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Experimental Investigation of Effects of Coastal Morphology on N-Waves

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Abstract

A Leading Depression N-wave which consists of a negative and a positive amplitude solitary wave was generated with the help of a special designed wave pallet at Istanbul Technical University Hydraulic Laboratory. In addition, generated N-Wave was verified by using verification of related analytical equations. Furthermore, the wave flume was narrowed by narrowing angles of 5°, 10° and 15° for analogy to morphology changes in coastal areas. It was determined that water level differences and phase shifts occurred to the narrowing effects.

Keywords: N-Wave, Leading Depression N-wave, Solitary Wave, Tsunami, Long Wave

Introduction

N-Wave which is a solitary wave type does not occur in the nature frequently so that the researchers can not examine it easily. Especially tsunamis generated due to sea bottom landslides and earthquakes cause these kinds of solitary waves. Therefore N-Wave is generated experimentally in the laboratory and investigated. Investigation of N-wave is crucial in understanding disasters like tsunamis which has devastating effects.

Scientists, in the beginning tsunami wave research, decided that tsunami is a solitary wave with only one crest (Synolakis and Bernard, 2006). This decision led to deeper research on solitary waves and theoretical approaches followed by numerical and physical modelling studies.

However due to unpredictability of tsunamis and lack of widespread visual recording devices, clear and well-founded studies were not achieved in simulation of a real tsunami wave (Synolakis and Bernard, 2006). Due to the dramatic advancement in digital technology, remote sensing becomes widespread and also video and photo capturing technologies improved so that each individual can have a camera of their own. Therefore observation, our first scientific tool, gave us the ability to improve our knowledge on tsunamis. At the end of 90s, a trough accompanying the crest is discovered in solitary waves (Tadepalli and Synolakis, 1994). The morphological similarity of solitary wave and Latin letter N caused the name N-Wave. Additionally two new definitions were made for N-Waves; the crest is followed by a trough 'Leading Elevation N-wave (LEN)' and the trough is followed by a crest 'Leading Depression N-wave (LDN)' (Tadepalli and Synolakis, 1994, 1996). In the following years researchers developed different theories and numerical models, but due to lack of real world tsunami records and lack of tsunami type wave generators in laboratories, they had problems in verification of their theories and models. In 26th of December 2004, a devastating tsunami formed during Sumatra Earthquake in Indian Ocean. During this disaster more than 230000 people from 14 countries lost their lives and incidentally a Belgium boat called 'Mercator' was able to take a record of water level variation during this tsunami (Synolakis and Bernard, 2006). After that break point, Synolakis and Bernard (2006) and Madsen et al. (2008) declared that the tsunami phenomenon could not be described by using the solitary wave approach. Furthermore, Madsen et al. (2008) brought up that the N-wave approach of the Tadepalli and Synolakis (1994, 1996) had hydrodynamic problems and this approach didn't truly describe physics of an N-wave. In addition, Madsen and Schaffer (2010) described N-wave as superposition of one positive and one negative amplitude solitary wave and came up with an N-wave equation presented below:

$$y(t) = A_1 \operatorname{sech}^2 \Omega_1 (t - t_1) - A_2 \operatorname{sech}^2 \Omega_2 (t - t_2)$$

In this equation y is free stream water level; A_1 and A_2 are positive and negative amplitudes, respectively; Ω_1 and Ω_2 are angular velocity and t_1 and t_2 are phase differences. Also these parameters are independent variables (Madsen and Schaffer, 2010).
Beside the theoretical studies on N-wave, physical experiment studies are so rare on this topic. Hydraulic Laboratory of Istanbul Technical University has a unique N-Wave generator with a special piston mechanism in a wave flume. Some experimental studies conducted by different researchers in this special wave channel. Gedik (2004) and Gedik et al. (2005) investigated long wave run-up and Gedik (2006) investigated run-down of this wave. In addition, Baş (2007) and Yüce (2007) conducted experimental studies in this channel about stability of rubble mound breakwaters and vertical faced coastal structures under N-wave generated in same channel, respectively. Furthermore, Irtem et al. (2009) investigated run-up of tsunami wave on a coastal shoreline covered with forest.
In the context of this study, physical properties of N-Wave were investigated to fill the gap in the literature. Tsunamis, emerged offshore, are affected from coastal morphologies as they approach the coast. In this study an experimental set-up was established for investigating LDN type N-Waves reaching estuaries and river mouths. In this set-up width of the flume was reduced gradually with 5, 10 and 15 degree angles. Water level variations were also measured for these 3 set-ups.

Material and methods

A special piston type wave maker equipped channel in the Hydraulics Laboratory of Civil Engineering Faculty at Istanbul Technical University was used for this study (Fig 1). The wave flume has the dimensions of 23.5m x 1.0m x 0.5m. Test section was established 10.80m far away from the wave pallet. Wave pallet has dimensions of 2.0m x 0.97m x 0.002m and it is made of Plexiglas. One end of the pallet was hinged to the bottom of channel and the other end was controlled by a pneumatic piston (Fig 1). Detailed working mechanism of the wave maker was presented by Gedik (2004) and Gedik et. al (2005).

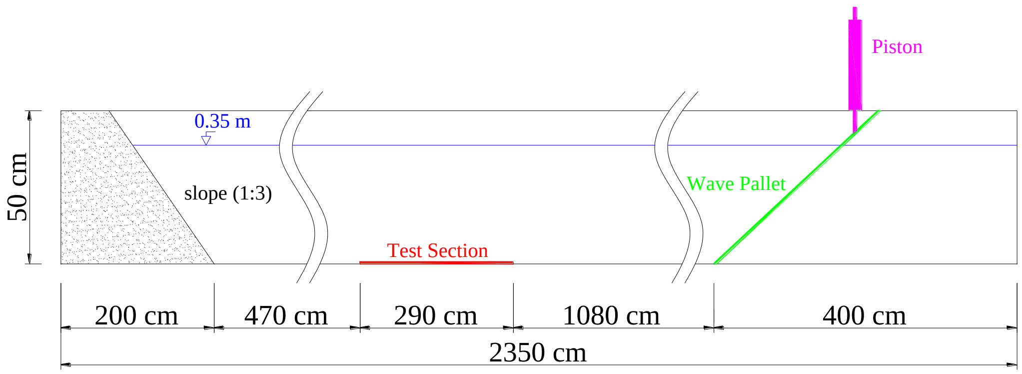

Fig 1. Wave Channel Cross Section

In this study, wave channel was narrowed by using 0.002m thick marine plywood which has a high durability in the water to simulate the entrance LDN type N-Waves reaching estuaries and river mouths. Channel was narrowed with three different reduction angles of 5°, 10° and 15°, respectively (Fig 2).

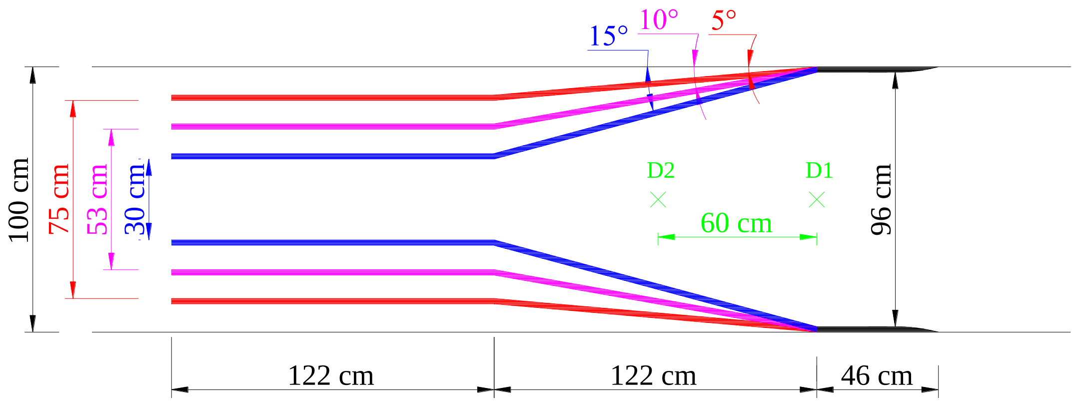

Fig 2. Test section and narrowing angles.

HR Wallingford resistant type wave probes were used to record water level variations. These measurements were done at the points D1 and D2 which are shown in Fig 2. Beside these points, an offshore probe was placed for recording undisturbed wave. Thus, characteristic of the wave was put forward. Still water level during the experiments was 0.35m.

Wave period at an oscillatory wave is defined as the time interval between two equivalent points. Thus, time interval between a crest and following trough is half period in an oscillatory wave motion. Considering this half period definition, a representative period is defined for N-wave motion. Time interval between first depression and elevation was defined half period (T/2) in this study Furthermore, height between these two points was also defined as wave height (H) for this study, as well (Fig. 3).

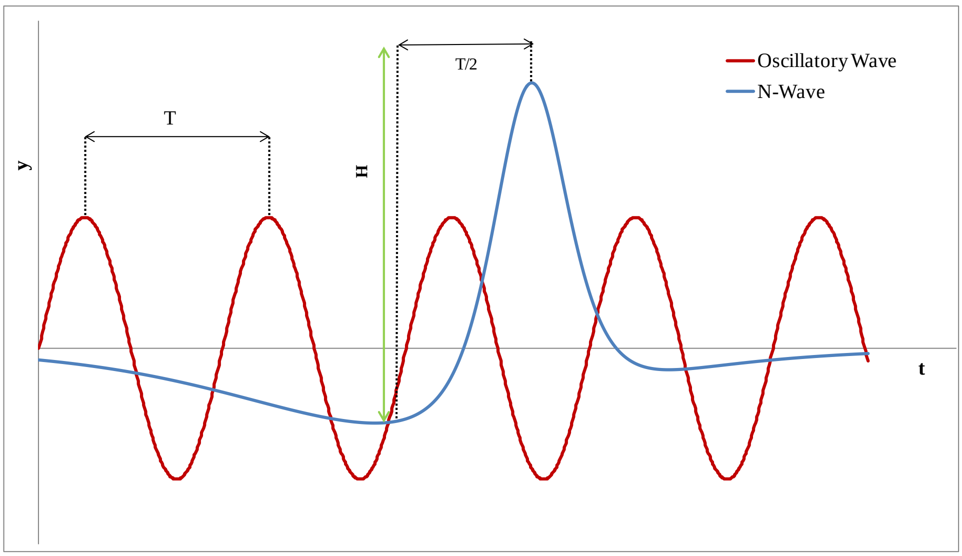

Fig 3. Representative wave period and wave height definition for N-wave.

Results

To define the characteristics of produced wave in the wave flume, water level measurement data at the offshore section was compared with the analytical equations of Madsen and Schaffer (2010). As it is clearly seen in Fig 4, a leading depression is obvious which is compatible with the line that was produced by using the mentioned analytical equations. Thus, it can be concluded that the wave produced is a typical LDN wave. The parameters of the Madsen and Schaffer (2010)'s equation were selected as
A_1=9.9cm where A_1 is the positive amplitude; A_2=2.4cm where A_2 is the negative amplitude; Ω_1=3.75rad/s and Ω_2=0.8rad/s where Ω_1 and Ω_1 are the angular velocity and t_1=2.68s and t_2=2s where t_1 and t_2 are the phase differences. High linear correlation values also proofs the compatibility such as linear correlation value is 0.9964 for t=0s and t=3.044s. According to this, linear correlation between t=0s and t=3.044s is 0.9964. Thus, it can be clearly said that there is a high positive correlation between experimental data and Madsen and Schaffer (2010) equation. Water level measurements at offshore and D1 points are presented at Fig 5. In this figure offshore data (η) was given blue line. Also D1 point was located just entrance of narrowing section as shown in Fig 2. While investigating the Fig 5, significant differences could not be determined at the first depression and elevation sections. In contrary, just after elevation section significant time phases were observed. These time phases were labelled as A and B in Fig 5. This time shift was especially obvious at narrowing angles of 10° and 15°. Moreover, wave height (H) was getting higher with the increasing angle of narrowing.

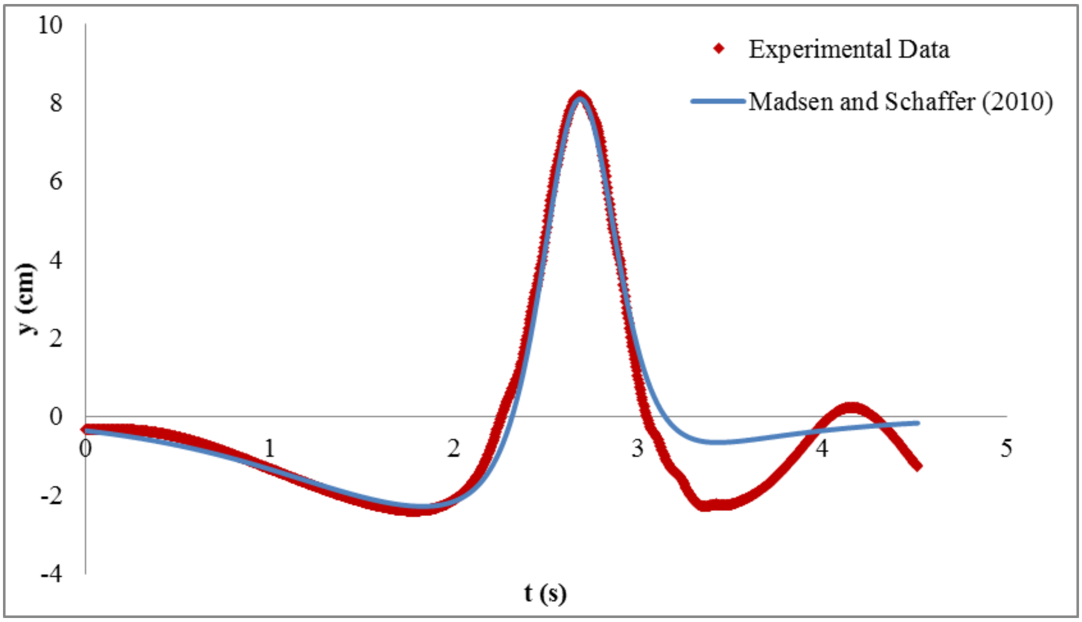

Fig 4. Comparison between experimental data at offshore measurement point and Madsen and Schaffer (2010).

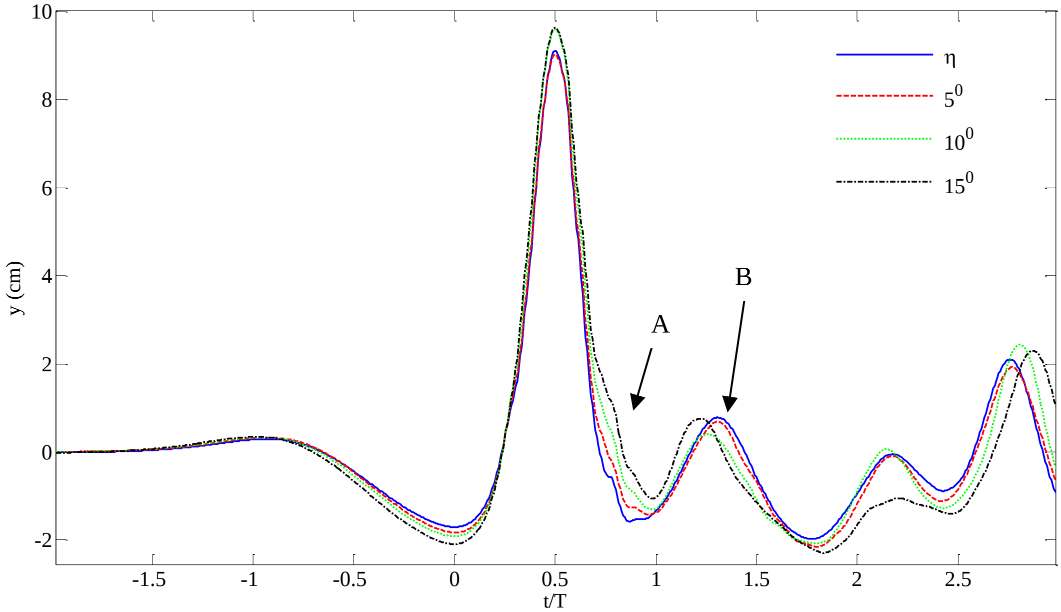

Fig 5. Water level measurements at offshore (η) and D1 point (5°, 10° and 15°)

In Fig 6 water level measurements at D1 and D2 points (Fig 2) compared for narrowing angle of 5°. There were minor differences between these two measurements. There was an increase of 0.45 cm in wave height. Also no phase shift was observed at the tail section.

In Fig 7 water level measurements at D1 and D2 points (Fig 2) compared for narrowing angle of 10°. Effect of narrowing was firstly detected at this angle. Wave height increase was 0.60 cm. Furthermore a time phase shift observed at the tail section of the wave. Phase shift at point C shown in Fig 7 was 0.08s.

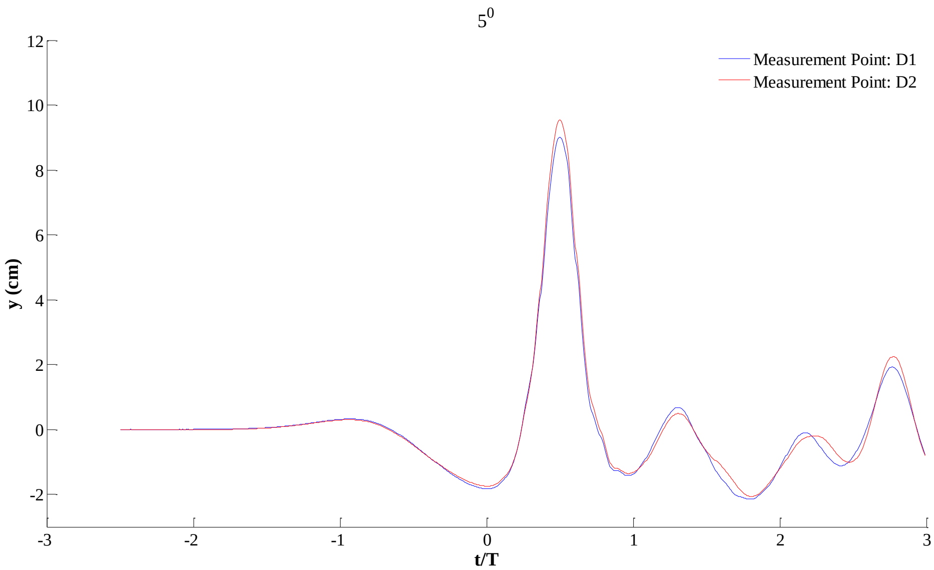

Fig 6. Water level measurements at D1 and D2 points for narrowing angle of 5°

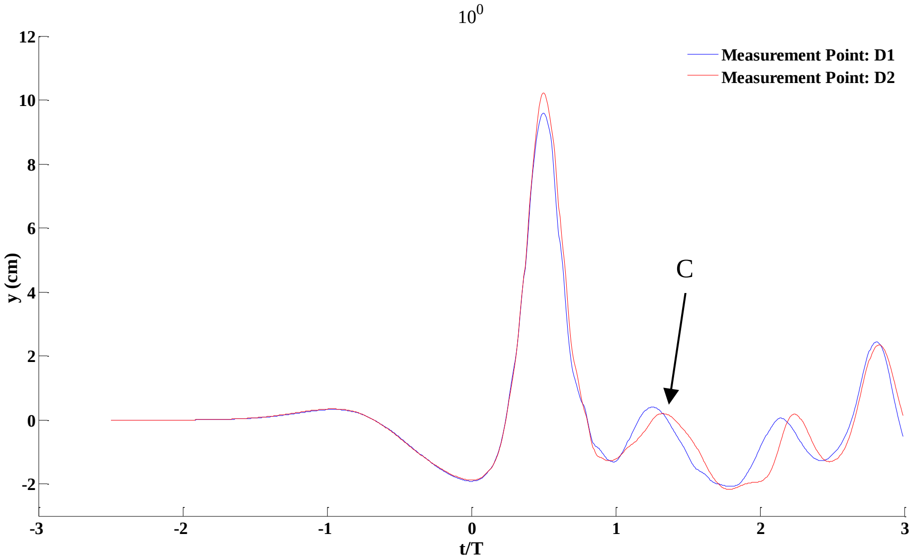

Fig 7. Water level measurements at D1 and D2 points for narrowing angle of 10°

In Fig 8 water level measurements at D1 and D2 points (Fig 2) compared for narrowing angle of 15°. Effect of narrowing was much more obvious in this angle. Wave height increase was 1.14 cm and phase shift at point C was 0.26s.

Effect of narrowing was summarized at Table 1. According to this table, it can be said that the wave heights increased and the wave periods decreased with increasing angle of narrowing.

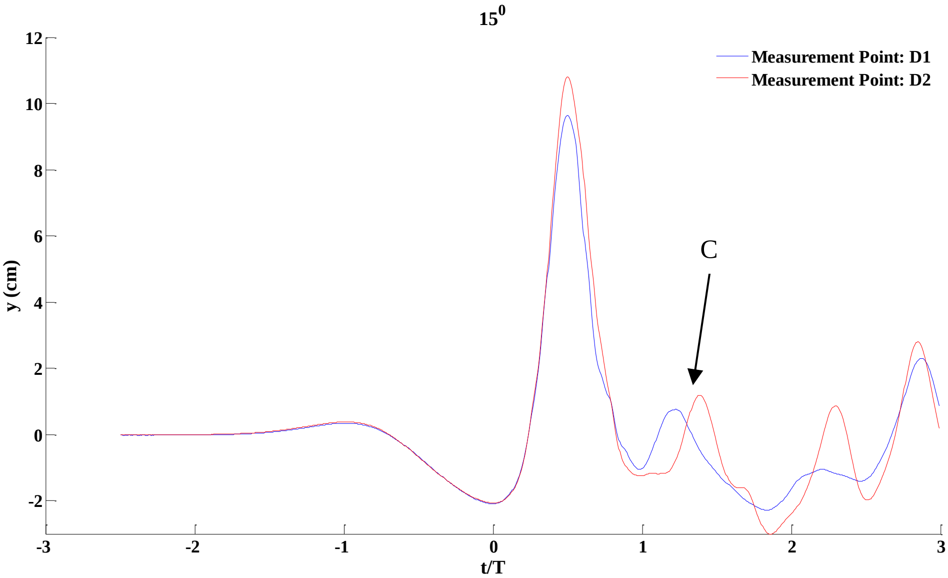

Fig 8. Water level measurements at D1 and D2 points for narrowing angle of 15°

Table 1: Effect of Narrowing

Narrowing Angle	Measurement Point	Wave Height H (cm)	Wave Period T (s)	Height Differences (ΔH) (cm)	Phase Shift at Point C (s)
5	D1	10.85	1.80	0.45	0
5	D2	11.30	1.80		
10	D1	11.51	1.78	0.60	0.08
10	D2	12.11	1.75		
15	D1	11.73	1.73	1.14	0.26
15	D2	12.87	1.71		

Conclusion

A LDN type N-wave which consists of one negative and one positive amplitude solitary wave were generated in the flume of ITU Hydraulics Laboratory. This generated LDN type N-Wave was verified by using verification of related analytical equations that were developed by Madsen and Schaffer (2010).

In addition, some experiments were executed for investigating the behaviour of mentioned waves in the case of entrance to the narrower coastal regions such as estuaries and river mouths. For this aim, 3 different narrowing angles were used during the experiments to simulate narrowing effects. As a result of these narrowing sections, increase of generated wave heights and decrease of generated wave periods were observed. Also a meaningful phase shift was determined at tail sections of N-wave for the experiments with 10° and 15° narrowing sections.

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