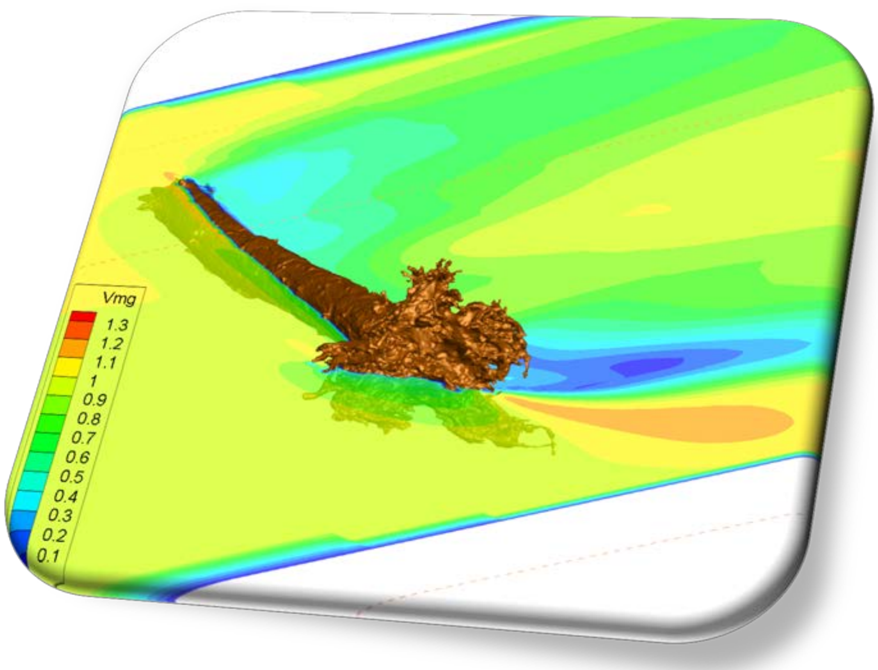
RECLAMATION

Managing Water in the West

Guide on Unsteady Flow Modeling with SRH-2D

Sedimentation and River Hydraulics – Two-Dimensional River Flow Modeling



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Guide on Unsteady Flow Modeling with SRH-2D

Sedimentation and River Hydraulics – Two-Dimensional River Flow Modeling

Prepared by

Yong G. Lai, Ph.D., Hydraulic Engineer

Bureau of Reclamation
Technical Service Center
Sedimentation and River Hydraulics Group

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Introduction

This section describes how to use SRH-2D to simulate unsteady, time-accurate, flows. Such flow modeling is relevant for flood, inundation, and dam-break simulation. Special attention is on the modeling of dam and levee break flows as they represent the highly unsteady flow with complex flow features such as the occurrence of moving hydraulic jumps. Modeling procedure is briefly described, along with key parameters needed.

Sample case studies are also presented to demonstrate the accuracy of SRH-2D. A user may also use these cases to test SRH-2D.

Modeling Procedure and Key Parameters

Steady state flow modeling with SRH-2D is relatively straightforward and simple to carry out. The only key modeling parameter is the time step, which is to ensure stability. For time-accurate unsteady solutions, stability is still determined by the time step. However, a few extra modeling parameters may be needed to ensure solution accuracy and they are discussed below.

For a time-accurate unsteady modeling, the following procedure is recommended:

- Initial Condition: it needs to be determined first. It may be set up using one of three ways: (1) ZONAL method; (2) DRY bed method; or (3) RST method. “ZONAL” method is to use SMS to divide the entire mesh into different zones represented by SMS material types. Within each zone, a user may set up a constant water surface elevation or a constant water depth. “DRY” bed is to let the entire mesh to have zero water depth. And finally, the RST method is to obtain a steady state solution with a constant flow discharge first. This solution, represented by the restart (or hot-start) file _RST.dat, is then used as the initial condition for a time-accurate unsteady modeling.
- Initial Time Step: An initial time step is estimated first. At present, we have not developed a guideline yet on how to estimate this. As a general rule, a time step of 0.1 to 1 second may be used for field cases; and smaller time step is needed for smaller scale problems. With time-accurate unsteady modeling, small time step is needed for solution accuracy purpose (not due to stability issue).
- Relaxation Parameter: Next, the relaxation parameter, RELAX_H, is determined, which is done using the _DIP.dat file. An initial recommended selection is RELAX_H=0.9. RELAX_H may have to be reduced (as low as 0.2) if instability occurs and reduction of time step does not help. A baseline solution should be obtained first with the initial time step and an appropriate RELAX-H parameter.
- Finally, a time step sensitivity study is recommended. One or two smaller time steps should be used, while keeping other parameters unchanged, and the solutions should be compared. The “final” solution is the one whose results do not change noticeably if the time step is reduced further. A good strategy is to reduce the time step at least by half.

Two extra parameters may be used in conjunction with the modeling of unsteady flows: DAMP and NITER (both may be set up in the _DIP.dat file). DAMP is used to activate the second-order numerical scheme. DAMP ranges from 0.1 to 1.0. A typical value of DAMP=0.35 is recommended. Smaller DAMP is closer to a “purely” 2nd-order central difference scheme which may leads to oscillatory results due to lack of damping. NITER is the number of iterations within each time step. A default setting of NITER=3 is used by SRH-2D. Occasionally, higher number may be used, e.g., NITER=5, particularly when smaller RELAX_H (e.g., below 0.4) has to be used.

In the following, a few time-accurate unsteady solution cases are presented. They demonstrate how SRH-2D may be used to compute the dam/levee break flows; and good and accurate unsteady solutions may be obtained. In general, we found that (1) the water front computation is less difficult and not sensitive to model parameters; (2) the traveling hydraulic jump is harder to predict and it is sensitive to a number of model parameters; and (3) laboratory flume cases are more sensitive to model parameters; while field cases are less sensitive.

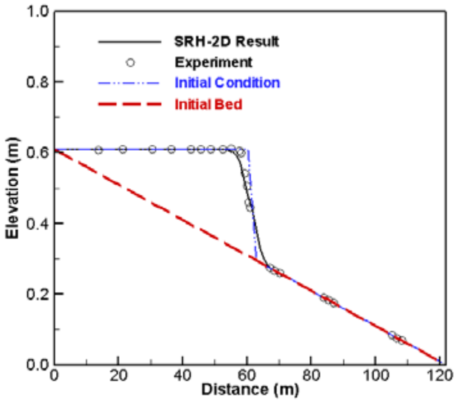
Case Study Results

Case 1: One-Dimensional Dam Break Flow over a Straight Channel

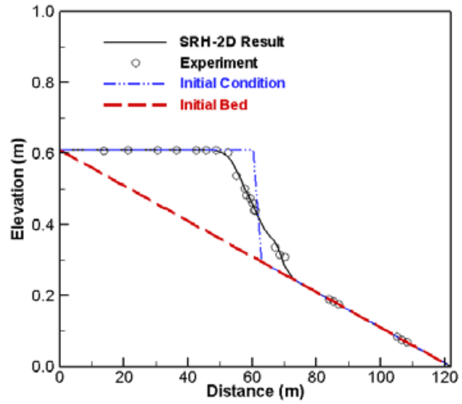
This case is selected from the dam-break flume experiment conducted by the U.S. Army Corps of Engineers Waterways Experimental Station (USACE, 1960, 1961). The rectangular flume has a length of 400ft, a width of 4ft, and a slope of 0.5%. Initially, water is stored upstream of the dam located at 200ft into the flume and the water surface elevation is leveled with the upstream of the flume (x=0); however, downstream of the dam is dry. At time zero, the dam is suddenly removed to represent an instantaneous breach.

The simulation with SRH-2D starts with a mesh consisting of 102 uniform cells in the flow direction and 3 lateral cells (a total of 306 cells). The upstream boundary is assigned as a “WALL” boundary condition type, the downstream boundary is a free out-fall boundary with “EXIT-EX” type, and two side boundaries are set up as “SYMMETRY” to model the 1D nature of the flow. The Manning’s roughness coefficient is 0.009 s/m**(1/3); it was recommended by the USACE report (USACE, 1960) and was also used by Wang and Bowles (2006) and Savant et al. (2010) in their numerical modeling. The initial condition is as follows at time=0: zero velocity everywhere; constant water surface elevation upstream of the dam and dry bed downstream of the dam. In addition, the following parameters are used (assigned with the DIP file): dtnew=0.1, niter=5, relax_h=0.9, and damp=0.35.

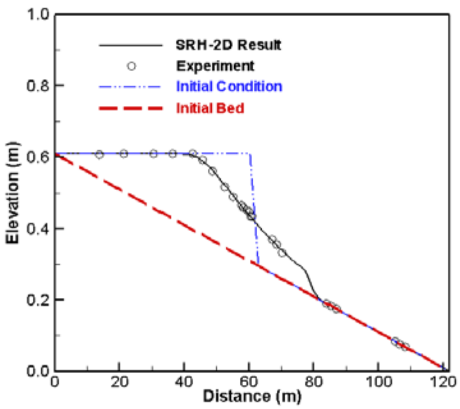
The simulated results are compared with the measured data in Figure 1 and 2. Overall, SRH-2D obtained good solutions that matched measured data well.



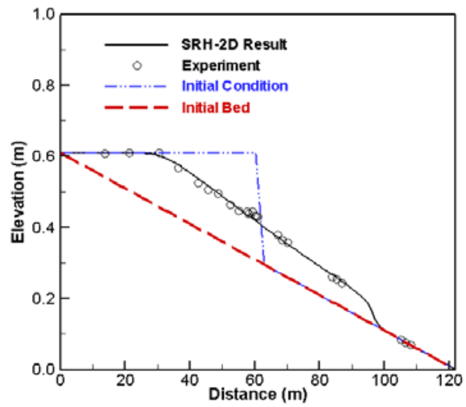
(a) Time = 2s



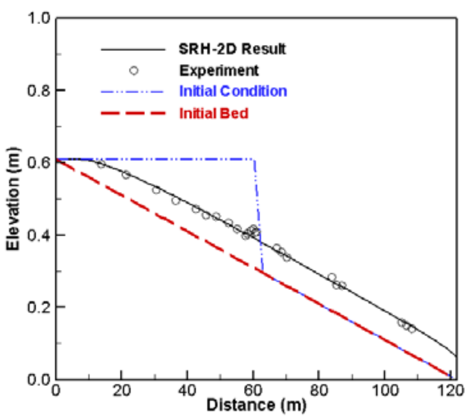
(b) Time = 5s



(c) Time = 10s



(d) Time = 20 s



(e) Time = 40 s

Figure 1. Comparison of predicted and measured water surface elevation at different times after dam-break for the 1D case.

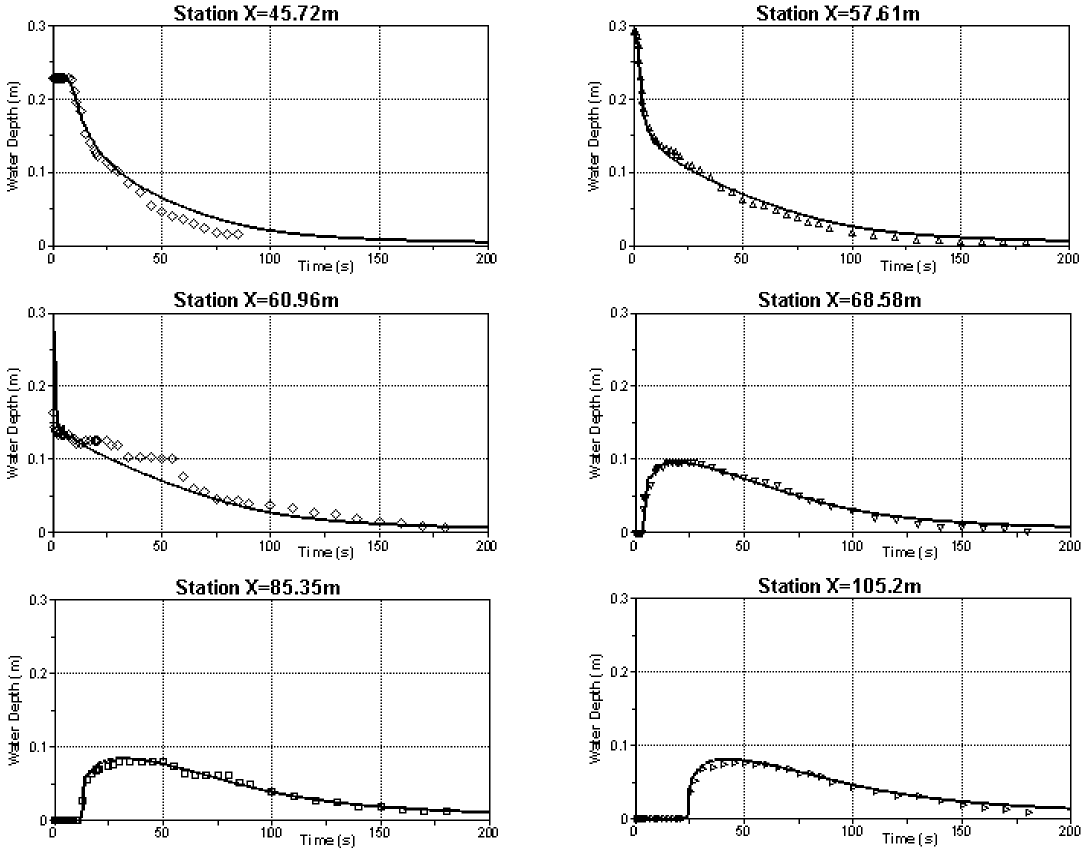


Figure 2. Comparison of predicted and measured water depth variation with time at the selected measurement stations for the 1D dam-break case.

Case 2: Two-Dimensional Dam-Break Flow over Two Channels with 45^o Angle

The test case is a benchmark test problem proposed by the European Union CADAM (Concerted Action on Dam-Break Modeling) project (Morris, 2000). Numerical model has been carried out by many researchers (e.g., Brufau and Garcia-Navarro, 2000; Zhou et al. 2004; Savant et al. 2010). The plane view of the test case geometry is shown in Figure 3. The case consists of a square-shaped upstream reservoir and a 45^o bend channel. The flow is essentially two dimensional in nature with two special dam break features: the damping effect of the corner and the upstream moving of the hydraulic jump (formed by the reflection at the corner).

The drainage channel is made of 4.25m and 4.15m long and 0.495m wide rectilinear reaches connected at 45^o angle by an element. The channel is flat without slope. The reservoir has a length of 2.44m and a width of 2.39; the reservoir is 0.33m below that of the channel, forming a vertical step at the entrance to the channel. The initial water depth in the reservoir is 0.58m but the depth in the channel is 0.01m. All boundaries are solid non-slip walls except the exit if the downstream channel. The exit is a free-fall boundary and the "EXIT-EX" boundary type is used by SRH-2D. However, when the flow at the exit is below subcritical, the "EXIT-EX" boundary produced unrealistic upstream-traveling waves. One way to implement the free-fall condition is to add a small section at the end of the channel with a steep enough bed to produce a supercritical flow. In this study, an extra 2 ft (0.615 m) section is added with a 1^o bed slope (1.63%). The energy loss of the flow is complex for the test case as it comes from several sources: bed roughness, side wall roughness of the channel, and contraction loss from the reservoir to the channel (see discussion by Zhou et al., 2004). Study of Zhou et al. (2004) showed that the upstream traveling of the hydraulic jump is sensitive to the contraction loss The CADAM workshop recommended the use of the Manning's roughness coefficient of 0.0095 for the bed and 0.0195 for the channel side wall. In this study, the head loss due to the contraction is added by setting the small section (length of 0.15 ft or 0.046 m) of the channel downstream of the dam to a Manning's coefficient of 0.06 (instead of the value of 0.095). The side wall roughness is incorporated through the approach presented by Lai and Greimann (2010) in which an effective roughness height is used. The effective roughness height (δ) of the side wall is estimated to be 2.34 mm, which corresponds to a Manning's coefficient (n) of 0.0195 if $n = \delta^{1/6}/18.7$ is assumed.

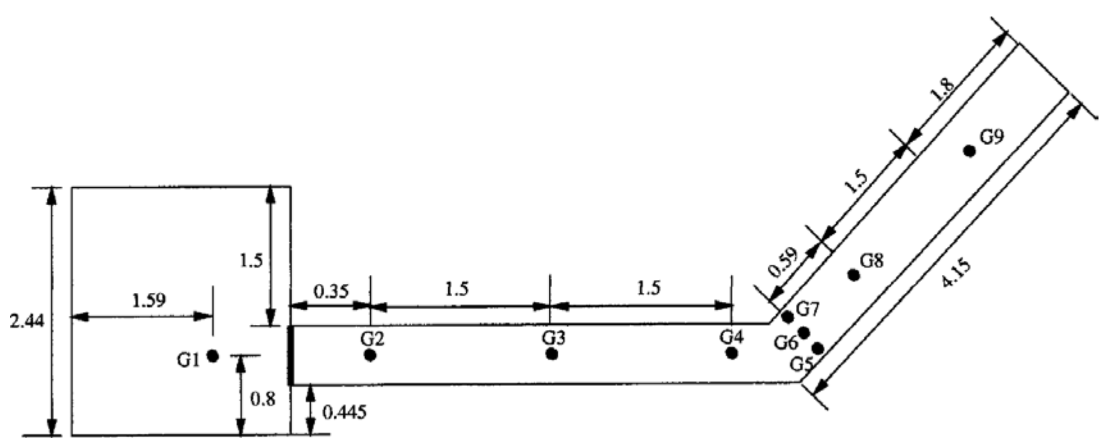
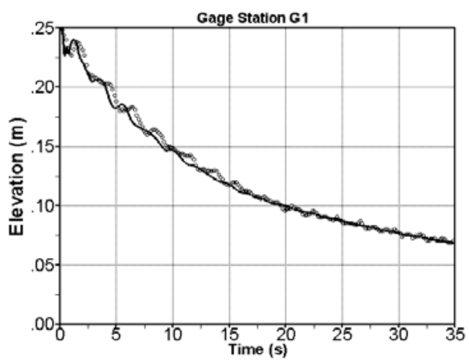


Figure 3. Plane view of the 2D dam-break case

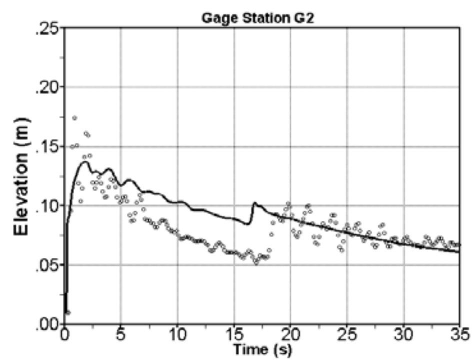
A quadrilateral mesh is generated with 11,500 cells, which has a similar mesh resolution to other studies (e.g., Savant et al. 2010). A small time step of 0.03 second is needed to obtain the time-independent solutions. Other simulation parameters include the following: NITER=5; RELAX_P=0.9; DAMP=0.25; and A_TURB=0.2.

Comparison of the model results with the measured data are made at nine gage points as shown in Figure 3. The water surface elevation in time was measured at all stations; and comparisons are shown in Figure 4. Overall, SRH-2D obtained reasonably good results in comparison with the measured data. The major mismatch is the prediction of the water depth at the gage station G2 (the nearest station to the dam).

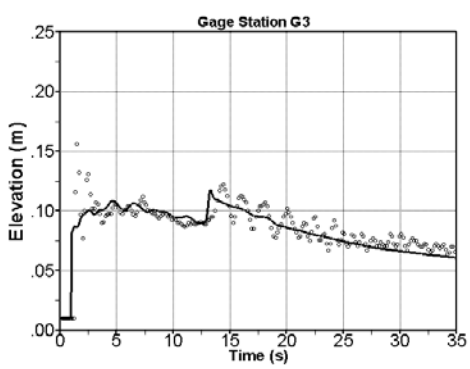
Parametric study showed that the movement of water front may be modeled well by the numerical model; but the modeling of the upstream traveling hydraulic jump caused by the corner is relatively more difficult to model. The predicted hydraulic jump is sensitive to a number of parameters such as the contract loss, side wall roughness, and the amount of turbulence.



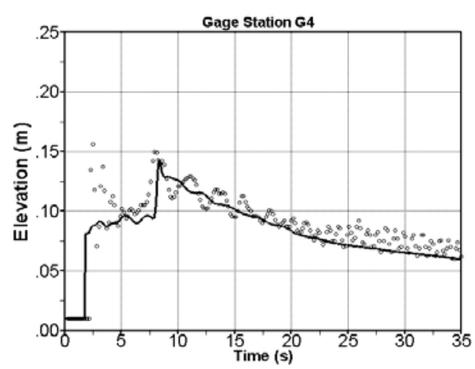
(a) Station G1



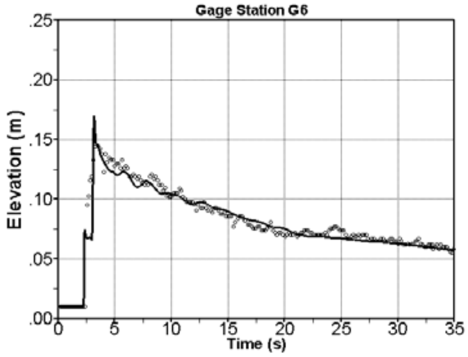
(b) Station G2



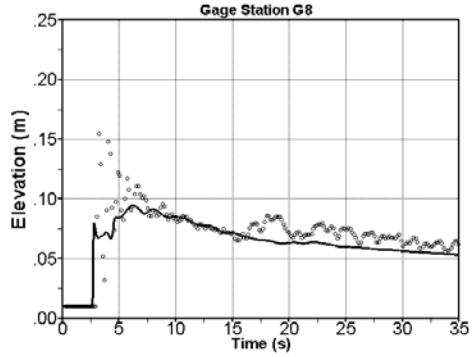
(c) Station G3



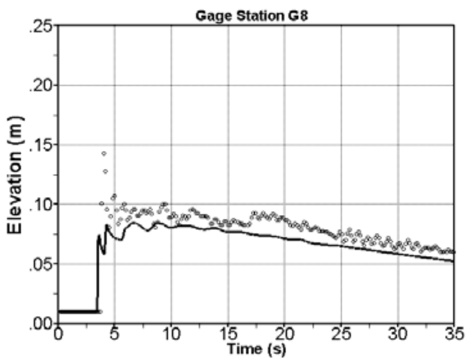
(d) Station G4



(e) Station G6



(f) Station G8



(g) Station G9

Figure 4. Comparison of predicted and measured water depth history at seven gage stations (see Figure 3 for the locations of all stations).

Case 3: Dam Break Flow of the Malpasset Dam

Finally, the third test case is also a benchmark problem proposed by the CADAM project (Morris, 2000), which represents a field case at the Malpasset dam. The dam was located in a narrow gorge of the Reyran river valley in France. It was a 66.5 m high arch dam with a crest length of 223 m and a maximum reservoir capacity of $55X10^6$ m^3. Downstream, the Reyran river valley is very barrow and has two consecutive sharp bends. Then the valley widens as it goes downstream and eventually reaches the flat plain (see Figure 5). The dam was failed in 1959 following an exceptionally high rainfall. After the dam failure, extensive field study was carried out to obtain the maximum water surface levels along the river valley with the dam break flow. The topography of the river before the dam failure was also obtained (see Figure 5). In addition, a physical model study (a scale of 1 to 400) was also carried out in 1964 to study the dam break process. Therefore, the maximum water level and the flood wave arrival time at various points of the river are surveyed or measured, which are available for numerical model verification or validation study. A detailed description of the Malpasset dam break case was available in the literature (e.g., Goutal, 1999; Hervouet, 2000), and is not repeated. Only relevant numerical model parameters are described next.

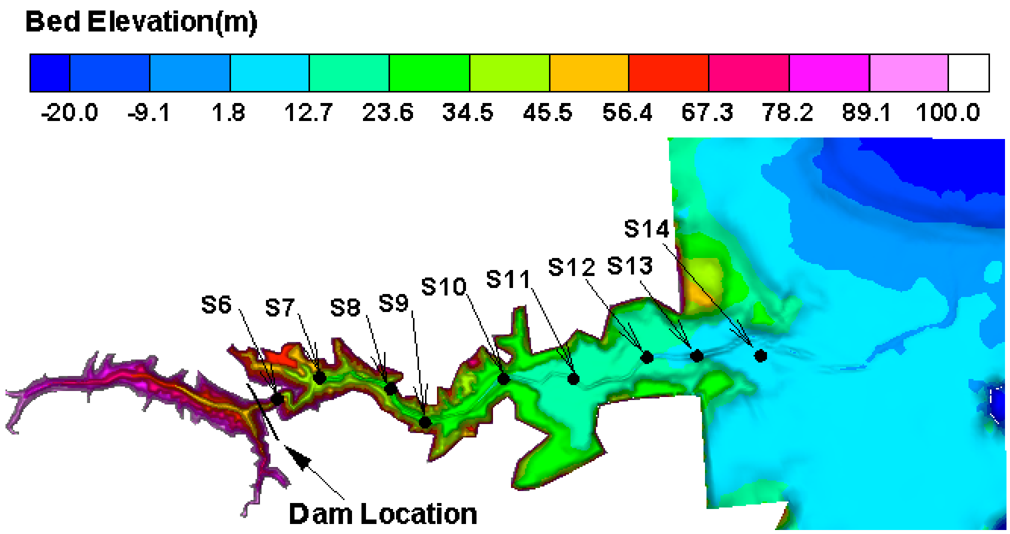


Figure 5. Topography of the Malpasset dam

A mixed quadrilateral and triangular cells are used to generate the mesh covering the flow domain shown in Figure 5. The mesh has 25,316 cells. Initially at time zero, water is still with a water surface elevation of 100 meters upstream of the dam. Downstream, the river is assumed to be dry. All boundaries are no-slip walls except the one in the ocean. Along the ocean boundary, EXIT-H boundary is used with zero water surface elevation. A constant Manning's roughness coefficient in the range of 0.025 to 0.033 was recommended by the CADAM workshop. Several numerical model studies used 0.033 (e.g., Ying and Wang, 2010); this study used the same value. Other simulation parameters include: a time step of 0.1 second, NITER=5 and RELAX_H=0.9. Model results are not sensitive to time step, turbulence model, or even the damping factor with the mesh selected.

The model predicted results are compared with the measured data at measurement stations (see Figure 5 for their locations) in Figures 6 and 7. Good prediction is provided by SRH-2D.

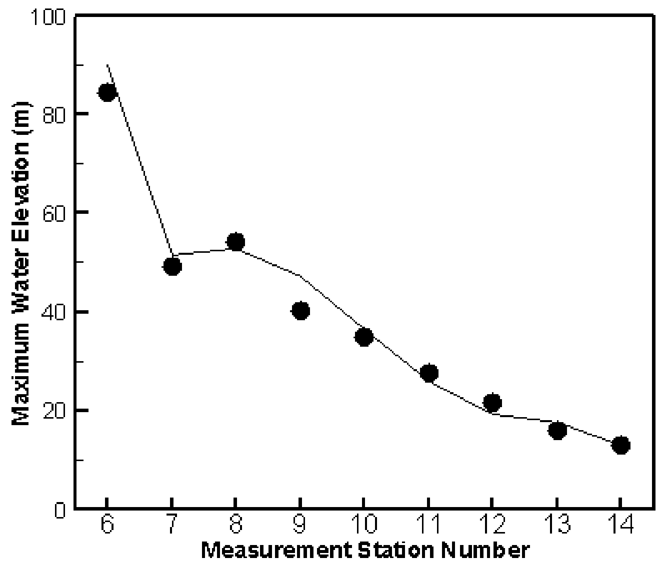


Figure 6. Comparison of predicted and measured maximum water surface elevation at measurement stations along the river during dam break (solid line: computation; symbols: measurement)

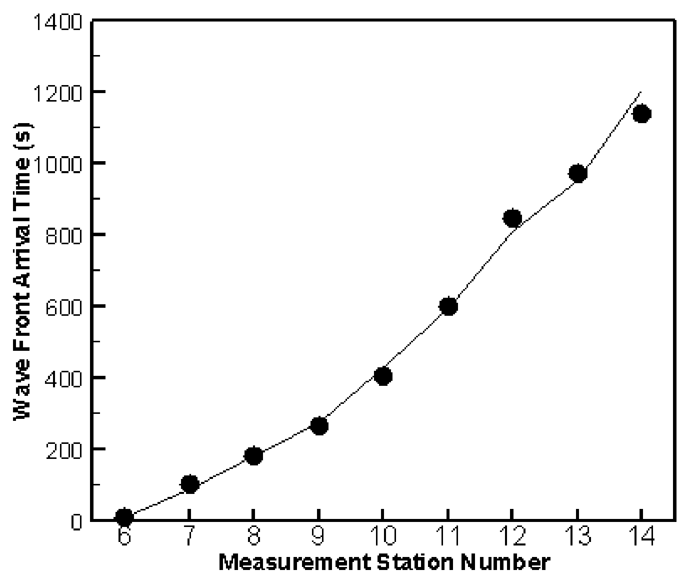


Figure 7. Comparison of predicted and measured arrival time at measurement stations along the river during dam break (solid line: computation; symbols: measurement)

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