Created in COMSOL Multiphysics 6.1

# Tsunami Runup onto a Complex 3D Beach, Monai Valley

## *Introduction*

On July 12, 1993, an earthquake with a magnitude of 7.8 occurred in the Sea of Japan, 55 km from the island of Hokkaido and 75 km north of the small island of Okushiri. Several tsunamis caused extensive damage on both islands, and the effects of the earthquake were also noticed along the Russian Pacific coast and the east coast of South Korea. In Japan, it produced the worst tsunami-related death toll in fifty years, with estimated 30 m runup heights and currents of the order of 10–18 m/s in the island of Okushiri. The extreme tsunami runup mark was discovered at the tip of a very narrow gully within a small cove at Monai.

This example is an established benchmark case that models a 1/400 scaled laboratory experiment of the tsunami runup in the Monai Valley in Japan; see Ref. 1 and Ref. 2. The experiment used a 205 m long, 6 m deep, and 3.4 m wide tank. The benchmark focuses on a region near the shoreline for which detailed experimental data is available. The tank is initially filled with still water, and a known incident wave is imposed at one of the boundaries. The wave makes the shoreline move back and forth, washing over the small island in the middle of the domain and completely covering it for rather long periods.

## *Model Definition*

This model considers small rectangular region of the experimental tank that is 5.448 m long and 3.402 m wide. The incoming wave is fed into the domain using Inlet feature on the left boundary where water depth is prescribed as a leading depression N-wave (LDN) with a –2.5 mm leading depression and a 1.6 cm crest behind it. The inlet velocity is extrapolated from the solution in the domain. The other boundaries are modeled as reflective walls. Both the total height at the inlet and bottom topography are available as text files in the National Oceanic and Atmospheric Administration (NOAA) website, Ref. 3, in the benchmark case "Tsunami runup onto a complex three-dimensional beach; Monai valley". The bottom height and profile of the incoming wave are plotted in Figure 1 and Figure 2, respectively.

In the experiment the water level was monitored at three points ($x = 4.52$ m and $y = 1.169$ m, $y = 1.669$ m, and $y = 2.169$ m). Three Domain Point Probes are added in the model to track the evolution of the water level at these points.

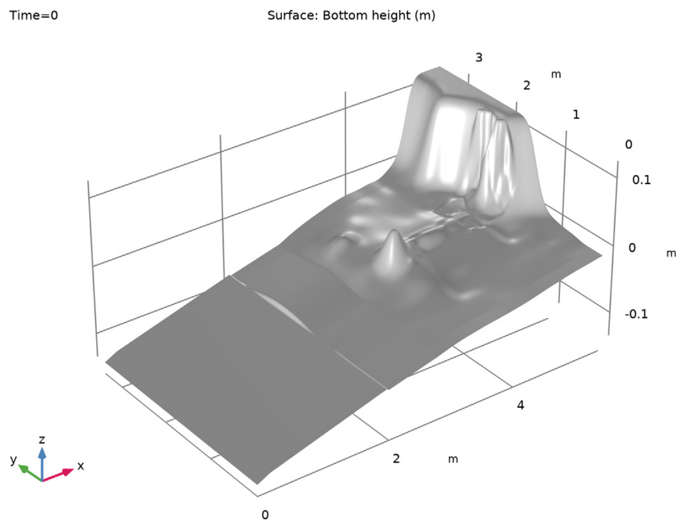


*Figure 1: Bottom topography.*

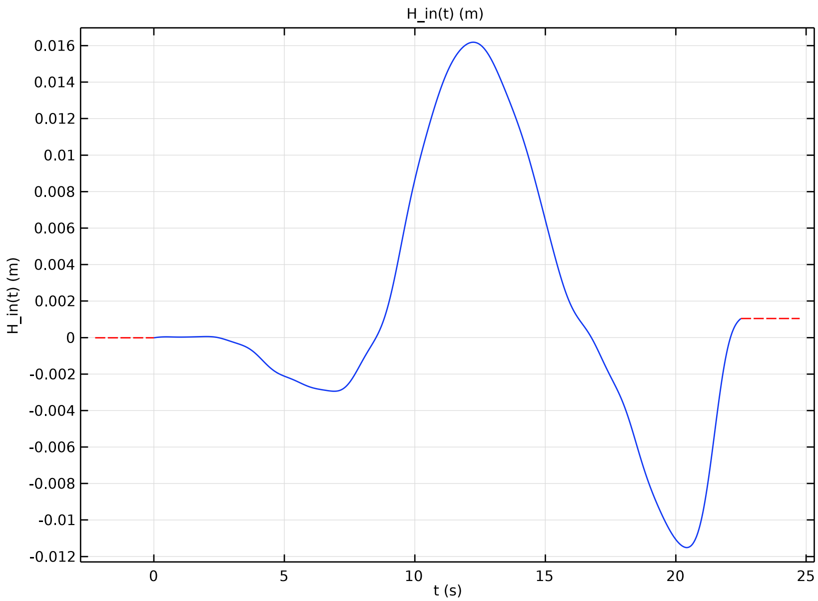


*Figure 2: Incoming wave profile.*

## Results and Discussion

The contours of water level at different times are shown in Figure 3. At $t = 12$ s the shoreline is moving backward due to the depression wave. Later, the high wave reaches the highest point in the shoreline and becomes reflected. At $t = 19$ s the flood wave has covered the small island in the middle and is moving backward. The island becomes visible again at $t = 22$ s.

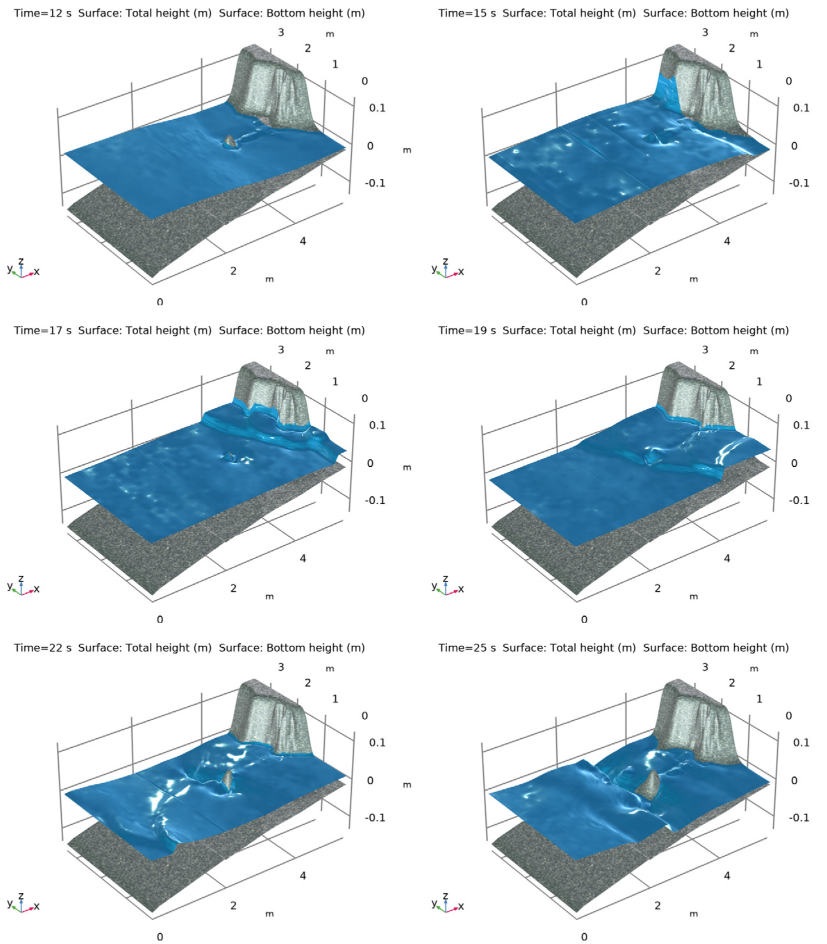


*Figure 3: Water level surface at t = 12 s, 15 s, 17 s, 19 s, 22 s, and 25 s.*

The water level at the three domain probe points is depicted in Figure 4. At all three points it first slowly reduces due to the depression wave and then increases in two sudden jumps: approximately at $t = 15$ s, when the high wave comes, and approximately at $t = 17$ s due to the reflected wave. The three points see the waves at different times due to the irregularities of the bottom. The results agree with the measured values presented in Ref. 3.

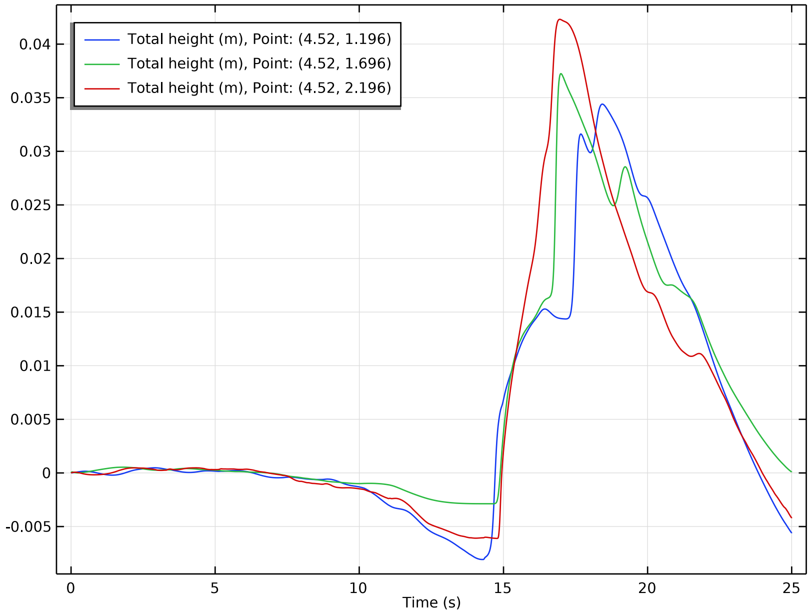


*Figure 4: Water level at three different points.*

## References

1. C.E. Synolakis and others, "Standards, criteria, and procedures for NOAA evaluation of tsunami numerical models," *NOAA Tech. Memo.*, OAR PMEL-135, NOAA/Pacific Marine Environmental Laboratory, Seattle, WA, 2007.

2. C.E. Synolakis and others, "Validation and verification of tsunami numerical models," *Pure Appl. Geophys.*, vol. 165, pp. 2197–2228, 2008.

3. NOAA, "Benchmark methods for tsunami model validation and verification", July 2020, https://nctr.pmel.noaa.gov/benchmark/.

**Application Library path:** `CFD_Module/Shallow_Water_Equations/monai_runup`

## Modeling Instructions

From the **File** menu, choose **New**.

## NEW

In the **New** window, click **Model Wizard**.

## MODEL WIZARD

1 In the **Model Wizard** window, click **2D**.
2 In the **Select Physics** tree, select **Fluid Flow>Shallow Water Equations>Shallow Water Equations, Time Explicit (swe)**.
3 Click **Add**.
4 Click **Study**.
5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Time Dependent**.
6 Click **Done**.

## GEOMETRY 1

*Rectangle 1 (r1)*

1 In the **Geometry** toolbar, click **Rectangle**.
2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
3 In the **Width** text field, type `5.448`.
4 In the **Height** text field, type `3.402`.

## DEFINITIONS

Import the bottom topography and the profile of the incoming wave from text files.

*Inverse of Bottom Topography*

1 In the **Home** toolbar, click f(X) **Functions** and choose **Local>Interpolation**.
2 In the **Settings** window for **Interpolation**, type `Inverse of Bottom Topography` in the **Label** text field.
3 Locate the **Definition** section. From the **Data source** list, choose **File**.
4 Click **Browse**.
5 Browse to the model's Application Libraries folder and double-click the file `monai_runup_bathymetry.txt`.
6 Click **Import**.
7 Select the **Use spatial coordinates as arguments** check box.

**8** Find the **Functions** subsection. In the table, enter the following settings:

| Function name | Position in file |
| --- | --- |
| zB | 1 |

**9** Locate the **Units** section. In the **Function** table, enter the following settings:

| Function | Unit |
| --- | --- |
| zB | m |

*Incoming Wave Profile*

**1** In the **Home** toolbar, click f(x) **Functions** and choose **Local>Interpolation**.

**2** In the **Settings** window for **Interpolation**, type `Incoming Wave Profile` in the **Label** text field.

**3** Locate the **Definition** section. From the **Data source** list, choose **File**.

**4** Click **Browse**.

**5** Browse to the model's Application Libraries folder and double-click the file `monai_runup_input_wave.txt`.

**6** Click **Import**.

**7** In the **Function name** text field, type `H_in`.

**8** Locate the **Units** section. In the **Argument** table, enter the following settings:

| Argument | Unit |
| --- | --- |
| t | s |

**9** In the **Function** table, enter the following settings:

| Function | Unit |
| --- | --- |
| H_in | m |

**10** Click **Plot**.

*Probe (x,y)=(4.52,1.196)*

**1** In the **Definitions** toolbar, click **Probes** and choose **Domain Point Probe**.

**2** In the **Settings** window for **Domain Point Probe**, locate the **Point Selection** section.

**3** In row **Coordinates**, set **x** to `4.52[m]`.

**4** In row **Coordinates**, set **y** to `1.196[m]`.

**5** In the **Label** text field, type `Probe (x,y)=(4.52,1.196)`.

### *Point Probe Expression 1 (ppb1)*

1. In the **Model Builder** window, expand the **Probe (x,y)=(4.52,1.196)** node, then click **Point Probe Expression 1 (ppb1)**.
2. In the **Settings** window for **Point Probe Expression**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Shallow Water Equations, Time Explicit>swe.H - Total height - m**.

### *Probe (x,y)=(4.52,1.696)*

1. In the **Model Builder** window, right-click **Probe (x,y)=(4.52,1.196)** and choose **Duplicate**.
2. In the **Settings** window for **Domain Point Probe**, type `Probe (x,y)=(4.52,1.696)` in the **Label** text field.
3. Locate the **Point Selection** section. In row **Coordinates**, set **y** to `1.696[m]`.

### *Probe (x,y)=(4.52,2.196)*

1. Right-click **Probe (x,y)=(4.52,1.696)** and choose **Duplicate**.
2. In the **Settings** window for **Domain Point Probe**, type `Probe (x,y)=(4.52,2.196)` in the **Label** text field.
3. Locate the **Point Selection** section. In row **Coordinates**, set **y** to `2.196[m]`.

## SHALLOW WATER EQUATIONS, TIME EXPLICIT (SWE)

### *Domain Properties 1*

1. In the **Model Builder** window, under **Component 1 (comp1)>Shallow Water Equations, Time Explicit (swe)** click **Domain Properties 1**.
2. In the **Settings** window for **Domain Properties**, locate the **Bottom Topography** section.
3. In the $h_B$ text field, type `-zB`.

### *Initial Values 1*

1. In the **Model Builder** window, click **Initial Values 1**.
2. In the **Settings** window for **Initial Values**, locate the **Initial Values** section.
3. From the **Water depth** list, choose **Specify total height**.

### *Inlet 1*

1. In the **Physics** toolbar, click **Boundaries** and choose **Inlet**.
2. Select Boundary 1 only.
3. In the **Settings** window for **Inlet**, locate the **Flow Properties** section.
4. From the **Water depth** list, choose **Specify total height**.
5. In the $H_0$ text field, type `H_in(t)`.

6 From the **Velocity** list, choose **From domain values**.

## MESH 1

### *Size*

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **Edit Physics-Induced Sequence**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section. In the **Maximum element size** text field, type `0.01`.

### *Free Triangular 1*

In the **Model Builder** window, under **Component 1 (comp1)>Mesh 1** right-click **Free Triangular 1** and choose **Delete**.

### *Mapped 1*

1 In the **Mesh** toolbar, click **Mapped**.

2 In the **Model Builder** window, right-click **Mesh 1** and choose **Build All**.

## STUDY 1

### *Step 2: Time Dependent*

1 In the **Model Builder** window, under **Study 1** click **Step 2: Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

3 In the **Output times** text field, type `range(0,1,10) range(10.25,0.25,25)`.

4 In the **Study** toolbar, click U t=0 **Get Initial Value**.

## RESULTS

### *Total Height (swe)*

In the **Model Builder** window, expand the **Total Height (swe)** node.

### *Height Expression 1*

1 In the **Model Builder** window, expand the **Results>Total Height (swe)>Total Height** node, then click **Height Expression 1**.

2 In the **Settings** window for **Height Expression**, locate the **Axis** section.

3 Select the **Scale factor** check box. In the associated text field, type `10`.

4 Clear the **Show height axis** check box.

*Filter 1*

1 In the **Model Builder** window, right-click **Total Height** and choose **Filter**.

2 In the **Settings** window for **Filter**, locate the **Element Selection** section.

3 In the **Logical expression for inclusion** text field, type `h>1e-4[m]`.

4 From the **Element nodes to fulfill expression** list, choose **All**.

*Probe Plot Group 3*

1 In the **Model Builder** window, under **Results** click **Probe Plot Group 3**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 From the **Position** list, choose **Upper left**.

## STUDY 1

In the **Study** toolbar, click **Compute**.

## RESULTS

*Total Height (swe)*

1 In the **Settings** window for **2D Plot Group**, locate the **Data** section.

2 From the **Time (s)** list, choose **25**.

3 In the **Total Height (swe)** toolbar, click **Plot**.