

# LABORATORY EXPERIMENTS ON THE RUNUP OF LEADING-DEPRESSION N-WAVES

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## INTRODUCTION

Real tsunamis often lead with a depression wave, causing coastal water level to lower before the main tsunami wave arrives and floods the coast. The widely used benchmark wave, the solitary wave, cannot capture this phenomenon, in addition to the many drawbacks in using the solitary wave as a model tsunami wave form (Madsen et al. 2008). Although alternative tsunami wave forms have been proposed to capture the water level withdrawal phenomenon, in particular the leading-depression N-waves (LDN), a consistent method for generating and characterizing LDNs had been lacking.

In this study we adopt the Lima et al. (2019) wave generation method to consistently generate LDNs in the laboratory. By comparing the evolution, shoaling, and runup processes of LDNs to those due to solitary waves of the same wave amplitude, we seek to identify the differences and similarities between the runup of LDNs and the runup of solitary waves. The ultimate objective is to provide a link between LDNs and solitary waves, so that the vast existing knowledge on solitary waves can be extended to study LDNs.

## LABORATORY SETUP

Laboratory experiments were conducted to investigate the evolution, shoaling, wave breaking, and runup of LDNs. As shown in Figure 1, the wave flume has a 13.5 m constant water depth of  $d=0.23$  m, with a piston-type wavemaker installed on one end, and a 1:10 slope installed on the other end. Four acoustic wave gauges (WG) were employed to measure the time series of water surface elevation; WG03 was placed at the toe of the slope. Five digital cameras (CAM) were used to record the wavemaking, wave shoaling, wave breaking, and wave runup processes.

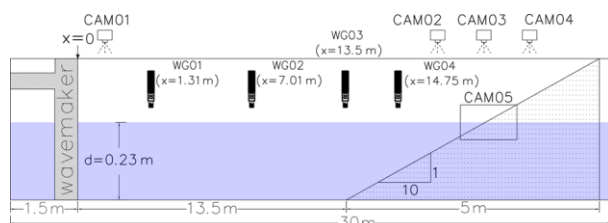


Figure 1 - Schematic sketch of our laboratory setup.

The wavemaker trajectory proposed by Lima et al. (2019) was adopted to generate LDNs following the Tadepalli and Synolakis (1994) definition. In total, three dimensionless parameters govern the wavemaker motion; each unique combination of the three parameters corresponds to a unique LDN. Due to the dispersive nature of LDNs, the waves continuously deform since generation. Hence, the propagation distance also impacts the wave shape.

For benchmarking purposes and to provide reference data, solitary waves were also generated in the laboratory following the Goring (1978) method. The wave shape and runup all compare favorably with existing literature.

## RESULTS

In our wave flume with a 13.5 m constant water depth section and a 1:10 slope, a total of 88 different LDNs and 24 different solitary waves were considered. Based on the runup trends and the wave profiles measured at the toe of the slope (WG03), we categorize the LDNs into three types. The runup results of each type of LDNs are compared with solitary waves in Figure 2.

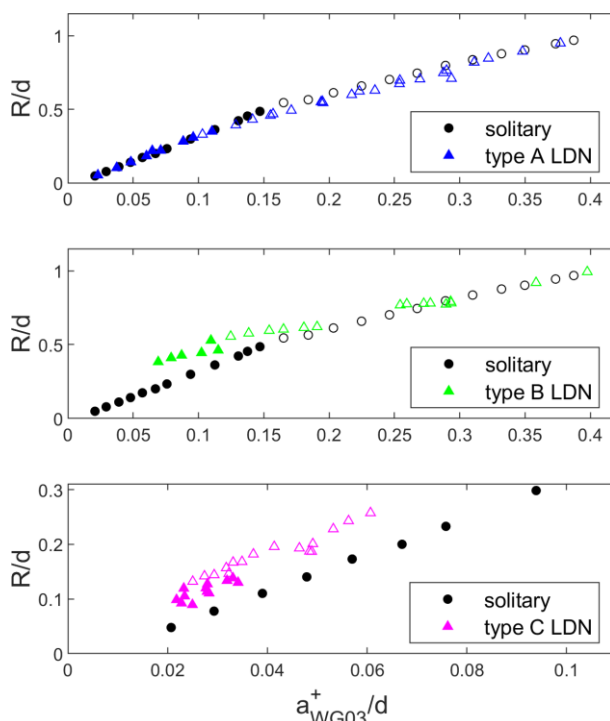


Figure 2 - Runup of three different types of LDNs compared with the runup of solitary waves. Filled symbol: nonbreaking wave; hollow symbol: breaking wave;  $a^+_{WG03}$ : wave amplitude at WG03; R: runup height.

Type A LDNs have similar runup to solitary waves for nonbreaking cases; type A LDNs have slightly lower runup than solitary waves for breaking cases. The main wave crest of a type A LDN is shaped similarly to the solitary wave of the same amplitude, as illustrated in the left panel of Figure 3. Hence, the main distinguishing feature of a type A LDN from the solitary wave is the leading depression. From the sideview recordings, Figure 4 for example, it is observed that the leading depression of a type A LDN facilitates wave breaking. Therefore, the wave breaking amplitude threshold for

type A LDNs is lower than that for solitary waves. For a nonbreaking type A LDN, its runup is similar to the solitary wave runup, since the two have similarly shaped wave crest. For a breaking type A LDN, the wave breaking process is more violent than that for the solitary wave of the same amplitude. Hence, more energy is dissipated, reducing the runup of the LDN and increasing the intensity of the swash flow.

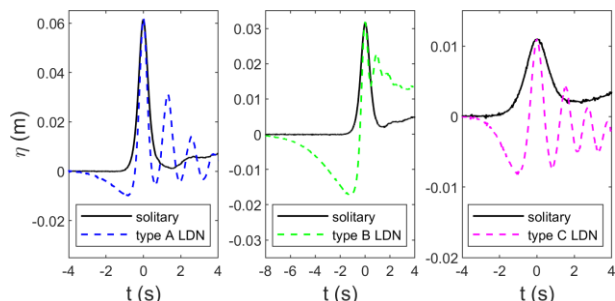


Figure 3 - Comparison of the wave profiles of LDNs and solitary waves of the same amplitude at the toe of the 1:10 slope.

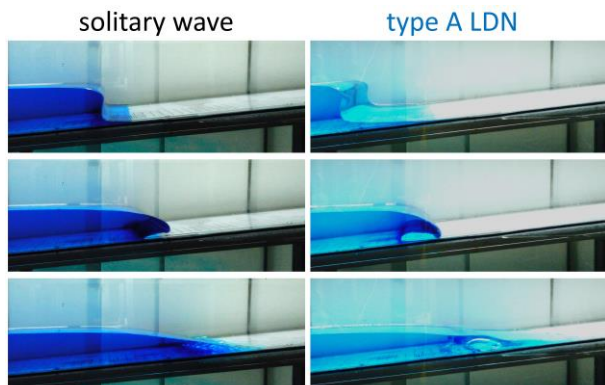


Figure 4 - The shoaling and wave breaking of a solitary wave compared with those of a type A LDN. The two waves have the same amplitude at the toe of the 1:10 slope.

Type B LDNs have pronounced trailing waves elevated above the still water level, resembling undular bores whose leading wave crests have the shape of solitary waves, as illustrated in the center panel of Figure 3. Undular bores can cause higher runup than solitary waves (Barranco and Liu 2021). On the other hand, as discussed for type A LDNs, the leading depression can reduce wave runup. Therefore, the runup of a type B LDN depends on the interplay between its bore feature and its leading depression feature. A type B LDN causes a higher runup than the solitary wave of the same amplitude if its bore feature dominates; a type B LDN causes a lower runup than the solitary wave of the same amplitude if its leading depression feature dominates.

Type C LDNs have a very steep wave front (as illustrated in the right panel of Figure 3) and are mostly nonbreaking or only mildly breaking. For nonbreaking long waves, Chan and Liu (2012) showed that the wave front steepness determines the wave runup. Type C LDNs follow the trend proposed by Chan and Liu: the steeper the wave front of a

type C LDN in comparison to the solitary wave, the higher the runup.

#### CONCLUDING REMARKS

As shown in Figure 2, based on the 88 LDNs considered in this study, we observed that the runup of small-amplitude LDNs can potentially be larger than the runup of solitary waves, whereas the runup of finite-amplitude LDNs has the same order of magnitude as the runup of solitary waves. Since tsunamis are generally small-amplitude waves, our laboratory observations suggest that using solitary waves as model tsunami waves may underpredict the runup significantly.

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