Bridge Hydraulics in HEC-RAS

Workshop

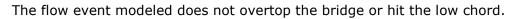
1 Objective

This workshop will help students learn how to use HEC-RAS to model bridges inside of a 2D flow area.

The workshop will begin by using the simplified 1D bridge solution and continue with developing detailed mesh to model the floodplain constriction. The shallow water equations (SWE) will be used. These simulations will then be compared.

2 Background

The figure below shows the terrain and bridge crossing (flow west to east). The floodplain is highly constricted at the bridge which includes four rows of piers, these piers are marked by purple lines in the view below. The square piers have 4ft sides.





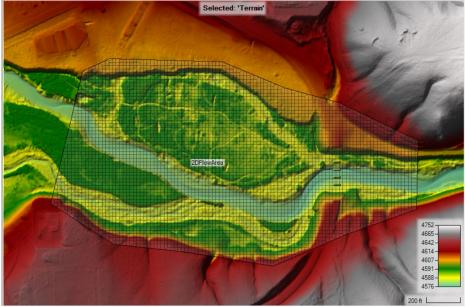


3 Part 1 – Simplified 1D Bridge Model

3.1 Create Initial Model Geometry

- 1. Open **HEC-RAS** and start a new project in the bridge modeling folder.
- 2. Open RAS Mapper
 - a. Set the **projection** ("GIS_Data" folder).
 - b. Add the existing **Terrain_NoPiers** from the "Terrain" folder.
 - c. Add a **New Geometry** (name it "**Initial**").

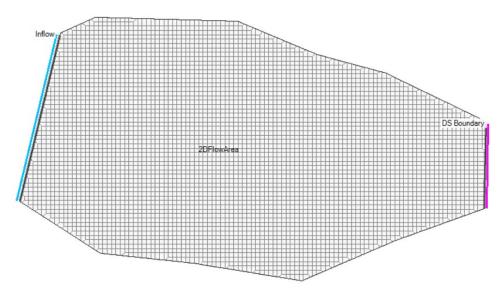
3. Set up a coarse 2D Flow Area mesh for the entire study area.



4. Try **20ft** cells with a Manning's n value of **0.04**.

📰 2D Flow Area Editor	×
2D Flow Area: DFlow Area	
Cell Properties	_
Computation Points	
Points Spacing (ft) DX: 20 DY: 20 🔊 Mesh State = Complete	
Generate Computation Points with All Breaklines Number of Cells = 4968 Average Face Length = 20 Average Cell Size = 406 Maximum Cell Size = 687 Minimum Cell Size = 314	
Generate Computation Points without Breaklines 00:00:00.078	
Hydraulic Cell/Face Properties	
Default Manning's n Value: 0.04	
Spatially varied Manning's n on face (Beta)	
Force Mesh Recomputation Close	e

- 5. Set up boundary condition lines
 - a. Inflow
 - b. DS Boundary



- 6. Stop **Editing** in RAS Mapper.
- 7. Close RAS Mapper
- 8. Open the **Geometric Data** editor.
 - a. Open the geometry **Initial** and inspect it.
 - b. Close the **Geometric Data** editor.

3.2 Enter Flow Data and Boundary Conditions

- 9. Open the **Unsteady Flow Data** editor.
- 10. Set the downstream boundary condition to **Normal Depth** with a friction slope of **0.005**.

Normal Depth Downstream Bounda	ary
2D: 2DFlowArea BCL	ine: DS Boundary
Friction Slope:	0.þ05
 2D Flow Area Boundary Condition Para Compute separate water surface el Compute single water surface for el 	levation per face along BC Line
	OK Cancel

11. Set the inflow boundary to **Flow Hydrograph**.

Use a constant flow of **15,000 cfs**. Set the EG Slope to **0.00075**, and turn on the **TW Check**.

-	ed Start Time: Date:	01jan2000 Time: 0000	
No. Or	dinates Interpolate Missing \	/alues Del Row Ins Row	
		Hydrograph Data	
	Date	Simulation Time	Flow
		(hours)	(cfs)
1	31Dec1999 2400	0:00:00	15000
2	01Jan2000 0100	1:00:00	15000
3	01Jan2000 0200	2:00:00	15000
4	01Jan2000 0300	3:00:00	15000
5	01Jan2000 0400	4:00:00	15000
6	01Jan2000 0500	5:00:00	15000
7	01Jan2000 0600	6:00:00	
Flow:	Multiplier:	 EG Slope for distributing flow along B	C Line: 0.00075 🔽 TW Ched

12. **Save** the flow data.

3.3 Create a Plan and Simulate

- 13. Open the **Unsteady Flow Analysis** window.
- 14. Set up the time window, time step, and mapping output interval.

15. Set the **Computation Options**

a. Set the Equation Set to **SWE-ELM (original/faster)** and the **Initial Conditions Time** as shown in the figure below.

Parameter	(Default)	2DFlowArea
1 Theta (0.5-1.0)	1	1
2 Theta Warmup (0.5-1.0)	1	1
3 Water Surface Tolerance [max=0.2](ft)	0.01	0.01
4 Volume Tolerance (ft)	0.01	0.01
5 Maximum Iterations	20	20
6 Equation Set	Diffusion Wave	SWE-ELM (original/faster)
7 Initial Conditions Time (hrs)		1
8 Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9 Number of Time Slices (Integer Value)	1	1
10 Turbulence Model	None	None
11 Longitudinal Mixing Coefficient	0.5	0.3
12 Transverse Mixing Coefficient	0.1	0.1
13 Smagorinsky Coefficient	0.05	0.05
14 Boundary Condition Volume Check		
15 Latitude for Coriolis (-90 to 90)		
16 Solver Cores	All Available	All Available
17 Matrix Solver	PARDISO (Direct)	PARDISO (Direct)
18 Convergence Tolerance		
19 Minimum Iterations	O	0
20 Maximum Iterations	0	0
21 Restart Iteration	10	10
22 Relaxation Factor	1.5	1.3
23 SOR Preconditioner Iterations	10	10

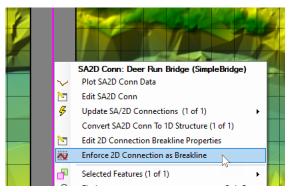
- 16. **Save** the plan data as "Base Plan".
- 17. Compute
- 18. **Computation Time Step Check** ensure solution is smooth and stable, pick a new time step and re-run if necessary.

3.4 Create new Geometry and Plan with 1D Bridge

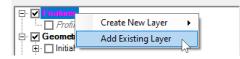
- 19. In **RAS Mapper** window use the "**Save Geometry as** ..." menu option to copy the base geometry to a new one.
- 20. Name the new geometry "Simple Bridge".
- 21. Start editing and draw a centerline for the bridge deck (draw from left to right looking downstream, which will be top to bottom in this case). For best results start and end the bridge at or near mesh nodes. Set the structure Name to "Deer Run Bridge", the Width to 40 ft, and the Structure Type to "Bridge (Inline to 2D Flow Area)".

Seliting Conne	ction Structure	×
	ea: Perimeter 1 ea: Perimeter 1 pe changed from connection ec	litor)
Name:	Deer Run Bridge	ĺ
Width (ft):	40	1
Structure Type:	Bridge (Internal to 2D Flow 💌	
Description:		
	OK Cancel	

22. Enforce the 2D cell spacing around the centerline as appropriate.



23. Add the Pier Centerline shapefile (in the GIS Data folder) by right-clicking on **Features** at the top of the project tree, and selecting Add Existing Layer.



	SA/2D Connections - Layer Properties (2D Flow Area + 1D Brid)	ge)
	Visualization and Information Features Source Files	
	Vector	Additional Options
	Point: Line: Fill:	Stationing Tick Marks
	Label Features with Attribute Column(s) Edit	Draw Points
	Surface	Label Segment Indexes Plot Width
	Plot Surface Update Legend with View	Plot Breach
200	Edit	
	Opacity: 100%	
+ 300		
1 - Contraction of the second s		1
	Contours / Hillshade	
	Plot Contours Interval: 5 Color:	
1400	Plot Hillshade Z Factor: Edit	
	Copy Symbology Paste Symbology Reset Symbology	
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500.02	and the second sec	

- 25. Note the bridge centerline stations where the piers cross it, you will need these stations when entering the pier data.
- 26. Go the main **Geometry Schematic** and open the **2D Connection Data Editor**.
- 27. Ensure the structure type is modeled as Bridge (Internal to 2D Flow Area).
- 28. Add a deck roadway that spans the full range width of the XS's with a flat top roadway at an elevation of **4615** and a low chord at **4607 ft**.
- 29. Set the upstream distance to 5 ft.
- 30. Select appropriate **Weir Coefficient** for this structure.

31. Add **4 Piers** that are **4 ft** wide at the stations you noted earlier where the <u>centerline crossed the pier centerlines</u> shapefile.

		1 au l			. 1.
A	dd Copy	Delete	Pier #	<u> </u>	
De	Row Ce	nterline Statio	n Upstream	241	_
In	s Row Ce	nterline Statio	n Downstream	241	
	ating Pier De		Apply floating	debris to this	Dier
-	Set Wd/Ht for		ris Width:		pici
-		Deb	ris widur:		
		Deb	ris Height:		
	Upstre		-	Instream	
	Upstre Pier Width		-	nstream Elevation	
1		am	Dow	1	-
2	Pier Width	am Elevation	Dow Pier Width	Elevation	
1 2 3	Pier Width 4	am Elevation 4570	Dow Pier Width 4	Elevation 4570	
2	Pier Width 4	am Elevation 4570	Dow Pier Width 4	Elevation 4570	
1 2 3 4 5	Pier Width 4	am Elevation 4570	Dow Pier Width 4	Elevation 4570	

Ele View Options Help Connectons: N Deerfield Rd A Apply Data Description From: DD Flow Area: 2DFlowArea Exet SA/2D Coverflow Computation Method Coverflow Computation Structure Type: Plot: US Inside Bridge N Deerfield Rd US Inside Bridge N Deerfield Rd US Inside Bridge N Deerfield Rd US Inside Bridge Current Terrain Help Plot Stopping Coverflow Coverflow Coverf	Section Wiew		ita Editor - 2D Flow Ar	ea + 1D Bridge				-		×
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Per Saday Per Saday Bridge Modeling A Bridge Bridge Bridge Bridge Bridge Stophnop Bridge Bridge Bridge Stophnop	Structure Typ	e: Bri	dge (Internal to 2D Flow	Area)	•	Cut profile f	rom terrain			
US hade Bridge	Plot:	US	Inside Bridge		- I t	Clip Weir Prof	le to 2D Cells			
0 100 200 300 400 500 600 Station (ft)	Pier Sloping Abutment Bridge Modeling	4610 4600 4590 4580		P v v			1	-	Ground Bank Sta	
		4570	0 100	200	300	400	500	600		
<u> </u>					Station (ft)					_
	-									Þ

32. Open the **Bridge Modeling Approach** and turn on the **Momentum** method and select an appropriate drag coefficient **Cd** for square nosed piers.

33. Open the **HTab** parameters and limit the curves for this simulation.

Connection Hydraulic Property Table Parameters				
Number of points on free	flow curve:	50		
Number of submerged cu	50			
Number of points on each	20			
Apply number of	points to all Connect	ions		
Head water maximum ele	4618.			
Tail water maximum eleva				
Maximum Flow (Recomme	20000.			
	ОК	Cancel		

34. Open the External and Internal Bridge Cross Section dialog.

🐨 Connectio	on Data Editor	r - 2D Flow Are	a + 1D Bridge

<u>F</u> ile	<u>V</u> iew	Options	Help	
Conne	ection:	Exte	rnal and Internal Bridge Cross Sections	
Descr	iption	Con	tr and Expan Coef for Bridge Cross Sections	Breach
Con	nections	Brid	ge Ineffective Regions	
From		Mo	mentum Equation	ir Length:
To:		Clas	ss B defaults	nterline Ler
	erflow Co Iormal 20	FIE	ssure flow criteria	Centerline
Struct	ture Type	e: Bridge	(Internal to 2D Flow Area)	Cut profile
Plot:		US Insi	de Bridge 📃 📘 🕇	Clip Weir Pro
Road	k/ way		N Deerfield Rd	

- 35. Set the Manning's values for the 4 XS's for this structure to use a value or **0.04**.
- 36. Save geometry file.
- 37. Save Plan As, to create another plan with this geometry.
- 38. **Compute**

3.5 Compare Results

- 39. Create a **Profile Line** for the river centerline. (turn on Plot Tick Marks to help find where the bridge is in the profile)
- 40. **Plot the WSE** and compare the results.

<u>*Question:*</u> What is the difference in WS between the Initial and Simple Bridge plans at the bridge?

<u>Question</u>: Look at the family of bridge curves and for the flow through the bridge track back the HW to find the prescribed TW and try to verify the loses were applied correctly.

<u>Question</u>: Is the cell size adequate for modeling the terrain, bridge, piers, etc.?

4 Part 2 – Detailed Mesh at Roadway

4.6 Create Initial Model Geometry

- 1. In RAS Mapper window use the "**Save Geometry as** ..." menu option to copy the "Initial" base geometry to start.
- 2. Name the Geometry "Detailed Mesh".
- 3. Add an existing **Terrain "Terrain"** ("Terrain" folder) (You should see piers in the terrain at the road crossing.)
- 4. **Associate** the detailed Terrain with the Detailed Geometry.
- 5. Close **RAS Mapper.**

4.7 DW - Create a Plan and Simulate

- 6. Open the **Unsteady Flow Analysis** window.
- 7. Select the Geometry and Flow files.
- 8. Set up the time window, time step, and mapping output interval.
- 9. Set the **Computation Options**
 - a. Set the Equation Set to **Diffusion Wave**.

	Parameter	(Default)	2DFlowArea
1	Theta (0.5-1.0)	1	1
2	Theta Warmup (0.5-1.0)	1	1
3	Water Surface Tolerance [max=0.2](ft)	0.01	0.01
4	Volume Tolerance (ft)	0.01	0.01
5	Maximum Iterations	20	20
6	Equation Set	Diffusion Wave	Diffusion Wave
7	Initial Conditions Time (hrs)		
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9	Number of Time Slices (Integer Value)	1	1

10. **Save** the plan data.

11. Compute

4.8 SWE - Create a Plan and Simulate

- 12. Open the Unsteady Flow Analysis window
- 13. Save Plan As, to create another plan.

14. Set the Computation Options

a. Set the Equation Set to the **SWE-ELM**

	Parameter	(Default)	2DFlowArea
1	Theta (0.5-1.0)	1	1
2	Theta Warmup (0.5-1.0)	1	1
3	Water Surface Tolerance [max=0.2](ft)	0.01	0.01
4	Volume Tolerance (ft)	0.01	0.01
5	Maximum Iterations	20	20
6	Equation Set	Diffusion Wave	SWE-ELM (original/faster)
7	Initial Conditions Time (hrs)		
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9	Number of Time Slices (Integer Value)	1	1

- 15. Set the **time step** to something more appropriate for **SWE**.
- 16. **Save** the plan
- 17. Compute

4.9 Compare DW and SWE Results

18. Use the **Profile Line** for the river centerline to **Plot the WSE** and compare the results.

<u>*Question:*</u> Is there a difference between DW and SWE, why would there be a difference, and what does this tell us about the model?

<u>Question</u>: What is the change in water surface through the bridge constriction?

Question: Is the cell size adequate for modeling the terrain, bridge, piers, etc?

4.10 Refine the 2D Bridge Model

Now that we have some understanding of the model, let's start to improve the runs.

- 19. Create a copy of the initial geometry using the **Save Geometry As** option in **RAS Mapper**.
- 20. Use your knowledge of the contraction and expansion zone through the bridge to add a **Refinement Region**, using a smaller cell size (**5 ft**).
- 21. Create a new **Unsteady Flow Data** file with modified initial conditions.
 - a. Click on File | Unsteady Flow Data As and name it "Flow with WSE"
 - b. On the Initial Conditions tab, choose Prior WS Filename
 - c. Select the results file from the SWE run (*.p04.hdf)
 - d. **Choose** the last profile

Initial Flow Distribution Method			
C Restart Filename:			Ē
Prior WS Filename: C:\Temp_RAS2D_2022\4.x W - Detaile	d Bridge \De	etailedBridge.p02.hdf	Ê
	Profile:	01JAN2000 03:00:00	•

e. Save

- 22. Save the SWE to a new Plan (SWE-5ft)
- 23. Select the new Geometry.
- 24. Set an appropriate time step.
- 25. Go back to the Unsteady Flow Analysis window.
- 26. **Re-save** the Plan.
- 27. Set the **Time Window**.

Starting Date:	01jan2000	Starting Time:	0300
Ending Date:	01jan2000	Ending Time:	0315

28. Run the new plan.

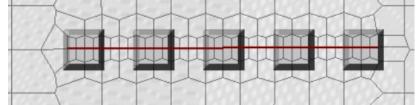
Question: How does the Refined Plan compare with the Initial SWE results?

Question: How does the Refined Plan velocity field look?

4.11 Refine Mesh Around Piers

Continue to improve the model.

- 29. Create a copy of the refined geometry using the **Save Geometry As** option in **RAS Mapper**.
- 30. Refine the area around the Piers using **breaklines** to create smaller cells. Use a cell spacing of **1 ft**.



- 31. Save As a new plan called "SWE-Piers".
- 32. Select the new **Geometry**.
- 33. Set an appropriate **time step**.
- 34. Compute.

<u>*Question:*</u> How does the Refined Pier Plan compare with other results?

<u>*Question:*</u> How else can the mesh around the piers be refined besides breaklines?

4.12 Turbulence Modeling

Add Turbulence to the model and review.

35. Save the "SWE-Piers" Plan to a new Plan called "SWE-Turbulence".

36. Turn on Turbulence Modeling.

	Parameter	(Default)	2DFlowArea
1	Theta (0.5-1.0)	1	1
2	Theta Warmup (0.5-1.0)	1	1
3	Water Surface Tolerance [max=0.2](ft)	0.02	0.02
4	Volume Tolerance (ft)	0.01	0.01
5	Maximum Iterations	20	20
6	Equation Set	Diffusion Wave	SWE-ELM (original/faster)
7	Initial Conditions Time (hrs)		
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9	Number of Time Slices (Integer Value)	1	1
10	Turbulence Model	None	Conservative
11	Longitudinal Mixing Coefficient	0.3	0.3
12	Transverse Mixing Coefficient	0.1	0.1
13	Smagorinsky Coefficient	0.05	0.05

37. Compute results.

<u>*Question:*</u> How does the Refined model with Piers and Turbulence compare with other results? Which run is the better run?