THE NEED FOR A PARADIGM SHIFT IN SUBAERIAL LANDSLIDE-TSUNAMI RESEARCH

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INTRODUCTION

Subaerial landslide-tsunamis (SLTs) are caused by mass movements such as landslides, rock falls or glacier calving. Research into SLTs is ongoing for many decades, however, the advancement in the physical understanding and reliability of hazard assessment methods is not reflecting the number of articles published per year. It appears that a paradigm shift in SLT research is required for a genuine advancement. This article critically reviews the state-of-the-art of SLT research, highlights current limitations and introduces potential candidates to perform this needed paradigm shift.

CURRENT RESEARCH APPROACHES

Catastrophes such as the 1958 Lituya Bay SLT, running up 524 m (Figure 1a), and the 1963 Vajont disaster, with nearly 2000 fatalities, triggered an increased research interest in SLTs in the 1960/70ties. The number of publications further increased once numerical models were able to complement or even replace laboratory studies. Despite of this large number of studies, reliable hazard assessments of SLTs is still lacking and to reliable predict SLT cases, such as the recent Lake Askja or Eqip Sermia cases shown in Figure 1, remains challenging.

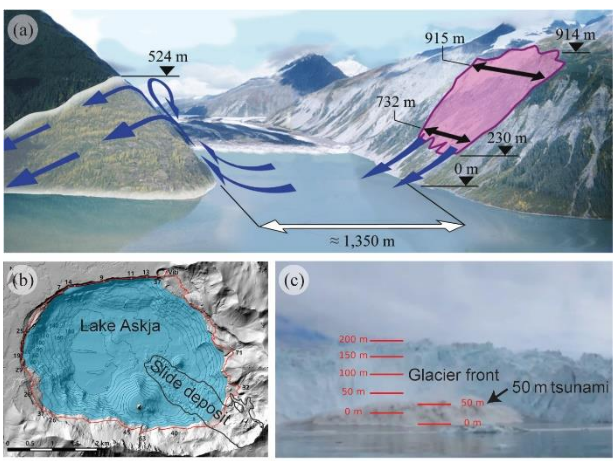

Figure 1 - Examples of SLTs: (a) 524 m runup observed in the 1958 Lituya Bay case in Alaska (Heller and Hager, 2010), (b) 2014 Lake Askja rockslide case in Iceland (Gylfadóttir et al., 2017) and (c) the 2014 Eqip Sermia case in Greenland (Lüthi and Vieli, 2016).

Currently, the most promising approaches to deal with SLTs are (I) prototype-specific physical and (II) numerical model tests and (III) generic empirical equations from experimental and numerical tests. Generally speaking, the approach (I) is most reliable, but time-consuming and expensive if the scale is sufficient large to avoid scale effects. Approach (II) requires less resources, but high-quality calibration and validation data. In approach (III) the governing parameters (slide velocity, volume, geometry, hill slope, water depth, etc.) are systematically varied under idealised conditions in flumes (2D) (e.g. Heller and Hager, 2010) or basins (3D) (e.g. Evers et al., 2019; Heller and Spinneken, 2015; Figure 2) and the wave parameters are then expressed through generic empirical equations as a function of these governing parameters. The application of such equations is very inexpensive and efficient, but provides preliminary estimates only, with increased uncertainty for complex water body shapes.

Most ongoing research into SLTs aims to reproduce individual SLT laboratory or nature cases numerically (approach II) or to create new empirical equations to add to (III). However, wave parameters predicted with empirical equations based on (III) vary by factors (Heller and Spinneken, 2013) such that the focus should be on the understanding of the reasons for these discrepancies rather than on additional parameter variations. Further, SLTs are composed of several components affected by frequency dispersion, which is ignored in approach (III) where the superimposed wave parameters are investigated.

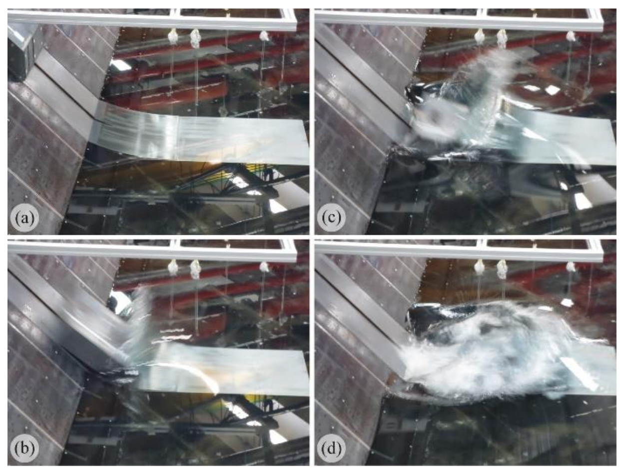

Figure 2 - Picture series of SLT generation in an idealised 3D laboratory experiment (Heller and Spinneken, 2015).

CANDIDATES FOR A PARADIGM SHIFT

Candidates for a SLT research paradigm shift are:

Generic empirical equation method: Until new methods including the two suggested hereafter are fully exploited, holistic approaches combining various empirical concepts from approach (III) including SLT generation, propagation and their effects on the shore, such as Evers et al. (2019), deliver preliminary wave parameter estimates, particularly for simple water body geometries and bathymetries. Machine learning, e.g. via Artificial Neural Networks (e.g. Ruffini et al., 2020), may be very instrumental to improve such holistic approaches.

Generic numerical code: Numerical models, in contrast to generic empirical equations, are able to consider complex slide scenarios, water body geometries and topographies. The development of a user-friendly and reliable numerical code which is able to provide realistic results over a wide range of SLT scenarios would be valuable. This would likely involve the coupling of different methods for slide propagation (e.g. the Discrete Element Method (DEM)), wave generation (e.g. the Reynold-averaged Navier-Stokes (RANS) equations) and wave propagation and runup (e.g. the non-hydrostatic non-linear shallow-water equations (NLSWEs)). Further, such a code involves challenges such as extensive computational cost, calibration and validation for a wide range of SLT scenarios, importing and handling topographic and bathymetric data and a user-friendly interface for users who are not highly trained in numerical modelling.

Korteweg-deVries (KdV) and Kadomtsev-Petviashvili (KP) equations: The KdV (for 2D wave propagation) and the KP (3D) partial differential equations describe the full theoretical wave type range from sines, Stokes, cnoidal to solitary waves. These partial differential equations can be used in combination with the (inverse) non-linear Fourier transform (NLFT) to describe and decompose data sequences such as the free water surfaces of SLTs (Figure 3). Further, the KdV/KP equations also explicitly consider nonlinear wave-wave interactions (Brühl and Becker, 2018). The superposition of these components and their interactions results in the original wave profile and, crucially, it has the potential to reliable predict wave profiles at any desired point in the far-field.

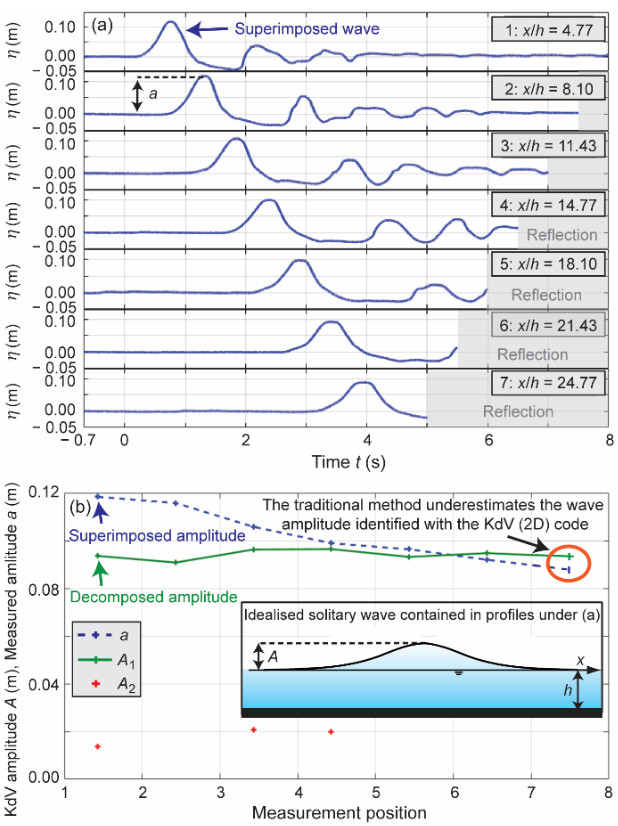

Figure 3 - (a) SLT profiles η (m) versus time t (s) measured at seven distances from the slide impact in a flume (2D) and (b) wave amplitudes a together with primary A_1 and secondary solitary wave amplitudes A_2 identified with the KdV (2D) method in the data in (a) (after Brühl and Becker, 2018).

Figure 3 illustrates the potential of the KdV equation based on 2D SLT laboratory wave train data measured at seven positions (Figure 3a). The decomposed wave train (Figure 3b) includes one dominant solitary wave. Whilst the superimposed wave amplitude a in the measured laboratory data is decaying, this dominant decomposed solitary wave amplitude A_1 remains essentially constant over all measured positions and beyond. This potentially most dangerous wave component propagates faster and will eventually separate from the wave train in the far-field. Generic empirical equations (III) describe SLTs only with the superposition of all amplitude a components, miss this underlying key-physical processes and extrapolate the decay of the superimposed a to predict the wave further downwave. This results in a dangerous underestimation of the wave magnitude in Figure 3b as the superimposed a is smaller than the individual decomposed components A_1 both at the encircled point and further downwave. Methods based on the KdV/KP equations have the potential to result in a physical-based prediction of SLTs.

CONCLUSIONS

Subaerial landslide-tsunami (SLT) research has insufficiently advanced over the last decades. A generic numerical code and the Kadomtsev-Petviashvili equation have been proposed as potential candidates to paradigm shift SLT research. Generic empirical equations, potentially supported by machine learning, are important until this paradigm shift is performed.

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