A CONCEPT FOR PREPAREDNESS AGAINST LEVEL 2 DISASTER RISK

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***ABSTRACT*:** The Japan Society of Civil Engineers proposed to introduce the earthquake motion of level 2 to reflect the seismic forces of the Great Hanshin-Awaji Earthquake in 1995. After the Great East Japan Earthquake in 2011, the undertaking of “human based” soft measures for evacuation in the case of tsunamis that exceed the conventionally assumed scale of level 1 was discussed; design methods that allow facilities to withstand tsunamis in addition to conventional seismic forces are in demand. The level 2 disasters experienced in Japan were incorporated into design concepts only after such large disasters occurred. However, actual level 2 disasters include events other than earthquakes and tsunamis. Increasing seawater temperature due to global warming will induce sea level rise, and typhoons will likely become larger in scale. Disastrous events that exceed conventional design conditions in high tides are more likely to occur. The three largest bay regions in Japan, where large hinterlands lie below sea level, require examination to clarify these risks.

The authors reviewed various phenomena and present that risk management on the basis of level 2 disaster risks is of great importance.

KEYWORDS: Level 2 Disaster, Disaster Risk, Risk Management

1. INTRODUCTION

Port facilities such as breakwaters and revetments in Japan are mostly designed to be safe against the maximum external wave force occurring during their normal service life of 50 years with a return period of 50 years and against seismic forces with a return period of 75 years. These designs balancing economic feasibility against safety have been established based on the history of Japanese modern port construction.

For Osaka Bay and Ise Bay, however, the return periods about 100 years have been used to set up higher sea embankments. Furthermore, the return periods of 100–200 years have been adopted for many river dikes under direct government control. The Netherlands, where one-fourth of the land is below sea level, ensures safety by using a return period of up to 10,000 years. This concept may be introduced by considering an enormous sum of social damage when excessive external force is generated.

The Japan Society of Civil Engineers proposed to introduce in design the earthquake motion of “level 2” to reflect the generated excessive seismic force appeared in the Great Hanshin-Awaji Earthquake in 1995. High seismic resistance quay walls with improved strength were introduced to ports, and some facilities were required to address the transport of emergency supplies and evacuees after a large-scale earthquake. In this case, the return period is reported to be several hundred to several thousand years.

After the Great East Japan Earthquake in 2011, the undertaking of “human based” soft measures for emergency evacuation in the case of a so-called level 2 tsunamis that exceed the conventionally prospected in design (i.e., level 1 tsunami) has been discussed. In addition to it, as “facility-based” hard measures, design methods that allow facilities to toughly withstand level 2 tsunamis have been studied so far in demand.

The level 2 disasters experienced in Japan have been incorporated into design concepts step by step after such large disasters occurred. However, level 2 disasters in society include events other than earthquakes and tsunamis. Increasing seawater temperature due to global warming will cause sea level rise. Typhoons will likely become larger in scale. Disastrous events that exceed conventional design conditions in high tides are more likely to occur. The three largest bay regions in Japan, Tokyo Bay, Ise Bay and Osaka Bay, where large hinterlands lie below sea level, require urgent studies to clarify these risks.

The authors reviewed various phenomena related to disaster and present that risk management based on level 2 disaster risks is of great importance.

2. HISTORY OF DISASTERS AND THE CONTRIBUTIONS OF CIVIL ENGINEERING

2.1 Residential Areas and Disaster Risks

Ever since rice cropping was introduced in Japan, Japanese people have found places to live on hills and other slightly elevated areas. They transformed the surrounding lowlands into rice paddies using irrigation from nearby streams and other sources. The land used for rice paddies was situated in the balance between locations where water was easily attainable and locations not vulnerable to floods or other disasters. The population of Japan gradually increased to about 10 million by the end of warlike ages, roughly late sixteenth centuries, as a result of rice production. Japan had difficulty feeding its citizens because every time it rained and flooding occurred, the flood plains downstream of large rivers (i.e., alluvial plains) would turn to wetlands, which meant the majority of plains were unsuitable for rice cropping. However, once dikes were built to stabilize river channels, the protected lands came to be used for new rice paddies. The stable and deepened river channels enabled ship transportation. This reclamation of land and stabilization of river channels increased food production and reduced flood risks after the sixteenth century. In addition, the large-scale reclamation of tideland at the mouths of rivers also enabled an increase in food production, causing the population to rapidly grow from about 10 million to 30 million[1)]. Throughout history, therefore, land use has taken into account disaster risks such as storm surges and floods. There has also been risk consciousness in areas prone to flood risk, such as reclaimed lands of the modern age where settlements have been developed along reclamation dikes on higher ground (Figure -1).

Figure -1 Example of reclaimed land
(houses along reclamation dikes) Google

Since the Meiji era (1868–1912), when modern civil engineering was introduced, large rivers have been improved so as to cause little flood damage, reducing the frequency of floods and storm-surge disasters. Figure-2 shows the number of fatalities from disasters after World War II. Looking at the history of postwar

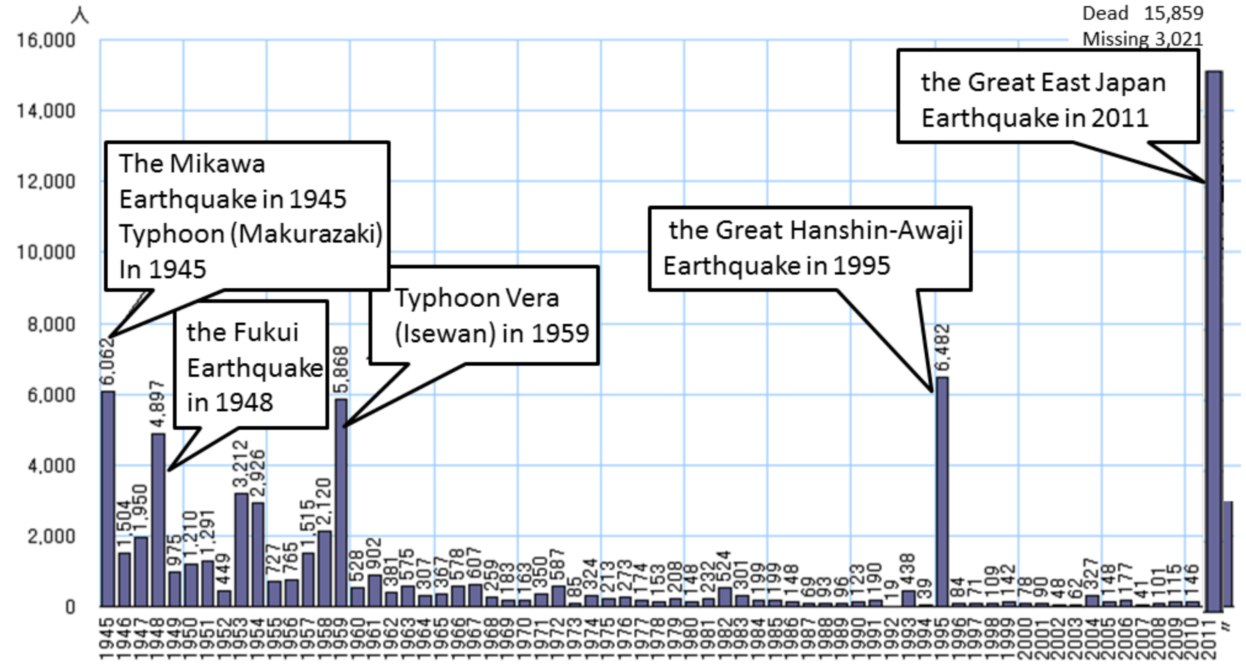


Figure-2 Changes in the number of missing and dead from natural disasters

(modified part of a 2011 white paper on disaster prevention)

disasters, while annual fatalities have fluctuated between hundreds and thousands, the numbers have not remarkably increased, aside from level 2 disasters that go way beyond design assumptions, such as the Great Hanshin-Awaji Earthquake in 1995 or the Great East Japan Earthquake in 2011, since the social infrastructure was energetically improved during the rapid economic growth era in Japan.

2.2 Zero-Risk Bias

Present cities have been developed as extensions of wet-rice farming and the associated societies and lives historically developed on the flood plains around the mouths of large rivers. The subsequent advancement of modern civil engineering provided urban functions for these flood plains and reclaimed land during the postwar period. Former wetlands and other poorly drained areas are now used as prime lands following the advancement of urbanization due to increases in population. Although some small- and medium-sized rivers could still flood, in addition to the risk of storm-surge disasters, the majority of large-city residents have become less familiar with disasters since there have been no opportunities to experience them.

Improved river dikes, sea embankments, and drainage pump stations tend to make us forget about inherent land risks over time. Urbanization due to an increase in population leads to the use of former wetlands, resulting in the misleading safety myth (or *zero-risk bias*). Improved disaster safety has altered the awareness of residents, causing them to believe risks are nearly nonexistent. People are less serious about risks, trying to find problems with the government when something happens. In fact, they are less prepared for disasters now since it is impossible to understand disasters they have not experienced. As evidenced by the Great Hanshin-Awaji Earthquake in 1995 and the Great East Japan Earthquake in 2011, however, level 2 disasters that go beyond the assumed disaster scale will cause catastrophic damage. Considering the current situation where poorly drained land originally unstable for use is fully utilized, disasters like floods, storm surges, or liquefaction due to earthquakes are likely to become more apparent in locations originally vulnerable to risk.

2.3 Calculating the Return Period for Storm Surges and Other Disasters

The current return period for storm surges is calculated to be as long as 1,000 years for the top end of the revetments in Tokyo using a storm surge height of 2.1 m with some margin allowances. In Nagoya and Osaka, it is calculated to be around 100 years—not necessarily long enough considering the seriousness of the disasters2). In Japan, the return period is often calculated to be between 100 and 200 years for most state-controlled river dikes.

In the Netherlands, where a quarter of the land is below sea level, a maximum return period of 10,000 years is used to ensure safety. This determines the optimal top-end height such that total costs are minimized on the basis of the construction costs for the dikes, the amount of damage when dikes are broken, and the frequency of the tide level. The embankments along the coast of the North Sea use a return period of 10,000 years, while river dikes use a period of around 1,250 years with the height calculated in relation to risk and economic performance. This idea considers the scale of risk in case excessive external force is applied. It is reported that the tide level comes under review once every five years depending on rises in sea level due to global warming or technical advancements, including estimations for storm surges3).

Recently, however, improvement and maintenance costs have ballooned due to an increase in the amount of damage caused when disasters exceed the planned external force. Therefore, it has been planned that while the so-called level 1 storm surge (10,000 years for Dutch sea embankments) is to be blocked by the embankments, land use is to be adapted for any larger storm surges instead of allowing water to overflow to a certain extent by promoting salt-damage compensation for hinterland farmlands and improvements to houses resistant to floods4).

This idea should be taken for granted considering it is not realistic to allocate a substantial budget toward improving facilities if one seriously thinks the risks of excessive external force resulting from global warming or other factors actually exist. Rather, this seems to be a means of hedging risks in case the return period of 10,000 years is not protective.

3. REAFFIRMATION OF LEVEL 2 DISASTERS

3.1 Introduction of Level 2 Earthquake Motion after the Great Hanshin-Awaji Earthquake in 1995

As shown in Figure-2, while the number of disaster fatalities in Japan remained high during the postwar years, the number fell below 1,000 after Typhoon Vera in 1959. The Great Hanshin-Awaji Earthquake was the first catastrophe in 36 years. After the earthquake, the Japan Society of Civil Engineers issued the first-to-third proposals5) on the new notion of level 2 earthquake motion for infrastructures. Technical Standards for port and Harbour Facilities in Japan introduced the concept of the level 2 earthquake motion in association with the proposals. The conventional technical standards were also based on the concept of seismic resistance for important facilities for which seismic performance should be improved. This was done by setting up cases where the importance factor used for improving the design calculated by the seismic coefficient method was 1.5. In response to the proposals from the Japan Society of Civil Engineers, the concept was summarized and used for facilities that were to be reinforced against earthquakes.

Technical Standards for port and Harbour Facilities in Japan as applied to regular facilities required that structural stability be ensured against any level 1 earthquake motion likely to occur during the facility's in-service period and that the sound functioning of the facility not be impaired. The standards also required facilities subject to improved seismic resistance to minimize the damage from level 2 earthquake motions, have functions recover quickly following earthquakes, and retain their expected functions.

Technical Standards for port and Harbour Facilities in Japan took the minimum required functions by clarifying the concept of the level 2 earthquake motion and installing high seismic resistance quay walls with improved strength in preparation for level 2 earthquake motion. Recently, however, the installation of such quay walls has not been sufficient to ensure port functions. The process of recovering ports has been forced to consider taking into chronological account not only the soundness and recovery of access roads from quay walls to the hinterland but also the recovery and resumption of organizations supporting port activities.

Whatever the case may be, the Great Hanshin-Awaji Earthquake in 1995 led to the political recognition of level 2 earthquake motion and its inclusion in the technical standards for design.

3.2 The Tsunami caused by the Great East Japan Earthquake in 2011

The Great East Japan Earthquake in 2011 caused a tsunami that went beyond what was anticipated by both civil engineers and earthquake researchers. The tsunami that attacked the Pacific coast of the Tohoku region might even be called a “level 2 tsunami.”

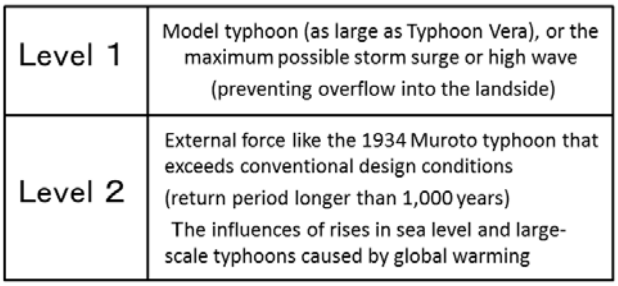
The Central Disaster Management Council, Cabinet Office, Government of Japan, established the Committee for Technical Investigation on Countermeasures against Earthquakes and Tsunamis based on the Lessons learned from the Great East Japan Earthquake in 2011 and concluded at the end of June 2011 that “the largest-possible mega earthquakes and tsunamis should be considered from every possible angle.” In May 2013, the Committee submitted its final report on the largest possible mega earthquakes assumed to occur at the Nankai Trough[6)]. The report indicates a need to consider tsunamis much larger than conventional ones by setting up new focal regions along the trough axis.

In addition to the level 2 earthquake motion of the Great Hanshin-Awaji Earthquake in 1995, the need to consider level 2 tsunamis was discussed. The relevant organizations were asked to develop the basic concept that level 1 earthquake motions and tsunamis should be addressed through disaster prevention based on “facility-based” hard countermeasures. Disaster mitigation for level 2 earthquake motions and tsunamis should mainly be addressed with “human-based” soft measures. It is needless to say that countermeasures against such external forces are not realistic unless they are socioeconomically feasible.

The two catastrophes after Typhoon Vera were milestones in considering level 2 earthquake motions and tsunamis. As discussed in section 2, even those locations originally unavailable for use have now been fully taken advantage of, consequently increasing their vulnerability to unanticipated disasters. Once an unanticipated disaster occurs, catastrophic disaster could result.

It is, therefore, important to consider every possible disaster outcome. Given that a 100-year return period is used for the top end of the current sea revetments in Nagoya and Osaka, a typhoon of the assumed level 2 shown in Table-1 could possibly cause socio-enormous economic damage. This might indicate the need to consider level 2 disasters and some realistic actions against them.

Table-1 Relationship between storm-surge level and assumed typhoon



Level 1	Model typhoon (as large as Typhoon Vera), or the maximum possible storm surge or high wave (preventing overflow into the landside)
Level 2	External force like the 1934 Muroto typhoon that exceeds conventional design conditions (return period longer than 1,000 years) The influences of rises in sea level and large-scale typhoons caused by global warming

4. ACTIONS AGAINST LEVEL 2 DISASTERS

4.1 The Probability of Level 2 Disasters

The great loss of life that occurred after the Great Hanshin-Awaji Earthquake in 1995 and Great East Japan Earthquake in 2011 led the nation to recognize level 2 earthquake motions and tsunamis in considering how facilities should be built. However, there are many disasters other than earthquakes and tsunamis. An earthquake alone could cause many other underaddressed disasters such as fires in densely populated cities, petroleum tank fires in the coastal areas of large cities, and the influence of long-term ground movement. Apart from earthquakes and tsunamis, Japan, which is frequently attacked by typhoons, is vulnerable to storm surges, and countermeasures should be discussed as soon as possible with regard to level 2 disasters (the tail risks that are unlikely to occur but are irretrievable if they do occur). Actions to be taken against other unexpected level 2 disasters—including torrential rain, tornados, high waves, and volcanic explosions—must also be fully considered.

Incidents with longer return periods are the historical phenomena no one has ever experienced, and when the external force of a disaster exceeds disaster prevention, it tends to be less recognized socially. In fact, when a disaster occurs somewhere, people living in other areas often do not believe they could one day be victims as well. People see what they want to see. Actions to be taken against risks should be considered on the basis of probability and socio-economic loss.

4.2 Global Warming Impact

Global warming causes not only seawater expansion and surface elevation with an increase in seawater temperatures but catastrophic typhoon attacks, which lead to an increased risk of storm surges in the future.

Yokota et al. examined the variable character of external forces in the coastal areas of the Kyushu region where global warming is expected to be influential on the basis of predicted climate values (MRI-AGCM3.2S)[7]. Figure-3 shows the frequency of typhoon passage by central pressure in the areas divided by longitude based on the data. Figure-3 shows that although the number of typhoons coming toward Japan will be reduced, there will be an increased number of the massive typhoons (central pressure of 900 hPa or less) in green.

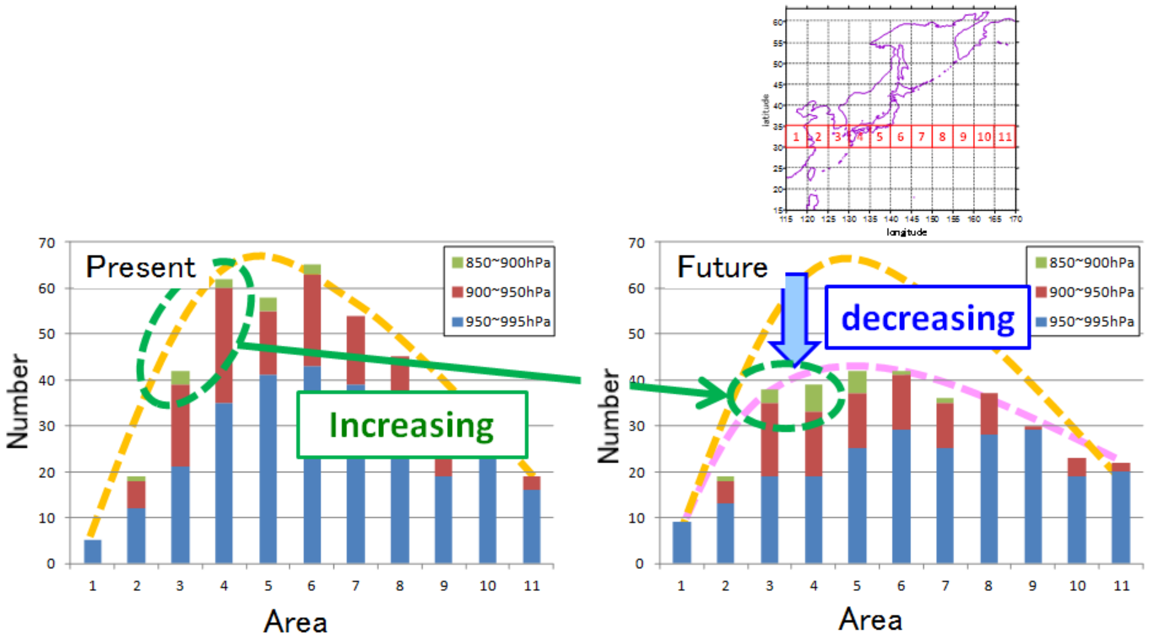


Figure-3 Comparison of typhoon passages by longitude resulting from global warming[7]

This means a level 2 storm surge is likely to attack Japan in the future, indicating a need to consider actions to be taken before and after such a disaster. Global warming also increases the frequency of torrential rain and causes phenomena that diverge significantly from conventional climatological statistics.

Figure-4 shows the annual number of days when daily precipitation reached 400 mm, as determined by the Automated Meteorological Data Acquisition System (AMeDAS); the Japan Meteorological Agency included this information in its Climate Change Monitoring Report 2012[8)]. This indicates that the consecutive average (the horizontal line in the graph) rapidly increased in 2013 and that heavy rain has become more likely to occur over the last three decades. Although it is unknown whether this is a long-term trend resulting from global warming, such increases in torrential rain raise the probability of disasters like floods, landslides and tornados.

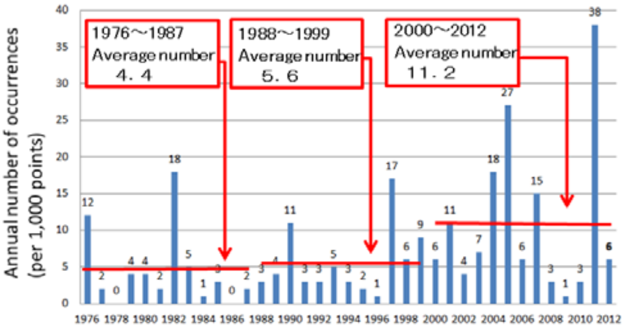


Figure-4 Annual number of days when meteorological observation points (AMeDAS) recorded a daily precipitation of 400 mm or higher[8)]

4.3 The Risk of Performance Degradation by Dilapidated Facilities

Of the 35,000 km of coastline in Japan, the coastal protection area extends about 15,000 km. The total length of sea embankments (dikes, revetments and parapets) is said to be about 9,700 km[9)]. The sea embankments were built after the enactment of the Coast Act (1956) and the damages resulting from the Great Chilean Earthquake (1960). Most are now at least 50 years old, and the number of facilities needing upgrades or improvements is expected to increase. The extent to which the performance of the sea embankments is degraded by age in case of storm surges or tsunamis is often unknown. The embankments often have unanticipated vulnerability due to their age and are at risk for washouts even when the waves during storm surges or tsunamis do not reach the top-end height. Furthermore, storm surges or other waves that exceed the height of the sea embankments could progressively cause structural deterioration. Even at the stage where no overflow occurs, there is great concern that overtopping waves remain submerged for a long time and swamp the areas at the back where no drain ditch is appropriately provided or influent quantity exceeds pumping capability due to the back areas being below sea level.

4.4 Preparation for Level 2 Disasters

As mentioned above, level 2 disasters can also include storm surges, torrential rains, tornados, high waves and volcanic explosions. “Disasters always look different,” as they say, and disasters are in fact likely to sharp-shoot socially vulnerable positions. Regarding measures against earthquakes, the amended Building Standards Act improved the seismic performance of houses, while social capital facilities like roads and ports have sequentially improved their seismic performance. This does not, however, mean discussion has been advanced on the performance of local economies or the continuity of social activities taking into account the Business Continuity Plan (BCP) regarding large-scale earthquake disasters. Existing houses built according to the former Building Standards Act, as well as social capital facilities designed by earlier standards, often do not satisfy seismic performance. Thus, once a major earthquake occurs, fires could disrupt urban functions and distribution bottlenecks could disrupt the functions of cities or ports, even if individual seismic facilities were to remain sound. Earthquake disaster prevention will remain the priority issue, and regional disaster prevention, or mitigation capability, must be ensured from the perspective of the Business Continuity Plan (BCP) at the time of an earthquake.

For the level 1 storm surge, the top-end height must be set up considering the drainage of overtopping into the landside, and the functions of the sea embankments (revetments) must be linearly ensured to protect the overall areas from the expected storm surges and waves. Current coast protection facilities have been upgraded to a certain extent. However, no sufficient plans or budget have been ensured for linear, integrated improvement works, including deterioration countermeasures and liquefaction countermeasures for settlement prevention at the time of an earthquake, and specific actions are apt to fall behind. Since the conventional level 1 disaster plan expects facilities to remain sound and flooding impact to be minor, there has been no sufficient discussion on plans for storm surges beyond level 1. Therefore, there is often a lack of discussion on the BCP and other issues. In the areas that include the three major Japanese ports, a storm surge with the safer probability of 10% in 50 years should not cause any greater damage than overtopping from the point of view of the population and industrial agglomeration. Necessary "facility-related" hard improvements should be provided upon the review of the BCP if possible.

Takahashi et al. presented the relationship between the degree of disaster damage and the importance of facilities[3]. Figure-5 shows this relationship, rearranged by the authors of this paper, along with the return period and probability. Figure-5 organizes the performances of facilities at the time of disaster, and facilities of higher importance are required to be resistant to the phenomena of longer return periods.

The service life of social capital facilities is often around 50 years. This is considered to be determined not from the engineering point of view but from the economic point of view. The actions used for design are usually considered in terms of level 1 external force, and the return period of 50 years is generally used for breakwaters. In this case, the probability of external force expected during the in-service period is 0.64, indicating the external force is very likely to occur. In those important areas where safety must be ensured against level 2 disasters, the probability should be lowered to *rare* (probability of 10% in 50 years) or

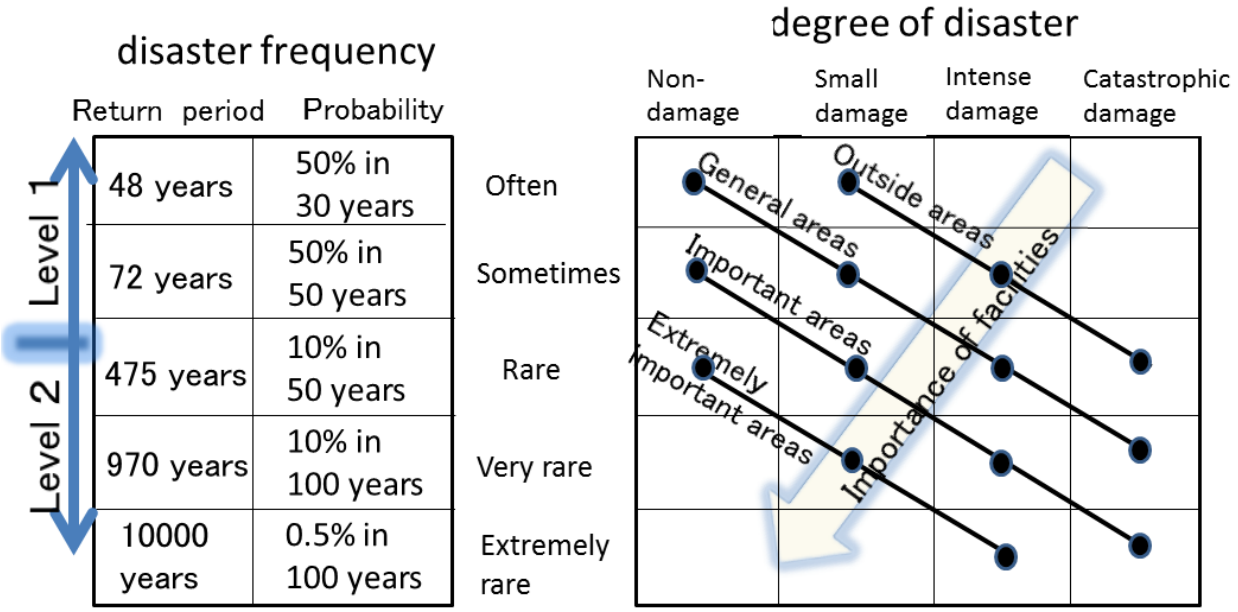


Figure-5 Relationship between the disaster performance matrix and frequency *very rare* (probability of 10% in 100 years), as shown in Figure-5, taking into consideration economic performance and social impact.

There is, of course, always a potential risk of disaster beyond one’s assumptions, no matter how much safety has been improved by “facility-based” hard improvement. To hedge the risk in such cases, it is necessary to protect lives with advanced communication and evacuation procedures, achieve the most efficient possible BCP for economic losses within the recovery period, and establish a new framework including insurance for the portion of losses that cannot be covered by the BCP. This is also applicable to the general areas shown in Figure-5. If a disaster results from excessive external force, it should be necessary for social equity not only to ensure the safety of lives but to promote bailouts, including insurance coverage.

CONCLUDING REMARKS

While earthquakes and tsunamis, including those occurring at Nankai Trough or directly under the Tokyo metropolitan area, are the urgent issues regarding level 2 disasters (tail risks), storm surges and high waves are similarly risky in probability, and their importance is never low in future social capital improvement. Another important issue to address is the recent increase in torrential rain that increases the likelihood of river flooding. Furthermore, there are several disaster risks of lower probability but catastrophe to be considered, including volcanic explosions and tornedos. The relevant parties and organizations as well as citizens should thus be ready for level 2 disasters that lay beyond expectations.

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