A note on preliminary assessment of far-field runup of Subaerial Landslide Generated Waves

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Abstract:
Subaerial Landslide Generated Waves (SLGW) have long been a matter of substantial concern due to originating catastrophe along shorelines. Comprehensive review on presented empirical equations for estimating far-field runup of SLGW has undertaken. Using physical scale modelling results, Accuracy of empirical equations is what has been done in the present study. Aiming to bring insight to coastal design, empirical equations have been applied to several real event of SLGW. Empirical equation of Hall and Watts has been presented the best consistency and Synolakis, Hughes and Li and Raichlen empirical equations predicts with the least deviations. The results presented in this paper may be useful for preliminary hazard assessment, where a simple and quick judgment of the resulting wave runup height and locations are required.

Introduction

Tsunamis are long water waves generated by impulsive geophysical events of the seafloor, volcanoes, asteroid impacts and landslides. Main damages from tsunami comes from the destructive and sudden (often without warning) nature of the waves, erosion effects that can undermine the foundations of structures built along coastlines, and fires that result from disruption of gas and electrical lines. Secondary effects include loss of crops and water and electrical systems which can lead to exiguousness, and disease.

In this paper, our attention was restricted to water waves generated by mass flows that originate subaerially and do not interact thermally with water, which we refer to as "Subaerial Landslides".

Ataie-Ashtiani and Najafi-Jilani (2006) have done a comprehensive review on the experimental and numerical studies [3, 4]. In the case of near-field characteristics Ataie-Ashtiani and Malek Mohammadi (2007a) [1], and Ataie-Ashtiani and Malek-Mohammadi (2007b) [2] have done a comprehensive review on experimental and analytical works that result in empirical equations.

Whereas scores of investigations have been done on solitary-like long wave runup, sense of necessity to review and comparison of presented empirical equations for special case of SLGW motivated authors to carry out this survey.

Empirical Equations and Real Cases

As slide plunging into water, three separated zones can be determined in water body, splash zone, near-field and far-field. The water surface in the splash zone, the length of which is comparable to the landslide run-out distance, is not only irregular

♣ Now, PhD student of Civil Engineering, Clemson University, U.S.A and unsteady but also forced. In the near-field, water displaced by the landslide has organized itself into a coherent waveform. In the far field, which get full of attention in the present study, dispersive effects become important. As small-scale tsunami waves propagate toward shoreline at the far-field what is observed is solitary or at least solitary-like long waves (cf. Synolakis 1987 [14]). Figure 1 illustrates schematic of the problem and essential parameters.

Many experimental, numerical and theoretical investigations have been done on solitary long wave runup (cf. Hall and Watts 1953 [6], Li and Raichlen 2001 [9], Synolakis 1987 [14]) which also resembles SLGW far-field runup. On top of that, some investigators studied runup of SLGW in large or small-scale laboratory modeling (cf. Huber and Hager 1997 [7], Panizzo 2005 [12]) while others studied by numerical modeling (cf. Lynett and Liu 2005 [10]). Most but not all of the experimental and analytical studies and some of numerical investigations lead to empirical equations for predicting near-field wave characteristics or far-field runup height of SLGW. Table 1 summarizes the main empirical equations for predicting SLGW runup.

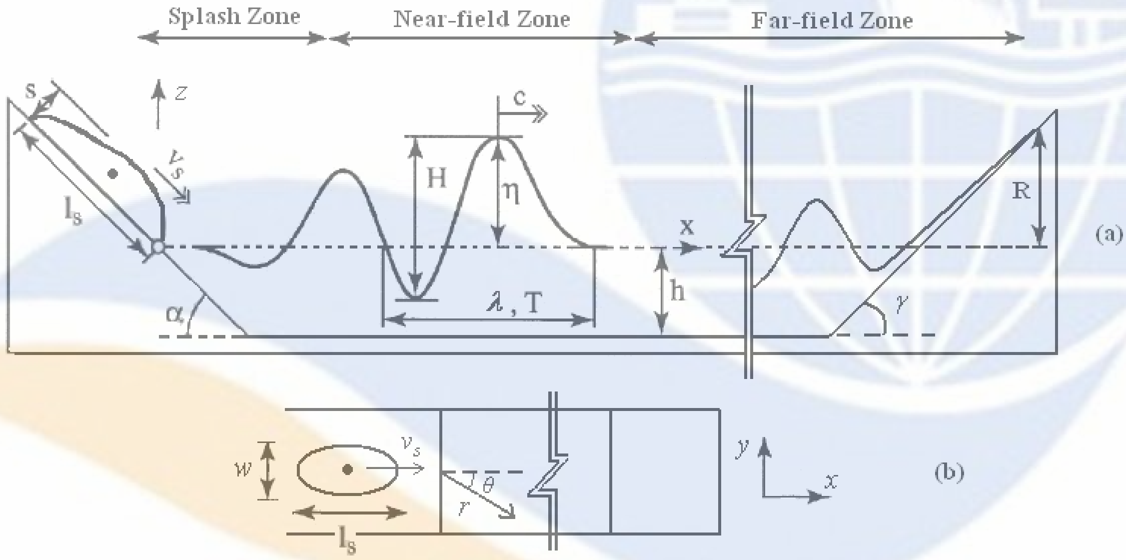

Figure 1: Illustration of separated zones, definitions of the slide, water body, and wave parameters

Table 1: An overview on empirical equations for estimation of SLGW far-field runup

Ref.	Type of Investigation	Flume Dimensions (m)	γ Range	η/h Range	Empirical Equation
Hall/Watts 1953 [6]	Experimental	26.0 x 4.3 x 1.2	5° – 45°	0.05 – 0.56	$R/\eta = K(S_S)(\eta/h)^{(a(S_S)-1)}$
Huber 1980[7]	Experimental	-	-	-	$R/h = 1.25(\pi/2\gamma)^{0.2}(\eta/h)^{1.25}(\eta/\lambda)^{-0.15}$
Synolakis 1987 [14]	Experimental/Analytical	37.7 x 0.4 x 0.61	2.9°	0.01 – 0.05	$R/h = 2.831(\cot\gamma)^{1/2}(\eta/h)^{5/4}$
Li/Raichlen 2001[9]	Experimental/Analytical	15.25 x 0.4 x 0.61	25.5°	0.03 – 0.35	$R/h = 2.831(\cot\gamma)^{1/2}(\eta/h)^{5/4} + 0.293(\cot\gamma)^{3/2}(\eta/h)^{9/4}$
Hughes 2004[8]	Analytical	-	-	-	$R/h = 1.82(\cot\gamma)^{1/5}(M_F/\rho g h^2)$ non-breaking $R/h = (1.39 - 0.027\cot\gamma)(M_F/\rho g h^2)$ breaking
Lynett/Liu 2004 [10]	Numerical	-	-	-	$R/s = 0.1(s/h)^{-1/4}(\rho_s/\rho_w)$
Panizzo et al. 2005 [12]	Experimental	4.0 x 0.11 x 0.4	22°, 37°, 84°	0.11 – 0.45	$R/h = 1.37(\eta/h)^{1.51}\left(T\sqrt{g/h}\right)^{0.47}(\sin\gamma)^{0.26}$

To compare these empirical equations, several best-documented real cases were selected and observed data extracted from the literature (see Ataie-Ashtiani and Malek Mohammadi (2007a) [1]). Discussion about predictability of far-field runup using empirical equations is what has been presented in the following sections. Based on authors' judgements, preliminary runup height assessment has been done for the possible coming events.

Comparison with laboratory and real case observed data

Series of experiments were carried out by Davidson and Whalin in 1972 [5] on 1:120 scale physical model of Libby dam which was constructed in WES♣ laboratory of U.S. Army ERDC♣ by considering four distinct scenarios for sliding area. Wave amplitude and runup height were measured in different points of the physical model. In order to examine empirical equations, comparisons have been made with reported laboratory data of Davidson and Whalin 1972 as shown in Figure 2.

♣ Waterways Experiment Station

♣ Engineer Research and Development Center

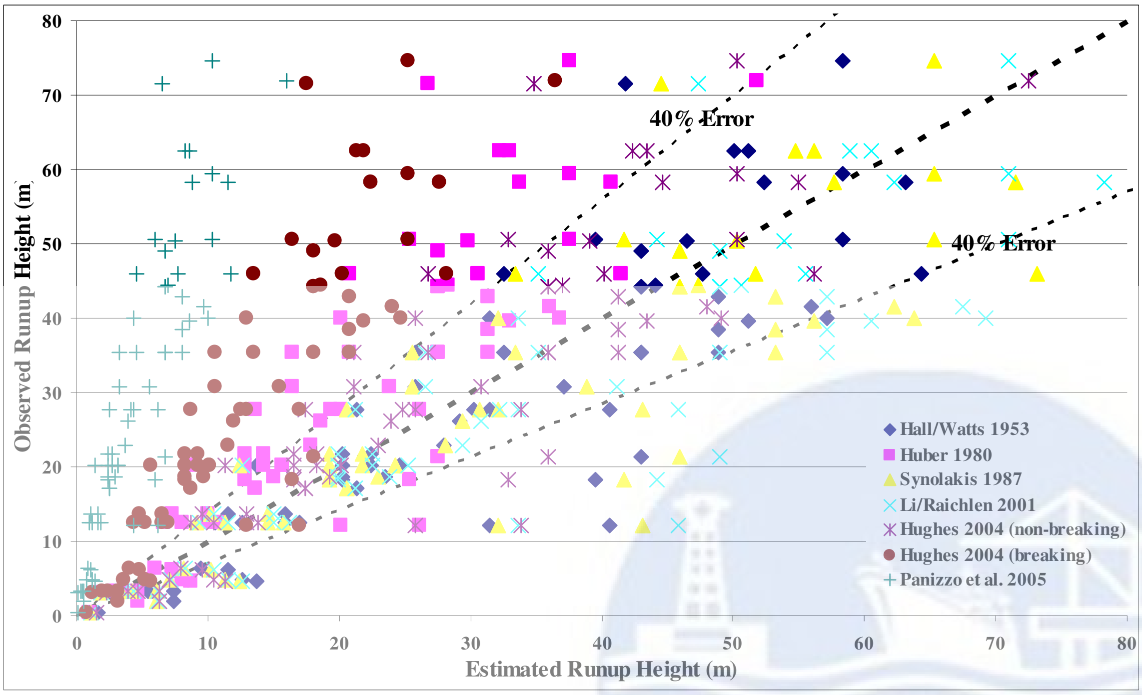

Figure 1: Comparison between estimated runup height and observed data in the laboratory

As shown in Figure 1, Hughes 2004 equation for breaking waves underestimates the runup height evidently. This discrepancy can be due to steep beach slope of the experimental model (11.5°), which did not allow waves to break. Panizzo empirical equation which underestimates the runup height may be suitable for more gentle slopes. Wave period in Panizzo equation has been determined using Panizzo empirical equation for wave period of SLGW (for details see Ataie-Ashtiani and Malek-Mohammadi (2007b) [2]). Huber 1980 empirical equation generally underestimate the runup height by a factor between 1.2 and 1.6. It is good to note that wavelength in Huber equation has been determined using Walder et al. (2003) empirical equation [15] (for details see Ataie-Ashtiani and Malek-Mohammadi (2007b) [2]). Hall and Watts 1953, Synolakis 1987, Li and Raichlen 2001 and Hughes 2004 non-breaking empirical equation have predicted the runup height satisfactory. Judgement about beach slope can not be considered, because in this case beach slope for all laboratory experiments are the same. Dimensionless wave height varied between 0.04 and 0.18 for these laboratory studies.

In order to bring insight to coastal design considerations, best-documented real cases have been selected through the literature and by applying each of selected empirical equations on them, accuracy of empirical equations have been examined in predicting real case studies. Table 2 illustrated this comparison.

Table 2: Comparison between estimated and observed SLGW runup height for real cases

Real Case	Reference	γ	η/h (m)	Observed R (m)	Estimated R (m)	Remarks
USA, Lituya Bay, Mud slide creek, 8 July 1958	Slingerland and Voight 1979 [12]	47.5°	64/146	183.0	-	Hall/Watts equ.
					141.5	Synolakis equ.

					147.0	Li/Raichlen equ.
					192.3	Hughes equ.
USA, Lituya Bay, Gilbert inlet, 8 July 1958	Slingerland and Voight 1979 [12]	45°	152/122	520.0	479.1	Hall/Watts equ.
					454.6	Synolakis equ.
					513.2	Li/Raichlen equ.
					980.4	Hughes equ.
USA, Disenchantment Bay – Gilbert point, 1905	Slingerland and Voight 1979 [12]	30°	4.5/81	9.0	9.9	Hall/Watts equ.
					8.1	Synolakis equ.
					8.2	Li/Raichlen equ.
					9.8	Hughes equ.
USA, Disenchantment Bay – Northwestern tip of Haenke Island, 1905	Slingerland and Voight 1979 [12]	17°	11.5/80	35.0	29.4	Hall/Watts equ.
					36.2	Synolakis equ.
					38.0	Li/Raichlen equ.
					28.0	Hughes equ.
USA, Disenchantment Bay – Northern tip of Haenke Island, 1905	Slingerland and Voight 1979 [12]	12°	5.5/80	16.5	15.1	Hall/Watts equ.
					17.3	Synolakis equ.
					17.9	Li/Raichlen equ.
					14.8	Hughes equ.
Italy, Vajont Reservoir, 1960	Panizzo et al. 2005 [11]	80°	8/160	10.0	-	Hall/Watts equ.
					4.5	Synolakis equ.
					29.6	Li/Raichlen equ.
					10.9	Hughes equ.

As indicated in Table 2, all of empirical equations predict SLGW real cases pretty well. Results of table 2 sketched in Figure 3 on logarithmic scale for better presentation and judgment.

Conclusion

The herein presented results of the study regarding the preliminary estimation of far-field runup of Subaerial landslide generated waves are as follows:

1- Empirical equations for predicting far-field runup of Subaerial Landslide Generated Waves (SLGW) have been collected from previous studies on SLGW problems or long solitary wave runup problems.
2- Empirical equations compared with observed physical scale modelling of Libby dam SLGW scenarios and ranges of overestimation or underestimation of each empirical equation is determined. Based on this judgement, empirical equations with the least deviation from observed laboratory data have been selected. Hall and watts, Synolakis, Li and Raichlen and Hughes empirical equations showed acceptable consistency with laboratory data.

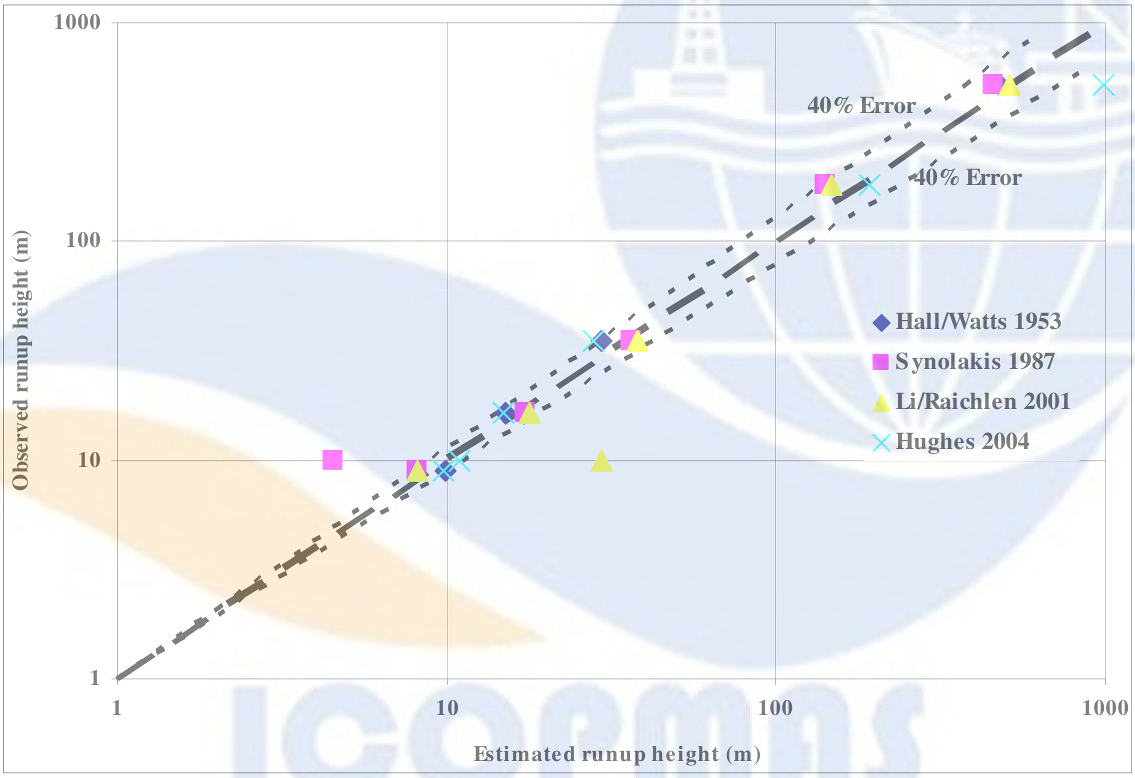

Figure 3: Comparison between estimated runup height and observed data in the real SLGW evens

3- Selected empirical equations have been applied for estimating of maximum runup height of the several SLGW real events. Pretty good agreement between estimation results and observed field data has been observed for all the empirical equations. The results were the best for Hall and Watts 1953 empirical equation because of the minimum mean square root of the deviations.
4- Based on this investigation, empirical equations based on runup of long solitary waves can be applied to small-scale tsunami waves due to SLGW in coastal areas. So application of these empirical equations for quick and

preliminary hazard assessment of the events is recommended but need more investigations.

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