars in front of their own entrances. The vehicles mark out each home's territory, serving as a buffer zone from passers-by (Photo 5).

In compiling reconstruction plans for areas hard hit by the tsunami, a key question is whether or not to relocate coastal communities to hilly areas. The Yoshihama district of Ofunato City's Sanriku Town (Photo 6) is often cited as an early and successful case of such relocation. The Meiji Sanriku Tsunami of 1896 inundated the locality, killing 204 residents (or about one in five members of the community). We are told that the village mayor at that time contributed his own money to push the community's relocation to higher ground. Yoshihama suffered only minimal damage from the March 11 tsunami, with just one resident missing and four houses severely impacted, either by collapse or being swept away.

Photo 6: In the Meiji era, Yoshihama community was located in green farmland near a bay (barely visible at left). Today's homes stand more safely in a hilly area, some 20 meters above sea level.

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Earthquake Preparedness and Business Continuity Plan (BCP)

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Damage Impact to Japanese Business

The Tohoku Pacific Earthquake of March 11 [*Great East Japan Earthquake*] wreaked damage upon many businesses through strong earth movement, and ensuing tsunami and soil liquefaction. Electricity shortages, resulting from damage to nuclear and other energy infrastructures, continue even now to plague them. Moreover, the effects of stalled production of parts, various components and certain raw materials have been felt across Japan, and also abroad, owing to severe supply chain disruptions, notably in the auto and tech sectors.

The Sendai Chamber of Commerce and Industry, in the major quake-hit city of Sendai, conducted a survey of local businesses about a month after the earthquake and tsunami, eliciting that precisely a third of the respondents had “suffered direct damage” to their business bases. A further 56.7 percent responded that the disaster “indirectly affected” them through damages to their business partners or customers. Another questionnaire, distributed by the Tokyo Chamber of Commerce and Industry from late March to early April, found that 92.7 percent of respondents believed the disaster had had a certain impact on business activities. Asked why, 78.2 percent cited a downturn in sales, customer visits and other activities due apparently to negative consumer sentiment and a slowdown in spending. Meanwhile, 59.6 percent reported an impact on supplies of materials, equipment and merchandise (multiple answers solicited).

Researchers believe the possibility to be high going forward for major jolts in Japan, in the so-called Tokai, Tonankai, and Nankai districts, as well as for a major Tokyo inland-epicenter earthquake. Unless certain steps be taken now to prevent disruptions similar to those which occurred this year, by reaping lessons from the March disaster, it may well be difficult to dispel concerns at home and abroad regarding Japan’s ongoing production and supply chains.

Affirming "Responsibility for Supply" and Thinking in Terms of "Outcome Event"

Many Japanese businesses have proactively set up their own Business Continuity Plan (BCP) in preparation for projected disaster scenarios. Assessing whether such BCPs proved effective with respect to the March earthquake and tsunami suggests that the presence of a "substitute strategy" in the plan appears to be key.

Let me expand on this feature. When compared with the conventional "disaster reduction" concept, a BCP needs to focus on "responsibility for supply." This is simply because, whenever supply is suspended beyond a tolerable waiting period, a business is likely to lose clientele and find its viability threatened. From a client's point of view, any suspension of parts or materials supply must in any case be avoided. A good BCP thus tends to deemphasize the "cause" of damage while stressing the particular "outcome event." In other words, a good BCP seeks from the outset to consider "what if this important base can no longer be employed or exploited" or "what if we should lose such and such key individual" as a result of any type of disaster whatsoever.

This line of thinking differs substantially from the concept of disaster reduction, hence its great merits. That is to say, if a business focuses exclusively on prediction of damages from a certain cause, it will have difficulty coping with damages that exceed such predictions. Furthermore, disruption of business can be occasioned by any one of a large variety of factors. To prepare for each and every one of these would be impossible. By contrast, thinking in terms of "outcome event" makes it easier to come up with a strategic plan for various purposes. Such thinking will also highlight the effectiveness of a concrete "substitution strategy" aimed at securing resources essential to business continuity. In terms of securing its own business base, a BCP must then focus on a strategy of substitution, rather than an on-the-spot recovery scheme.

Had the BCP of a given company impacted by the March 2011 disaster not had in place a substitution strategy—but aimed merely at protecting its base or key executives—the company in question would have found itself at a loss coping with the impact of seismic and tsunami damages that in the actual event far surpassed the government's damage prediction matrices. If, on the other hand, the same company had given thought, however slight, to a substitution strategy, it would likely have been able to find a way in which to cope with these extraordinary events. Indeed, certain businesses were able successfully to deal with the March disaster's aftermath thanks to well-thought-out BCP substitution strategies.

How to Secure a Substitute Base

To secure a substitute base is not simple or easy, however, especially in terms of its cost. One approach is to undertake advance preparation, insofar as possible, in order to put in place a substitute base at an early date in the event of disaster. For example, a business may specify an alternate site from which contact with key clients is possible (the president or CEO's home is one such option), as a sort of communications base including a backup store of key data. In the case of factories, where investment in a substitute production base is virtually impossible, a business can nonetheless decide in advance on an intended location and ways to set up such a base in case of emergency and also conduct tabletop exercises in setting it up.

An alternative is for one's company to reach an agreement of mutual cooperation in time of disaster with another firm in the same sector that is located in a distant place. Even if one suffers damage that is unrecoverable in the short term, it will be able to share technology and know-how through cooperating with the other and, in this way, somehow maintain a quasi-normal relationship with its own clients. Unfortunately, few such arrangements appear to have been concluded so far, but it is our hope that businesses will actively consider such a shared strategy going forward.

Supply Chain Question

Another challenge in ensuring business continuity is the issue of dealing with disruptions in parts-, or materials-, supply chains. Here once again, a substitution strategy is required—multiplexing supply sources (including confirmation that upstream suppliers two tiers up, or higher, do not actually converge at a single point) and requesting that any single supplier likewise seek to multiplex production bases. In addition, it is necessary that each business and/or industry sector should modify corporate values—even refraining to some extent from strategies of cost-cutting, over-differentiation of products or fencing-in particular suppliers—in order to ensure, or at least emphasize, stable supply in time of crisis. For example, a business may need to lay greater emphasis, in deciding product specification, on how first of all to secure a supply of substitute parts. Even if it pursues substantial product differentiation, a manufacturing firm should try to make use of as many common parts as possible, with the limited exception of requisite core parts and elements.