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BOUSS-2D Wave Model in SMS: 2. Tutorial with Examples

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PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to demonstrate the use of BOUSS-2D in three example applications. The BOUSS-2D is a Boussinesq wave model that is now part of the U.S. Army Corps of Engineers (USACE) Surface-Water Modeling System (SMS). Demirbilek et al. (2004) gives a detailed description of the SMS interface of BOUSS-2D. This second technical note in BOUSS-2D series is a step-by-step tutorial that shows the usage of the model through illustrative examples. The next CHETN in the series will describe the time-series and frequency-domain analysis utilities and techniques developed for post-processing BOUSS-2D model results. Details of the BOUSS-2D model theory, numerical implementation, and example applications are presented in a technical report (Nwogu and Demirbilek 2001).

BACKGROUND: As a phase-resolving nonlinear wave model, BOUSS-2D can be used in the modeling of various wave phenomena including shoaling, refraction, diffraction, full/partial reflection and transmission, bottom friction, nonlinear wave-wave interactions, wave breaking and dissipation, wave runup and overtopping of structures, wave-current interaction, and wave-induced currents. A comprehensive understanding of the BOUSS-2D interface in SMS is necessary for maximizing the benefits of this tutorial. This CHETN will also prepare users for the third follow-up note in this series about analysis utilities developed for BOUSS-2D model.

Wave estimates in navigation design, maintenance and operation studies, channel sedimentation, inlets, and harbors are affected by the seabed topography, tidal currents and coastal structures present in the areas of interest. These features cause temporal and spatial changes in the wave field that can be estimated using an advanced nearshore wave propagation model such as the BOUSS-2D. The model employs a time-domain solution of fully nonlinear Boussinesq-type equations, valid from deep to shallow water, representing the depth-integrated equations of conservation of mass and momentum for waves propagating in water of variable depth. Input waves to BOUSS-2D may be periodic (regular) or nonperiodic (irregular), and both unidirectional or multidirectional sea states may be simulated.

The governing equations in BOUSS-2D are solved in the time domain with a finite-difference method, from which water-surface elevation and horizontal velocities are calculated at the grid nodes in a staggered manner. Waves propagating out of the computational domain are absorbed in damping layers placed around the perimeter of the domain. Damping and porosity layers can also be used to simulate the reflection and transmission characteristics of jetties, breakwaters, and other structures existing in the modeling domain. These and other details about BOUSS-2D model are provided in the model report, containing six examples that illustrate model's versatility and features (Nwogu and Demirbilek 2001).

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14. ABSTRACT
The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to demonstrate the use of BOUSS-2D in three example applications. The BOUSS-2D is a Boussinesq wave model t at is now part of the U.S. Army Corps of Engineers (USACE) Surface-Water Modeling System (SMS). Demirbilek et al. (2004) gives a detailed description of the SMS interface of BOUSS-2D. This second technical note in BOUSS-2D series is a step-by-step tutorial that shows the usage of the model through illustrative examples. The next CHETN in the series will describe the time-series and frequency-domain analysis utilities and techniques developed for post-processing BOUSS-2D model results. Details of the BOUSS-2D model theory, numerical implementation, and example applications are presented in a technical report (Nwogu and Demirbilek 2001).

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The SI engineering units are used in BOUSS-2D calculations. Data in English units can be imported into the SMS interface and converted to metric. For example, bathymetric data in latitude/longitude can be converted in the model interface to UTM or State Plane coordinates. Likewise, model results can be presented in English units using conversion tools and data calculator features available in SMS. The interface of BOUSS-2D in SMS *(*Zundel et al. 1998; and Zundel 2005) facilitates grid generation and specification of model parameters. Model input and output may be pre- and post-processed in different formats, using two- and three-dimensional (2- and 3-D) display and visualization options and a variety of animation types (see Demirbilek et al. 2004). The bathymetry, wave data, and model parameters used in BOUSS-2D simulations are formatted into specific file formats in the SMS interface. The users must assemble input bathymetry and wave data for a BOUSS-2D simulation from appropriate data sources. Data sources are accessible from within SMS for bathymetry and coastlines, and other commercial databases that may also be used to assemble the requisite input for BOUSS-2D model

The emphasis of this CHETN is to provide description of a few typical examples for BOUSS-2D simulations. The examples should be helpful to users in practical applications. In the first example, step-by-step instructions are described in a complete BOUSS-2D simulation for prediction of the wave climate in Barbers Point Harbor, HI. In this case, details of each step are presented for the understanding of the modeling process used in BOUSS-2D. In the last two examples, the model's features and capabilities for wave-structure interaction problems are demonstrated. The second example shows application of the model to a jettied inlet, illustrating the use of porosity layers around jetties or breakwaters. The third example demonstrates the use of a simplified 1-D version of the Boussinesq model to estimate wave runup and overtopping of idealized sloping structures.

EXAMPLE 1 – BARBERS POINT HARBOR, HI:

Images: It is often useful to have background images to help orient numerical grids in a simulation, and to place coastlines and structures with precision that exist in the modeling region. These images may be digital bathymetry charts or aerial photographs. In this example, two images were downloaded from the TerraServer site http://terraserver.homeadvisor.msn.com. These digital bathymetric charts cover a small portion of coast on southwest corner of the island of Oahu, HI. Use *File|Open* and select the file topo1.jpg to read in the first image. The Internet-based resource also provides a world file to geo-reference this image. Should SMS ask if image pyramids are desired, select the toggle to not ask this question again and click **Yes**. Repeat the file opening procedure for file topo2.jpg. SMS will piece together these two images (Figure 1).

After reading these images into SMS, tell it what coordinate system the data are referenced to. The coordinate system is dependent on the data source. For the TerraServer site, all world files register the images to UTM coordinates in NAD83. To pass this information to SMS, select *Edit|Current Coordinates*, and specify UTM NAD 83 (US), select the horizontal and vertical units as "meters" and the UTM Zone as Zone 4. Images may be used to define land boundaries of modeling domain and structures.

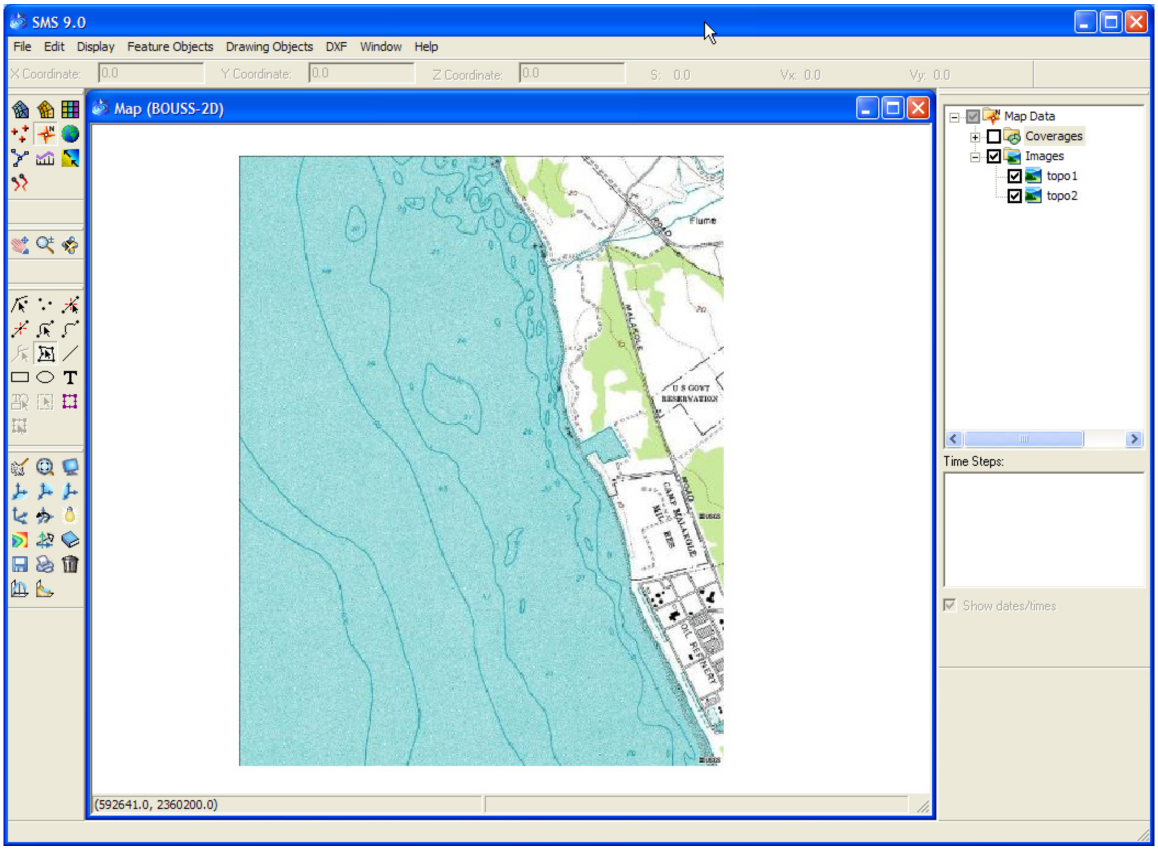


Figure 1. Images of simulation region

Bathymetry: BOUSS-2D needs bathymetric data to define the shape of the seafloor. For this example, a local survey was performed and bathymetry was available in ASCII files. To bring the survey into SMS, select *File|Open* and select the file BP_bathy_filtered.pts. This file includes depth values in the Barbers Point Harbor and the immediate coastal region outside the harbor. These data are referenced to UTM Zone 4. The survey points displayed over the background image are shown in Figure 2. SMS triangulates the points to create a piecewise linear surface covering the entire region. The outer lines around the points depict the extent of this surface. It should be noted that regions of coastal land are covered by this surface, but not represented since all of the survey data points were in the water. The triangles covering the land must therefore be deleted in order to define which areas are land and which are water, otherwise SMS will interpolate between the harbor and coast without realizing there is land between them.

Coastlines: A coastline can be used to define the interface between land and water. For this example, the coastline for the island of Oahu has been extracted. To see this region, select *File|Open* and choose the file BP_coast.cst. The coastline will be read in and displayed as shown in Figure 3.

There is more coastline here than is needed, which includes many other harbors, land features, and islands unrelated to Barbers Point Harbor. The user may use the following steps to trim the coastline to the area involved:

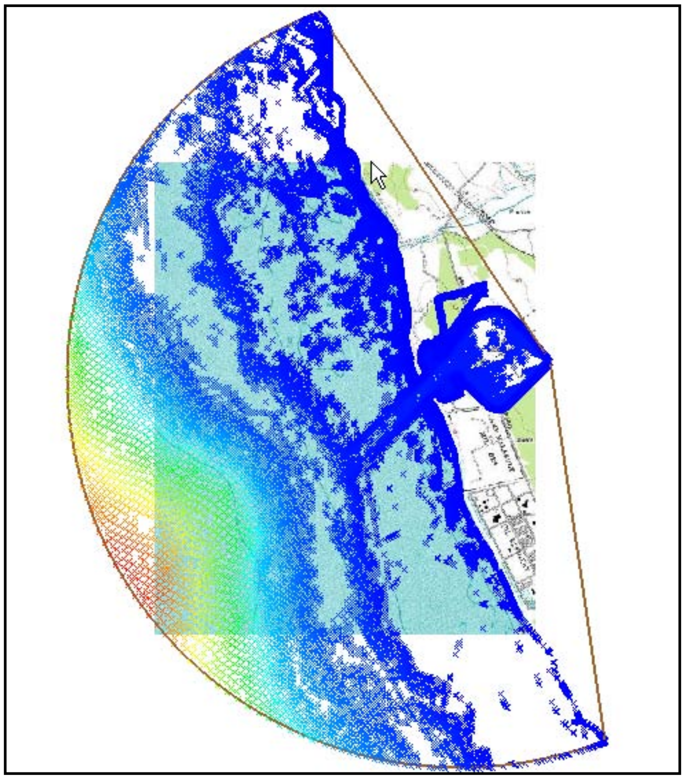


Figure 2. Bathymetry points for sample problem

a. Zoom into the area being modeled.

b. In the Map module , select the *Create Arc tool* .

c. Click on the coastline just north of the data (P1 in Figure 4), then click inland (P2) and then on the coastline east of the simulation area (P3).

d. Switch to the *Select Arc tool*  and select the coastline away from area of interest and hit the **Delete** key to eliminate this arc (Arc to delete in Figure 4).

e. Frame the display and drag a box around the island arcs and delete them. (This is easily done by dragging a box around the islands on the north side of Oahu and deleting them, and then dragging a box around the islands on the east side.)

f. Build a polygon to represent the land around Barbers Point by selecting *Feature Objects|Build Polygons*.

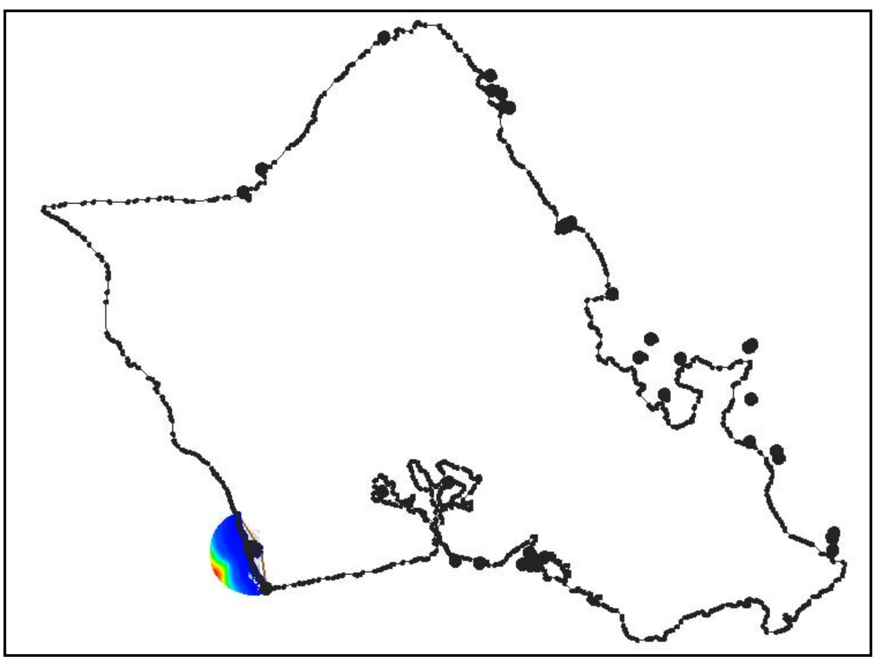


Figure 3. Coastline of Oahu

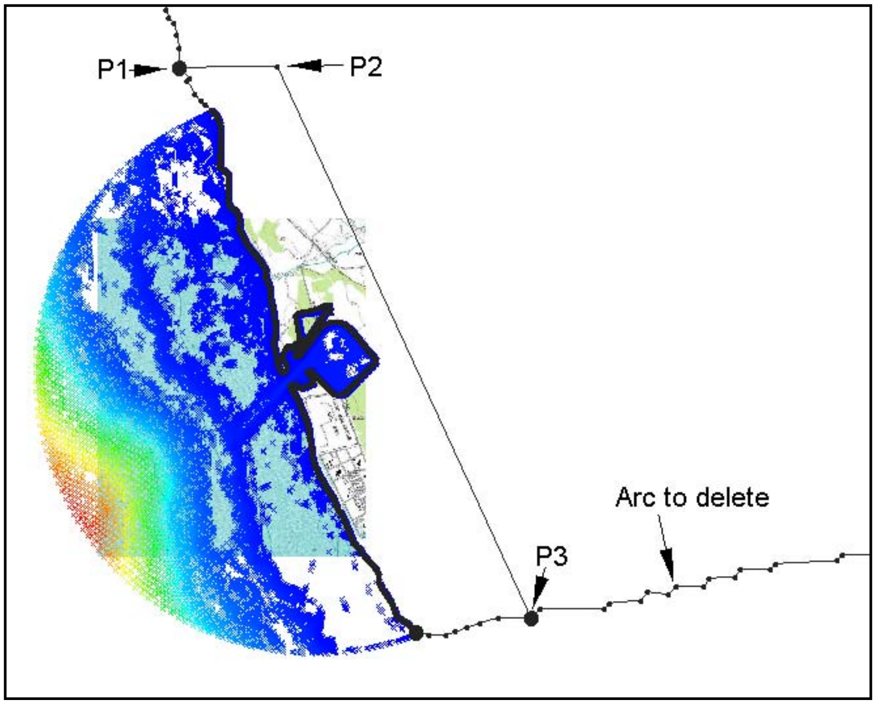


Figure 4. Bisecting arc separates areas around simulation from rest of island coastline

g. Select the *Select Polygon tool*, and select the land polygon.

h. Choose *Feature Objects|Select/Delete Data …* This brings up the dialog shown in Figure 5. Set the options to delete triangles inside the polygon and click **OK**.

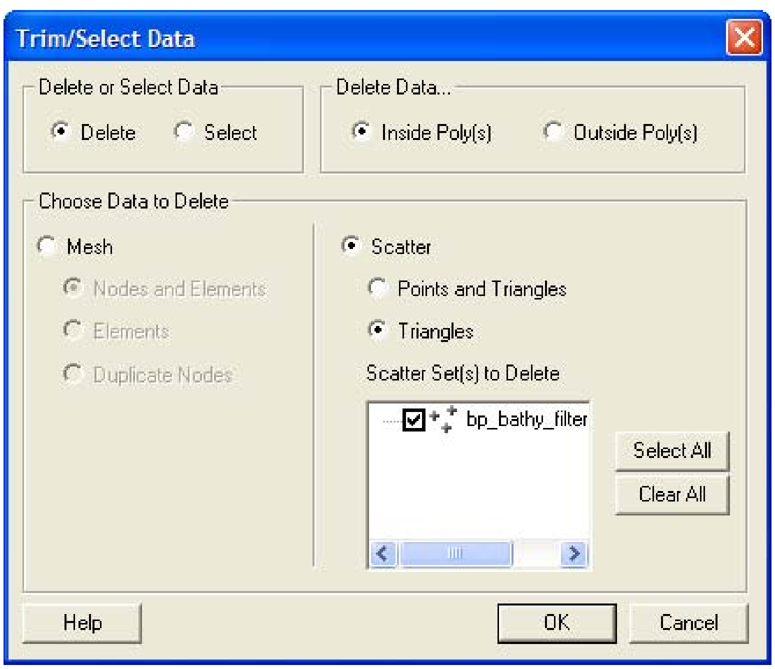


Figure 5. *Trim/Select Data* options

There is now a surface that represents the seabed around the region of Barbers Point Harbor in Hawaii. The next step is to create a computational grid for BOUSS-2D.

Create Grid: The computational domain of BOUSS-2D is a Cartesian grid that can be defined with three clicks. In this example, instructions are provided to ensure consistency. To create the grid, follow these steps:

a. Zoom into harbor as shown in Figure 6.

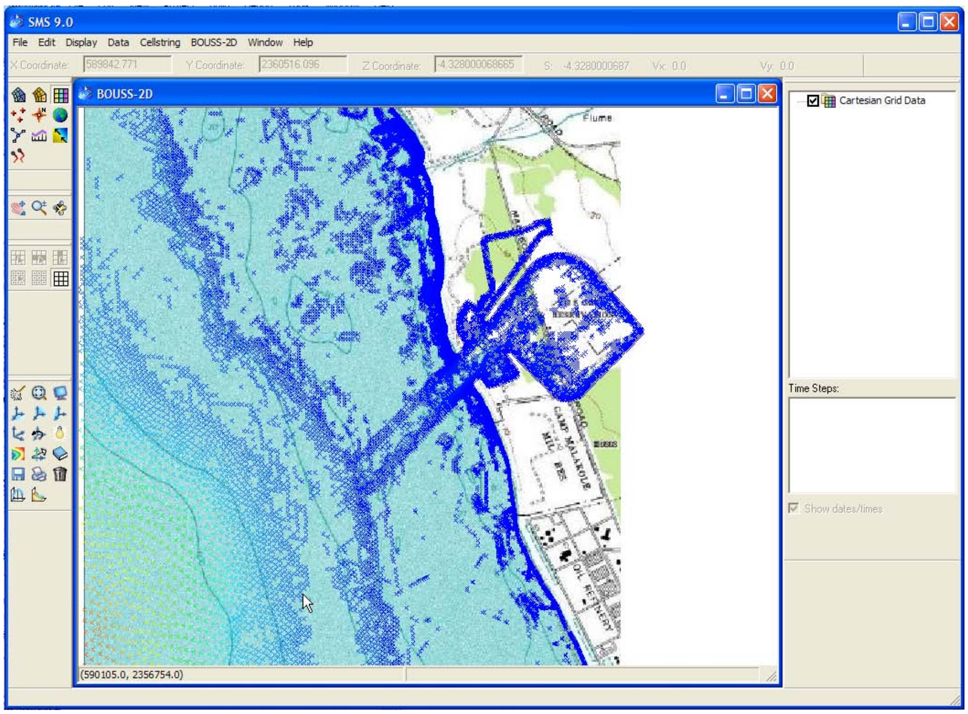


Figure 6. Zoomed view displaying area for creating computational grid

b. Make sure the *2D Cartesian Grid Module*  is the current module and that BOUSS-2D is the active model. User should see a BOUSS-2D menu at the top menu bar in SMS. If this is not the case, select *Data|Switch Current Model* and select *BOUSS-2D*.

c. Select the *Create Grid tool*  - Click near the point P1 (Figure 7). An exact location of points can be specified later. The coordinates of the cursor are displayed on the lower left corner of the window.

d. Move the mouse toward shore and inland. At the bottom of the window, the size of resulting grid is displayed. Click on point P2 (Figure 7), approximately 2,500 m from the first point.

e. Move the mouse up to include harbor approximately 2,000 m from second point and click in the area of point P3 (Figure 7).

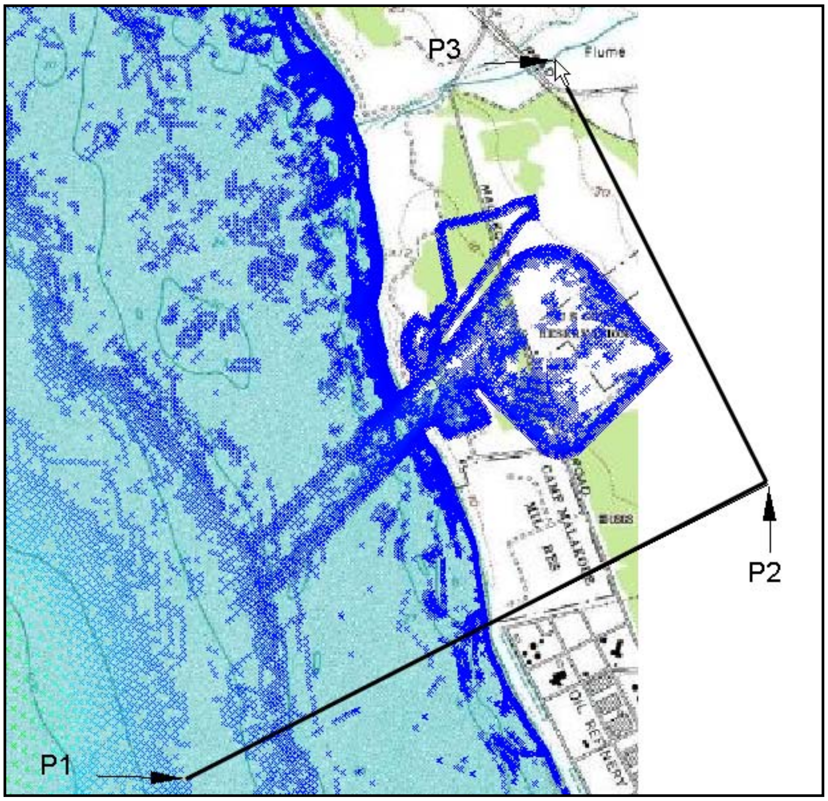
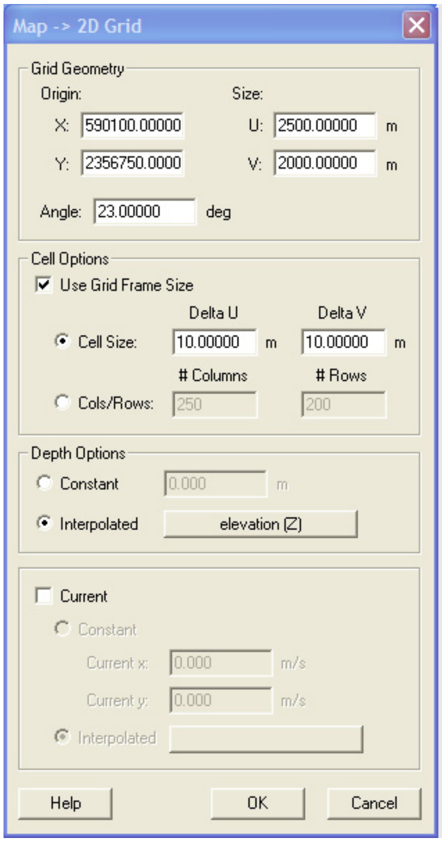


Figure 7. First and second click point when defining grid

f. After the third click, SMS will display a dialog to create the grid (Figure 8). For consistency in this exercise, modify the grid parameters in this dialog to match the values in the dialog as shown. The cell sizes are dependent on the wavelength. The Courant number that controls the stability of numerical solution in BOUSS-2D is used to determine time-step from the cell size. Note that the cell size is generally expressed as a fraction of the wavelength. Care should be exercised in selecting cell sizes. The model report (Nwogu and Demirbilek 2001) describes how to determine cell size based on wavelength. Smaller cell sizes may guarantee stability of runs, but require excessive computing time. Larger cell sizes will cut down the runtime, but may cause model instability. It may be necessary to also check sensitivity of model results to cell sizes using more than one grid.

With the previous issues in mind, users should determine the most appropriate grid resolution (cell size) in an application based on consideration of both the available resources and model computational requirements. The cell size of 10 m is used in this example. In the *Depth Options*, click the button labeled **elevation (Z)**. This will bring up the *Interpolation* dialog (Figure 9). Set the extrapolation elevation on the left side to 1 m that will assure the land will be treated as land. This step would not be required if survey data included points on the shore with positive elevations. Click the **OK** buttons on both the dialogs to create the grid.



Grid Parameter	Value
Grid Origin X	590100.0
Grid Origin Y	2356750.0
Angle	23.0º
Grid Size U	2500 m
Grid Size V	2000 m
Cell Size Delta U	10 m
Cell Size Delta V	10 m

Figure 8. Parameters to create grid

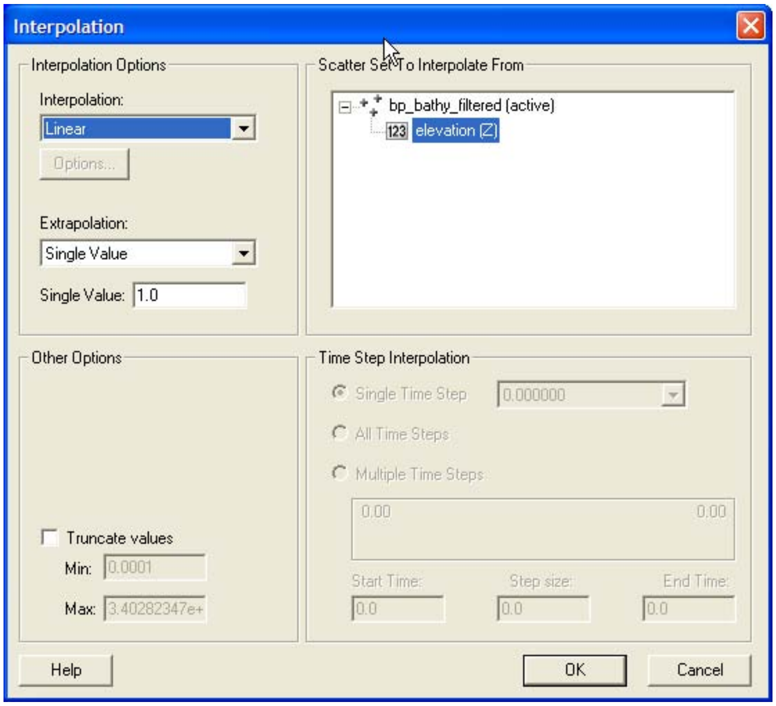


Figure 9. Interpolation options to assign bathymetry values

Figure 10 shows the resulting grid boundary. The computational (ocean) area is outlined in the darker colors. The area on the right (land) is inactive, and model calculations are not performed in the land regions.

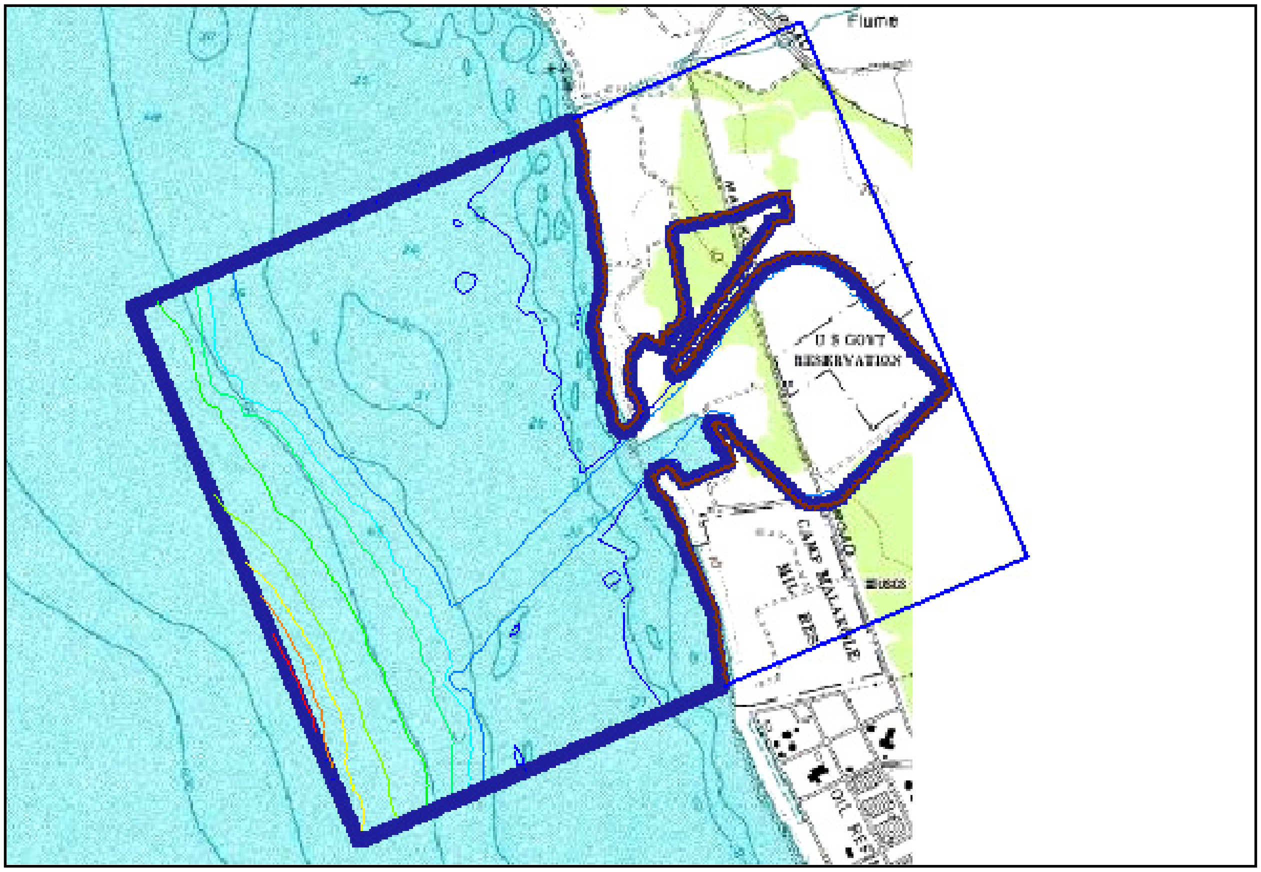


Figure 10. Resulting grid

Define Wave Maker: The BOUSS-2D is a numerical wave tank, and the layout of its modeling domain is similar to the setup of a laboratory (physical model) study. The BOUSS-2D wave maker must be positioned along a straight line that can be referred to here as a "cell string" in the SMS terminology, and at a desired location where depth is ideally constant. The previously defined grid creation process automatically generates cell strings along the edges of the computational area. Cell strings can also be created manually to specify the location of structures, wave makers, and areas where damping and/or porosity layers may be necessary. To define a wave maker, follow these steps:

a. Select the *Select Cell String* tool .

b. Select the cell string (in red) on the left side of the grid as shown in Figure 11, where wave maker is to be situated.

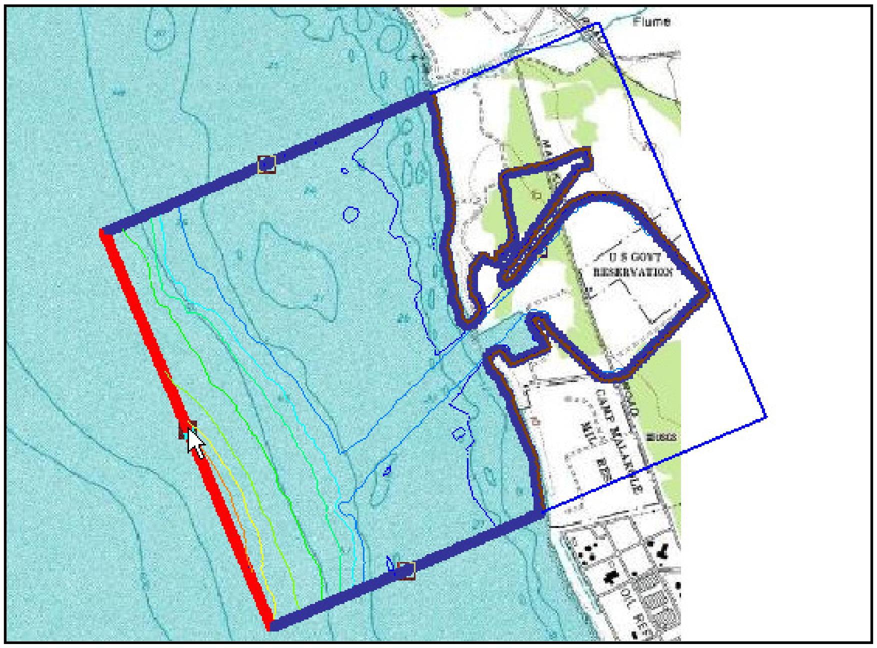


Figure 11. Wave maker cell string selected

c. Select *BOUSS-2D|Assign BC* command. Select the *Wave Maker* radio button and click on the **Options** button. This brings up the *BOUSS-2D Wave Generator Properties* dialog. On the left side of this dialog select the type of wave to simulate, i.e., irregular unidirectional waves. Select the defaults to synthesize the time series and generate them from parameters. Specify the series duration as 1,500.0 sec in this example. On the right side, select the spectra type to be JONSWAP, and the option to specify significant wave height and peak period values, H_s and T_p. Enter values of significant wave height and peak period as 3.0 m and 15.0 sec., respectively. Click **OK** to close both the dialogs. For further details on wave spectra types and associated spectral parameters, users should consult Demirbilek et al. (2004) and Nwogu and Demirbilek (2001).

d. As SMS generates the wave maker, it may find that the offshore edge of the grid is not of constant depth, and warn the user. At this point the user is given the option of extending the grid to a constant depth to improve model stability. Click the **Yes** button to extend the grid in order to complete proper definition of the wave maker location.

Define Damping Layers: Damping layers may be specified along boundaries of the computation zone where waves need be absorbed. Damping layers prevent waves from reflecting back into the computational area. This may be necessary since reflected waves will affect the incident waves. In this example, damping layers will be assigned to both lateral boundaries of the modeling domain that will absorb waves leaving the domain. To do this:

a. Select the cell strings along the open sides of the grid between deep water and the coastline. To select two cell strings, click on the first and hold the **SHIFT** key to click on the second cell string.

b. Select *BOUSS-2D|Assign BC...* and select *Damping*.

c. Enter values of 40 m for the width of damping layers and 1.0 for the damping coefficient and select **OK**. The width value for the damping depends on several factors including wave type and grid resolution. Consult Demirbilek et al. (2004) and Nwogu and Demirbilek (2001) for details.

In applications where the depth transition from water to land is not gradual, excessive reflection would occur as the model overpredicts reflection from the coast. To prevent this, place a damping layer along the coastline. This coastline damping-layer may be defined as:

a. Select the cell string along the coastline.

b. Select *BOUSS-2D|Assign BC…* and select *Damping*.

c. Enter values for width and damping coefficients of 20 m and 0.5, respectively, and select **OK**. These values allow for partial reflection.

Specify Other Model Parameters: The next step in preparing a simulation is to specify other model input parameters. Select *BOUSS-2D|Model Control* to specify *Project Title* as “Barbers Point Sample Run.” In the *Input Data Sets*, select **Use Cellstrings** for damping. For *Porosity and Current*, choose **None**. For *Time Control*, enter 1,500 sec for duration of the run, and 0.2 sec for the time-step. For *Animation Output*, check *Output WSE, Output Velocity* and *Override Defaults* toggles. Enter 1,425.0 for the beginning time; 1,500.0 for the ending time; and 1.0 sec for the output interval to save an animation output for approximately the last five waves. Select the **OK** button to close the dialog box.

Save and Run Simulation: The final step before running a simulation is to save the BOUSS-2D files. Select *File|Save New Project* and enter **BarbersPoint_Tutorial** for project name, and click **OK**. The simulation may now be launched by selecting *BOUSS-2D|Run Bouss*. A message will be displayed for the default location of the model executable (Bouss2d.exe). Click on the folder icon to select the location of “Bouss2d.exe” file, and click on the **Run** button. SMS now launches BOUSS-2D. This simulation takes approximately 1 hr to run on a Pentium 4 processor (3 GHz clock speed) with a 0.2 sec time-step. The model run time would increase to nearly 3 hr for a grid using 5- × 5-m cells, and the run time would reduce to below 20 min for a grid with 20- × 20-m cells.

Visualize Simulation Results: The model will create five solution files that include spatially varying results at the grid nodes. Three of these are steady state data sets that include the results for mean wave height, mean current direction, and mean water level. The other two are temporally varying results, output at user-specified intervals. These include computed water levels and currents (u and v). BOUSS-2D saves these results in the independent files named BarbersPt_hs.grd, BarbersPt_mean_uv.grd, BarbersPt_mwl.grd, BarbersPt.eta and BarbersPt.uv. The model can also write all of these in one binary metafile named BarbersPt.h5 in HDF5 format. When the model run is completed, the user can select a toggle to read the type of solution files for SMS to display. Refer to Demirbilek et al. (2004) and the SMS users manual and tutorials for guidance on how to visualize the model output files.

After the model run is complete, make sure the toggle to read the solutions is checked and click the **Exit** button. To display a functional surface of the water surface, select the *Display|Display Options* command and turn off the cells toggles (both water and land) and turn on the *Functional Surface* toggle. Click on the **Options** button right below the toggle to bring up the *Function Surface Options* dialog. In the upper left corner select the *User defined data set* option, click the **Select** button and choose *WSE Animation* from the list of data sets. Next, click the **Select** button in the *Select Data Set* dialog. You can use the *Choose Color* button to select a color for the functional surface, followed by clicking **OK** to close the *Functional Surface Options* dialog. Back in the *Display Options* dialog, choose the *General* tab and set the *Z magnification* to 20.0. Next, select the *Contours Options* tab and change the *Contour Method* to *Color Fill*, and click **OK**.

To give the surface some feature, select *Display|Lighting Options* and select *Use light source*. Turn on the *Smooth features,* click on the upper right side of the sphere, and then click **OK**. Finally, select the *Depth* data set for contouring the bottom of ocean, and select *Display|View|View Angle* and enter values of 40 and 25 for the bearing and dip. Figure 12 shows this functional surface of the water surface overlaying the bathymetric surface.

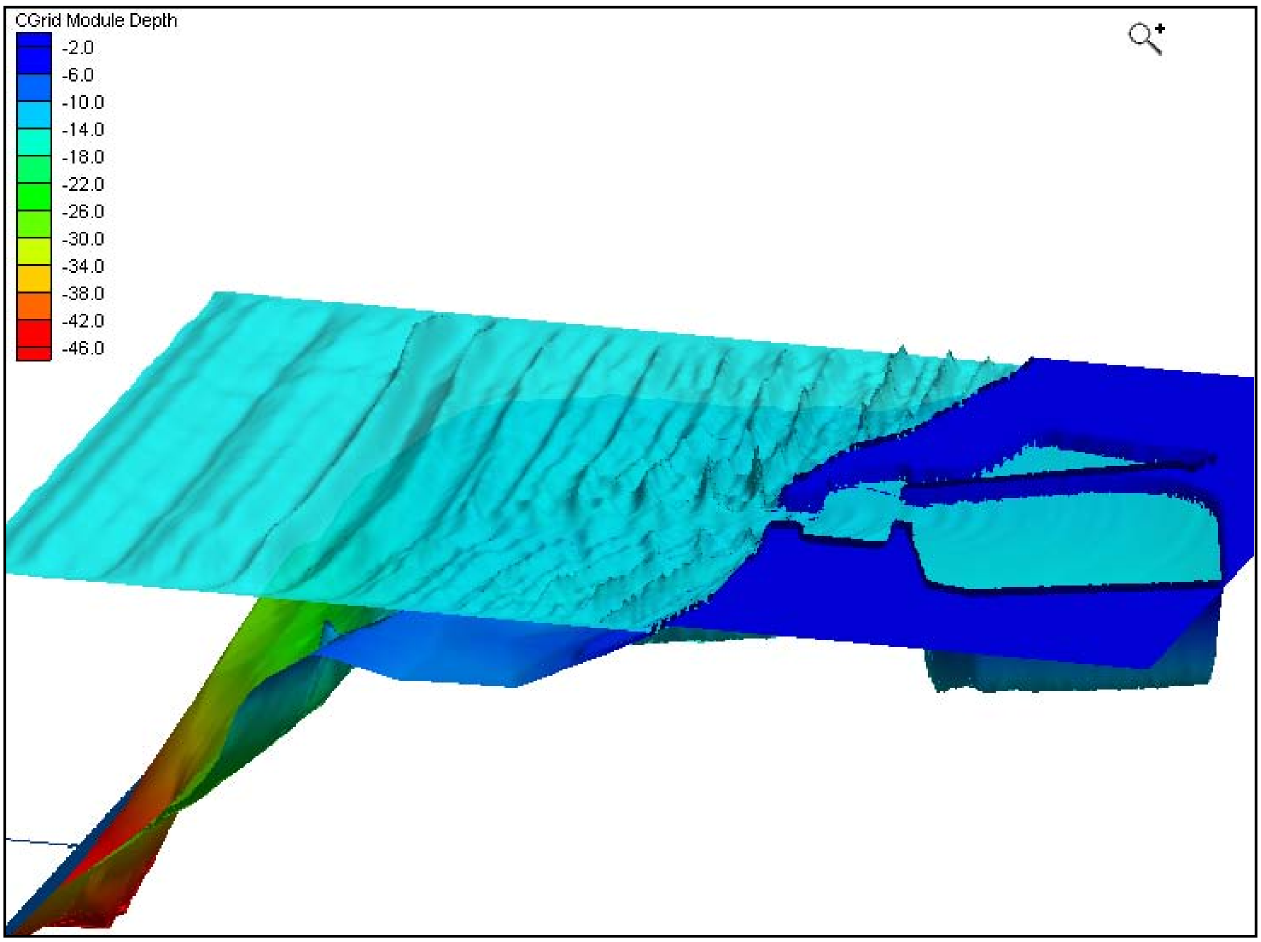


Figure 12. Functional surface of water levels over bathymetry (magnified 20x)

EXAMPLE 2 – MODELING WAVES AT A JETTIED INLET:

All the necessary steps have been shown in Example 1 for constructing a complete BOUSS-2D simulation. In this example, the only discussion will be the creation of porosity layers that were not used in the first example. For illustration purposes, porosity layers will be placed around one of the jetties in this example. All other features to be considered in this application are the same as in Example 1, and will therefore be omitted. To start a new project from an existing SMS application, select the **File|Delete All** command to clear out the Barbers Point simulation. Now select the **File|Open** command and choose the file IdealInlet.par to open the existing simulation of an ideal inlet that has a jetty on either side of the inlet. The modeling domain is shown in Figure 13. This grid was generated following steps described in Example 1.

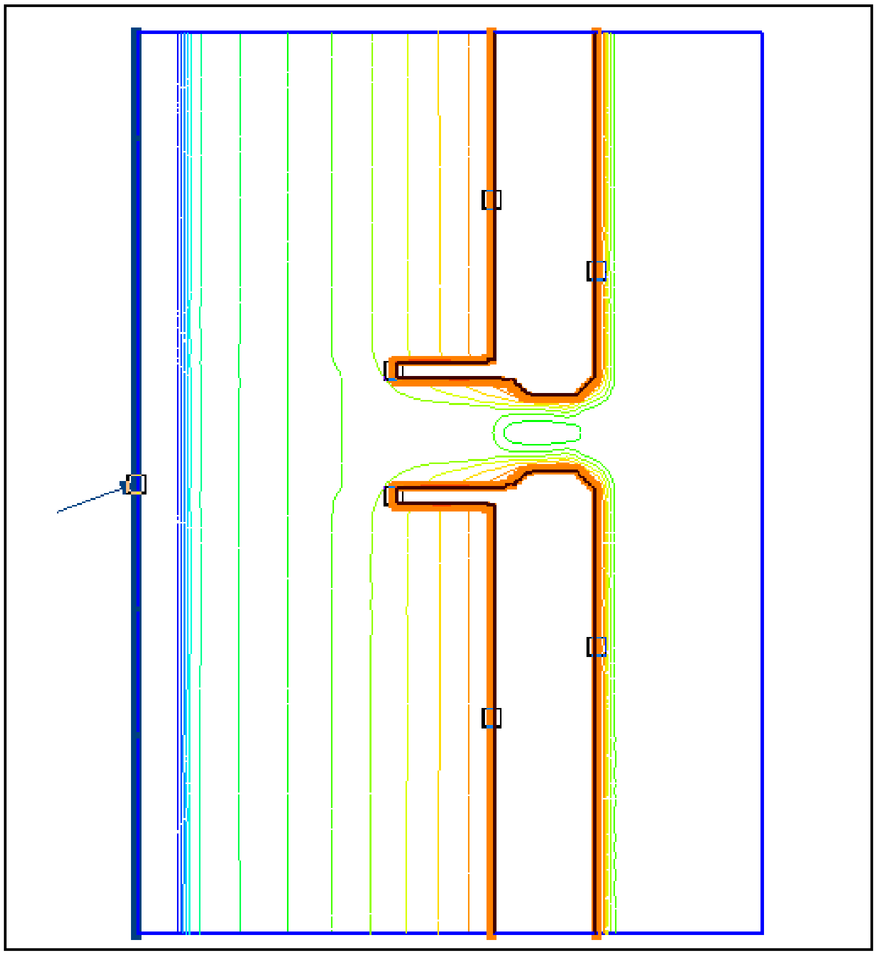


Figure 13. Ideal inlet test application

The existing grid was set up with the damping layers placed along the coastlines and around both jetties. To be consistent, damping layers should be used for coastlines and porosity layers for breakwaters and jetties. Porosity layers will be placed around the south jetty for modeling the interaction of waves with a porous structure. The following steps can be used:

a. Select the cell string that goes along the south jetty.

b. Select the **BOUSS-2D|Assign BC** command. Choose the *Porosity* radio button and enter a value of 20 m for the width and 0.5 for the porosity value. Click the **OK** button. For details on how to select appropriate values for these parameters, users should refer to Demirbilek et al. (2004) and Nwogu and Demirbilek (2001).

c. Select the *BOUSS-2D|Model Control* command. In the upper right corner, set the *Porosity* choice to **Use Cellstrings**. Enter a value for the characteristic stone size on the right side of the dialog as 0.75 m. Click the **OK** button to exit the *Model Control* dialog.

d. Save the simulation with the **File|Save BOUSS-2D** command. When asked, tell SMS to replace the damping function. This simulation is now ready to be run. Follow the steps given in Example 1.

Figure 14 shows the waves around the porous jetty (in the foreground) as compared to the extra bending of the waves on the nonporous jetty.

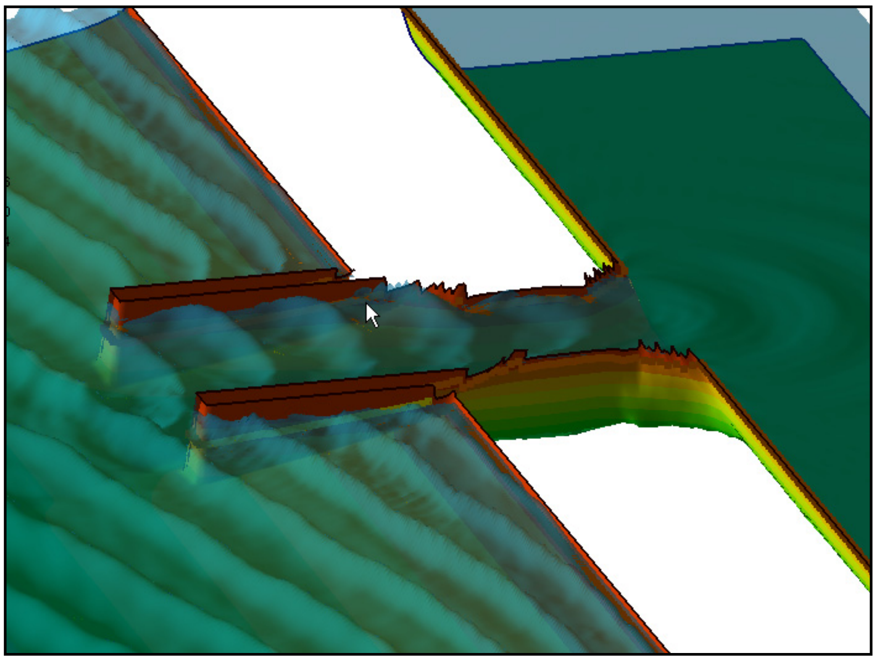


Figure 14. Waves around porous jetty

EXAMPLE 3 -- WAVE RUNUP AND OVERTOPPING OF BREAKWATER:

BOUSS-2D can simulate the wetting and drying of arbitrary 2-D coastal topographies. A simplified version of the 1-D model (BOUSS-1D) has been developed to predict the runup and overtopping of impermeable coastal structures. In this example, the usage of BOUSS-1D for prediction of wave runup on a sloping structure will be demonstrated. The model supports any geometrical profile, but for design purposes, the runup and overtopping calculator in SMS automatically creates a profile of the form shown in Figure 15. This geometric template is similar to the physical modeling work done by Saville (Saville 1955).

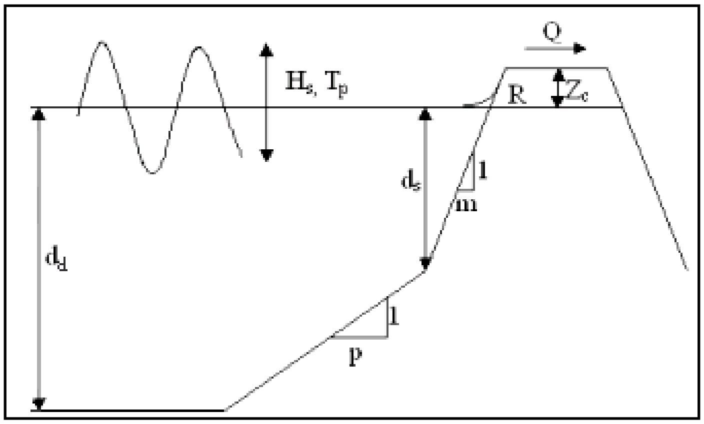


Figure 15. Profile shape generated by SMS for BOUSS-1D

The user enters a wave height and period along with the geometrical description of the structure. These are the maximum depth (d_d), toe depth (d_s), crest elevation of the structure (z_c), structure slope (m) and a beach slope (p). Described here are the steps in applying BOUSS-1D to the estimation of maximum wave runup situations.

The runup and overtopping calculator is accessed by selecting the **BOUSS-2D|Calculators** command and choosing the *1D Runup and Overtopping* tab (Figure 16).

The BOUSS-1D utility tries to predict wave-surface elevation time-history, from which estimates of wave runup and overtopping are computed. For regular incident waves, the estimated runup is the maximum runup, whereas for irregular waves, it is the $R_{2\%}$. The overtopping refers to the volume of fluid passing over the crest width of the structure, which determines the amount of fluid arriving on the backside of the structure.

As an example, if the user enters the values shown in Figure 16, and click on the **Calculate** button, SMS will create the input file for the simulation and bring up a prompt asking for the version of Boussinesq model to run. Select *BOUSS-1D* to run and click **OK** button. At this point SMS launches BOUSS-1D and displays the progress. This may take 10 to 20 sec to run. The model wrapper indicates the model run is complete and the user selects the **Exit** button. The runup and overtopping values appear in the bottom section of the calculator.

It should be pointed out that the Boussinesq equations on which the model is based implicitly assume that the seabed or structure slope is mild, relative to the characteristic wavelength. When SMS constructs the input file, the wavelength at the toe is compared to the wetted length of the structure. If the mild slope assumption is violated (i.e., a characteristic wavelength cannot fit on the structure, SMS modifies the slope term “m” to be a maximum value computed as the wavelength at the toe of the structure divided by 2 times the depth at the toe of the structure. In this case, a message will be echoed to the screen indicating that the mild slope assumption was violated and the predicted runup value may be not reliable or less accurate. If the model fails, it returns a value of 0.0 for runup. For the mild slope structures (1:6 and 1:10 slopes) tested in the Saville experiments (Saville 1955), the BOUSS-1D model predicted values of runup are generally within 20 percent of the physical model data. The prediction of runup can be improved by calibrating the model with the experimental data.

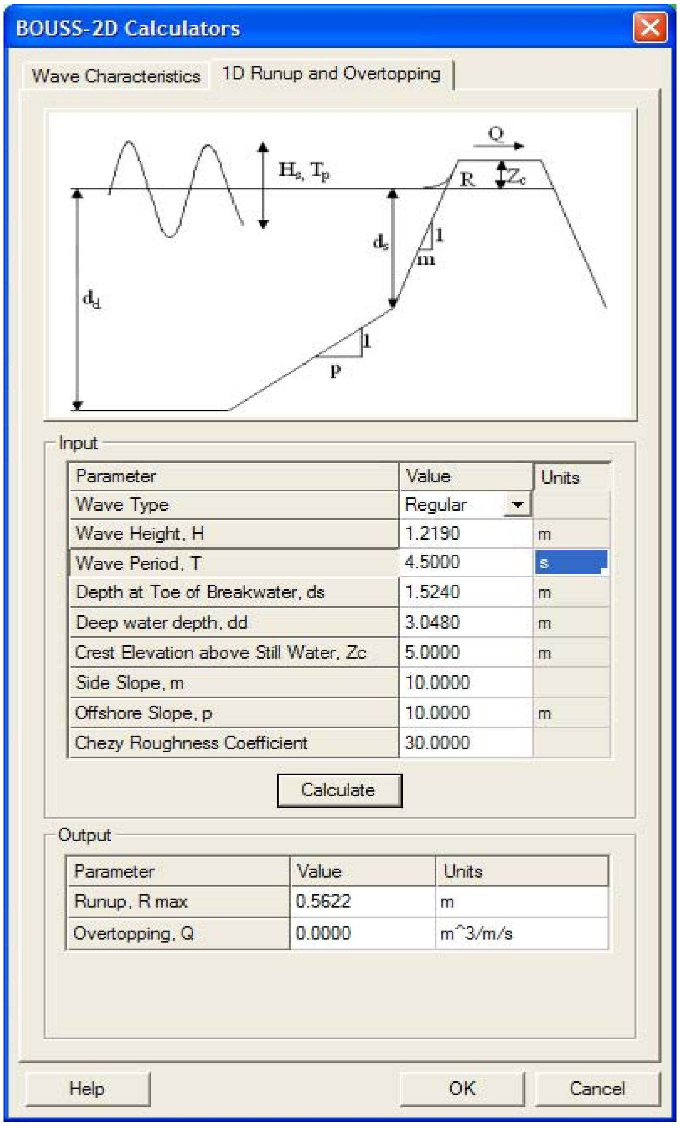


Figure 16. Wave Runup and Overtopping calculator

SUMMARY: This note is applicable to the Version 1.0 of BOUSS-2D. Three examples have been used in this CHETN to illustrate the steps involved in typical application of BOUSS-2D. These involve modeling waves in a harbor, a jettied inlet and the prediction of wave runup and overtopping of a sloping coastal structure. Coastal projects may require simulation of many wave conditions and different grids representing different structures or other modifications as required in the study site. The users can explore a number of features and capabilities of BOUSS-2D in such cases. Specific guidance is provided to the users in this CHETN to ensure a solid understanding of the methodology when applying BOUSS-2D model to different engineering problems. With increasing use of BOUSS-2D in engineering projects by the community, it is expected that both the model and its interface will evolve, and the Version 1.0 of BOUSS-2D model and its SMS interface will continue to undergo future revisions. Feedback and suggestions are welcome from users about design, implementation, and usage of the present and future versions of BOUSS-2D model.

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