Tsunami Waves

Equations needed:

\[ v = (g \times h)^{1/2} \]

where \( g \) is the acceleration due to gravity and \( h \) is water depth

\[ L = v \times T \]

where \( L \) is wavelength, \( v \) is velocity, and \( T \) is period

1. Calculate the wavelength of a wave with a period of 11 seconds traveling over a depth of 32 m.

2. A tide station 2300 km from location X at the coast identifies a tsunami at 02:00 (local time at location X). The tsunami has a period of 22 min. Estimate the time of arrival at X of the tsunami if it travels over a mean depth of 440 m. Also determine the wavelength of the tsunami.

The 1929 Grand Banks earthquake, submarine slide, and turbidity current

This exercise explores the cause of a sequence of broken undersea cables that occurred following a magnitude 7.2 earthquake with an epicenter beneath the continental slope off eastern Canada (see map) in November 1929. After the earthquake a number of transatlantic communication lines were severed. A small tsunami inundated harbors in southeastern Newfoundland after the earthquake. The timing of cable breaks was determined from disrupted communications, and the location of the breaks was determined by electrical resistivity tests and also during subsequent cable repair efforts. A number of the cables were broken simultaneously with the earthquake, but a series of breaks occurred later, with a distinctive pattern of increased delays with distance from the continental shelf edge. Heretofore, density-driven submarine turbidity currents were not known to occur in the open ocean. Part of this exercise is to determine the pattern of breaks and investigate the velocities of the turbidity current (or, underwater mass movement) that broke the cables. Learning to quickly interpret contour plots (in addition to topographic maps or bathymetric charts) is an important skill, especially for understanding hazards and risks. In this exercise you will plot cable break times and partly contour these values. You are given an Excel table with the numbered cable break locations and times. The numbers in the table correspond to the numbers on the bathymetric chart.
1) For each cable break location (# 1 through 28) write on the map - next to the cables location (denoted by a star) - the time (in minutes) after the earthquake that the cable break occurred. Note: there are a number of breaks for which the breakage time was not accurately determined (e.g., 20). They are shown to indicate where, but not when, breaks occurred.

2) On the bathymetric chart you have just annotated, contour the times-of-break after the first cable break; i.e., time zero equals first cable break. Use a contour interval of 60 minutes (1 hour). Mark where the initial sea floor failure probably occurred. Contour lines represent lines of equal values - usually associated with elevation. You notice that the map you have has bathymetric contour lines that show the change in ocean depth away from the eastern Canadian margin. It is worthwhile to note that contour lines never cross one another because you can never have different values at the exact same location.

3) Use the distance scale (km) on the bottom of the map and the bathymetric contours to construct a rough bathymetric profile (a cross section of depth) from near the quake epicenter (at the shelf/slope break) down to the abyssal plain (out past the last cable break). Use a line of section that runs approximately NNW to SSE. This is analogous to a topographic cross-section. Essentially you’re making an x-y plot, where \( x = \text{distance (km)} \), and \( y = \text{depth (m)} \). So that deeper will appear lower (as opposed to higher) on your cross-section, you can plot negative depth (\(-m\)), which equals the elevation relative to average sea level. For example 200 m water depth = -200 m elevation. Your cross-section will need to be vertically exaggerated; i.e., 100 m elevation will not equal 100 m of horizontal distance on your graph. After measuring distances and noting location of depth contours, you can enter these depth-distance pairs into Excel and plot them there, then print out your graph. I recommend drawing your cross section line on your map first, which should go from the epicenter straight across the paper, through stations 26 and 27, and ending at the edge of the map. By choosing your cross-section line in this way you get an optimal profile of both elevation change, as well as time change. If you have completed your contour lines correctly your cross section line should be roughly orthogonal to your contours. After you have sketched your line, use the edge of a piece of scratch paper and line it up with your cross-section line. Then, make little tick marks every time a bathymetric contour interval crosses your paper and every time a time contour interval crosses your paper. Make sure you note the contour interval's value for reference on your scratch piece of paper. Finally using the scale bar on the map, measure the distances from the edge of your scratch paper (edge of section line) to the individual ticks and record these lengths, along with their respective values, in excel. When complete you should be able to make two plots, one of elevation versus distance and one of time versus distance.

4) What is the vertical exaggeration of your bathymetric section? Meaning, how much larger is each length interval of elevation than each length interval of distance. For comparison, make a section with no vertical exaggeration - meaning the length of 10 km on the vertical axis is equal to 10 km on the horizontal axis.
5) Use your new data of distance and time of cable rupture to calculate the velocity of the debris flow from EQ epicenter out to the deep ocean. Also, partition the entire distance (from approximate location of break #6 to #27) into four segments (#5 to 17; 17 to 19; 19 to 22-23; and 22-23 to 27-28), and calculate average speeds (both km/hr and m/sec) for those four segments.

6) How does the current’s velocity change over the length of the turbidity current’s path? How does this relate to bathymetry? Make a plot that has both bathymetry and speed versus distance. Because the values of speed and elevation are so different, select **format data series** for the speed data, select **axis** and then select **secondary axis**. This will change the scale of the velocity data and put its values to the right of the plot – making it easier for comparison purposes.

7) Use the data in the table to calculate the average north-to-south speed in knots (nautical miles per hour) of the flow over its length from break #6 to break #27. To determine the total N-S distance, use the fact that one degree of latitude equals about 60 nautical miles. Of course you’ll need to convert minutes to hours as well. How does this compare with velocities of the individual segments?

8) Geologists believe that turbidity currents sometimes evolve from slope failures that behave initially as coherent landslides. This being the case, can you explain the swarm of instantaneous cable breaks on the upper continental slope?

9) How might you explain the 14-minute delay before breakage of cable #15?

10) As was seen in lecture, tsunamis typically have very long wavelengths. This means that they usually behave as “shallow-water waves” even in the open ocean. The forward speed (velocity) of shallow-water waves is equal to the square root of gravity times water depth:

    \[
    \text{velocity} = (g \times h)^{1/2} \quad \text{where} \quad g = \text{gravitational acceleration of } 9.81 \, \text{m/sec}^2, \\
    \text{and} \quad h = \text{water depth (m)}. 
    \]

    Given this relationship, how long would it have taken for a tsunami that began where the cables first broke to reach the southern coast of Newfoundland. Assume an average depth on the continental shelf of 200 m.
GEOL 209  HW#6  1929 Grand Banks Earthquake and Turbidity Current
Bathymetric Map: depth contours in meters below sea level

epicenter —> Newfoundland

Grand Banks