Effect of a possible Anak Krakatau explosion in the Jakarta Bay

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Abstract

Plans to build a sea dike in the Jakarta Bay to solve the multiple water problems in the Jakarta area should take into account the possibility of tsunami waves from a possible future explosion of Anak Krakatau. To obtain a rough indication of the possible waves we took the waves caused by the 1883 explosion of the Krakatau as guidance. The inverse problem to determine a possible generation scenario that produces similar waves as in 1883 is considered here using a relatively simple phreato-magmatic explosion model. For the simulations we use a Finite Element implementation of a linear Variational Boussinesq model.

Keywords: *tsunami wave, tsunami initialization, Variational Boussinesq Model, Anak Krakatau*

I. INTRODUCTION

To tackle the serious and multiple water problems of the Jakarta area, one of various options is the building of a ‘Giant Sea Wall’ [1]. In view of the possibility that a tsunami may hit the Jakarta Bay (JB) at some time in the future, the wall should better be constructed in such a way it can withstand a tsunami. This is particularly important since the recent tsunami in Japan 2011 has made it clear that even specifically designed tsunami-defense walls could not prevent overtopping, and even some of them collapsed. Nonlinear effects play a significant role in the oblique collision of a tsunami against a wall. In Yeh [2] and references therein it is argued that the wave height during collision may be four times higher than the height of the incoming tsunami, very different from the linear theory that predicts at most a two-fold amplification. It will be wise to take this knowledge into account in the design of a possible sea wall in the Jakarta Bay.

In view of Jakarta’s position at the Java Sea, the most possible source of a tsunami seems to be an explosion of Anak Krakatau (AK in the following); see [3] for informal activity reports of the volcano. The explosion of the Krakatau in 1883 (K1883) caused a tsunami. Fortunately the resulting waves were measured in the Jakarta Bay, see Fig.1. Surface elevations of 2m crest height and negative elevations of 3m must have occurred at that time [4]; see [5, 6] for more information.

In order to be able to investigate the tsunami- wall interaction in more detail, more information than wave heights at one location only will be needed. Therefore our aim is to simulate tsunami waves in the Jakarta Bay that originate from a possible AK-explosion and resemble in a sufficiently good way the K1883 tsunami waves. This will be done in section II, where also details about the numerical code will be given. In Section III we present some results of the tsunami simulations. Conclusions will be formulated in Section IV.

II. TSUNAMI GENERATION AND PROPAGATION

In Subsection A we describe the numerical model that has been used for the simulations. In Subsection B the most critical aspect of the modeling is described: the initiation of the tsunami such that the waves in JB resemble the K1883-waves.

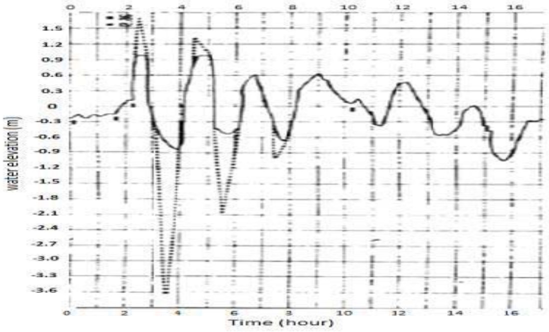

Fig. 1. Tide gauge signal (solid) of the wave elevation caused by the Krakatau 1883 explosion as measured in the Jakarta Bay and as measured (dashed) by Verbeek [4].

A. *Variational Boussinesq Model*

An explosion of AK will create large waves that will bounce at and between the coasts of South Sumatra and West Java. Part of the waves will travel northwards through the Sunda Street and enter the shallower Java Sea. Diffraction effects will send much lower waves in the eastward direction. The islands of Pulau Seribu will perturb the waves and absorb some energy. The waves will enter JB by diffraction and refraction. The domain that has been taken for the simulation is shown in Fig.2; land boundaries were treated as hard wall, and sea boundaries as fully transparent.

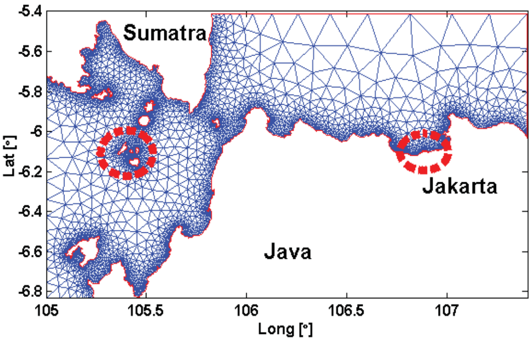

Fig. 2. Plot of the simulation domain with the Krakatau area and the Jakarta Bay. The triangular grid is to illustrate the changing gridsize with bathymetry; for simulations a much finer grid is used.

The numerical model we used is the Variational Boussinesq Model (VBM) that has been developed in the past years in collaboration between the institutes of the authors. The model has been used for tsunami simulations before, [8-10], and has been further developed for coastal zone applications with wind waves, see [11, 12].

The basic idea behind VBM is that the exact equations of irrotational water waves can be described as a variational problem. An action principle leads to the form of the equations as a Hamiltonian system with the surface elevation and the fluid potential at the free surface as symplectic variables. Both variables depend only on horizontal coordinates, i.e. the depth variable is absent, which leads to a dimension reduction that is profitable for numerical efficiency.

In order that this formulation becomes practically useful, the interior fluid motion has to be modeled so that and explicit expression of the Hamiltonian, in particular the kinetic energy, in the basic variables is obtained. Any approximation will retain the Hamiltonian structure, and therefore exact energy conservation and stability properties. Neglecting depth dependence in the internal motion leads to the shallow water equations. Improving this by taking a parabolic depth dependence will lead to an inclusion of dispersion that has shown to be sufficient for tsunami simulations. Furthermore, since nonlinear effects can be expected to be small, we used the linear variant of the model for the simulations in this paper.

For the simulations in the complicated geometry and varying bathymetry, we used a Finite Element implementation on a triangular grid. The variable grid size adapts to the bottom variations in such a way that the decrease in wave length in shallower water is compensated to retain sufficient accuracy. For the simulations in the domain of Fig.2 we used a grid with 250.000 elements. The waves were calculated until 6 physical hours after initiation of the tsunami; since it takes approximately 2 hours before the waves arrive in JB, this means that relevant time traces of 4 hours are available for comparison with the K1883-measurements.

B. *Tsunami Generation*

The initiation of a tsunami is the most crucial element in tsunami modeling: any difference in the generation will cause differences in the propagating waves. This holds for tsunamis generated by tectonic plate motions, but even more so for tsunamis generated by volcanos. Physical details of the K1883 explosion are not known, and evidently also not for a possible future AK explosion. Our aim to find an initiation that resembles the K1883 wave measurement in JB disregards any physical generation mechanism, but leads to a very ill-posed inverse problem.

In a recent paper [13] the same inverse

problem was approached by studying various variants of three basic generation scenarios: a pyroclastic flow model, a caldera collapse model and a phreato- magmatic explosion model.

After a careful consideration it was concluded that one variant of the (physically most probable) pyroclastic flow model gave the best match in the comparison of wave signals in JB. For the simulation an advanced 2-fluid model was used, with the pyroclastic flow as generating source of the water waves; the propagation of the water waves was modelled by a nonlinear shallow water code (non-dispersive).

We adopted the phreato-magmatic explosion model as generation source. The initial water elevation is then of the form as shown in Fig. 3, with parameters (*R*,*H*,*D*) for the radius, height and depth.

Comparison with the K1883-measurements learns that the wave period as well as the height is much too small for this simulation. Since the period is completely determined by the extent of the generation area, i.e. the value of *R*, we enlarged the generation area by a factor given by the quotient of measured and simulated period. Keeping *H* and *D* the same, the result of the new simulation is shown in Fig 5.

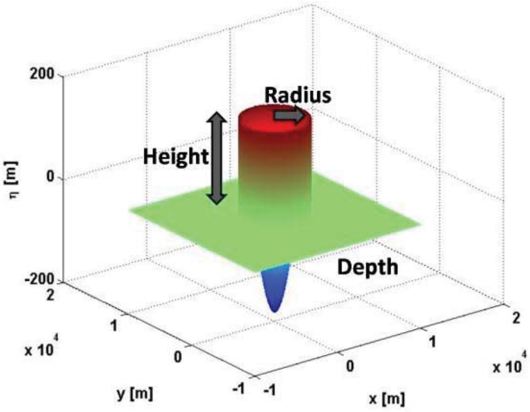

Fig. 3. Form of the water elevation for a phreato- magmatic explosion model, with the meaning of the parameters *R*, *H* and *D* indicated.

Using the same parameters as in [13] for this model, we found the signal in JB given in Fig. 4, which is comparable to the result in [13].

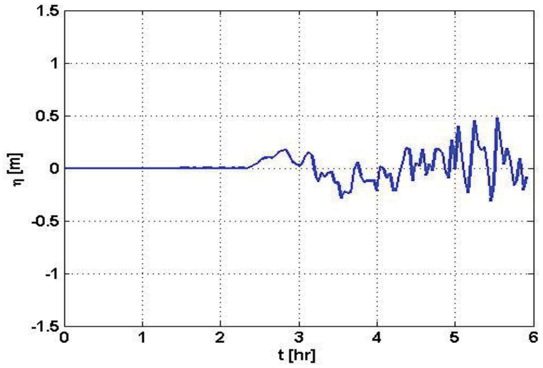

Fig. 4. Wave signal in the Jakarta Bay by using the phreato-magmatic explosion model, with parameters (*R*,*H*,*D*) = (3.5km, 200m, 200m).

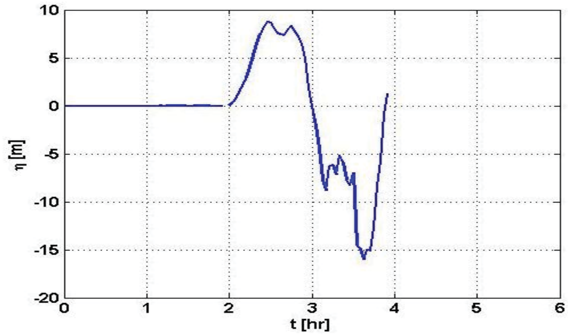

Fig. 5. Wave signal in the Jakarta Bay by using the phreato-magmatic explosion model with parameters (*R*,*H*,*D*) = (28km, 200m, 200m).

This shows that indeed the period is adjusted and approximately correct, but that the amplitude is much too high. The form of the first wave is reasonably comparable with the first K1883 wave, but successive waves show more variation in our simulation. To correct the amplitude, the values of *H* and *D* were adjusted in a trial-and-error way, roughly guided by energy arguments [14]. Two reasonable variants were found for *H*=30m, *D*=30m and *H*=40m, *D*=30m; the signal of the last most extreme case is shown in Fig.6.

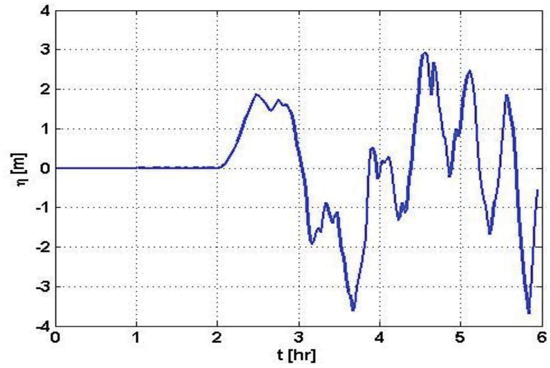

Fig. 6. Wave signal in the Jakarta Bay by using the phreato-magmatic explosion model with parameters (*R*,*H*,*D*) = (28km, 40m, 30m).

Although details of the signals are different, the amplitude and period agree sufficiently well with the K1183-signal to trust that waves with these characteristics are likely to may appear in a future AK explosion of the same strength as K1883. Therefore, these waves are taken for further consideration.

III. SIMULATION RESULTS

Using the tsunami waves in the JB as simulated for the variants described above, we are able to investigate wave heights at all locations in the bay. For forces on a dike, also the direction of the waves has to be taken into account, but we will not consider that here.

In Fig. 7 we show plots of maximal and minimal wave elevations as density plots over the whole JB for the simulation with *H*=40m, *D*=30m. Furthermore, we considered a sea dike at a hypothetical position; for 8 locations at this dike, the maximal and minimal elevations are given in Fig.8 for both simulation variants.

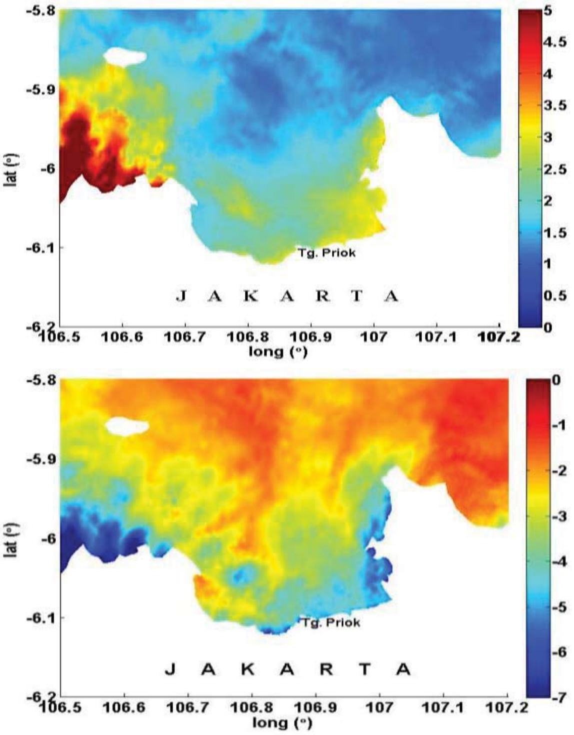

Fig. 7. Density plots of the maximal (upper plot) and minimal (lower plot) water elevation in Jakarta Bay.

Given all uncertainties in predicting future tsunami generation scenarios, the results obtained here lead us to the conclusion that in the Jakarta Bay the maximal elevation at locations of a possible future dike can be as large as 2.5 m and as low as - 4m during the first 4 hours after arrival of the waves.

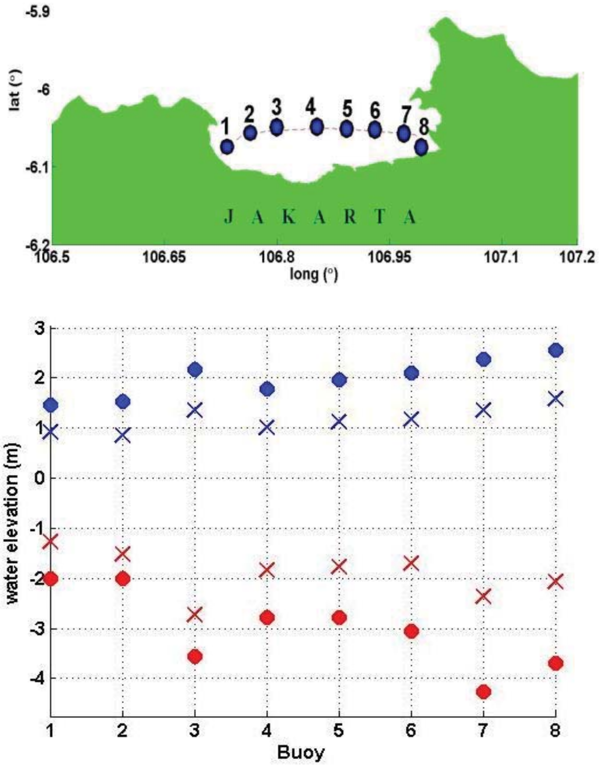

Fig. 8. Schematic drawing of a hypothetical sea dike (upper plot) and maximal and minimal elevations at each of 8 locations indicated at the dike; dots are used for results with the simulation variant *H*=40m, *D*=30m and crosses for the variant *H*=30m, *D*=30m.

IV. CONCLUSIONS

We have been able to design a simple tsunami initiation of the type of a phreato-magmatic explosion model that roughly produces the same signal as the 1883 waves observed in the Jakarta Bay. Our initiation model can describe the first arriving wave quite well: the period and crest height are almost the same as the 1883 observation data. But the successive waves are too high with too many oscillations. It may be noted that our initiation model is much simpler than the pyroclastic model used in [13] that performs approximately just as well.

ACKNOWLEDGEMENT

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