Experimental study on the effects of a canal on the tsunami bore-induced forces exerted on a column

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KEYWORDS
Tsunami, experimental, impact force, abatement measures

RESEARCH NEEDS AND NOVELTY

In recent decades, tsunamis exerted significantly destructive impacts on infrastructure located near the coastlines and caused the death of numerous people (Nistor et al., 2009).

Damage related to tsunami inundation has different causes, including direct hydrostatic and hydrodynamic loading due to inundation, impact forces from water-borne debris, fire spread by floating debris and combustible liquids, and scour and slope/foundation failure.

Various design provisions and planning/zoning measures have been introduced to reduce the tsunami-induced effects on coastal infrastructure. Researchers have identified natural features and man-made solutions to reduce the energy of tsunami inundation, such as sea walls, breakwaters, canals, and forests are among such features/solutions (Oetjen et al., 2022).

Post-tsunami forensic engineering field investigations (Chock et al., 2012) have shown that a canal parallel to the coastline can dissipate the energy of incoming tsunami inundation. During the 2004 Indian Ocean Tsunami, the Buckingham Canal situated along the coastline of Chennai, which was 30m wide and 10m deep, was found to have significantly attenuated the energy of the tsunami surge. Several studies have shown that canals have the potential to significantly reduce tsunami inundation energy (Rahman et al., 2017; Elsheikh et al., 2022).

Although several guidelines and regulations for designing coastal structures against tsunami effects have been proposed, further studies are required to add new provisions for abatement measures against tsunamis. In this study, in the premiere, the authors *measured and quantified* the magnitude and time-history of the force exerted by tsunami bores on a structural column when passing over a water canal, showing its attenuating effect.

EXPERIMENTAL SET-UP

To investigate the impact of a canal as a physical abatement measure to diminish the force of a tsunami bore on a structure located behind the canal, a series of experimental tests were carried out in a 15.60 m long, 0.38 m wide, and 0.60 m deep glass-walled tilting flume in the Water Resources Engineering Laboratory at the University of Ottawa, Canada (Figure 1).

There are different methods in the literature to produce tsunami bores. In recent years, the dam-break method has been demonstrated to be one of the most adequate methods to generate tsunami-like hydraulic bores and has been used by researchers to model tsunami bores, either experimentally or numerically. To allow the formation of well-developed dam-break waves, gate-opening time should meet the following criteria: $T_0 = t_0 (g/D)^{0.5} < 2^{0.5}$ where t_0 is the gate opening time, g is the gravitational acceleration, and D is the water impoundment depth (Vischer and Hager, 1998).

As shown in Fig. 1, the tsunami bore was generated by the quick release of water impounded behind a vertically lifting gate, which was installed 7.76 m from the upstream end of the flume (gate location was chosen as the origin of the system of coordinates, $x=0$).

A canal, positioned transversally to the canal's longitudinal axis, was located 3 m downstream of the gate and was filled with water. To study the effect of the canal in reducing tsunami bore energy, three different depths (h) and widths (w) of the canal were considered. A 15 cm height PVC false floor was installed to build mitigation canals with different geometries. A 1V:6H ramp was installed at the upstream end of the gate location to reduce flow separation and vortex formation.

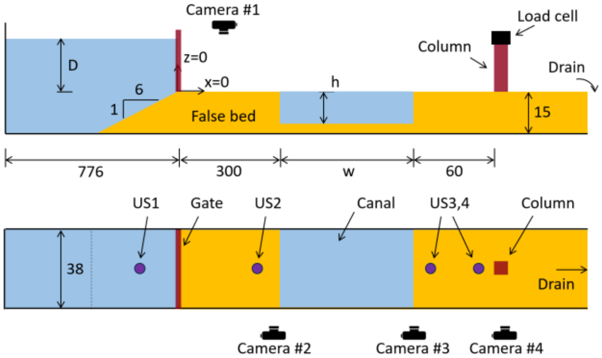

Figure 1 – Schematic of the experimental setup (side and plan view - not at scale, all dimensions in cm)

A 4 cm (side length) square column, positioned vertically downstream of the canal, was attached to a 6-axial load cell (6A154 Interface) mounted atop the column to record the time-history of the forces exerted by the bore onto the column. To avoid the connection to the false bed, a 0.5 mm gap was set between the column and the latter.

Four ultrasonic sensors (MASSA, M-5000/220, Massachusetts, USA), with a sampling frequency of 1200 Hz, were deployed upstream and downstream of the gate along the flume (100 cm upstream of the gate, 30 cm before and after the canal, and in front of the column) to record the time-history of the water surface level.

Four GoPro Hero5 video cameras were employed to monitor the propagation of the bore along the flume, its behavior before (Camera #2) and after (Camera #3) entering the canal, and around the column (Camera #4). In addition, another camera (Camera #1) was placed atop the flume downstream of the gate to record the movement of the bore front and check the gate-opening time.

The test design was based on the water impoundment depth (D), location of the mitigation canal, and column. For example, test number D40-C300360-h10-S420 stands for a test with D=40 cm, in which the 60 cm mitigation canal is located at x=300 cm to x=360 cm, and the column was installed at x=420 cm.

RESULTS AND DISCUSSION

To determine the gate-opening time and bore velocity, video analysis was conducted to track the locations of the gate and bore front as well as colored balls (Figure 2). The data were then compared with the wave celerity equation $U = \alpha\sqrt{gd_0}$ where α is the coefficient recommended 1.25 by Wutrich et al. (2018).

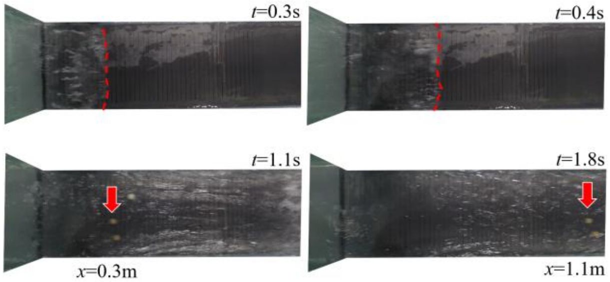

Figure 2 - Determination of bore front and surface velocity by video analysis (captured by Camera #1)

Figure 3 shows the time-history of the bore surface at x=390 cm for various combinations of canal dimensions and column locations. In this test, a 60 cm wide canal was placed with its upstream edge between x=300 cm and x=360 cm, while the column was installed at x=420 cm.

The impact of the bore on the canal results in water discharge from the canal. This discharge is the reason for the higher water level (t-t_0<12 s), as depicted in Fig. 3, when the canal was present (yellow line), compared to the water level without the canal and column (black line).

As depicted in this figure, the presence of the column results in a noticeable run-up occurring at approximately time=10 s, (indicated by the red and blue lines). This run-up subsequently leads to an increase in the force exerted on the column, as shown in Fig. 4.

Figure 4 illustrates the time-history of the force exerted on the square column for various canal widths. In all tests shown in this figure, the impoundment water depth was kept constant at 40 cm, and the column position remained the same in all tests (x=660 cm), ensuring that the bore traveled the same distance from the gate.

As depicted in Fig. 4, while the impact of a 60 cm wide canal was not significant, the presence of 160 cm and 300 cm wide canals significantly reduced the initial impact and run-up forces on the column. In particular, the 300 cm wide canal resulted in a 25% reduction, with the maximum force magnitude decreasing from 15.2 N to 11.4 N.

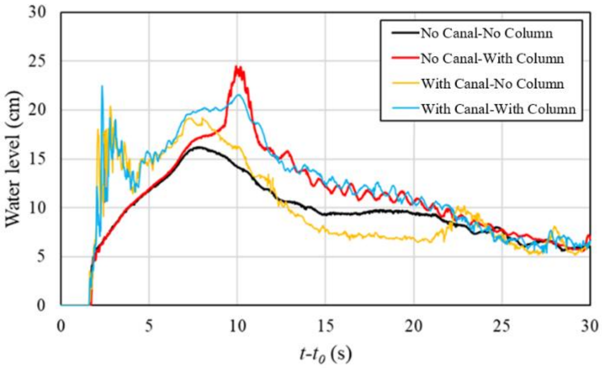

Figure 3 - Time-history of the water surface level at location x=360 cm

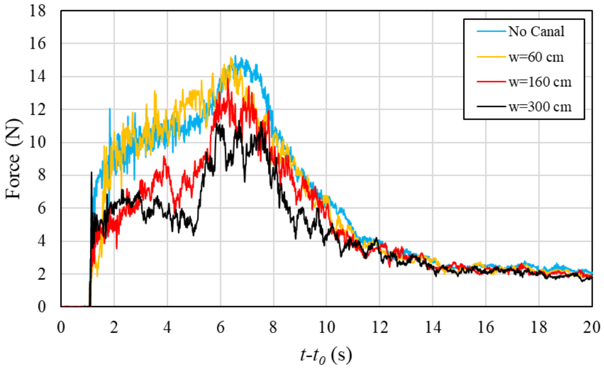

Figure 4 - Time-history of force exerted onto the column in the presence of canals with different widths (in all tests D=40 cm, h=15 cm, upstream edge of canals was located at x=300, and the column was installed at 660 cm)

CONCLUSION

In recent decades, several regions of the world's coastlines have witnessed the destructive power of tsunamis, which inflicted severe damage to infrastructure and resulted in a substantial loss of life.

Various solutions have been investigated to mitigate the impact of tsunamis on nearshore structures. Field studies have shown that the presence of a canal running along the coastline can reduce the tsunami inundation energy. Although guidelines and standards account for the adequate design of critical infrastructure, research focused less on abatement measures against the impact of tsunamis on infrastructure.

The present study examined how a water-filled canal affects the forces induced by tsunami bores exerted onto a column. A series of laboratory tests revealed that the presence of such a canal could diminish the energy of tsunami bores and that the rate of reduction is directly related to the geometry of the canal.

REFERENCES

Due to space limitations, the references mentioned herein are not listed.