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Generation, propagation, run-up and impact of landslide triggered tsunami: a literature review

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Abstract. Submarine landslide is the most serious threat on both local and regional scales. Tsunami phenomenon induced by submarine slide has put us on the challenge in understanding from generation mechanism to propagation and coastal inundation and mitigating the risk from it. Submarine slides can trigger tsunamis with high run-up affecting offshore structures, subsea facilities and human lives along the shoreline. Unfortunately, there are no effective numerical models that could simulate simultaneously all stages of generation, propagation and run-up of tsunamis phenomena. This paper presents a comprehensive review on the landslide tsunami phenomenon.

Introduction

Geohazards represent a world-wide concern in deep water and have potentiality in leading to damage or uncontrolled risk. They are always associated with geological or geotechnical features and processes in the vicinity of a planned offshore structure. Important offshore geohazards include i) slope instability (consisting of submarine slides, debris-flows, turbidity currents); ii) pore pressure phenomena (e.g. shallow gas accumulations, gas hydrates, surface erosion by shallow water flows, mud volcanism) and iii) seismicity. Geohazards need to be carefully evaluated before field development can start, as they present threat to human life, environment, seabed installation and drilling operation. Figure 1 illustrates schematically different geohazards. However, the geohazard natures and their impact are not well known.

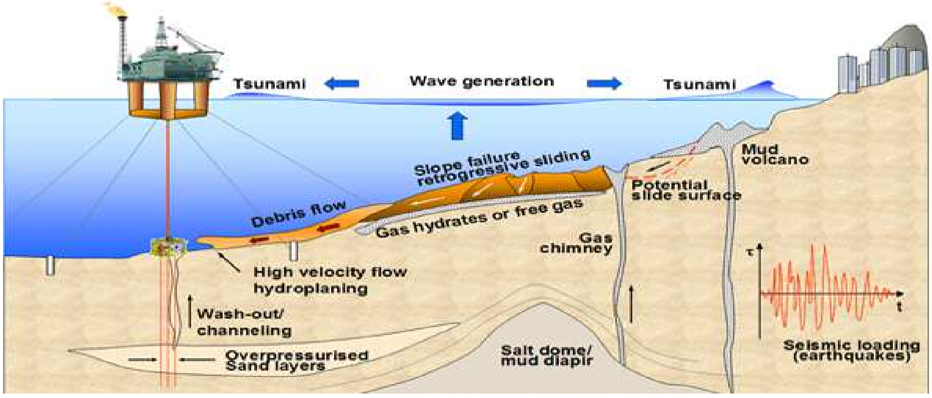

Figure1: Schematic diagram of different geohazards [1]

The submarine landslide is now accepted as an important source of tsunami wave generation. It is the second in frequent tsunami source for about 10% of all tsunami waves [1].

Submarine mass failure (SMF) or submarine landslide is the most serious threat on both local and regional scales. In addition to damaging directly offshore installations, slope failures may also cause devastating tsunami. Thus, tsunamis become a serious natural hazard for the environment and populations in exposed areas.

Tsunami waves due to submarine slide are sophisticated phenomena that may be divided into three parts: i) triggering mechanism, ii) tsunami generation, iii) propagation and run-up at the beach or offshore structure.

Literature review

a) Initiation of tsunami wave by submarine landslide

Only part of all submarine landslides cause of generating tsunamis [2]. There have many papers that deal with the efficiency of submarine landslides to cause tsunami waves.
Murty cites basic physics to scrutinize the validity of hydrodynamic simulations as applied to landslide tsunamis [3]. He assumes that tsunami generation from submarine landslides depends on some factors including: the weight of the slide material, density and speed of the slide material, duration of the slide, angle of the slide, water depth, etc.
Ruff compares energy of generating tsunami by earthquakes with submarine landslides by experiment [4]. He concludes that large tsunami wave can be generated by some submarine landslide.
Okak and Synolakis [5] present a simpler physical model than Ruff [4]. They used two source mechanisms: seismic dislocation and underwater slumps. They assess amplitude of energy generated into a tsunami wave using two source above. They concludes that both source can generate tsunamis of energy.

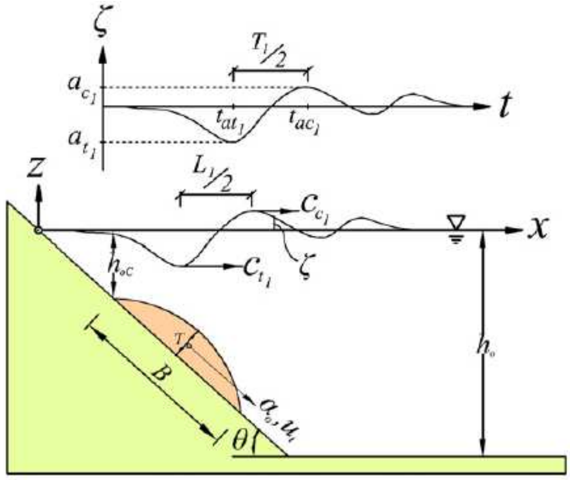

Figure 2: General feature of tsunami generation by solid block motion [6]

S. T. Grilli and P. Watts introduced the first simple model to emulate a landslide is solid block sliding down a slope [6]. The volume and speed of sliding mass are the main factors to generate tsunami wave. All forms of submarine slides can have the potential to generate tsunami [7].
In addition the application of these models to wave generation is also important. The first application for tsunami wave simulation was based on conventional nonlinear shallow water (NSW) wave equations due to its simplicity. But it is known that the NSW equations do not correctly capture the interaction between slides and wave generation [8]. P. J. Lynett, J. C. Borrero have derived and used a fully nonlinear BM rather than an NSW model to simulate SMF tsunami generation [9].

b) Propagation of tsunami wave

Generated tsunami by submarine landslide are basically linear and have long waves. The amplitude of the soil motion does not effect to linear waves. And we have the formula to describe concern between wave speed and wave length.

$$C = \sqrt{gH} \quad (5)$$

Where g is the acceleration of gravity, and H is the local water depth.

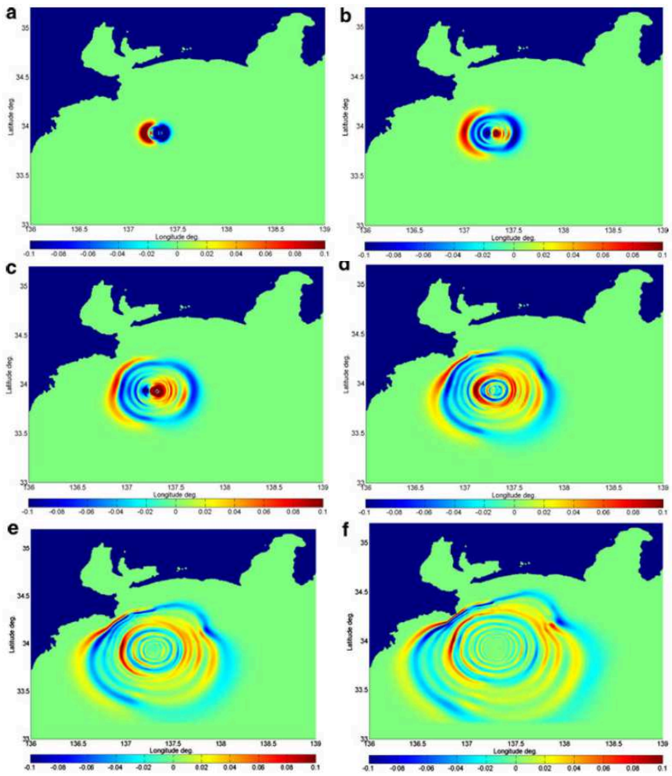

Figure 3: Simulated water surface elevation [9]

Nature of tsunami waves can be characterized as nonlinearity effects and frequency dispersion which causes shorter waves to propagate at a slower speed and thus causes an initial packet of waves to disperse as it propagates. Regarding this, the Boussinesq-type models (BM) are more efficient and accuracy than models developed based on Nonlinear Shallow Water (NSW) equations which can lead to errors in the wave shape and arrival time [10]. The BM relaxes the restriction on nonlinearity of NSW and originally includes the effect of frequency dispersion.

Clearly, the inclusion of the dispersive effects is important for the determination of the time history of the wave motion at a point. The wave profiles are in good agreement with experiment. The BM model has shown a significant improvement over previous simulation made with an earlier tsunami source and shallow water wave tsunami propagation models by reproducing correctly times of tsunami arrival relative to strong after shock that occurred roughly 20min after the main shock [10]. Reynolds averaged Navier-Stokes (RANS) equations with the k - ε turbulence model could provide capacity and accuracy in predicting the breaking of wave in generation and propagation [11].

c) Run up of tsunami wave

The modeling of tsunami flows at most types of shorelines remains a difficult but important problem. For coastal communities within the wave run-up region, the tsunami flows around, through, and over buildings. This turbulent, fast-moving flow results in building damage, collapse, or floating away. People are drowned, due to the high water, the difficulty of withstanding the fluid forces, coping with the large turbulent eddies, or impact with debris. In order to simulate the inundation on shoreline by a tsunami, a numerical model must be capable of allowing the shoreline to move in time. However, the accurate prediction of run-up onto real coastlines with structures and human habitation still remains incomplete. Especially, tsunami wave were generated by submarine landslide; they have long wave and large run-up heights [12]. Pedersen generalized from the progress of wave run-up modeling into two directions: one is the integration of run-up facilities in general wave propagation models with high order inherent dispersion and another is the involvement of the representation of accurate shoreline in models.

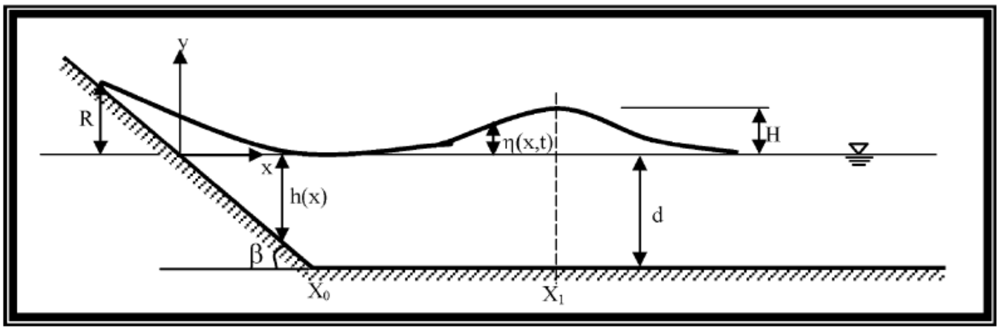

Fig. 3 Solitary wave run-up [12]

The NSW and BM models can provide good prediction with laboratory results of run-up height and inundation over coastal terrain. Figure 3 shows the run-up of a tsunami, represented by a solitary wave, on uniform slope [13]. The principal limitation to their accuracy in predicting shoreline inundation in tsunami applications stems from factors not covered by the basic theory: frequency dispersion and the interaction with fixed obstacles and the interaction the mass of transported debris resulting from destruction of structures. In addition, it is clear that, for the case of breaking tsunami wave, the Boussinesq's model is superior to NSW due to the exclusion of accumulation of dispersion effects in the NSW model [13]. However, this more advanced method has been unable to capture fully flow of tsunami when it breaks onto a beach, and very computationally expensive. RANS model [14,15] was proposed to predict breaking wave in deep and shallow water, including wave pre-breaking, overturning and post-breaking processes. However, this more advanced method has been unable to capture fully flow of tsunami when it breaks onto a beach, and very computationally expensive.

Table 2: Summary of governing equation

	Navier Stoke equation	**NSW model**	**BM model**	**RANS model**
Propagation Stage	- Simplicity	-	- Taking into account the nonlinearity & frequency dispersion. - Reproducing correctly arrival time	- Predicting well the breaking wave
	-	-	-	-
Run-up Stage	-	- Predicting well run-up height on a uniform slope	- Predicting well run-up height on a uniform slope	- Treating well the breaking wave and interaction with structures
	- Leading errors in wave shape and arrival time	- Excluding the frequency dispersion and nonlinearity	- Inaccurately predict the full structure of flow	- Very computationally expensive
All stages	NOT GOOD -	NOT GOOD -	GOOD ✓	GOOD ✓

d) Impact of tsunami wave

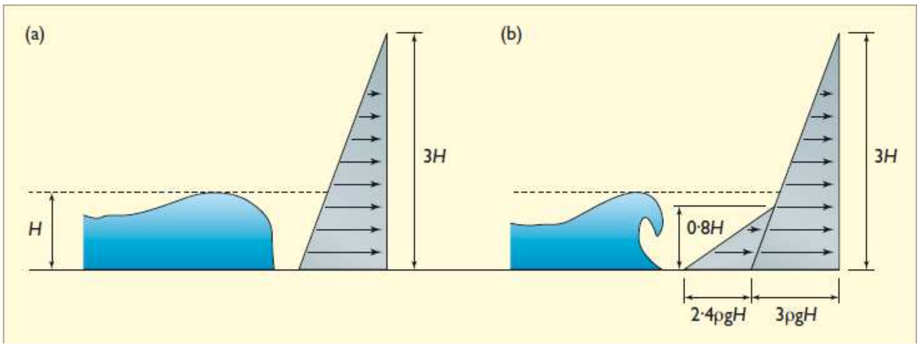

Figure 4: The Japanese design method assumes tsunami wave pressure [16]

Okada et al. proposed a Japanese design method for tsunami loading on structures [17]. Figure 4 (a) showed that the impact force is equivalent hydrostatic load. The pressure distribution will be truncated at the height of the building if the height of the building is less than 3H.

There have three type of tsunami impact force: i) Overflow; ii) Bore; iii) Breaking. The power of the tsunami is greatly different depending on the place and the condition [18]. But type 3: breaking is the type of tsunami that causes the most serious damage. Figure 5 shows the impulsive bore force in type 3 is so higher than two remain type.

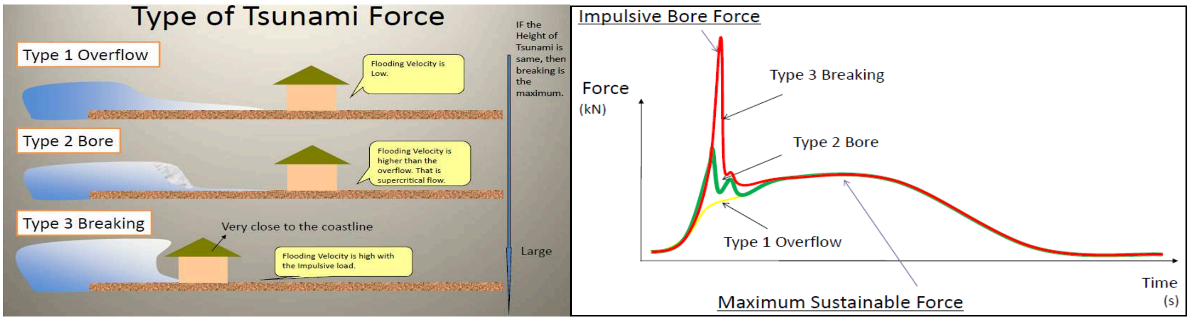

Figure 5: Type of tsunami force [18]

There is very little guidance provided by structural design codes for the forces induced by tsunami effects on coastal construction. A set of generalized equations were created from currently available building codes and published literatures, which contain information and recommended equations on flooding, breaking waves and tsunamis (Pacheco and Robertson, 2005). The existing design codes investigated are the City and County of Honolulu Building Code (CCH 2000); the 1997 Uniform Building Code (UBC 1997), the 2003 International Building Code (IBC 2003); the SEI/ASCE 7-02 (ASCE 7, 2002); and the Federal Emergency Management Agency Coastal Construction Manual (FEMA 2000).

Conclusion

Now, physical understanding of slide tsunami hazards is poor. How to understand substance of tsunami clearly and how to find methods to reduce damage from tsunami wave. This is not simple task because of the complexity and multi scale of process.

Understanding tsunami wave loading on coastal houses is important to improve the design of coastal structures. It is very dangerous with these structures close to coastline because they may be damaged by tsunami force.

Therefore, the need for comprehensive model base on mesh free method that could cover all aspects of tsunami phenomena and provide real-time modeling of the event would be one of good future research direction.

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