International Journal of Navigation and Port Research
Vol.29, No.4 pp. 319~325, 2005 (ISSN-1598-7701)

The Influence of Tsunamis on Moored Ships and Ports

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Abstract : *Planning for the construction of ports and harbors usually takes place without the consideration of tsunamis because of their rare occurrence, approximately once every 100 years. However, recent warnings indicate that massive earthquakes could occur in Japan within the next 30 years. Earthquakes may generate large-scale tsunamis. Therefore, any tsunamis in the vicinity of Japan would also be expected to affect eastern Korea.*

Therefore, with the looming concerns of tsunamis and earthquakes, immediate attention must be given to the planning of ports and harbors. The warnings deserve an immediate response. The threatened regions cover a very large territory, and the degree of severity of the tsunamis is forecasted to be varied. Therefore, any modeling of the potential scenarios will require a broad array of possibilities. The objective of this paper is to consider the potential damage from tsunamis to ports and moored ships in Japan and Korea.

In addition, consideration will be given to how the construction plans of ports and harbors should be changed to cope with the threats from earthquakes and tsunamis.

Key words : *Tsunami, Moored ship motions, Ports and harbors, Potential scenarios*

1. Introduction

A natural disaster was not a conventionally assumed object of examination in port and harbor planning because its return period was too long.

However, recent warnings indicate that there is a potential risk of massive earthquakes in Japan within the next 30 years. These earthquakes could produce large-scale tsunamis. Then, these potential calamities could also affect Korea. Although big earthquake does not occur generally in Korea, there was damage inflicted by the tsunamis generated in Japan in 1983 and 1993 years.

This is the first time that a big earthquake is being argued in modern ages. For this reason, there is no precedent. Consequently, we need to consider an assumed scenario according to the opinion exchange of experts and numerical simulations.

This paper is the first step toward a detailed examination of the main problem. We show the importance of a tsunami research from harbors and ship activities by showing many possible scenarios. A tsunami has a great impact on ships, harbors and logistics after an earthquake disaster

Furthermore, it is necessary to distinguish the case where the return period is long in earthquakes as being different from the case where the long periodicity is decided from probability theory.

2. Potential scenarios of tsunamis on ships and ports

2.1 The characteristics of a tsunami wave

1) Periodic characteristics of a tsunami

Generally, tsunamis can be generated when the sea floor abruptly deforms and vertically displaces the overlying water, hence it is brought that the rise and descent of a loose water level.

Tsunamis have the characteristics of a long period wave from several minutes to about 1 hour, according to records maintained by the National Museum of Japanese History (2003). It turns out that those long period wave characteristics are amplified in a harbor or inside bay. The period of several minutes becomes an important factor in a resonance problem, when interacting with the natural period of a moored ship (Kubo et al., 1999).

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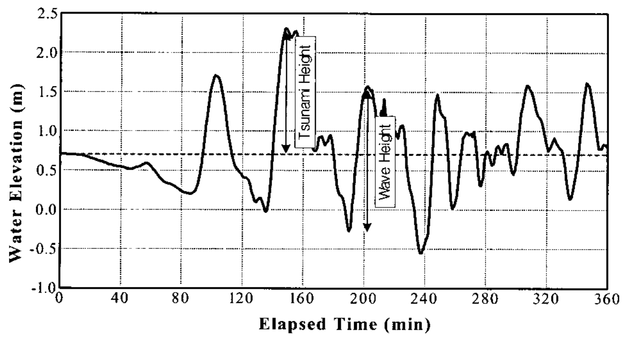


Fig. 1 Numerical calculation of a tsunami wave profile by Koshimura

Fig. 1 is an example of a numerical computation of a tsunami wave profile (Koshimura, 2003). It turns out that tsunamis have the various long period components. In this particular figure, the predominant period shows 50 minutes.

As the domain for the study of a tsunami becomes larger, a more detailed mesh is required in order to achieve an accurate numerical simulation. For this reason, detailed topographic effects will be discussed in a future work.

It is reported, as seen in a video taken during the 1983 earthquake in Japan, that the wavelength of the tsunami was comparable to the length of a fishing boat. Furthermore, it is said that the short period waves occur by reflection as the tsunami crashes against the islands. A sample computation of the height of the tsunami resulting from the Nankai earthquake and the Tonankai earthquake is reported now. According to this, when the height of the tsunami is about 5m in the pacific coast, then height of tsunami in the Setonaikai becomes about 2-3m. In this case, the Setonaikai is considered to be safe. However, from the viewpoint of periodicity, the reflection of the tsunami will be repeated for about 8 hours in the Setonaikai producing short period waves in the process. Thus, it produces a dangerous condition regarding moored ship. For these reasons, further improvement in the accuracy of numerical computation is required.

2) Duration of a tsunami

It is generally thought that the duration of a tsunami is brief. Although it is considered to be over after the arrival of the first wave, we had better think that it will continue for a considerably long time.

The reflection coefficient depends on the wavelength. Usually, wind waves disappear considerably easily because the reflection coefficient of beach or quay is 0.3 to 0.5. However, as the wave period becomes longer, the coefficient increases close to 1. It is for that reason that the coefficient on a boundary is set to 1 on the conventional calculations of harbor oscillations. Because of tsunami having the long period wave, the coefficient becomes closer to 1.

For this reason, reflection will be repeated inside the bay and it will not disappear easily. Consequently, in the case when there is a harbor inside a bay, it is necessary to consider the danger for both cases of high and low tide level.

When the tide is high, tsunamis progress inland wards. As a result, ships run aground. On the other hand, when the tide is low, ships become stranded.

3) Effect of the difference of wave direction by wave period

The period of a tsunami is shorter than a half day tide. For this reason, it will have a resonance characteristic according to the size of the bay or harbor. Fig. 2 shows an example in which the stream direction is calculated for different wave period inside the port (Kubo et al., 1996).

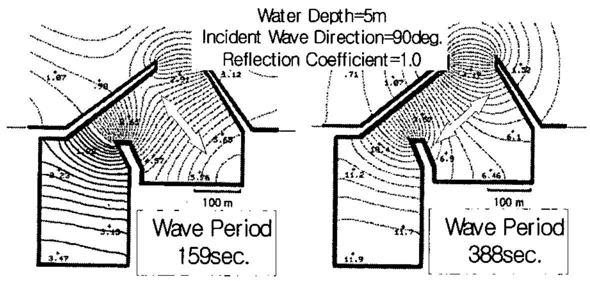


Fig. 2 Change of stream direction by wave period

It turns out that the direction of the current inside a port changes remarkably according to the wave periods. The difference in this current direction will have a big influence on the fluid dynamic force of a moored ship (Ueda, 1984).

(1) Influence on the fluid dynamic force of a mooring ship by the difference of current direction.

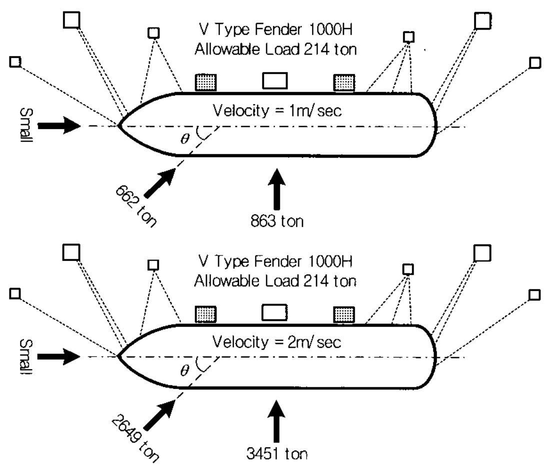


Fig. 3 Change of drag force by wave direction

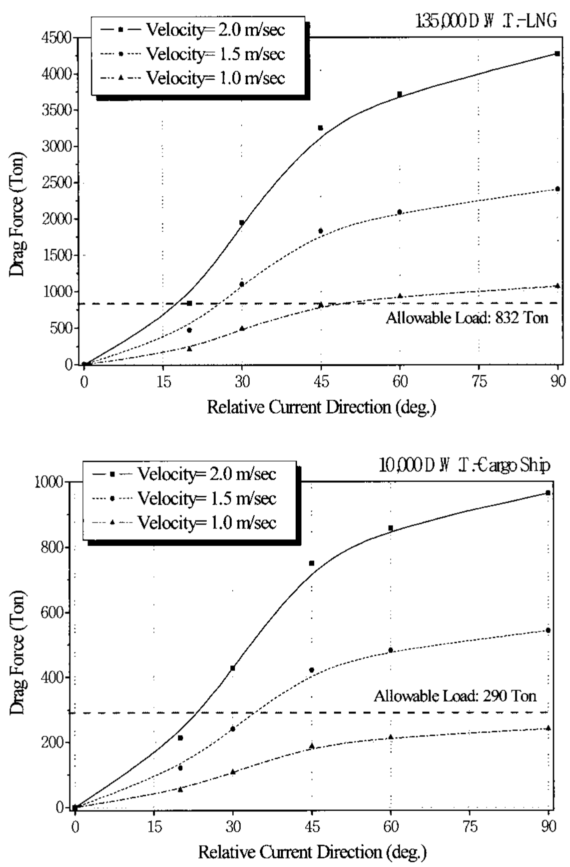


Fig. 4 Change of drag force by velocity

Fig. 3 shows the difference in the fluid dynamic force that a ship receives for the wave direction when a 10,000-D.W.T tanker is moored. Fig. 4 shows the result of the drag force in the case of a 135,000-D.W.T LNG and a 10,000-D.W.T cargo ship. If it received on a transverse direction and the flow velocity doubles, then the drag force increased 4 times by Eq.(1) (The Overseas Coastal Area Development Institute of Japan, 2002). Such a dynamic force translates into the destruction of fenders and breaking of mooring lines.

$$R=0.5\rho_0 CV^2B \quad (1)$$

where R is the drag force, ρ_0 is the density of seawater, C is the current pressure coefficient, V is the flow velocity, and B is the side-projected area of the hull below the waterline.

(2) Comparison of kinetic energy levels during an ordinary berthing and during a tsunami

The kinetic energy of a ship during berthing E_0 is given by $mV_0^2/2$, with m being the virtual mass of the ship and V_0 being its berthing speed. The kinetic energy of a ship E_t as it is being carried away by a current velocity V_t is given by $mV_t^2/2$. For this reason, the ratio of kinetic energy and kinetic energy at berthing is given by the following formula.

$$\frac{E_t}{E_0}=\frac{V_t^2}{V_0^2} \quad (2)$$

The berthing speed is about 10 cm/s, since when the current velocity of a tsunami is assumed to be 100 cm/s, the energy is 100 times higher. Considering the kinetic energy by a tsunami strikes, berthing facilities cannot bear it when a ship is being carried away.

2.2 Effect of water rising produced by a tsunami

1) The landing of the drifting material produced by a tsunami

A Tsunami has not only periodicity, but also entails high water level rise. This has certain similarity with storm tide under typhoon.

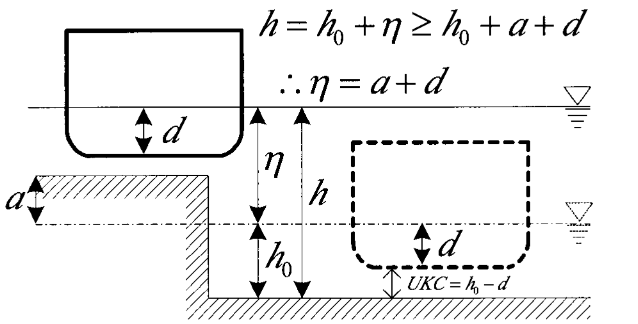
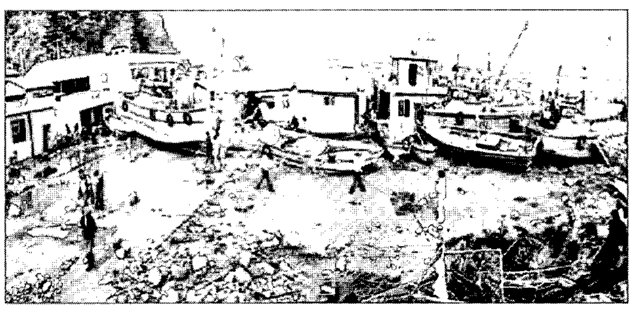


Fig. 5 Elevation of tsunami and landing condition of ships

Fig. 5 illustrates the geometric condition in case of a ship running on a quay. If the height of the tsunami(η) exceeds the sum of the height of the quay(a) and the drift(d), a ship landing occurs as depicted in this figure.



(http://www.nidp.go.kr/html/m3/research3/research3-3-3-2.html)

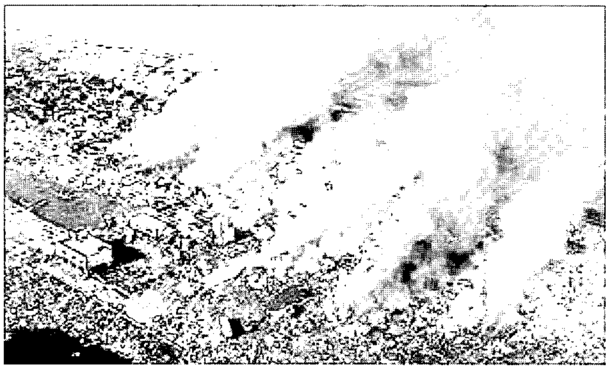
Fig. 6 Ship Landing at Imwon port in 1983

Fig. 6 is a photograph showing landed ships at Imwon port, Samcheok City in Korea, after the tsunami strike in

1983. On this photograph, a lot of ships can be seen to have run aground after the tsunami.

A small ship, a pleasure boat, a car, lumber and an empty container are afloat besides a big vessel. And it is necessary to examine destroying possibility of land structures like fuel tank, etc. by drifting objects.

These floating objects may end up occupying the road, and thus obstructing logistics. The recovery of land transportation starts by the removal of waste from the sea, while at the same time the main role for relief activities must be played by the maritime transport.



(http://www.dosanko.co.jp/okushiri/what/yume01.html)

Fig. 7 Large-scale fire disaster caused by fuel oil from a landed ship

2) Chain of tsunami and fire

It is generally thought that there is no correlation between tsunami and fire because of the tsunami being water. However, since vehicles such as ships and cars have fuel, they may cause a fire when being crashed by a tsunami.

Fig. 7 shows a large-scale fuel oil fire caused by a landed ship. According to a report, it is said that these fire were caused by ship fuel.

3) First big ordeal after modernization

The last massive earthquake occurred in the Edo era. At that time, the used energy was just firewood. And judging from an aspect of a fire, it may be said that it was a very tough social system.

On the other hand, our present life is carried on with the help of energies such as oil, LNG and LPG. Many energy facilities are located in areas along the shore. Therefore, city life and energy facilities are closely related.

Following the process of modernization, cities have grown closer to and more dependent on energy related facilities. If a fire breaks out in an oil tank, it is said that it would be necessary to use every available fire extinguisher in the country to put it out. It is known that given the right circumstances, an earthquake with a period of 5-7 seconds may cause sloshing phenomenon inside a tank as to break the tank lid and cause a fire by the release of oil fumes. Fire prevention measures will become an urgent problem as long as oil remains being the energy fueling our lives.

It is necessary to consider the possibility of tank destruction either by the force of the impact wave of the tsunami or by collision with objects adrift.

It is the opinion among the people concerned with tsunamis, that fuel tanks along the shore should be underground as a way of minimizing risks in case of a tsunami strike.

4) Tsunami hazard chain

As noted before, big external forces that we had never considered until now do act on vessels and fuel storage tanks. We should not consider the phenomena individually, but as a chain instead.

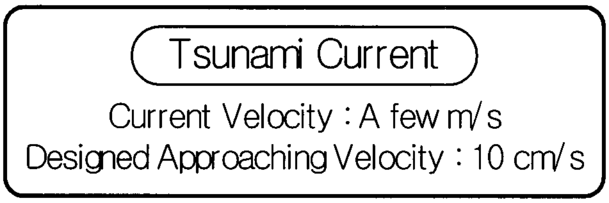


Fig. 8 Effect of tsunami current

The external force of the tsunami current produces a big fluid dynamic force that affects ships. As depicted in Fig. 8, a conventional design is planned for an approaching velocity of about 10 cm/s. The flow created by a tsunami is of several m/s. If a ship rides on that current, it would collide with a quay with almost same speed. In this case, kinetic energy increases drastically and will exceed the strength limit of the facility (Kubo et al., 2001).

It is possible for a tsunami to create such an external force starting a hazard chain which might lead to the spilling of hazardous material. This is shown in Fig. 9.

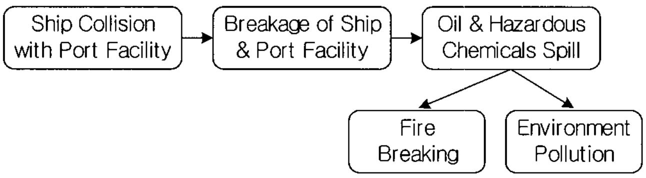


Fig. 9 Tsunami hazard chain leading to the spill of dangerous materials

Although the case of a big ship is considered in Figure 9, there are many objects in a harbor having a high potential to become adrift in case of a tsunami strike, i.e. small ships, fishing boats, pleasure boats, cars, lumber, etc. Since most countries have empty containers stored on coastal regions, they could easily become adrift. As fishermen live close to their fishing boats, they could have an immediate response in case of a tsunami. However, since there are almost no owners of pleasure boats living near the harbor, they could hardly respond in time. It is because of this reason that there is a strong possibility for pleasure boats to become adrift.

When such objects are carried away by the high current velocity, and collide with the other objects, they will be destroyed. The most dangerous objects are fuel and hazardous material storage tanks.

In the worst scenario, an outflow of oil or flammable liquids such as LNG and LPG would take place. If such a flammable substance leaks out, it would ride on the tsunami and spread with it. If the spill reaches a populated area, it could result in a fire and if it spreads out into the sea it may lead to fishery damage. Whenever there is an accident resulting in oil spillage, the consequences will be disastrous.

Considering what is mentioned above, the phenomena occurrence probability differs according to whether it happens inside a harbor or at berth. In the future, these issues need to be accurately evaluated. Moreover, research on how to cut off the potential scenario becomes important. If we can evaluate this problem, then prevention measures could be naturally implemented.

5) Ship escape from port

When many ships in port begin to escape at the same time in a disorganized manner, confusion or collision may take place near the harbor entrance. In such a case, the harbor entrance could be blocked. Being contrary to the original intention, greater damage might occur.

A tsunami is similar to a storm tide under typhoon. Then a continuous water rise takes place. We must keep in mind that because of this water rising, the current has a remarkable high speed from the outside of the harbor towards the inside. For this reason, it is said that an escaping ship could be pulled back inside and then meet with a disaster. The escape should be attempted with enough time margin before the arrival of the tsunami.

Consequently, it is important that by prior agreement a refuge place should be appointed for disaster reduction in every port.

In addition, most large harbors are under the control of a harbor authority or a vessel traffic system, in which case it is necessary to follow the direct operations including the forced movement of vessels if deemed necessary.

6) Sand drift, waterway burying, stranding and ceasing of logistics function

Generally, the current in a port is weak and its velocity is less than 1 knot. However, in the case of a tsunami the velocity is nothing like this. According to a numerical computation, it is said that a current of 8 knots could appear at the harbor entrance.

Such a strong current poses a big threat to a ship. It also causes the sand at the sea bottom to drift which might result in the filling of channels, ship stranding and the closing of the port. Under these circumstances it would make entering ports impossible and would cause the ceasing of all logistic functions.

3. Coping with port works

3.1 The problem of support work

Ship activities are supported by many cross-industrial workers. For example, when a large ship carry out an urgent departure, the support of tugboat is needed. However, the tugboat also needs its own refuge. In other words, the range of possibility of mutual cooperation has to be settled between cross-industrial worker.

Usually, it cannot be said for the ships to go out all at once from the harbor. It is necessary to decide an order of departure for many ships to escape from the harbor in a short time. In other words, the present system cannot respond adequately in the case of an emergency. It is also necessary to investigate which ships can stay in port without need of an urgent departure.

3.2 Examination of urgent own departure

A large ship cannot leave port without the support of a tugboat. It is necessary to also investigate the possibility of leaving port by its own means, even at the risk of damaging the ship or the quay facility according to the circumstances. In order to leave port without tug support, we should examine the rearrangement of harbor facilities, as well as the mooring of the ships in order to allow an easier and faster departure by its own means. For example by mooring ships looking towards the harbor entrance instead of the opposite case.

4. Taking tsunamis into consideration at port planning

4.1 Periodicity of tsunami

There was an evaluation item about a tsunami by a conventional harbor plan, but it actually excluded from an evaluation object. Since there has been almost no ship damage by tsunami in the past, it is thought that it has been removed from evaluation item until now.

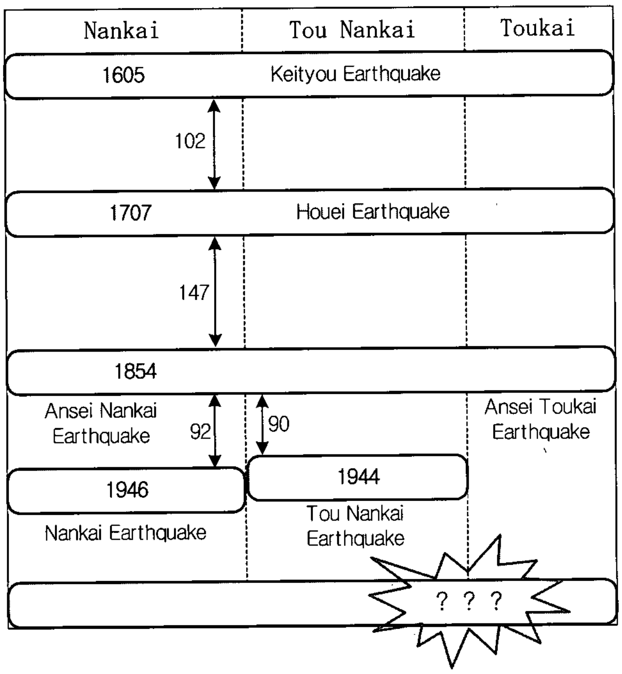


Fig. 10 Earthquake intervals for a prolonged period (unit : year)

Fig. 10 shows the earthquake intervals for a prolonged period in Japan. As it goes back historically, it turns out that these earthquakes happened with a certain periodicity. In this case, the probability of occurrence certainly increases with every passing year since the last time when it happened.

4.2 Taking tsunamis into consideration at port planning

It is thought that a process mentioned above is the reason why tsunamis have not been considered during harbor planning until now. However, as harbor planning is being reconsidered, we realize that this was clearly a mistake.

It is required to reexamine port plans from such a viewpoint from now on. It is reported that there is a high chance for a tsunami to strike around the year 2030. Because there still remains considerable time, we should review those things that can be corrected by making changes in port rearrangement.

5. Conclusion

The main conclusions of this study are summarized in the following paragraphs.

(1) This tsunami matter began after modernization. A potential scenario setting becomes important because there is no precedent. For this reason, we enumerated disaster scenarios from the viewpoint of the tsunami accident prevention.

(2) In order to achieve the best numerical computation it is very important for researchers and managers in charge of port arrangements to exchange opinions on the matter.

(3) In the future, port plans should be formally estimated with regards to natural periodical disasters such as tsunamis. Furthermore, we should also put port rearrangement plans through a wider range of considerations. We wish to continue the research in order to be able to cope with the extension of damage from the coast to populated areas in the future.

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Received 29 April 2005
Accepted 24 June 2005