ERDC/CHL TR-10-6

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Wailupe Stream, Channel Improvement at Kalanianaole Highway, Honolulu, HI

Billy D. Fuller

August 2010

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Final report

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Abstract: A 1:25 scale model was constructed to study structural improvements to the Wailupe Stream drainage basin. This drainage basin is located approximately eight miles southeast of Honolulu, HI. Structural features that were evaluated include the concrete lining of the stream and modification of the Kalanianaole Highway Bridge (KHB).

Concrete lining near the KHB and KHB modification was designed to allow stream flow to pass under the existing bridge without overtopping. This required raising the upstream channel walls (flood walls) and adding a parapet wall on the upstream side of the bridge. During large flow events, the channel beneath the bridge will act as a conduit with pressurized flow passing beneath the bridge deck. Measured piezometric pressures and current velocities will be used to determine hydraulic loadings for design of a bridge deck restraint system.

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Preface

The model investigation reported herein was performed for the U.S. Army Engineer District, Honolulu (POH). The study was authorized by POH in September 2005. The study was directed by Steven Yamamoto and James Pennaz, from Honolulu District, and Rene Vermeeren from the Los Angeles District.

Model experiments were performed by personnel of the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC) under the general supervision of Dr. William D. Martin, Director, CHL; Jose E. Sanchez, Deputy Director, CHL; Dr. Rose Kress, Chief, Navigation Division, CHL; Dr. Jacqueline Pettway, Chief, Harbors, Entrances and Structures Branch, CHL; and Elizabeth Burg, Acting Technical Director, CHL. The experimental program was led by Billy D. Fuller. Model tests were performed by Messrs. Thomas E. Murphy and Larry R. Tolliver.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	0.0254	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
pounds (force) per square inch	6.894757	kilopascals

1 Introduction

The Prototype

The Wailupe Stream Flood Damage Reduction Project is currently investigating potential structural and non-structural improvements for the 3.12 square mile Wailupe Stream drainage basin. The drainage basin is located approximately eight miles southeast of Honolulu, HI. An aerial photograph of the project location is shown in Figure 1. Structural features that are being evaluated include concrete lining of the stream, modification of the Kalanianaole Highway Bridge (KHB), and upstream debris basins. Concrete lining near the KHB and KHB modification will be designed to allow high flow to pass under the bridge without overtopping. Real estate restrictions prohibit raising the bridge and, its close proximity to the Pacific Ocean prevents lowering the channel invert. Therefore, structural design alternatives will be focused on containing large flood events and allowing safe passage of flow beneath the bridge. This will require raising the upstream channel walls (flood walls) and adding a parapet wall on the upstream side of the bridge to contain flow and to prevent overtopping.

The Purpose of the Model Study

The proposed channel alignment near the bridge and the skewed bridge opening (Figure 2) will create substantial head losses and force a hydraulic jump some distance upstream of the bridge. These losses and resulting hydraulic jump location and flow depth can not be determined accurately without the use of a physical model.

The purpose of this model study is to determine the flood wall height and upstream extent necessary to contain subcritical flow during high flow events. Another study purpose is to determine an efficient parapet wall design that will contain large flows and minimize further head loss at the bridge area.

During large flow events, the channel beneath the bridge will act as conduits with pressurized flow passing beneath the bridge deck. Bridge decks are not designed to resist upward or horizontal forces. District engineers will need loading information resulting from horizontal forces acting on the parapet wall and uplift forces resulting from pressurized flow beneath the deck. Piezometric pressures and current velocities, from the model study, will be used to determine the hydraulic loadings that will be used to design a bridge deck restraint system.

Figure 1. Arial photograph of modeled portion of Wailupe Stream .

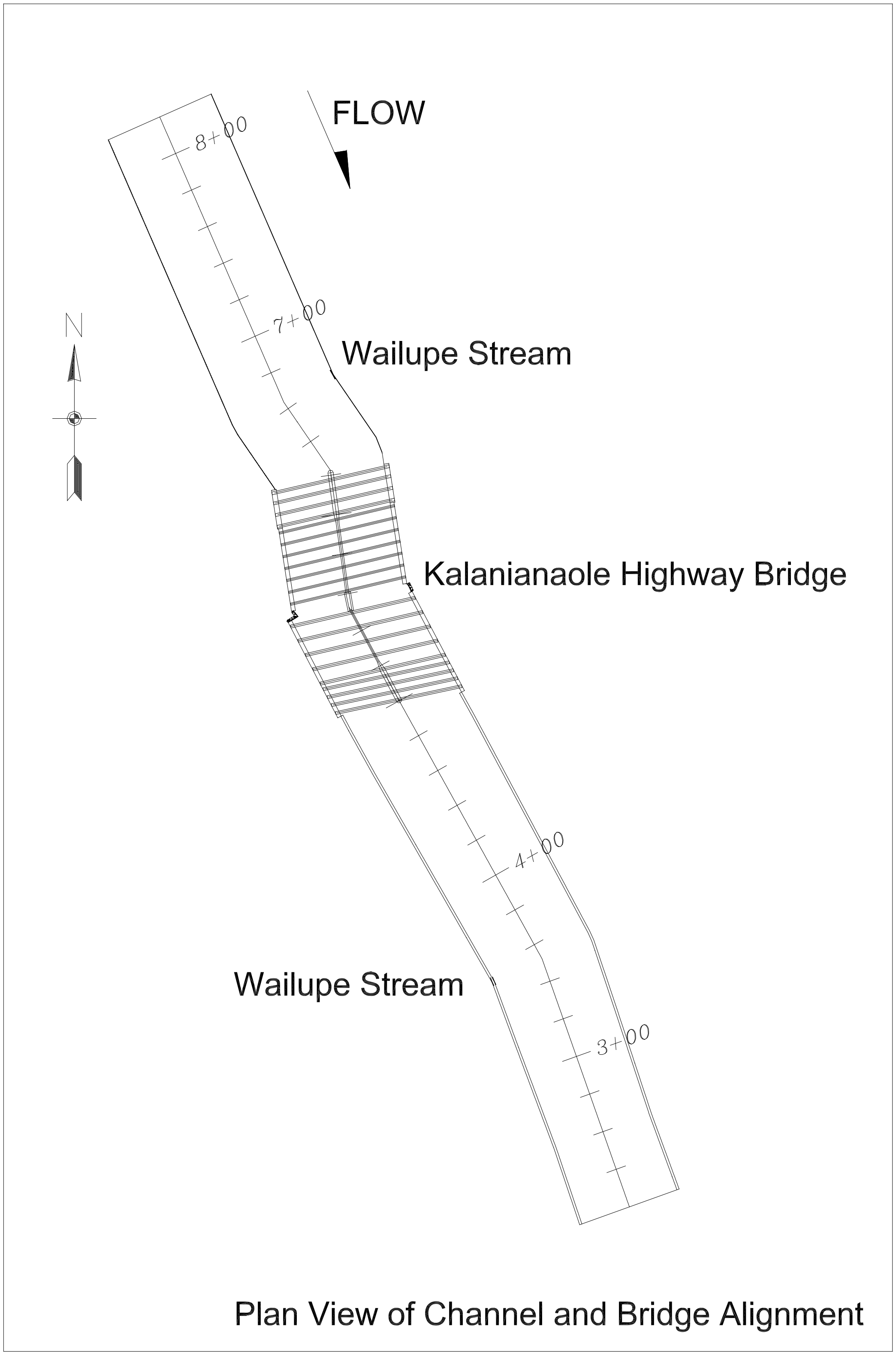

Figure 2. Plan view of channel and bridge alignment.

2 The Model

Description

A 1:25 scale model was constructed that reproduces 2400-ft of the lined Wailupe Stream channel and the modified Kalanianaole Highway Bridge (Figures 1 and 3). The water supply system was designed to provide a maximum discharge of 9,000 cfs prototype through the channel. The water supply system is capable of reproducing the target flows listed in Table 1.

The upstream portion of the channel (Station 24+00 to Station 14+00) transitions from a trapezoidal cross-section to a rectangular cross-section. Typical channel cross-sections are shown in Figure 3. The channel's rectangular cross-section continues downstream to its confluence with the Pacific Ocean. The model channel was constructed of marine grade plywood. A Mannings n-value of 0.016 is represented. The model bridge was constructed using acrylic plastic. The model channel and bridge are shown in Photographs 1 - 4.

Water used for the operation of the model was supplied by a constant head tank. Discharges were measured with volumetrically calibrated paddle wheel flow meters. Velocities were measured with a propeller type velocity probe. Water-surface elevations were measured with a point gage and stilling well system.

Similitude

Similitude between model and prototype units and dimensions is required for accurate transfer of model data to prototype quantities. Dimensional analysis indicates the dominant forces in a free-surface flow are inertial and gravitational. Similitude requires that the ratio of these two forces be equal in the model and prototype. This is referred to as Froudian similitude, where the Froude number in the model is equal to the Froude number in the prototype for a given flow condition.

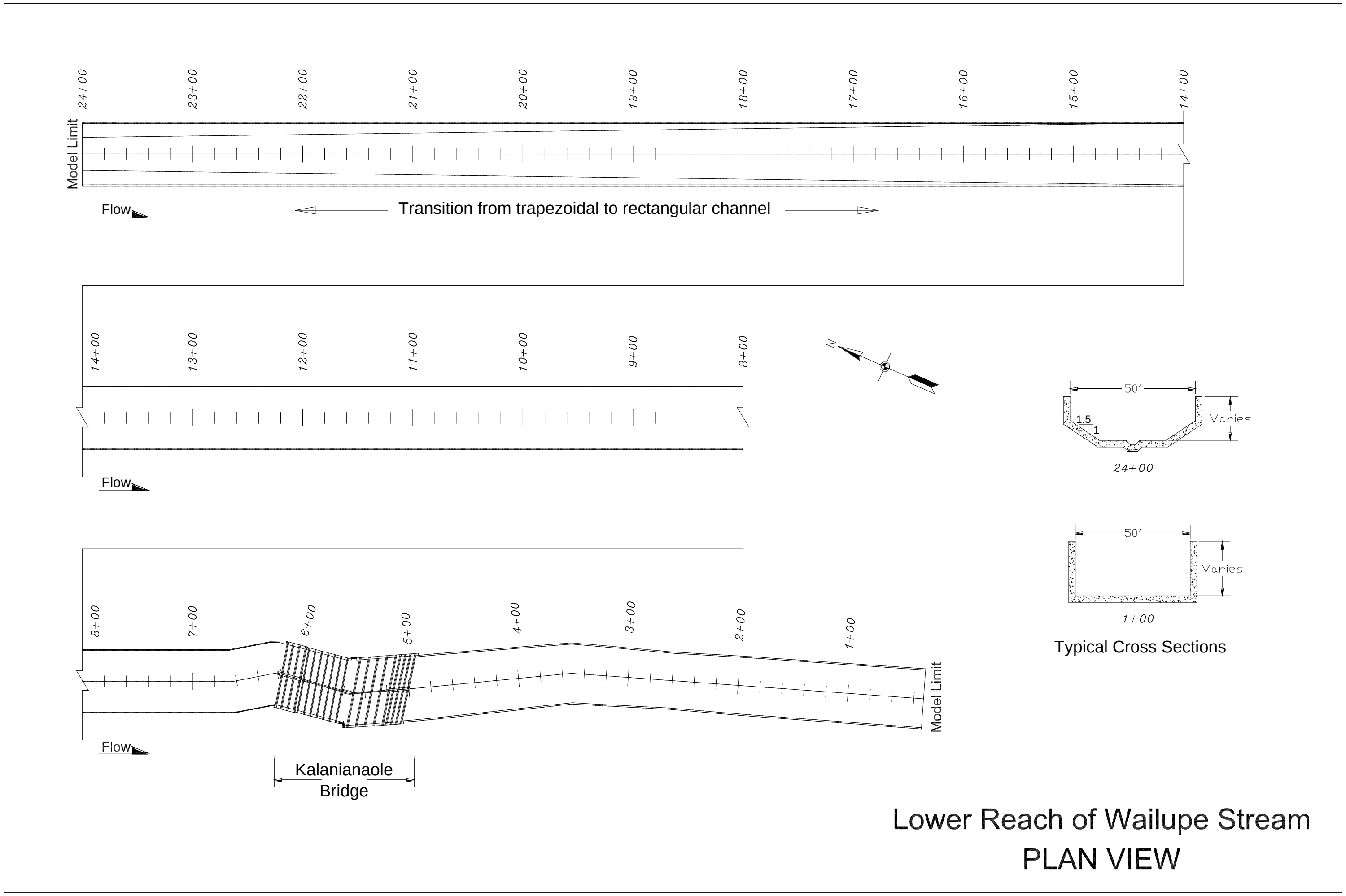

Figure 3. Model layout.

Table 1. Modeled flow conditions

Flow Condition	Discharge, cfs
50-year event	4395
100-year event	5505
200-year event	6770
500-year event	8695

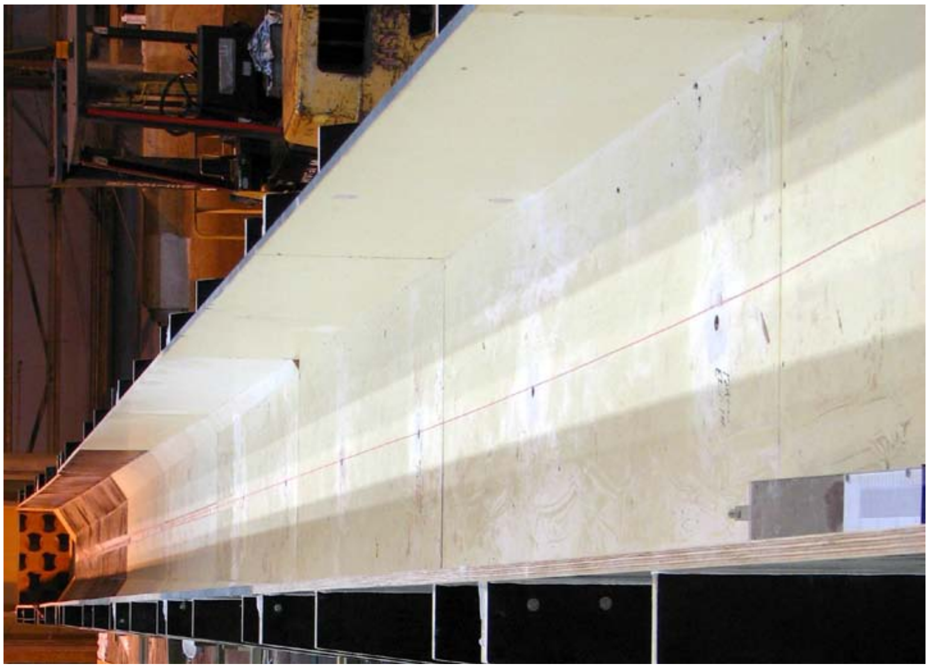

Photo 1. Channel looking upstream.

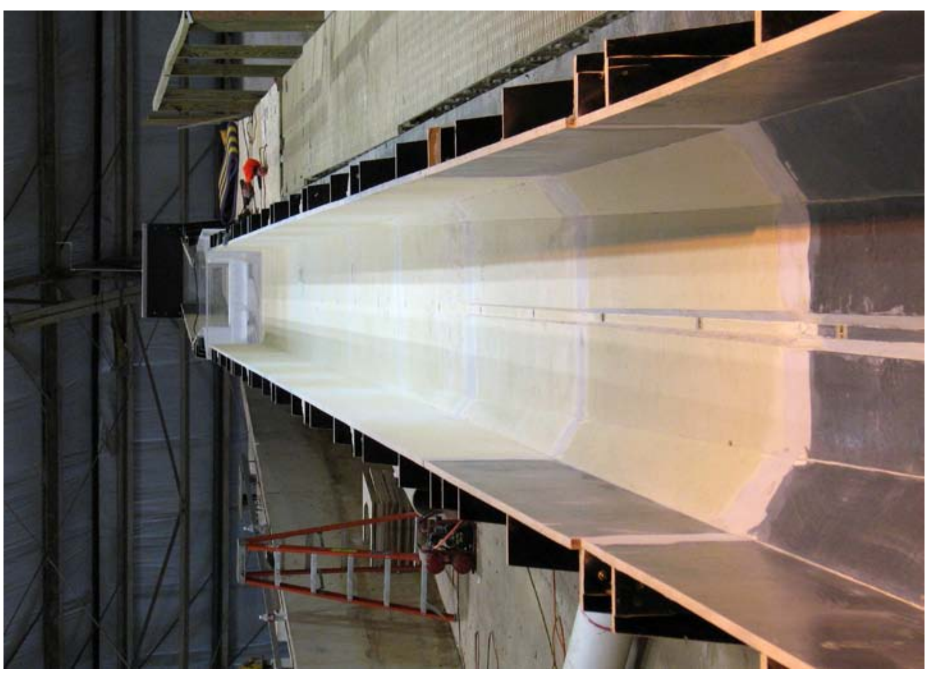

Photo 2. Channel looking downstream.

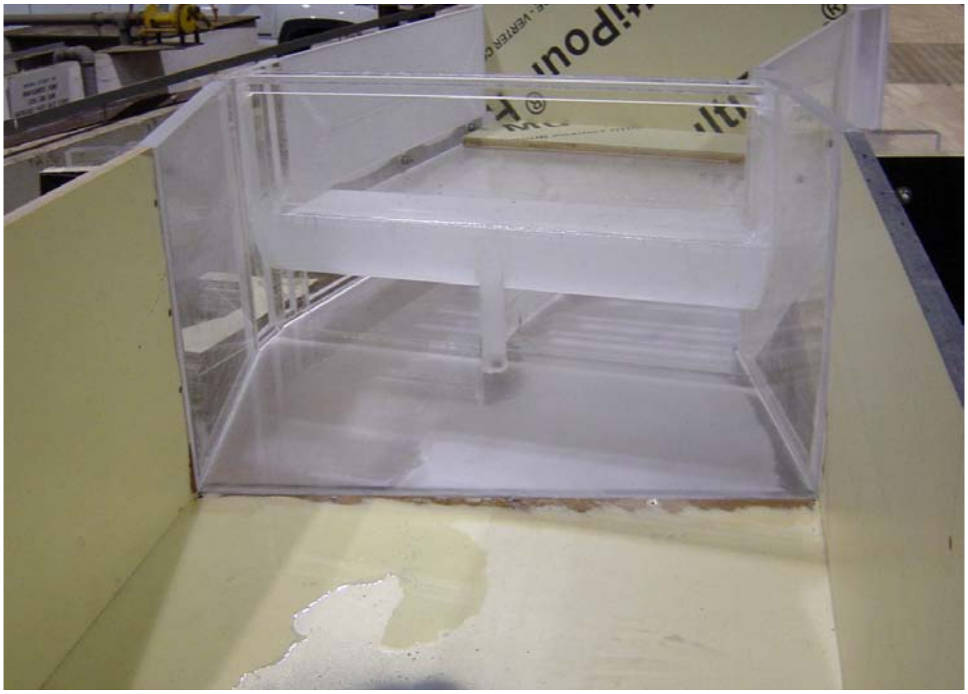

Photo 3. Bridge looking downstream.

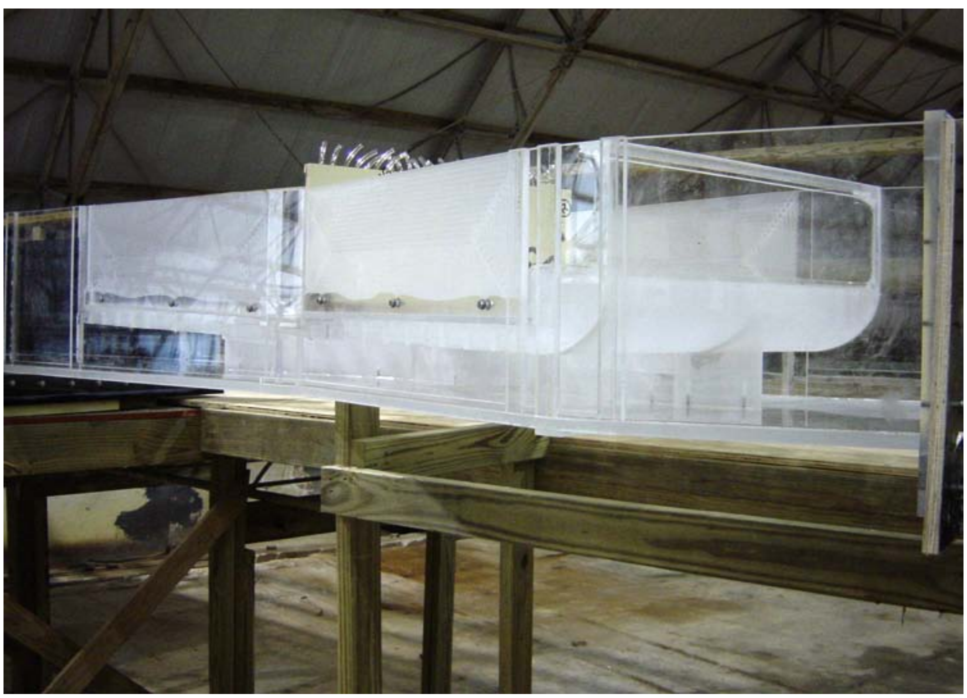

Photo 4. Bridge side view.

Similitude also requires the Reynolds number in the model be equal to the Reynolds number in the prototype. That is, the ratio of inertial forces to viscous forces be equal for a given flow condition. However, it is impossible to simultaneously meet Froudian and Reynolds criteria in a scaled model.

The solution is to scale a model such that, for the flow conditions to be investigated, the Reynolds number in the model is greater than 5000. At Reynolds numbers of 5000 or greater, scale effects associated with viscosity are negligible. By using a scale at which viscous effects are negligible, Froudian criteria can be used to develop scale relationships.

The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. The general relations expressed in terms of the model's scale or length ratio, L_r, are expressed in the tabulation below:

Table 2. Scale relations

Dimension	Ratio	Scale Relation
Length	L_r	1:25
Area	$A_r = L_r^{2}$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3125
Time	$T_r = L_r^{1/2}$	1:5

Measurements of each of the dimensions or variables can be transferred quantitatively from model to prototype equivalents by means of the above scale relations. All model data are presented in terms of prototype equivalents.

3 Experiment

Type 1 Parapet Wall Design

Description

The Type 1 parapet wall design utilizes a simple, 10-ft radius design to prevent flood flow from overtopping the bridge and to provide a smooth transition of free-surface flow to pressurized flow beneath the bridge. The radiused parapet wall and pier nose is extended upstream a distance of 10-ft. A cross-sectional drawing of this design is shown in Figure 4.

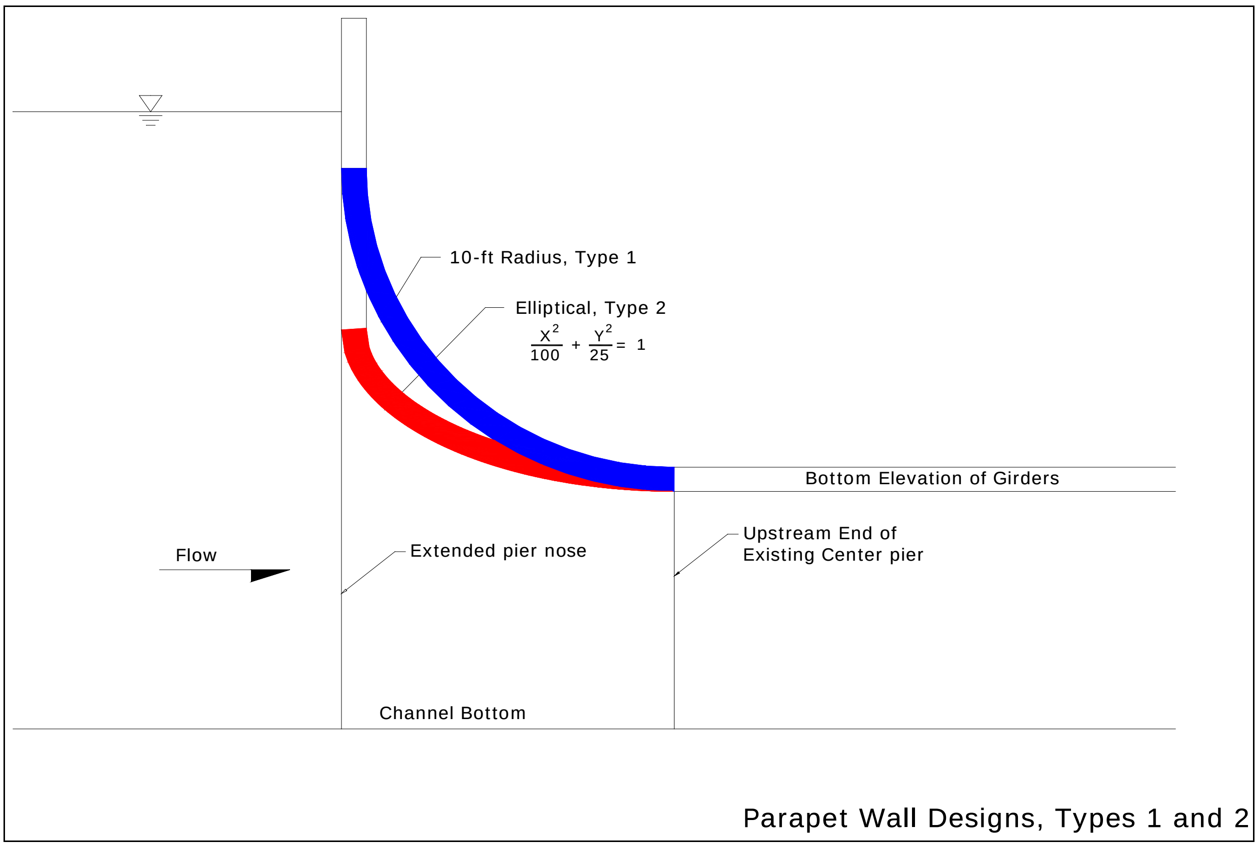

Figure 4. Parapet wall designs.

Data Collection

A sensitivity study was performed to determine the impact of a hurricane or tidal surge event occurring during a flood event. The sensitivity testing was performed by incrementally increasing the tide and noting its influence on the water surface elevation and hydraulic jump location upstream of the bridge. The normal high tide is 2.5[1]. A change in upstream hydraulic conditions was not apparent below a tide elevation of 10.25. Thus, the flow characteristics upstream of the bridge were controlled at the bridge and unaffected by normal ocean tide.

Water-surface profiles were measured along the channel centerline to determine the flood wall height and length necessary to contain flood flows for this parapet design. Measurements were also collected with simulated debris on the pier nose. Accumulated debris was represented with a section of rubberized fiber (routinely used for modeling debris) that extended fully into the water column and represented an accumulation of debris that protruded 2-feet on each side of the pier (Photograph 5). Table 3 tabulates the water-surface profiles for the 50-yr, 100-yr, 200-yr and 500-yr events. (The 50-year event was added to testing for the Type 1 design only). Water-surface elevations are presented graphically in Figures 5 and 6.

Determining the location of the hydraulic jump for each flow condition is necessary for determining the required extent of the flood wall. The documented jump location is shown graphically in Figure 7.

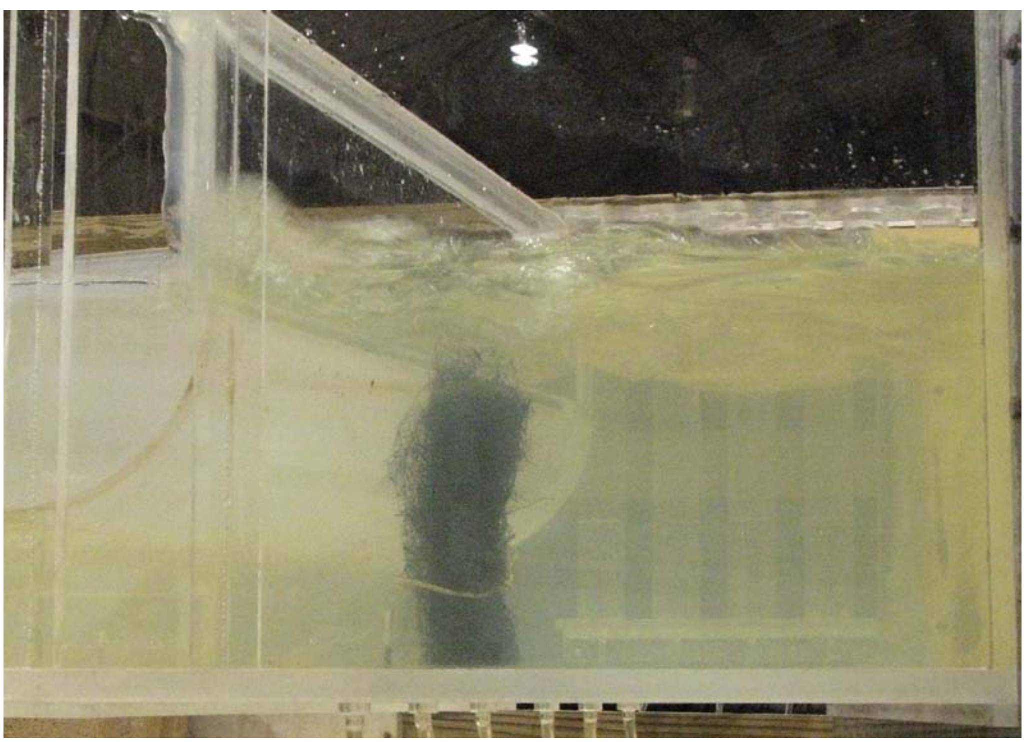

Photo 5. Debris on pier nose.

[1] Unless stated otherwise, all elevations (el) cited herein are in feet as referenced to Mean Sea Level (MSL). To convert feet to meters, multiply by 0.3048.

Table 3. Type 1 parapet design, water-surface elevations, ft MSL

<table>
<tr><th rowspan="2">Station</th><th>50-year event</th><th colspan="2">100-year event</th><th colspan="2">200-year event</th><th colspan="2">500-year event</th></tr>
<tr><th>no debris</th><th>no debris</th><th>with debris*</th><th>no debris</th><th>with debris</th><th>no debris</th><th>with debris</th></tr>
<tr><td>1+00</td><td>0.4</td><td>1.3</td><td>1.2</td><td>2.2</td><td>2.7</td><td>3.2</td><td>3.7</td></tr>
<tr><td>2+00</td><td>1.8</td><td>2.0</td><td>1.5</td><td>3.2</td><td>3.3</td><td>4.8</td><td>4.7</td></tr>
<tr><td>3+00</td><td>3.3</td><td>2.6</td><td>3.1</td><td>3.6</td><td>3.7</td><td>5.1</td><td>5.1</td></tr>
<tr><td>4+00</td><td>4.6</td><td>5.1</td><td>5.8</td><td>6.5</td><td>6.4</td><td>7.9</td><td>8.1</td></tr>
<tr><td>5+00</td><td colspan="7">Bridge</td></tr>
<tr><td>6+00</td><td colspan="7">Bridge</td></tr>
<tr><td>7+00</td><td>6.5</td><td>8.4</td><td>9.2</td><td>11.6</td><td>11.5</td><td>16.3</td><td>16.5</td></tr>
<tr><td>8+00</td><td>4.6</td><td>7.9</td><td>8.4</td><td>11.3</td><td>11.2</td><td>16.1</td><td>16.4</td></tr>
<tr><td>9+00</td><td>2.9</td><td>3.2</td><td>8.0</td><td>10.6</td><td>10.2</td><td>16.0</td><td>16.4</td></tr>
<tr><td>10+00</td><td>3.6</td><td>4.0</td><td>4.3</td><td>9.7</td><td>9.9</td><td>15.8</td><td>16.1</td></tr>
<tr><td>11+00</td><td>4.6</td><td>4.4</td><td rowspan="11">unaffected by debris</td><td>5.8</td><td>5.6</td><td>15.0</td><td>16.1</td></tr>
<tr><td>12+00</td><td>4.9</td><td>5.0</td><td>5.7</td><td rowspan="10">unaffected by debris</td><td>14.3</td><td>15.2</td></tr>
<tr><td>13+00</td><td>5.7</td><td>5.8</td><td>6.9</td><td>6.9</td><td>8.5</td></tr>
<tr><td>14+00</td><td>6.8</td><td>6.7</td><td>7.6</td><td>8.1</td><td>8.6</td></tr>
<tr><td>15+00</td><td>7.0</td><td>7.0</td><td>8.2</td><td>8.6</td><td rowspan="7">unaffected by debris</td></tr>
<tr><td>16+00</td><td>7.5</td><td>7.8</td><td>8.7</td><td>8.5</td></tr>
<tr><td>17+00</td><td>8.4</td><td>8.0</td><td>9.6</td><td>8.9</td></tr>
<tr><td>18+00</td><td>9.0</td><td>8.4</td><td>10.0</td><td>10.2</td></tr>
<tr><td>19+00</td><td>9.9</td><td>9.6</td><td>10.2</td><td>12.3</td></tr>
<tr><td>20+00</td><td>10.9</td><td>11.5</td><td>11.4</td><td>13.7</td></tr>
<tr><td>21+00</td><td>11.9</td><td>12.4</td><td>13.2</td><td>13.4</td></tr>
<tr><td colspan="8">* See Appendix A</td></tr>
</table>

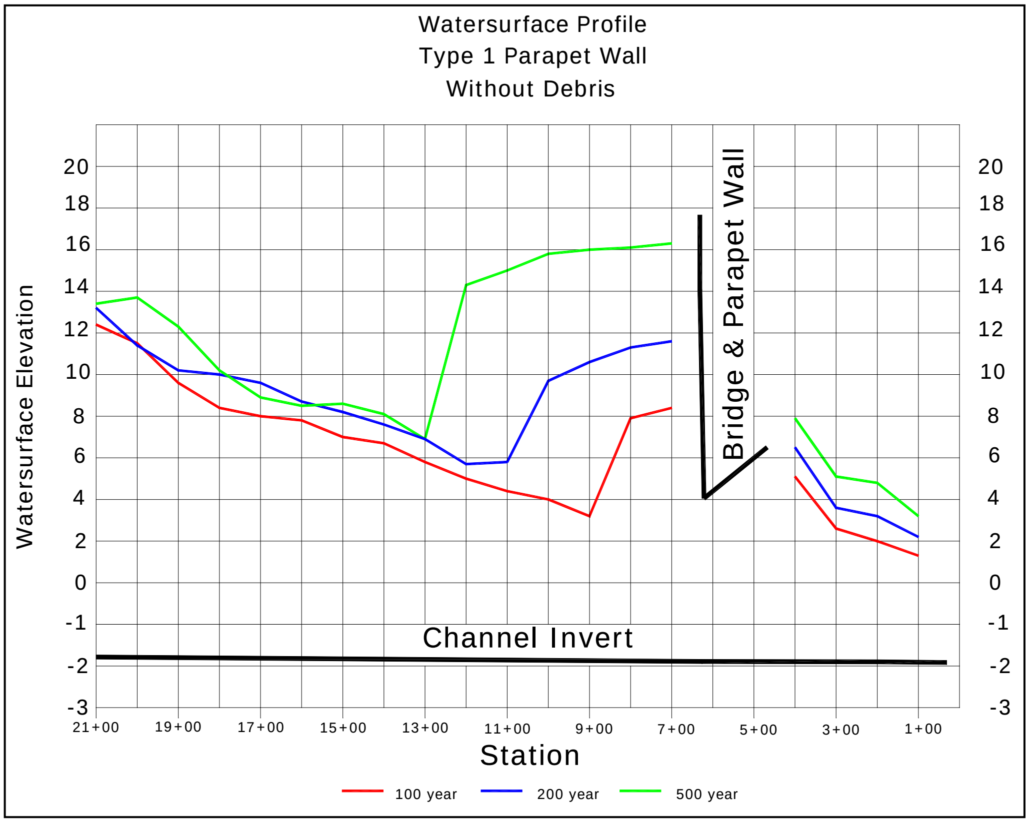

Figure 5. Water-surface profile for type 1 design without debris on pier nose.

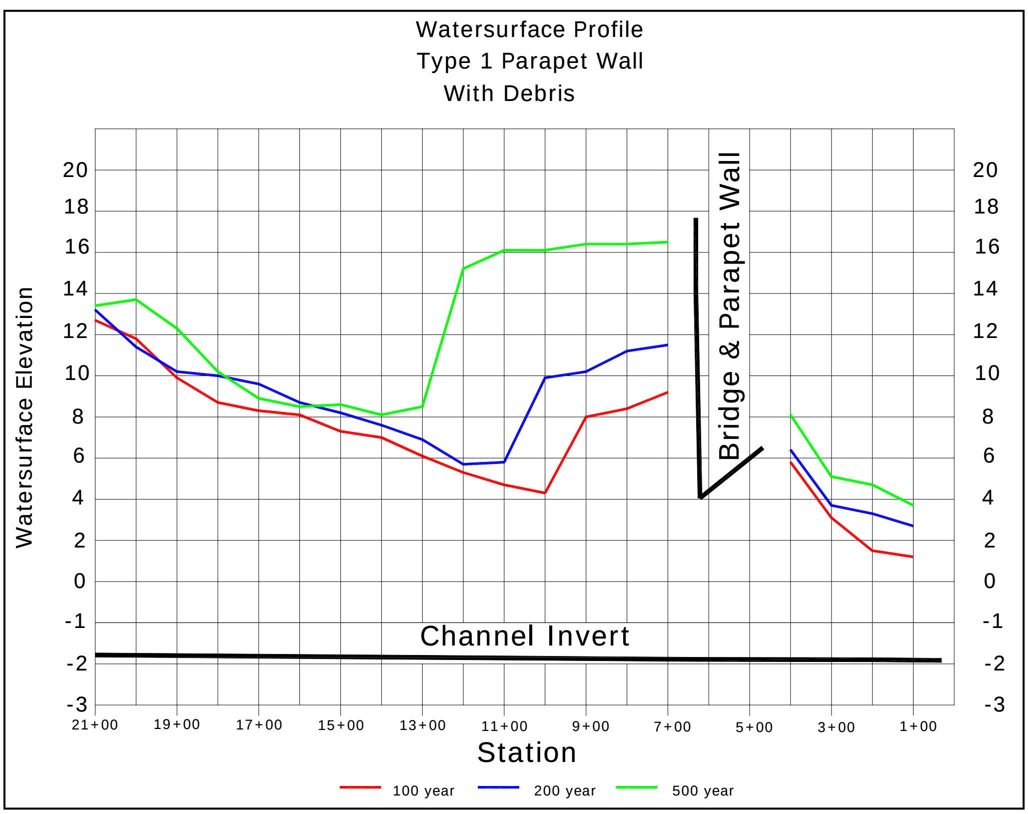

Figure 6. Water-surface profile for type 1 design with debris on pier nose.

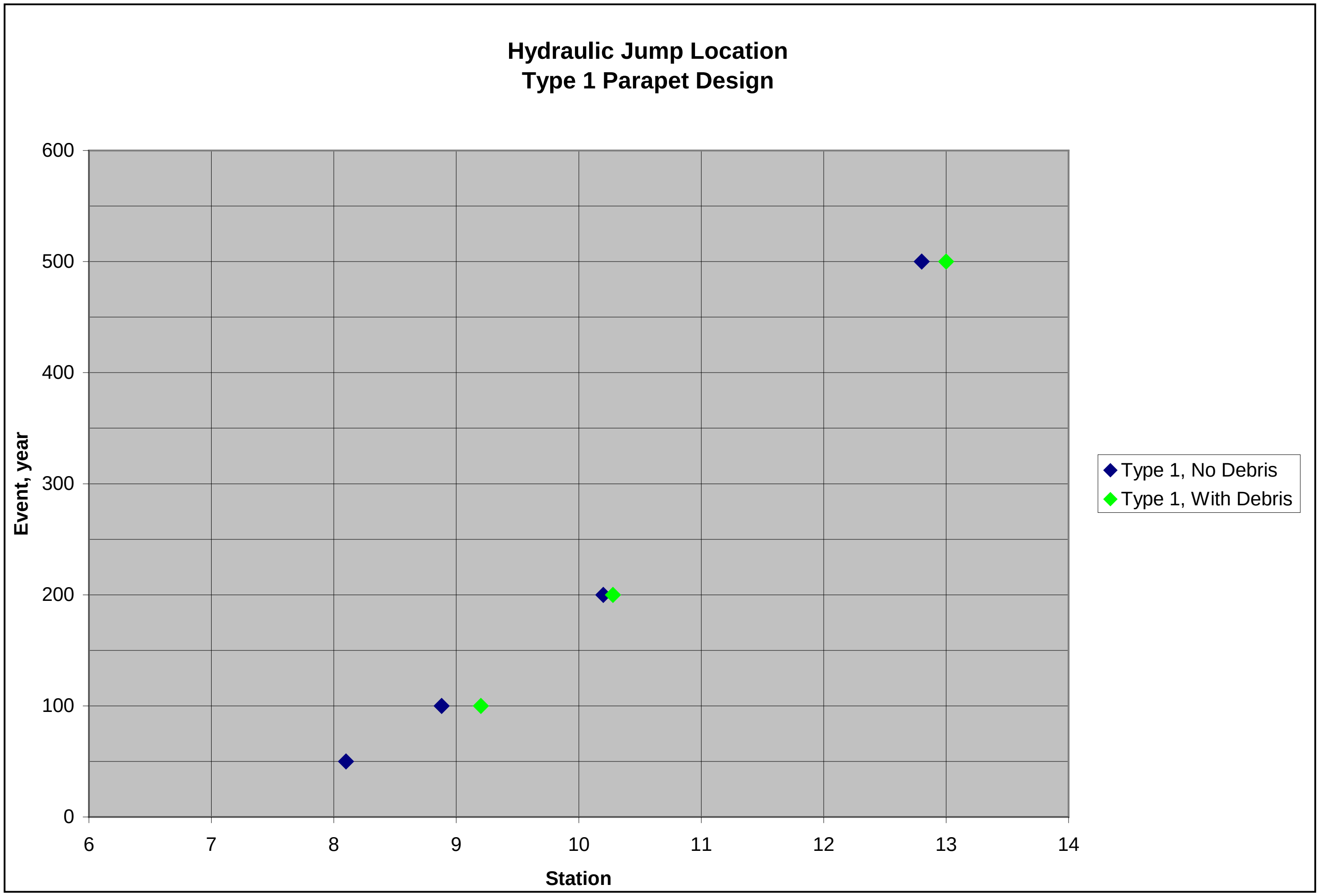

Figure 7. Hydraulic jump locations for Type 1 parapet wall.

Due to the skewed alignment at the upstream edge of the bridge, the water-surface elevations measured at the channel centerline near the parapet wall may not be representative of the cross channel water-surface profile. The water-surface will likely have some inclination toward the left bank as the flow turns to enter beneath the bridge. Cross channel measurements were made to document the water-surface inclination at the parapet wall. This data is shown in Tables 4 and 5 as water-surface elevation and depth of flow respectively. The elevations are presented left to right looking downstream (see Figure 8).

Piezometric pressures were measured on the bridge deck. The taps were located on the bridge deck (Figure 9) near the upstream face of the girders. The tabulated pressure data is presented below in Tables 6 through 8. Piezometer readings are in feet and referenced to the bottom of the bridge deck (0.0' at bottom of deck).

Table 4. Type 1, cross-channel water-surface elevation just upstream of bridge, ft MSL

	50-year event	100-year event		200-year event		500-year event	
Location	no debris	no debris	with debris	no debris	with debris	no debris	with debris
1	6.5	8.6	9.0	11.3	11.1	15.5	15.4
2	6.3	8.5	8.9	11.2	11.0	15.5	15.6
3	6.4	8.6	8.9	11.4	11.3	15.9	15.7
4	6.5	8.9	9.4	11.4	11.3	15.8	15.8
5	6.3	8.9	9.3	11.3	11.2	16.0	15.8
6	6.6	8.6	9.3	11.2	11.5	16.1	16.1

Table 5. Type 1, cross-channel depth, in feet, just upstream of bridge

	50-year event	100-year event		200-year event		500-year event	
Location	no debris	no debris	with debris	no debris	with debris	no debris	with debris
1	9.5	11.6	12.0	14.3	14.1	18.5	18.4
2	9.3	11.5	11.9	14.2	14.0	18.5	18.6
3	9.4	11.6	11.9	14.4	14.3	18.9	18.7
4	9.5	11.9	12.4	14.4	14.3	18.8	18.8
5	9.3	11.9	12.3	14.3	14.2	19.0	18.8
6	9.6	11.6	12.3	14.2	14.5	19.1	19.1

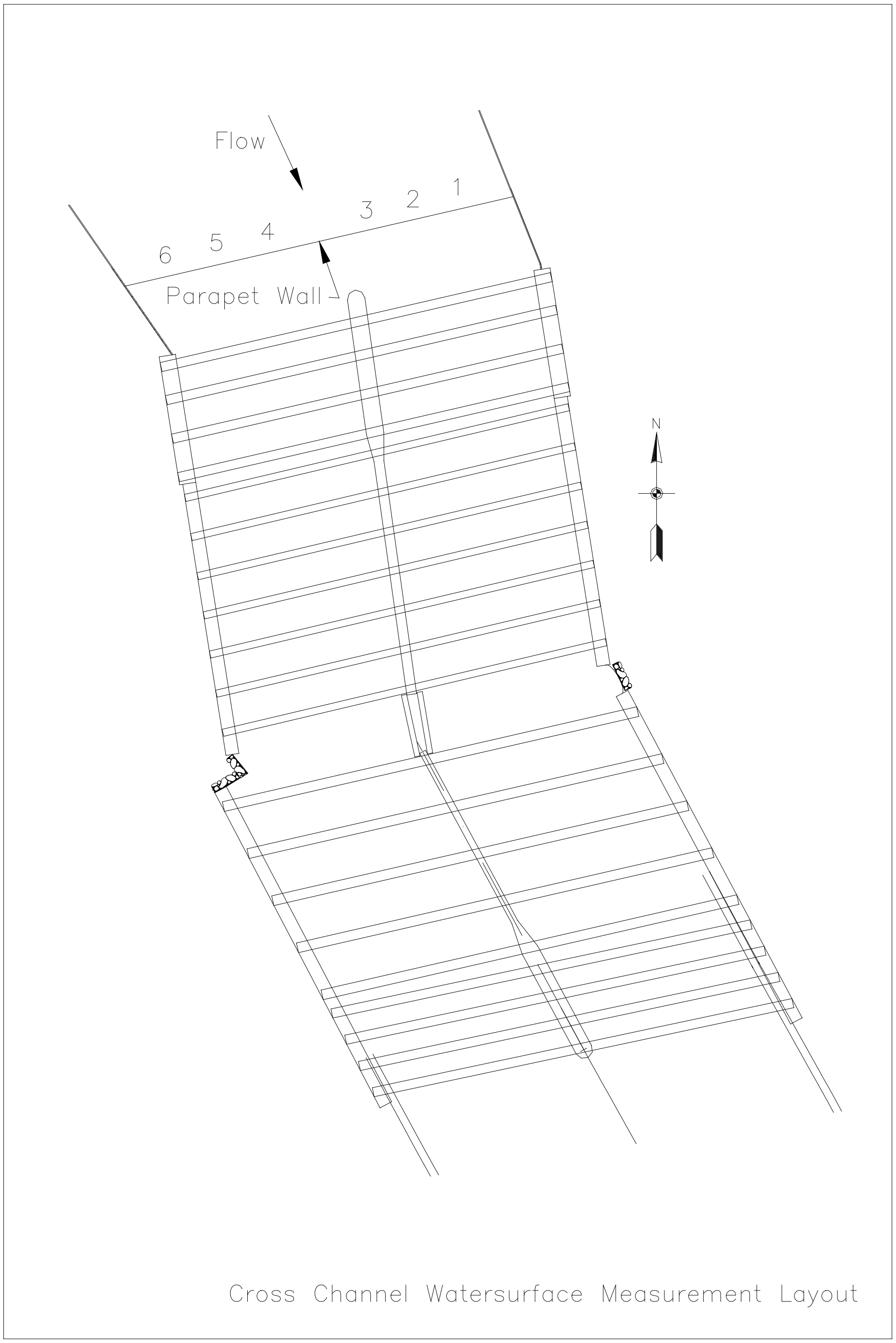

Figure 8. Cross channel water-surface measurement locations.

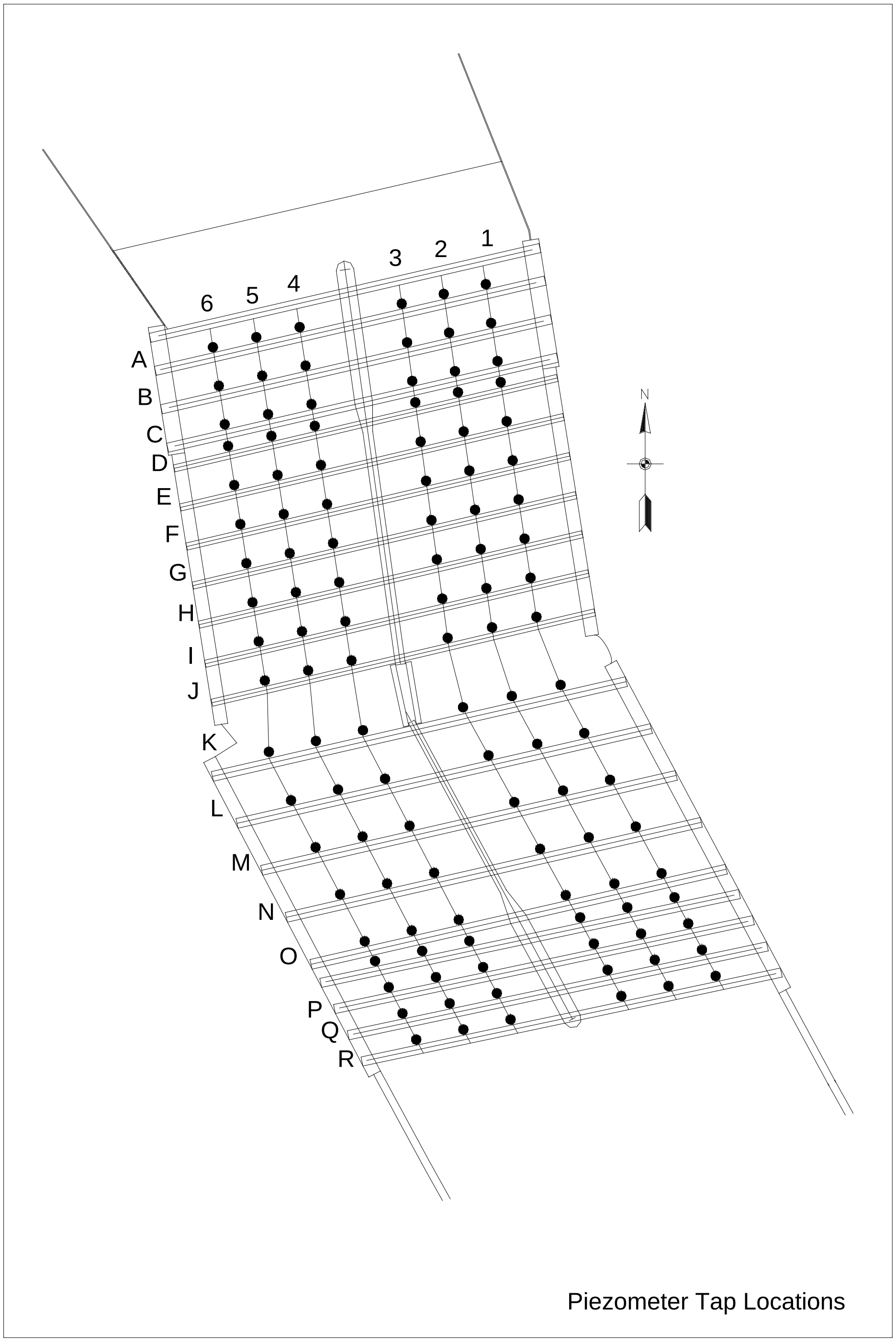

Figure 9. Piezometer tap locations.

Table 6. Piezometric pressures under bridge for type 1 parapet design, ft

100-year event						
Location	1	2	3	4	5	6
A	*					
B						
C					1.0	
D						
E						
F	1.5	1.5				
G	1.5	1.5				
H	2.0	2.3				
I	1.0	1.0		1.0	1.5	1.0
J					1.5	
K						
L		1.0	1.5			
M			1.0			
N						
O						
P						
Q						
R						
* Cells with no data are aerated locations with atmospheric or “zero” pressure.						

Table 7. Piezometric pressures under bridge for type 1 parapet design, ft

200-year event						
Location	1	2	3	4	5	6
A	1.0	1.0		2.0	2.0	
B	1.5			3.0	3.0	3.0
C	1.5			2.7	1.5	1.0
D				2.5	1.5	1.0
E		1.0		2.0	1.5	
F	1.5	1.5		1.0	1.0	
G	1.0	1.5		1.5	1.5	1.0
H	2.0	2.0		2.5	1.0	1.0
I	2.0	2.0			2.0	1.5
J	2.0	2.0	1.5	1.5	1.0	
K			2.0		2.5	
L	2.0	2.0	3.1			1.5
M		1.5	3.3			1.5
N			2.0			2.0
O						
P						
Q						
R						

Table 8. Piezometric pressures under bridge for type 1 parapet design, ft

500-year event						
Location	1	2	3	4	5	6
A	3.7	3.6	1.0	5.8	3.8	2.0
B	3.5	2.5	1.0	5.7	4.3	3.1
C	2.2	2.5	2.0	5.8	3.7	2.5
D	1.5	1.0		3.7	3.7	2.8
E	3.0	2.5		4.5	3.4	2.5
F	1.5	3.0		3.5	2.8	2.2
G	2.5	2.5	1.0	4.0	2.8	2.5
H	2.5	2.2	2.0	4.0	2.5	3.2
I	2.0	2.0	1.0	3.5	3.0	2.7
J	1.0	1.5	1.5	2.8	2.5	2.5
K	2.0	2.0	5.0		2.5	2.5
L	3.0	2.5	7.1		2.0	2.5
M	2.5	2.5	7.5		1.5	5.0
N	2.0	2.0	6.7			4.5
O	2.5	2.5	3.6			1.5
P	1.5	2.0	2.5			
Q						
R						

Velocity data was collected just upstream and under the bridge. This data will be used by design engineers to determine the dynamic loadings on the parapet wall and bridge deck. The velocity information upstream of the bridge was collected in 1.5-ft depth intervals beginning at 1.5ft above the channel bottom. Velocity data beneath the bridge were collected at mid-depth, along the centerline of the left and right conduits. The measurement locations are shown in Figure 10. Velocity data are presented in Table 9.

A range of current velocities were measured at location 10 to define a typical velocity distribution underneath the bridge. This profile is typical of locations under the bridge. The velocity data are listed in Table 10 and shown graphical in Figure 11.

Type 2 Parapet Wall Design

Description

The Type 2 parapet wall design utilizes the same 10-ft offset distance as the Type 1 design, but the simple radius is changed to an elliptical shape. A cross-sectional drawing of this design is shown in Figure 4.

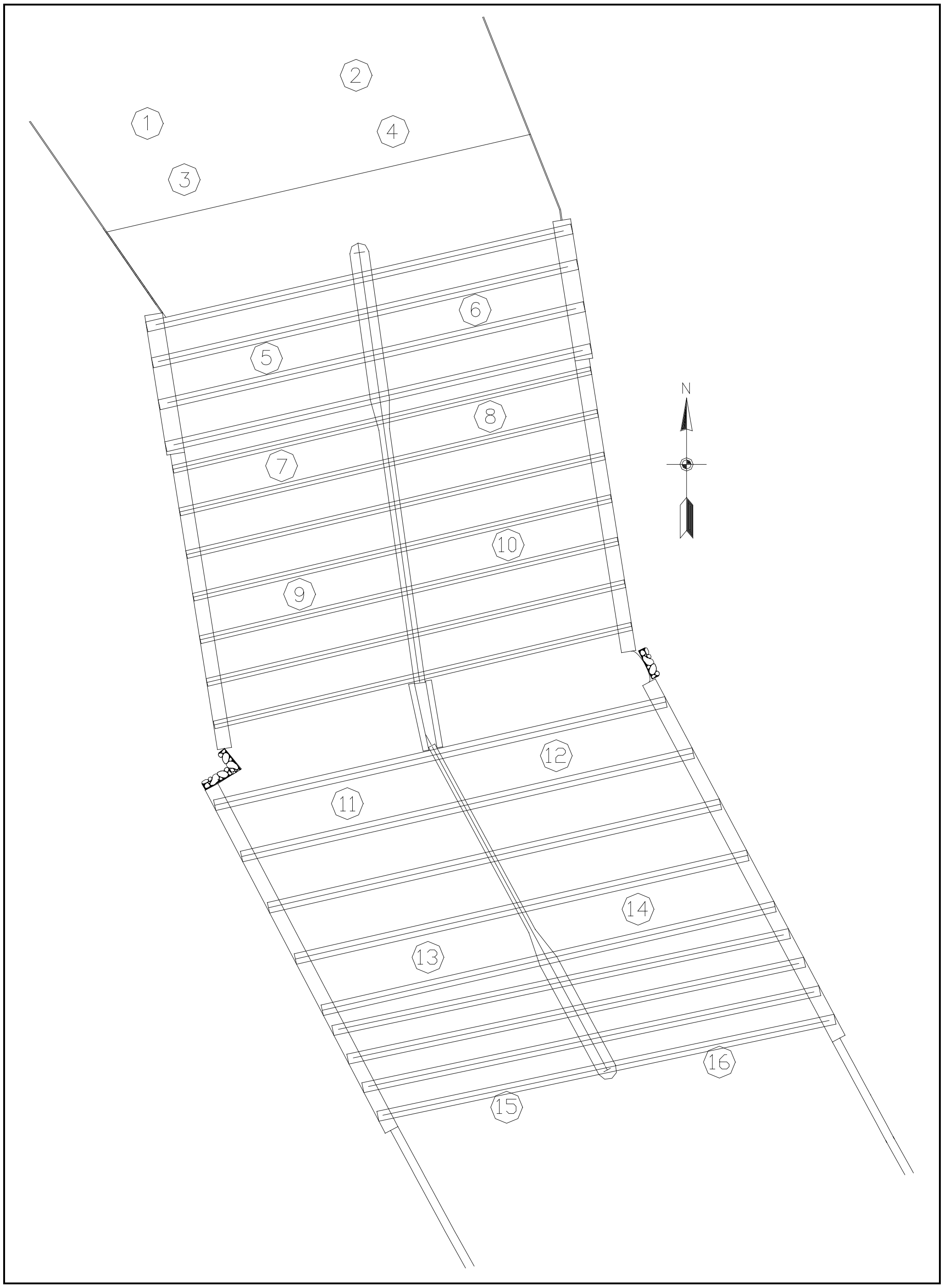

Figure 10. Velocity measurement locations.

Table 9. Type 1 design, channel velocities, fps

Location	Dist from Channel Bottom, ft	100-year event	200-year event	500-year event
1	1.5	6.6	6.1	5.7
	4.0	8.2	7.0	7.2
	6.5	9.3	7.5	7.5
	9.0	11.4	7.6	7.5
	11.5	above water-surface	9.0	7.8
	14.0	above water-surface	above water-surface	7.9
2	1.5	5.9	9.5	7.5
	4.0	7.4	9.6	8.5
	6.5	8.4	9.6	8.8
	9.0	9.8	9.8	9.0
	11.5	above water-surface	9.6	9.3
	14.0	above water-surface	above water-surface	9.4
3	1.5	6.1	12.4	6.7
	4.0	8.2	11.1	7.8
	6.5	9.1	10.6	8.2
	9.0	9.4	10.2	8.1
	11.5	above water-surface	9.8	8.2
	14.0	above water-surface	above water-surface	8.0
4	1.5	6.4	12.1	8.3
	4.0	7.5	10.6	9.1
	6.5	8.4	10.9	9.1
	9.0	9.8	10.6	8.9
	11.5	above water-surface	10.0	8.7
	14.0	above water-surface	above water-surface	8.4
5	mid-depth	15.6	17.5	23.2
6	mid-depth	15.4	18.8	23.4
7	mid-depth	15.7	18.1	22.4
8	mid-depth	16.0	18.7	24.7
9	mid-depth	16.3	19.2	23.8
10	mid-depth	16.3	19.8	25.2
11	mid-depth	17.0	19.6	25.5
12	mid-depth	7.4	19.4	24.5
13	mid-depth	9.9	18.0	18.6
14	mid-depth	14.4	18.3	21.8
15	mid-depth	16.2	18.2	14.3
16	mid-depth	14.4	17.8	18.8

Table 10. Velocity profile data

Location	Distance From Channel Bottom, ft	Proto Vel, fps
10	1.3	25
	2.5	25
	3.8	25
	5.0	25
	6.3	23
	7.0	20
	7.6	15
	8.3	8

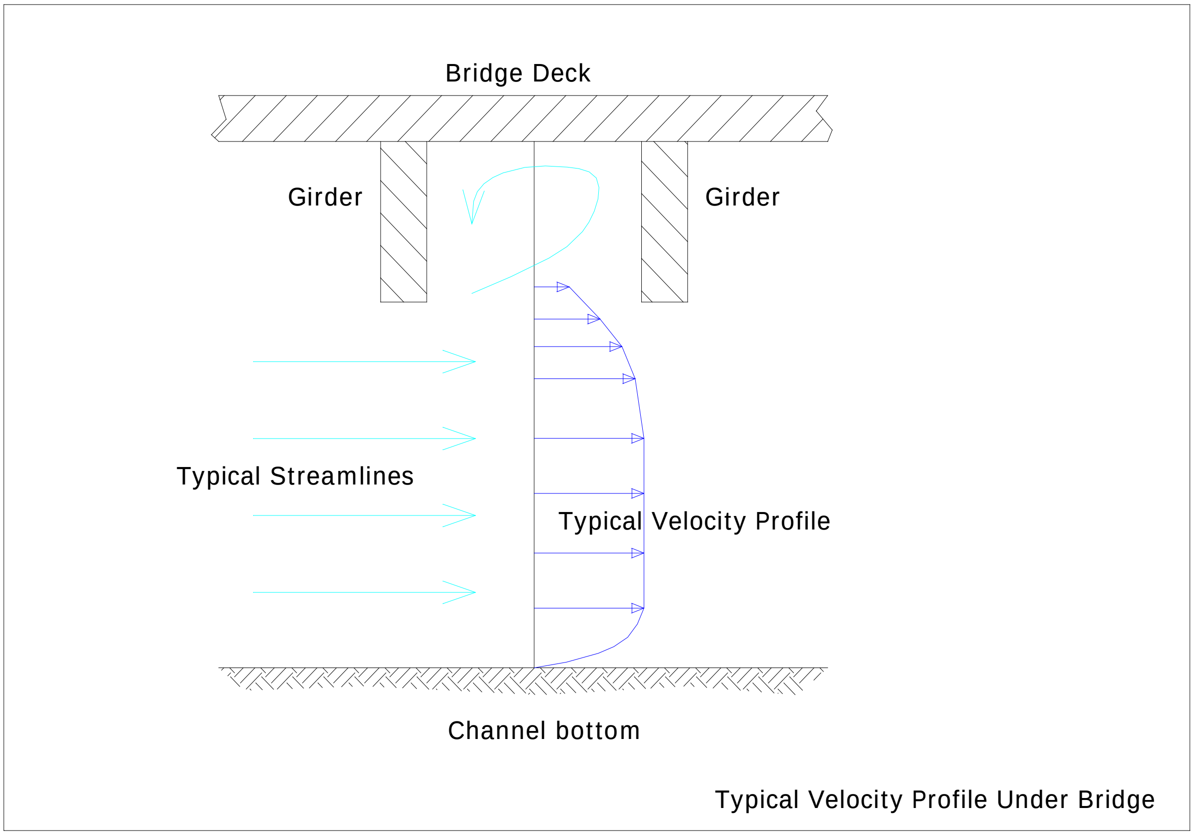

Figure 11. Typical velocity profile under bridge.

Data Collection

Similarly to the Type 1 data collection, water-surface profiles were measured along the channel centerline to determine the flood wall height and length necessary to contain flood flow for the Type 2 design. Measurements were also collected with and without simulated debris on the pier nose. Table 11 tabulates the water-surface profiles for the 100-yr, 200-yr and 500-yr events. Water-surface elevations are presented graphically in Figures 12 and 13.

Resulting hydraulic jump locations for the Type 2 design are shown graphically in Figure 14.

Table 11. Type 2 parapet design, water-surface elevations, ft MSL

<table>
<tr><th rowspan="2">Station</th><th colspan="2">100-year event</th><th colspan="2">200-year event</th><th colspan="2">500-year event</th></tr>
<tr><th>no debris</th><th>with debris</th><th>no debris</th><th>with debris</th><th>no debris</th><th>with debris</th></tr>
<tr><td>1+00</td><td>1.3</td><td>1.2</td><td>2.3</td><td>2.7</td><td>3.9</td><td>3.9</td></tr>
<tr><td>2+00</td><td>2.2</td><td>2.2</td><td>3.3</td><td>3.3</td><td>3.6</td><td>4.7</td></tr>
<tr><td>3+00</td><td>3.2</td><td>3.1</td><td>3.7</td><td>3.6</td><td>5.1</td><td>5.1</td></tr>
<tr><td>4+00</td><td>5.5</td><td>4.6</td><td>6.5</td><td>6.3</td><td>8.0</td><td>7.8</td></tr>
<tr><td>5+00</td><td colspan="6">Bridge</td></tr>
<tr><td>6+00</td><td colspan="6">Bridge</td></tr>
<tr><td>7+00</td><td>9.0</td><td>9.2</td><td>11.9</td><td>12.2</td><td>16.8</td><td>16.7</td></tr>
<tr><td>8+00</td><td>8.4</td><td>8.6</td><td>11.7</td><td>12.0</td><td>16.5</td><td>16.6</td></tr>
<tr><td>9+00</td><td>8.0</td><td>8.1</td><td>11.2</td><td>11.7</td><td>16.5</td><td>16.5</td></tr>
<tr><td>10+00</td><td>4.3</td><td rowspan="12">unaffected by debris</td><td>9.8</td><td>11.1</td><td>16.4</td><td>16.5</td></tr>
<tr><td>11+00</td><td>5.1</td><td>5.6</td><td>5.7</td><td>15.6</td><td>16.4</td></tr>
<tr><td>12+00</td><td>5.9</td><td>6.2</td><td rowspan="10">unaffected by debris</td><td>16.5</td><td>16.1</td></tr>
<tr><td>13+00</td><td>6.3</td><td>6.8</td><td>8.5</td><td>12.7</td></tr>
<tr><td>14+00</td><td>7.3</td><td>7.5</td><td>8.9</td><td rowspan="8">unaffected by debris</td></tr>
<tr><td>15+00</td><td>7.6</td><td>8.0</td><td>9.3</td></tr>
<tr><td>16+00</td><td>7.9</td><td>8.7</td><td>9.4</td></tr>
<tr><td>17+00</td><td>8.4</td><td>9.7</td><td>9.6</td></tr>
<tr><td>18+00</td><td>9.3</td><td>9.8</td><td>10.3</td></tr>
<tr><td>19+00</td><td>10.2</td><td>10.2</td><td>12.2</td></tr>
<tr><td>20+00</td><td>11.9</td><td>11.8</td><td>13.7</td></tr>
<tr><td>21+00</td><td>12.4</td><td>13.6</td><td>13.6</td></tr>
</table>

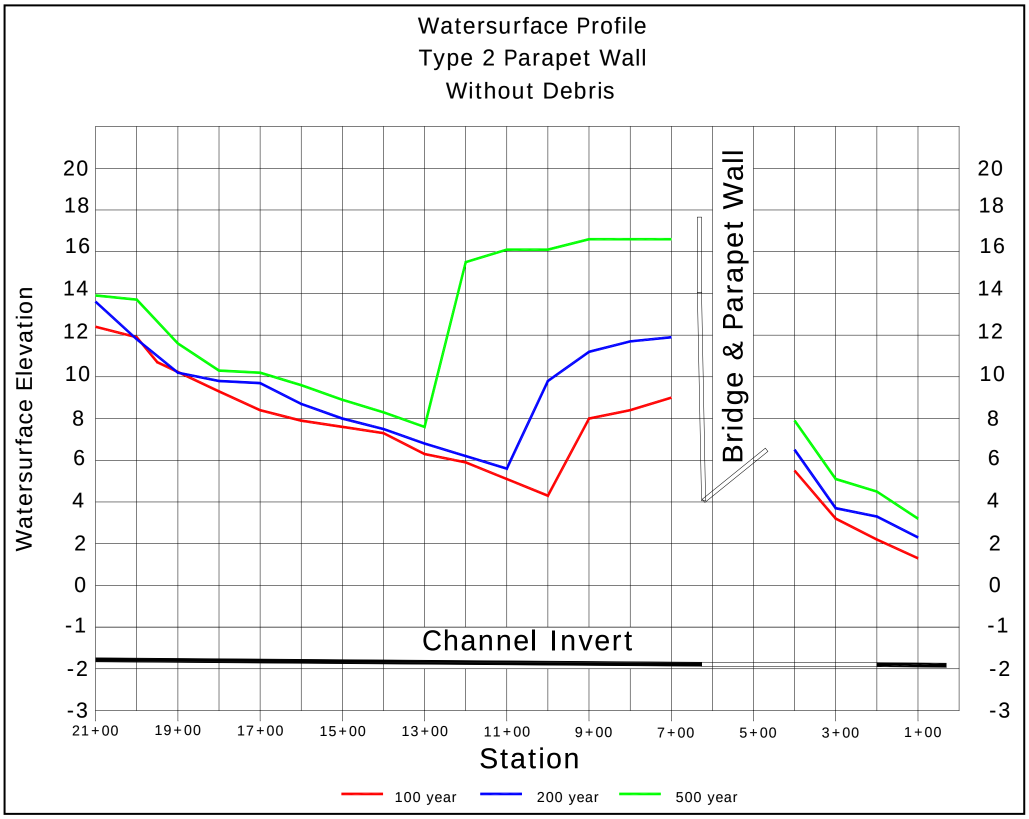

Figure 12. Water-surface profile for type 2 design without debris on pier nose.

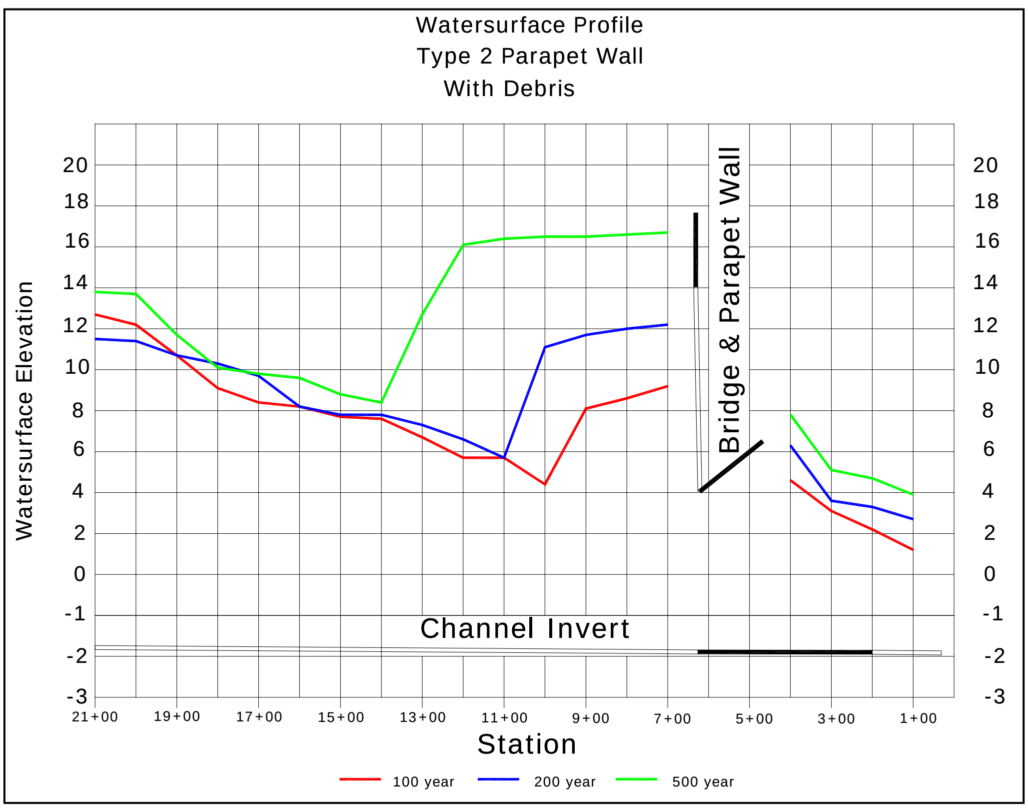

Figure 13. Water-surface profile for type 2 design with debris on pier nose.

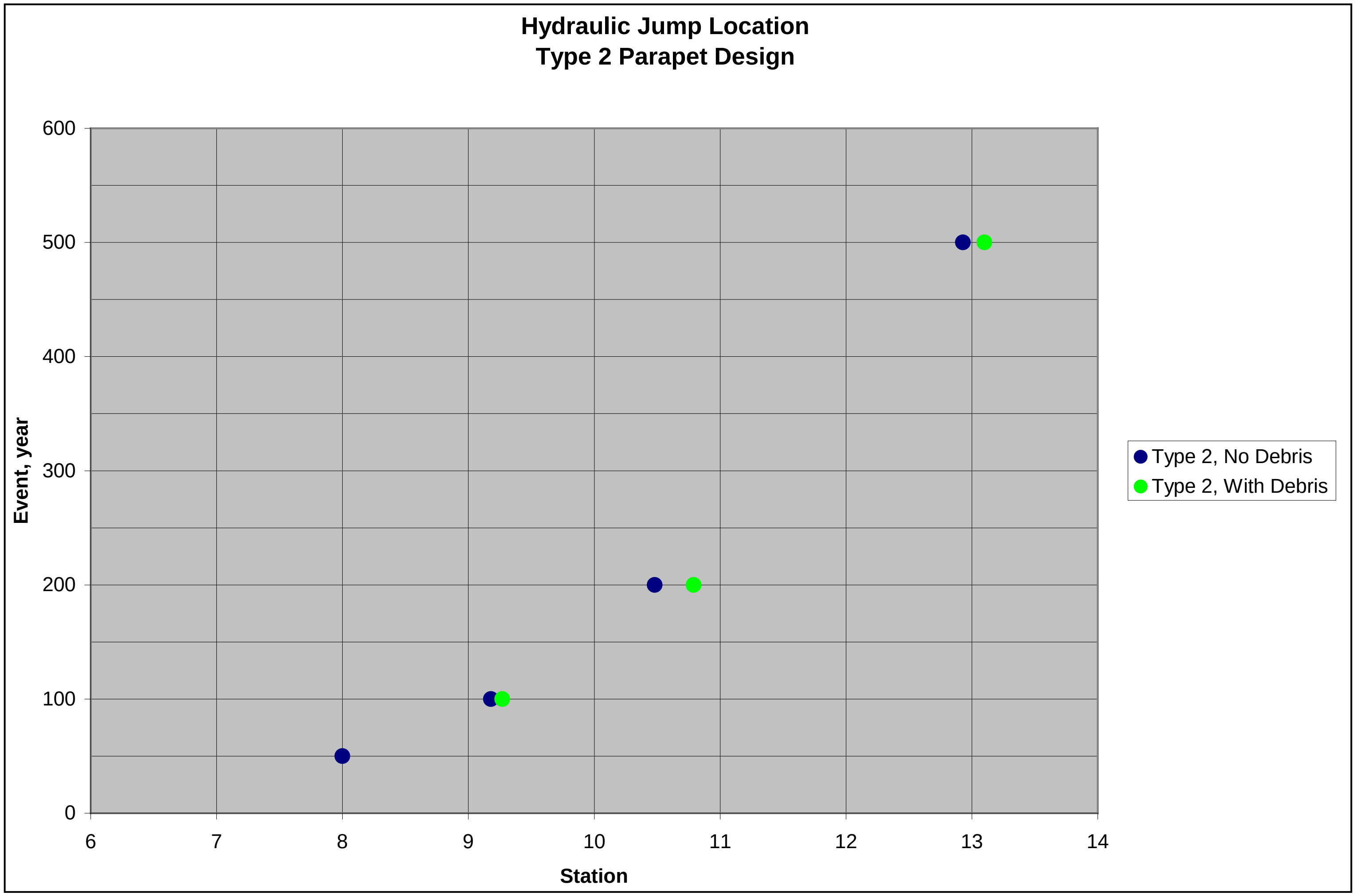

Figure 14. Hydraulic jump locations for Type 2 parapet wall.

Piezometric pressures were measured on the bridge deck. The taps were located on the bridge deck (Figure 9) near the upstream face of the girders. The tabulated pressure data are presented below in Table 12 – 14. Piezometer readings are in feet and referenced to the bottom of the bridge deck (0.0' at bottom of deck).

For the Type 2 parapet wall design, velocity data were again collected just upstream and under the bridge. The velocity information upstream of the bridge was collected in 1.5-ft depth intervals beginning at 1.5ft above the channel bottom. Velocity data beneath the bridge were collected at mid-depth, along the centerline of the left and right conduits. The measurement locations are shown in Figure 10. Velocity data are presented in Table 15.

Table 12. Piezometric pressures under bridge for type 2 parapet design, ft

100-year event						
Location	1	2	3	4	5	6
A	*					
B						
C				0.5		
D						
E						
F						
G		2.0				
H				1.5		0.5
I						
J						
K						
L						
M						
N						
O						
P						
Q						
R						
* Cells with no data are aerated locations with atmospheric or “zero” pressure.						

Table 13. Piezometric pressures under bridge for type 2 parapet design, ft

200-year event						
Location	1	2	3	4	5	6
A				2.5	2.5	2.5
B	2.0			2.5	2.0	2.0
C				2.7	1.0	1.0
D				2.5		
E	1.0	1.0		2.0	1.0	
F	1.0	2.5		2.0	2.0	
G	1.0	2.0		2.5	2.5	1.5
H	1.5			1.5	1.5	1.0
I		1.0		2.0	2.0	
J			1.5	1.5	2.0	
K			2.0		1.5	
L		1.0	3.0			2.0
M		1.0	4.0		1.0	2.5
N			3.0			2.5
O						
P						
Q						
R						

Table 14. Piezometric pressures under bridge for type 2 parapet design, ft

500-year event						
Location	1	2	3	4	5	6
A	3.3	3.3		6.1	3.7	2.6
B	3.3	2.7	1.5	5.5	3.8	2.7
C	2.2	2.2		6.4	3.3	2.0
D	2.5			3.7	2.5	2.0
E	2.7	2.7		4.8	2.5	2.5
F	2.5	2.7		3.8	2.5	2.5
G	2.0	2.5	2.0	4.0	2.5	2.0
H	2.5	2.5	2.7	3.8	3.3	3.0
I	2.5	2.5	2.0	3.0	2.7	2.6
J	2.7	2.7	2.3	2.6	2.8	2.8
K	2.0	2.5	5.3		2.5	3.0
L	3.3	2.8	7.2		2.5	3.0
M	2.8	3.5	7.2		2.5	4.6
N	2.5	2.5	6.7		2.5	3.6
O						
P						
Q						
R						

Table 15. Type 2 design, channel velocities, fps

Location	Dist from Channel Bottom, ft	100-year event	200-year event	500-year event
1	1.5	4.7	6.1	6.1
	4.0	7.6	7.2	7.0
	6.5	9.3	7.8	7.0
	9.0	10.7	8.3	7.1
	11.5	above water-surface	8.7	7.0
	14.0	above water-surface	above water-surface	6.9
2	1.5	6.3	8.1	7.7
	4.0	7.7	8.6	8.7
	6.5	8.7	9.0	9.1
	9.0	10.1	9.4	9.2
	11.5	above water-surface	9.9	9.3
	14.0	above water-surface	above water-surface	9.3
3	1.5	5.6	6.6	8.4
	4.0	7.4	7.4	9.0
	6.5	8.1	7.6	8.9
	9.0	10.0	8.3	8.6
	11.5	above water-surface	8.6	8.1
	14.0	above water-surface	above water-surface	7.8
4	1.5	6.3	7.9	10.1
	4.0	7.4	8.3	10.1
	6.5	8.1	8.7	9.8
	9.0	9.0	9.3	9.2
	11.5	above water-surface	9.5	8.4
	14.0	above water-surface	above water-surface	8.0
5	mid-depth	14.5	18.4	22.9
6	mid-depth	15.7	19.2	24.6
7	mid-depth	15.9	18.4	22.6
8	mid-depth	16.3	20.0	25.7
9	mid-depth	16.1	19.3	22.3
10	mid-depth	16.5	20.4	25.7
11	mid-depth	17.2	20.4	26.6
12	mid-depth	15.0	20.0	26.2
13	mid-depth	16.5	16.0	21.1
14	mid-depth	13.6	16.0	24.1
15	mid-depth	16.0	12.6	16.5
16	mid-depth	14.0	16.8	19.2

4 Summary and Recommendations

Type 1 vs. Type 2 Parapet Wall Designs

When comparing parapet wall designs, the more efficient design will produce the least amount of head loss through the bridge section of the channel. The design that produces the minimum depth of flow upstream of the bridge and causes the hydraulic jump to occur closest to the bridge is the most efficient design.

Comparison of hydraulic jump locations and water-surface profiles indicates that the simple radius, Type 1 parapet wall design is more efficient than the elliptical, Type 2 design.

The flow depth at the parapet wall is on average 0.5-ft higher for the Type 2 design (Figure 15). The hydraulic jump location is 13-ft to 30-ft further upstream for the Type 2 design (Figure 16). The Type 1 parapet wall design is the recommended design.

Flood wall height and extent upstream of bridge

The minimum flood wall height upstream of the bridge was determined by measuring the average cross channel water-surface elevation at the parapet wall for each event and rounding up to the nearest 0.5ft. Table 16 tabulates the minimum wall height needed for each evaluated flow. Additional top of wall elevation should be considered to account for wave action at the parapet wall. Table 17 shows typical water-surface oscillations, in this case, oscillations for the Type 1 parapet design without debris. Progressing upstream toward the jump, wall height can be decreased as flow depth decreases. Freeboard should be added to the tabulated wall height, the amount of which should be determined by design engineers and approved by District personnel.

The minimum upstream extent of the heightened flood wall is tabulated below (Table 16) and was determined by documenting the jump location for each event and rounding up to the nearest half station (50-ft). Type 1 data indicate that the jump location moves upstream at an approximate rate of 100-ft per 1000 cfs in the 100- to 200-year event range of flows and

140-ft per 1000 cfs in the 200- to 500-year event range of flows. Additional length should be added to the minimum distances for uncertainty associated with flow determination and modeling variability. The amount of additional length should be decided upon by the design engineer and approved by District personnel.

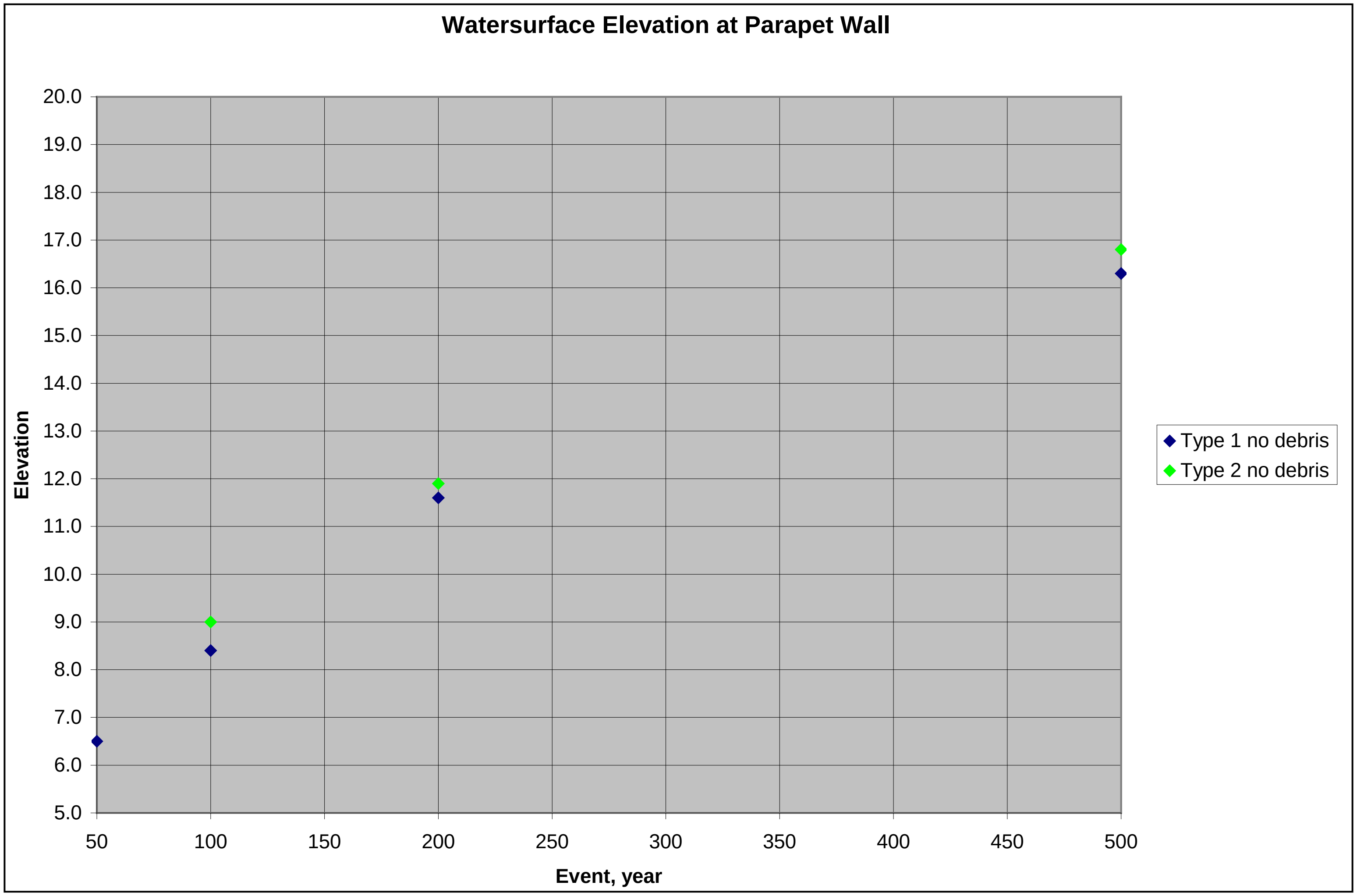

Figure 15. Type 1 and Type 2 water-surface elevations at parapet wall.

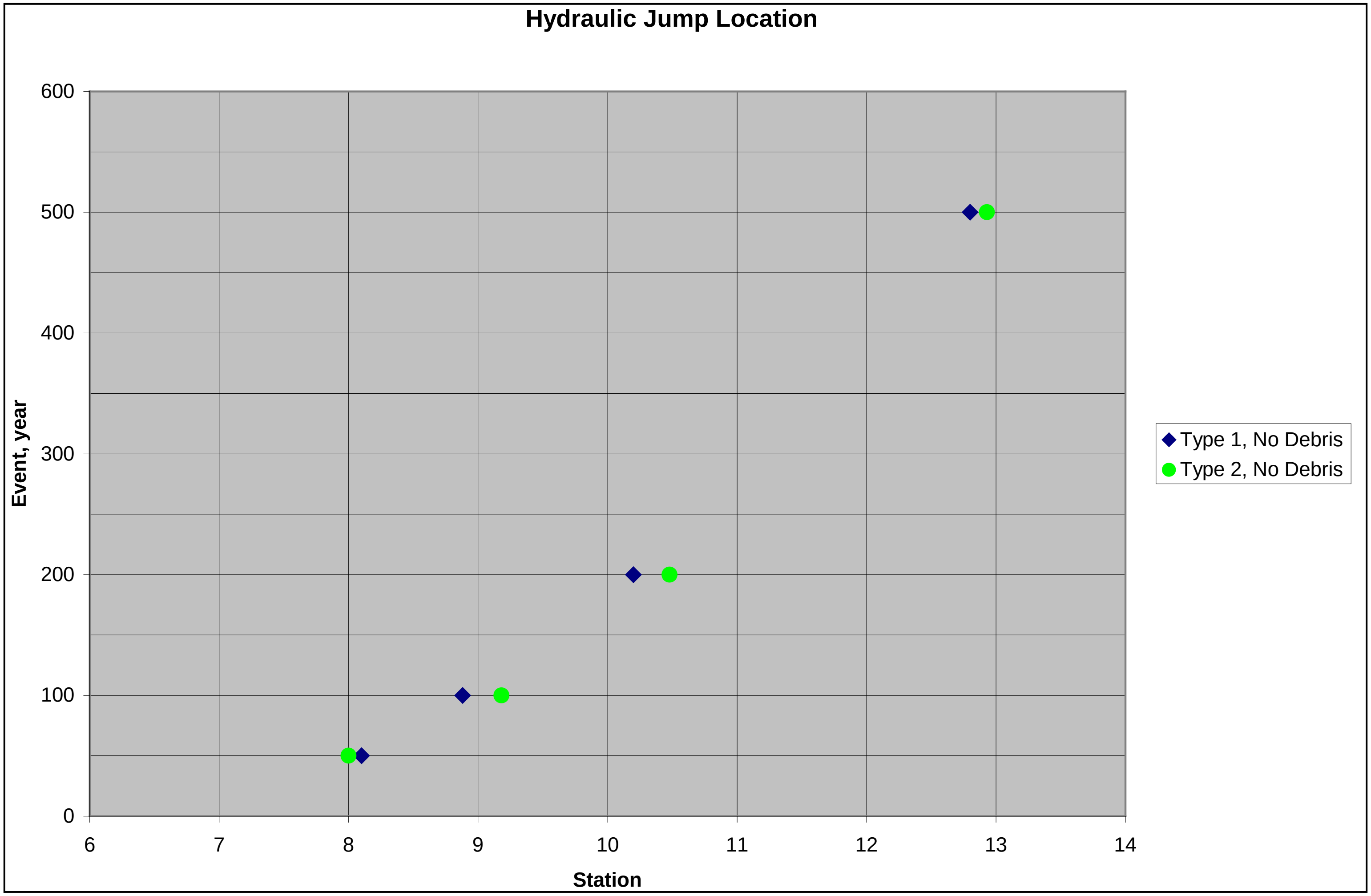

Figure 16. Type 1 and Type 2 hydraulic jump locations.

Table 16. Necessary elevation of top of flood wall and extent

Design	Event	Minimum Distance Upstream, Station	Minimum Top of Wall Elevation at Parapet, ft MSL
Type 1	50	8+50	6.5
	100	9+00	9.0
	200	10+50	12.0
	500	13+00	16.5
Type 2	50	not measured	not measured
	100	9+50	9.5
	200	11+00	12.5
	500	13+50	17.0

Table 17. Type 1 design, oscillations at parapet wall, ft MSL

	100-yr event	200-yr event	500-yr event
Minimum	11.0	14.9	19.0
Maximum	15.1	19.0	23.3

Appendix A

In some instances, the tabulated water-surface profile for flow events with debris accumulation on the pier is slightly lower than the water-surface elevation for the same event without debris. These slight differences in water-surface profile are attributed to slight variations in inflow discharge. For each event, model discharge was set using a gate valve and monitored with a data industrial flow meter. The inflow was stable for each event but exhibited slight variations due to re-setting the model discharge. The repeatability of discharges for this study is within 1.5% of the target discharge.

The headloss resulting from flow through the bridge is significantly higher than any loss caused by the presence of debris; therefore, the headloss associated with the modeled accumulation of debris is insignificant.

The testing sequence was to collect model data for the parapet wall configuration without debris for the four events. Then, reconfigure the model with debris and re-evaluate the parapet design. This sequence of testing required setting the model discharge separately for the same stream discharge for both cases. An alternative way to accomplish this testing would have been setting a model flow and evaluating the parapet designs without debris and then installing debris and re-evaluating without having to change the discharge.

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14. ABSTRACT A 1:25 scale model was constructed to study structural improvements to the Wailupe Stream drainage basin. This drainage basin is located approximately eight miles southeast of Honolulu, HI. Structural features that were evaluated include the concrete lining of the stream and modification of the Kalanianaole Highway Bridge (KHB). Concrete lining near the KHB and KHB modification was designed to allow stream flow to pass under the existing bridge without overtopping. This required raising the upstream channel walls (flood walls) and adding a parapet wall on the upstream side of the bridge. During large flow events, the channel beneath the bridge will act as a conduit with pressurized flow passing beneath the bridge deck. Measured piezometric pressures and current velocities will be used to determine hydraulic loadings for design of a bridge deck restraint system.						
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