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ON THE EFFECT OF TSUNAMIS ON NEARSHORE WAVE ENERGY CONVERTERS

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Summary With an increasing emphasis on renewable energy resources, wave power technology is fast becoming a realistic solution. The question posed here is whether a nearshore wave energy converter could withstand the force of an incoming tsunami. An analytical 3D model is developed within a linear theory and applied to an array of fixed plates. The time derivative of the velocity potential allows the hydrodynamic force to be found. The hydrostatic force can be found from the difference in free surface heights on either side of the device.

INTRODUCTION

Wave energy devices are slowly becoming a reality. Various prototypes are now being tested in harsh sea conditions (storms). What about tsunamis? Even if offshore wind turbines seem to have survived the 2011 tsunami in Japan, it is legitimate to ask whether wave energy converters (WECs) will resist tsunamis. For deep sea WECs, such as Pelamis [1], tsunamis are not anticipated to be a threat since they are located far from the shore (the present Pelamis prototype operating at EMEC, Orkney, is located 2 km from the shore). On the other hand, for nearshore WECs, such as Oyster [2], it is important to take a closer look at the effect of tsunamis (the present Oyster prototype operating at EMEC, Orkney, is located 500 m from the shore). Unfortunately there is very few wave data away from the shoreline. One exception is the Mercator yacht, anchored 1.6 km away from the shore in Thailand during the 2004 Indian Ocean tsunami. The water depth was about 12–13 m and the yacht experienced four major waves, one "depression" wave (–2.8 m) and three "elevation" waves (3.8 m, 1.7 m and 4.2 m) [3]. And the problem is quite different from the problem of wave forces acting on flat-type storm surge barriers [4] because the periods involved are different.
Kajiura [5] considers the amplification of tsunamis which advance toward shore over a gentle slope. Let us define the relative height $\varepsilon_0 = H_0/h_0$. Green's law gives $\varepsilon = \varepsilon_0 (h_0/h)^{5/4}$. If one takes $H_0 = 1$ m, $h_0 = 3$ km and a slope of 0.02, then finite amplitude effects come into play ($\varepsilon = 10^{-1}$) when the distance from the shore becomes less than 1.5 km, which is about one seventh of the wave length of a tsunami with a period of 10 minutes. Here the wave steepness is 0.0003 and the Ursell parameter is much larger than one, indicating that dispersion is relatively minor compared with the non-linearity except for the front part of the wave. From these considerations, it is reasonable to conclude that the solution of the linear shallow-water equations used offshore should be matched to the inner solution of the nonlinear shallow-water equations at a distance from shore of about a quarter of a wave length of the tsunami.

DESCRIPTION OF THE GEOMETRICAL SET UP

We consider here the following idealized problem: a flap-type structure mounted at the sea bottom pierces the surface of the ocean. The structure is assumed to be fixed. What is the load on the flap due to a tsunami wave? Two models are considered: a linear one based on the linear water-wave equations (dispersion is included) and a nonlinear one based on the shallow-water approximation. It is assumed that there is no debris in the flow and that the load is mainly due to the hydrodynamic force. Even within this idealized framework, it is not clear what the main force is going to be. In the document "Development of design guidelines for structures that serve as tsunami vertical evaluation sites", by Yeh, Robertson and Preuss, several forces are described: buoyant force (not important since WECs are buoyant), surge force, hydrodynamic force (combination of the lateral forces caused by the pressure forces from the moving mass of water and the friction forces generated as the water flows around the flap – neglected in our study), breaking wave force (neglected here). Another way to look at forces is through the integral of the stress tensor. Since friction is neglected, the only contribution comes from the pressure term. In turn the pressure term can be evaluated through Bernoulli's equation. Introduce the dynamic pressure p^* defined as the difference between the pressure p and the hydrostatic pressure. In the linear model, p^* is simply equal to the $-\Phi_t$ term. In the weakly nonlinear model, there is in addition the $\frac{1}{2}U^2$ term.

LINEAR MODEL

The analytical 3D model developed by Renzi & Dias [6] is used to compute the load on the flap. Until now, this model had only be used to compute forces under normal operational conditions for WECs, that is waves with periods between 5 and 15 seconds. Even though there is no assumption on the wave period in the derivation of the model, special care must be taken when evaluating the solution for long waves. The jump in the pressure across an 18 m plate for a tsunami wave as described in the Introduction, if a fixed flap is in $h_0 = 10.9$ m depth (impact wave amplitude ≈ 4m) is shown in figure 1. For comparison reasons, results for a typical swell (period 5 s, amplitude 3 m) are shown in figure 2.

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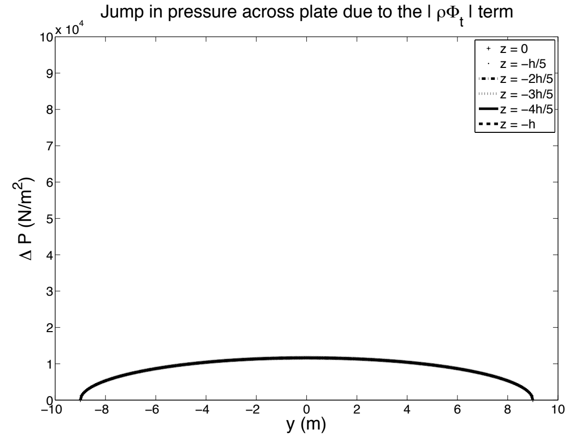

FIGURE 1. The jump in pressure for a typical tsunami across an 18 m plate, in a depth of h = 10.9 m at 6 depths from the free surface to the ocean floor

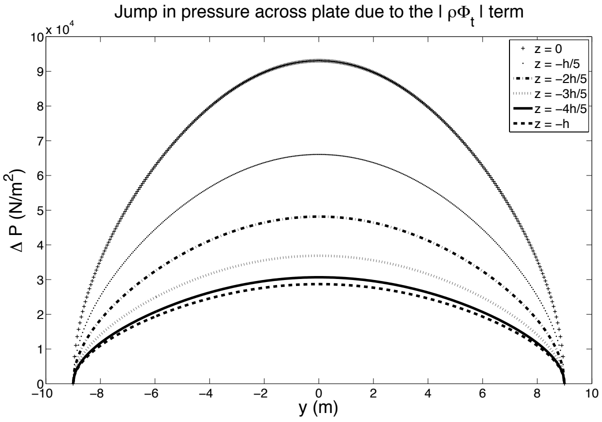

FIGURE 2. Various jumps in pressure across an 18 m plate for a typical swell. (The same scales have been used in Figures 1 and 2.)

NONLINEAR MODEL

Next we consider the 2D nonlinear shallow water equations. The numerical integration is performed first with the VOLNA code, a non-dispersive code developed by Dutykh et al. [7]. The WEC is modelled as a thick plate. Then the numerical integration is performed with a dispersive code, developed by Bingham et al. [8]. Results will be presented during ICTAM 2012.

DISCUSSION AND CONCLUDING REMARKS

We believe that in the operational areas of nearshore WECs, a tsunami still is simply a fast tide, with the water going up and down uniformly. We therefore expect the pressure to be almost the same on the front and back sides of the flap. But the influence of nonlinearities should be studied in more details.

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References

[1] **www.pelamiswave.com**

[2] **www.aquamarinepower.com**

[3] Rossetto T., Allsop W., Charvet I., Robinson D.: Physical modelling of tsunami using a new pneumatic water wave generator. *Coastal Engineering* **58**:517-527, 2011.

[4] Tomita T., Shimosako K., Takano T.: Wave forces acting on flap-type storm surge barrier and waves transmitted on it. *Proc.13th Int. Offshore and Polar Engineering Conf., Honolulu, Hawaii, USA*. 639-646, 2003.

[5] Kajiura K.: Local behaviour of tsunamis. In Waves on Water of Variable Depth, edited by D. Provis ans R. Radok, Lecture Notes in Physics **64**, Springer-Verlag, Berlin: 72-79, 1977.

[6] Renzi E., Dias F.: Resonant behaviour of the Oscillating Wave Surge Converter in a channel. *J. Fluid Mech*., submitted for publication, 2012.

[7] Dutykh D., Poncet R., Dias F.: Complete numerical modelling of tsunami waves: generation, propagation and inundation. *Eur. J. Mech. B/Fluids* **30**:598-615, 2011.

[8] Bingham H.B., Madsen P.A., Fuhrman D.R.: Velocity potential formulations of highly accurate Boussinesq-type models, *Coastal Engineering* **56**:467-478, 2009.