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MODELLING OF TSUNAMI FOR MULTIPLE MASS MOVEMENTS UNDERSEA

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Abstract

The purpose of this study is to determine the near-field amplitudes and their interactions of the multiple mass movements on the sea floor during the tsunamigenic earthquakes. To figure out the nature of the problem, for simplicity, twin masses moving toward each other are taken into account. Two different twin models are considered, one model includes two blocks, the other includes two slides. The interaction of near field tsunami amplitudes are discussed with different velocities, depths and distances related to masses, respectively. To define masses, two source models are assumed as the sliding and spreading blocks. This approach gives an opportunity to see the source model effect on tsunami amplitudes easily. Tsunami wave forms and tsunami peak amplitudes are presented for selected parameters. The results show that during the source process, when the velocity of masses are much faster than the velocity of tsunami, the displacements on the free surface above the source resembles the displacement of the floor. As the velocity of spreading masses approach the long wavelength tsunami velocity, the tsunami waveforms have progressively larger amplitudes. These large amplitudes are caused by wave focusing. As a result, source type is not a very effective parameter on amplitudes. The interaction of the tsunami waveforms are examined for different parameters, and also illustrated.

Keywords: Tsunami source model; near field tsunami amplitudes; interaction of tsunami amplitudes

1. Introduction

Tsunamis are one of the dangerous outcomes from activities of dynamic earth system. The official definition of tsunami is "a wave train, or series of waves, generated in a body water by an impulsive disturbance that vertically displaces the water column" [1]. Due to this characteristic, tsunami waves are different from normal sea waves. Tsunami wave has long wavelength and at long periods velocity of tsunami wave is equal to the square roots of the gravity acceleration and the water depth, $\sim\sqrt{gh}$. In the deep ocean, tsunami travels high-speed. Propagation speed makes tsunami one of the major natural disasters. To prevent this and to take precautions, it is necessary to know generation mechanism and approximate results about peak amplitudes. There are many studies about tsunamis modeling either analytically [2] or numerically in the literature [3]. Pioneering studies suggest that submarine slumps and slides may generate tsunami [4]. Also, tsunami generated by submarine slides using kinematic source models are examined. The purpose of those studies is to contribute to understanding of the nature of wave forms of tsunami. In this study, the interaction of two near field tsunami amplitudes are discussed with different velocities, depths and distances, masses are assumed as sliding blocks and slides. In some seas(like Marmara Sea) or oceans having the narrow edges where two slopes are opposite, the slums and slides might move toward to each other during the tsunamigenic earthquakes(see Fig1)

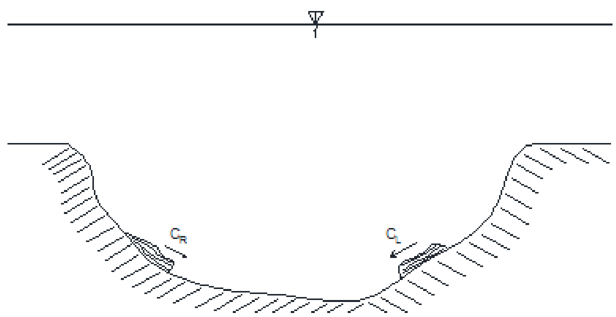


Fig. 1 – The schematical drawing of the original problem

Due to the assumption of the linearized shallow water theory, the problem turns into a linear type like Fig. 3. This simplification helps us to write and solve the equations of system. By this means, it will be possible to choose depth as constant. According to the velocity equation, there is a direct proportion between water depth and the velocity of tsunami wave. This relation shows that tsunami waves behave fundamentally different in the open ocean and close to the coast. To understand the effect of water depth on near field tsunami amplitudes, masses are investigated and illustrated for different water depths range from 0.5 km to 2 km. Since changing of water depth affects the velocities, the other examined parameter is velocity effect. Pioneering studies suggest that tsunami amplitudes have different values when the velocity of masses are faster , smaller or equal to tsunami velocity [5]. To find out the effect, two masses are taken into account in different directions with different velocities. To see how change the amplitude values related the interaction time different distances are considered.

2. Method and Theory

The basic kinematic model is used to define tsunami wave generation. That is the motion of a fluid domain, D, bounded by the rigid ocean floor at z= -h, and the free surface at z=0. ζ (x,y;t) is a sudden uplift of the bottom surface, resulting of the free surface uplift η (x,y;t).

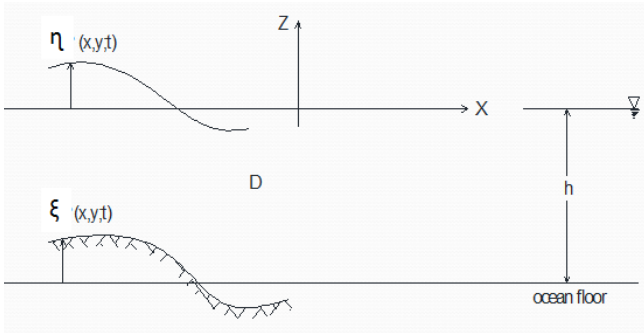


Fig. 2 – Mathematical model

If it is assumed that the fluid is incompressible and the flow is irrotational, the motion of fluid layer is such that the fluid velocity potential Φ(x,y,z;t) satisfies the Laplace differential equation[6], and the potential Φ (x,y,z;t) must satisfy the following boundary conditions;

$$\nabla^2 \phi(x, y, z; t) = 0 \quad (1)$$

$$\Phi z\,(x,y,z;t) - \eta(x,y;t) = 0 \quad \text{at } z=0 \quad (2a)$$

$$\Phi t\,(x,y,z;t) - g\,\eta\,(x,y;t) = 0 \quad \text{at } z=0 \quad (2b)$$

$$\Phi z\,(x,y,z;t) - \xi t\,(x,y;t) = 0 \quad \text{at } z=0 \quad (2c)$$

The solution can be obtained by the transform methods (Laplace in time and Fourier in space), defined as

$$\bar{f}(\vec{k};s) = \int_{-\infty}^{\infty} e^{ik2y}[\int_{-\infty}^{\infty} e^{ik1x}[\int_{0}^{\infty} e^{-st} f(x,y;t)dt]dx]dy \quad (3)$$

Transformation of the equation of motion and boundary condition, and the assumptions of linearity and shallow-water lead to the following solution for the transform of η , η(k;s), in terms of the transform of ζ, ζ(k;s).

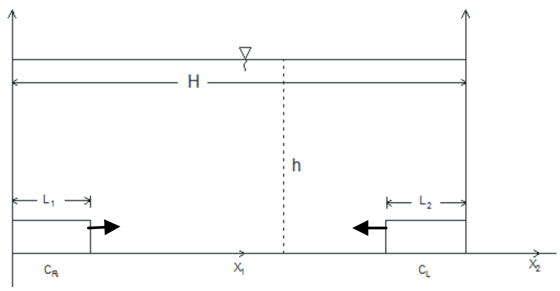
It can be evaluated η(x,y;t) for specified ζ(x,y;t) by computing its transform ζ(k;s), substituting it into following equation and inverting η(k;s) to obtain η(x,y;t);

$$\bar{\eta}(\vec{k};s) = \frac{s^2 \bar{\varsigma}(\vec{k};s)}{s^2 + \omega^2} \frac{1}{\cosh kh} \quad (4)$$

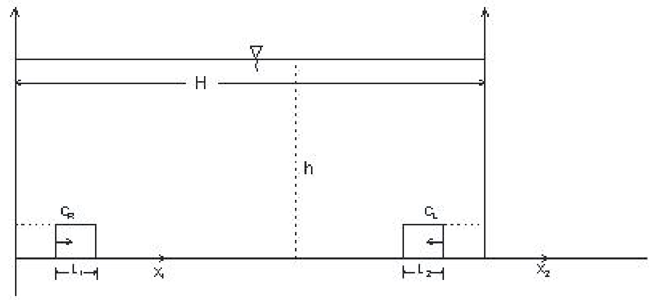
where

$$\omega^2 = gk \tanh kh$$

and ω is the circular frequency of the wave motion. To obtain final solution, following steps are calculated in order. Firstly, ζ(x,y;t) is transformed to obtain ζ(k;s), then η(k;s) is computed by using equation (4). Finally, η(x,y;t) is calculated by using inverse Fast Fourier Transform (FFT) method. In this paper, Mathematica programme is used for computing equations.



a) Submarine Slides, Model 1B



b) Submarine Blocks, Model-S1

Fig. 3 – Linearized simple kinematic models

In this paper, two main different source models are taken into account(see Fig3a,b). Formulation of motion of floor is computed as follow, by using these equations as noted above, final displacements can be calculated for each different cases.

$$\varsigma_R = \int_{L1}^{L1+cRt_1} e^{ik_1x}\Big(\int_{(\frac{x-L1}{cR})}^{\infty} \varsigma_0 e^{-st}dt\Big)dx - \int_{0}^{cRt_1} e^{ik_1x}\Big(\int_{(\frac{x}{cR})}^{\infty} \varsigma_0 e^{-st}dt\Big)dx \tag{5}$$

$$\varsigma_L = \int_{H-L2}^{H-L2-cLt_2} e^{ik_1x}\Big(\int_{(\frac{H-x-L2}{cL})}^{\infty} \varsigma_0 e^{-st}dt\Big)dx - \int_{H}^{H-cLt_2} e^{ik_1x}\Big(\int_{(\frac{H-x}{cL})}^{\infty} \varsigma_0 e^{-st}dt\Big)dx \tag{6}$$

The other model is for slides. When source models change, the equations also change. In second source model equation, two slides are taken into account in constant depth, and moving in different directions. Formulation of motion of floor is computed as follow, by using these equations as noted above, final displacements can be calculated for each different cases.

$$\varsigma_R = \int_{0}^{cRt_1} e^{ik_1x}\Big(\int_{(\frac{x}{cR})}^{\infty} \varsigma_0 e^{-st}dt\Big)dx \tag{7}$$

$$\varsigma_L = \int_{H-cLt_2}^{H} e^{ik_1x}\Big(\int_{(\frac{x-H}{cL})}^{\infty} \varsigma_1 e^{-st}dt\Big)dx \tag{8}$$

ζ_R represents the uplift of right slide and c_R is the velocity of right slide and ζ_L is for the uplift and c_L is velocity of left slide.

The solution in this article constitues in ‘linearized’ solution, which is known as the ‘shallow water solution’. It works well if the water depth is much smaller than the length of water waves. Inclusion of neglected non-linear terms in the boundary conditions would have permitted a solution involving solitary waves [7].

3. Numerical Results

To determine the effects of submarine multiple mass movements on the near field tsunami amplitudes using simple source model, two twin slides and blocks are taken into account in constant depth for different velocities in opposite directions. The interaction of two near field tsunami amplitudes are discussed with different velocities, depths and directions of mass movement respectively.

To understand the effect of these parameters on the amplitudes, two equal-sized sliding masses and blocks are considered as L x W = 30 x 30 km^2. *H* represents the distance between masses, *h* shows constant ocean depth, c_T is assumed as tsunami velocity, and t_1 is duration time of land slide motion. To see the velocity effect, three main scenarios are derived as Table 1. Ratio of mass velocities and tsunami wave velocity are different for all. Conditions of $c_R=c_L=c_T$, $c_R=c_L=50c_T$ and $c_R=c_L=0.5c_T$ are investigated for all models in this paper.

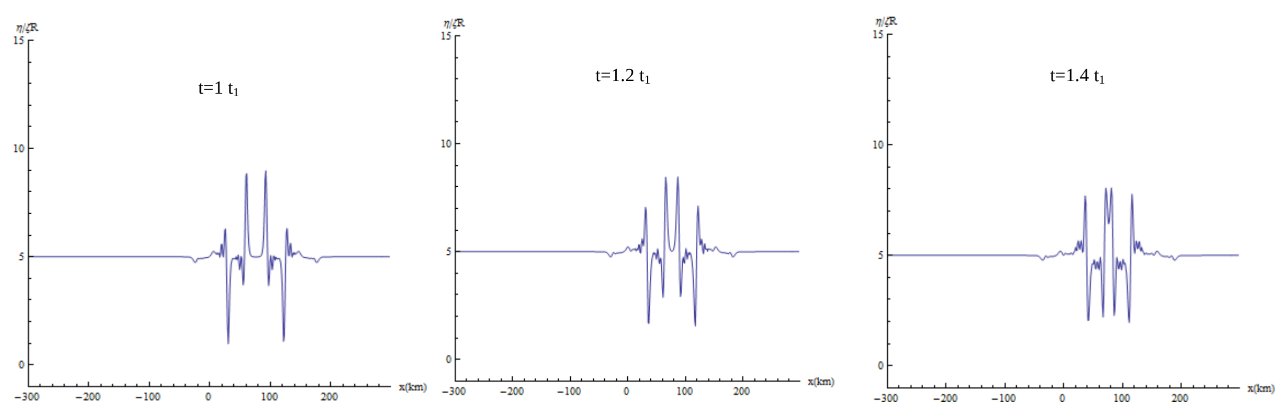
Table 1 – Scenarious for different velocities

Model	c_R/c_L	c_R/c_T	c_L/c_T	**Explanation**
1	1	1	1	$c_R=c_L = c_T$
2	1	50	50	$c_R=c_L > c_T$
3	1	0.5	0.5	$c_R=c_L < c_T$

This table indicates the ratios of velocities. Model 1, 2 and 3 are applied on both slide models that are called as Model-S and Model-B.

Moreover, two other cases are investigated that includes Model 1, 2 and 3. One case is about changing of water depth; the water depth is ranging from 0.5 km to 2 km, and for distance as *H*= 200 km, 100 km and 50 km.

Model 1 in Table 1 shows the first scenario, as that two sliding masses have the same velocity that is equal to tsunami wave velocity. In Model 2, masses move faster than tsunami. The last scenario is for slow movement of masses. To decide the effect of velocity, *H* is assumed as 150 km and *h* is assumed as 1 km. The following figures belong to the analysis results.



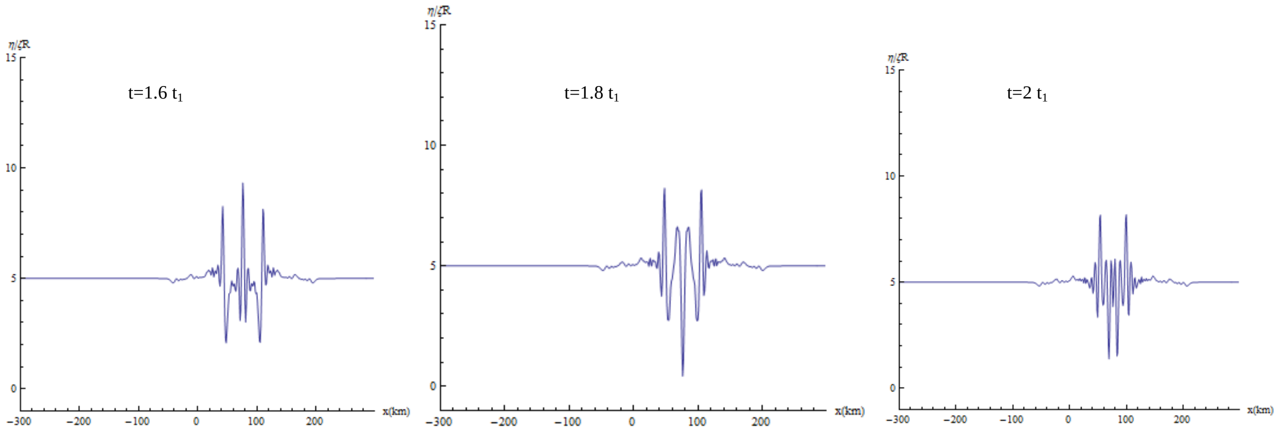


Fig. 4 – Model B-1 ($c_R=c_L=c_T$, block model)

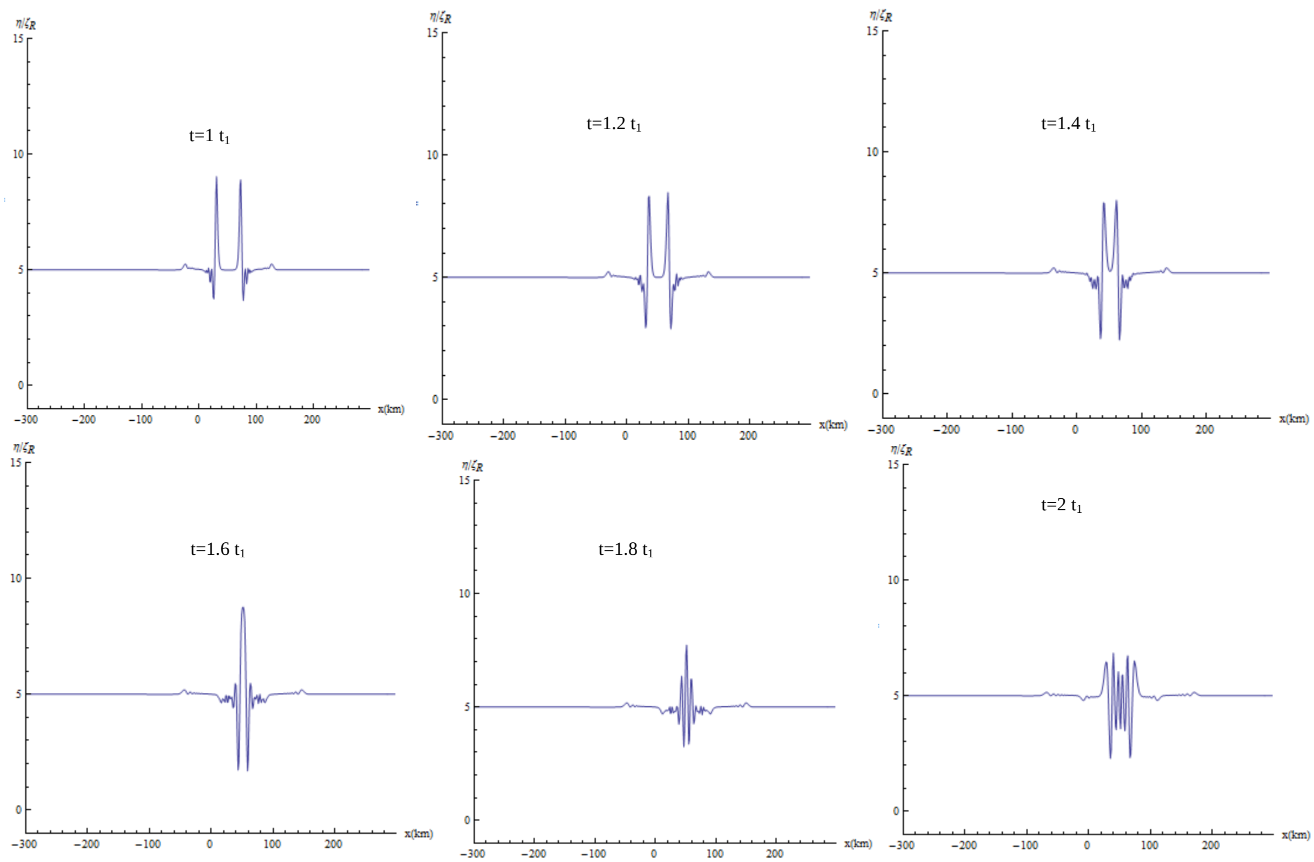


Fig. 5 – Model S-1 ($c_R=c_L=c_T$, slide model)

The amplitudes plotted versus the time. As seen in the fig.5, the amplitudes are changing while masses are approaching each other. At the time of interacting (at time t=1.6t1), the amplitude has the biggest value, and after this time the interaction decompose. The important point is that this case is valid for both Model S and Model B. In fact, as the velocity of spreading mass approaches the tsunami velocity, the tsunami waveform has progressively larger amplitude, and with higher frequency content, in the direction of slide spreading. These large amplitudes are caused by wave focusing.

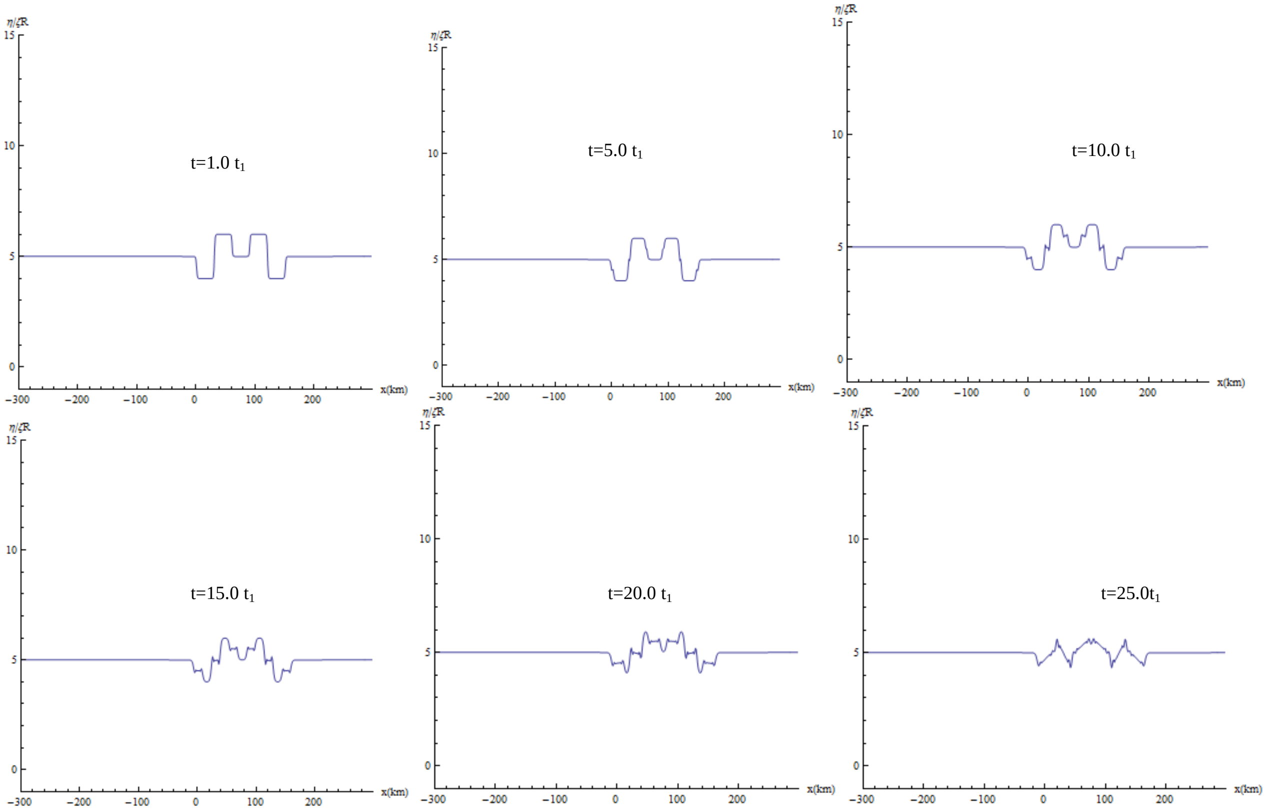


Fig. 6 – Model B-2 (c_R=c_L>c_T, block model)

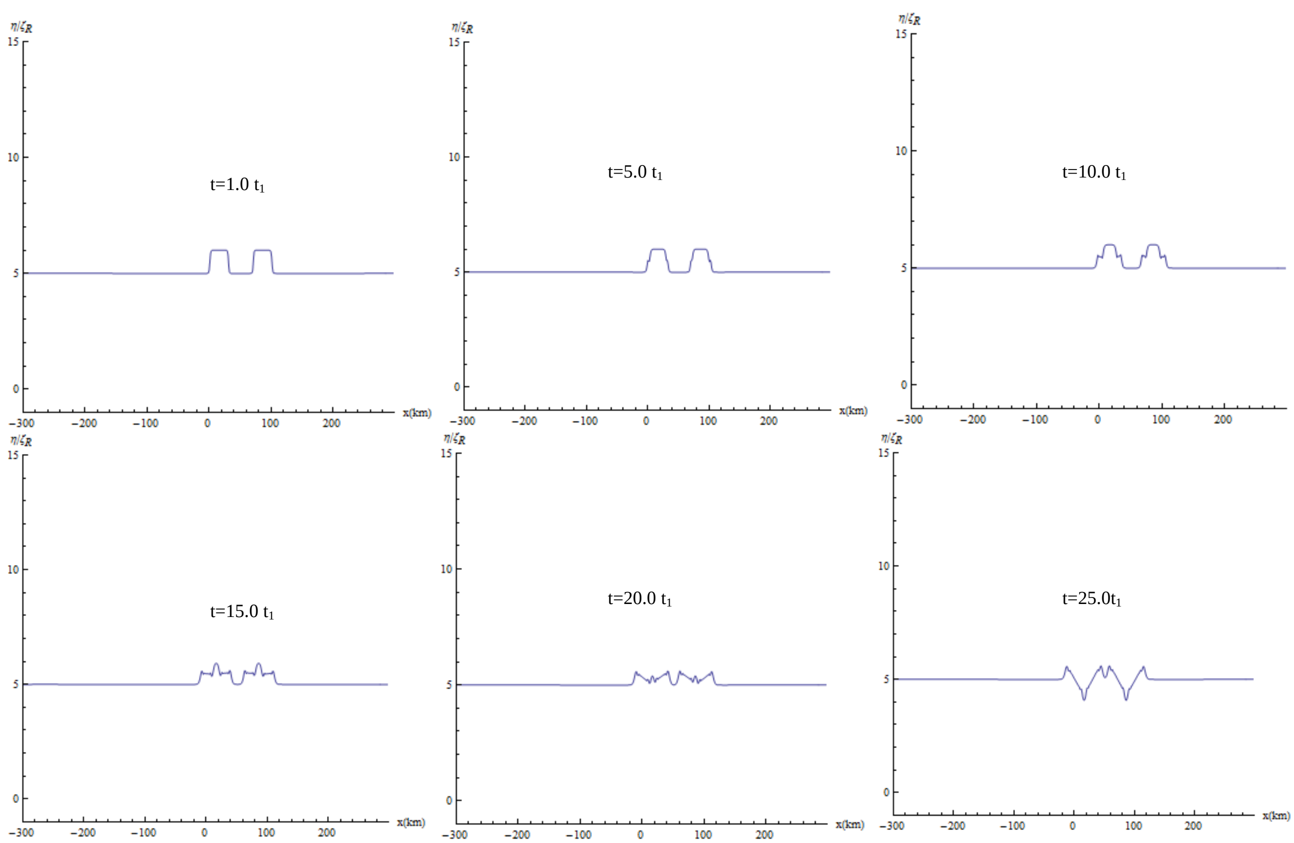


Fig. 7 – Model S-2 (c_R=c_L>c_T, slide model)

In figure 6 and 7, when the velocity of masses are higher than the tsunami velocity $c_{T,}$, the shapes of the wave forms have nearly the same as the shape of the masses. The other claim about shape of the masses which moves faster than the tsunami wave is similar to the shape of the wave forms as shown in fig.6 and 7.

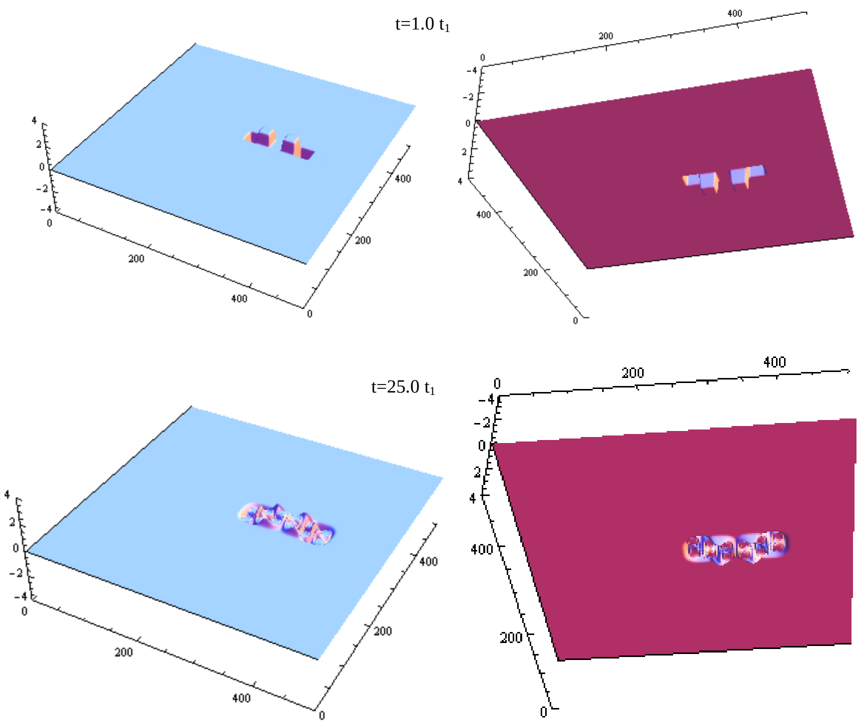


Fig. 8a – Model B-2 (c_R=c_L>c_T, block model)

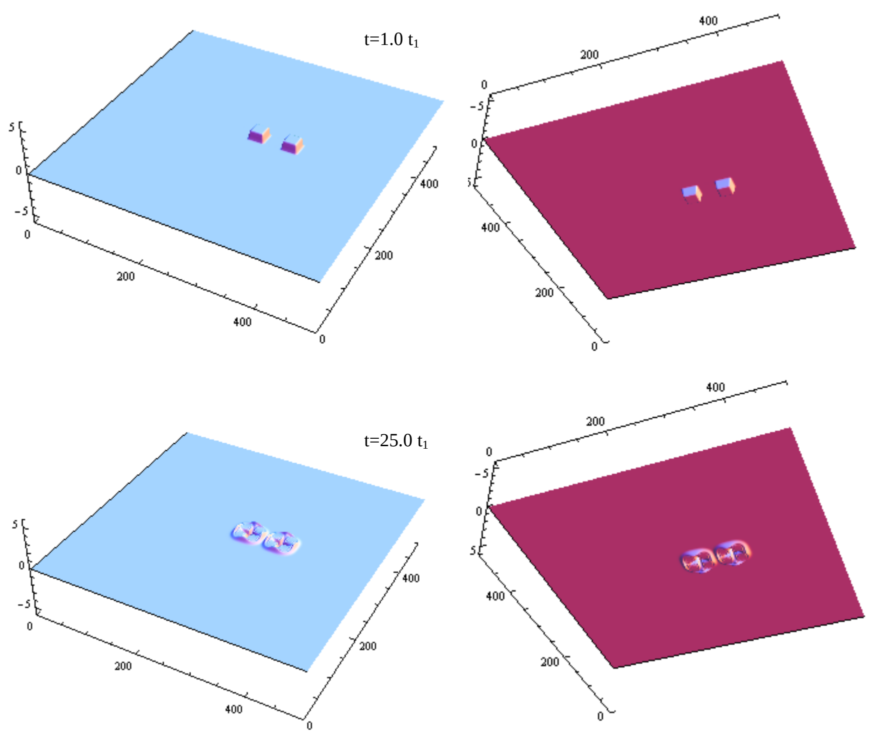


Fig. 8b – Model S-2 (c_R=c_L>c_T, slide model)

As seen from Fig.8a and 8b, deformations on the free surface and ocean bottom are the same at the duration time t_1 and after this time, dispersion of tsunami amplitudes take place.

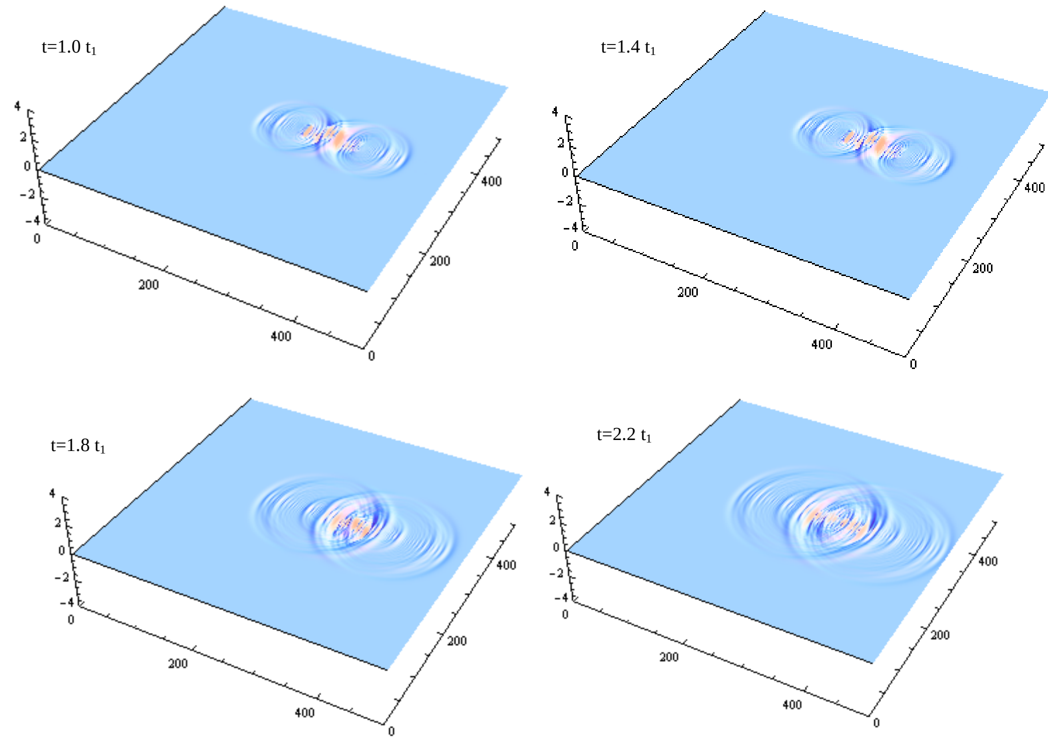


Fig. 9 – Model B-3 (c_R=c_L<c_T, block model)

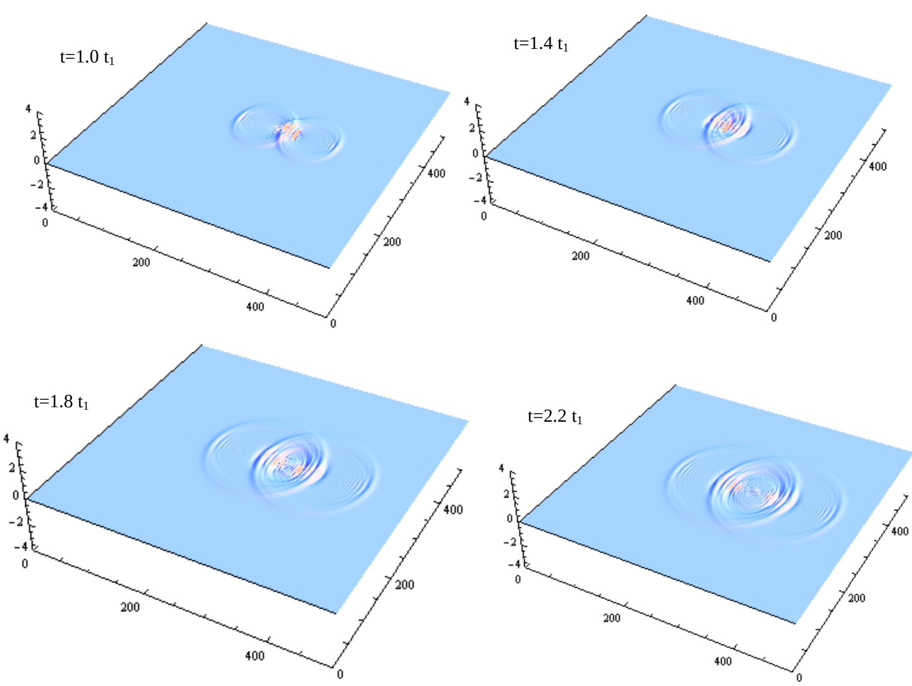


Fig. 10 – Model S-3 (c_R=c_L<c_T, slide model)

The fig.9 and fig.10 show that the amplitude values are very small when the velocities of masses, both block and slide, are smaller than the long wavelength tsunami velocity.

To see the depth effect on the amplitudes, some graphs are given in Fig. 11. Previous results show that the maximum amplitude values are seen on c_R/c_T ~1 (i.e. Fig.4). The following figure is a plot of the peak amplitude η_{max}/ζ_0 versus c_R/c_T for different ocean depths. The slide model is used.

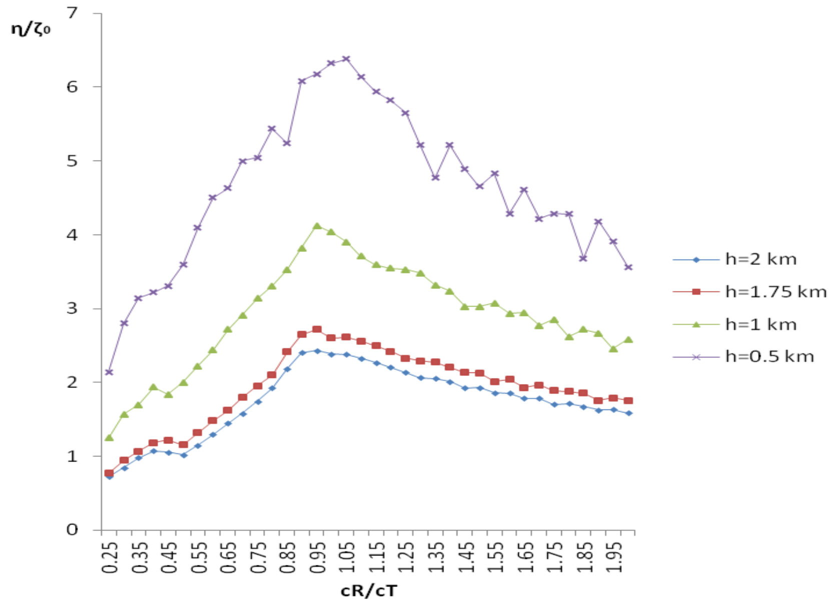


Fig. 11 – Positive peak amplitudes for different depths

According to the graph, the maximum amplitude values are seen on c_R/c_T ~1 for all depths. But the peak values change to the ocean depth.

As mentioned above, wave focusing is important factor to get higher amplitude values. The interaction time is essential parameter on amplitude values, too. It is thought that the distances between two masses affect the interaction time, and amplitude value by related this. The block model is used with different distances to investigate the distance effect. As the result of this investigation, it is seen that interaction time is shortening when the blocks are close to the each other. The interaction times are 6s, 3s, and 1.8s for H=200km , 100km and 50km respectively. The other outstanding result is that that the closer the blocks, the higher the amplitude. This result is illustrated as follow at the interaction time for all distances;

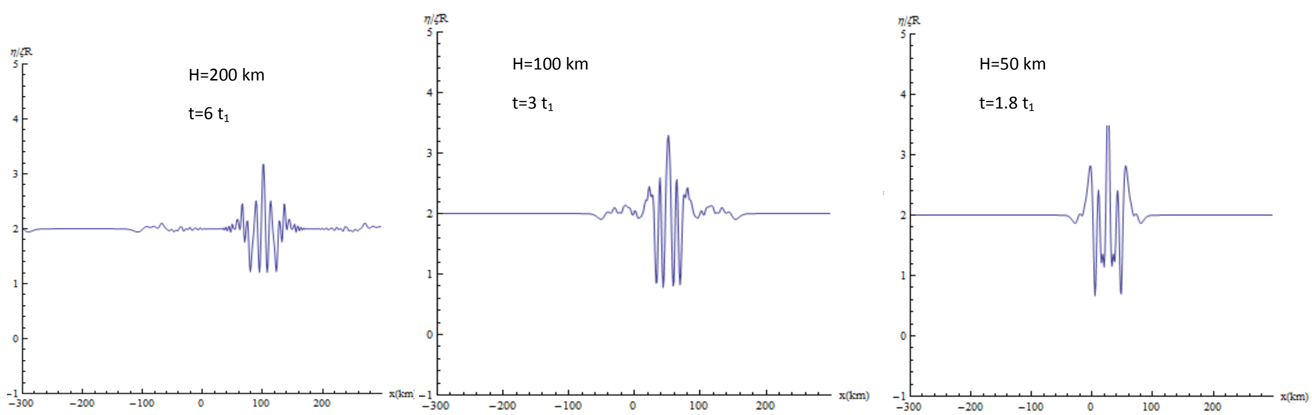


Fig. 12 – The peak amplitudes for different distances on the interaction time

4. Conclusions

The purpose of this study is to determine the interaction of the tsunami amplitudes, triggered by multiple mass movements on the sea floor, interfering with each other. Both the slide and block masses are considered. For simplicity, two twin masses for both cases are taken into account in this study. Simple source models are used to find out these near field tsunami amplitudes for these submarine masses, in the case of the same duration times. The results show that the tsunami amplitudes are predominantly generated by the spreading velocities and thickness of the masses, and water depths. For both models, similar results are observed. When the velocities of masses are much faster than the velocity of tsunami, the displacements on the free surface resemble the disturbances on the sea bottom. When the velocities of spreading masses approach the tsunami velocity, the tsunami amplitudes have gradually higher scales depending on the wave focusing phenomena. The tsunami amplitudes are getting amplify, while the tsunami wave amplitudes formed by a single mass approach each other. Due to the interaction, the highest amplitudes created by two masses are higher than the highest amplitudes derived by a single model. Finally, it is concluded that the wave interactions have big influences on the tsunami amplitudes.

5. References

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