

**THE FLORIDA FLUME
A FEASIBILITY STUDY**

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The flume in the Hydraulics Laboratory at the University of Florida has been used almost continuously for the past ten years for FDOT projects. These projects ranged from basic research to the measurement of local sediment scour at existing and proposed bridge piers on Florida bridges. The results of these tests have saved millions of dollars in construction costs and have provided the information required to develop scour prediction equations and methods that will be used to save even more money in the future. In spite of its usefulness the UF flume was limited in its capabilities and was at the end of its useful life when it was dismantled as part of a building renovation project. Even though much has been learned about scour at bridge foundations over the last ten years there are areas that need to be researched. This is particularly true for high velocity flow situations (the live bed scour regime) and cases where surface waves play a significant role in the scour process. Much work is also needed in the areas of abutment and contraction scour, increased scour due to debris, the use of scour protection on new construction, etc. The current state-of-the-art in predicting abutment and contraction scour is such that the predictions must be very conservative and thus costly to the taxpayer. These are areas where significant advances can be made provided funding for facilities and research are available.

Fundamental to this work is the existence of a hydraulics flume with live bed scour and wave generation capabilities. The flume should be tilting, large enough to minimize scale effects, be able to recirculate sediment as well as water and be capable of generating waves and currents simultaneously. Such a facility, with state-of-the-art controls and instrumentation, would be useful for a wide range of hydraulics/fluid mechanics and sediment transport problems confronted by the FDOT. Florida with its vast coastline and coastal waters has many hydraulics and sediment transport related problems associated with its roadways and bridges. These problems increase with the state's rapidly increasing coastal population.

It seems imperative that a flume be constructed in the State of Florida. The location, size, capabilities, ownership, maintenance, operation, use scheduling, etc. as well as the cost and

potential users of such a facility needed to be established. This feasibility study addressed the following issues:

1. What are the potential uses of the proposed facility?
2. What is the optimum size of the flume and what capabilities should it have?
3. What kinds of problems can be addressed in the proposed facility?
4. Who are the potential users of the facility?
5. Where should the facility be located?
6. Ownership and responsibility for operation and maintenance?
7. Preliminary design and initial and operational cost estimates?
8. Cost/benefit analysis?

1.2 APPROACH

Large test facilities are expensive to construct and operate. For such a facility to be practical its benefit in improving design and reducing costs must outweigh its initial and operational costs. A workshop with participants from the FDOT Central Office in Tallahassee, all of the FDOT districts, the Federal Highway Administration in Tallahassee and Washington, DC and the US Army Corps of Engineers Research Laboratory in Vicksburg, Mississippi was held to address the issues presented above. Ken Morefield, Assistant Secretary of the FDOT, opened the workshop with some general comments on research facilities from the FDOT's perspective. Basically any facility funded by FDOT must be directed at FDOT problems and must be cost effective. The workshop was very productive with much discussion and many useful comments and suggestions by the participants. All of the important issues were addressed and recommendations made regarding how the feasibility study should proceed. Following the workshop a more detailed flume design was completed along with an improved cost estimate. Two possible sites for the flume were selected and site preparation costs estimated. In order to gain insight into potential FDOT cost savings that would result from research conducted in the proposed facility, one of the potential research topics, "time rate of bridge scour," was investigated in detail. Estimated reductions in design scour depths for a number of Florida Bridges were made and sent to Henry Bollmann at FDOT. Using the results of his analyses of these bridges Mr. Bollmann estimated potential cost savings to the FDOT for bridges planned for the next 5 years.

It should be pointed out that these savings are only for one area of research. Other areas such as the use of scour protection for new bridge piers have the potential for equal or even greater cost savings. This facility would, of course, be open for use by researchers throughout the state and country with priority and cost benefits given to those working on FDOT projects. A preliminary flume design is presented in Chapter 3. This is followed by a cost-benefit analysis in Chapter 4. Chapter 5 is a summary and conclusions and Chapter 6 is information on the principal investigators.

CHAPTER 2

WORKSHOP

2.1 OBJECTIVES

A workshop was held in Gainesville, Florida on June 25 and 26, 2002. The purpose of this workshop was to bring knowledgeable people in the FDOT (and representatives from FHWA and COE) together to consider a proposed facility that would be constructed at the University of Florida, but would also be available to other researchers and engineers. During the two half-day sessions, the following topics were discussed:

1. What are the present and future hydraulics/sediment transport problems facing the FDOT that require the use of a large flume?
2. Are there other uses for the facility such that it will be fully utilized?
3. If a flume is needed how large should it be and what features should it have?
4. What are the initial and operating costs for such a facility?
5. Would such a facility be cost effective?

The number of invitees was limited to allow ample opportunity for discussion and exchange of ideas. All FDOT districts, with the exception of the Turnpike, were represented at the Workshop along with representatives from FHWA (Tallahassee and Washington) and the Corps of Engineers Waterways Experiment Station in Vicksburg.

There was unanimous support for the proposed facility. FDOT enthusiasm was particularly helpful in the “brain storming” sessions where a number of new and refreshing ideas regarding uses of the facility were introduced such as widening the flume from 12 to 20 feet and making one of the walls adjustable, modeling ship impact, and modeling scour protection alternatives.

2.2 AGENDA

Tuesday June 25, 2002

- 1:00 - 1:15 Welcome - Dr. Joseph Tedesco (Chairman of Civil and Coastal Engineering)
and Dr. Pramod Khargonekar (Dean of the College of Engineering)
- 1:15 - 1:30 Introductions - Max Sheppard
- 1:30 - 1:45 FDOT Perspective - Ken Morefield, Henry Bollmann
- 1:45 - 2:00 Background - Max Sheppard
- 2:00 - 3:00 FDOT Requirements – Rick Renna
- 3:00 - 3:30 Coffee
- 3:30 - 4:00 Existing Facilities
Facilities Applications – Max Sheppard
- 4:00 - 5:00 Proposed Facilities – Bill McDougal
- 5:00 Adjourn
- 6:30 Hosted dinner at Harry's (110 SE 1st St)

Wednesday June 26, 2002

- 7:30 - 8:30 Continental Breakfast
- 8:30 - 9:30 Facilities Open Discussion - Bill McDougal
- 9:30 - 10:00 Applications Open Discussion - Max Sheppard
- 10:00 - 10:30 Coffee
- 10:30 - 11:30 Fiscal Considerations
- 11:30 - 12:00 Recommendations
- 12:00 Adjourn

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2.4 FOLLOWUP LETTER

Dear _____

This letter is to thank you for your participation in and contributions to the Flume Feasibility Workshop and to give you an update on the status of this project. We are pleased that so many of you feel, as we do, that there is a definite need for such a facility in Florida to address FDOT's present and future hydraulics and sediment transport needs. All FDOT districts, with the exception of the Turnpike, were represented at the Workshop along with representatives from FHWA (Tallahassee and Washington) and the Corps of Engineers Waterways Experiment Station in Vicksburg. We were fortunate to have in attendance, Mr. Ken Morefield, Director of Research for the FDOT, to give us his perspective on the criteria for FDOT sponsored research.

It was rewarding to have so much interest from the structural and geotechnical engineers for a facility that is primarily one for addressing hydraulics, drainage and sediment transport issues. Their presence and enthusiasm was particularly helpful in the "brain storming" sessions where a number of new and refreshing ideas regarding uses of the facility were introduced. (20 ft wide with false wall, ship impact, scour protection).

Since the workshop a plan of action has been developed. Rick Renna and Henry Bollman met with Ken Morefield regarding FDOT funding. Mr. Morefield made it clear that FDOT funds for such a project would have to be justified on potential cost savings to FDOT through a detailed cost-to-benefit analysis. Rick, Henry, Bill McDougal and I will be doing such an analysis over the next two to three months. This will include the prediction of design scour depths for a number of bridges that have been built in Florida over the last 10 years, using techniques and equations available today. We will then estimate these same scour depths taking into consideration the ability to account for time dependency of both local and contraction scour and the use of effective scour protection resulting from research conducted in the proposed flume facility. Henry will then compute the cost savings for these bridges resulting from the knowledge obtained from the research in the flume. Based on these findings estimates of future savings for bridges to be built in Florida for the foreseeable future can be made. There are many other DOT related problems that can be addressed in this facility. Use of the facility may not always result in a cost savings, but it will always result in a better and safer design.

We will keep you posted on our progress. In the meantime, you can help by informing the proper people in your organization of your views on this endeavor.

Once again, we thank you for taking time from your busy schedule to contribute to this project. Florida has taken a leadership role in this field and with your help we can maintain this position.

Sincerely,

D. Max Sheppard

Professor

2.5 CONCLUSIONS

As stated above there was much discussion during the course of the workshop on all aspects of the proposed flume. There was a consensus on a number of items and these are listed below:

1. There is a need for a flume of the approximate size and with the capabilities of that proposed.
2. There are many FDOT hydraulics and sediment transport problems and potential problems that can be addressed and solved in this flume. These include 1) time dependent bridge scour problems, 2) ship impact loading on bridge piers, 3) scour protection at new bridge foundations, 4) wave/current induced scour, 5) improved culvert design, 6) improved contraction scour prediction, 7) improved abutment scour prediction, 8) improved hydrodynamic loading on bridge foundations, and 9) improved pressure flow scour analysis.
3. The flume should be widened from the proposed 12 ft to 20 ft with a movable internal wall that can reduce the flume width to 12 ft when very high velocity flows are required.
4. Other funding sources should be investigated for providing a portion of the funds required to design and build the flume.

CHAPTER 3

FLUME

3.1 FLUME DESCRIPTION

The proposed facility is a very large-scale recirculating, live-bed, tilting flume. The large size of this facility enables the examination of sediment transport and scour processes at much larger scales than any existing facilities. These large scale results can be used to develop, optimize, or verify scour protection designs. The proposed channel in the flume is 200 ft long, variable 12 - 20 ft wide and 12 ft deep. The overall dimensions of the flume including catch basins and supporting structures are 240 ft long, 34 ft wide, and 35 ft high. The flume has a maximum flow water rate of 1,000 cfs and sediment slurry rate of 200 cfs and can be tilted from 0 to 5%. Water and sediment are both recirculated and full live-bed conditions can be developed. Figure 3.1 shows the flume channel in plan, profile, and cross-section. At the downstream end of the flume is a catch basin which separates sediment and water before being returned by pumps to the upstream end of the flume. The flume has two test areas which will be used for routine testing. Each of these areas has a deep well section which is 4 ft deeper than the adjacent flume bottom. This will allow the testing of deeper soil conditions. Each drop section is 15 ft long. Figure 3.2 shows these drop sections and viewing windows that are installed along this portion of the tank. Most of the tank will be constructed from steel. However, in these two test areas there will be porthole windows. Porthole windows were selected rather than large single panels due to the large hydrostatic pressures developed and to minimize mechanical damage from instruments and equipment in the tank banging the windows. Figure 3.2 also shows cross-bracing used to support the side walls. The flume is supported on I-beams which span across the tank. Hydrostatic forces on the wall are approximately 2 tons/ft. Therefore, the walls are heavily stiffened with I-beams and supported with braces. The overall width of the flume including these structural members is 34 ft.

Most tilting flumes are supported on a hinge located near the center of the flume. Typically at the upstream end of the flume is a screw jack or hydraulic ram mechanism which is used to tilt the flume. Figure 3.3 shows a typical screw jack on a tilting flume in New Zealand. The weight of the proposed flume, water, and sediment is approximately 1,500 tons. With only

two supports the loads on the pivot point and jack would be on the order of 750 tons each which is unreasonable. An alternative is to provide a number of jacks along the length of the flume. Figure 3.4 shows the placement of jacks along the flume and in cross-section. A hinge is located near the downstream end of the flume where the pumps are located. There is a large weight concentration at this end and locating the hinge near the pumps means the pumps will experience a smaller vertical displacement when the flume is inclined. The conceptual design calls for 13 pairs of hydraulic rams down the length of the flume. Even with this number of rams, the load per individual ram is quite large, being on the order of 50 tons. The flume is a very long and slender structure and has very low torsional stiffness. The displacements of the rams must be carefully coordinated. Both the forces and displacements in the rams must be balanced to not induce rocking in the flume. One potential vendor for the hydraulic rams and computer control system is MTS of Minneapolis, MN.

Handling the return water for such a high flow rate is a difficult consideration. On smaller flumes at the downstream end there is a collection box, with a pump that returns the water to the upstream end of the flume through a pipe that runs under the flume. The pump is usually located at an elbow beneath the collection box. This configuration has several advantages. The collection box, pump, and return pipe are all rigidly attached to the flume. When the flume is tilted, this return water system moves with the flume. As a result, there are no free surfaces on the return flow except at the collection box and discharge port. This greatly reduces the potential for flooding problems.

This type of return water system is most desirable and will be considered as a primary option for the Florida Flume. However, the return pipes are extremely heavy and will require structural elements to support them. Also, the diameter of the return pipes is quite large. Therefore, rather than run the pipes beneath the flume as is typical, the return pipes will be run along the sides of the flume. Figure 3.5 shows the return pipes. At the downstream catch basin end, there are four pumps. The two pumps on the left side return water through a single pipe on the left side and the two pumps on the right side of the flume return the water to a second pipe on the right side. The cross section drawing shows that the two return pipes will run along the flume supports underneath the knee bracing. These water return pipes are each 5 ft in diameter. Also shown in the cross section drawing are the two sediment slurry return pipes.

Except for the viewing windows in the two test sections of the flume, all side walls will be steel. To provide observation in areas other than those with viewing windows, a catwalk is provided along the entire length of the flume. This is shown in Figure 3.6. The catwalk is 4 ft wide and is 4 ft below the top wall of the flume. This will provide viewing access as well as access to equipment and visual observations. Along the top of each wall of the flume will be an instrument track. This track will be used for supporting instruments mounted on carriages such as profilers, point gages, turbidity meters, and current meters.

At the downstream end of the flume the water and sediment are separated. Figure 3.7 shows a simple gravity separation mechanism for a flume in New Zealand. This view is from the flume looking into the drop section where water is collected. The first section captures most of the sediment. This sediment water slurry is returned through a set of slurry pumps. Behind this are two drop sections which feed into water return pipes. A system much like this will be designed for the present flume system. However, due to the size, it will be much larger and the downstream end of the flume will also include an adjustable weir. This way a range of flow depths can be examined in addition to normal flow conditions with an open end in the channel. Figure 3.8 shows the water pump beneath the drop section in Figure 3.7. The pump is driven by an external motor through a shaft into the elbow. A similar system will be employed in the present flume. An advantage of this system is there is no free surface on the water in the return system and therefore less chance of flooding the laboratory. Figure 3.9 shows the configuration to be used in the Florida Flume. There will be four return pumps for water and two return pumps for sediment. Rather than have the pumps beneath the drop sections, the drop sections will taper to the sides and the return pipes will come out of the sides of the drop section. Due to the size of the pipes, this greatly reduces the vertical height requirement of the flume.

Figure 3.10 shows the upstream end of a flume with the return pipes for the water and the sediment. In the water return pipes, the water is distributed across the width of the tank and is introduced near the tank floor. The sediment return is above the water return and the sediment slurry is discharged into the water flow. In the present application, a different means of reintroducing the flow is required. This is because a future consideration for the Florida Flume is the inclusion of a wavemaker. The wavemaker is not a part of the initial proposal but may be added at a later date. Therefore, injecting the water and sediment at the back of the tank is not compatible with the use of a wave maker. Figure 3.11 shows the return pipes coming along the sides

of the tank in the plan view and louvered flow straighteners in the side walls of the tank in the elevation view. By reintroducing the water and sediment in the side walls as opposed to the back of the tank allows a wavemaker to be accommodated. The location of the wavemaker is also shown in yellow in Figure 3.11. The wavemaker is a module which may be raised or lowered in the tank depending on the water depth and/or sediment depths. The 200 ft flume length, 12 - 20 ft variable width, and 12 ft depth would make the Florida Flume one of the largest wave flumes in the western hemisphere. The only wavemaker in the United States which is larger is at Oregon State University which is 342 ft long, 12 ft wide, and 15 ft deep. The present facility offers a combination of unique benefits not offered by any other facility in the United States:

- 1) The flume can be tilted which allows a wider range of conditions to be studied than the typical flow.
- 2) The flume has recirculation which enables the examination of combined waves and currents. For example waves propagating into a tidal inlet with strong currents.
- 3) The flume supports moveable bed studies with sediment recirculation.

Therefore, large-scale sediment transport studies can be conducted such as pier scour in a tidal inlet that has a combination of tidal flow and wave action.

The target design for the wavemaker is the capability to produce a wave height of 4 ft with a period of 3.5 seconds in 8 ft of water depth. This corresponds to near maximum breaking wave conditions that can be generated in the flume and maintain sufficient free board. This wave is very similar to the maximum wave that can be generated at the Oregon State facility which has a 5 ft height and 3.5 second period in an 11 ft water depth. To generate these waves will require a peak power of approximately 5 kW and stroke of 4 ft if there is water on one side of the wavemaker or 10 kW if there is water on both sides. This large wavemaker will be driven by computer controlled hydraulic ram. The wavemaker will have the ability to generate simple periodic and random waves. A wave gage will be installed on the front face of the wavemaker to measure local wave conditions. This allows for active wave absorption which cancels reflected waves and is necessary to conduct long-term studies.

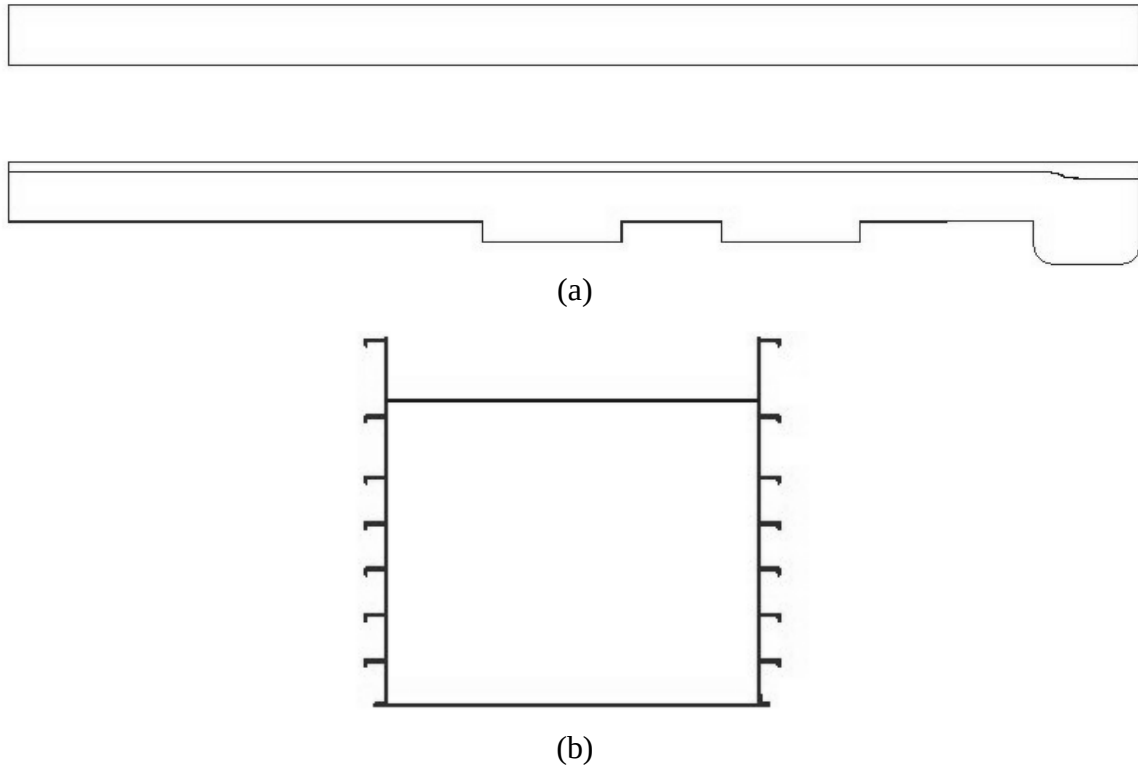


Figure 3.1 Plan, profile, and cross-section of proposed flume channel.

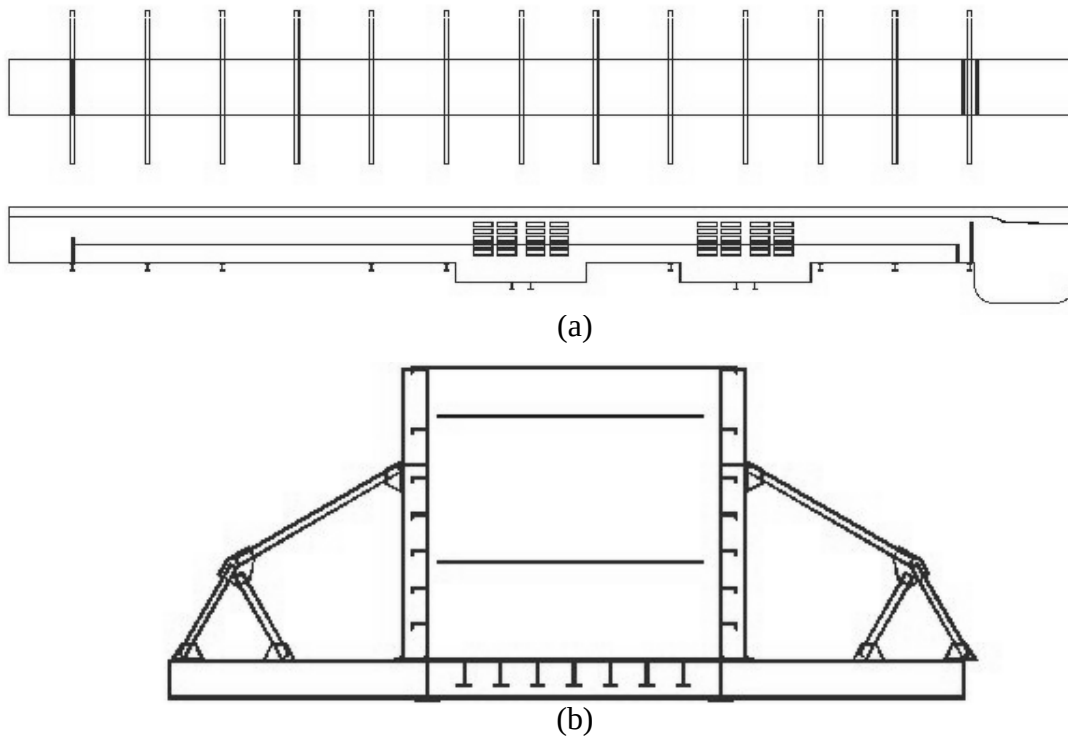


Figure 3.2 Viewing windows and side wall supports.

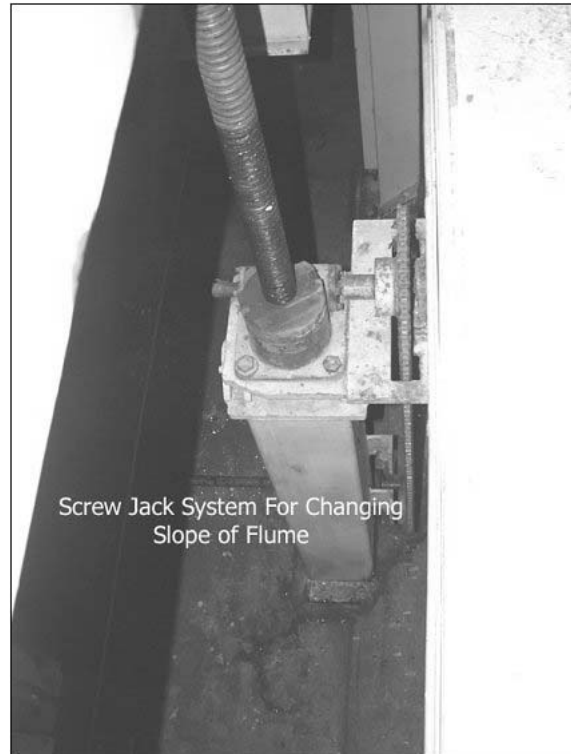
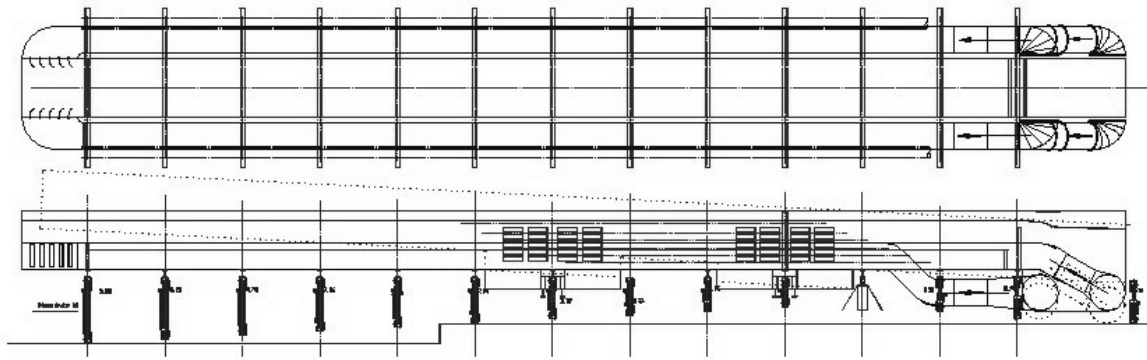
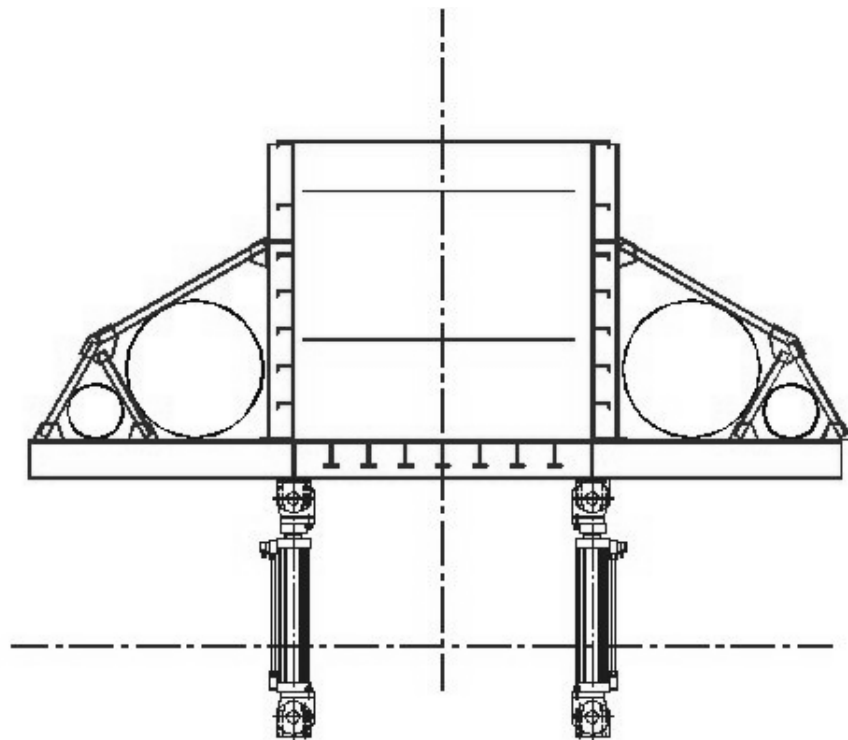


Figure 3.3 Screw jack for tilting flume in New Zealand.



(a)



(b)

Figure 3.5 Return pipes.

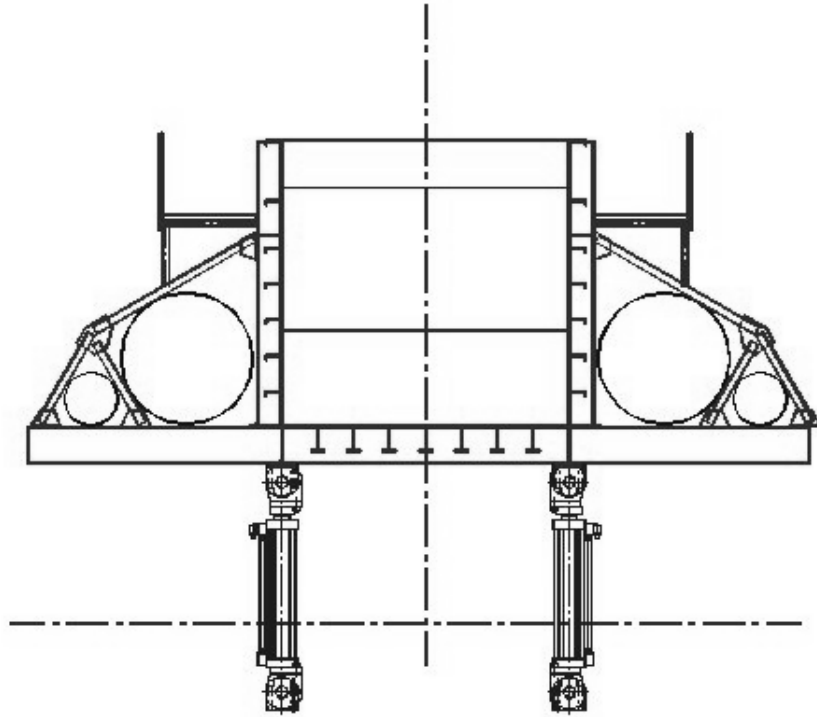


Figure 3.6 Cat walks.



Figure 3.7 Catch basin at downstream end of flume.

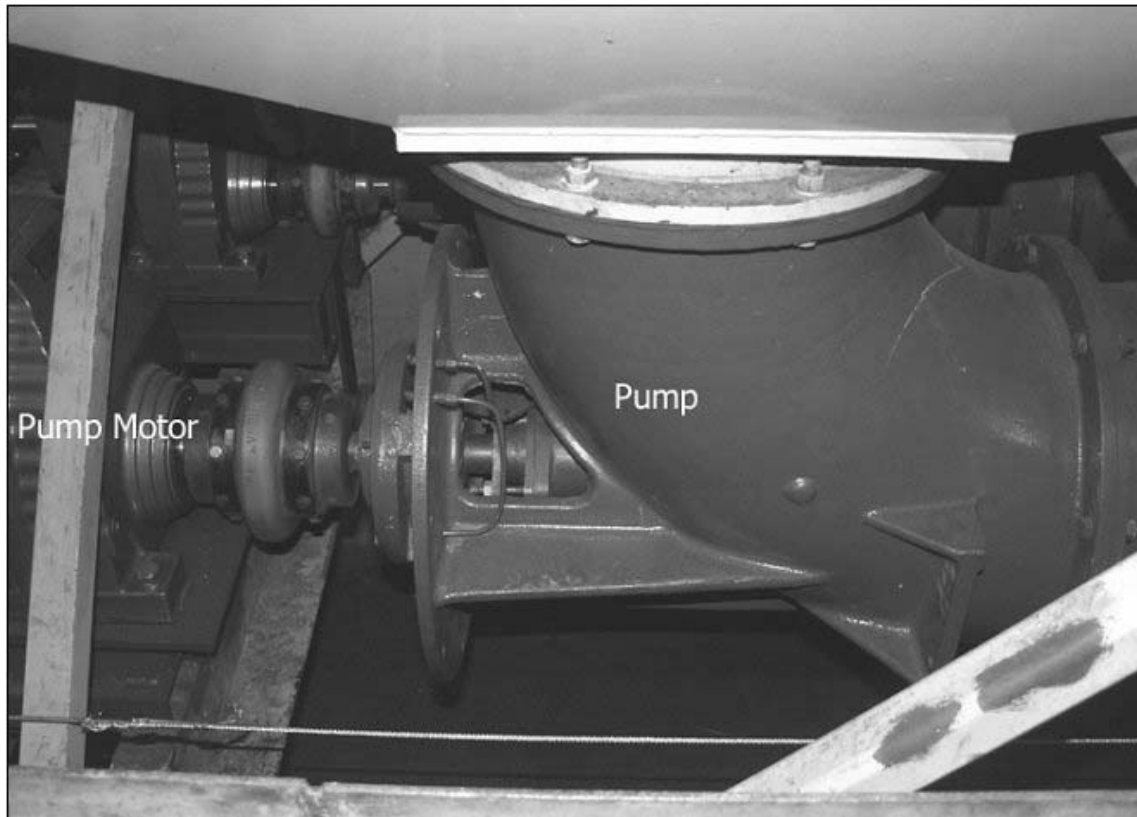


Figure 3.8 Example of a return pump installation.

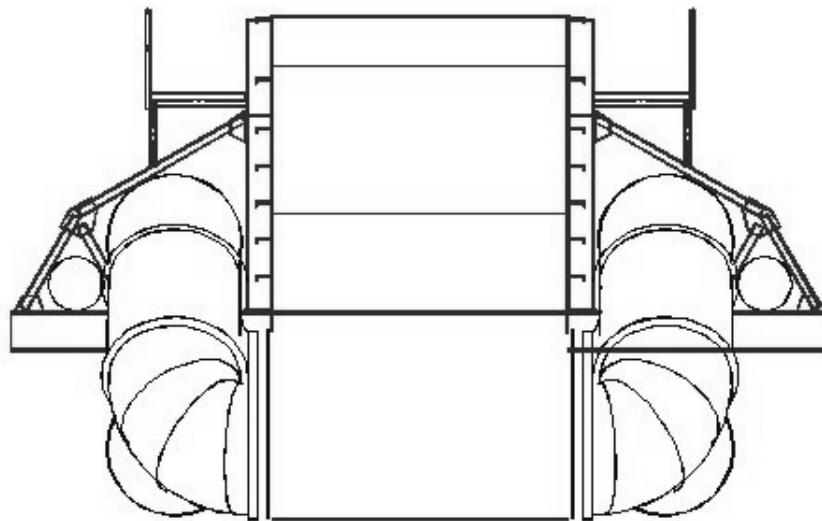
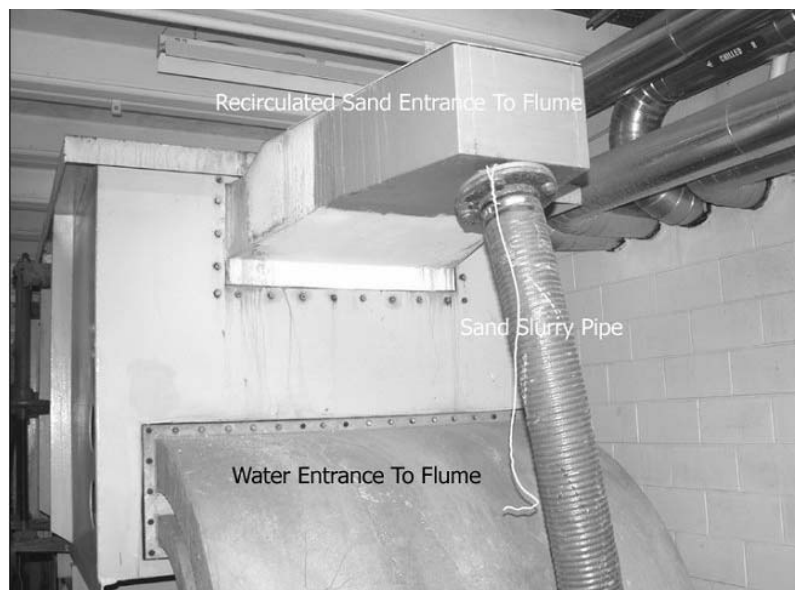


Figure 3.9 Return pipe configuration for proposed flume.



(a)



(b)

Figure 3.10 Water and sediment returns at upstream end of flume.

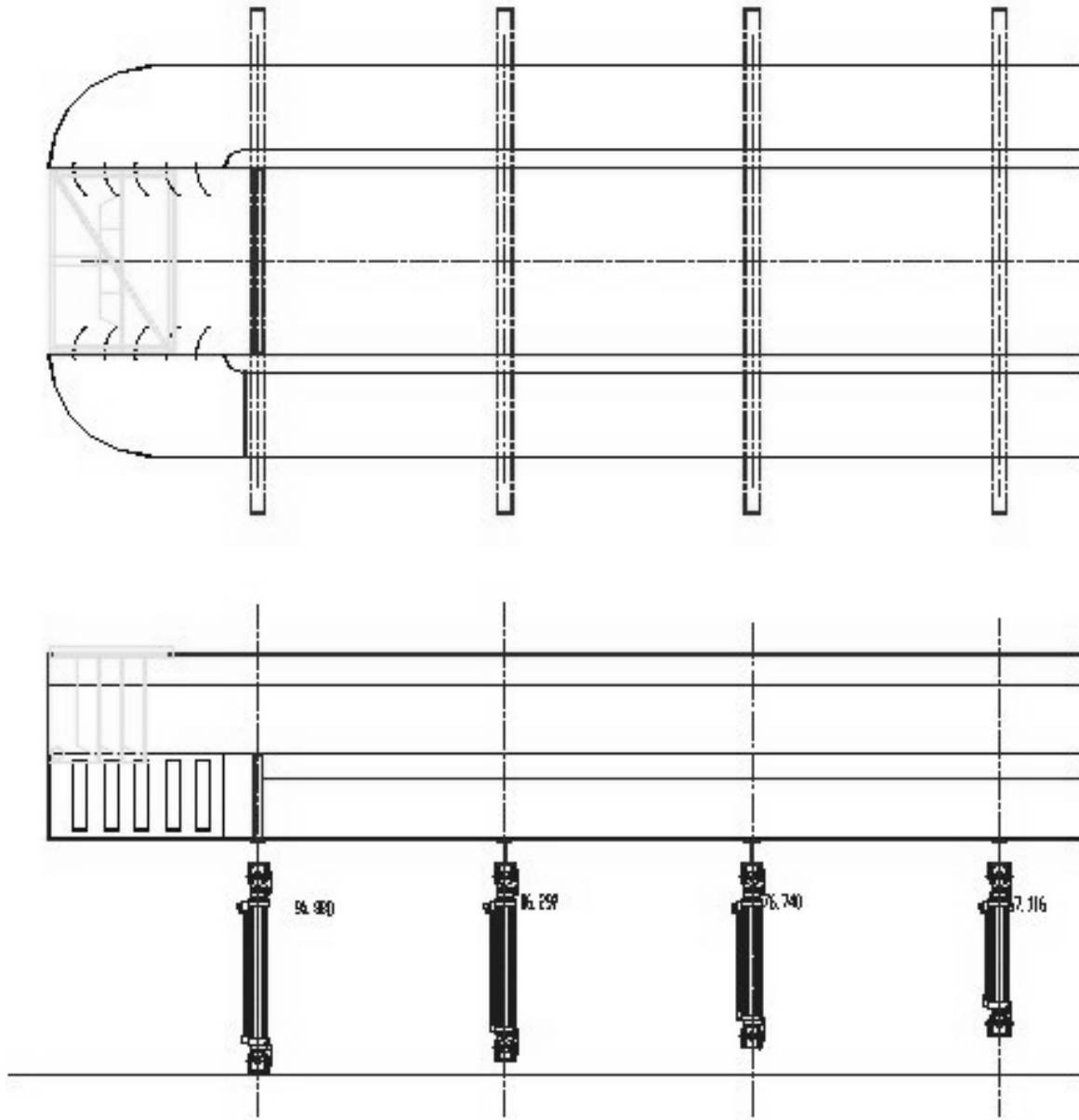


Figure 3.11 Louvers and flow straighteners on return flow to accommodate wavemaker.

3.2 FLOW CONDITIONS

The target flow conditions for the flume are to obtain a Froude number of 1.0 at a depth of 6 ft. The resulting velocity is 13.9 ft/sec. and the flow rate for a 12 ft wide channel is 1,000 cfs. These flow conditions are sufficient to develop live bed conditions.

It is desirable to have the maximum sized cross-section possible to allow the examination of large-scale models. However a large cross-section significantly increases the pumping requirements. The proposed cross-section for the flume is 12 ft wide and 12 ft deep. This would correspond to a large-scale operating condition of 4 ft of sediment, 6 ft of water, and 2 ft of free board. As a result of the workshop and comments from FDOT engineers, it was recommended that the width of the channel be increased to 20 ft. A false wall could be installed to provide a width of 12 ft, but for very large structures the false wall could be removed and the full 20 ft section tested. Figure 3.12 shows hypothetical flow conditions assuming smooth side walls on the flume and a 0.2 mm sand bed on the bottom. If no sediment is placed in the flume, then the maximum operating depth is approximately 10 ft. The slope of the flume required to maintain normal flow conditions is shown over this range of depths for three flow rates; 100, 500, and 1,000 cfs. A slope of 0.05 is sufficient to achieve normal flow conditions at the maximum flow rate of the pumps. At the shallower flow depths with a 0.2 mm grain size, super-critical conditions can be obtained. Again, a flow depth of 6 ft with a channel width of 12 ft and flow rate of 1,000 cfs corresponds to a Froude number of 1.

As a rule of thumb, the width of the pier in the model studies should not be more than approximately 15% of the flume width. This is necessary to avoid blockage problems and the influence of side wall confinement. For the 12 ft wide flume, this yields a model pier width of 1.8 ft. The width of the local scour hole should not exceed approximately half of the flume width. This gives a scour hole width of approximately 6 ft. Figure 3.13 shows the scour width for different pile diameters and flow rates. It is seen that the 1 ft and 2 ft pile diameters exceed the restriction that the scour hole width be less than one-half the flume width. This observation was a significant motivation for the FDOT engineers recommending that the flume width be increased to 20 ft. In that case, a pile diameter of 1 ft could be examined at all flow conditions. A pile diameter of 2 ft could also be examined at all flow rates because the maximum velocities in the 20 ft wide tank are greatly reduced.

The depth of the scour hole must also be accommodated by the flume. Figure 3.14 shows the live bed scour depth as a functional flow rate for 3 ft pile diameters. It is seen that for all flow conditions, the 4 ft deep well section plus the typical 2 to 4 ft of sediment in the bottom of the flume can accommodate the maximum anticipated scour depths.

Figure 3.15 shows the velocity vs. depth at a flow rate of 1,000 cfs for a flume width of 12 ft and a flume width of 20 ft. Also shown (the black line) is the critical flow condition. As discussed above, for a 12 ft width, critical flow is obtained at a depth of 6 ft. For a 20 ft width the maximum depth at which critical flow can be obtained is approximately 4.5 ft.

Figure 3.16 shows sediment transport rates for different flow conditions for three different sediment transport models. For most live bed test conditions, the sediment transport rates will be between 3 and 10 cfs. At a sediment transport of rate of 10 cfs and slurry pumps with a total flow rate capacity of 200 cfs, the percent solids will be approximately 10%. For most flow conditions, the slurry concentration will be below 5%. However, note that for very steep slopes, very large sediment transport rates can develop. For these cases, a significant portion of the sediment will be recirculated through the water pumps as the sediment volume can not be accommodated by the slurry pumps alone.

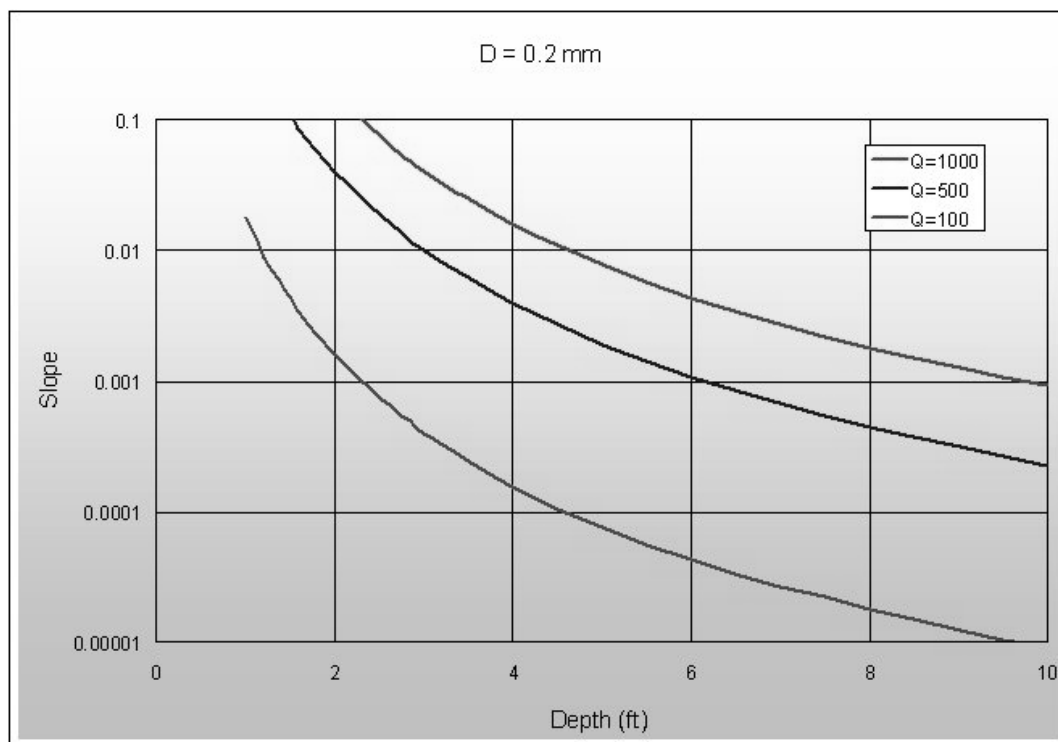


Figure 3.12 Normal flow conditions for 12 ft width.

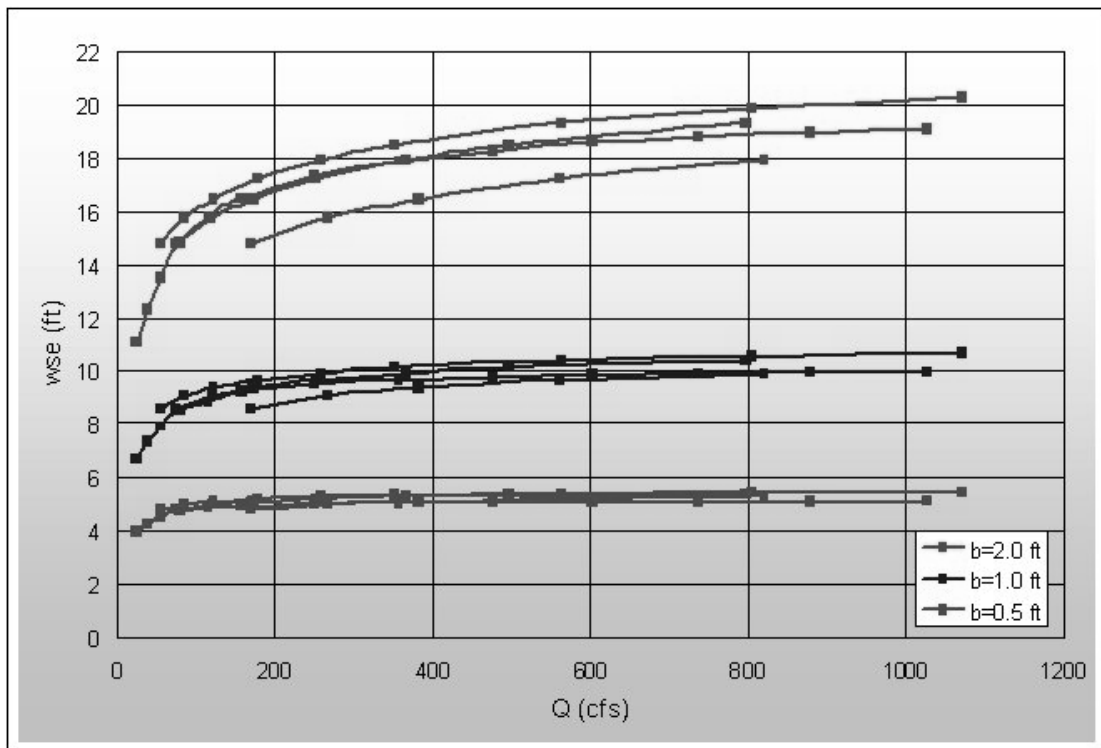


Figure 3.13 Scour hole width for four different sand grain sizes.

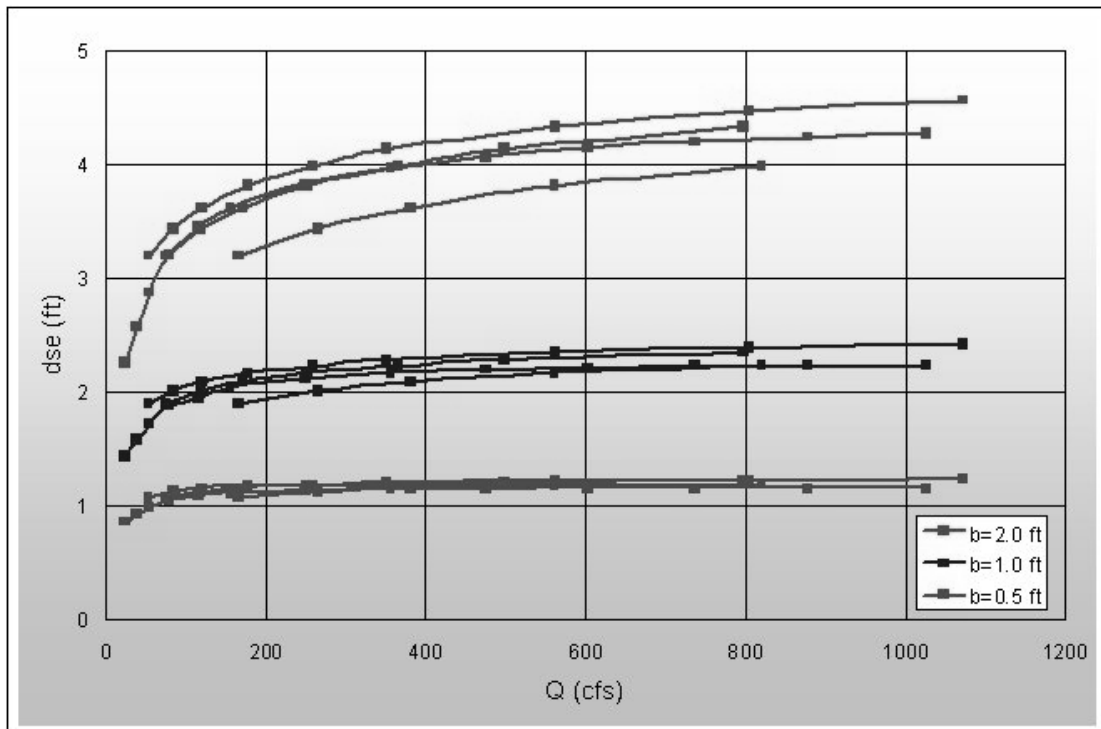


Figure 3.14 Scour hole depth for four different sand grain sizes.

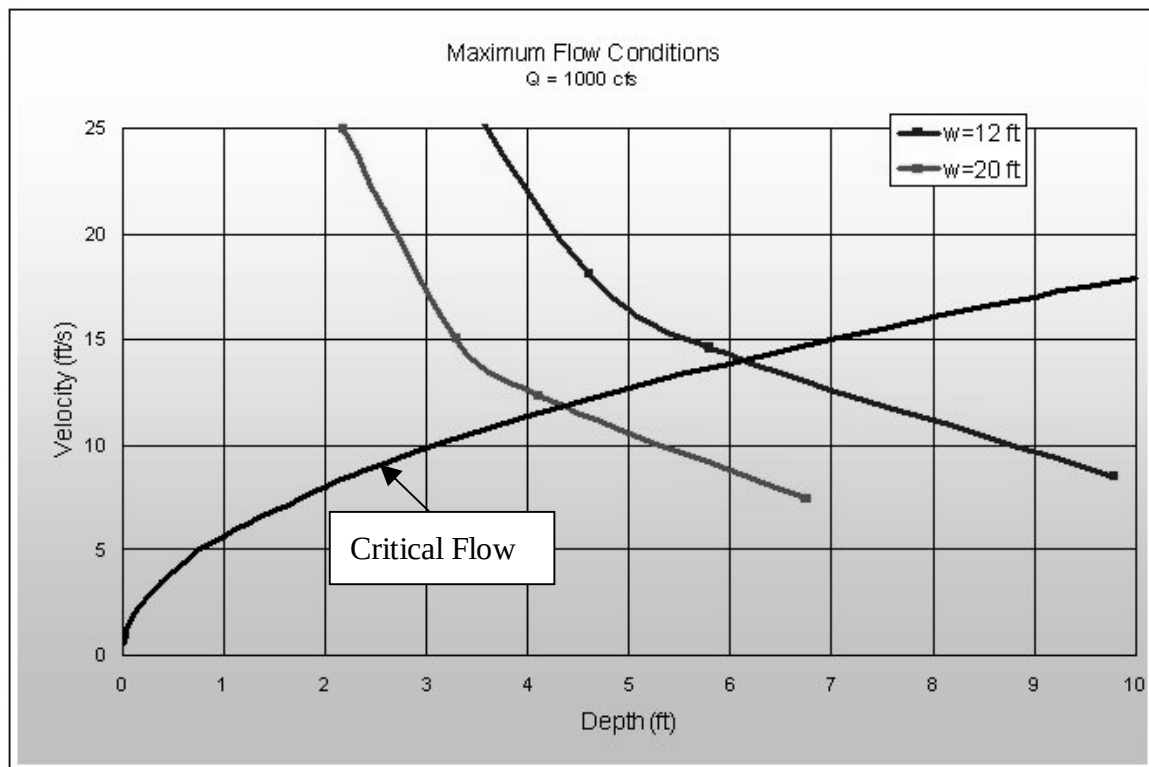


Figure 3.15 Flow comparison for 12 and 20 ft flume widths.

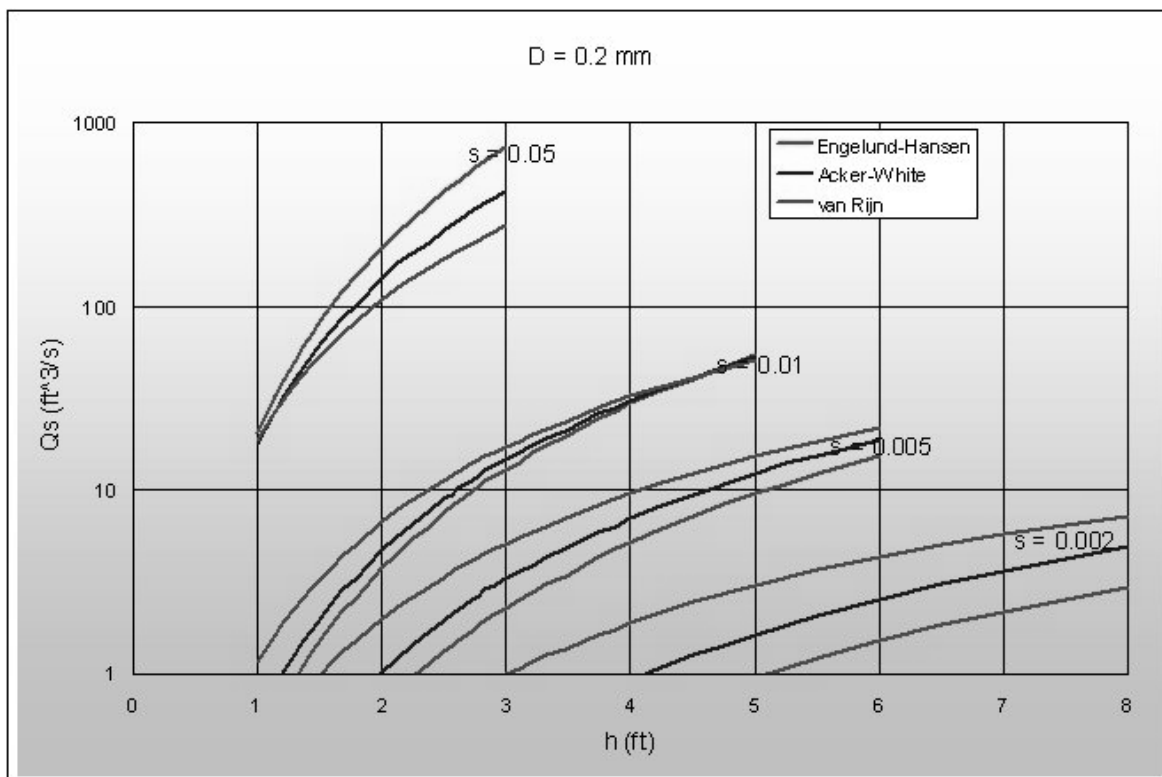


Figure 3.16 Sediment transport rates.

3.3 PUMPS

The design flow rate of 1,000 cfs for the water pumps necessitates a very large pump capacity. The pumps must provide a pressure head on the order of 20 ft depending on the flow rate and slope of the flume. Figure 3.17 shows the pump power requirements for different flow rates at two different pump efficiencies. It is seen that at the design flow rate of 1,000 cfs the pump power requirement is approximately 1.8 megawatts or 3,300 horsepower. If the slurry pumps, which provide an additional 200 cfs, are included in this same power computation, then approximately 2.5 megawatts of power or 5,500 horsepower are required.

The pumping options are to have one large pump or several smaller pumps in parallel. Pumps in parallel provide the more desirable option. Not all experiments will be conducted at the design flow rate of 1,000 cfs. For lower flow rates a single, smaller pump may be used. Pumps in parallel also allow a pump to be taken off-line for maintenance and provide redundancy in a system. Several smaller pumps are less expensive to purchase than one larger pump. Figure 3.18 shows a pump curve for a 60 in. axial flow pump. With this size pump, four pumps would be installed in parallel. This is an axial flow pump from MWI of Deerfield Beach, Florida. Each pump has a flow rate from approximately 200 to 300 cfs. The pump efficiency is 80 to 86% in the operational range.

These pumps may be configured in several different ways; direct-drive electric motors or hydraulic motors which are driven by either diesel or electric motors. Figure 3.19 shows an electric direct-drive installation. For the electric direct-drive, the motors are not variable speed. However, the motors can be obtained with two sets of windings so they run at two different speeds. With four pumps and two speeds, 14 different discrete flow rates may be achieved from 200 cfs to approximately 1,200 cfs. This is shown in Figure 3.20. The cost for four complete pumps and dual speed motors is approximately \$1,200,000. At present Gainesville Regional Utilities (GRU) rates, power costs for the maximum operating conditions are approximately \$50/hr.

Figure 3.21 shows possible installations for hydraulically driven pumps. The hydraulic pumps may be driven by either diesel or electric motors. A pump is shown in Figure 3.22. The cost for the four pump system including water pumps, hydraulic pumps, and diesel engines to

drive the pumps is approximately \$2,000,000. The fuel consumption rate for the four diesel engines is approximately 160 gallons/hr at the maximum flow condition. This fuel cost is approximately \$200/hr. The cost for the four pump system including water pumps, hydraulic pumps, and electric motors is approximately \$1,600,000. At present GRU electric rates, power costs are approximately \$60/hr.

Using hydraulics to drive the pumps provides a more straight-forward means to control flows. However, hydraulic pumps must be provided and the hydraulic pump water combination has a lower efficiency of around 65%. An advantage of the hydraulic approach is that there are other hydraulic systems in the flume which may also be driven by the hydraulic pump. The electrical power requirements are very large. Neither site under consideration for the flume, the FDOT warehouse nor the COE laboratory are wired to provide this level of service. Providing this power will require a transformer and significant site improvements.

As an alternative to using GRU power, an on-site diesel power plant was considered. A pair of 2,000 KW stationary plants costs approximately \$500,000 and operational costs are on the order of \$250/hr. This is not cost effective compared to the other alternatives. The preferred alternative is a hydraulic system because the hydraulic system provides more control over flow rates. Using electric motors and purchasing power is the least cost means of providing this type of system. The cost of the pumps and installing the electric supply is approximately \$1,800,000. The least cost system is to use direct-drive pumps with 14 discrete flow rates at a cost of \$1,365,000.

In addition to the four water pumps, 2 sand slurry pumps are also required. As noted above, the water pumps are capable of passing all of the sediment that is expected to occur under most test conditions. However, the mechanical damage to the pump and piping systems has a very high maintenance cost for the large pumps. It is more cost effective to use smaller slurry pumps and concentrate the maintenance expenses in the smaller pumps where they are less expensive. For the slurry pumps, two 24" sand pumps with a 3 cfs sediment transport rate at 5% are specified. As mentioned above if the sediment concentration goes to 10% then larger transport rates can be accommodated. Beyond this, some sediment must be passed through the main water pumps. For the return pipes, two 24" HDPE pipes were selected. These pipes are recommended for use with abrasive materials, such as sand and water mixtures. These pumps

will be relatively high maintenance items, requiring a re-build every 6 months of heavy operation. The re-build cost is approximately \$30,000 per pump.

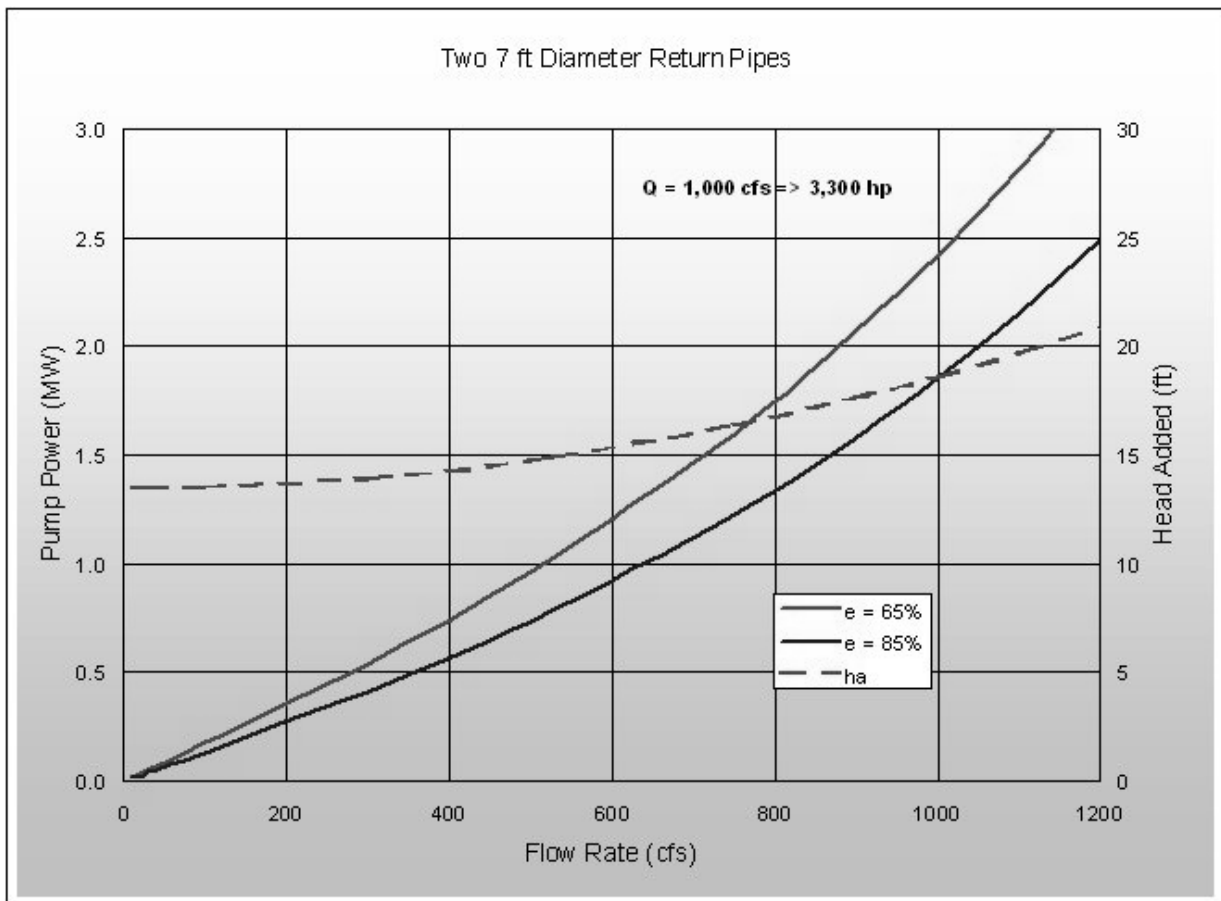


Figure 3.17 Pumping power requirements.

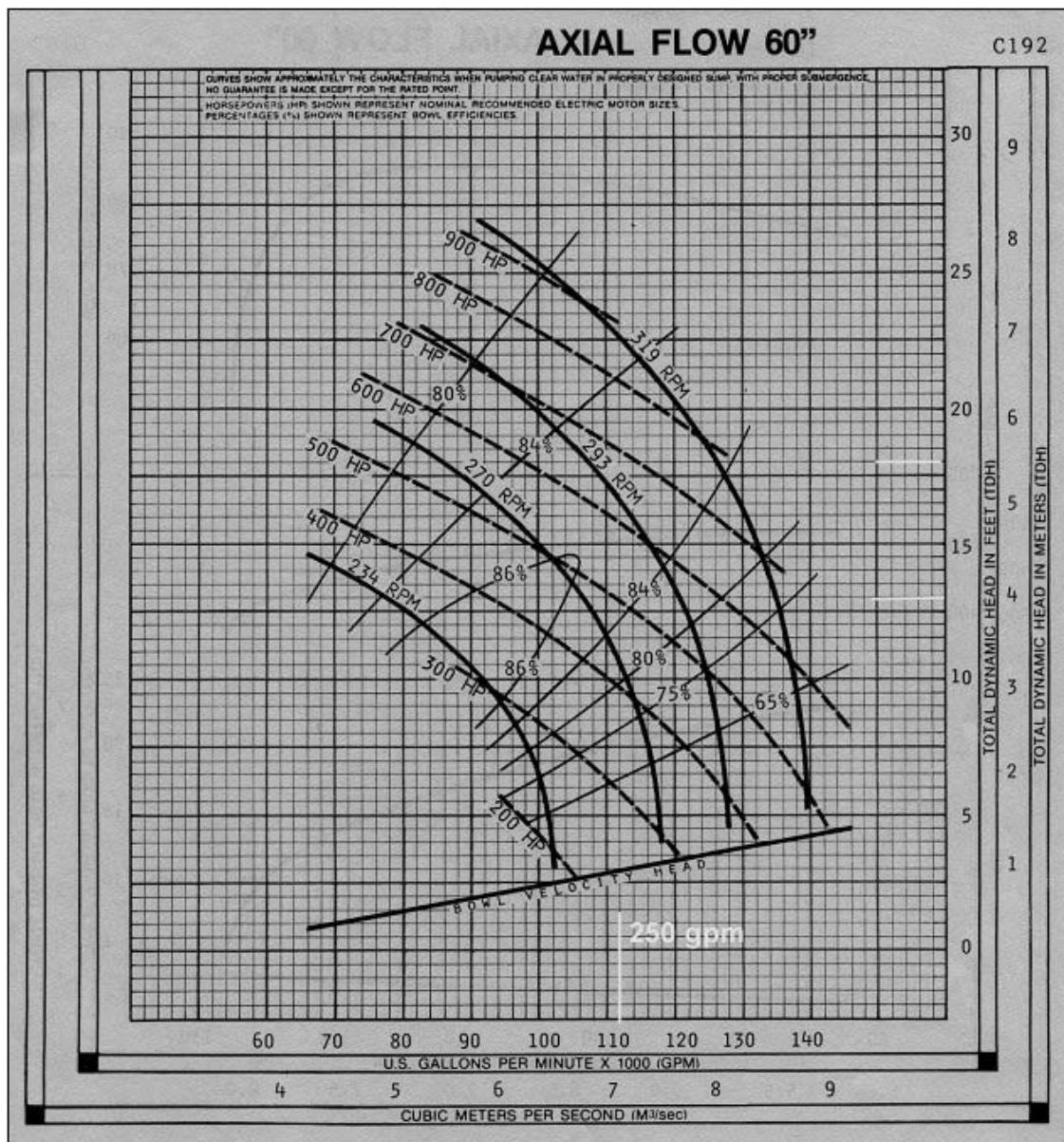


Figure 3.18 Pump curve.

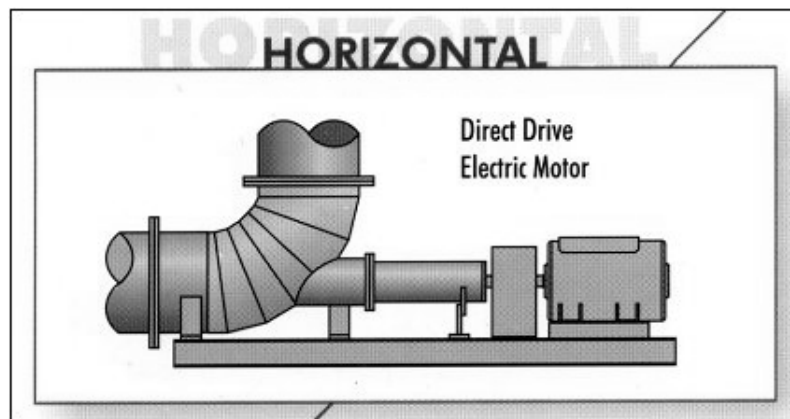


Figure 3.19 Direct drive pump installation.

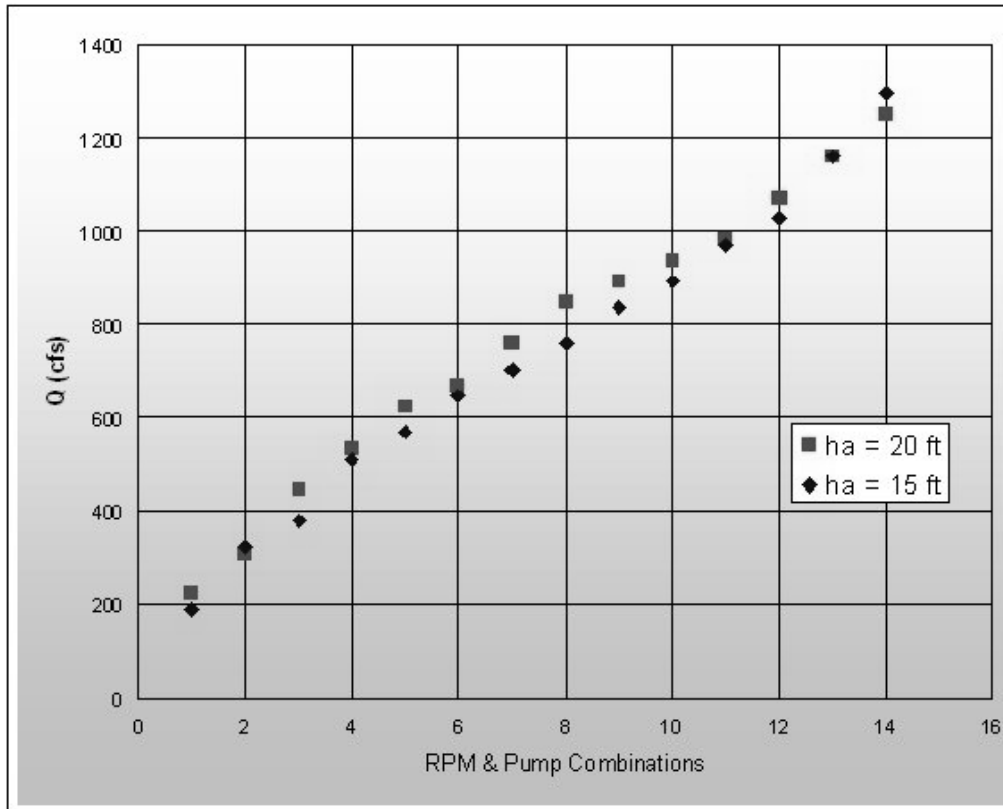


Figure 3.20 Discrete flow rates with 4 two-speed pumps.

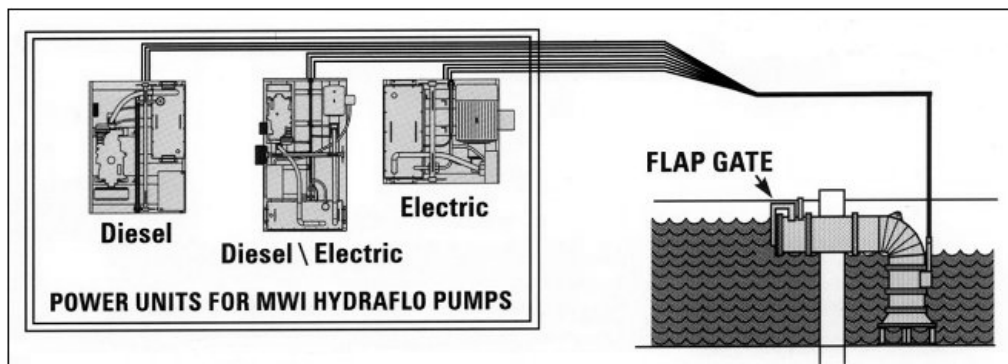


Figure 3.21 Hydraulically driven pump installations.

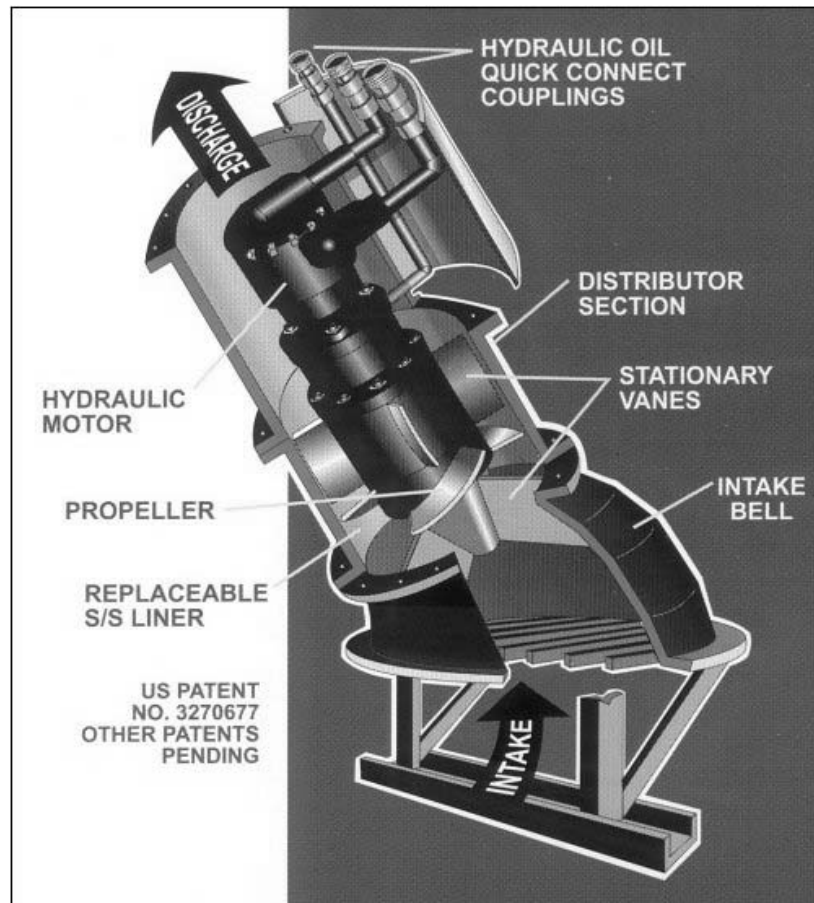


Figure 3.22 Hydraulic pump.

3.4 BUILDINGS AND SITE WORK

Two alternatives are being considered for housing the flume. The preferred alternative is the FDOT warehouse located at the corner of 39th Street and Waldo Road. This site has one main building and several smaller buildings. A summary of the floor space is given in Table 3.1. The distribution of floor space is excellent for the large flume laboratory and almost identical to the existing Coastal Engineering Laboratory (COEL) floor space. The FDOT building is long enough and wide enough to house the flume however the ceiling is too low. Figure 3.23 is an exterior photograph of the main warehouse building at the FDOT facility. Figure 3.24 shows a drawing of the FDOT property. The total property is almost 5 acres which is fenced. In addition

to the main warehouse, which is approximately 41,000 sq.ft., there is 4,000 sq.ft. of office space, 5,700 sq. ft. in a secure metal building for storage, and 2,000 sq.ft. available in a block building. There is also parking, storage, and a large area which could be used for water storage. Figure 3.25 is a photograph inside the main warehouse. The concrete roof is supported by double T beam panels set on concrete beams which are supported on concrete columns. To obtain the necessary vertical clearance for the flume, one section of the roof must be raised. Figure 3.26 shows the columns and roof structure. It also shows the modification of increasing the height of one set of columns and lifting the roof. The feasibility of this change and the associated engineering and construction costs were provided by construction engineering management faculty in the Department of Civil and Coastal Engineering at the University of Florida (UF).

If the FDOT warehouse is not available, an alternative is to construct a metal building at the COEL site on 6th Street. This would be a pre-engineered metal building 100 ft wide by 300 ft long by 38 ft high. The cost for the building shell (roof, walls, windows, doors, insulation, slab, and fabrication) is about twice that of raising the roof at the FDOT warehouse. Some of the cost differential for a building located at the 6th Street site would be borne by the University of Florida. Figure 3.27 shows the layout for the metal building.

The FDOT site has several advantages in that it uses an FDOT facility for work which is related to FDOT objectives. It is also located close to the Waldo FDOT facility and the new FDOT research lab. The COEL site has the advantage of being close to the other hydraulic laboratory facilities which include a shop and access to a wide range of instrumentation. However, either site can meet all of the building requirements to house the flume.

At both sites significant site improvements are required. These primarily relate to the large power requirements and large water volume handling requirements. The power requirements for the pumps are extremely large. Power will have to be brought in directly from the GRU service and a transformer installed. When the pumps are operating at their maximum capacity, the flume will be the largest single building consumer of electricity in the GRU system. The cost of electricity given above for the pumps was based on bulk consumer use. However, it was based on prime-time usage and 24 hour availability. This cost was necessary, as opposed to off-hour peak demand costs, because flume tests must be run continuously without interruption during the testing. Therefore, the least expensive power rate could not be obtained. The other

significant site improvement is water handling and storage. The flume requires a very large volume of water (on the order of 35,000 cubic ft). At the COEL water is provided by an on-site pump. At the FDOT facility water would be drawn from the city water system. The cost would be approximately \$250 to fill the tank at present GRU rates. In either case, refilling the flume with water for each test would result in excessive water use. Also, the use of new water introduces temperature variations into the water being used for the test and may introduce chemical variations due to off-gassing of chlorine as the water ages. For these reasons it is desirable to have on-site storage for the water and recycle as much water as possible for the tests. If the on-site storage basin is 15 ft deep then the planned area is approximately 50' × 50'.

Water that is stored on-site may need to be cleaned for reuse. This necessitates a sediment removal system. The storage area would be constructed as a set of settling basins to allow sediment to be removed from the water by natural settlement. It is possible that chemicals may be added to the water during some experiments. These could be used to reduce surface tension or fluorescent dyes to monitor dispersion processes. Chemicals may also be necessary to control algae or other biofouling. In cases where these chemicals accumulate to a level that interferes with the testing or the instrumentation, replacement of the water may be required. If chemicals are added to the water, then the water will have to be treated as wastewater. If no chemicals are added to the water then it may be possible to discharge into surface waters.

An independent pumping system will be used to fill and dewater the tank. The system should have the capacity to fill the flume in one hour or less to avoid down time. A flow capacity of 8.3 cfs meets this requirement and can be provided by a 30 horsepower pump and a 12" return pipe system. This system feeds into the return pipe just downstream of the 4 main water pipes.

At both sites, foundation work will be required. The weight of the flume is excessive and will require a substantial foundation. Since the vertical requirement for the flume is 34 ft, a portion of the flume will be placed below grade in an excavation. This will reduce the height requirements on the building.

The hydraulic motors which drive the pumps are extremely noisy. Therefore, some type of sound isolation should be installed to isolate these hydraulic motors. At either the FDOT or

COEL sites it is recommended that an outside building be constructed to house the hydraulic pump motors to contain the noise associated with them.

Table 3.1 FDOT warehouse floor space.

Type of Space	FDOT Warehouse (sf)
Lab	40,954
Office	1,624
Shop	2,000
Storage	5,700
Total	50,278



Figure 3.23 FDOT warehouse.

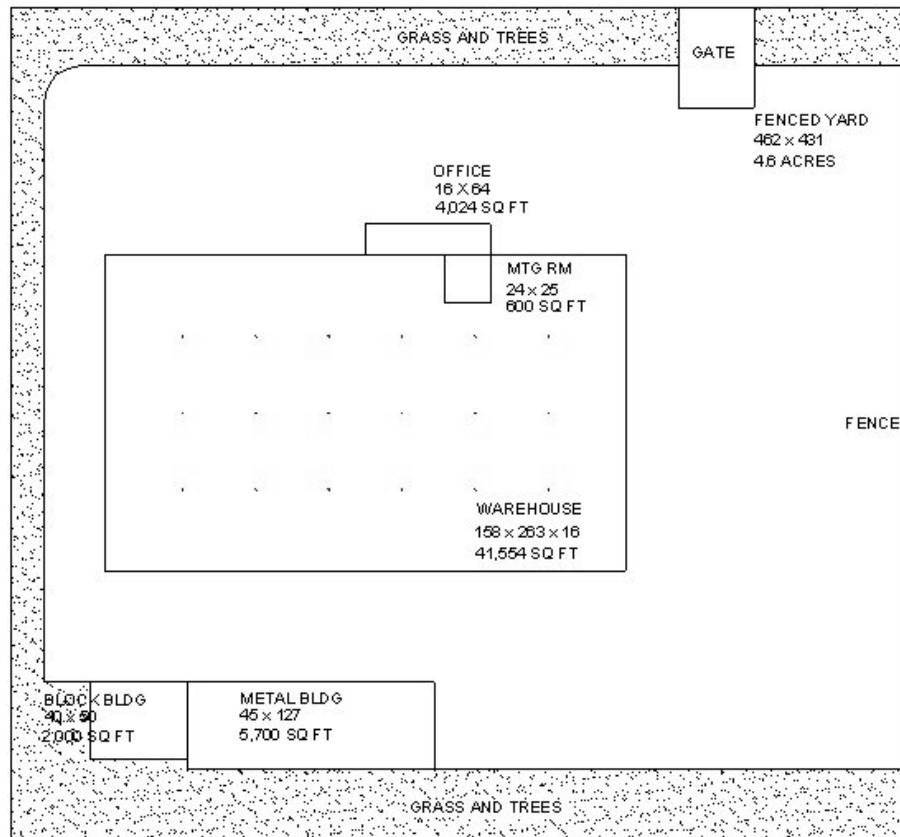
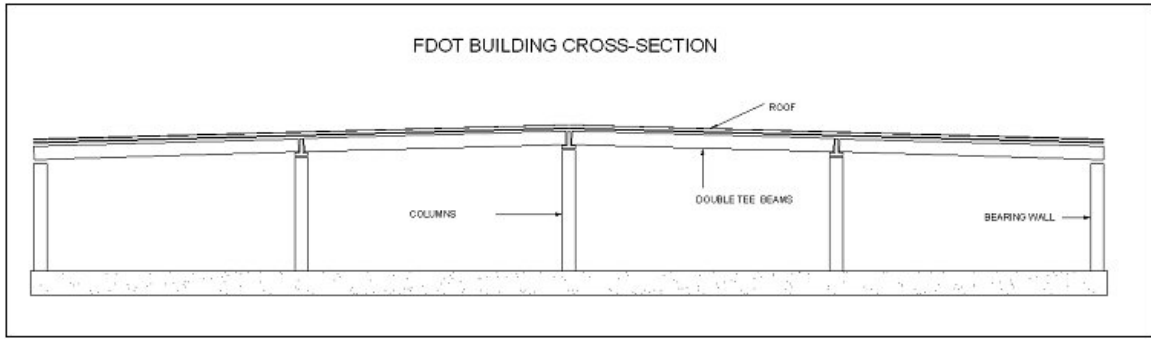


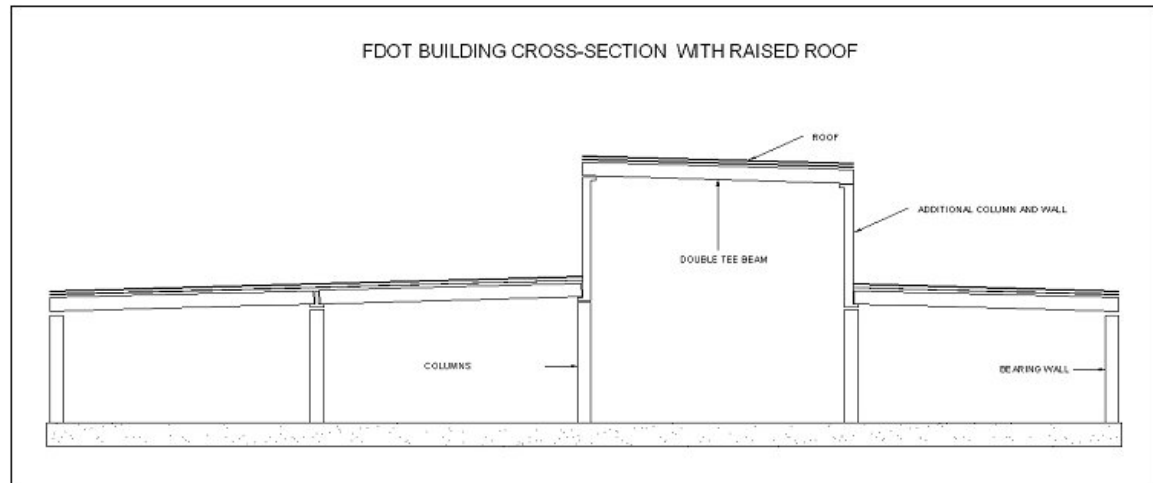
Figure 3.24 FDOT property.



Figure 3.25 Photograph inside FDOT warehouse.



(a)



(b)

Figure 3.26 Roof raising option for FDOT warehouse.

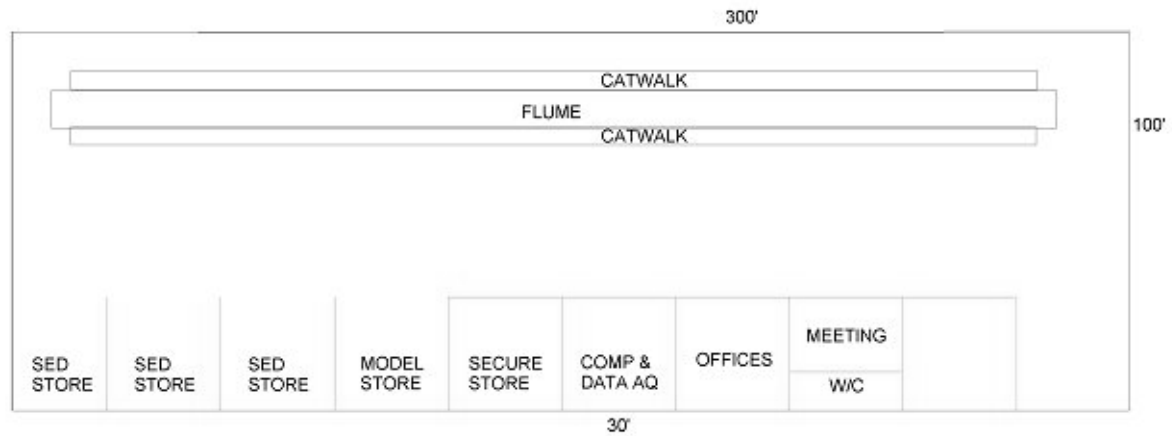


Figure 3.27 Metal building.

3.5 EQUIPMENT COSTS AND INSTRUMENTS

The COEL has a variety of equipment necessary for conducting large-scale hydraulic tests. These include a loader, forklift, pickups, trailers, etc. The COEL also has a full machine shop which includes Acetylene, MIG and TIG welding, milling machines, and a full wood shop with band saws, table saws, etc. In addition, the COEL has a variety of instruments for conducting hydraulic research and design. For velocity measurement there are electro-magnetic current meters, acoustics doppler velocimeters (ADV), and acoustic doppler current profilers (ADCP). For measuring suspended solids there are optical back-scatter sensors (OBS) and turbidity meters. For bottom surveying the COEL has several multi-transducer ultrasonic arrays (MTA) with 3.5 MH and 5 MH with sonar scanning heads. For water measurements, there are continuous flow water density measuring apparatus, conductivity temperature instruments, wave gages, and pressure transducers. For force measurements, there are a variety of strain gages and torque gages. For grain size analysis, there is a sediment analysis lab with roto-taps, a rapid sediment size analyzer, an LISD particle size analyzer, and a sand dyeing capability using fluorescent dyes. The laboratory has a variety of photographic capabilities including underwater still and video cameras, time lapse, video recorders, and remote controllers. All of this equipment would be available to the Florida Flume facility. Also, the technicians and engineers at the lab have experience installing and using these type of instruments and analyzing the output data.

However, several pieces of equipment will need to be purchased as a component of this project. The first is a bridge crane and track hoist to span the flume. The bridge crane will be installed across the downstream end of the flume. The crane will be used to place and remove models, equipment, and sediment in the flume. The capacity of this stationary bridge crane will be sufficient to place a bobcat in the flume. Models at this large scale require the use of equipment for sediment handling in the models. A bobcat would be used to move sediment in the flume and shape the models.

Large scale facilities, such as the proposed flume, involve large volumes of sediment. Typical test conditions in the Florida Flume will involve the use of approximately 400 cubic yards of sediment. Sediment could be placed in the flume using the bridge crane and distributed using bobcats. However, this is an inefficient approach. An alternative is to use a sediment conveyor. Portable sand conveyors are commercially available. A conveyor with a length of 60

ft is necessary for the vertical elevations associated with the Florida Flume. This greatly reduces the time required to replace the sediment in the tank. The sediment can be placed in the tank using the conveyor or the conveyor can be placed in the tank and sediment dumped out over the edge of the tank into a truck to remove sediment.

At both the FDOT and COEL facilities, on-site sediment storage is included. Sediment used in experiments is normally ‘washed’ sediment so that fines do not preclude photographic or visual observations. It is anticipated that three grain sizes would be kept on site. These would be representative of typical grain sizes for Florida applications.

An additional instrumentation requirement is a mobile cart that runs on the rails on the top of the flume. One or more work carts would be required for making measurements and supporting instruments. At least one cart will require accurate positioning so that it can be used to do high-resolution bottom profiling.

3.6 COSTS

Costs were estimated for the first 3 years of the project. All costs are based on those provided by contractors or suppliers of the respective materials or services. Costs were developed in June of 2002. The proposed schedule is to design and begin construction of the flume during year 1. Construction would continue during year 2 and the implementation of instrumentation would also commence. During year 3 the flume will be operated to calibrate and test. After year 3, the flume would be calibrated and available to do project specific work. This schedule is summarized in Table 3.2.

The costs associated with the facility are broken down into the following categories: flume (the channel and the pumps), site work, equipment, instruments, personnel, and operation. The three-year costs associated with each of these categories are summarized in Tables 3.3 through 3.8. The flume costs are summarized in Table 3.3. The cost for the channel was based on estimates provided by MTS Corporation. The costs for the water pumps and sand pumps were provided by MWI. The channel cost is spread over year 1 and year 2. It involves material and labor costs for fabrication. The flume will be built on-site using a low bid contractor. Costs associated with site work are summarized in Table 3.4. Costs associated with raising the roof at the FDOT facility and strengthening the foundation were provided by the construction

engineering department at UF. The costs associated with installing a larger service and transformer to the facility were provided by GRU. All site costs occur in year 1. This is because all are necessary (except for water handling) as a component of the project progress. Equipment costs are summarized in Table 3.5. Instrumentation costs are summarized in Table 3.6. The design and start-up of the flume facility will require a great deal of faculty participation. Personnel costs are summarized in Table 3.7. In addition, UF staff will participate in the project as well as several graduate students in the Civil and Coastal Engineering Department. Table 3.8 summarizes operational costs. The first year these costs are rather minor. However, as projects are undertaken and models are constructed, these costs will become more substantial. After year 3, all such costs will be borne by project work.

Table 3.9 gives a project cost summary. The total project cost is approximately \$6.5 million. Of this total cost 49% is for the fabrication of the channel, and 27% is for the acquisition of the pumps. All other cost components are 10% or less of the total project cost. These costs were based on a flume width of 12 ft. As noted above, FDOT engineers recommended increasing the width to 20 ft with the ability to install a false wall at a 12 ft width. This will primarily influence the channel cost. All other components of the project remain essentially unchanged. MTS engineers did not provide a modified cost estimate for the 20 ft width but estimated that costs would increase approximately 30% for this change. This would represent an increase in total project cost of approximately \$1 million. This brings the total project cost for a 20 ft wide flume to \$7.5 million.

Table 3.2 Project schedule for first three years.

Year 1	Year 2	Year 3
Design & Build	Build & Instrument	Calibrate & Test

Table 3.3 Flume costs.

	Year 1	Year 2	Year 3
• Channel	1,500,000	1,700,000	0
• Water Pumps	0	1,600,000	0
• Sand Pumps	0	170,000	0
	1,500,000	3,470,000	0

Table 3.4 Site work.

	Year 1	Year 2	Year 3
• Roof	300,000	0	0
• Foundation	50,000	0	0
• Power	150,000	0	0
• Water Handling	50,000	0	0
• Interior	10,000	0	0
	560,000	0	0

Table 3.5 Equipment costs.

	Year 1	Year 2	Year 3
• Crane & Hoist	77,000	0	0
• Conveyor	0	30,000	0
• Cart	0	8,000	0
• Cat Walk	20,000	0	0
	97,000	38,000	0

Table 3.6 Instrumentation costs.

	Year 1	Year 2	Year 3
• Data Acquisition	0	20,000	0
• Data Archive	0	5,000	0
• Water Elevation	0	5,000	0
• Bottom Profiler	0	20,000	0
	0	50,000	0

Table 3.7 Personnel costs.

	Year 1	Year 2	Year 3
• Faculty	96,854	111,904	126,064
• Staff	55,922	70,679	81,327
• Grad Student	17,640	37,044	38,896
	170,416	219,627	246,287

Table 3.8 Operational costs.

	Year 1	Year 2	Year 3
• Materials	10,500	31,500	10,500
• Fee Waiver	5,134	11,320	11,886
• Water/Power	0	14,700	27,300
• Pump Main	0	5,250	10,500
• Travel	2,100	2,100	4,200
	17,734	64,870	64,386

Table 3.9 Project cost summary.

	Year 1	Year 2	Year 3	Total	%
Channel	1,500,000	1,700,000	0	3,200,000	49
Pumps	0	1,770,000	0	1,770,000	27
Site Work	560,000	0	0	560,000	9
Equipment	97,000	38,000	0	135,000	2
Instruments	0	50,000	0	50,000	1
Personnel	170,416	219,627	246,287	636,330	10
Operation	17,734	64,871	64,386	146,321	2
	2,345,150	3,842,498	310,674	6,498,321	

CHAPTER 4

COST-BENEFIT ANALYSIS

4.1 APPROACH TAKEN

A cost to benefit analysis was performed for one of the potential uses of the proposed facilities. Most of Florida's population is concentrated along the coast. Likewise most of the FDOT's larger and more expensive bridges are over tidal waterways and streams. Design water flow conditions in Florida's coastal waters are almost all produced by hurricane storm surges. These storm surges produce high water levels and large flow velocities but for short durations. Sediment scour at bridge foundations require a finite amount of time to reach an equilibrium value. It is difficult to predict the rate at which scour occurs and thus the FHWA bridge foundation scour manual (Hydraulic Engineering Circular No. 18) requires that equilibrium scour depths be used for design. Miller and Sheppard at the University of Florida recently developed a mathematical (and computer) model for estimating the rate at which scour occurs. This model which works well for laboratory scale structures has yet to be verified for large scale prototype structures. It does however show that scour depths at large bridge piers never reach equilibrium values during a storm surge generated flow event. In some cases scour depths are less than 10% of the equilibrium value. If this model can be verified this could result in substantial reductions in design scour depths and therefore foundation cost savings for larger bridge piers. The proposed flume facility is large enough to test prototype piers at design flow velocities that simulate storm surge generated flow conditions. It is for this reason that the "time rate of pier scour research" was chosen for the cost/benefit analysis. Other research topics that could have been used include 1) the use of scour protection measures on existing and new bridges, 2) wave induced scour at bridge piers, bridge abutments, revetments protecting roadways, etc.

4.2 SCOUR ANALYSES

Several recently constructed bridges were used in the cost/benefit analysis since the design flow conditions were already known from the bridge hydraulics reports (BHRs). The bridges used were as follows:

1. SR. 30 Hathaway Bridge over St. Andrews Bay (B.N. 460112 & 460113)
2. SR 105 (A1A) Ft George River Inlet Bridge (B.N. 720692)
3. SR 300 over Apalachicola Bay – St. George Bridge (B.N. 490100)
4. Jensen Beach Causeway – Frank A Wacha Bridge (B.N. 890145)
5. Evans Crary (A1A) State Road Bridge (B.N. 890158)
6. Ernest F. Lyons (A1A) Bridge over the ICWW/IRL (B.N. 890060)

These bridges represent a range of pier size, design flow velocity and sediment size conditions. Equilibrium scour depths were already known for the piers on these bridges from the BHRs. Equivalent circular pier diameters were computed for each of the complex piers using techniques developed at the University of Florida in conjunction with researchers at FHWA and included in the current version of HEC-18. The Miller and Sheppard model was then run for the unsteady flow conditions produced by the 100 year return interval storm surges for each pier on these bridges. The maximum scour depth computed for each pier was recorded along with the equilibrium value.

4.3 COST SAVINGS ANALYSIS

The scour difference information obtained in section 4.2 was provided to structural engineer, Henry Bollman in the FDOT central office. Mr. Bollman redesigned the piers on the subject bridges based on the new design scour depths. In some cases this resulted in smaller and/or a fewer number of pier components while in other cases it only reduced the depth of required pile penetration. When he finished analyzing these bridges he extrapolated the results to include the bridges proposed for construction in Florida over the next 5 years. The results of his analysis were presented to Mr. Ken Morefield in the form of a letter, a copy of which is presented below.

From: Henry T. Bollmann, Senior Bridge Designer

To: Ken Morefield,

Copies: Rick Renna,

William Nickas,

Bob Nichols, title what should go here?

Dr. Max Sheppard, Hydraulics Professor, U of F

Subject: Large Hydraulic Flume / Bridge Cost Savings

Dear Ken,

As you know, a new large Flume has been proposed at the University of Florida for our use and for others, especially Florida Universities. The FDOT has been approached as a possible funding source.

I have attempted to estimate the construction cost savings brought about through the use of better bridge scour predictions that involve the time rate of scour and also through the use of scour mitigation measures applied to new construction.

I believe that a construction cost savings of about 1.0 dollar per square foot of bridge deck is likely to be derived for bridges over water where ship impact is not the controlling load case (because the ship impact design load case is not conducted with 100 year scour present).

Based upon past bridge project history in Florida one could conservatively estimate that an annual savings in excess of \$500,000 is likely. This can be seen by reviewing the cost savings predicted and shown here.

The \$ savings can only be roughly estimated because the multitude of variables involved make each bridge site unique.

Additional details and discussion follow:

a. Why a large Flume?

The FDOT has experienced many hydraulics, sediment transport, and sediment scour problems over the years and there will be new problems in these areas in the future. Many of these problems require the use of a laboratory flow channel (flume) for their solution. One example problem is sediment scour at bridge piers. In this case, a flume is needed both to conduct scale model tests of actual piers and to conduct research to improve the methods and equations for design scour depth prediction. FDOT sponsored research at the University of Florida over the last decade has resulted in a number of improvements in scour depth prediction and savings in bridge foundation costs. There is, however, much more work that needs to be done, especially for the types of design flow conditions that exist in Florida (short duration storm surge generated flows). Florida has been on the forefront of bridge scour research due to its vast number of large bridges and a number of astute and conscientious FDOT employees that recognized the cost benefits of research in this area. Other states are now seeing these benefits and recognizing the needs for additional work as evidenced by one of the new NCHRP initiatives (\$600,000 project to investigate time rate of scour at large, skewed structures starting in 2004). Having a flume such as the one proposed in Florida would insure that these types of national research funds would come to the state.

Notably, the analysis presented here only addresses one of many FDOT hydraulics and sediment related problems that can be addressed in the proposed flume facility. The FDOT cost benefits associated with some of the uses of the flume are more difficult to predict but it is anticipated that additional savings will result in these areas as well and thus should be taken into consideration in the overall assessment of the proposal. The following analysis only addresses bridge scour related issues and potential cost benefits that can be derived from scour research in the proposed flume.

Existing scour prediction methods (HEC 18) do not properly include the time rate of scour. Thus the equilibrium scour predicted (100 year scour) may actually not “have time” to develop during a storm event.

Currently we are not permitted to use scour mitigation, such as the placement of rubble around pier foundations, on new bridge construction. The reason for this is a general lack of confidence in the design procedures associated with designing the protective rubble blanket.

Research conducted in a large Flume, where the significance of scale is reduced, is needed to develop new design procedures which account for time rate of scour and also where scour mitigation techniques can be tested so that this may be used as an effective means in the future to eliminate scour altogether (as is current practice in some other countries).

b) How much scour reduction is predicted when time is included in the analysis method?

This varies with soil conditions, water velocities, water depth and foundation size and shape.

Dr. Max Sheppard has made some estimates for FDOT to use in order to estimate construction cost savings if time rate of scour were included to predict the 100 year scour event.

The St. George Island Bridge over the Apalachicola Bay currently under construction:

For the 30 waterline foundations supported on clusters of 54 inch diameter cylinder piles HEC-18 predicted 33 feet, Sheppard's equations (used by contractor) predicted 21 feet and if time is included in the prediction the 100 year scour is just 6 feet.

For the 125 piers which each consist of 3 free standing cylinder piles (pile bents) HEC-18 predicted 18 feet, Sheppard's equations (used by contractor) predicted 9 feet and with time included the scour is just 2 feet.

The Hathaway Bridge located in St Andrews Bay and currently under construction:

Typically 25 feet less scour is predicted at each of 20 water line footings supported on 60-inch diameter cylinder piles when including time. Sheppard's equations show 33 feet of scour and with time accounted for only 8 feet of scour.

The Jensen Beach Causeway Bridge over the ICWW north of the St Lucie Inlet currently under construction:

There are 7 water line footings supported by clusters of plumb 30 inch piles. The water velocities are low and the 100-year scour predicted is 14 feet. Because the velocities are low the reductions in scour with time are also relatively small, only about 4 feet.

The Evans Crary Bridge crossing the St Lucie River between Stuart and Sewall's Point:

There are 16 waterline footings supported on clusters of plumb 30 inch piles. The 100 year scour is about 11 feet and the reduction anticipated by including time is only about 3 feet.

The Ernest F Lyons (A1A) Bridge over the ICWW connecting Hutchinson Island to Sewall's Point.

There are 28 waterline footings supported by clusters of plumb 30 inch piles. The 100-year scour is typically 15 feet and the reduction anticipated by including time is about 7 feet.

SR 105 (A1A) Fort George River Inlet Bridge

There are 16 freestanding pile bents. Each bent consists of 7 plumb 30-inch piles. The 100-year scour is 35 feet and the reduction anticipated by including time is only 3 feet. (This is not a typical situation because the channel migrates (thalweg) from one end of the bridge to the other.

c) How is bridge design affected by a reduction in the 100-year design scour either through mitigation measures or by including time in the analysis?

The upper layers of soil typically carry only a small portion of the axial design load and thus axial capacity is usually not the primary beneficiary of a reduced scour. However the lateral support derived by the soil, even weak soil near the mud line is beneficial and greatly reduces pile-bending moments. This reduction in bending moment often will result in allowing the designer to utilize a reduced pile size or even less piles.

There is a definite trend to design bridge foundations utilizing plumb piles. There are two primary reasons for this: Construction costs for piles installed plumb can be as much as 50% less than when driven on a batter. Rapid advances in computerized design techniques allow for the computation of non-linear soil structure interaction.

d) What \$ savings can be expected for some of the bridges mentioned in b above?

St George Island Bridge: The design of the main piers, which all have waterline footings, is controlled by ship impact and thus scour is not an issue. Using rubble to control scour would be an unlikely solution here because of environmental reasons.

The designs of the 125 bents which have 3 free standing 54 inch piles is controlled by AASHTO group loadings and not ship impact. This section of bridge is 15,371 feet long. For these bents the reduction in time dependent scour (7 ft) allows for some reduction in bent forces and a reduction in pile size from 54-inch diameter to 50-inch diameter. The estimated savings are \$783,000 or \$1.00/sq ft of bridge deck.

Hathaway Bridge: The design is not controlled by ship impact but is controlled by axial pile loading. The significantly less scour depth (25 ft) allows for a theoretical reduction in pile size to achieve the same structural performance ratio as the original design. The construction cost savings are estimated to be about \$486,000 or \$1/sq ft.

Jensen Beach Causeway Bridge: Eliminating scour with the use of rubble would save about \$144,000 in pile costs less \$50,000 in cost of rubble protection for a savings of \$94,000 or \$2.00/sq ft.

The Evans Crary Bridge was controlled by ship impact and thus scour is not an issue here.

Fort George Inlet Bridge: Eliminating scour with the use of rubble would save about \$320,000 in pile costs less \$163,000 in cost of rubble for a savings of about \$157,000 or \$1.0/ sq ft.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

This report covers an investigation of the feasibility of designing and constructing a large hydraulic/sediment transport flume in Florida to address Florida Department of Transportation present and future problems in these areas. A survey of existing flumes at government laboratories and Universities was conducted to see if there is an existing flume with the capabilities of the proposed facility. It was determined that such a flume does not currently exist. This was followed by a workshop with representatives for all FDOT districts and the central office, the U.S. Army Corps of Engineers, the Florida Department of Environmental Protection and the University of Florida. A preliminary flume facility design was presented at the workshop for the purpose of initiating discussion. Many aspects regarding the feasibility of such a facility such as 1) is a flume with the proposed capabilities needed to address FDOT existing and anticipated hydraulics/sediment transport problems, 2) is the proposed facility the proper size and does it have adequate capabilities, 3) where should it be located, 4) what agency/institution should own and/or maintain the facility, and 5) how would the design/construction be funded were discussed. There was a consensus among the workshop attendees on a number of the discussion topics and these are summarized below:

1. There is a need for a flume with the approximate capabilities of the proposed facility. With Florida's vast coastline and elaborate roadway and bridge system in areas subject to storm surge inundation and with Florida's active research program in coastal engineering, coastal hydraulics and bridge scour Florida is a logical site for such a facility.
2. Regarding the size and capabilities of the flume it was recommended that the width of the flume be expanded from the proposed 12 ft to 20 ft with an adjustable wall that could reduce the width to 12 ft when very high flow velocities are required. It was agreed that the flume should be designed for a wave maker but that this could be added at a later date to minimize the initial cost.
3. A cost-benefit analysis should be performed to determine if the cost savings to the FDOT resulting from the research justify the cost of the facility. Since such a wide range of research could be conducted in the proposed facility it is difficult to anticipate many of the benefits and cost savings. For this reason one of the main areas of research should be analyzed and the results extrapolated.
4. The FDOT felt that facility ownership should not be with the FDOT.

5. If the facility is constructed the FDOT would consider covering the operation and maintenance for some limited period of time (on the order of 5 years) after which the University would cover these costs with overhead from externally funded research contracts and grants.

A cost benefit analysis was performed by Henry Bollman with the FDOT based on potential scour depth reductions resulting from flume research provided by the University of Florida. He analyzed the cost savings for several actual bridges constructed in Florida over the last few years and extrapolated the results to those bridges to be constructed in Florida over the next five years. His analysis shows substantial savings resulting from this single line of research. The total cost savings and improvements in roadway and bridge design would be many times this value when all potential research in the proposed facility is taken into consideration.

5.2 CONCLUSIONS

A facility such as that described in this report is needed to help provide answers to current and future hydraulics/sediment transport problems confronting the Florida Department of Transportation. Many of the problems experienced by Florida are experienced by other states, especially the states on the East and Gulf of Mexico coasts. The DOTs in these and the other states would provide a source of steady funds for testing and research once the facility is constructed and operational. There are less applied types of research such as that supported by the National Science Foundation and the Office of Naval Research that can also be conducted in the proposed facility. This is yet another source of funding for research in the facility that will benefit the FDOT in the future and make it self sufficient.

As with any major research facility, the most difficult part is in obtaining the necessary funds for design and construction. Most agencies are willing and eager to fund good research in the facility once it is online. Ideally all of the state DOTs and the other agencies that would benefit should share in the construction costs. This, however, if not impossible, is impractical. The University of Florida has agreed to provide a site for the facility and is committed to maintaining qualified researchers and support staff needed to address FDOTs problems in these areas of applied research. The Civil and Coastal Engineering Department at UF is particularly committed to this line of research and has a proven track record in providing research results that improve design and save money and resources. The proposed facility is world class and as such

would attract researchers and funds from outside the U.S. as well as other states. The FDOT is currently a leader in the country in this area of research due to the vision and hard work of a number of its employees. In order to continue this leadership role it is recommended that the FDOT give serious consideration to funding the proposed facility.

CHAPTER 6

PRINCIPAL INVESTIGATORS

This project will be directed by Drs. Max Sheppard and Bill McDougal. Dr. Sheppard has been a major contributor to recent advancements in scour protection and design. He has a long-term relationship with the FDOT and was the co-recipient (with Rick Renna of the FDOT) of the Davis Productivity Award in 1995 for cost savings in the millions of dollars to the FDOT. Dr. Sheppard has a keen sense of the FDOT's hydraulics and bridge scour problems. Over the last 15 years he has directed most of his research efforts toward FDOT related issues.

Bill McDougal is a new member of the faculty at the University of Florida. He was previously in the Civil Engineering Department at Oregon State University which is the site of the largest wave flume in the United States. Dr. McDougal has considerable experience in large-scale physical modeling.



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**DONALD MAX SHEPPARD
RESUMÉ**

Education:

1969	Arizona State University	Ph.D. in M.E.
1962	Texas A & M University	M.S. in M.E.
1960	Lamar State University	B.S. in M.E.

Areas of Interest/Expertise:

Bridge Scour
Structure Induced Scour
Coastal and Ocean Hydrodynamics/Processes
Aeolean Sand Transport
Response of Ocean Structures To Hydrodynamic Loading
Hydrodynamic Forces on Fixed and Floating Structures

Abbreviated Employment History:

3/04-Present	Professor Emeritus, Civil and Coastal Engineering Dept., University of Florida
9/99 - 2/04	Full Professor, Civil and Coastal Engineering Department, University of Florida
7/84 - 9/99	Full Professor, Coastal and Oceanographic Engineering Dept., Univ. of Florida
9/81 - 5/84	Head, Oceanography Group, Mobil Research & Development Corporation, Dallas, Texas, Full Professor (on leave of absence)
6/78 - 8/81	Acting Chairman, Coastal and Oceanographic Engineering (COE) Department and Director of COE Laboratory

Relevant Experience:

Clearwater Local Scour Research – USGS-BRD Laboratory Turners Falls, Massachusetts
Development of Single Pier Scour Equations Used in Florida
Live Bed Local Scour Research – University of Auckland
Numerous Physical Model Studies for Bridges in Florida, Maryland, California
Storm Surge Hydrographs for Florida Coastline
Effects of Suspended Fine Sediment on Equilibrium Scour Depths
Local Scour at Complex Bridge Piers
Time Rate of Local Scour Predictions
Field Measurements of Local Scour at Bridge Piers
Development of Test Apparatus for Measuring Rate of Erosion Properties in Non-Cohesionless Sediments and Rock
Flow Discharge and Tide Measurements at Nine Tidal Inlets in SE Florida

BRIEF RESUME

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FIELDS OF SPECIALIZATION

Coastal and ocean engineering, hydraulic engineering, erosion control

DEGREES

B.S., Oceanography, Humboldt State University 1976
B.S., Environmental Engineering, Humboldt State University 1976
MCSE., Civil Engineering, University of Delaware, 1979
Ph.D., Civil Engineering, Oregon State University, 1982

PROFESSIONAL REGISTRATION

Civil Engineering (Oregon and Alaska)
Water Rights Examiner (Oregon)

ACADEMIC POSITIONS

Instructor through Professor, Oregon State University, 1978-2001
Director, Coastal Engineering Lab, University of Florida, 2002- present
Eight international visiting scholar positions

PROFESSIONAL SOCIETIES

American Geophysical Union, American Society of Civil Engineers, American Society of mechanical Engineers, Association of Coastal engineers, International Erosion Control Association, International Association of Hydraulic Research, International Navigation Association, Shore and Beach, Sigma Xi

Professional Service

Served on many professional committees. Several examples are:

Editor in Chief, *Journal of Waterway, Port, Coastal and Oceanographic Engineering*, ASCE, 1990
1992; Organizing Committee, International Conference on Coastal Engineering, Orlando, Florida,
1996; Co-Chairman, Coastal Sediments '99 Conference, Long Island, New York, 1999

Publications

Approximately 100 journal and conference publications on many topics in fields of specialization.
Text Book: *Structural Dynamics* (1998) Tedesco, McDougal and Ross, Addison-Wesley, 816pp.

Consulting Activities

Projects in variety of areas including: river and marine outfalls; marina layout and flushing; revetment and breakwater design; rock, gabion, and flexible mat channel stabilization; river, marsh, and tide pool rehabilitation; wave hind casting, transformation, and statistics; beach profile and shoreline change modeling; wave forces on fixed and floating structures; artificial island design; shoreline recession and inundation; co-owned and operated erosion control construction company

International Experience

Host for more than 10 visiting international scholars

Foreign expert for World Bank

Participated in research and engineering projects in over 25 countries