Investigate the Effectiveness of Seawall Construction using CADMAS Surf 2D

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Abstract. Tsunami that hit Japan in 2011 shocked the world. The earthquake at the coast of the Pacific Ocean was 9.0 on Richter scale leading to 10 meters of wave. The epicentre was reported to be off the coast of Oshika Peninsula, at the east coast of Tohoku, at a depth of 244 kilometres. The earthquake and tsunami caused more than 20,000 victims in six prefectures. In an effort to anticipate to the tsunami, Japan has long build walls around the beach directly face the Pacific Ocean—the walls are known as seawall. In this paper, facts show that the effectiveness of seawall in reducing the energy of tsunami is accompanied by tremendous destructive energy. Analysis in this research was done using a software named CADMAS Surf 2D with numerical analysis method. Observations were made using two variants of heights of seawall, two meters and three meters. Both are observed based on the heights of the wave coming from the Ocean, after passing through the seawall, and at some points of observation. The level of damage caused by the seawall was due to turbulence just behind the construction that resulted in crushing, scouring, and or destructive energy, the energy was even bigger after passing the seawall. Nevertheless, tsunami wave height and velocity decreased significantly after the seawall.

1 Introduction

The earthquake and tsunami was the most devastating natural phenomenon in human civilization. Both strike without warning, affecting all levels of society, in the form of losses of life, injury, property damage, and changes in socioeconomic structure. Several major earthquakes caused by tsunami, which in turn affects the condition of coastal and island communities [1].

Tsunamis can be generated by geophysical phenomena such as earthquakes, volcanoes, submarine landslides, and meteorite impacts. Historically, tsunamis in the world (1790 to 1990) are mostly generated by earthquakes (90.3 percent), volcanoes (6.4 percent), and landslides (3.3 percent) [2-3]. According to the Integrated Tsunami Data Base, at least

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1,963 tsunamis have been recorded since 1628 to 2005 [4]. Earthquakes with a relatively close distance generate most tsunamis in tsunami-prone countries. As a result, the arrival of the tsunami varied from a few minutes to tens of minutes or a few hours. In such cases, the death toll from the tsunami waves can be very large, as seen in Aceh, which is located very close to the epicenter of the Indian Ocean, 2004. For other countries further away from the epicenter, the arrival times vary from one or two and up to ten hours. For example, Sri Lanka, India, and Thailand were struck by the 2004 tsunami around 2 and 2.5 hours after the quake. Some research shown that numerical simulations can predict the arrival time in such good enough way. History of the tsunami disaster showed that Indonesia is the country most vulnerable to tsunamis [5].

In this study, analysis was performed using numerical simulations to determine the behavior of the current wave hitting the seawall, when passing through it, and right after passing the walls. There are several important phenomena related to the failure of the seawall to halt tsunami, and this research report will show some of the facts related to the reduction rate of waves, decreased inundation, but with bigger destructive energy.

2 Literature review

Seawall is a huge wall built on the seafront, which is intended as a protector toward sea waves. Seawall to protect the city from tsunami waves is built high enough to prevent tsunami waves. In fact, seawall aimed as protector of the tsunami wave is one of the factors leading to the worst effect of tsunami itself. It can be seen from the massive damage despite being fortified by the tsunami retaining structures. One thing that must be understood to date is that the structure of any kind has not been able to withstand the enormous catastrophe of tsunami. Experience shows that buildings that surround the beach are directly destroyed when the tsunami comes (Fig. 1).

Fig. 1. Tsunami overtops seawall [6].

Seawall in the beginning is intended to withstand tsunami. The construction which is unsound or not in accordance with the magnitude of tsunami simply destroys it when the first wave comes before it reaches the buildings located around the coast. It becomes fatal when the tsunami moves with hydrodynamic force, a dynamic force that may increase from time to time. Therefore, when seawall is not able to withstand tsunami waves and then destroyed, then the collapse of the seawall will only increase the hydrodynamic force of the tsunami; and this is worse when seawall is built using concrete with large internal energy. Just imagine the accumulation of a large tsunami hydrodynamic force due to the collapse of the seawall, which makes the accumulation of tsunami wave to easily overtop and move quickly to settlements.

In the last decade, the construction of seawalls continues to grow, and at least two major anti-tsunami seawalls are under construction. One in Kuji, a city in Iwate Prefecture once damaged by the tsunami and is scheduled to be completed soon. Seawall in Taro City is regarded as one of the most powerful anti-tsunami achievements in the world. It was built about 10 meters (30 feet) after the Sanriku quake in 1933 when the tsunami destroyed the village (Fig. 2).

Fig. 2. Collapsed seawall after being hit by tsunami [7].

3 Methode

This study uses CADMAS-Surf / 2D to perform numerical simulations. The equation used is composed of the continuity equation, the Navier-Stokes equation in the x-direction and the z direction as advection equations to discover water level. Last equation includes the F functions (x, z, t), which means the ratio of the volume of water in each cell numerically.

$$\frac{\partial \gamma_x u}{\partial x} + \frac{\partial \gamma_z w}{\partial z} = S_p \quad (1)$$

$$\begin{aligned} \lambda_v \frac{\partial u}{\partial t} + \frac{\partial \lambda_x u u}{\partial x} + \frac{\partial \lambda_z w u}{\partial z} = & -\frac{\gamma_v}{\rho} \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left\{ \gamma_x v_e \left(2 \frac{\partial u}{\partial x} \right) \right\} \\ & + \frac{\partial}{\partial z} \left\{ \gamma_z v_e \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right\} - D_x u + S_u - R_x \end{aligned} \quad (2)$$

$$\begin{aligned} \lambda_v \frac{\partial w}{\partial t} + \frac{\partial \lambda_x u w}{\partial x} + \frac{\partial \lambda_z w w}{\partial z} = & -\frac{\gamma_v}{\rho} \frac{\partial p}{\partial z} + \frac{\partial}{\partial z} \left\{ \gamma_z v_e \left(2 \frac{\partial w}{\partial z} \right) \right\} \\ & + \frac{\partial}{\partial x} \left\{ \gamma_x v_e \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right) \right\} - D_z w + S_w - R_z - \gamma_v g \end{aligned} \quad (3)$$

$$\gamma_v \frac{\partial F}{\partial t} + \frac{\partial \gamma_x u F}{\partial x} + \frac{\partial \gamma_z w F}{\partial z} = S_F$$

In the above equation, t mean time, x and z are horizontal and vertical coordinates, p is pressure, u and w means of horizontal and vertical velocity components. Then ρ is the fluid density, ν is the summation of the molecular kinematic viscosity and eddy kinematic viscosity, g is the acceleration due to gravity. $\nu \gamma$ is porosity, γ_x and γ_z is a component of air porosity, SF, Su and Sw is the source of wave generation, Dx and Dz is the coefficient for the sponge layer, and Rx and Rz is a resistance component due to the porosity on the x axis and z.

Figure 3 is a schematic waveform flume for numerical simulations in the study. Flume has a length of 750 meters and height of 35 meters. Offshore depth wave is maintained at 10 meters as shown in Figure 3. The slope of the beach is 1/25. The size of the grid for the numerical simulation of the x and z direction are set respectively as 0.25 meter and 0.25 meter.

Fig. 3. schematic waveform flume for numerical simulations.

In the numerical simulation, it is assumed that the topography in numerical flume is in watertight condition, and the flatness of the topography is set as the original form so that the behavior of the wave before entering the beach will be the same as the original.

Based on reports from the height of the tsunami observed in the village of Lampon [8], numerical simulation in this study produces the type of bore waves like a tsunami with a height of 6 meters. This bore wave will produce a puddle with a height of around 3.5-5.0 meters on the shoreline. Simulation using CADMAS-Surf 2D takes time streak based on water level and velocity of fluid at the beginning of the boundary line so that it can generate tsunami waves with such profiles. This study assumes bore profile in offshore areas at first, and the velocity profile associated with the bore wave profile is obtained by using the equation below [9].

$$U = \frac{C\zeta}{H} = \zeta \sqrt{\frac{g(H+h)}{2H(H-\eta\zeta)}} \quad (4)$$

In this equation, U means the speed of an average water depth and g means gravitational acceleration. Which value of $H = h + \zeta$ means the total depth of the datum and ζ also means the height of temporal bore. And η is the coefficient derived from the ratio between the water depths early in the propagation area of total depth and set as 1.03 in this study.

4 Results and discussion

In this study, observations were made on water level and flow velocity was measured at three locations, 350 meters, 600 meters, and 625 meters respectively. The measurement points were chosen as a reference point for evaluating the effects of a reduction in the flow of tsunami inundation as shown in Figure 3 above.

Theory of the pressure profile of the impact of waves on the walls has been studied in detail by Peregrine [10]. It is said that violent impact of waves on the walls makes the speed and pressure to have far greater magnitude than those associated with ordinary wave

propagation under gravity. This effect has been obtained by calculation of irrotational flow and to investigate the role of propagation and effects of trapped airwaves.

Figure 4 shows snapshot of the tsunami inundation in Cases 2 and 3 while Case 1 is a simple case where there are no obstructions on the topography of seawall. Reflection of flow can be observed on the ground slopes away from the wall when the flow overtops this embankment configuration. Reflections of this flow become greater at the measurement point of 350 meters after the waves hit the seawall.

Fig. 4. Snapshot on Case 2 and 3 at t 60 seconds.

Fig. 5. Profile of maximum inundation and velocity of the wave at the measurement point of 350 meters, 600 meters, and 625 meters.

Reflection of flow at 600 and 625 meters respectively decreased approximately 1.00 meter compared to Case 1. Figure 5 shows the surface profile of the water and the speed at the location of 625 meters of the boundary input. Table 1 below shows the maximum value for the depth of flow and velocity obtained at several measuring points.

Table 1. The maximum inundation and velocity of the wave at the measurement point of 350 meters, 600 meters, and 625 meters.

Case	Wave height (m)			Velocity (m/s)		
	350m	600m	625m	350m	600m	625m
1	6.18	3.24	3.15	7.01	6.42	6.29
2	5.02	2.43	2.28	6.82	5.71	5.48
3	4.53	2.11				

Table 1 shows the maximum inundation and velocity of the wave at the measurement point of 350 meters, 600 meters, and 625 meters from the profile at Figure 5. By analysing the waves ovetop the seawall, we can calculate the value of the Froude using the following equation.

$$Fr = \frac{v}{\sqrt{gh}}$$

(5)

Gravitation and wave height in this equation is used to calculate the speed for small amplitude on the long wave of the shallow water. It is obtained by assuming the hydrostatic pressure in the momentum equation. Hydrostatic assumption is no longer valid and the wave velocity depends on the wavelength.

Table 2. The Froude value at the measurement point of 350 meters and 600 meters

Case	350			600		
	v	h	Fr	v	h	Fr
2	6.82	5.02	0.96	5.71	2.43	1.16
3	5.91	6.18	0.75	5.45	2.11	1.19

Table 2 shows the value of the Froude at the measurement point of 350 meters and 600 meters. In this table, it is known that $Fr_{350} < 1$ and $Fr_{600} > 1$, which means the flow of the waves at 350 meters is lower than usual and at 600 is higher. The influence of the flow of this phenomenon directly affects the coverage area of inundation on the ground because the horizontal force transformation that occurs in the case of a seawall.

Figure 6 below shows the behaviour of waves a few moments before and after hitting the seawall. From the figure below, it can be seen that waves come up with great speed and energy, having retained the seawall and then transcend and turbulence occurs directly behind the seawall bottom.

Fig. 6. Snapshot of tsunami waves hitting seawall.

Fig. 7.

Figure 7 shows the big volume of water that comes during the tsunami, and then passes the seawall, and causes continue turbulence at point A. Referring to Figure 2, it can be seen that the failure of seawall in Iwate prefecture is not because the seawall is damaged after the tsunami, but because the construction is toppled.

It is caused by erosion (scouring) on the sand foundation that the seawall is the toppled. In addition, the profile in Figure 8 shows that the velocity of the wave is going up and down with irregular frequency so that the destructive force behind the seawall becomes larger.

Fig. 8. Turbulence at the bottom of the seawall that could potentially.

One of the causes determining the amount of damage caused by the presence of seawall is that tsunami is a sea wave that moves with hydrodynamic power is a kind of force that may increase from time to time. When seawall built is not able to withstand the tsunami, it is actually going to add to the strength of hydrodynamic power.

If the seawall collapsed, the large internal energy adds to the hydrodynamic power making tsunami waves easily pass the seawall and quickly inundate settlements by bringing the seawall material.

5 Conclusion

Based on these results, it is known that the presence of seawall is capable of lowering the water level and reduces the speed of the wave at a distance of more than 300 meters from the construction of seawall. However, right behind the seawall, the opposite phenomenon occurs, the water level is getting higher yet the wave speed is not significantly reduced.

The large tsunami energy accumulates on the back of wave-retaining construction, where the dynamic hydrodynamic force is growing over time accompanied by the effects of turbulence. Turbulence in the incoming wave has resulted in erosion (scouring) at the bottom of the foundation, so the seawall is easily toppled a while after hit by the tsunami waves. According to the results of this research found that the seawall construction cannot reduce the effects of the tsunami. The existence of seawall construction adds horizontal force linear with greater energy which affected after tsunami hit the seawall.

References

1. Gajendra Prasad, Jack Rynn, Atu Kaloumaira, *Sci. Tsunami Hazards*, **18**, 35 (2000)
2. F. Imamura, H. Latief, N.T. Puspito, *Journal of Natural Disaster Science*, **22**, 25 (2000)
3. F. Imamura and H. Latief, *Proceedings of 2000 congress of Japan Society of Civil Eng.* (Tohoku Area, Morioka, Japan, 2000)
4. Tsunami Laboratory, *Integrated tsunami database for the world ocean*, (ICMMG SD, RAS, Novosibirsk, Russia, 2005)

5. H. Latief, D.H. Natawidjaya, H. Sunendar, A.R. Gusman, Y. Tanioka, *Proceedings third international conference on urban earthquake engineering, Japan*, 259 (2006)
6. <http://blogs.reuters.com/photographers-blog/2012/03/07/one-year-from-that-day/> (2014)
7. <http://www.gettyimages.com/detail/news-photo/collapsed-sea-wall-stands-in-an-area-damaged-by-last-years-news-photo/151756230>, (2014)
8. Y. Tsuji, F. Imamura, H. Matsutomi, S. Harada, Jumaidi, K. Arai, *Pure. Appl. Geophys.*, **144**, 839 (1995)
9. Y. Fukui, S. Hidehiko, M. Nakamura, Y. Sasaki, *Coast. Eng. J.*, **9**, 44 (1962)
10. D.H. Peregrine, *Annu. Rev. Fluid Mech.*, **35**, 23 (2003)