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WHEN A TSUNAMI THREAT IS IMMINENT AIR-SEALED TYPE OF ENCLOSURES CAN SERVE AS TEMPORARY SHELTERS TO SAVE LIVES RELIABLY AND ECONOMICALLY

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ABSTRACT

Twenty-two thousand people died when the 11 March 2011 Tohoku earthquake and tsunami struck Japan with little or no warning from Civil Defense authorities. Both the earthquake and the tsunami also resulted in the failure and destruction of the Fukushima Daiichi Nuclear Power Plant and in large-scale distribution of radioactive elements. The seawalls along the affected coasts were easily destroyed by the tsunami, which also stirred up sludge and sediments from the seabed on land, thus making evacuation extremely difficult. Therefore, it becomes obvious that when a destructive tsunami hits again Japan, all coastal plains will continue to be dangerous zones. People living in such areas do not have enough warning time – particularly from local earthquakes and tsunamis - to evacuate to safer areas inland. Therefore, and in order to protect the people in such vulnerable coastal areas, tsunami shelters must be used or constructed to provide for their short-term protection until the tsunami danger subsides. Rapid escape of the people in danger areas to air-sealed type of existing or constructed enclosures serving as temporary shelters, can save their lives. Specifically, air-tight shelters, even in tsunami flooded coastal areas, can provide temporary protection until there is no threat. Such temporary shelters can be cheaply constructed and reliably save lives. Building codes can be amended for building air-filled tsunami shelters in oceanfront buildings, and thus provide safety from normal-level tsunamis at relatively low cost. Tsunami shelters can be constructed even in subway facilities or underground shopping malls, and thus minimize or reduce to zero losses of human lives, not only from tsunamis, but also from large fires, If coastal towns were equipped with tsunami shelters, the number of deaths from tsunamis as well as from large fires could be minimized and even be reduced to zero.

Keywords: *Japan; tsunami; seawalls; air-reservoir-type tsunami shelter; submarine-type tsunami shelter; Sanriku Coast; Okawa Elementary School; debris flow; tsunami warnings.*

INTRODUCTION

If a local destructive tsunami is generated near an inhabited coastal area from an earthquake source within a distance generally less than 200 km away, it is characterized as a near-field event according to the revised first edition of the tsunami glossary (Pararas-Carayannis, http://www.drgeorgepc.com/TsunamiGlossary.pdf), since there is no sufficient time for the authorities to give a timely warning for inland evacuation of local residents. For such low-lying, inhabited coastal areas, the earthquake's strong shaking motions should be a warning that a tsunami may be shortly arriving and that people should take immediate measures to save their lives. Even if a short term warning of an expected tsunami is announced by civil defense authoties, the given estimate of its height may not be properly forecast for the areas that will be affected and in fact it may be much greater.

Based on current tsunami prediction technology, the actual height of a tsunami could be between half or even double the predicted height, depending on the state of the local tide at that time and the coastal topography (Ministry of Land, et al., 2011). The "height" of a tsunami is defined as the difference in sea level compared to the normal tide level. However, based on local topography and the concurrent arrival of waves from different directions of the source area, the run-up height (elevation) of the tsunami could significantly increase from that on the coast. In some instances, the run-up height of the tsunami can be significantly augmented by as much as four times the initial height on the coast.

Some local governments in Japan have created hazard maps (inundation prediction maps) showing areas that are likely to be flooded in the event of a tsunami. According to the "Table of Tsunami Wave Height and Degree of Damage" (modified from Shuto (1993)), even reinforced concrete buildings can be destroyed by a tsunami with a height of 18 m.

However, it is dangerous to claim that the actual height of a tsunami is one-half to twice the predicted height. This would mean that a tsunami forecast to have a height of 10 m, its actual run-up height could range between 5 and 20 meters. Tsunami countermeasures that are based on height predictions with this varying degree of accuracy, could result in many deaths.

For example, damage caused by the tsunami of March 11, 2011 could have been predicted as the seawalls in the affected areas were not sufficiently high and the tsunami easily exceeded them. As a result, residents who had trusted that the seawalls would protect them did not try to escape and thus they were killed. In addition, the danger zones shown in existing tsunami hazard maps are narrow, and the 2011 tsunami affected people who thought that no tsunami would reach them. Also, existing shelters were also located at elevations that were too low.

In brief and as a result of these mistakes, 22,000 people were killed by this tsunami, and a serious accident also occurred at the Fukushima Daiichi Nuclear Power Plant and the resulting and long-lasting effects of radiation (Pararas-Carayannis, 2011). These misjudgments indicated the need for Japan to use more complete tsunami countermeasures, which must be based on the collection of more accurate data and of proper interpretation. Because a tsunami can have a run-up heights of up to four times of its initial, it can be expected that a height of 10 meters can have a run-up height of up to 40 meters, based on the momentum of motion. In reality this means that all coastal plains are danger zones and that people should not simply rely on the tsunami hazard maps produced by local governments. Also, local authorities responsible for tsunami protection should provide better guidance to residents on how to interpret these hazard maps.

Historically, the Great Meiwa Tsunami that hit Ishigaki Island in 1771, is reported to have had a run-up height of 85 m (AIST, 2018). An undersea landslide generated this catastrophic tsunami. Another earthquake on 15 June 1896 in Sanriku, killed 22,000 people and another one on 2 March 1933 in the same area, resulted in 3,000 deaths (Pararas-Carayannis 2011; 2014).

In brief, Japan's high seismicity is attributed to its location near oceanic trenches where the oceanic plate subducts under the Japanese archipelago – these being the Chishima, the Japan, and the Nansei Islands trenches, as well as the Sagami and the Nankai troughs. This high seismicity of Japan has also led to the formation of cliffs that rise from the sea floor, meaning that even a weak earthquake can result in undersea cliff collapses and in the generation of larger tsunami waves.

All coastlines on Japan are vulnerable to tsunamis striking with little or no warning at all, thus preventive measures that rely on present estimates of wave heights cannot prevent damage. For example, the height of the 2011 tsunami was much greater than anticipated, and easily destroyed seawalls for about 190 km of the 300 km seawall along the Sanriku Coast (Tarui et al., 2012). In addition, a tsunami with a height of 18 m or more can even destroy buildings constructed with reinforced concrete (Ministry of Land, Infrastructure, Transport and Tourism, 2011). Tsunami waves can also generate debris flows that lift up sediments from the ocean floor, as indicated from past inland tsunami deposits on shore that have thicknesses of up to 50 cm. Furthermore, a large tsunami accompanied by debris flows can easily destroy seawalls, and even tall concrete buildings reinforced with rebars. Thus, all tsunami protection shelters must be able to withstand such great destructive forces. The following sections of this report recommend that air-sealed enclosures can serve as temporary shelters, as well as properly constructed submarine-type of shelters.

2. AIR-SEALED ENCLOSURES CAN SERVE AS A SAFE TEMPORARY, RELIABLE AND ECONOMIC SHELTERS FOR LOCALLY GENERATED TSUNAMIS IN VULNERABLE COASTAL AREAS WHEN A STRONG EARTHQUAKE IS FELT

At the basement level of a building, the momentum of a tsunami is reduced and drifting objects cannot enter. In such environment—although they would be immersed in seawater—people would be safe as long as diving equipment with adequate air supply was available.

Similarly, in ships that have sunk, air pockets form, and people can survive as long as they can reach one of these air pockets. An air reservoir-type tsunami shelter based on the same principle is easy to make: it simply requires the construction of a room from which air is prevented from leaking through the ceiling. Seawater that enters the room will rise and fall according to the height of the tsunami, but air pockets will form near the ceiling.

To provide a suitable location for a tsunami shelter, the building in which it is housed also needs to be able to withstand the pressure produced by tsunamis and the impact of drifting objects. When tsunamis strike, debris flows lift up sediment from the ocean floor, and the destructive power of a tsunami varies greatly depending on the state of the seabed, the location and elevation of buildings, and other factors.

A building does not need to withstand the pressure caused by the height of the tsunami because the tsunami heights inside and outside the building are almost identical. Therefore, a room in an ordinary building can be made into a tsunami shelter simply by ensuring that the air cannot leak through the ceiling. As shown in Fig. 1, even wooden houses can be considered safe if the basement is used as a tsunami shelter. Alternatively, one room can be converted to a shelter by reinforcing it against the outside hydrostatic pressure of tsunamis. Even if the upper part of the house is washed away by the tsunami, a properly constructed air-tight basement will survive, so this can be the safest part of such a house. Therefore, a revision of the building structure could incorporate the installation of tsunami shelters provided that the ceiling is sealed and contained air does not escape.

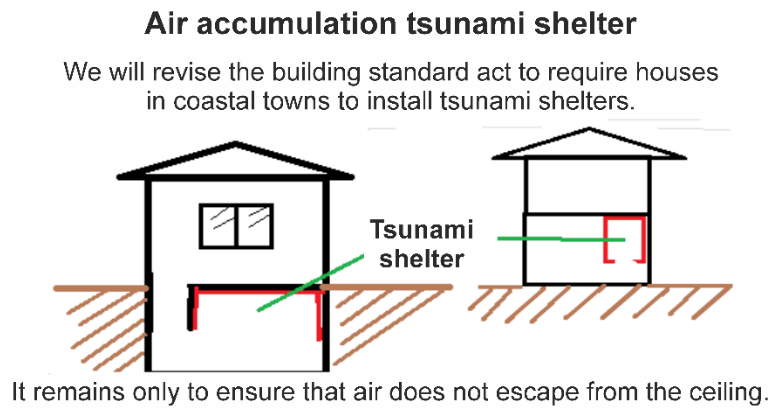

Fig. 1 Construction of an air accumulation tsunami shelter.

To convert a high-ceilinged room into an air-reservoir-type tsunami shelter, scaffolding-enabling access to the air reservoir near the ceiling could be constructed.

The main disadvantage of this type of shelter is that people get wet, which is a serious problem in winter. However, it is also easy to create a dry space by constructing the shelter in such a way that large air pockets that can easily be accessed form; people lying or sitting on top of floating furniture, who will not get wet, can perhaps access these. The disadvantage is that pressure associated with the height of the tsunami will also affect the human body. A 10 meter high tsunami will exert a pressure of 1.0 kg/cm^2 on the human body, causing no serious harm. In scuba diving, even beginners can dive up to 20 m, so this level of water pressure is relatively safe.

Larger tsunamis are more problematic but are encountered less frequently. A tsunami can strike suddenly at any time (even during the night) without any warning. Therefore, a safe tsunami shelter must be reachable very quickly. Moreover, when a tsunami warning is issued during the daytime, not all workers can cease working and escape rapidly. Thus, many tsunami shelters are needed along vulnerable coasts, where the imminent occurrence of a tsunami can be monitored before ordering evacuation.

An adult diver requires 15 liters of air per minute, or 0.9 m^3/hour. Therefore, 50 m^3 of air (5 m × 10 m × 1 m) will support five people for 11 hours. However, in a real tsunami situation, the people will not be submerged for that long.

Submarines make use of well-established technologies that are based on the amount of air required by the crew and the need to remove carbon dioxide. The construction of tsunami shelters can be based on the same principles.

At atmospheric pressure, the above amount of air is sufficient. In an air reservoir during a tsunami, the pressure exerted by the tsunami reduces this volume. During the 2011 tsunami, one person survived within a 20 cm–high pool of air formed in the ceiling of an apartment building.

To protect houses in coastal areas against moderate tsunamis, the relevant building codes can be amended to require one room with airtight ceilings. Seawalls are expensive: they cost about 2.5 billion yen/km to construct and are easily destroyed by large tsunamis. This was the subject of the NHK special broadcast “Black Tsunami: The Unknown Reality” (NHK, 2019).

At the time of the 2011 tsunami, samples of seawater were taken. The seawater was black and was found to consist of 10% sludge. Seawater containing this amount of sludge would hit the seawall with twice as much force as ordinary seawater. The bottom of the bays adjacent to large cities such as Tokyo and Osaka are covered with deep sludge. Any tsunami hitting those bays would stir up this sludge and destroy the seawall.

One year after the 2011 tsunami, another tsunami warning was issued, and radio and television broadcasts instructed people to evacuate to higher ground. However, the tsunami that actually hit was a small one with a height of about 1 m. People who heeded the warnings, left work, and fled to higher ground then faced criticism.

Because seawalls protect against small tsunamis, residents often ignore tsunami warnings. This means that when a large tsunami subsequently hits, many residents again trust the seawall to protect them and thus become victims. This has happened repeatedly along the Sanriku Coast since ancient times. In 1896, 21,959 people died in the Meiji Tsunami, 3,034 people died in the Showa Tsunami of 1933, and 22,000 people died in the 2011 Heisei Tsunami; in addition, 142 people died in the tsunami that hit Chile in 1960. In just 115 years, these four large tsunamis have caused a great number of casualties. It is, therefore, clear that current tsunami countermeasures are not effective.

A tsunami shelter such as the one shown in Fig. 2 constructed in the center of an office building would allow people to escape from a tsunami. As a tsunami with a height of 18 m or more can destroy even buildings made of reinforced concrete, it is safer to shelter in a low-rise building than a high-rise one. By collecting air from a large space into one room, a secure, dry space that offers protection from a tsunami can be created, thus avoiding the need for people to flee to higher ground.

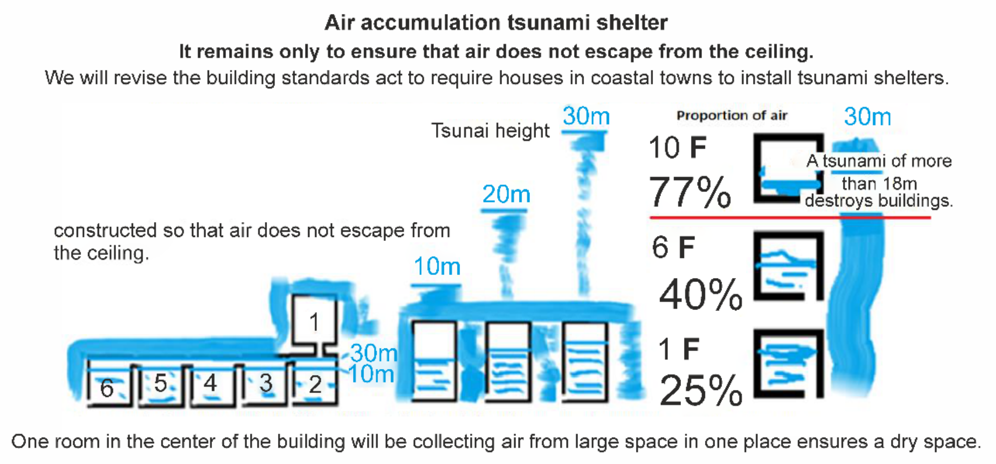

Figure 2. Details of a tsunami shelter that could be installed in buildings in coastal areas.

3. SUBMARINE-TYPE OF TSUNAMI SHELTERS

Fig. 3 shows a submarine-type tsunami shelter that could be used to offer short-term protection of people in coastal areas from a future large locally generated tsunami. This type of suggested shelter is essentially an easy-to-build sealed structure on the coast that could remain dry until the tsunami danger ends and could provide a safe space for everyone, including children and vulnerable adults. The shelter is equipped with an oxygen supply and a means of removing the carbon dioxide produced by the users. It could also be equipped with an emergency power supply, an external communication system, a toilet, and an emergency air-intake valve.

The shelter is designed to withstand the destructive power of a tsunami and is built of reinforced concrete with a thickness of 2 m. Further details of how such a shelter could be constructed are the are as follows. The proposed shelter consists of a 2 m–thick reinforced concrete box with internal dimensions of 10 m × 10 m × 3 m, outer dimensions of 14 m × 14 m × 7 m, and an approximate weight of 2600 tons. The entrance passage is 1m wide and 2m high, with watertight doors on the inside and sturdy iron doors on the outside. Within this space, 20 m^2 is used for oxygen storage, automatic oxygen supply equipment, carbon dioxide absorbers, toilets, lighting, communication equipment, emergency food supplies, and other commodities.

Applying the permanent capacity standard of trains in Japan (0.14 m^2/person), this area can accommodate 571 people in an emergency. However, the capacity of the proposed shelter is set for 200 people, allowing for adequate sitting down. The estimated cost of this shelter can be calculated as follows.

3A. Construction of Submarine-type of Tsunami Shelters

For proper construction of a submarine-type of tsunami shelter it is estimated that 1072 m^3 of reinforced concrete is required. The estimated cost of such construction would be 1072 m^3 × 80,000 yen/m^3 = 85,760,000 yen. The shelter would require an oxygen supply system and another for the removal of the carbon dioxide. The amount of oxygen which will be required will be 15 liters/min × 60 min × 0.21 = 0.189 m^3/person/hour.

Therefore, based on such rate of consumption, if 571 people remain in the shelter for 10 hours, they will require up to1,080 m^3 / 7 m^3/cylinder = 155 cylinders of oxygen. The cost of 1 cylinder of oxygen = 30,000 yen 30,000 yen × 155 = 4650,000 yen, which is not a large amount of money. The amount of carbon dioxide that would be generated will be 4%, equivalent to 15 liters/min per person × 60 min × 0.04 = 0.036 m^3/person/hour. The 206 m^3 of carbon dioxide that would be produced by 571 people sheltered for 10 hours can be absorbed by a slaked lime suspension. Thus, the volume occupied by the oxygen cylinders and other equipment, and the cost of these, will not be a problem.

A watertight door, an outer door, an automatic oxygen supply device, a carbon-dioxide absorption device, an emergency power supply, an external communication device, a toilet, emergency food, and other necessary commodities can be prepared for less than 100 million yen. Based on the above calculations, the total construction cost of this shelter is around 200 million yen/unit. Fig. 3 is a diagram depiction of this type of reinforced concrete submarine-type of tsunami shelter, with thickness of walls of two meters, weight of 2,800 tons and a capacity to provide protection for 200 people for a reasonable time and until the termination of the tsunami danger.

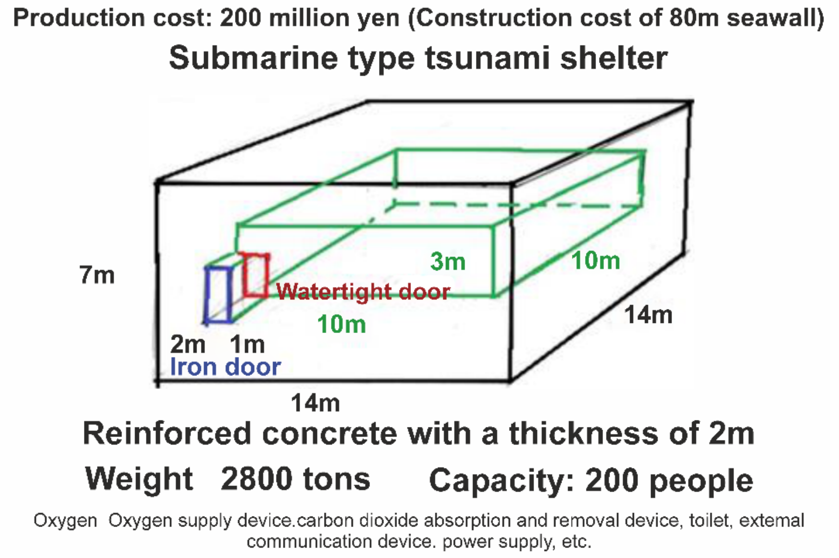

Figure 3. Diagram of a submarine-type shelter designed to withstand large tsunamis

Specifically, such submarine-type of shelters could be constructed in populated cities vulnerable to inundation by locally generated tsunamis, like Yamada-Machi, a town located in central Iwate Prefecture, which is part of the Sanriku Region of Japan on the coastline on the Pacific Ocean. The main industries of this city are fishing and tourism, which are centered on the Rias Coast and also include some small and medium-sized factories in the mountainous areas inland.

The 2011 tsunami completely destroyed the seawall of the city of Yamada-machi. The sturdy iron gates on the road between the port and the city were also easily swept away, and houses on the flat areas near the ocean were destroyed. A total of 825 people out of a population of 19,270 were killed, and the remaining population was reduced to 14,821.

Regarding the expenditure for the construction of a submarine-type of tsunami shelter for 200 people the cost 200 million yen per shelter, and it would cost 15 billion yen to build the 75-tsunami shelters which would be needed to accommodate the entire population of Yamada-machi. This can be compared with seawalls, which are more expensive - 2.5 billion yen/km. Thus, tsunami shelters that could accommodate the entire population of Yamada-machi could be built for the same cost as only 6 km of seawall which – as it has been explained - do not protect adequately against tsunamis.

When implemented, the revised Building Standards Law in Japan will require the installation of air reservoir-type tsunami shelters in all homes built on flat land close to the coast. This will provide protection from moderate tsunamis at little cost. However, in order to protect against larger tsunamis, which have tremendous destructive power, submarine-type shelters could also be built. In the case of warehouses and factories, banks of soil can be used to provide a cushion against tsunamis and turn them into air reservoirs.

Unfortunately, the most worrying thing about the 2011 tsunami is that it was not large enough to be considered as a giant tsunami. The tsunami had a maximum height of 19.0 m (as measured at Miyako Island) (nippon.com, 2011), and can thus be considered to be a moderate size of a tsunami - although it killed 22,288 people, destroyed 1.153 million buildings, forced 347,000 people to move to evacuation centers, and caused damage estimated at approximately 16.9 trillion yen (Pararas-Carayannis, 2011; 2015).

If a giant tsunami were to occur, the seawalls in the affected areas would easily be destroyed. It is thus, impossible to prevent a giant tsunami from entering residential areas, and tsunami shelters would be the only way to save lives.

If there was a tunami shelter at Okawa elementery school, 74 people would not have died.

Strengthen the walls of the classroom, add watertight doors, and you’re done.

If you prepare oxygen cylinders and carbon dioxide absorbers, many people can stay in the room forever.
Tsunami shelters protect lives cheaply and reliably.

Figure 4. Okawa Elementary School, where 74 people died in the 2011 tsunami

In 2011, 74 people died at Okawa Elementary School as a result of failings in national tsunami countermeasures. Back then, if we had tsunami shelters like Fig. 4, these people wouldn't have died. Following national government guidance, the government of Miyagi Prefecture had produced a tsunami hazard map that was based on the height of tsunamis known to have hit the area in the past. According to this map, Okawa Elementary School is located in a safe zone and has been designated as an evacuation center by Ishinomaki City authorities. Nevertheless, this school is only one meter above the sea level. On the day of the tsunami, both the teachers and students who had lined up in the schoolyard were swept away and died. If the school had not been designated as an evacuation center, these people would have climbed the mountain behind the school and survived; in fact, one student and one teacher did manage to save themselves in this way.

Neither the national government nor tsunami researchers understand the basic nature of tsunamis. A giant tsunami that scoops up sediment from the seabed can easily destroy seawalls. In addition, the height of a tsunami that hits land can be dramatically affected by the local topography. A tsunami sourced from the front of a bay will hit the coast of that bay at a large height. However, the neighboring bay may be much less seriously affected because the cape between the bays will block the tsunami to some extent. A seawall built in the neighboring bay will prevent small tsunamis such as those occurring in the past but will not deter large tsunamis occurring in front of the bay. Thus, countermeasures based on the known heights of past tsunamis are flawed. Both the government and tsunami scientists are developing tsunami countermeasures based on the erroneous premise that a tsunami of the same magnitude as past tsunamis will occur where they were reported in the past.

3B. Proposed use of subways and underground shopping malls as tsunami shelters

Subways and underground shopping malls are the best locations for tsunami shelters. As can be seen from Fig. 5, it is easy to create a large dry space underground.

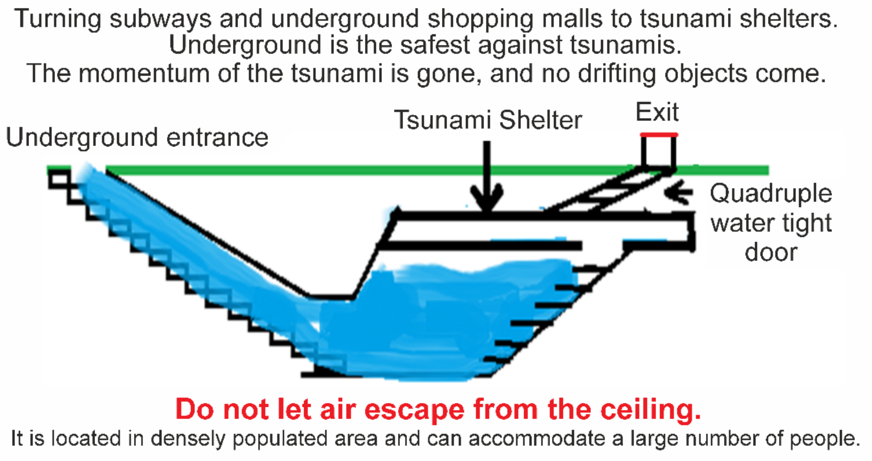

Figure 5. Proposal for adapting subway stations and underground shopping malls to act as tsunami shelters

Also, underground, people are protected against the destructive power of a tsunami and drifting debris. In densely populated areas, shelters such as this can accommodate travelers and other people who are out and about. However, subway stations can be used as gigantic tsunami shelters if water entry through the subway entrances is blocked and water coming along the tracks is contained. Such technology has already been implemented in New York subways (Teresa McKemer, 2019). In 2012, Hurricane Sandy flooded the New York City subway tunnels and nine stations, causing billions of dollars of damage to the city's transportation system. The Metropolitan Transportation Authority (MTA) has implemented measures to protect the subway from flooding.

Flex gates are among several tools that protect low-lying metro stations from storm surges and unusual seawater rises caused by strong storms that bring seawater ashore. Developed by the engineering firm ILC Dover, a flex gate is a Kevlar-woven balloon that can block a subway entrance in minutes when operated by a single person. The MTA has already installed 65 flex gates at various locations.

Subway tunnels have also been blocked with 32-foot-long balloons called "resilient tunnel plugs." Such devices are very useful during tsunamis that can suddenly strike without warning. The tunnel can be immediately blocked within a safe location. Moreover, underground tunnels have countless holes leading to the surface, which must be closed simultaneously. Any hole left unclosed will admit the tsunami into the underground passageway. If the underground passages are divided into smaller sections and blocked with such devices in advance, the risk of underground flooding remains low and damage is minimized.

The methods implemented in New York are intended to protect subways from flooding. In Tokyo and Osaka, there is marked ground subsidence and most areas are below sea level. If seawalls and waterproof gates at the coast were destroyed, seawater would flood into these areas. The subways would also be completely submerged within a few hours. Because of this, disaster prevention plans based on the policy of escaping from subways as quickly as possible have been devised. However, these plans should be revised as the safest place to be in the event of a tsunami or flooding is underground.

As has been stated, buildings used as evacuation centers can be completely destroyed by a tsunami with a height of 18 m or more. However, even a ship that has sunk to the bottom of the sea will contain air reservoirs. Similarly, in a subway, as long as air cannot leak through the ceiling, it will store there. If air can be collected from a large volume, a dry space where people can shelter can then be created. However, if the area above ground is flooded, watertight doors will also be needed to keep the water out.

The oxygen requirement of one person is small: One 7-m^3 oxygen cylinder can supply one adult with oxygen for 150 hours. The carbon dioxide produced by people in a shelter can be removed using wet slaked lime. The same technologies are already used in submarines. The exit allows passage out above the water on the ground.

During the Second World War, the London Underground was used as an air-raid shelter. Even in the event of large fires that can occur after a major earthquake, subways can offer a safe refuge. Also, even if smoke from distant fires drifted along the tracks, air bags such as the ones described above can be used to prevent its spread.

In contrast to the above-described measures, Japan's tsunami countermeasures were of limited use in 2011. Instead, they magnified the amount of damage caused. If suitable tsunami shelters were installed along the coast of Japan, the number of deaths due to tsunamis could be reduced to zero.

As has been demonstrated four times in the last 115 years, seawalls cannot protect against large tsunamis. However, even after the 2011 tsunami, the Japan government spent 1 trillion on the construction of useless new seawalls. A submarine-type tsunami shelter for 200 people that could withstand a giant tsunami would cost 200 million yen. Thus, at a cost of one trillion yen, shelters that could accommodate one million people could be built. Of the Iwate Prefecture's population of 1.2 million, more than 1 million live inland and only about 200,000 live on the coast. This means that the cost of making the 200,000 people living in the coastal areas of Iwate Prefecture safe from a giant tsunami is only 200 billion yen, which is equivalent to the cost of only 80 km of seawall.

The government has announced that 230,000 people will die in the massive tsunami following the Tonankai earthquake, which is predicted in the near future (Miyazaki and Nagamatsu 2020). The chance of this earthquake occurring within the next 30 years has been estimated as 70%–80%. Thus, day-care centers and schools in coastal towns need to be equipped with tsunami shelters urgently.

The Japanese archipelago is a disaster zone where 40% of the world's major earthquakes have occurred. Since ancient times, people in Japan have lived in fear of the tsunamis that strike at intervals of several decades. However, if enough suitably equipped tsunami shelters were constructed, it would be possible to reduce the number of deaths from tsunamis and large fires to zero.

CONCLUSIONS

The ineffectiveness of the Japanese government's tsunami countermeasures has been demonstrated by the fact that four tsunamis have severely damaged Japan in the 115 years since the Meiji Tsunami. Besides the three large tsunamis occurring nearby, a tsunami sourced from distant Chile caused casualties. Seawalls can easily be destroyed by tsunamis that scoop up sludge and sediment from the seabed, and all flat areas near to the coastline should be considered danger zones.

Tsunami shelters that are designed to remain at the bottom of a tsunami are inexpensive and offer reliable protection. If the Building Standards Law is revised to require the creation of air reservoir-type tsunami shelters in buildings in coastal areas, this will provide relatively inexpensive protection from moderate tsunamis at little cost.

To protect against giant tsunamis, submarine-type tsunami shelters should also be built. This type of shelter, which can accommodate 200,000 coastal residents in Iwate Prefecture, can be built for 200 billion yen, the cost of 80 km of seawall. Subways and underground malls could also be used as tsunami shelters if they were suitably equipped. By installing shelters such as these in coastal areas, the number of deaths due to tsunamis and large fires could be reduced to zero.

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