CHAPTER ONE HUNDRED SIX

A NEW OSCILLATORY FLOW TUNNEL FOR USE IN SEDIMENT TRANSPORT EXPERIMENTS

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ABSTRACT

The details of a new oscillatory flow tunnel at Scripps Institution of Oceanography are discussed. The flow tunnel has a large cross-section and large water excursion distance. The piston motion is programmable. The test bed can be tilted. These, and other aspects, make the facility useful to a wide variety of oscillatory flow sediment transport experiments.

INTRODUCTION

A new research facility, an oscillatory flow sediment transport tunnel, has recently been completed at the Hydraulics Laboratory, Scripps Institution of Oceanography, University of California, San Diego. The facility simulates many aspects of sediment transport on beaches, and its primary purpose is to be used in experiments which increase the understanding of granular-fluid mechanics in oscillatory flows. The facility is shown in Figure 1. It is built in the shape of a flat U-tube with a long, rectangular, center section and cylindrical risers on either end. When being operated, the facility is completely filled with water, and a piston in one of the vertical risers creates an oscillatory flow which moves sediment in the test section (the center portion of the horizontal section). The main components of the facility, as shown schematically in Figure 2 from right to left, are:

1) a hydraulic ram which drives the piston,
2) the piston and piston cylinder,
3) a flow straightener and turbulence decay section,

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FIGURE 1: Photograph of the Oscillatory Flow Tunnel at Scripps Institution of Oceanography.

4) a sediment trap,
5) the test section,
6) a pivot with jack to tilt the entire facility,
7) a recirculating pump,
8) a second trap, decay secton and flow straightener, and
9) a reservoir.

DESCRIPTION OF THE FLOW TUNNEL

TEST SECTION

The maximum oscillatory water particle displacement in the test section is 1.75 meters. At a minimum period of 3.5 seconds, the maximum sinusoidal velocity is 1.6 m/s. A maximum steady flow of 0.2 m/s, driven by the recirculating pump, can be superimposed upon the oscillatory flow. The steady flow can be run in either direction.

The test section is 39 cm wide by 40 cm high. The working cross-section with a 10 cm deep sand bed is 39 cm by 30 cm. The test section is 7.0 meters long (four water particle excursion lengths). The test section has clear acrylic plastic side walls (3.2 cm thick) and top wall (5.0 cm thick). These are externally reinforced by steel I-beams. The thick sides and lid were designed to minimize deflection and consequent attenuation of the water column velocity.

At the center of the test section, there is a window on each side that is unobstructed by external supports for 1.75 meters (a maximum excursion length). This can be used for photography or other visual observations. The other windows vary in length from 50 to 75 cm. The bottom (also I-beam reinforced) is made of fiberglass coated plywood.

The top of the entire test section is hinged and sealed with an O-ring. It can be opened with a hand-operated worm screw winch to allow easy access to the test bed. Between experiments, the bed is re-leveled by means of a cart, which rides on the top surface of the side walls (the O-ring sealing surface). The cart has an adjustable wiper blade which extends down to plane the bed. When in operation, the lid is clamped shut at each vertical I-beam support. The lid has a series of small ports which can be used to inject dye into the tunnel and to purge trapped air bubbles.

The test section is an integral part of a deep steel truss framework which was designed for minimum structural deflection with a full water load. When filled with water and unsupported at the ends, the maximum deflection of the truss is approximately 3mm. During construction, an initial camber was fabricated into the truss so that when loaded, the test section would become flat.

TRAP AND TURBULENCE DECAY SECTIONS

There are identical sediment traps at each end of the test section. These sections are 1.75 meters long (an excursion length) by 39 cm wide

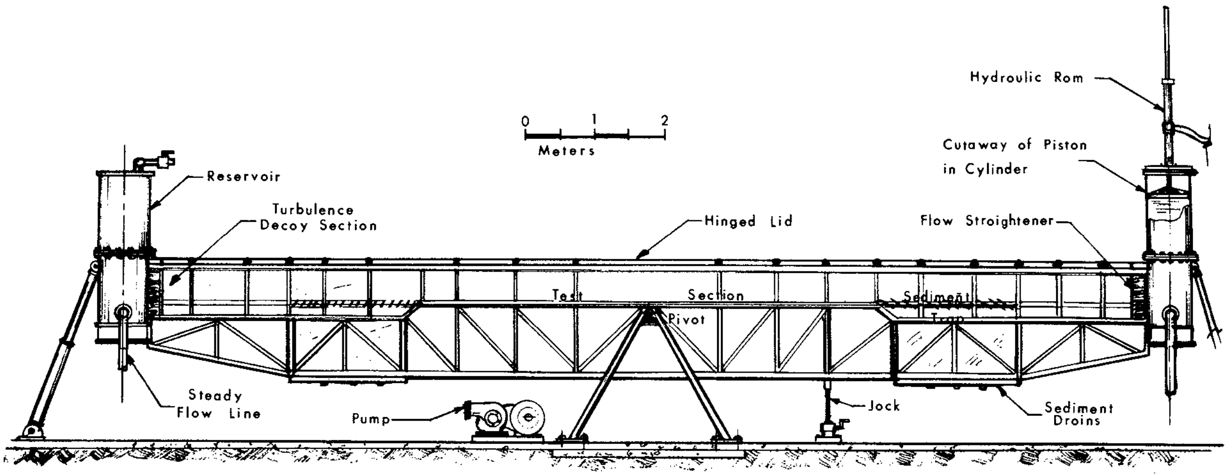

FIGURE 2: Schematic of the Oscillatory Flow Tunnel showing the important sections.

by 1.41 meters deep. Between each trap and vertical riser, there is a turbulence decay section. The turbulence decay sections are 1.75 meters long, by 39 cm wide by 57 cm deep. One of the two side walls of the trap and decay sections is made of I-beam reinforced clear acrylic plastic (3.2 cm thick). The other side and the bottom are made of I-beam reinforced, fiberglass coated plywood. The top of the trap and decay section is also a hinged clear acrylic plastic lid (5.0 cm thick), sealed in the same manner as the test bed lid. The three lids allow easy access to the entire horizontal portion of the facility.

The sediment traps have servo actuated, horizontal, louvered covers. When a trap is the upstream trap, the louvers close, and the water flows past a flat plate boundary. When the flow reverses and a trap becomes the downstream trap, the louvers open to allow the sand to enter the trap. The louvers are actuated by the same electronics that control the piston motion. An offset can be added to account for a superimposed steady flow.

The sediment is both carried into the trap by gravity and by a small current. This current exits the trap through a one-way valve and then flows beneath a false bottom in the turbulence decay section and finally into the vertical riser. The one-way valve stops any return current when the flow reverses.

The top of the trap covers are nominally 2 cm below the level of the sand bed (32 cm from the top of the channel). However, this elevation has been made adjustable to allow for changes in the sand bed thickness or the distance between the top of the bed and the top of the louvers. The louvers can be set anywhere between 27 and 37 cm from the top of the channel.

There are nine rectangular funnels which cover the bottom of each trap (arranged 3 x 3) with a drain valve beneath each. These allow the sediment to be removed. The three center funnels (on the lengthwise axis of the facility) are each 10 cm wide and are the only ones used to collect data. The sediment that collects in the outside funnels are affected in unknown ways by the side walls of the channel and trap covers. The bottom of the trap is bolted to the sides and sealed with an O-ring. The bottom, with the funnels and drains attached, can be dropped out to allow further access to the trap area.

The turbulence decay section has a false bottom whose elevation is adjustable to match the elevation of the louvers. Beneath the false bottom is the one-way flow section described above. In each turbulent decay section next to the vertical riser, there is a flow straightener. This consists of a cloth screen sandwiched between two pieces of honeycomb. The screen is a fine mesh plankton net (nominal 0.05 mm mesh size opening) which stops sand from reaching the vertical risers (and the piston O-ring). The honeycomb nearest the vertical riser has 4.7 mm (3/16th inch) stainless steel cells. Its primary purpose is to support the screen. The honeycomb on the test section side supports the screen and also (along with the screen) acts to eliminate the large scale turbulence created by the elbow in the flow. This honeycomb is made of packed soda straws (double hole coffee stirrers) 12.5 cm long by nominally 1.5 mm in diameter.

PISTON

The piston is driven by a hydraulic ram mounted directly above it. The ram moves the piston in response to an electronic input signal which modulates a 2.5 liter per second (40 gpm) Moog electro-hydraulic servo valve. Hydraulic fluid is supplied by a 22 kW, 21 MPa (3000 psi) hydraulic power supply. This system allows the piston to be moved in any reasonable manner, not only sinusoidally as would be the case with a piston rod mounted eccentrically on a flywheel. Thus, Stokes wave motion or random wave motion are easily produced.

Oscillatory water motions are created digitally on an IBM PC XT computer. The computer is equipped with a MetraByte Dascon-1 board that provides the digital to analog converter (DAC), producing a varying +/- 5 VDC signal. This signal is converted to a modulated 2 kHz signal by a Vetter FM Recorder Adaptor and recorded on a standard audio cassette tape. The cassette tapes are then available for repeated use as an input signal for the piston.

During operation, the recorder outputs the demodulated +/- 5 VDC signal. A pair of 10 turn pots (for redundancy), attached to a gear rack on the piston rod, track the piston position. A servo amplifier sums the recorder signal with the negative feedback signal from the position pots. As the input signal changes, the output of the servo amp tends to move away from zero. This signal is fed to the servo valve which opens one of two high pressure hydraulic ports, moving the ram in the appropriate direction and thus changing the feedback voltage which decreases the magnitude (absolute) of the servo amp signal. In this way, the position of the piston is an accurate analog of the input signal. The servo system also allows manual adjustment of the piston position for use during filling and other system checkout. A sight gauge, attached to the outside of the piston cylinder, allows accurate manual positioning.

The piston has a working stroke length of 0.75 meters and a diameter of 0.62 meters giving a displacement volume of 0.22 cubic meters. The piston head is fabricated from clear acrylic plastic to allow for observation of trapped air. The air can be removed by a purge valve in the piston face. The piston cylinder is made from heavy wall steel tubing, precisely machined, coated with aluminum metal spray, and top coated with sprayed fused teflon. The seal is a teflon coated O-ring.

If the piston were to accidentally travel too far in either direction, the hydraulic ram would stop the piston abruptly at the end of the ram's excursion length. Under operation, this could easily cause a water hammer of serious proportions. To avoid this problem, both mechanical and electronic safeguards were installed in the system. An electronic safety circuit automatically shuts the system down if any of a number of conditions occur. These include the piston going outside a specified range, the piston traveling at too high a velocity, the pressure in the tank exceeding a specified limit, or the two feedback pots not agreeing on the piston position. The position feedback pots provide the position signal which is differentiated to obtain the velocity. The pressure limit is provided by a pressure switch set at 62 kPa (9 psi). The safety circuit uses a series of comparators to monitor these signals. When an unsafe condition is sensed, an electric dump valve to the main hydraulic power supply is opened which bypasses the hydraulic flow to the piston servo system.

Should this safeguard system fail, a passive mechanical system would disconnect the piston face from the water column, and still avoid a water hammer. If traveling upward, before the ram reaches the end of its stroke, the piston will unseat from the piston cylinder. If the piston is traveling downward, before the ram reaches the limit of its stroke, the piston will push out a blow-out plug by shearing four restraining pins. The blow-out plug is the entire bottom of the vertical riser. Thus, water will drop out of the vertical riser, avoiding the over pressure of a waterhammer. Water pressure on the face of the blow-out plug will cause the pins to shear at pressures exceeding +/- 88 kPa (12.7 psi). Along with the piston face, the blow-out plug is made of steel braced clear acrylic plastic for visual inspection of the interior of the vertical cylinder.

RESERVOIR

The other vertical riser acts as a reservoir and has the only air-water interface in the system. The air in the reservoir is open to the atmosphere through a quarter turn PVC valve. This valve is used when the tank is being filled and can be opened or closed during operation. If closed, the air in the reservoir acts as an air spring which decreases the power requirements on the piston. By initial adjustment of the water level in the airspring before closing the vent valve, the midpoint of the alternating pressure range can be offset with respect to atmospheric pressure. There is a sight gauge on the reservoir to monitor the water level during filling and experimentation. A second blow-out plug, identical to the one beneath the piston, forms the bottom of the reservoir.

STEADY FLOW

A 15 hp, high head centrifugal pump is used to superimpose a steady flow on the oscillatory flow in the facility. The steady flow system is shown schematically in Figure 3. A 35 meter long inertia section is used to reduce pressure from the high head pump. Consequently, the oscillating pressures in the tank cause only a small change in the total head seen by the pump. Since the pump has a relatively flat pressure vs flow curve, the changing pressures in the tank cause a negligible change in the pump flow.

The flow goes through a bank of five different sized valves connected in parallel. This allows a large number of flow velocities (32) in the tank to be easily and reliably reproduced. The flow then goes through a four-way valve which directs the flow to and from either end of the tank. The steady flow enters and leaves the tunnel in the vertical risers and so the water flows through the flow straighteners before reaching the test bed.

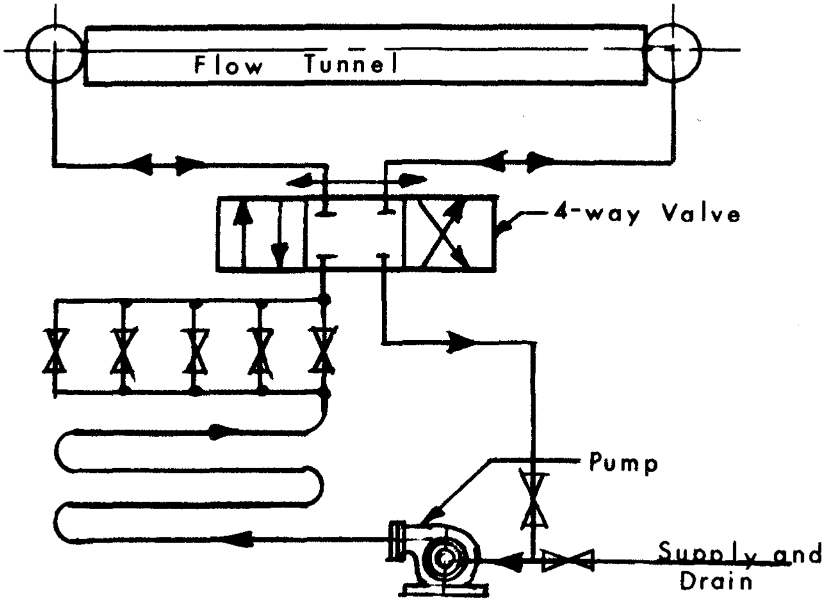

FIGURE 3: Schematic of the steady flow system.

The same pump is also used to fill the tunnel. Water is drawn from a wave basin, another facility at the Hydraulics Laboratory. The wave basin has a large expanse of shallow water. Since this acts as a settling basin, the water used in the oscillatory flow tunnel is free of both fine sediment and air bubbles.

TILT

In order to simulate the effects of cross-shore sediment transport on a sloping beach, the entire facility can be tilted between -5.7 degrees and +9.1 degrees from the horizontal. The pivot point is located at the bottom of the center of the test section. A hand-operated worm screw jack, which changes the tilt, is located near one of the sediment traps. One degree of tilt is produced by 40 crank handle turns. There are adjustable braces at the ends of each vertical riser to help support the facility and to minimize vibrations.

Physically, the facility is nearly symmetrical about the pivot point. Thus, experiments can be duplicated by completely reversing the flow, tilt, etc., to check for any bias in the system. The only assymetries are that the facility tilts above 5.7 degrees only in one direction and that there is a piston only at one end. The piston causes larger pressure excursions at one end than the other. However, the flow is driven by the derivative of pressure, dp/dx, not the magnitude of the pressure itself.

FLOW FIELD IN THE WATER TUNNEL

In the water tunnel, the fluid is oscillated in a closed rectangular tube over a test bed. There is no free surface and thus waves are not formed. In the test section, there are thin boundary layers along each wall. The rest of the fluid (the core region) moves irrotationally. The boundary layers do not grow to meet in the middle as they do in steady pipe flow.

The flowfield does not entirely duplicate wave motion in that there are no vertical oscillatory velocities and no horizontal oscillatory variations in velocities. Longshore currents, turbulence associated with breaking waves, percolation flow, etc., are also not produced. However, the horizontal flowfield produced by an Airy wave can be exactly reproduced in the water tunnel, both in the boundary layer and in the core region. The horizontal fluid velocities of a Stokes wave can be exactly reproduced in the core region or at any one elevation in the boundary layer. The flow at all other elevations is closely approximated.

The turbulence generated in this facility is a factor that has been carefully considered. Since the turbulent structure of the surfzone is very poorly known, an attempt has been made to isolate the test bed from all turbulence sources except the turbulence generated at the bed boundary layer. Thus the sediment transport in this facility most closely resembles the cross-shore bed load transport seaward of the breaker zone on a beach. The design requirement has been that the rms artifact turbulence level in the sediment test section should be much much less than the fall velocity of the sediment. The fall velocities of the sediments (grain diameters of .1 to 1 mm) are on the order of 1 to 10 cm/s.

Artifact turbulence could be convected or diffused to the test bed from the flow straighteners. Also the turbulence produced by the side and top wall boundary layers of the test section could diffuse to the bed. The flow straighteners are located two excursion lengths from the ends of the test section. Theory and observation have shown that the turbulence generated by these structures decays before it can diffuse or be convected to the test section. Likewise, theory and observation have shown that the turbulence generated by the side walls of the test section do not influence the test bed other than at the very edges. Since sediment from only the middle 10 cm of the 39 cm wide test bed is used in data collection, results are not affected by the turbulence created by the side (or top) wall boundary layers.

TABLE I: COMPARISON OF OSCILLATORY FLOW TUNNELS

	1	2	3	4	5	6	7	8	9
Type of design	U tube	loop	U tube	U tube	loop	dble U	U tube	U tube	U tube
Driving mech	cmp air	hyd ram	cmp air	cmp air	ecc fly	ecc fly	hyd ram	ecc fly	hyd ram
Type of flow	sinu	random	sinu	sinu	sinu	sinu	random	sinu	random
Max Amp (m)	3.5	2.4	.46	.41	2.0	1.2	.34	.75	.80
Mean flow (m/s)	0	0.6	0	0	0.6	0	0.2	0	0.2
Tot Length (m)	17.	13.	5.0	4.0	15.	5.0	12.	6.0	16.
Bed Length (m)	10.0	9.1	1.8	3.0	12.	2.5	2.0	2.0	7.0
Flow Height (m)	.31	2.3	.31	.048*	1.0	.30	.40	.25	.30
Bed Width (m)	.41	.51	1.2	.025*	.50	.21	.30	.25	.39
Meas Sed Trans	no	no	no	no	no	no	no	yes	yes
Max Bed Slope	flat	flat	flat	flat	flat	flat	flat	flat	9.1 deg

* 51 mm diameter circular pipe

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COMPARISON WITH OTHER WATER TUNNELS

A number of other water tunnels have been reported in the literature. The characteristics of these are shown in Table 1. Some of these tunnels have been used without sediment to study the nature of fluid boundary layers. Others have had sand beds and have been used to study the initiation of sediment motion and or the structure and growth of ripples. Only one tunnel, reported in Horikawa, et al, 1983, has been used thus far to measure sediment transport.

As can be seen from Table I, the Scripps tunnel is one of the larger tunnels that have been built and one of the more versatile. It is unique in that it is the only tunnel with a test bed whose slope can be adjusted.

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