Interaction of Tsunamis with Short Surface Waves: An Experimental Study

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12th International Workshop on Wave Hindcasting and Forecasting and 3rd Coastal Hazard Symposium
Motivation

2004 Indian Ocean Tsunami from Koh Jum Island
Motivation

- Generally – default paradigm for tsunamis: solitary wave
  - Used for lab studies of tsunami damage

- Madsen et al. (2008)
  - Solitary wave paradigm flawed
  - Cause order of magnitude errors in spatial and temporal evolution over a sloping bottom

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Interaction with the Swell Wave Field

• Hypothesis:
  – Overlying swell wavefield can have some subtle effect on underlying tsunami
    • Front face steepness
    • Wave-wave interaction
• Run long wave through random swell field
• Use transient analysis (wavelet, Hilbert-Huang) to investigate effects
NEES Payload

- One year project from NEES program, National Science Foundation
- Use NEES Tsunami facility at Oregon State University
- Tsunami Wave Basin:
  - 48.8m x 26.5m x 2.1m
  - 29-paddle multi-directional piston wavemaker
  - 4 resistance gages and 2 ADVs
  - on movable bridge
Test Conditions

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Hs (cm)</th>
<th>Tp (s)</th>
<th>kh</th>
<th>δ=a/h</th>
<th>Ur</th>
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<td>2</td>
<td>1</td>
<td>0.033</td>
<td>0.033</td>
</tr>
<tr>
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<td>0.033</td>
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<td>10</td>
<td>2</td>
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<td>4</td>
<td>0.45</td>
<td>0.067</td>
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</tbody>
</table>

Tsunami “height” ~30 cm

Water depth 0.75 m

Different runs with tsunami either in middle or end of swell record

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Experiments

Tsunami Only

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Tsunami with Swell
Analysis

**Maximum Surface Elevation**
- As proxy for waveheight: maximum surface elevation in record
- Maximum surface elevation reached earlier with combined conditions than with either alone.
- Different results with tsunami in middle or at end of swell record.

![Graphs showing maximum surface elevation with and without swell and tsunami](image-url)

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Wavelet Analysis

Morlet Wavelet Transform

- Data from experiment – periodic signal interacting with a transient signal
- Standard Fourier Transform techniques not suitable
- Wavelet transform – time-dependent frequencies
- Spectral densities as a function of frequency and time

\[ WT(a, \tau) = \int_{-\infty}^{\infty} x(t) \psi_{a,\tau}(t) \, dt, \]

\[ \psi(t) = \pi^{-1/4} \exp\left(-\frac{t^2}{2}\right) \exp(i\omega t), \]
Wavelet Analysis

Gage 1

Gage 8

Gage 16

Gage 20

Tsunami Only

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Wavelet Analysis

Tsunami with Swell: $H_s=5\text{cm}$, $T_p=2\text{s}$
Wavelet Analysis

Tsunami with Swell: $H_s=5\text{ cm}$, $T_p=4\text{ s}$
Hilbert-Huang Transform

*Hilbert Transform plus Empirical Model Decomposition*

- Take original nonperiodic signal
- Calculate envelope with Hilbert Transform, then calculate mean
- Subtract mean from original signal
  - New signal
- Do this on each updated signal $k$ times
- Result – mode $c_1$
- Subtract mode $c_1$ from original data – obtain new data
- Perform sifting process again
- Advantage:
  - No *apriori* basis function
  - Modes usually have some physical basis
HHT of Tsunami

Blue: Gage 1
Green: Gage 8

Blue: Gage 16
Green: Gage 20

Blue: Gage 1
Green: Gage 8
Blue: Gage 16
Green: Gage 20
HHT of Combined Tsunami-Swell
Steepness

Breaking: related to wave steepness $\frac{\partial \eta}{\partial x}$:

- Deduce steepness from:
  - Time series
  - Combined HHT modes (long/short motions)
- Look for maximum steepness

Approximate steepness by linear wave equation:

$$\frac{\partial \eta}{\partial x} = -\frac{1}{\sqrt{gh}} \frac{\partial \eta}{\partial t}$$
Steepness

1. Blue: Tsunami
   Green: Tsunami with swell
   Red: Tsunami with swell – long wave

2. Blue: Tsunami with Swell 1 (green)
   Tsunami with Swell 2 - long wave (red)

3. Blue: Tsunami only (blue)
   Tsunami with Swell 3 (green)
   Tsunami with Swell 4 - long wave (red)

4. Blue: Tsunami only (blue)
   Tsunami with Swell 4 (green)
   Tsunami with Swell 4 - long wave (red)
Conclusions Thus Far

- It was hypothesized that the overlying swell field might have some effect on a long tsunami (front face steepness, etc.)
- Experiments were run at the NEES Tsunami Facility at Oregon State University
- Some indication of swell affecting maximum surface amplitude of overall wave field
- Wavelet analysis: spectral structure of tsunami affected by swell
- Use Hilbert-Huang Transform to break motion up into scales
- Analysis of steepness in combined motion: strong energy shift to high frequencies made more efficient with swell present.