

PHYSICAL MODELING OF TSUNAMI WAVE PROPAGATION IN A MEANDERING CHANNEL

H. Anıl Arı Güner, Yıldız Technical University, aari@yildiz.edu.tr
Cem Yılmaz, Yıldız Technical University, cemyilmazer92@gmail.com
Yalçın Yüksel, Yıldız Technical University, yuksel@yildiz.edu.tr
Mehmet Öztürk, Yıldız Technical University, meozturk@yildiz.edu.tr
Cihan Şahin, Yıldız Technical University, cisahin@yildiz.edu.tr
G. Güney Doğan, Middle East Technical University, gguneydogan@gmail.com
Ahmet Cevdet Yalçiner, Middle East Technical University, yalciner@metu.edu.tr

INTRODUCTION

Tsunamis can cause serious damage not only to coastal areas but also to riverine infrastructures and areas due to the long distance of waves ascending in rivers in the form of a bore. When a tsunami wave enters a river channel, it encounters a countercurrent, and the wavefront transforms into an undular or breaking bore. Some of the bores have the form of one initial wave with a train of smaller waves known as whelps (undular bore). In the others, such a wave train does not appear and only a step with a flat water surface behind can be observed (breaking bore) (Tsuji, 1991; Yasuda, 2010; Whuppukondur and Baldock, 2022). Field observations of tsunamis show that tsunami waves travel faster and further along coastal rivers than inland mainly due to low-elevation and water existence (in wet conditions), reduced obstructions, meanders, and converging boundaries. Tsunami propagation in coastal areas has been widely studied, but there is a limited number of studies investigating tsunami propagation into a river channel.

The interaction between the propagating tsunami and countercurrent along the meandering stream and varying cross-sectional area and geometries along the stream is a complex problem. This research aims to investigate this problem by using physical modeling approaches along a meandering stream.

EXPERIMENTAL SETUP AND METHODOLOGY

The experimental study was conducted in the meandering channel established in the “Hydrodynamics Research Laboratory” at Yıldız Technical University to simulate tsunami propagation along such channels. Experiments were performed in a 0.6 m wide, 0.90 m deep, and 32.9 m long laboratory flume with vertical sidewalls made of plexiglass and aluminum bottom, consisting of a 13.7 m long straight section followed by a 180° bend with a constant radius of curvature of $R = 3.3$ m and a 120° bend with the same radius of curvature. The waves are generated by a tsunami wave generator located downstream of the channel. To produce steady flow, the channel is equipped with a water supply mechanism (maximum discharge of $0.05 \text{ m}^3/\text{s}$) at the upstream end (Figure 1).

In this study, a pneumatic-type tsunami generator was constructed capable of generating through-led N-wave within a physical model (Figure 1).

Tsunami wave characteristics in front of the river mouth were determined using the data and information from the 30 October 2020 tsunami in the Aegean Sea reported by Dogan et al. (2021) and the 2011 Tohoku tsunami

reported by Tanaka et al. (2012). Four different types of leading depression N-waves with different bore strengths ranging from 0.24 to 0.95 were used, where bore strength is the ratio between the difference in flow depth to undisturbed water depth ($\alpha = a + / h$, where $a +$ is the positive wave amplitude). Three different water depths ($h = 15, 20, 25$ cm) are used in the experiments. The experiments were performed under two main hydraulic conditions: (1) the still-water condition (no local flow), and (2) the local flow condition with the discharges ranging from 16 to 50 l/s. Resistance-type wave gauges were used to measure surface elevation (at 100 Hz) at 5 sections along the channel. Flow velocities were measured at the same locations, using an Acoustic Doppler Velocimeter (ADV), at 200 Hz. The plan view of the meandering channel and the picture of the experimental setup are shown in Figure 1.

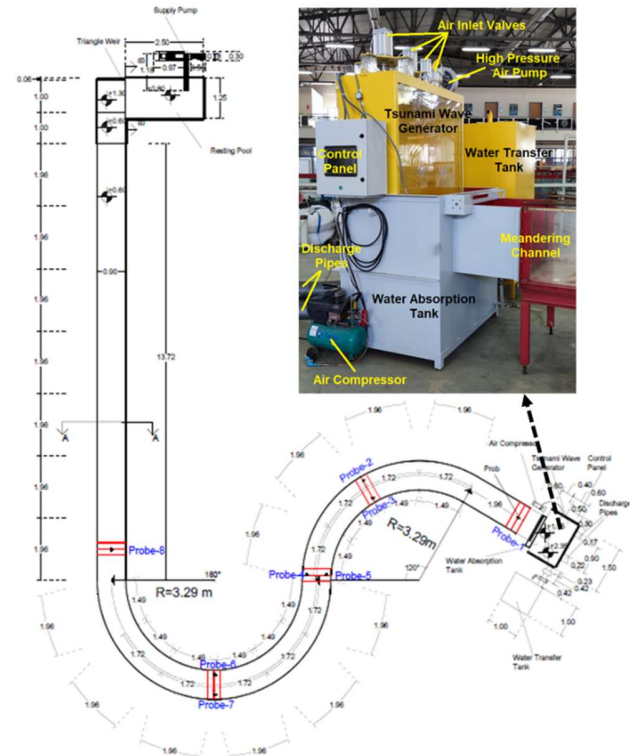


Figure 1 - Plan view (drawing) of the meandering channel and picture of the tsunami generator

RESULTS

For $a+/h=0.24$, an undular tsunami bore was observed which had a smooth free-surface profile with more than three whelps. For $a+/h=0.48$, weak breaking was observed at the first wave crest, and the ensuing smaller waves became flatter as the tsunami bore propagated through the channel. At the largest bores (for $a+/h=0.95$ and $a+/h=0.69$), the bores had a significant roller and seemed to be quasi-two-dimensional. The bore rollers exhibited intense turbulent mixing. The size and strength of the roller increased with the increasing bore strength ($a+/h$).

The positive wave amplitude increased in the first and last outer bend by a factor of 1.9 and 2.1, respectively for $a+/h=0.24$ (Figure 2). In contrast, it decreased immediately after wave breaking at an amount of 40% and 50% for $a+/h=0.69$ and $a+/h=0.95$, respectively. There was not any significant change in positive wave amplitude for $a+/h=0.48$ except for the last bend.

The countercurrent reduced the average celerity of the wave therefore a delay becoming more pronounced with the increasing discharge in tsunami propagation was observed. Additionally, the countercurrent increased the number and clarity of the whelps (free-surface undulations) at the last bend (Probes 6 and 7) and measurement section (Probe 8).

For all conditions ($a+/h=0.24$, 0.48, 0.69, and 0.95), as the wave propagated upstream the period and negative amplitude of the wave decreased directly proportional to the increasing discharge.

The reduction of the through amplitude was observed earlier (after the first meander) for the breaking bores ($a+/h=0.69$ and 0.95).

Figure 2 shows an example of the measured temporal waveforms for the bore strength of $a+/h=0.69$.

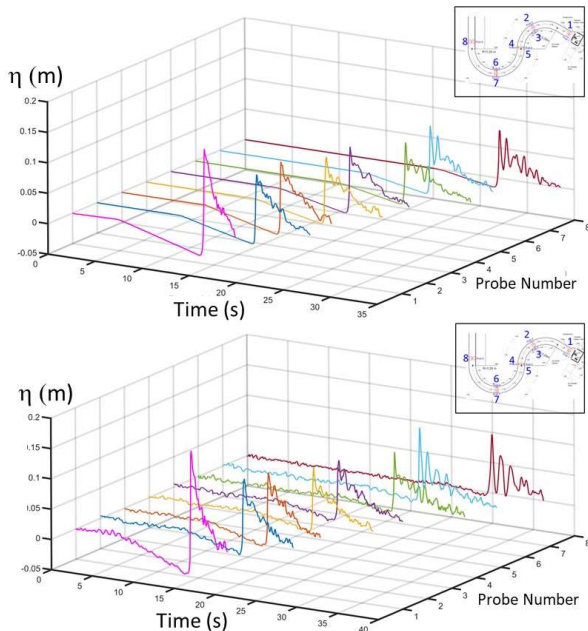


Figure 2 - Measured temporal waveforms for $a+/h=0.69$
a) the still-water condition ($Q=0$ l/s) b) the flow condition with the discharge of $Q=50$ l/s.

ACKNOWLEDGEMENT

This study was supported by TUBITAK (the Scientific and Technological Research Council of Turkey) as part of a research project (128M858).

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