INVESTIGATION OF FLOATING BOOM STRUCTURES

BY

DAVID C. POOLE

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

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by :

David C. Poole

A thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirement
for the Degree of Master of Science

DEPARTMENT OF CIVIL ENGINEERING

Winnipeg , Manitoba

ABSTRACT

Floating boom structures are installed in bodies of water to protect sensitive and/or dangerous areas from floating ice, debris, and boaters. Manitoba Hydro has many of these structures located at various locations in Manitoba. However, two of their structures were not operating properly. They were submerging or behaving erratically under high velocity conditions.

This problem was addressed in two ways. First, the behaviour of the floating boom sticks was analyzed based on theory extrapolated from classical fluid mechanics. Various assumptions in the theory required empirical measures for confirmation. This was the physical modelling phase of the research. The objective was to simulate the conditions that caused the floating boom sticks to submerge in the field and confirm the theoretical development phase of the research.

The conditions that occurred in the field were simulated in the laboratory and the results indicate that classical fluid mechanics can be extrapolated to analyze the behaviour of the floating boom sticks. However, some of the assumptions that were made in the physical modelling phase turned out to be incorrect once the test results were analyzed. Further study is required to better understand the interaction between the physical characteristics of the floating boom sticks and the hydrodynamic forces.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank many people for their contributions throughout the completion of my studies. First, I would like to thank Manitoba Hydro for their financial contribution to this project. I appreciate the technical guidance and support provided by Phillip Wang, Dennis Lemke, and Randy Raban of Manitoba Hydro.

I would also like to send my sincere thanks to Dr. Slobodan Simonovic for his encouragement and advice throughout my studies. I thank him for giving me the opportunity to participate in this project. I would like to thank Dr. Cass Booy for his technical support and advice during Dr. Simonovic's absence and Dr. J. Doering for loaning me his computer so I could finish the thesis in a reasonable period of time.

I would also like to thank my colleagues and friends at the university for their kinship and support during the extensive hours of study and research.

Finally, I would like to thank my parents for their support throughout my years at school. Without their encouragement and support, I would not have been able to achieve so much in that time.

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1. INTRODUCTION

The objective of the research presented in this thesis is to document the examination of the behaviour of floating boom sticks under hydrodynamic conditions. The results of the research are used to compose a series of guidelines to be used in the design of future floating boom sticks under hydrodynamic conditions.

Floating boom structures are structures that are installed in bodies of water such as rivers or dam forebays to keep boaters, ice, and debris out of certain areas. There are three types of floating boom structures; ice, safety, and trash booms. As the names imply, ice booms restrain ice, safety booms prevent access to dangerous and/or sensitive areas from swimmers or boaters, and trash booms restrain debris. Floating boom structures usually consist of individual sticks connected either end to end in series or in parallel to a main cable spanning the body of water.

The incentive for initiating the research was that Manitoba Hydro observed the erratic behaviour of certain floating boom structures. One such structure was an ice boom that currently operates in the forebay of the Jenpeg generating station. The Jenpeg generating station is located on the Nelson River approximately 65 km. north of Lake Winnipeg. It is the first generating station on the Nelson River and discharges 52,000 cfs on average. The ice boom is located in the forebay as illustrated in Figure 1.

The optimal location of the ice boom was based on physical modelling of the ice retention process of the ice boom in various locations on a scaled model of the Jenpeg forebay. Once the location was determined, the ice boom was installed in October, 1988. The ice boom consists of 2-11 boom stick sections and 1-10 boom stick section with a

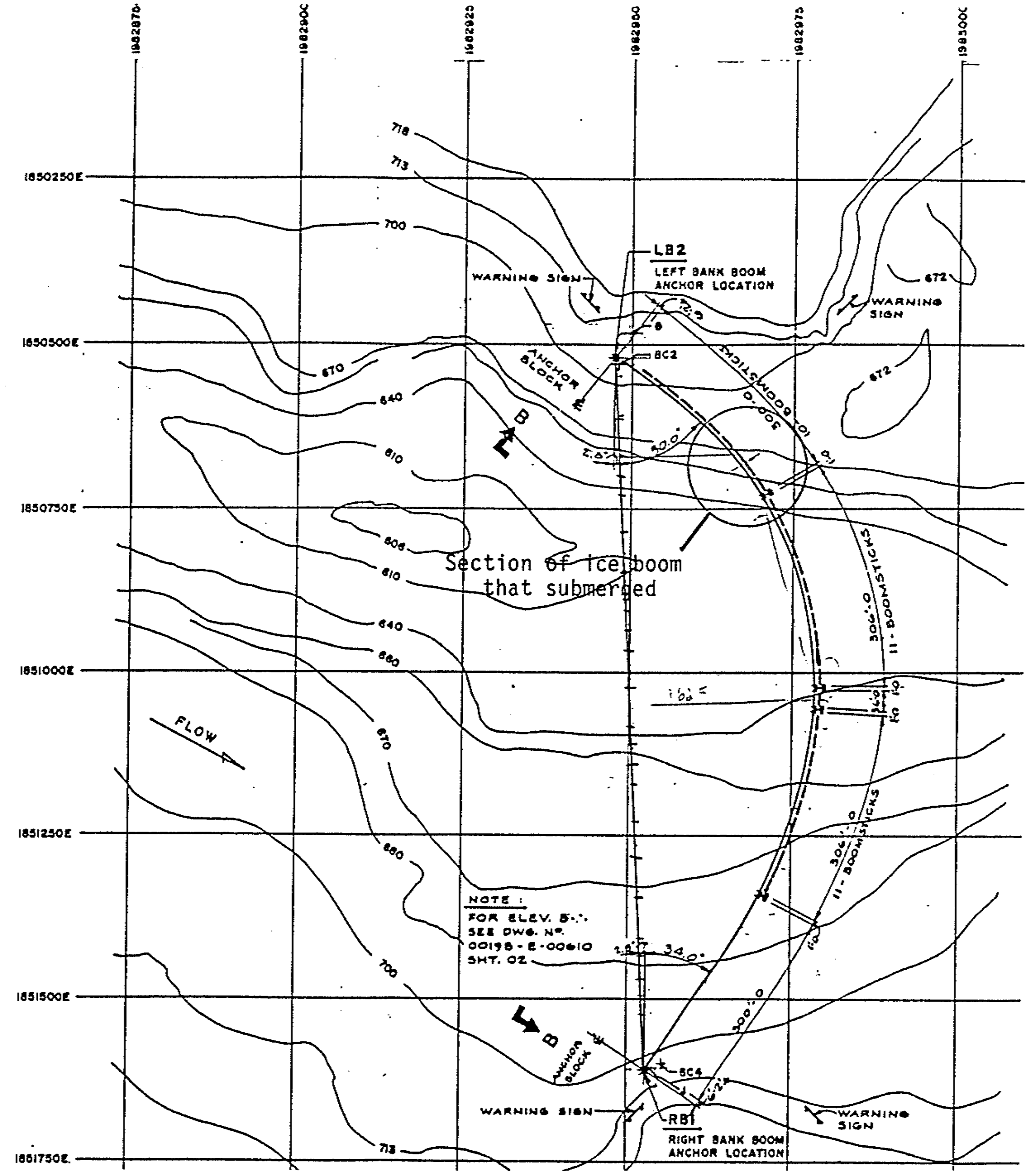


Figure 1 : Location of Ice Boom at Jenpeg Generating Station

total span of 1249'. The ice boom was installed to stop movement of ice that is generated upstream of Jenpeg.

Upstream of Jenpeg, large amounts of frazil ice are generated during freeze-up conditions in early November. The frazil ice coagulate and float downstream to the generating station as floating ice pans. Once the ice reaches the generating station, it would get drawn down into the trash racks and reduce the discharge through the generating station. In order for the blockages to be removed, the generating units that are affected would have to be shut down, resulting in a loss in generating power.

The objective of designing an ice boom is to simulate the leading edge of a stable ice cover which will retain the floating ice pans. However, it was observed that a section of 4 to 5 ice boom sticks were submerging under open flow conditions. The affected ice boom sticks are located near the left bank boom anchor location and are illustrated in Figure 2. This picture depicts the submergence of 4 to 5 ice boom sticks on October 23, 1990. The flow in the picture is from right to left. The location of the submerged ice boom sticks correspond to the section of the forebay with the highest surface velocity. As a result, the frazil ice pans could not be contained by the ice boom and become lodged in the trash racks of the generating station.during freeze-up conditions.

Another floating boom structure that was behaving erratically was a safety boom that was installed in the tailrace section of the Grand Rapids generating station. Grand Rapids is a hydroelectric generating station operated by Manitoba Hydro and is located on the Little Saskatchewan River, approximately 4 km upstream of the outlet to Lake Winnipeg.

The tailrace region of Grand Rapids is known by fishermen to contain large population of fish. The fishermen would travel up the tailrace to the generating station and anchor their boats to fish. Usually, the fishermen would anchor their boats near the outlets of generating units that were off-line. However, the operator at Grand Rapids

Figure 2 : Section of Jenpeg Ice Boom Submerging Under High Velocity Conditions

could bring certain units on-line to meet power demands at any time during the day. Boaters are warned of this in the form of signs posted along the sides of the tailrace region and on the generating station. This warning is reinforced with a warning klaxon that is sounded when units are about to be brought on-line. Often, the fishermen would ignore the warnings, and when a unit(s) is brought on-line, the sudden increase in discharge would sweep any boat located near that unit downstream. If the anchor catches on the bottom of the tailrace, the boat could capsize and endanger the fishermen.

Manitoba Hydro decided to rectify the problem by installing a safety boom across the tailrace downstream of the generating station. The safety boom consisted of 30 cylindrical sectioned safety boom sticks with 3 inch spacings, spanning a distance of 351 feet. The cable spanning the tailrace was threaded through the boom sticks and the boom sticks were anchored to the cable to prevent the sticks from spinning. The boom sticks were constructed out of fibre-reinforce plastic (FRP) with a polyurethane foam core to prevent waterlogging. The purpose of the safety booms was to act as a physical barrier to prevent boaters from entering the tailrace. As long as the safety boom was visible, it would act as an effective barrier to the boaters.

Unfortunately, the safety boom did not perform as expected by Manitoba Hydro. Instead of the safety boom floating on the tailrace, it would oscillate violently in the vertical direction. As a result, boaters could ram the safety boom sticks and pass overtop of them and proceed upstream to fish. Manitoba Hydro decided to remove the safety boom and install it in another location since it was ineffective in preventing boaters from entering the tailrace.

The behaviour of the ice and safety booms were addressed in two ways. The first approach involved the use of physical modelling to understand the dominant hydrodynamic forces which act on the ice and safety booms. The results of the physical modelling were reinforced with the theoretical development of the behaviour of the ice and safety booms based on classical fluid mechanics. A series of guidelines was developed to benefit Manitoba Hydro in the design of future floating boom structures in high velocity conditions. The guidelines were based on the results of the physical modelling of the floating boom sticks.

The documentation of the research follows the format described below. Chapter 2 examined the literary database for articles related to the behaviour of floating boom structures. The literature that was accumulated was used to develop the theoretical background regarding the behaviour of the ice and safety booms in Chapter 3. Chapter 4 discussed the testing program that was developed to investigate the behaviour of the ice and safety boom sticks. The results of the testing program was chronicled and analyzed in Chapter 5 to formalize the theoretical development phase of the thesis. To apply the thesis to practical situations, a series of design guidelines was developed in Chapter 6. Conclusions on the research done and recommendations for future work was documented in Chapter 7.

2. LITERATURE RESEARCH

The literary research of floating boom structures involved soliciting information from private and governmental agencies in the U.S. and Canada that operate floating boom structures and searching the literary database. The rationality of contacting the private and governmental agencies is to investigate common practices used in the design, installation and operation of floating boom structures, searching for instances where these boom structures submerged or did not behave properly under high velocity conditions. In the literary database, any articles involving theoretical research on floating boom structures were documented. The literature that was accumulated is subdivided into the following categories: 1) theoretical literature and 2) case studies.

2.1 THEORETICAL LITERATURE

2.1.1 Ice booms

Theoretical analysis of ice booms has been limited to modelling ice jams and predicting the ice forces which act on ice booms. Researching ice forces began in the U.S.S.R. (Petrunitchen and Mamaieff, 1914; Proskuriakoff, 1941; and Zubov, 1935). Their research came to the conclusion that the total thrust exerted by the ice sheet must be transferred directly to the hydraulic structure (ie. ice boom). However, Latyshenkoff (1946) discovered that the total thrust exerted by an ice sheet on a hydraulic structure does not increase indefinitely, but reaches a limiting value when the length of the ice sheet upstream is 4 to 5 times the width of the field. It was not until 1958, when Kennedy (1958) used the Janseen theory of grain elevators to prove that the limiting value of the thrust on a boom holding wood logs occurs when the reaction of the shore equals the incremental thrust due to accumulation of logs. Beccat (1959) applied this theory to the accumulation of ice.

Pariset and Hausser (1961) demonstrated that another limiting factor in the total thrust exerted by an ice sheet is the discharge under the sheet. A limiting value for the discharge, when exceeded, causes the ice sheet to become unstable. B. Michel (1965) used this theory to develop equations for the hydrodynamic force on the front edge of an ice cover, the tangential force due the weight of the cover and the force due to the flow of wind and water on an ice cover.

Uzuner and Kennedy (1976) developed a mathematical model for predicting the velocity at the leading edge of the ice jam, the streamwise distribution of the flow, the water depth and ice jam thickness, the normal and shear stresses in the ice jam and the time required for the jam to reach equilibrium. Spyridon Beltaos (1983) reviewed the theory of ice jams and developed two methods for analyzing ice jams, the first method is based on dimensionless equations relating ice jam characteristics and the second method compensates for the lack of knowledge of the thickness of ice jams by introducing a relationship between the hydraulic roughness of the ice jam and the jam's thickness.

2.1.2 Safety Booms

Safety booms consist of cylindrical sections or pontoon style sections chained to a main cable that is anchored to the shoreline. Since safety booms are not required to withstand large forces, safety booms are constructed out of timber or a high density polyethylene shell (HDP) with a expandable urethane foam interior to maintain water tightness.

There has not been any theoretical research into the behaviour of safety boom sticks (ie. cylindrical sections) in open flow conditions. The design criteria for safety booms is that as long as the safety boom is visible, it is an impediment to boaters and swimmers.

2.1.3 Trash Booms

Extensive research has been undertaken by various agencies to analyze the forces acting on the trash held by trash booms. Kennedy (1957) investigated the forces acting on pulpwood as it is transported to the mill yard. The intent was to develop methods for calculating the total force exerted by the water on the pulpwood held by the boom.

This research was extended by Kennedy (1965) to investigate methods of protecting holding grounds from the accumulation of ice. The methods involve injecting air bubbles into the water to deliver warm water to the surface to dissipate the ice. Kennedy developed methods for predicting the wave characteristics for an area which would be used to design breakwater structures to protect the logs held by the holding booms.

2.2 CURRENT PRACTICE

2.2.1 Ice Booms

Case studies of ice booms have been limited to the performance and/or feasibility of ice booms at certain locations. Extensive research has been undertaken on the performance of ice booms operating in the Great Lakes region. Bryce (1968) discussed the remedial measures taken to initiate a stable ice cover on the Niagara River near Lake Erie and on the St. Lawrence River between Cardinal, Ontario and Ogdensburg, New

York. The region is prone to ice jams due to the accumulation of frazil ice generated in fast flowing reaches of both rivers upstream. The objective was to find the optimal location of ice booms in the fast reaches to control the frazil ice growth. His research involved extensive field measurements and information from large scale models of the areas to determine the optimal location for the ice booms. Perham (1974) studied the same ice booms near Cardinal, Ontario to determine the ice forces generated on the ice booms and the natural phenomenon causing these forces.

Uzuner, Peter, and Robb (1976) studied the ice forces on a navigable ice boom installed at Copeland Cut in the Wiley-Donden Canal near Massena, New York to test the feasibility of winter navigation through an ice boom. A model study of the St. Mary's River was undertaken by Cowley, Hayden, and Willis (1977) to develop an arrangement of ice booms with an open ship passage which would not impede traffic. The optimal location was decided based on the model tests.

One report dealt with appraising the performance of an ice boom installed on the Allegheny River upstream of the confluence with Oil Creek at Oil City, Pennsylvania by Deck and Gooch (1984). The objective of the ice boom was to initiate a stable ice cover to decrease the generation of frazil ice. The report dealt with the performance of the ice boom after operating for one winter. The study reported that the ice boom operated satisfactory but stated that the floating characteristics of the pontoons were inadequate for accumulating ice rapidly. Deck and Gooch suggested that either the pontoons increase in size or increase the number of pontoons to support the structure..

Another report dealt with studying the feasibility of installing an ice boom on the Salmon River, near Salmon, Idaho by Axelson et.al., (1990). The city was experiencing severe ice jams caused by the accumulation of frazil ice generated upstream. The report recommended that a weir be constructed to raise the water level in the river to decrease the stream velocity and install an ice boom to initate a stable ice cover. The formation of natural occurring ice jams were studied at the proposed location of the ice boom to gauge the potential effectiveness of the ice boom.

As was mentioned earlier, ice booms usually consist of timber or steel sections chained to a main cable anchored to the shoreline. The ice booms simulate the leading edge of an ice cover. However, Calkin (1990) has developed a new concept for ice control, *longitudinal ice control structures*. Basically, the ice boom sticks are aligned parallel to the flow, effectively reducing the width of the channel. Since the ice boom sticks are aligned parallel to the shoreline, the vertical surfaces of the boom sticks will support the load transmitted by the ice. With the additional support, the thickness of the ice cover is decreased at equilibrium which results in a lower stage level upstream of the ice cover.

2.2.2 Safety Booms

The only investigation of safety boom designs was undertaken by the U.S. Bureau of Reclamation (Wahl, 1990). Currently, the Bureau of Reclamation uses timber boom sticks due to their wide availability and ease of construction but recently, the cost of replacing timber boom sticks has increased and their availability has decreased. The purpose of the study was to investigate alternatives to the use of timber boom sticks for safety booms and to appraise their potential for various Reclamation projects. The report recommended man-made materials such as durable plastic, steel, aluminum, or fiberglass can be used for constructing the shell with polyurethane foam core to increase floatation.

2.2.3 Trash Booms

Shawinigan Consultants (1982) investigated current practices of Canadian and U.S. utility companies in designing trash and log booms which resulted in the development of a series of recommendations for determining the design loads and the selection of materials and details for the trash booms. The design loads dealt with estimating the wind friction drag, wind form drag, water friction drag, water form drag and the force due to gravity on the accumulated trash and the impact force of floating trash on the leading edge of the accumulated trash. The design loads would be used to design the anchors and the trash boom sticks. The report recommended that trash booms should not be located in a high velocity area because the floating trash would tend to get pulled under the trash boom.

Current practices for controlling floating debris were investigated by Perham (1987). The objective of the report was to investigate current practices for controlling and removing floating debris. The investigation involved soliciting various agencies to observe floating debris control systems, literature searches, and a limited laboratory study. The report did not uncover any situations where the trash booms submerged under high velocity conditions or current practices used to alleviate the submergence of trash booms.

The Bureau of Reclamation in the U.S. investigated alternatives to the use of timber boom sticks for holding floating debris and assessed their feasibility for use in various Reclamation projects, (Wahl, 1990). Timber sections had become increasingly unavailable and expensive and alternatives were being sought to decrease replacement and maintenance costs. The report recommended using trash booms fabricated out of steel with a polyurethane foam core, or use boom sticks constructed of sawn lumber as alternatives to timber boom sticks.

2.3 CONCLUSION OF LITERATURE REVIEW

Soliciting information from government and private agencies and searching the literary database has resulted in little information dealing with the performance of floating boom structures subjected to high velocity conditions. The development of the theoretical background for predicting the hydrodynamic characteristics of floating boom structures will be based on analyzing the flow pattern around the floating boom structures using ideal flow theory. Ideal flow theory assumes the fluid is incompressible, irrotational and non-viscous. Theoretical analysis is presented in the following chapter.

3. THEORETICAL DEVELOPMENT

The velocity field around a floating boom structure consists of two parts - the flow field that contains the flow around the structure and the zone of separation immediately adjacent to the structure.

The velocities in the zone of separation are associated with the vortices that are generated there. These are extremely variable and give rise to rapid local turbulent pressure variations. Analyzed over time, however, the piezometric level in the zone of separation is constant and the pressure distribution hydrostatic.

In the flow field proper, the effect of fluid viscosity is small. The flow is in contact with the solid boundary over a very small distance and the fluid resistance along the zone of separation is also very small compared to the pressure forces, the gravity forces and the inertia effects.

In the flow field, the flow can therefore be analyzed using ideal flow theory. Three properties are characteristic of ideal fluid flow :

1. The energy level is constant between any two points
2. The Bernoulli's equation can be applied between any two points
3. The velocity distribution can be analyzed using a flow net.

These properties will be used in a theoretical analysis of the floating boom sticks. The subsequent physical model analysis will show up any discrepancies due to the simplifications. Two types of floating boom sticks will be analyzed, trapezoidal shaped ice boom sticks and cylindrically shaped safety boom sticks.

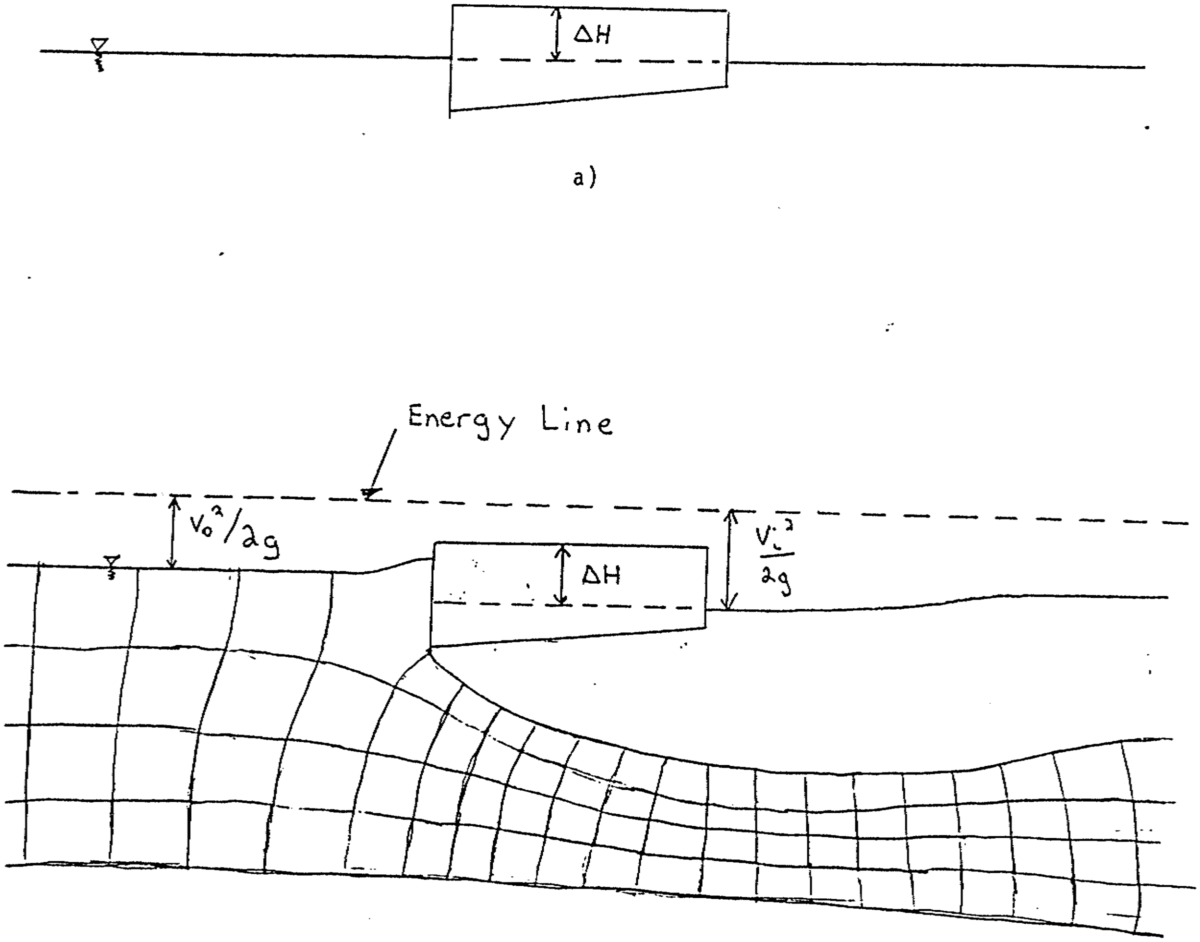
3.1 ICE BOOM STICKS

The objective of the analysis is : a) to theoretically predict the submergence velocity for an ice boom stick and ; b) to calculate the drag force acting on the ice boom stick as a function of the free-stream velocity. Figure 3 illustrates the positions of an ice boom stick under hydrostatic and hydrodynamic conditions.

Figure 3a) shows the position of the ice boom stick under hydrostatic conditions. ΔH is the average free-board height of the ice boom stick. Since the velocity of the fluid is zero, the piezometric surface anywhere in the fluid and also under the ice boom stick coincides with the phreatic surface. The force counteracting the weight of the ice boom stick is the buoyancy force which is equal to the weight of the volume of water displaced by the boom stick.

Figure 3b) shows the flow field around the ice boom stick for a given free-stream velocity V_0. As mentioned in the beginning of the chapter, the energy level throughout the flow field is constant and is above the free-stream surface by the velocity head $V_0^2/2g$. The flow net shows the velocity distribution in the flow field. The spacing between the flow lines is inversely proportional to the magnitude of the velocity along the flow line. As can be seen, the flow lines under the ice boom stick are closer together, resulting in the velocity to be higher than the free-stream velocity. Along the flow line defining the zone of separation, the velocity is V_i.

The level at which the ice boom stick floats is determined by the piezometric level in the zone of separation. The piezometric level is determined by the velocity along the flow line defining the zone of separation. The piezometric level can be determined by



a)

b)

Figure 3 : Position of Ice Boom Stick under - a) hydrostatic and b) hydrodynamic conditions

applying Bernoulli's equation between the free-stream surface and any point along the flow line defining the zone of separation:

$$h_0 + \frac{V_0^2}{2g} = h_i + \frac{V_i^2}{2g} \tag{3.1}$$

where h_0 and h_i are the piezometric levels at the free-stream surface and under the ice boom stick respectively. It is assumed that the piezometric level at any point along the flow line defining the zone of separation is the same within the zone of separation because the velocities within the zone are essentially zero.

Since the velocity under the ice boom stick is greater than the free-stream velocity, the piezometric level under the ice boom stick must be less than the piezometric level at the free-stream surface. The total depth that the ice boom stick sinks is equal to the difference in velocity head between the free-stream surface and the piezometric level under the ice boom stick or :

$$h_0 - h_i = d_s = \frac{V_i^2 - V_0^2}{2g} \tag{3.2}$$

The ice boom stick totally submerges when $d_s = \Delta H$ or :

$$\Delta H = \frac{V_i^2 - V_s^2}{2g} \tag{3.3}$$

where V_s is the free-stream velocity at submergence. The flow net indicates that there is a constant relationship between V_0 and V_i. If this relationship is :

$$\frac{V_o}{V_i} = n \tag{3.4}$$

Substituting (3.4) into (3.3) results in ΔH to become :

$$\Delta H = \frac{V_s^2}{g} \frac{(n^2 - 1)}{2} \tag{3.5}$$

where $(n^2 - 1)/2$ is the constant C_1. The constant C_1 will depend on the shape of the cross-section of the ice boom stick because the shape dictates how the flow line separates from the ice boom stick which defines the increase in velocity under the ice boom stick. In the case under investigation, there is a sharp angle so that the separation takes place at this point. Empirical measurements are required to determine the value of C_1 for a given ice boom stick.

The drag force which acts on the ice boom stick will be based on integrating the pressure forces acting on an ice boom stick in the x-direction :

$$
\begin{aligned}
F_D &= \int_s p_i \cos\theta \, dA_i \\
&= \int_s \left[\frac{1}{2} \rho V_0^2 + \rho g z_i - \frac{1}{2} \rho V_i^2 \right] \cos\theta_i dA_i \qquad (3.6) \\
&= \frac{1}{2} \rho V_0^2 \int_s \left[1 + \frac{\rho g C_{2i} H_{front}}{1/2 \rho V_0^2} - \frac{1/2 \rho C_{3i}^2 V_0^2}{1/2 \rho V_0^2} \right] \cos\theta_i dA_i
\end{aligned}
$$

where p_i is the pressure acting on a differential area dA_i with an orientation θ_i with respect to the x-axis as illustrated in Figure 4. z_i is the elevation of point *i* with respect to the free-stream surface.

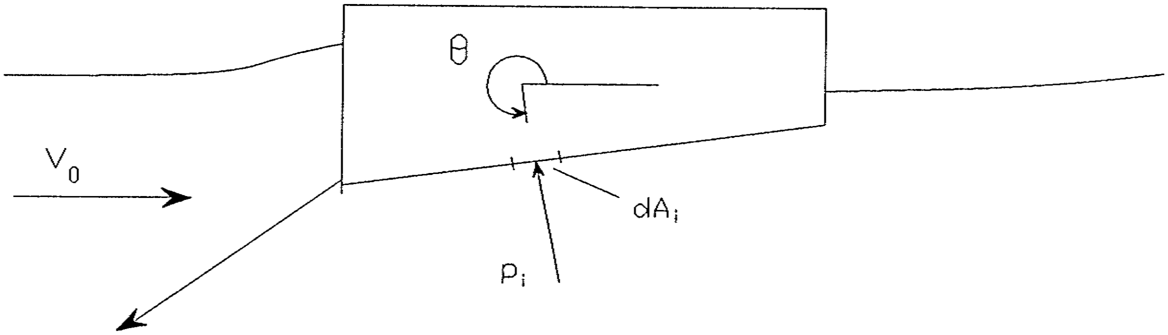


Figure 4 : Diagram of Pressures Acting on an Ice Boom Stick

The differential area is related to the projected area normal to the free-stream direction by :

$$d\alpha_i = \frac{dA_i}{A} \tag{3.7}$$

where A is the projected area normal to the free-stream direction and $d\alpha_i$ is the ratio of the differential area to the total projected area.

Substituting (3.7) into (3.6) and reducing results in :

$$F_D = \frac{1}{2}\rho V_0^2 A\left[C_2 + \frac{C_3}{Fr^2}\right] \qquad where\ Fr^2 = \frac{V_0^2}{g H_{front}} \tag{3.8}$$

The value inside the brackets represents the drag coefficient C_D where C_2 and C_3 are constants. The term with the Froude Number represents the effect of gravity on the drag force. For a completely submerged object, only C_3 should be present. Equation (3.8) indicates that gravity dominates the drag coefficient for very small free-stream velocities because the Froude Number is very small. As the free-stream velocity increases, gravitational effects become less significant and the drag coefficient is influenced more by the value C_3. Empirical measurements are required to validate this assumption.

3.2 SAFETY BOOM STICKS

The objective of theoretically modelling the circle cylindrical safety boom sticks is to predict the free-stream velocity at which the stick would start to oscillate violently. The behaviour of cylindrical safety boom sticks under hydrodynamic conditions can be compared to the behaviour to cylinders under hydrodynamic conditions in an unbounded fluid.

The flow pattern around a cylinder immersed in an ideal fluid is illustrated in Figure 5. A particle of water travelling from A to B to C and to D must first decelerate from point A to point B, resulting in an associated increase in pressure. At point B, the velocity is zero and has the highest pressure. When the particle travels from B to C, it must accelerate, resulting in a decrease in pressure. Since the highest velocity occurs at C, this is the point of the lowest pressure. From C, the particle has sufficient momentum to reach D and then accelerates from D to point E. The resulting pressure distribution is illustrated in Figure 6.

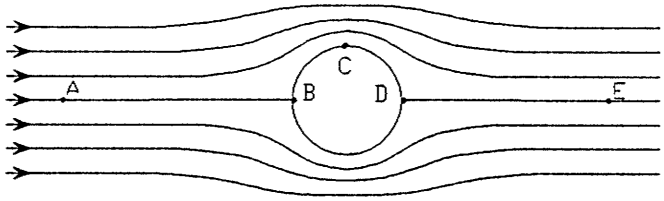


Figure 5 : Ideal Flow Around a Cylinder in an Unbounded Fluid

The flow pattern of a real fluid is quite different from an ideal fluid due to the development of a boundary layer along the surface of the object in which the flow is subjected to fluid resistance. The flow pattern in a real-fluid around a cylinder is illustrated in Figure 7. The flow pattern upstream of the cylinder is similar to the flow pattern in Figure 5 except that close to the surface of the object, the surface resistance reduces the velocity of water particles.

While in irrotational flow, the water particles will just have enough momentum to travel to D. In the real-fluid, the velocity of particles next to the solid boundary is

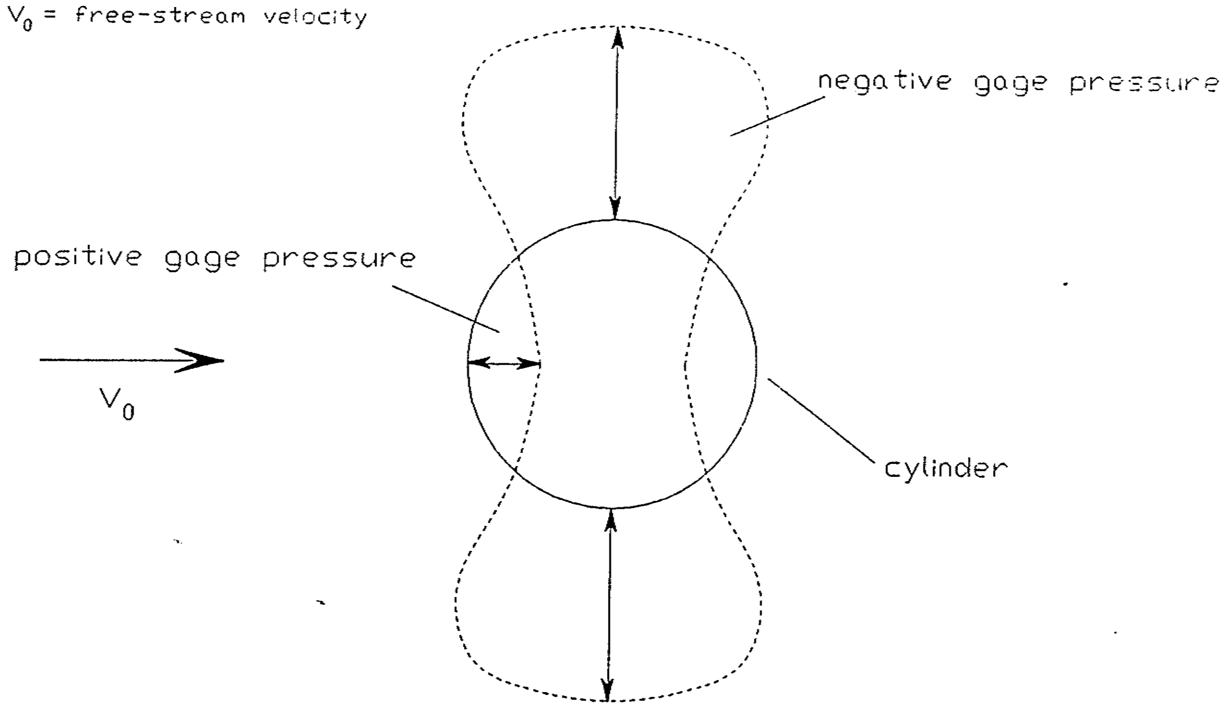


Figure 6 : Pressure Distribution Around a Cylinder - Ideal Flow

decreased due to resistance, so the particles can only travel a short distance to D before stopping. Once the particles stop, they separate from the boundary, creating a zone of separation. The point of separation depends on the roughness of the surface of the cylinder and the viscosity of the fluid.

When separation occurs, there is a drastic change in pressure distribution around the body. Within the zone of separation, the pressure is reduced and in combination with the positive pressure at the front of the cylinder, a net force acting in the free-stream direction is generated. This force is called the drag force. Since the velocity immediately outside of the zone of separation is high in relation to the velocity within the zone, eddies are generated and are periodically shed by the cylinder as in Figure 8. As can be seen, eddies are shed alternately between the top and the bottom portion of the cylinder. This

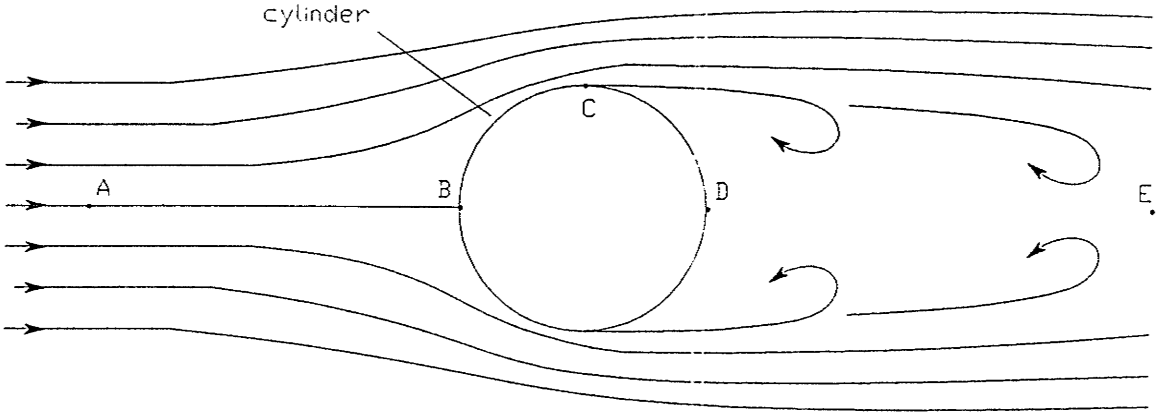


Figure 7 : Real Flow Around a Cylinder

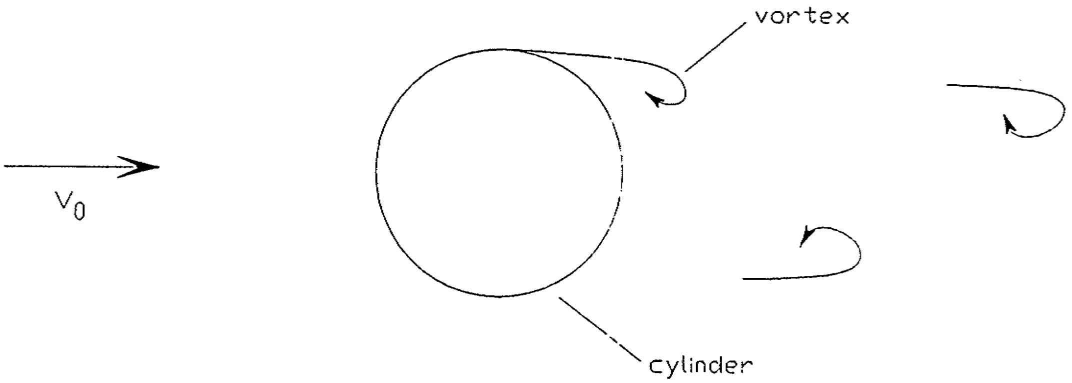


Figure 8 : Vortices Shed Behind a Cylinder

regular change in vortices also changes the pressure on the cylinder with consequent periodicity. If resonance occurs between this periodicity and the natural vibration frequency of the cylinder, then large movements may result.

Floating safety boom sticks under hydrodynamic conditions are also subject to the effect of vortex shedding. However, there is a complex interaction between the movement of the safety boom sticks and surface waves generated by the movement. Much better instrumentation would have been needed to pursue this interaction phenomenon and the result on the frequency and magnitude of the oscillation. Therefore, it was decided to concentrate on the relationships between the physical characteristics of the cylindrical safety boom sticks and the velocity at which large oscillations occurred which are :

1) diameter d
2) length l
3) density of the boom stick ρ_{sb}
4) fluid density ρ
5) free-stream velocity V_0
6) gravity
7) method of anchoring the safety boom sticks

Chapter 4 discusses the testing programs developed for investigating trapezoidal shaped ice boom sticks and circular cylindrical safety boom sticks. The testing programs attempt to verify the assumptions made in this chapter.

4. PHYSICAL MODELLING OF FLOATING BOOM STICKS

The objective of physically modelling the ice and safety boom sticks is to study the hydrodynamic forces that were discussed in Chapter 3. There are two objectives in physically modelling the ice boom sticks. The first objective is to study the submergence characteristics and the drag forces acting on the ice boom sticks. The second objective is to study the pressure distribution around the ice boom sticks. The objective of physically modelling the safety boom sticks is to understand their interaction with the free-stream velocity.

Results from physical modelling have to be interpreted to represent results that should occur in the field. Results that occur in the field are referred to as prototype conditions while results that occur in the lab are called model conditions. To interpret laboratory results, two sets of criteria have to be met; 1) geometric similitude and 2) dynamic similitude.

The requirement of geometric similitude is that the prototype and the model must be geometrically similar or:

$$\frac{l_m}{l_p} = \frac{w_m}{w_p} = \frac{d_m}{d_p} = n_l \tag{4.1}$$

where l,w,d are the length, width and depth dimensions, the subscripts m and p denote the variables associated with the model and prototype respectively, and n_l is the length scale or the scale ratio between the model and the prototype.

To achieve dynamic similitude, the ratio of the physical forces acting on the model to the forces acting on the prototype must be the same. There are three types of forces which act on the floating boom stick: a) F_g which is the force of gravity: b) the pressure force F_P and: c) the viscosity force F_υ. Since F_P is dependent on the gravity and viscosity forces, dynamic similitude can be achieved if the ratio of gravity forces and viscosity forces are modelled.

To achieve dynamic similitude of gravity forces,

$$Fr_m = Fr_p \tag{4.2}$$

the model Froude Number must be the same as the prototype.

To achieve dynamic similitude of viscous forces,

$$R_{e_m} = R_{e_p} \tag{4.3}$$

or the Reynold's Number in the prototype must be the same as in the model.

Therefore, to achieve dynamic similitude, the Reynold's Number and the Froude Number must be the same in the model and the prototype. Using the Froude number, the velocity of the fluid in the model is related to the velocity of the prototype by:

$$V_m = V_p \cdot n_l^{\frac{1}{2}} \tag{4.4}$$

and using the Reynolds number, the velocity of the fluid in the model becomes:

$$V_m = V_p \cdot n_l \tag{4.5}$$

Comparing (4.4) and (4.5), the only way to achieve dynamic similitude is if the length scale is equal to 1, which is in most cases impractical due to geometric constraints of the lab facility. Therefore, to achieve dynamic similitude, a decision needs to be made about the predominant forces acting on the floating boom sticks.

4.1 ICE BOOMS

Two types of tests were devised to study the ice boom sticks. Each test was designed based on the objectives of the testing program. The first test involves installing scaled models of ice boom sticks in the flume and subject the specimens to a range of velocities until the models were observed to submerge. As well, a load measuring device was attached to the ice boom sticks to measure the drag forces acting on the models.

The second test involved measuring the pressure distribution around a fixed model of an ice boom stick. The pressure measurements were used to estimate the submergence velocity for the ice boom stick models and compare the results to the measured submergence velocities in the previously mentioned test. For both tests, it was assumed that boundary effects caused by the flume floor were minimal since the size of the ice boom stick models with respect to the depth of water in the flume is small. Therefore, the models should not adversely confine the flow of water under the models and artificially increase the velocities.

As mentioned in Chapter 1, Manitoba Hydro was motivated to initiate the project because they were experiencing the erratic behaviour of one of their ice booms located at Jenpeg. It has been observed that sections of the ice boom submerge under high velocity conditions. Since the objective of the physical modelling is to investigate the hydrodynamic forces acting on the ice boom sticks, the prototype conditions at Jenpeg were modelled to provide the basis from which any test results can be compared to verify the methodology of the testing program.

A schematic of the Jenpeg ice boom stick is illustrated in Figure 9. The boom stick weighs 2380 lbs. and is connected to a 2½ inch diameter steel wire cable by two five foot chain. According to Manitoba Hydro, the ice boom operates in approximately

50 feet of water and the estimate of the submergence velocity of the effected section of the ice boom is 1.4 m/s.

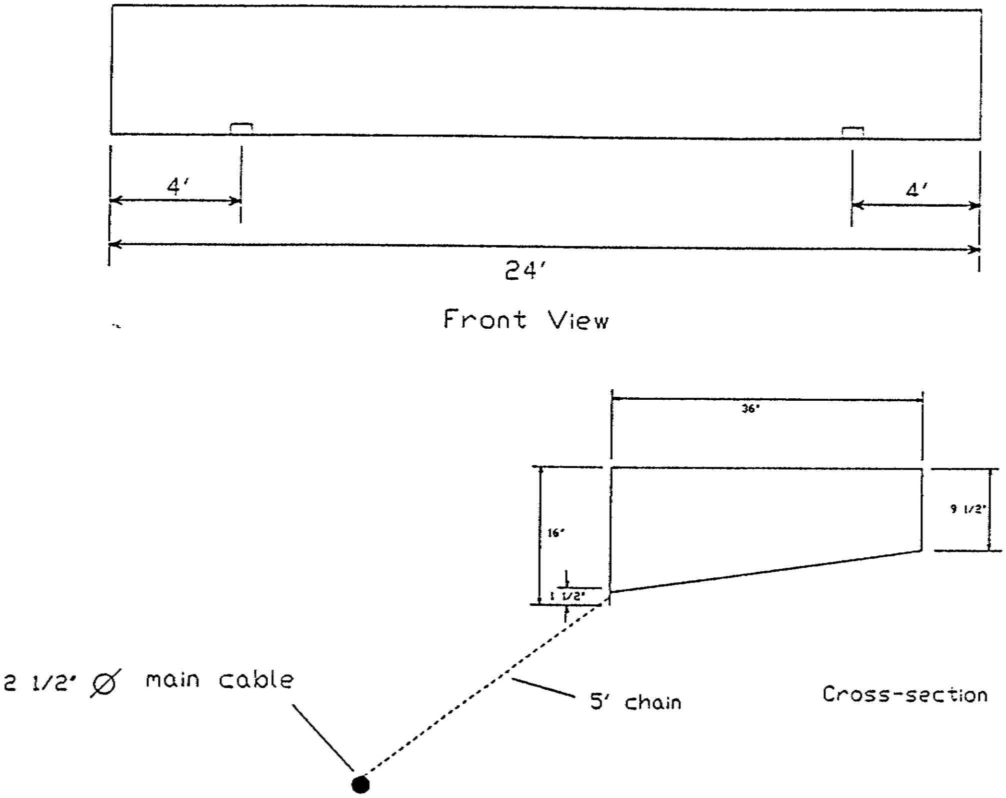


Figure 9 : Schematic of Jenpeg Ice Boom Stick

The estimate of the prototype submergence velocity was based on velocity and sounding measurements taken in the Jenpeg forebay for the initial ice boom study. Velocity measurements were taken at various points across the section of the forebay where the ice boom was eventually located. The cross-section of the forebay was subdivided into tributary areas, based on the locations of the measurement points. The velocities and the measured forebay elevations at the points were used to calculate the discharges through the tributary areas. Knowing the total discharge through the generating station at the time of the velocity measurements, the ratios of the discharges through the tributary areas to the total discharge were calculated.

When the ice boom was observed to submerge, the discharge through the generating station was recorded to be 75,979 cfs. Assuming the unit discharge to total discharge ratios were constant with respect to the total discharge, the velocities along the section of the forebay were calculated. The highest calculated velocity corresponded to the location of the ice boom where the sticks submerged and this value was used as the estimate of the submergence velocity of the Jenpeg ice boom stick.

Similitude requires that the physical characteristics of the prototype have to be scaled down in the model. In terms of scaling the dimensions of the prototype in the model, there are a number of limiting factors. The first factor is the size of the flume available to do the testing. The model must be short enough to fit inside the flume. However, if the ice boom stick behaves like an infinitely long member, then the length does not have to be scaled.

The Aspect Ratio A_S, which is equal to the ratio of the length of the prototype to the width of the prototype, is used to measure the two-dimensionality of the ice boom stick. If the Aspect Ratio $\gg 1$, it implies that the flow will be nearly independent of the transverse co-ordinate z, and two-dimensional flow theory can be used to model the behaviour of the ice boom stick. The calculated Aspect Ratio for the Jenpeg ice boom stick was 8, which is considered large enough to model its behaviour using two-dimensional flow theory.

The other limiting factor is scaling the prototype submergence velocity. The maximum velocity generated in the flume will dictate the minimum length scale to model the submergence velocity. Since the length of the ice boom stick does not have to be modelled, the width of the flume can be narrowed to increase the flow. Based on these two constraints, a length scale of 1/5 was chosen.

Similitude dictates that the weight of the prototype ice boom stick has to be scaled down in the model. The weight scale n_W, is equal to n_l^3 if the model behaves three-dimensionally. However, as indicated by the Aspect Ratio, the Jenpeg prototype ice boom stick can be analyzed using two-dimensional flow theory. Therefore, $n_W = n_l^2$. This means that the weight of the model is based on the weight per unit length of the prototype ice boom stick.

As was mentioned in the beginning of the chapter, the physical modelling of the ice boom sticks is attempting to fulfil two objectives. The first objective is to simulate the hydrodynamic forces acting on the ice boom stick models and measure the free-stream velocities at which the models submerge. This test is called the Velocity Submergence Test (VST).

The other objective is to measure the pressure distribution around fixed ice boom stick models. The results are used to compare the estimate the submergence velocities for the models in the VST to the measured submergence velocities. This test is called the Pressure Measurement Test (PMT).

4.1.1 Velocity Submergence Test

The objective of the test is to study the behaviour of the ice boom stick models in open flow conditions. The test will associate the hydrodynamic forces acting on the models and the position of the models to the free-stream velocities. Also, the test will measure the free-stream velocities at which the models submerge.

Two ice boom sticks were tested, the Jenpeg ice boom stick mentioned in the previous section and an ice boom stick which was identical to the Jenpeg ice boom stick except the height of the boom stick was increased by 6 inches. The reason for testing this particular model is to study the influence of increasing the buoyancy of the ice boom stick on the submergence velocity. The model designations were JP015 and JP021 respectively. The length scale chosen for both models is 1/5 and the models were 0.3937 m. long. JP015 weighed 2.503 kg. and JP021 weighed 2.647 kg.

Since the prototype boom sticks were supported by a main cable, this type of anchoring system was simulated in the model. The anchoring system to support the model in the flume is illustrated in Figure 10. As can be seen, the suspension brackets are adjustable to ensure the suspension cable is horizontal, so as not to induce a vertical load on the system. Nylon coated woven steel fishing line was used as the suspension lines with fishing leaders to connect the lines to the main cable. The model chains equivalent to the prototype consisted of two 12" fishing leaders and the main prototype cable was modelled as a ½ inch diameter steel wire cable. The boom stick models were constructed out of plexiglass and given the correct model weights.

The suspension cable was connected to a load cell. The force measurements were recorded from a strain indicator that was calibrated to the load cell. Velocity measurements were taken by a hand-held propeller velocity meter. The relevant parameters investigated are illustrated in Figure 11. The force that the load cell measured is called F_M and the drag force which acted on the cable due to the free-stream velocity is F_{DC}. The angle of the model chain to the x-axis is ϕ and the angle of rotation of the front face of the ice boom stick to the vertical axis is β.

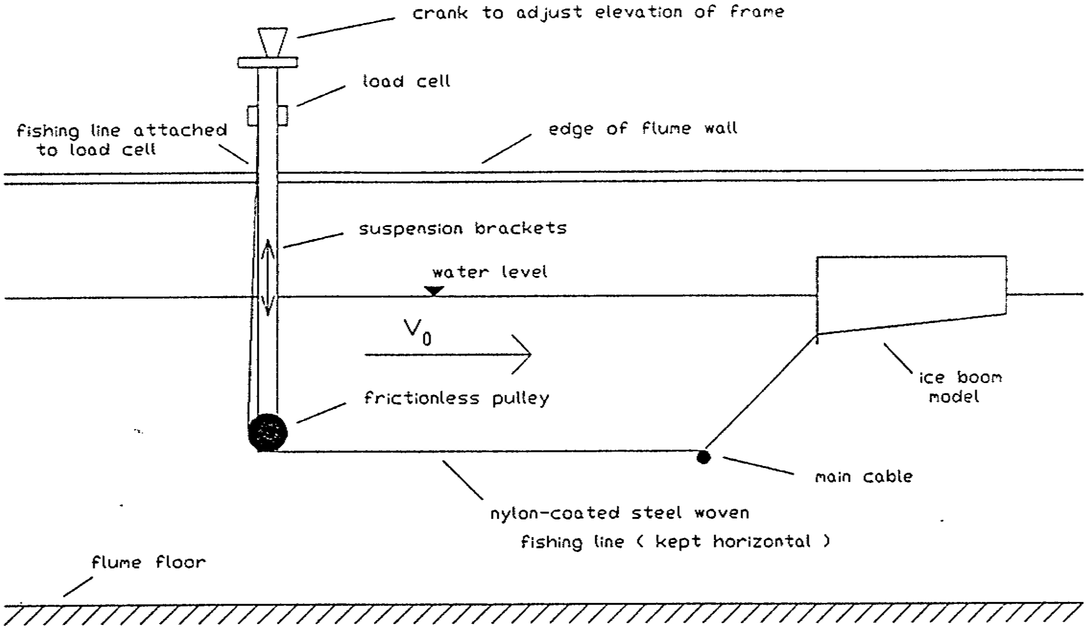


Figure 10 : Diagram of Velocity Submergence Test Model System

The load cells measured the drag force which acted on the model system. To measure the drag force on the ice boom stick model, the drag force acting on the main cable had to be known. However, it was not possible to physically measure the drag force acting on the main cable. Therefore, the drag force on the cable was estimated based on the drag force acting on a cylindrical object in an unbounded fluid. This provided a reasonable estimate of the drag force since the main cable was not very large with respect to the depth of water in the laboratory flume.

The angle ϕ that the chain made with the x-axis was measured to analyze the free-body diagram of the main cable. The horizontal component of the force in the chain is the drag force acting on the ice boom stick model while the vertical component of the

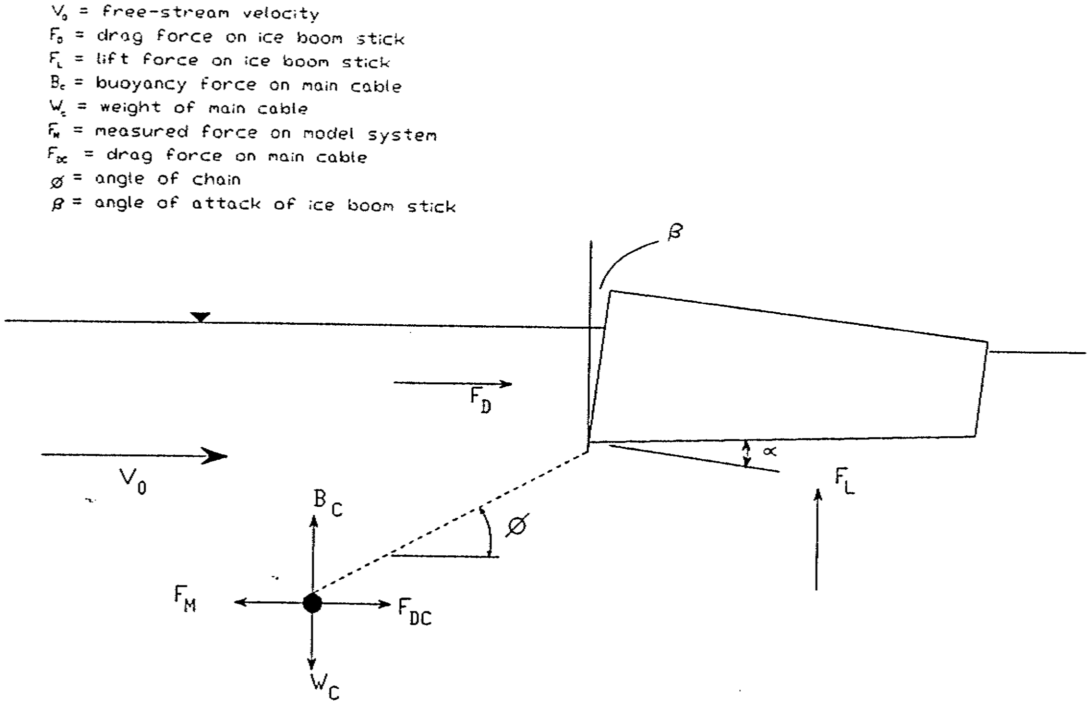


Figure 11 : Free-body Diagram of Ice Boom Stick Model

force in the chain equals the submerged weight of the main cable. The measured ϕ's were compared to the calculated ϕ's based on the analysis of the free-body diagram of the main cable using the force measurements that were recorded.

The angle the front face of the ice boom stick models made with the vertical axis was measured to calculate the horizontal projection of the wetted areas. The horizontal projected areas were required to calculate the drag coefficients for the models.

Test procedures for each test run involved measuring the drag force on the model system, photographing the boom stick cross-section against a transparent grid to measure the angles ϕ and β, and the wetted depth of the front face, D_{front} and measuring the free-stream velocity using the velocity meter. Each model was subjected to free-stream velocities ranging from 0.15 m/s until submergence, in increments of approximately 0.04 -

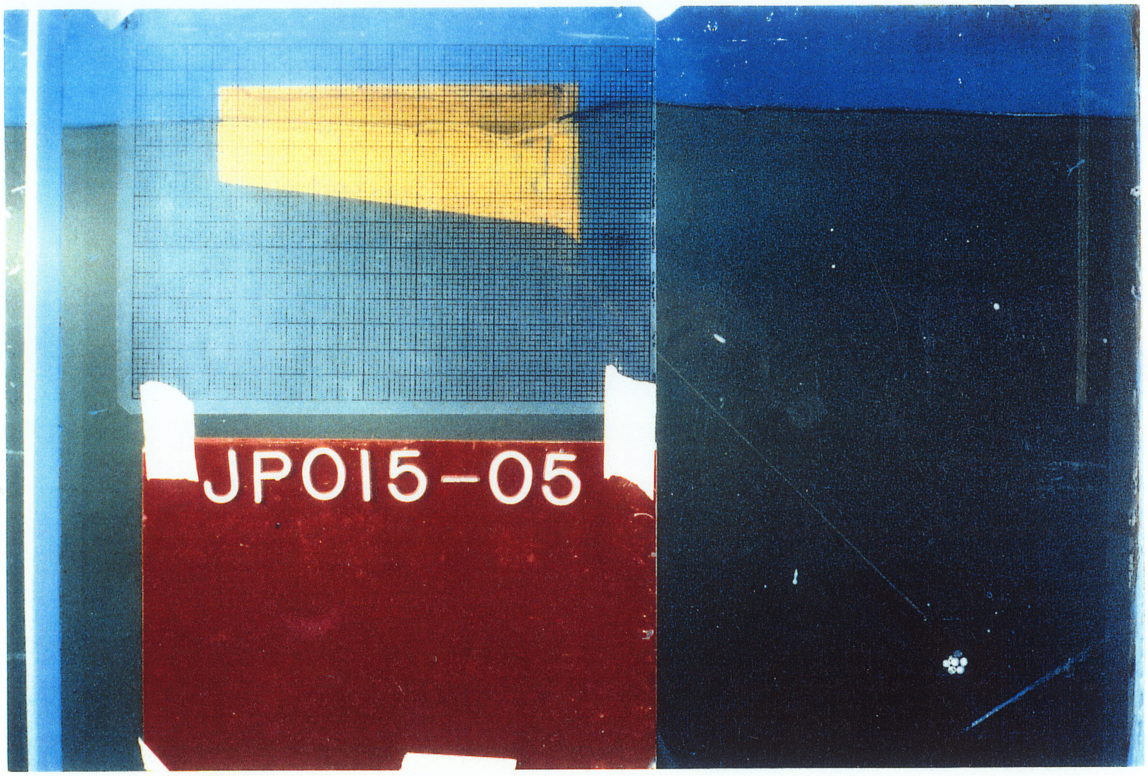


Figure 12 : VST Run of Ice Boom Model JP015

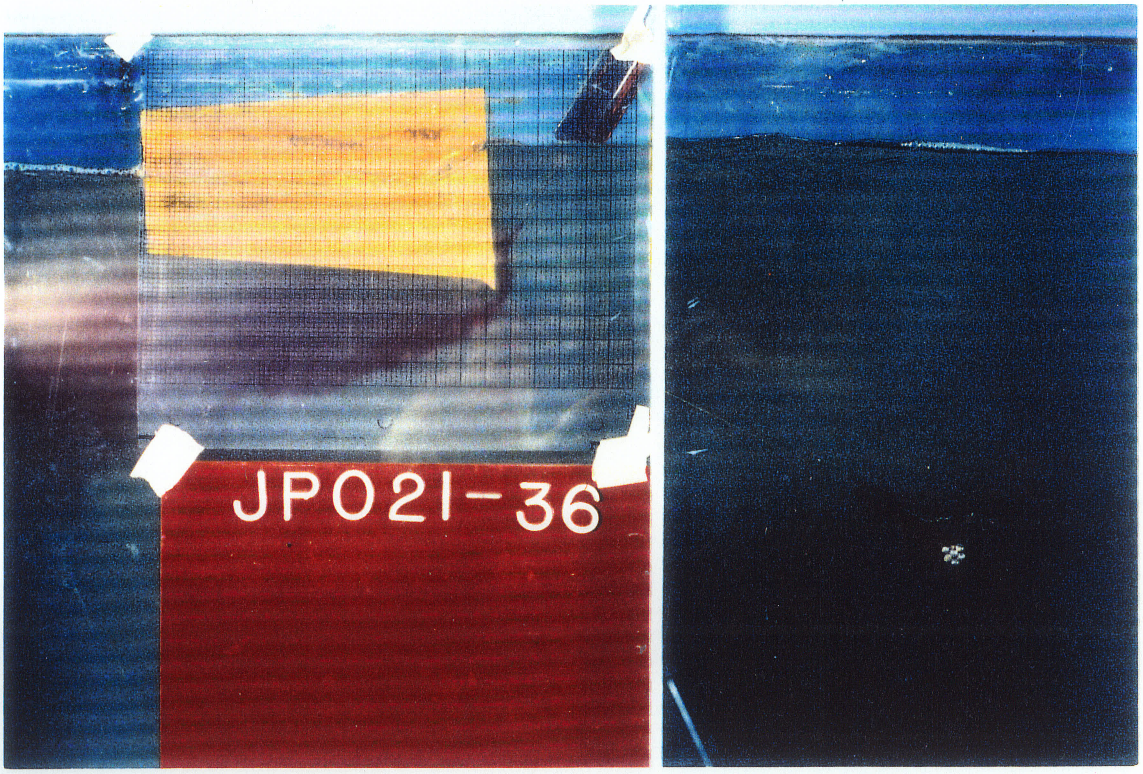


Figure 13 : VST Run of Ice Boom Model JP021

0.05 m/s. These test runs were repeated several times to minimize any systematic error that may have occurred in the test procedures. The test results are tabulated in Appendix A. Sample photographs of JP015 and JP021 runs are illustrated in Figures 12 and 13.

In Figures 12 and 13, the water is flowing from right to left. The pictures' perspective is from the side of the transparent section of the flume wall. As one can see, the transparent grid is situated such that the positions of the models can easily be measured off the pictures. Each grid is 1/10 of an inch.

4.1.2 Pressure Measurement Test

The objective of the test is to study the pressure distribution around the Jenpeg ice boom stick cross-section in open flow conditions. The pressures that will be measured will indicate the relationship between the pressure distribution and the shape of the ice boom stick to the free-stream velocity. As well, the pressures will be used to calculate the submergence velocities of the VST models and compare the values to the velocities that were measured.

One type of model was tested, a 1/5 scale replica of the Jenpeg boom stick which was fixed into position in the flume. Pressure taps were inserted into the front, back, and bottom faces of the model along the centre line. A total of 12 taps were installed, three in the front, 6 along the bottom, and three in the back. The pressure taps were zeroed with respect to the free-stream surface which was kept constant. Three views of the model are illustrated in Figures 14 to 16. Figure 14 shows the view of the front face upstream of the model. The tubes emanating from the model are connected to the pressure taps inside while the other end of the tubes are connected to standpipes where the water levels inside are measured using point gages. Figure 15 displays the downstream view of the model

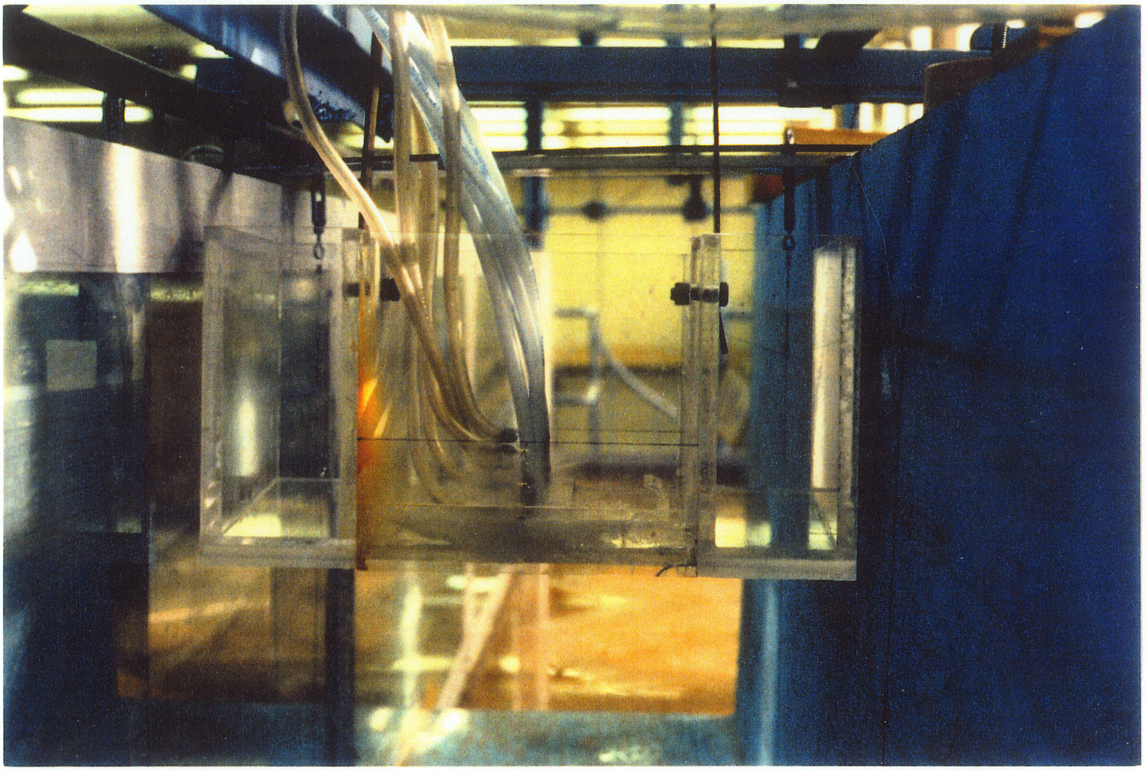


Figure 14 : Upstream View of Pressure Measurement Test Model

and Figure 16 shows the cross-section of the model viewed from outside through the transparent section of the flume wall. Figure 17 illustrates the schematic of the pressure taps inside the model.

Two sets of test runs were completed, one where $\beta = 3°$ called JP01P and the other where $\beta = 8°$ called JP02P. The model was fixed in the flume in such a manner that the wetted height of the front face corresponded to the height of the front face of the VST model JP015. In a sense, the model was fixed in the submerged position. The angle was set at 3° because this was the angle that was observed when the Jenpeg ice boom stick submerged. The angle was changed for the second test to investigate the influence of the angle of the front face on the pressure distribution on the bottom of the model and thus the submergence velocity.

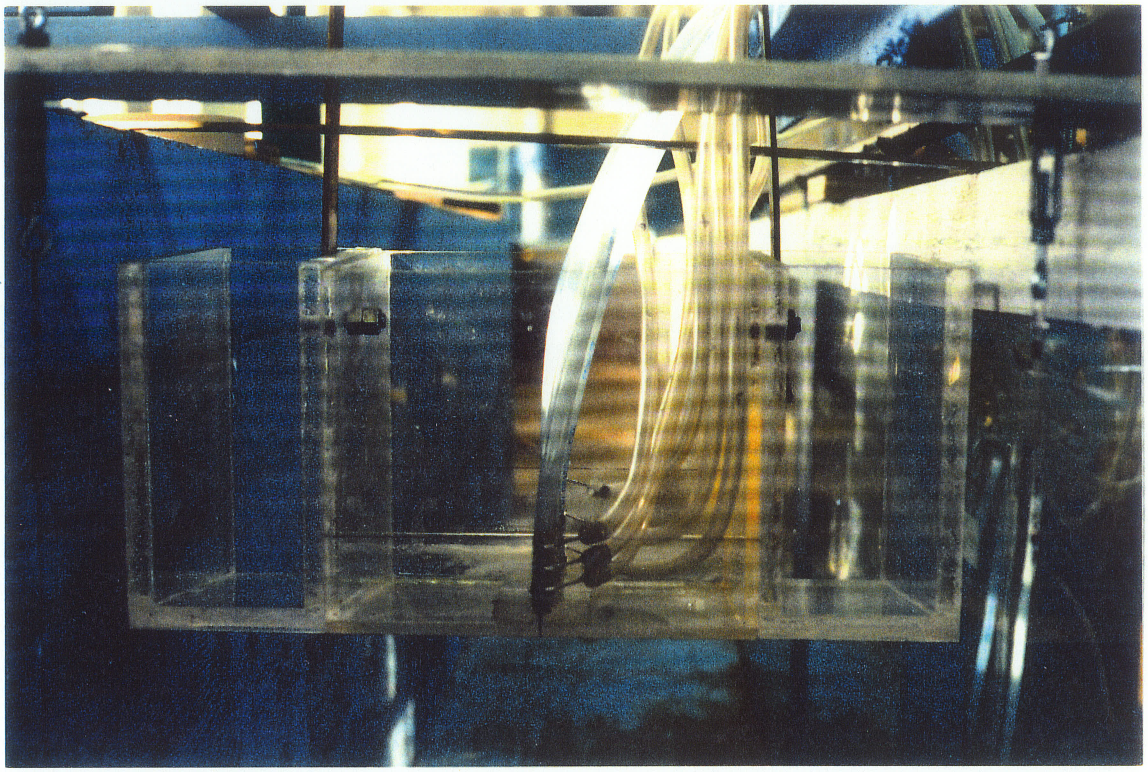


Figure 15 : Downstream View of Pressure Measurement Test Model

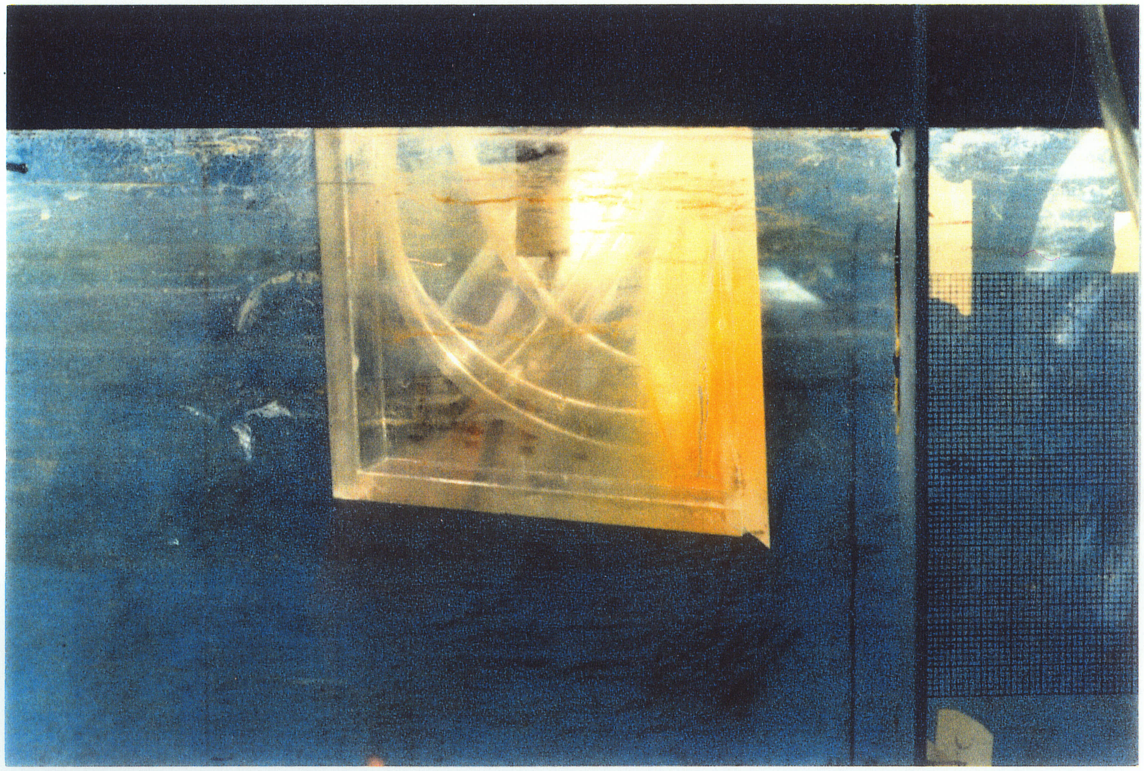


Figure 16 : Cross-sectional View of Pressure Measurement Test Model

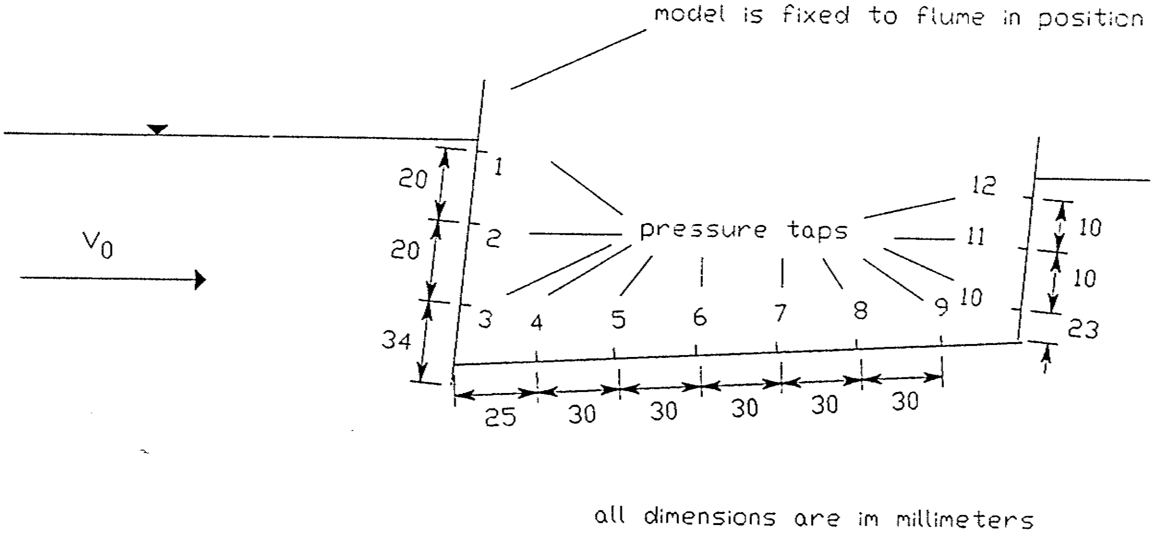


Figure 17 : Schematic of Pressure Measurement Test Model

To zero the point gages with respect to the free-stream surface, the model was immersed in still water to the desired depth. The pressure taps inside the model transmitted the corresponding water levels to the standpipes. Test runs involved subjecting the model to free-stream velocities of various magnitudes, while maintaining free-stream surface at a constant elevation. The velocities ranged from 0.1 m/s to 0.57 m/s in increments of 0.04 m/s. For each test run for both model positions, the water levels in the standpipes were measured and recorded. The results of the test runs for JP01P and JP02P are documented in Appendix B.

4.2 SAFETY BOOMS

The objective of studying safety boom sticks is to understand the relationship between the physical characteristics of cylindrical safety boom sticks with a circular cross-section and magnitude of the free-stream velocity that causes the safety boom sticks to oscillate. To achieve the objective, a test was developed to measure the velocity at which oscillation occurs for various safety boom stick models. The measurements were used to analyze the relevant physical parameters that influence the oscillation velocities of circular cylindrical safety boom stick. The test is called the Oscillation Velocity Test.

4.2.1 Oscillation Velocity Test

The objective of the Oscillation Velocity Test is to study the interaction between the safety boom sticks and the free-stream velocity. As mentioned in the previous chapter, the oscillation of the safety boom sticks is a function of the diameter d and the length l of the safety boom stick, the kinematic viscosity υ, the density of the boom stick ρ_{SB}, the density of the water ρ, the free-stream velocity V_0, and the force of gravity g.

To determine the number of different models necessary to investigate the relationship between the point of oscillation and the parameters mentioned above, dimensional analysis is applied as in the case of analyzing the pressure coefficient in Chapter 3. Non-dimensionalizing the parameters mentioned above results in the following relationship:

$$\textit{oscillation velocity} = \left(\frac{\rho}{\rho_{sb}}, \frac{V_0}{\sqrt{gd}}, \frac{l}{d}, \frac{V_0 d}{\upsilon} \right) \qquad \textbf{(4.6)}$$

where the first term is the ratio of the density of water to the density of the safety boom stick, the second term is the Froude Number based on the diameter of the safety boom stick and free-stream velocity V_0, the length-to-diameter ratio of the safety boom stick and the Reynold's Number based on V_0 and the diameter of the safety boom stick.

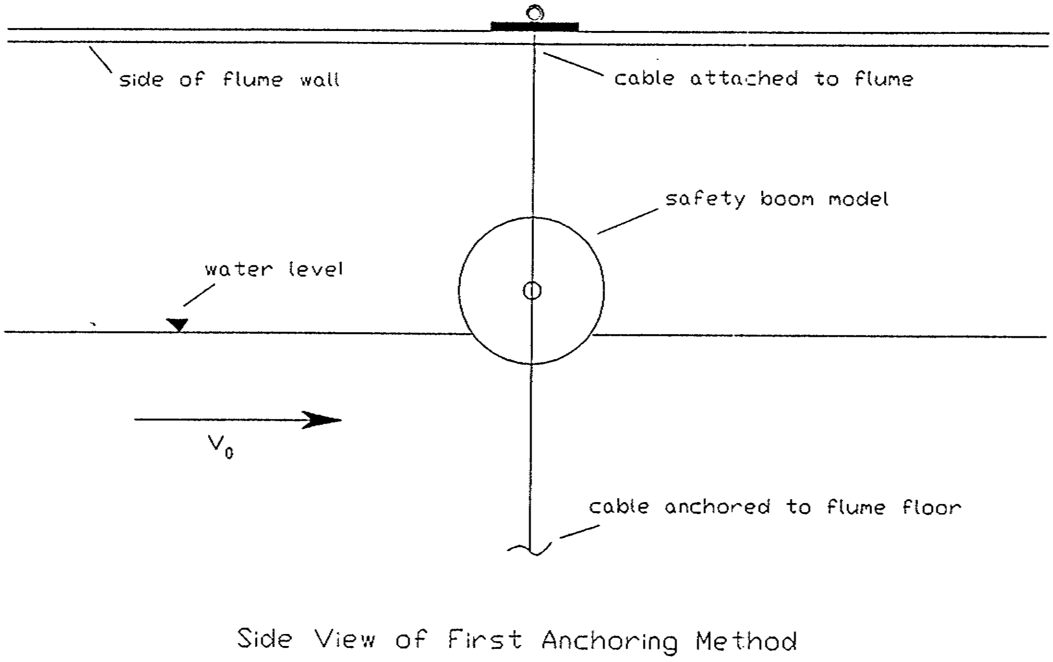


Figure 18 : Side View of First Anchoring System

The range of Reynold's Numbers tested have little effect on the rate of shedding of vortices from the safety boom stick models. Therefore, it was decided to ignore viscous effects.

It was decided to construct cylindrical models with L/D ratios from 1 to 5 in increments of 0.5 with a diameter of 3". Models were made of styrofoam and sealed to prevent water logging. Two types of foams were used, one with $\rho = 1.0$ lb/ft^3, called SB01 and the other with $\rho = 1.5$ lb/ft^3, called SB02.

Circular cross-sectioned cylindrical safety boom sticks are usually anchored individually to a main cable or connected in series. These two methods were reproduced in the laboratory. Two types of anchoring systems were used to support the models in the flume - 1) laterally supported at the ends of the models and 2) supported by cables anchored upstream of the models.

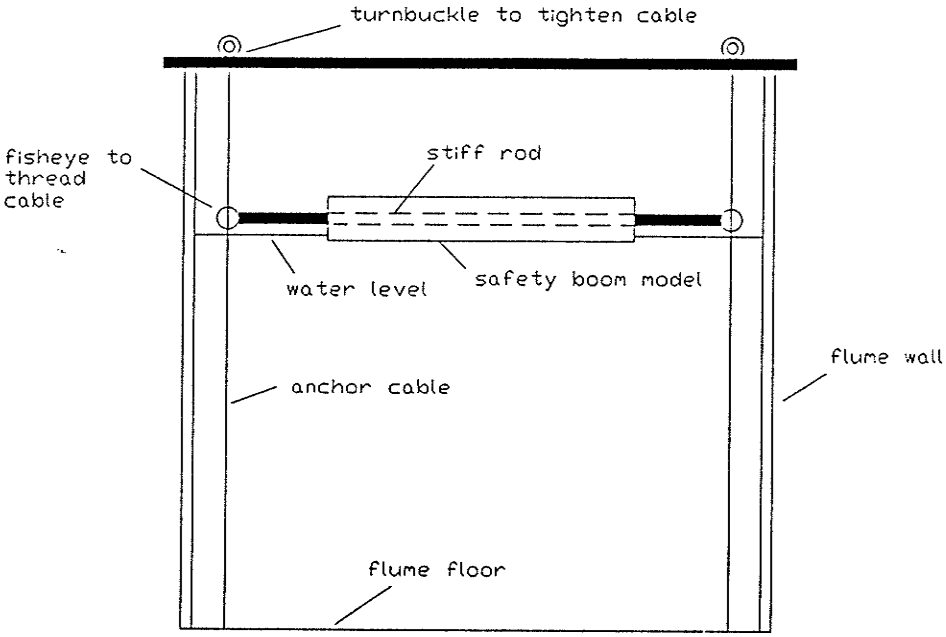


Figure 19 : Downstream View of First Anchoring System

Figures 18 and 19 display the system where the safety boom models were anchored laterally. Figure 18 displays the side view of the anchoring system while Figure 19 displays the downstream view of the anchoring system. The safety boom models were supported by a stiff rod anchored to the cables at both ends which was tightened until the slack was negligible. During test runs, the models were allowed to move in the vertical direction but not in the direction of flow.

The second anchoring system is displayed in Figure 20. The safety boom models were supported downstream of the anchoring system and the models' movements were not

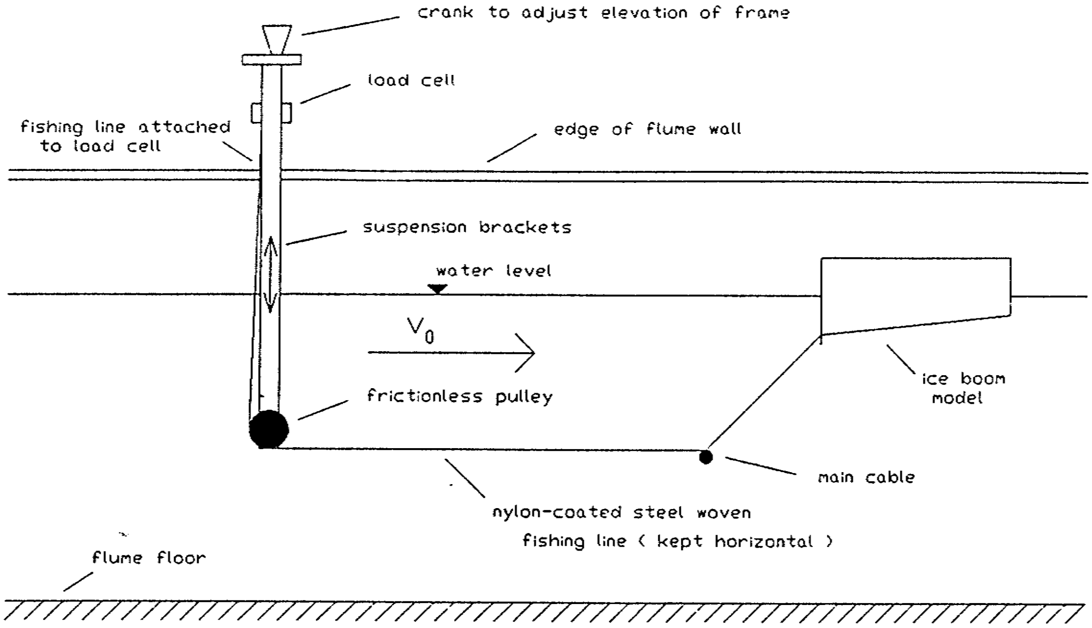


Figure 20 : Second Anchoring System

restricted. As can be seen, the anchoring system is virtually identical to the anchoring system used in the Velocity Submergence Test. The results of the testing are tabulated in Appendix C.

5. ANALYSIS AND DISCUSSION OF TEST RESULTS

The objective of physically modelling the ice and safety boom sticks is to understand the interaction between the hydrodynamic forces and the physical characteristics of the floating boom sticks. The conceptual design of the physical testing program is based on the theoretical formulation phase in Chapter 3. There were three main objectives : a) measure the cable force restraining an ice boom stick for a given free-stream velocity; b) measure the submergence velocities for various ice boom stick models and; c) measure the oscillation velocities of various circular cross-sectioned cylindrical safety boom stick models. The theoretical formulation phase of the project analyzed the behaviour of the ice and safety boom sticks based on classical fluid mechanical theory. The purpose of this chapter is to link the objectives of the theoretical development phase with those of the physical modelling phase.

5.1 ICE BOOMS

The ice boom sticks were modelled to analyze the forces that cause the submergence of the sticks under high velocity conditions. To that end, two types of tests were devised - the Velocity Submergence Test and the Pressure Measurement Test.

5.1.1 Velocity Submergence Test

The objectives of the VST are to observe the submergence characteristics of the ice boom sticks, measure the drag forces and document the position of the boom sticks under different flow conditions.

An ice boom stick model subjected to increases in the free-stream velocity begins to sink deeper under the free-stream surface. The model also generates a wave upstream of the front face, and as the velocity increases, the wave increases in height. A point is reached when the wave that develops in front of the model overtops the front face. This is called the point of initial submergence. Figures 21 and 22 illustrate the positions of the ice boom stick models JP015 and JP021 when they initially submerged.

As one can see, at this point, only the front face of the boom sticks is submerged due to the waves that are generated. Also, Figure 21 and 22 indicate that the free-stream surface upstream of the models is lower than the top edge of the front face and a portion of the back face is above the free-stream surface downstream of the models.

As the free-stream velocities increases, the front and back faces submerges until a point is reached when the entire boom stick models are below the free-surface, depicted in Figures 23 and 24. This is the point of final submergence. The submerged depths for JP015 and JP021 are different due to the oscillating effects of the models.

The observed values for both the initial and final submergence velocity for JP015 and JP021 are listed below:

	Initial Submergence Velocity m/s	Final Submergence Velocity m/s
JP015	0.51	0.61
JP021	0.60	0.68

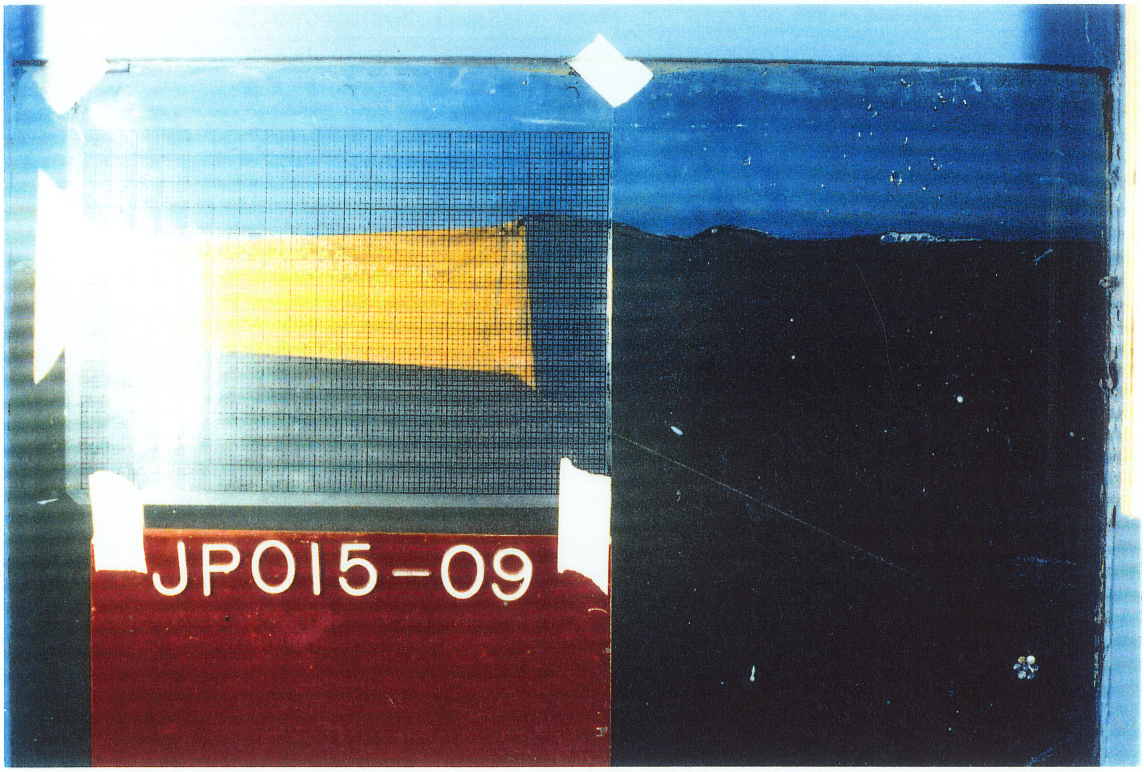


Figure 21 : Initial Submergence of Ice Boom Model JP015

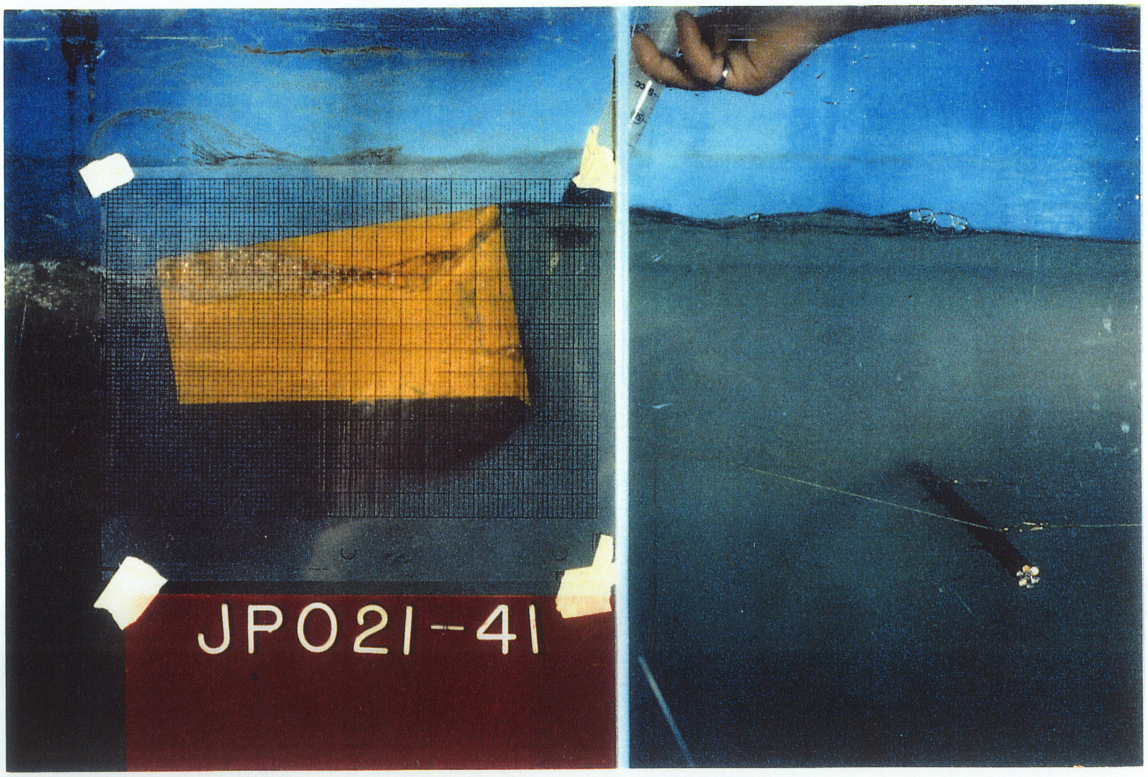


Figure 22 : Initial Submergence of Ice Boom Model JP021

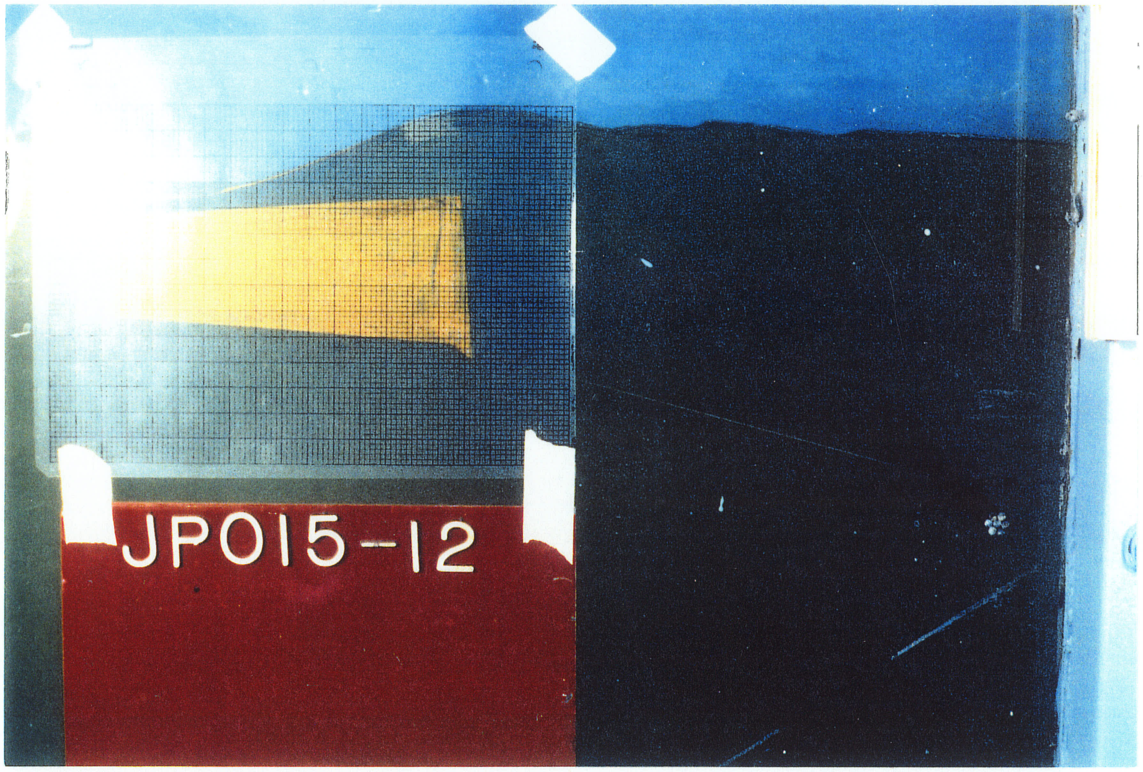


Figure 23 : Final Submergence of Ice Boom Model JP015

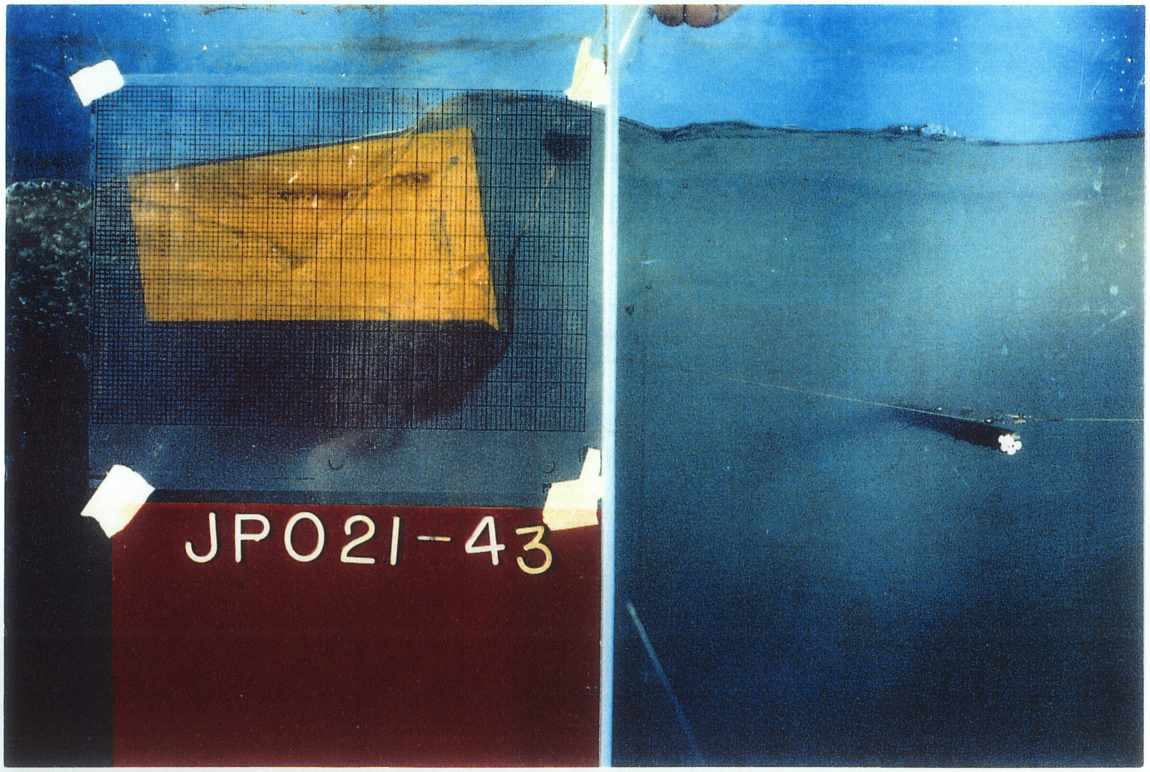


Figure 24 : Final Submergence of Ice Boom Model JP021

The observed submergence velocity of the prototype Jenpeg ice boom stick the field was approximately 1.4 m/s corresponding to 0.62 m/s model velocity. This value agrees with the observed final submergence velocity of JP015 at 0.60 m/s. Therefore, it is reasonable to conclude that the model does properly simulate the prototype conditions in this respect.

One of the assumptions made in chapter 3 was that the drag coefficient for an ice boom stick would reach a limiting value for high Froude Number's. To validate this assumption, the forces that were measured for both models were converted into their non-dimensional form - the drag coefficient. As mentioned in Chapter 4, the force measured by the load cell includes the drag force on the main cable as well as the drag force acting on the ice boom stick model. Therefore, an estimate is made of the drag force acting on the main cable using :

$$F_{DC} = \frac{1}{2} \rho C_D A_{cable} V_0^2 \tag{5.1}$$

where A_{cable} is the projected area of the main cable. Estimating the drag coefficient to be 1.2 from Roberson and Crowe (1985), the drag force acting on the boom stick model is equal to:

$$F_D = F_m - 3.0 V_0^2 \tag{5.2}$$

where F_m is the measured force by the load cell.

Applying (5.2) to the measurement results for JP015 and JP021, the drag force on the ice boom stick models versus the free-stream velocities are illustrated in Figure 25. The data plots seems to illustrate a quadratic trend but further analysis is necessary.

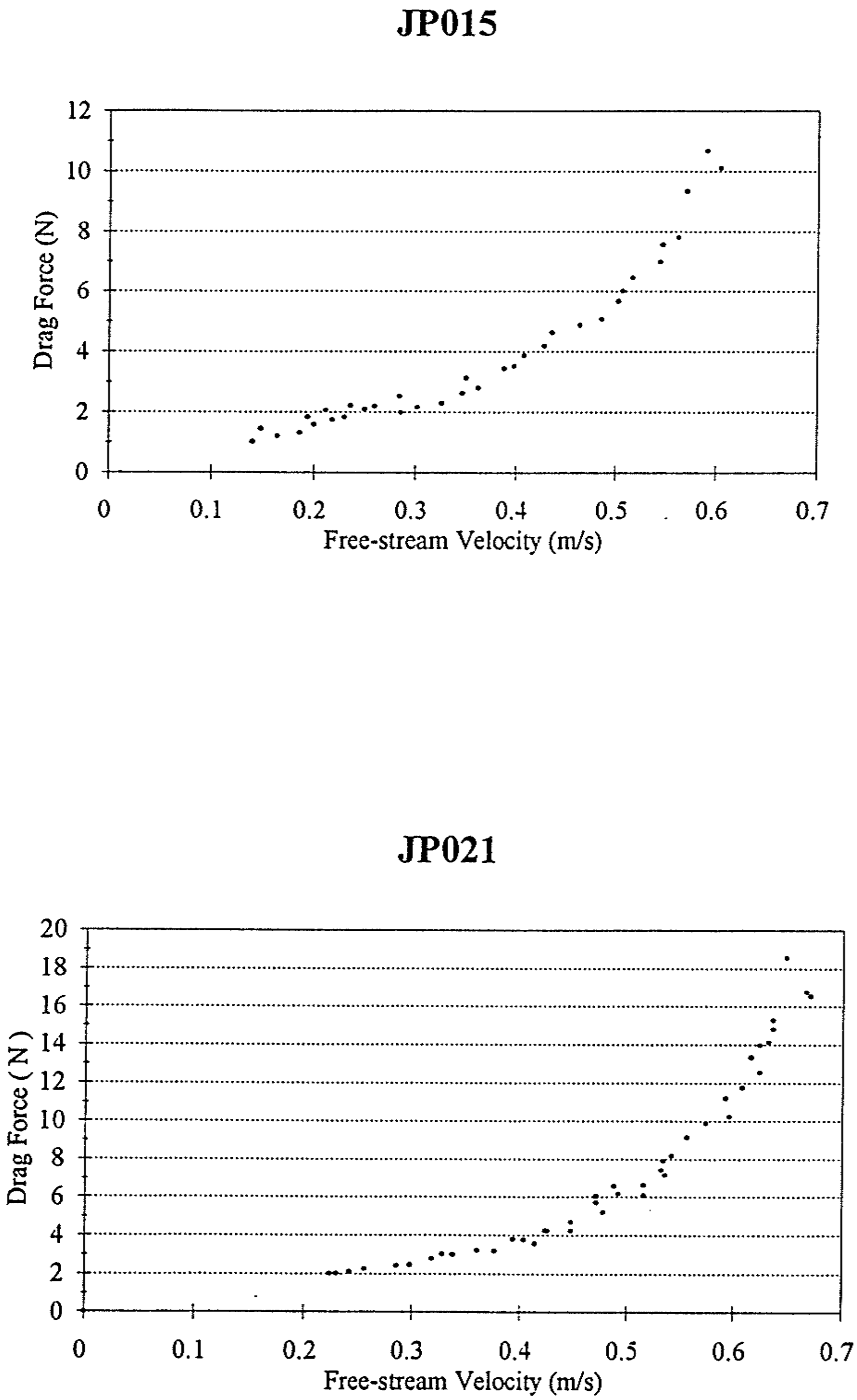


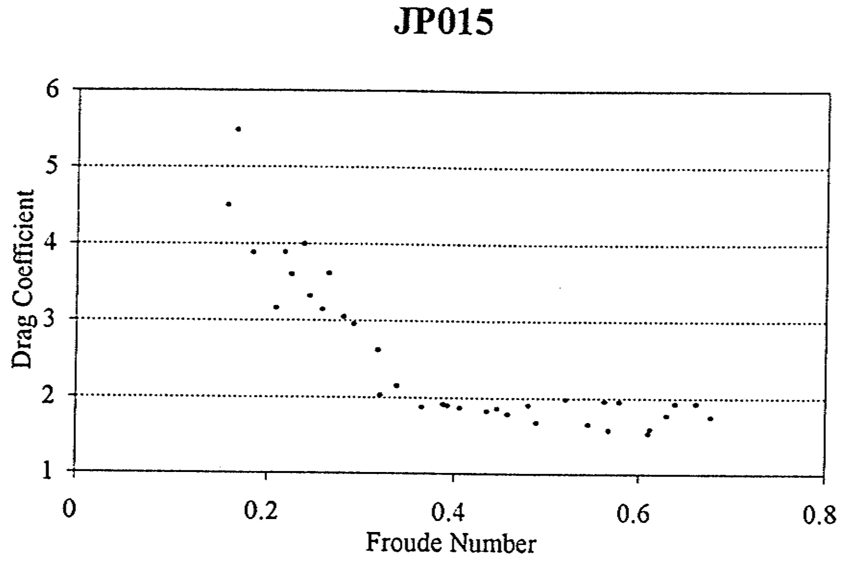
Figure 25 : Drag Force versus Free-stream Velocity for JP015 and JP021

The data results were converted into their non-dimensional form; the drag forces into drag coefficients and the free-stream velocities into Froude Numbers. The plots for JP015 and JP021 are illustrated in Figure 26.

For JP015, the drag coefficient decreases until the Froude Number is about 0.35 then levels off at a value of 1.8. As the Froude Number increases, there is more scatter in the drag coefficient. For JP021, the drag coefficient decreases until the Froude Number is 0.4, then increases again with the lowest drag coefficient being about 1.1. The plots show that the test results for JP015 support the theory that the drag coefficient decreases until a limiting value but the test results for JP021 do not contradict the theory yet do not support it as well. There is too much scatter in the data for an accurate interpretation. The test results indicate that some unknown condition(s) are not being taken into account when analyzing the drag forces.

The initial hypothesis is based on the assumption that the proximity of the flume floor would not influence the behaviour of the models. If this was invalid, one may expect some discrepancies in the test results. Therefore, the flume bottom is incorporated into the analysis of the drag force using the momentum equation.

The momentum equation is applied to the control volume illustrated in Figure 27 to analyze the test results. Here, V_0 is the free-stream velocity, $\tilde{v}$ is the velocity along the streamline defining the zone of separation and V_2 is the average velocity crossing the control volume at section 2. ΔH is the kinematic pressure head, d_o is the initial wetted depth of the front face, D_{front} is the depth of the front face when V_0 is greater than 0, p_1 and p_2 are the hydrostatic pressures acting on the control volume at section 1 and 2, and F_M is the force necessary to hold the ice boom stick in place. Summing the forces in the x-direction must equal zero or:


JP015

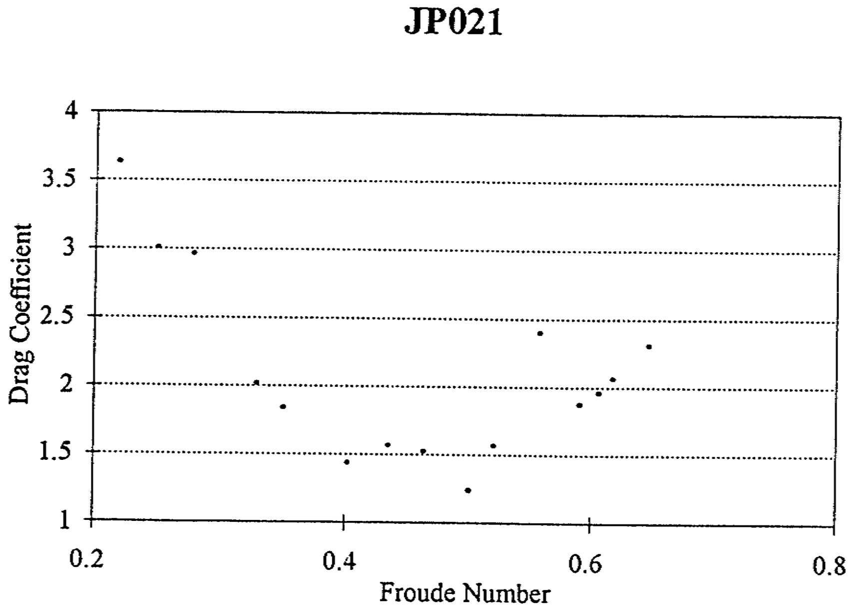

JP021

Figure 26 : Drag Coefficient versus the Froude Number for JP015 and JP021

V_0 = free-stream velocity
P_1 = hydrostatic pressure acting at Section 1
P_2 = hydrostatic pressure acting at Section 2
D_{front} = wetted height of the front face of the ice boom model
d = draught depth of the ice boom model
ΔH = kinematic pressure head
F_M = measured force on model system
V_2 = velocity at Section 2
$\acute{V}$ = velocity along streamline defining zone of separation
Y_1 = depth of water at Section 1
Y_2 = depth of water at Section 2

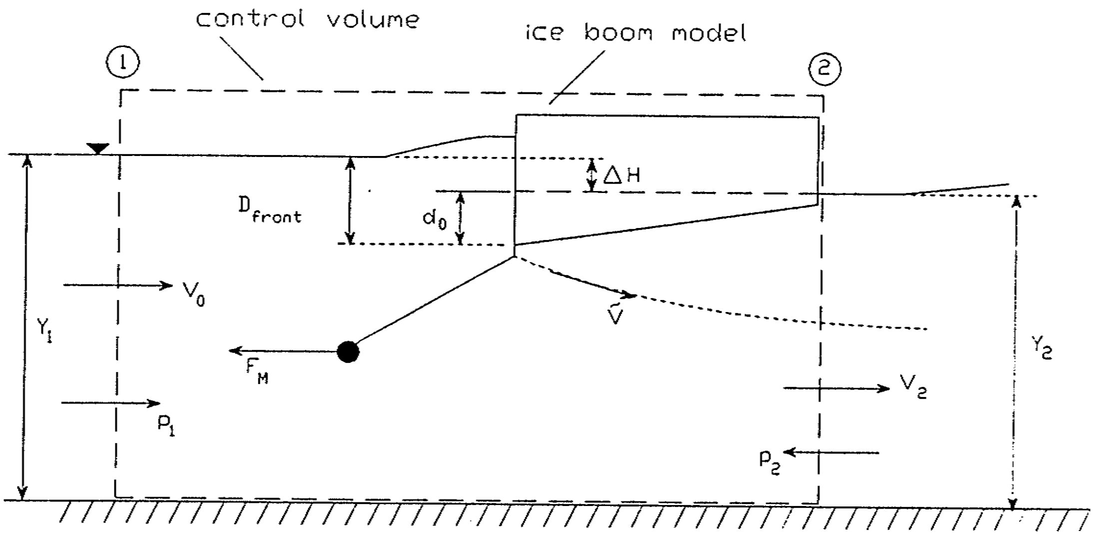


Figure 27 : Definition Sketch of Control Volume for Momentum Equation

$$\frac{1}{2}\rho y_1^2 g B - \frac{1}{2}\rho y_2^2 g B - \rho y_1 B V_0 (V_2 - V_0) - F_m = 0 \tag{5.3}$$

Assumptions in analyzing (5.3) are that $V_2 \cong 1.67 \bullet V_0$ from analyzing the test results, $(y_1^2 - y_2^2) \cong \Delta H \bullet 2 y_1$ and $\Delta H = C_1 \bullet V_0^2/g$. Substituting these values into (5.3) and reducing yields:

$$F_m = \rho B L y_1 V_0^2 (C_1 - 0.67) \tag{5.4}$$

or in dimensionless form:

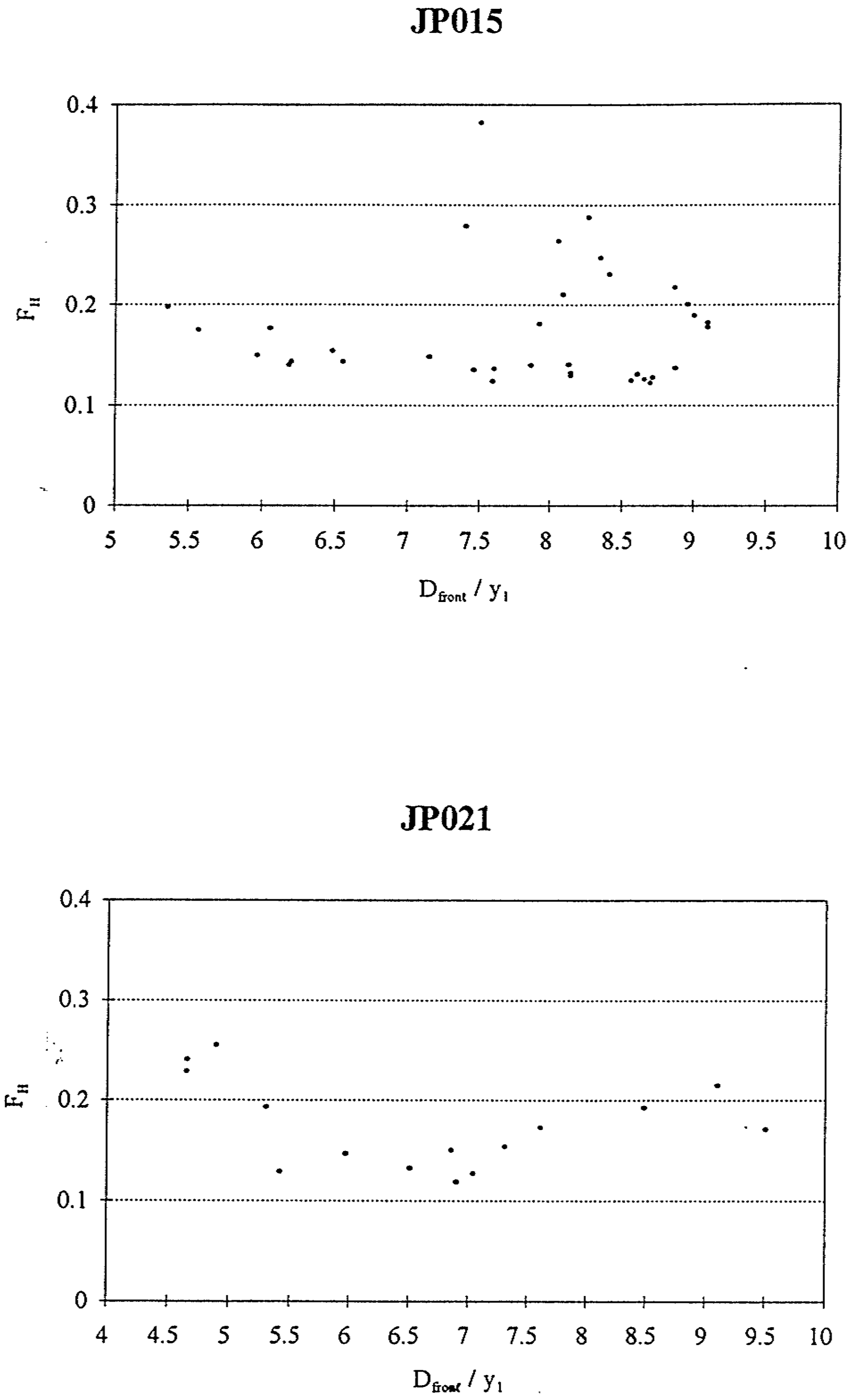


Figure 28 : Plots of F_H versus D_{front}/y_1 for JP015 and JP021

$$F_H = \frac{F_m}{\rho B y_1 V_0^2} = C_1 - 0.67 \tag{5.5}$$

F_H should be constant with respect to the non-dimensional form of the depth of submergence D_{front}. The resulting graphs for JP015 and JP021 are illustrated in Figure 28. As can be seen, JP015 gave better results because there were more pictures to analyze than JP021. The results for JP015 indicate that F_H is equal to approximately 0.15. There is a bit of scatter because the original test did not incorporate the influence of the flume floor. The data results for JP021 also indicate that F_H is equal to 0.15. Using the value of F_H to be 0.15, C_1 = 0.82. This value can be verified by analyzing the Pressure Measurement Test results.

5.1.2 Pressure Measurement Test

There were two types of test runs, JP01P and JP02P. The original purpose of the test runs was to confirm the submergence velocities of the floating boom models. The data that was accumulated for both tests are illustrated in Figures 29 and 30. Refer to Figure 17 for pressure tap positions. The kinematic pressure distribution for the first six points is highly correlated for both series of test runs. All three taps in the front show the same kinematic pressure with respect to the free-stream velocity as does points 4 through 6. The front three taps indicate a positive kinematic pressure head for all free-stream velocities which is to be expected since the velocities at the front of the model are reduced as in the unbounded case of a flat plate analyzed in Chapter 3.

The back six taps show a high degree of scatter. One reason for this is that a degree of mixing and turbulence within the zone of separation was observed for both test

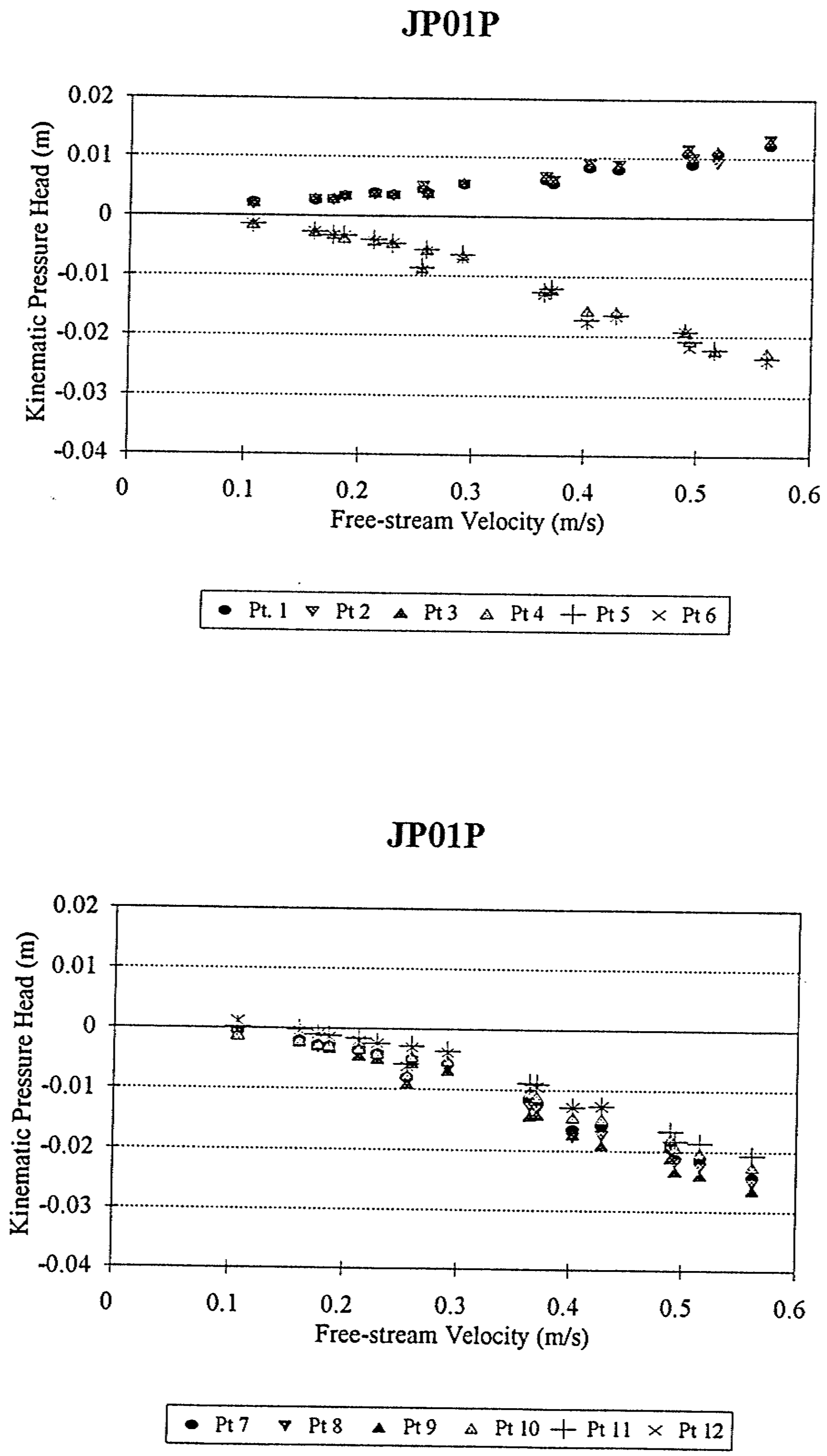


Figure 29 : Pressure Readings for JP01P

runs, resulting in the velocities to fluctuate. This would influence the pressure readings because the velocities in the zone of separation would be measured by the pressure taps along the underside of the model.

The pressure readings measured for points 4 to 9 will be used to calculate the submergence velocities for JP015 and JP021. The data results were made non-dimensional by dividing the kinematic pressure head by the wetted depth of the front face and the velocity was converted into the square of the Froude Number using the height of the front face of the model, which in this case is the same as the wetted height of the front face of the model. Since the kinematic pressure head is a function of Bernoulli's equation, the dimensionless relationship should be linear and take on the following form:

$$\frac{\Delta H}{D_{front}} = C_1 Fr^2 \tag{5.6}$$

The data are plotted in Figure 31. Analysis of the trend in the data confirms the original assumption that the relationship should be linear. Applying regression analysis to the data results in a slope of 0.844 for both test runs. This shows that the kinematic pressure head under the model is independent of the range of β's tested. The value of the slope corresponds very well to the estimated value of C_1 = 0.82 from the analysis of the VST results. This reaffirms the hypothesis that the flume floor did influence the drag force on the floating models.

Equation (5.6) can be used to estimate the submergence velocity for JP015 and JP021 by calculating the ΔH corresponding to the free-board that the floating boom models have when the free-stream velocity is equal to 0. Using the free-board values for JP015 and JP021, the estimated submergence velocities are 0.55 m/s for JP015 and 0.75 m/s for JP021.

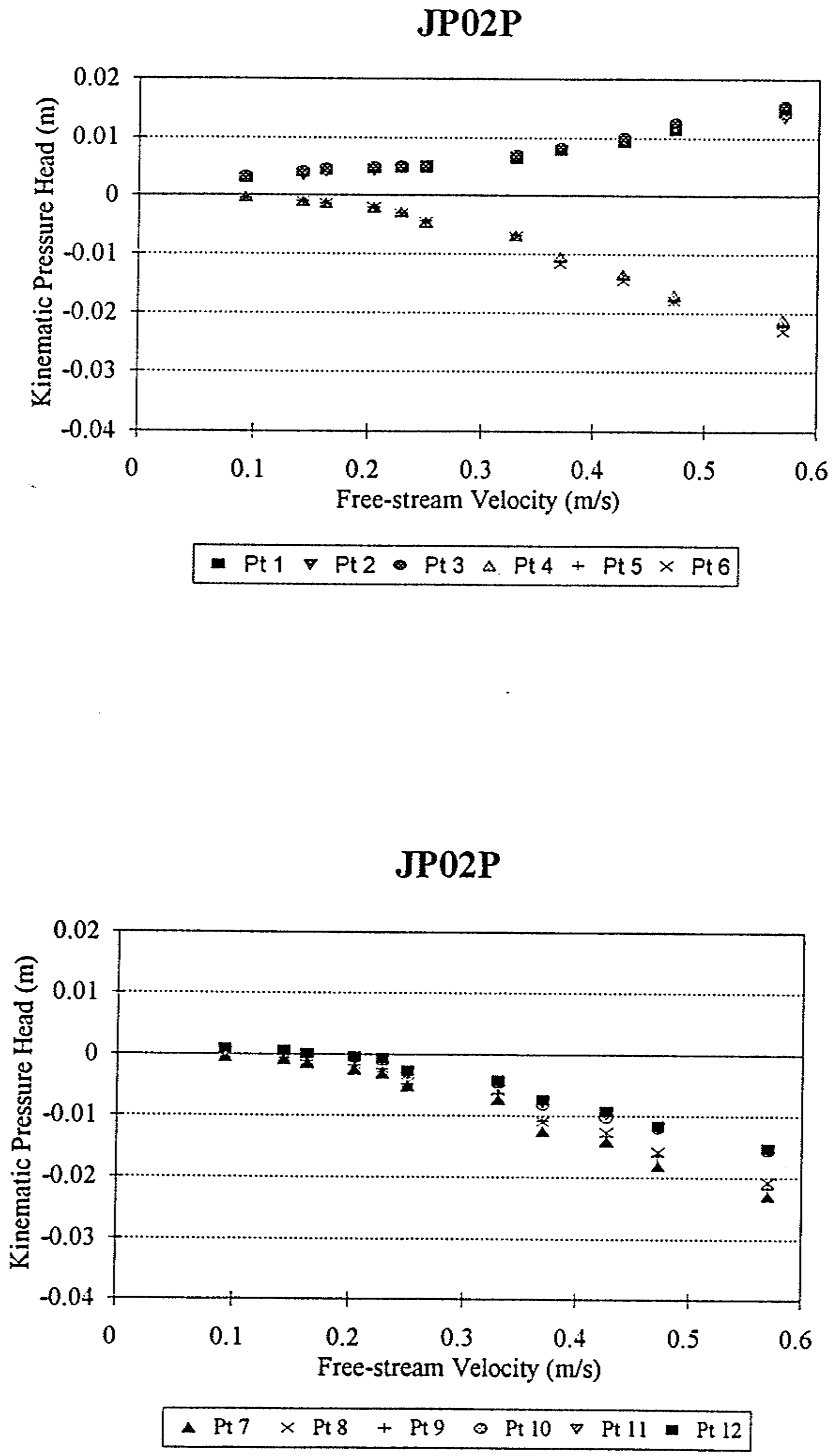
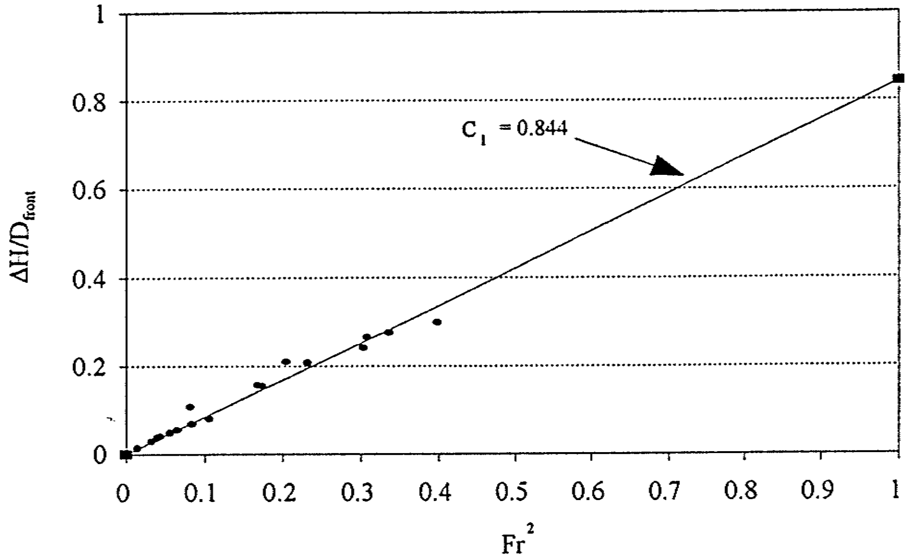


Figure 30 : Pressure Readings for JP02P

JP01P



JP02P

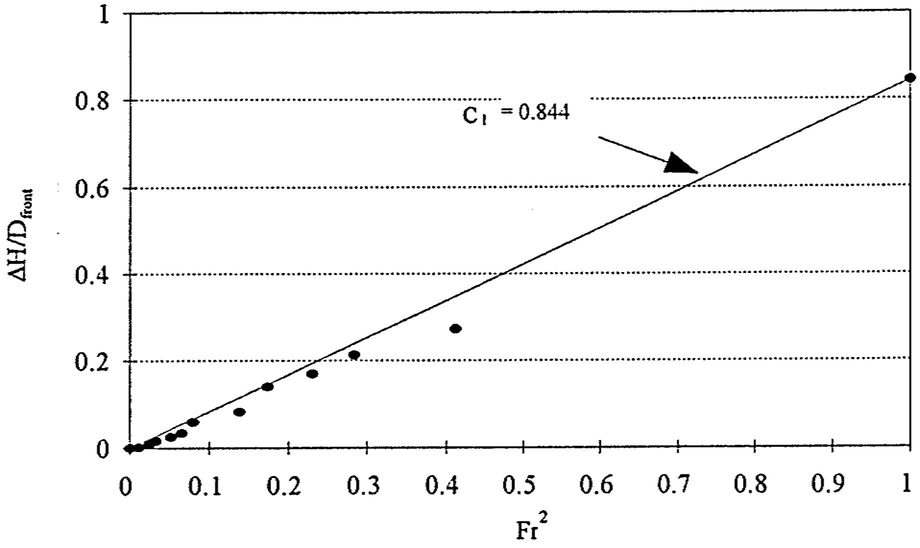


Figure 31 : $\Delta H / D_{front}$ versus Fr^2 for JP01P and JP02P

The range of submergence velocities for JP015 was between 0.506 m/s and 0.60 m/s. The PMT does corroborate this measurement since 0.55 m/s lies within this range. One should note that when JP015 initially submerged, it was due to the overtopping of the front face by a wave generated by the model. This is a somewhat subjective interpretation of the initial submergence of the model. In the PMT, the pressure head was measured with respect to the free-stream surface. This means the submergence velocity that was calculated was the velocity at which point the elevation of the free-surface corresponded with the top of the front face.

The zone of submergence for JP021 was between 0.61 m/s and 0.67 m/s, so the PMT of 0.75 m/s overestimated the submergence velocity. The difference could again be due to the wave effect. Another possible reason could be boundary effects caused by the flume floor which were not originally anticipated and could influence the VST results.

5.2 SAFETY BOOM

The safety boom sticks were modelled to investigate the relationship between the physical characteristics of the safety boom sticks and the free-stream velocities which causes the safety boom sticks to oscillate. A test was devised to achieve this objective. It was called the Oscillation Velocity Test.

5.2.1 Oscillation Velocity Test

The oscillation velocity test investigated the relationship between the physical parameters and the oscillation velocities of the safety boom sticks. The physical parameters that were investigated were the length to diameter ratio and the density of the safety boom sticks. As well, the method of anchoring the models were investigated. Two methods were used: a) anchored laterally to sides of the flume and; 2) anchored upstream of the model. The results are tabulated on the next page.

Some of the models did not yield meaningful results. The models with L/D ratios of 1.0, that were anchored using the second anchoring system, became highly unstable under low velocity conditions and oscillated laterally. One possible reason could be that the models were influence by edge effects due to their small aspect ratio.

L/D	First Anchoring System		Second Anchoring System	
	SB01	SB02	SB01	SB02
1.0	0.93	0.93	N.A	N.A
1.5	0.93	0.93	0.84	0.84
2.0	0.93	0.93	0.81	0.81
2.5	0.90	0.90	0.79	0.79
3.0	0.87	0.87	0.78	0.78
3.5	0.85	0.85	0.76	0.76
4.0	0.84	0.84	0.73	0.73
4.5	N.A.	N.A.	N.A.	N.A.
5.0	N.A.	N.A.	N.A.	N.A.

It was observed that there was a definite transition point from stability to instability for each model. Just before a model would become unstable, it would start to vibrate, but not at a definable frequency. As the velocity was increased slightly, the model would begin to oscillate. There is no difference in oscillation velocity between SB01 and SB02. The reason for this is that the volume of water displaced by both models is the same for the same l/d ratios. Also, the buoyancy force is very large relative to the weight of the models, so the specific gravity for both models is essentially the same. The type of anchoring system greatly influenced the velocity at which oscillations began. The measurement of the oscillation velocities was highly subjective, therefore the results were treated with caution. Also, equipment available to do sensitive testing was not available, so it was decided to discontinue further research.

6. PRACTICAL APPLICATIONS OF THE RESEARCH

Chapter 6 focusses on the practical applications of the research on floating boom sticks. There are two objectives established in this chapter: a) to derive a set of guidelines to be used by engineers in the design of floating boom sticks and: b) to develop an intelligent decision support system tool to be used by engineers or technicians interested in physically modelling floating boom sticks. The design guidelines are limited to the design of a trapezoidal ice boom stick to withstand a given free-stream velocity. The decision support system tool will be useful for people interested in investigating floating boom sticks but lack the knowledge to formalize a testing program to achieve the objective.

6.1 DESIGN GUIDELINES

The evaluation of the data results in Chapter 5 provided a basis for the design of floating boom sticks to withstand high velocity conditions. There are many considerations involved in the overall design of ice boom sticks such as : a) the estimate of the ice forces acting on the ice boom sticks: b) the optimal location of the ice boom to retain ice flows: and c) the design and spacing of the ice boom sticks. The guidelines developed here are limited to the design of individual ice boom sticks of similar trapezoidal shape as the Jenpeg ice boom stick.

Several factors must be considered when designing such an ice boom stick. In particular : a) the length of the ice boom stick, weight of the ice boom stick, type of construction material to withstand the impact forces of the floating ice pans, and the required height of the front face of the ice boom stick to retain the floating ice pans and other floating debris.

Experience with the boom at Jenpeg shows that this design functions well, provided the boom sticks are not submerged because of the high velocity. For this reason, the design guidelines focus on the free-board that is required to ensure that the boom stick will not submerge for a given maximum velocity.

The design proceeds by trial and error with an assumed cross-section. The draught depth of the ice boom stick is determined by making the weight of the displaced water equal to the weight of the ice boom stick or :

$$d_0 = \frac{W_{boom}}{BL\rho_{water}} + B\sin\alpha \tag{6.1}$$

where d_0 is the draught depth of the ice boom stick, W_{boom} is the weight of the ice boom stick, α is the angle of the bottom face of the boom stick as illustrated in Figure 11, B is the cross-sectional width of the ice boom stick, L is the length of the ice boom stick and ρ_{water} is the density of water. The first term is the average draught depth of the ice boom stick and the second term is to take into account that the cross-section of the ice boom stick is trapezoidal.

The required free-board of the ice boom stick to withstand the design free-stream velocity is calculated using (6.2) :

$$\Delta H = 0.844\frac{V_{design}^2}{g} \tag{6.2}$$

where ΔH is the free-board height, V_{design} is the design free-stream velocity and g is gravity.

The required height of the front face for the ice boom stick is calculated by adding (6.1) and (6.2) or :

$$H_{front} = d_0 + \Delta H \tag{6.3}$$

where H_{front} is the required height of the front face of the boom stick. If the available height of the front face is less than (6.3), then the height should be increased or the weight of the ice boom stick be decreased for the ice boom stick to remain afloat for the design velocity.

The effect of the angle of the bottom was not investigated. It is probably small. It would seem advisable to stick with the angle of 8 to 10 degrees since that seemed to work well with the Jenpeg boom stick. It made the height of the front face somewhat larger than the average depth. This is desirable because : a) the submergence due to overlapping by the front wave occurs sooner than the sinking of the stick due to the reduced piezometric level underneath it and ; b) a larger front face works better to prevent floating ice pans from passing underneath the structure.

6.2 EXPERT SYSTEM APPROACH TO TESTING ICE BOOM STICKS

The intent of the decision support system (DSS) is to guide the user in the composition and implementation of a testing program for ice booms. The objective of the system is to research the hydrodynamic characteristics of individual ice boom sticks in the absence of ice. Trapezoidal shaped ice boom sticks are assumed to be the general type of ice boom sticks to be studied. VP-EXPERT (1987) is a rule-based expert system development tool which was used to develop and operate the DSS.

Any type of research involving physical modelling and testing is time consuming and requires the expertise of many disciplines. Sometimes, this expertise is difficult to acquire which further hinders research. The system attempts to alleviate this shortfall by supplementing available expertise with the knowledge stored within the DSS. The advantage is that the system saves time by guiding the user through the stages required to formulate and implement a practical testing program..

This type of system would be useful in hydraulic laboratories because the testing program formulated depends on where the testing will take place. Research assistants and/or engineers interested in investigating the characteristics of ice boom sticks would benefit from using this system. The system will tell the user what type of tests can be done on the prototype ice boom sticks, how to build and install the models, and provide instructions on how to use the equipment available in the lab that are required to perform the tests. However, the limitations of the system are due to the equipment that was available in the hydraulics laboratory at the Department of Civil Engineering at the University of Manitoba.

The domain expertise for the system originated from the author's prior experience in dealing with the investigation of the hydrodynamic forces acting on ice boom sticks. Further expertise was acquired from a professor with experience in physical hydraulic modelling. The professor provided the basis for the expertise regarding the scaling of the prototype and the instructions required to operate the testing equipment.

6.2.1 Prototype System

The description of the prototype system is to be discussed in the following section. It consists of a brief narrative non-procedural description of the system, followed by a narrative delineation of the structure of the DSS. Each knowledge base in the system will be scrutinized by a step by step explanation of the principles used for formulating the control organizations, major goals, and tasks.

6.2.1.1 System Overview

The system consists of two phases, the ***Test Formulation Phase*** and the ***Test Consultation Phase***. The system starts with the Test Formulation Phase. The purpose of this phase of the system is to compile the testing program for the user to implement. The composition of the testing program is a function of the prototype conditions (ie. velocity, depth of water at the site and the dimensions of boom stick), capacity of the pumping system, dimensions of the flumes, and the equipment available in the hydraulics laboratory. Using this information, the system creates the testing program for the user to implement.

Once the testing program has been compiled, the system enters the Test Consultation Phase. Here, the system displays instructions on various subjects to aid the user in facilitating the implementation of the testing program. Information on testing equipment, test procedures and construction and installation procedures are contained in the system. The system is driven by user prompts, instructing the system what information is to be displayed. Figure 32 illustrates the structure of the DSS.

6.2.1.2 Organization of Decision Support System

6.2.1.2.1 Test Formulation Phase

The knowledge base, **scale.kbs** controls the Test Formulation phase of the system. The first task of the system is to determine the scale of the model which is a function of

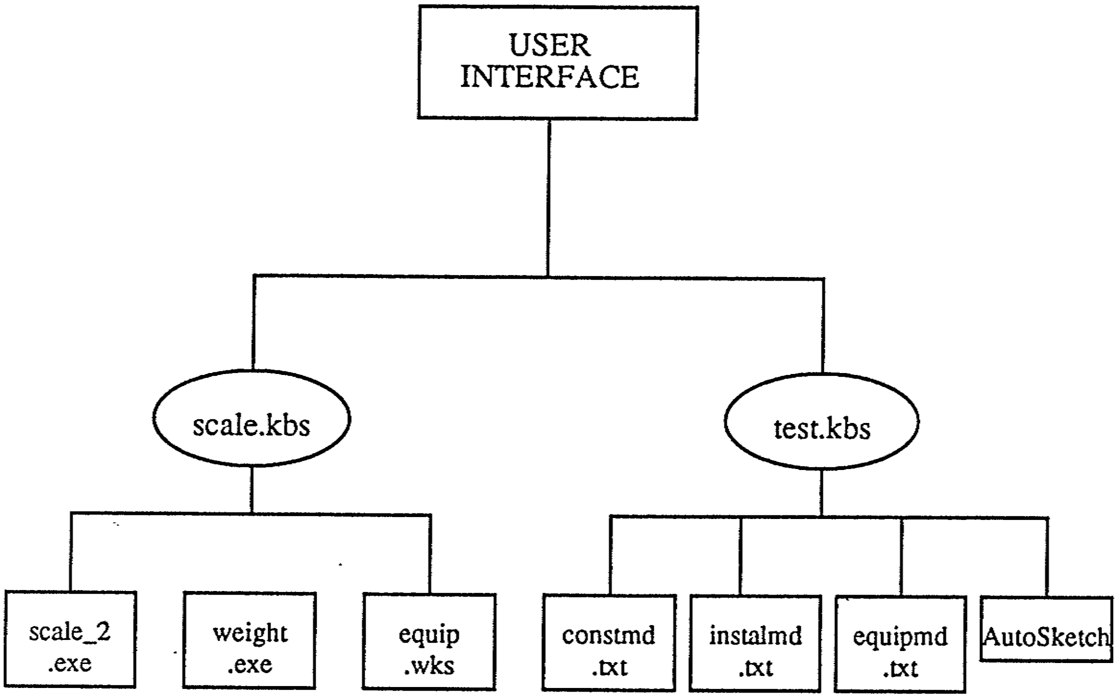


Figure 32 : Structure of DSS

the length, width, height of front face, height of back face and the space between the boom sticks in the prototype. As well, the scale is a function of the prototype velocity and depth of water at the location of the ice boom sticks. Once this information is acquired, the knowledge base calls an external routine, **scale_2.exe**, to calculate the length scale required. The knowledge base then checks to see whether the calculated scale is ≤ 10. If the calculated scale fails the test, the knowledge base tells the user that the hydraulics lab does not have the capability of modelling the prototype conditions.

The next objective is to calculate the model construction parameters; the weight of the model, the dimensions of the model, and the thickness of plexiglass required to construct the model which are a function of the weight of the prototype ice boom stick, the anchoring system used in the prototype and the length scale. Once these conditions are known, the knowledge base calls an external routine **weight.exe** to calculate these variables.

The last goal is to formulate the possible tests that can be performed on the model in the hydraulics lab. The testing program that can be implemented by the user is a function of the type of equipment available in the lab. The information on available equipment is stored in a Lotus-123 format database spreadsheet file called **equip.wks**. The knowledge base accesses the database file and checks to see whether there are any velocity meters available. If there are not any velocity meters available, the knowledge base tells the user that a velocity meter is crucial to perform any tests and recommends that one is purchased. If velocity meters are available, then the knowledge base formulates the tests that can be performed. The knowledge base then stores all the system variables in a file that is transferred to the **Test Consultation Phase**. The knowledge base then chains to the test consultation phase of the system.

6.2.1.2.2 Test Consultation Phase

This phase of the system is controlled by a knowledge base called **test.kbs**. When this phase of the system is activated, a menu is displayed, prompting the user to choose the subject he/she is interested in. Information on the following subjects are available:

1) Test Equipment
2) Test Procedures
3) Construction Procedures

The user has the option of quitting the consultation phase and exiting the system.

If the user requires information on test equipment, the knowledge base informs the user that instructions on the following equipment is available - 1) velocity meter, 2) data acquisition system, 3) pressure transducers, 4) load cells, 5) visual measurement devices and 6) visual data acquisition system.

If the user requires information on the tests that were compiled in the previous knowledge base, a menu appears on the screen, listing the tests that can be performed. When the user chooses one of the four possible options, information on the test procedures for that particular test is listed, including equipment that is required, the objective of the test and recommendations for implementing the test.

The construction consultation portion of the system guides the user in the construction and the installation of the model in the flume. When this option is chosen by the user, the knowledge base asks the user whether he/she wants information on construction or installation procedures. If the user requires information on construction techniques, the knowledge base displays the dimensions of the model, the weight of the model and the thickness of plexiglass needed to build the model. Then the knowledge base displays a set of instructions to guide the user in the construction of the model. This information is stored in the text file **constmd.txt**

If the user requires information on the installation of the model, the system displays this information. The information includes instruction on installing the anchoring system and the model in the flume and is stored in the text file **instalmd.txt**. As well, the knowledge base accesses AutoSketch schematics of the anchoring system for the model to help the user visualize the system.

6.2.1.3 Knowledge Base Control Structure

The control structure of the system is goal-directed because VP-Expert incorporates backward chaining in its inference engine. This means that in order to achieve any goal, the system must find the subgoals that are required to reach the main goal. The following two sections will discuss the control structure for the two knowledge bases in the system.

6.2.1.3.1 Test Formulation Knowledge Base

The first goal of the knowledge base is to find the scale to be used for building the model. Therefore, the knowledge base needs to ask various questions to reach this goal. These questions deal with the prototype conditions. Once the prototype conditions are known, the external routine, **scale_2.exe** is executed to calculate the length scale required to build the model. The routine is based on the principles of the **Froude Model** which states that the Froude number of the prototype must be the same as the Froude Number of the model. Therefore, the length scale is equal to the square of the velocity scale. There are many conditions that have to be tested to calculate the proper length scale. The first condition that is tested is whether the ice boom stick behaves like an infinitely long member (two dimensional) or behaves three dimensionally.

This is accomplished by calculating the **Aspect Ratio** which is equal to the length of the prototype divided by the width of the prototype. The aspect ratio indicates whether the flow pattern around an object is two dimensional or three dimensional. Common practice is to use an Aspect Ratio of 6 as a benchmark to determine whether a member behaves two or three dimensionally. If the aspect ratio is ≥ 6, then the ice boom stick behaves two dimensionally and the length of the prototype does not have to be scaled. If the aspect ratio is < 6, then the ice boom stick behaves three dimensionally and the length of the prototype must be scaled. In the routine, the length of the model is set to the width of the flume if it is two dimensional. If it is three dimensional, the routine calculates an associated length scale equal to the ratio of the length of the prototype and the space between the ice boom sticks divided by the width of the flume in the hydraulics lab.

The next condition to check is whether there are any boundary effects caused by the depth of water at the prototype's location. If the ratio of the depth of water to the height of the front face of the prototype is ≥ 6, then there is negligible boundary effects and the depth of water does not have to be scaled and the depth of water in the flume is set to a default value. However, if this ratio is < 6, then an associated length scale is calculated equal to the ratio of the depth of water in the prototype to the maximum depth of water allowable in the flume.

The final condition is to determine whether the pump in the lab can produce high enough velocities in the flume. The highest velocity that can be produced in the flume is compared to the prototype velocity. An associated length scale is calculated based on the square of the ratio of the prototype velocity to the flume velocity.

Using length scales calculated based on the three conditions, the routine selects the largest value as the scale to be used for constructing the model. The next goal is to check whether the calculated scale is ≤ 1/10. If the model is constructed using a scale larger than 10, then there is a significant possibility of scaling effects occurring. This means that forces that normally dominate in the prototype will be scaled to insignificance and be replaced by forces which should not dominate (ie viscous forces). This check ensures that the model will simulate the behaviour of the prototype.

Once the length scale has been determined, the next goal is to determine the weight of the model and the thickness of plexiglass required to build the model. The knowledge base calls an external routine **weight.exe** to calculate the model weight and the thickness of plexiglass. The weight of the model is a function of the aspect ratio of the boom stick. The program calculates the aspect ratio and if it is ≥ 6, then the weight of the model is based on the scaled weight per unit length of the prototype. This means that the weight of the model is equal to:

$$W_{model} = \frac{\left(\frac{W_{prototype}}{l_{prototype}}\right)}{scale^2} \times l_{model} \qquad \textbf{if aspect} \geq \textbf{6} \qquad \textbf{(6.4)}$$

If the aspect ratio is < 6, then the weight of the model is based on the scaled weight of the prototype:

$$W_{model} = \frac{W_{prototype}}{scale^3} \qquad \textbf{if aspect} < \textbf{6} \qquad \textbf{(6.5)}$$

When the routine calculates the thickness of plexiglass, it is initially set to a default value of 0.0032 m. The routine calculates the weight of the model based on the thickness of the plexiglass and the density of the plexiglass. If the calculated weight is less than the scaled weight, then the plexiglass thickness is increased by 0.0032 m. and the weight is recalculated. This process continues until the calculated weight becomes greater than the scaled weight. When this occurs, the routine decreases the thickness of the plexiglass by 0.0032 m. The system tells the user in the consultation phase that the model weight will have be increased by adding weight until it equals the scaled weight.

The final goal is to formulate the testing program. The first task of the knowledge base is to read the database file with the list of equipment available in the hydraulics laboratory. After the database file is read, the knowledge base checks to see whether there is a velocity meter in the inventory. This check is required because a testing program cannot be formulated without a means of measuring the velocity of the water in the flume. It is a way of preventing the user from progressing too far into the system when it is not appropriate.

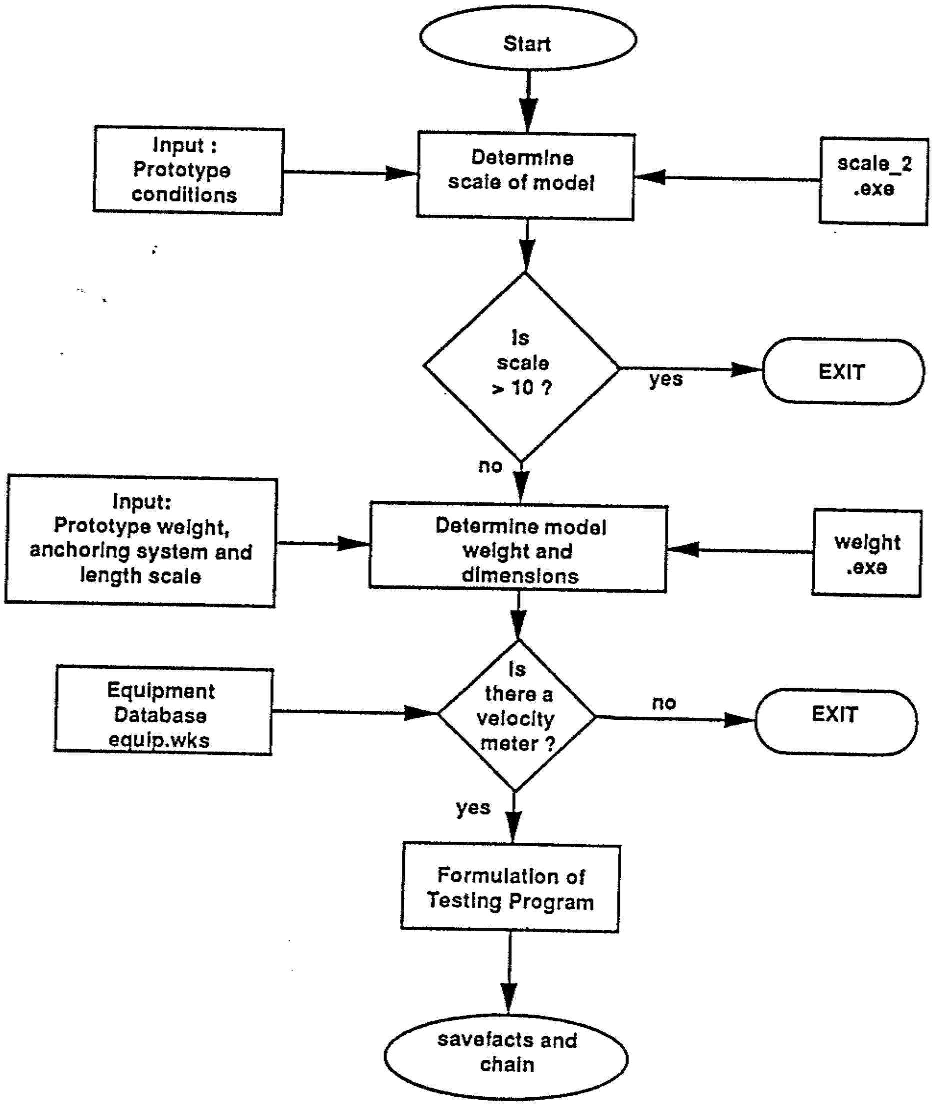


Figure 33 : Delineation of Control Structure for Test Formulation Knowledge Base

The knowledge proceeds to the task of formulating the testing program if the velocity meter check passes. The knowledge base draws upon a set of rules which incorporates the role of each type of equipment and the limitations when used for performing experiments. The knowledge base currently contains knowledge of four types of tests that can be performed on the model:

1) relationship between the free-stream velocity and the ice boom's position
2) relationship between the free-stream velocity and the hydrodynamic forces acting on the ice boom.
3) relationship between the free-stream velocity and the flow field around the ice boom.
4) observe the velocity at which the ice boom stick submerges.

There are two ways the tests can be analyzed, as the real-time study of the relationships or the average time study of the relationships. A real-time relationship means that the measurements are sampled instantaneously and recorded on a continual basis. This type of sampling can only be accomplished by using a data acquisition system. In order to do real-time studies, a data acquisition is required and both the velocity meter and the other equipment required for each test must be capable of sampling on a continual basis. If any of the equipment for each test does not have this capability, then the tests can be performed using average measurements for each trial run. The knowledge base saves all the system variables because they are required for the consultation phase. Figure 33 illustrates the control structure for the Test Formulation knowledge base.

6.2.1.3.2 Test Consultation Knowledge Base

When the consultation phase of the system begins, the knowledge base's first goal is to determine which subject the user is interested in. The knowledge base displays the menu listing the three subjects mentioned in the previous section. The subject chosen by the user determines which goal is to be determined next.

If the user chooses to inquire information on testing equipment, the next goal of the knowledge base is to determine which instrument the user requires information on. As mentioned in the last section, there are six types of equipment available for instructions. When the user chooses one of the six possible options, the knowledge base searches an indexed text file for information on that piece of equipment. For example, the user wants information on how to operate the velocity meter and the type of velocity meter available is a hand-held propeller meter. The knowledge base contains the following rule for this type of velocity meter:

```
IF      velocity_meter=propeller AND
        data_acquisition=no
THEN velocity_description=propeller_manual
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;
```

This rule states that if the velocity meter is a hand-held propeller meter and there is not a data acquisition system available, then the system variable *velocity_description* is equal to *propeller_manual*. The next command SHOWTEXT tells the knowledge base to search the file equipmd.txt for a heading equal to the system variable *velocity_description*. In the text file equipmd.txt, a section of text dealing with a particular subject is preceded with a heading. This heading begins with **.pa** followed by the heading name on the next line. For this case, the heading would be **propeller_manual**. Therefore, the knowledge base would find the heading and display all text after that heading until another heading is encountered.

If the user inquires information on testing procedures, the knowledge base displays the titles of the tests that can be performed and prompts the user to select one of the tests for instructions. When the user chooses one of the tests, the knowledge base searches the indexed text file **testmd.txt** for information on that test. The procedure involved in extracting the portion of the text file dealing with the subject chosen is the same as was previously mentioned.

There are two options the knowledge base prompts when the user requests information on construction procedures; construction instruction for building the model and anchoring system as well as instructions for installing the model in the flume. If the user chooses construction procedures, the knowledge base searches the indexed file **constmd.txt** for the required information. However, this information is a function of the anchoring system used in the prototype. There are two types of headings the knowledge searches for, 1) main_cable if the anchoring system incorporates a main cable and 2) connected_series if the boom sticks are connected in series. Each set of instructions are unique to the type of anchoring system that is used.

The headings used in the text file for installation instructions is a function of the aspect ratio and the type of anchoring system. The knowledge base searches the text file **instalmd.txt** for the heading corresponding to the aspect ratio and the anchoring system of the prototype. The first page of instructions are displayed and the knowledge base then executes the external program **AutoSketch** to illustrate the anchoring system that should be installed in the flume. There are two schematics the knowledge base can display; **icemain.skd** which illustrates the anchoring system which uses a main cable and **iceserie.skd** which illustrates the anchoring system which incorporates the fact that the ice boom sticks are connected in series. Once the user is finished analyzing the drawings, the knowledge base retrieves the second page of instructions from the indexed text file. Figure 34 illustrates the control structure for the Test Consultation knowledge base.

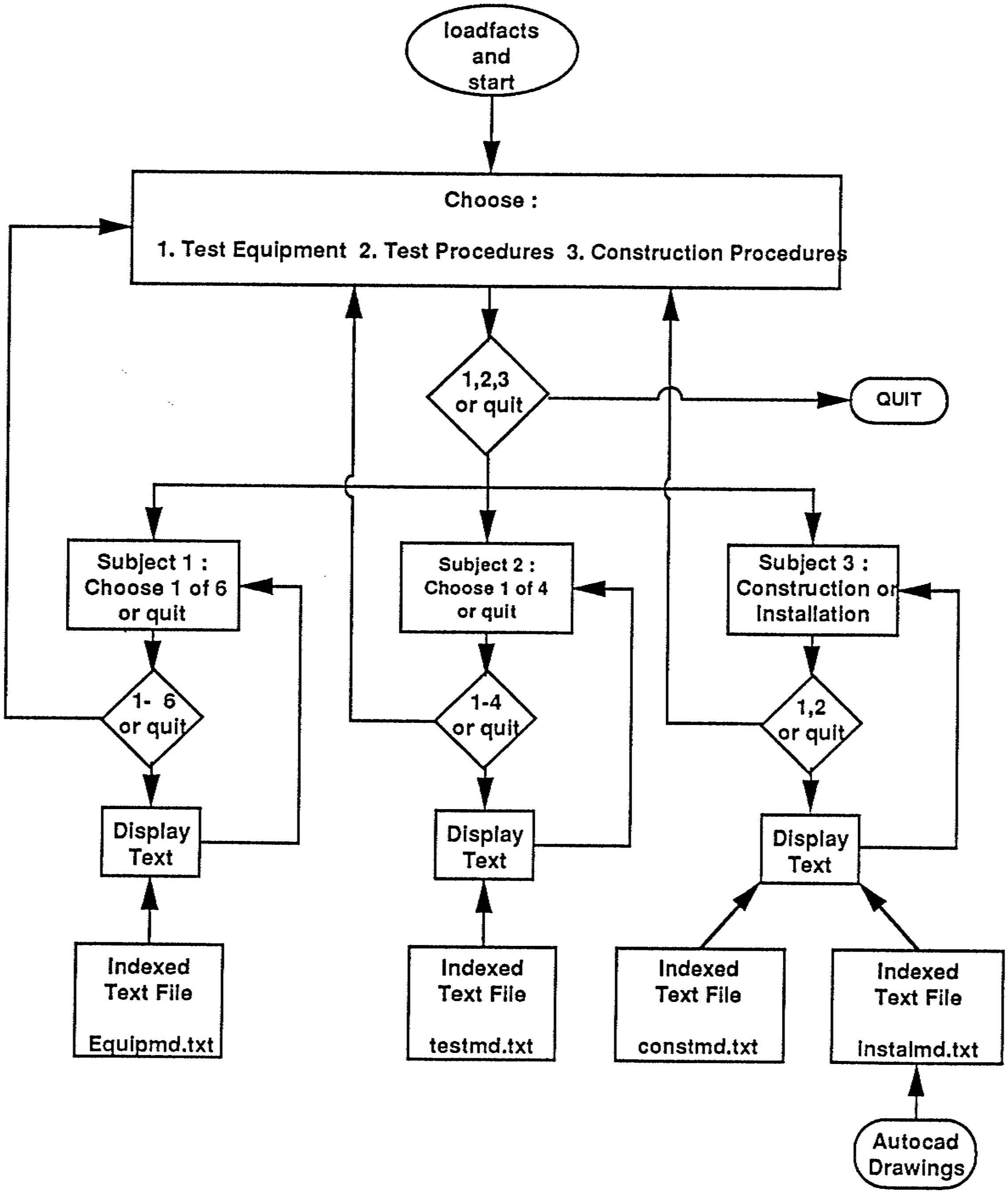


Figure 34 : Delineation of Control Structure for Test Consultation Knowledge Base

6.2.1.4 User Interface

The user interface consists of a series of prompts activated by the knowledge bases, requesting the user for input. In the knowledge base **scale.kbs**, the user is asked to input the length, width, height of front face and the height of back face of the ice boom stick. As well, the user must enter the layout of the ice boom (ie. space between the ice boom sticks). After the scale has been calculated, the knowledge base prompts the user to round up the scale to the nearest whole number if it passes the scale check.

The next set of prompts informs the user to input the weight of the prototype and the type of anchoring system used in the prototype. After the weight of the model and the thickness of plexiglass has been calculated, the knowledge base compiles the testing program and displays it on the screen. The knowledge base then informs the user that the system is entering the consultation phase.

The knowledge base **test.kbs** controls the prompts in this phase of the system. The first set of prompts informs the user that information on testing procedures, test equipment and construction and installation procedures can be accessed. The knowledge base then gives a brief synopsis of the content of each subject. Once the user prompts the knowledge base to access a certain subject, another menu is displayed on the screen. The knowledge base prompts the user to select the item he/she is interested in and that information is displayed on the screen. Once the user is finished with the consultation process, he/she has the option of exiting the system and any point.

6.2.2 Prototype Evaluation

6.2.2.1 Scope

The tasks that were necessary for the system to function properly were implemented in the proper sequence. The scale had to be calculated in the beginning because all the other goals in the knowledge base depended on the value of the scale. If the scale was too large, the knowledge base exited the system because it was not necessary to continue on in the system. Since the weight of the model and the thickness of the plexiglass depended on the scale, this task executed next. Although the testing program does not depend on the scale for the model, this task was performed last. It did not make sense to compile the testing program at the beginning of the system if the scale for building the model was too large.

The test formulation phase had to precede the consultation phase because the outcome of the test formulation phase determines the subjects that the knowledge base in the consultation phase access. Within the consultation phase, there is only one way the tasks can be implemented, from the general to the more specific.

6.2.2.2 Results of System

The system produces the right results because the system was customized to give the proper results. There are not any areas within the system where bias in the results can occur. The FORTRAN programs designed to calculate the scale of the model, the weight of the model and the thickness of plexiglass to build the model can only give one answer for a particular set of prototype conditions and laboratory conditions. Where the results may start to become subjective is when the flume where testing may occur is modified in either width or height. This will modify the outcome of the calculated scale.

The results in the consultation phase cannot be placed under the category of useful output. Whether the output from this phase is useful or not depends on the user's perceptions of the instructions that are contained in the output.

6.2.2.3 Environment

A good formalism was chosen for the system. Each rule triggered the execution of another rule in a logical progression to the final goal, which was the determination of the testing program and the construction parameters of the model. Since VP-EXPERT's inference engine incorporates backward chaining, rules were the only way to formalize the system.

VP-EXPERT was very useful in implementing this DSS. Drawbacks of the system are that certain portions of the rule-base cannot be executed separately to determine whether it operates properly. The only way to test a certain section of the rule-base is to execute the entire system. This is not an issue for this system because the rule-base is not very large, but if it is, checking portions of a rule-base can be time-consuming. Another drawback of VP-EXPERT is the inability to cut and paste sections of a knowledge to another knowledge base. This can be very time-saving option if one decides certain portions of a knowledge base belong in another knowledge base. Complete listing of the code is listed in Appendix D.

7. DISCUSSION OF THESIS

7.1 SUMMARY

The objective of the research project was to analyze the behaviour of floating boom sticks under high velocity conditions. The research was focused on trapezoidal sectioned ice boom sticks and safety boom sticks circular cross-section. The impetus for the project was that under high velocity conditions, portions of an ice boom operated by Manitoba Hydro submerged under water and that safety boom sticks oscillated violently.

The ice boom in question is located in the forebay of the Jenpeg hydroelectric generating station. It consists of two boom sections with eleven sticks and one boom section with ten sticks. Total span of the ice boom was 1249 feet. A section of 4 to 5 ice boom sticks were submerging under high velocity conditions. As a result, Manitoba Hydro had to cut back flow through the generating station to raise the forebay to reduce the velocity enough to correct the problem.

The safety boom that was observed to behave erratically was located in the tailrace section of the generating station at Grand Rapids. Manitoba Hydro installed the safety boom to prevent fishermen from entering the tailrace region next to the generating station. The tailrace region is a popular place for recreational fishing and boaters would anchor next to the generating station to cast for fish. However, there was a danger that the boaters would anchor next to a generation unit that was off-line. If the plant operator decided to bring the unit on-line, the resulting surge in flow would sweep the boat downstream, endangering the fishermen.

Manitoba Hydro hoped the safety boom would act as a sufficient deterrent to the fishermen. However, the safety boom would oscillate which decreased its effectiveness in obstructing the boaters. Therefore, Manitoba Hydro removed the safety boom and installed it in another location.

The investigation of the behaviour of the ice and safety booms was addressed in two ways, physical modelling and theoretical analysis. The theoretical analysis addressed the behaviour of the ice and safety boom sticks using the principles of classical fluid mechanics.

7.2 ICE BOOM STICKS

There were two objectives of modelling the ice boom sticks: a) investigate the submergence velocities of ice boom sticks, and: b) investigate the drag forces acting on ice boom sticks.

Two types of tests were designed to study the behaviour of the ice boom sticks. The first test, The Velocity Submergence Test, measured the submergence velocities of floating ice boom stick models. Two models were studied. The first model, JP015, was a 1:5 scale replica of the Jenpeg ice boom stick and the second model, JP021, was a modified Jenpeg ice boom stick with 6 inches added to the height. The tests also measured the drag forces acting on the models. The JP015 model was used to compare the laboratory measurements with those observed in the field to confirm the validity of the testing procedures.

The second test, The Pressure Measurement Test, measured the pressure distribution around a fixed scaled replica of the Jenpeg ice boom stick. The measurements were used to confirm the submergence velocities measured in the Velocity Submergence Test. The model was fixed in two positions. For the first set of test runs, the angle of the front face was set at 3° to the vertical to simulate the position of JP015 when it submerged. This series of test runs was called JP01P. For the second series of test runs, JP02P, the angle of the front face was set at 8° to study the effects of the change in angle on the pressure measurements.

The results of the Velocity Submergence Test are:

	Initial Submergence Velocity m/s	Final Submergence Velocity m/s
JP015	0.51	0.61
JP021	0.60	0.68

The submergence velocity observed in the field was 1.4 m/s or 0.62 m/s in model conditions which is near the measured final submergence velocity of 0.60 m/s for JP015.

The results for JP01P and JP02P are virtually identical and are listed below.

	Calculated Submergence Velocity m/s
JP015	0.55
JP021	0.75

The calculated submergence velocity for JP015 lies within the measured velocity in the zone of submergence. The calculated submergence velocity for JP021 over-predicted the measured submergence velocity.

The drag forces were measured for JP015 and JP021 to determine the relationship between the free-stream velocity and the drag force. In particular, the aim was to determine the relationship of the dimensionless drag coefficient to the Froude Number based on the front face and the free-stream velocity. Theoretical analysis predicted that the drag coefficient would be composed of a constant plus another constant divided by the Froude Number squared where the Froude Number would be based on the height of the front face of the ice boom stick and the free-stream velocity. It was assumed boundary effects caused by the flume floor were minimal. This assumption may not be quite correct.

Analyzing the drag forces based on the momentum equation indicate that the flume floor may influence the forces on the models but the tests were not designed to investigate this effect. Further research into this area is needed.

7.3 SAFETY BOOM STICKS

The objective of modelling the safety boom sticks was to investigate the free-stream velocities that would cause the boom sticks to oscillate violently.

The oscillation effects of cylindrical sectioned safety boom sticks were analyzed by testing the effects of the L/D ratio on the velocity at which oscillation occurred. This test was called The Oscillation Velocity Test. Two types of models were tested. The first model SB01 had a density of 1.0 lb/ft^3 while SB02 had a density of 1.5 lb/ft^3. The L/D ratios varied from 1.0 to 5.0 in increments of 0.5 and were anchored using two methods. The first method involved anchoring the models laterally and the second method involved anchoring the models upstream.

Accurate measurements of the oscillation velocities for the models with L/D ratio equal to one and anchored using the second method were not possible because they began to oscillate laterally, making measurements difficult. Measurements for models with L/D ratios of 4.5 and 5.0 were not possible because the models did not fit in the flume where the testing took place.

The measurements that were documented were highly subjective due to the equipment available to do the tests. However, these tests do indicate that there is a relationship between the L/D ratio and the oscillation velocity. More accurate equipment is needed to study this phenomenon in greater detail.

7.4 PRACTICAL APPLICATIONS

The design of the required front face of an ice boom stick involves a trial and error procedure. The first step involves calculating the draught depth of the ice boom stick based on an assumed cross-section. The next step is to calculate the required free-board of the ice boom stick to withstand the maximum free-stream velocity. The required height is then equal to the draught depth and the free-board height. If this value is less than the assumed height, then the height should be increased or the weight of the ice boom stick should be decreased for the ice boom stick to remain afloat for the design velocity.

Expert system technology is beneficial in implementing an intelligent decision support system tool to create and implement a testing program to investigate floating boom sticks. Any testing program for hydraulic modelling is a function of the type of equipment available in a hydraulic lab and the constraints of the lab. The decision making process in choosing the equipment is highly subjective and requires much expertise. Also, the design, construction, and installation of the model requires expertise that the user might not have. This means that conditions and certain rules have to be met which is the essence of expert system technology.

7.5 RECOMMENDATIONS FOR FUTURE WORK

There are many areas worth pursuing to extend the system. The system deals with only trapezoidal shaped ice boom sections. The system should be extended to include other shapes such as cylindrical cross-sections. Another area to be extended is the system's knowledge of testing equipment. Currently, the system is limited in the knowledge of testing equipment to equipment that the author and certain experts have knowledge of. The problem with this area is that there many types of equipment that can perform certain jobs but their set-up is a function of other types of equipment which creates many combinations.

In order for the system to be useful for hydraulic's laboratories, the task structure of the system must be radically altered to encompass generic hydraulic testing such as three dimensional physical modelling of sites, hydraulic modelling of structures such as dams, spillways, etc. The system formulates a testing program based on the equipment that is available and is implicitly confined to tests regarding ice booms in open flow conditions. The system must be modified so the user explicitly defines the objective of the testing program.

There are a number of recommendations for future work based on the research done thusfar. The physical modelling phase raised many questions that need to be answered to better analyze the behaviour of floating boom sticks under high velocity conditions. What is the influence of the length of the ice boom stick on its behaviour? Does the angle of the bottom face influence the submergence velocity of the ice boom stick?. If the shape of the front face of the ice boom stick is varied, how will it influence the submergence velocity? Does the diameter, as well as the length to diameter ratio influence the oscillation velocities of the safety boom sticks?

The research that was carried out indicates that the behaviour of floating boom sticks can be analyzed using the fundamentals of fluid mechanics. The theory can be simplified and verified with empirical measures. Further research into this area is required to better understand the behaviour of a fluid as it flows around a floating object and the interaction between the flow pattern and the type of object.

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Appendix A : Velocity Submergence Test Results

Velocity Measurement Test Results

Ice Boom Model - JP015

Point 1 = Elevation of toe of front face of model

Water Depth in.	Elevation Point 1 in	$\boxed{\phi}$ degrees	$\boxed{\beta}$ degrees	Vo m/s	Fm gm.
19.00	16.70	67.00	0.00	0.14	109.40
18.00	15.60	61.00	0.00	0.15	153.47
19.20	16.90	65.00	0.00	0.16	130.67
19.40	17.00	63.00	0.00	0.19	144.20
18.50	16.00	55.00	0.00	0.19	198.07
19.50	17.30	58.00	0.00	0.20	173.47
18.50	16.20	52.00	1.80	0.21	224.27
19.70	17.50	56.00	0.00	0.22	191.20
19.80	17.60	53.00	0.00	0.23	202.40
18.50	16.30	48.00	0.00	0.24	242.87
20.00	17.80	49.00	0.00	0.25	232.73
20.00	17.80	49.00	0.00	0.26	244.67
19.00	16.60	45.00	1.80	0.28	283.27
19.50	17.10	49.00	0.00	0.29	228.47
19.50	17.30	47.00	1.80	0.30	248.20
19.70	17.40	47.00	0.00	0.33	266.27
19.90	17.60	42.00	1.80	0.35	304.87
19.30	16.60	37.00	1.80	0.35	356.73
20.00	17.70	43.00	1.80	0.36	327.00
19.00	16.50	37.00	1.80	0.39	396.67
19.50	17.10	34.00	3.60	0.40	408.07
19.40	16.80	34.00	0.00	0.41	445.40
19.50	17.10	32.00	3.60	0.43	481.53
19.00	16.10	31.00	1.80	0.44	528.93
19.58	17.30	26.00	3.60	0.46	561.93
19.70	17.10	27.00	3.60	0.49	588.33
20.00	17.70	26.00	3.60	0.50	654.80
18.50	15.50	25.00	5.40	0.51	691.20
19.50	17.00	21.00	7.20	0.52	739.27
19.00	15.90	21.00	7.20	0.54	802.53
19.00	15.80	20.00	5.40	0.55	862.60
18.00	15.20	18.00	7.20	0.56	892.33
18.00	15.00	16.00	7.20	0.57	1051.93
17.00	12.80	14.00	5.40	0.59	1194.73
17.60	14.30	15.00	7.20	0.60	1143.13

Velocity Measurement Test Results

Ice Boom Model - JP021

Point 1 = Elevation of toe of front face of model

Water Depth	Elevation Point 1	$\boxed{\varphi}$	$\boxed{\beta}$	Vo	Fm
in.	in	degrees	degrees	m/s	gm.
N.A.	N.A.	N.A.	N.A.	0.30	280.00
N.A.	N.A.	N.A.	N.A.	0.32	314.53
N.A.	N.A.	N.A.	N.A.	0.33	340.80
N.A.	N.A.	N.A.	N.A.	0.40	434.80
N.A.	N.A.	N.A.	N.A.	0.42	489.33
N.A.	N.A.	N.A.	N.A.	0.47	687.27
N.A.	N.A.	N.A.	N.A.	0.49	743.60
N.A.	N.A.	N.A.	N.A.	0.53	891.93
N.A.	N.A.	N.A.	N.A.	0.59	1248.27
N.A.	N.A.	N.A.	N.A.	0.62	1475.93
N.A.	N.A.	N.A.	N.A.	0.63	1562.60
N.A.	N.A.	N.A.	N.A.	0.67	1825.00
N.A.	N.A.	N.A.	N.A.	0.38	368.27
N.A.	N.A.	N.A.	N.A.	0.39	434.20
N.A.	N.A.	N.A.	N.A.	0.43	488.93
N.A.	N.A.	N.A.	N.A.	0.45	539.60
N.A.	N.A.	N.A.	N.A.	0.47	652.13
N.A.	N.A.	N.A.	N.A.	0.49	705.80
N.A.	N.A.	N.A.	N.A.	0.52	758.07
N.A.	N.A.	N.A.	N.A.	0.53	841.53
N.A.	N.A.	N.A.	N.A.	0.54	922.80
N.A.	N.A.	N.A.	N.A.	0.56	1026.60
N.A.	N.A.	N.A.	N.A.	0.60	1152.07
N.A.	N.A.	N.A.	N.A.	0.62	1398.33
N.A.	N.A.	N.A.	N.A.	0.64	1682.67
N.A.	N.A.	N.A.	N.A.	0.65	2021.07
N.A.	N.A.	N.A.	N.A.	0.23	223.20
N.A.	N.A.	N.A.	N.A.	0.24	234.40
20.00	17.80	51.00	2.00	0.22	219.73
19.50	17.20	48.00	2.00	0.26	251.20
19.00	17.00	46.00	2.00	0.29	272.07
19.00	16.40	43.00	2.00	0.34	340.93

18.50	15.80	41.00	2.00	0.36	368.27
20.00	17.10	30.00	2.00	0.41	417.00
19.00	16.30	30.00	2.00	0.45	493.87
19.50	16.50	27.00	3.00	0.48	602.47
20.00	16.30	23.00	4.50	0.52	702.93
19.00	15.80	20.00	6.00	0.54	817.87
19.00	16.50	18.00	3.00	0.57	1108.20
18.00	14.60	15.00	4.00	0.61	1311.60
17.00	13.30	15.00	9.00	0.62	1543.07
16.50	12.90	12.00	10.00	0.64	1635.20
16.00	12.70	8.00	8.00	0.67	1844.20

Appendix B : Pressure Measurement Test Results

JP01P Test Results

Velocity	Pt. 1 Dynamic m.	Pt 2 Dynamic m.	Pt 3 Dynamic m.	Pt 4 Dynamic m.	Pt 5 Dynamic m.	Pt 6 Dynamic m.
0.1060	0.0022	0.0018	0.0022	-0.0014	-0.0014	-0.0014
0.1600	0.0026	0.0026	0.0030	-0.0026	-0.0026	-0.0026
0.1760	0.0028	0.0026	0.0030	-0.0030	-0.0032	-0.0032
0.1860	0.0034	0.0032	0.0036	-0.0036	-0.0032	-0.0034
0.2120	0.0040	0.0036	0.0040	-0.0040	-0.0040	-0.0042
0.2280	0.0036	0.0034	0.0038	-0.0044	-0.0046	-0.0046
0.2540	0.0046	0.0050	0.0048	-0.0086	-0.0086	-0.0090
0.2580	0.0040	0.0036	0.0040	-0.0056	-0.0056	-0.0058
0.2900	0.0054	0.0054	0.0058	-0.0064	-0.0064	-0.0070
0.3640	0.0062	0.0068	0.0070	-0.0122	-0.0126	-0.0130
0.3700	0.0056	0.0062	0.0064	-0.0120	-0.0120	-0.0122
0.4020	0.0084	0.0090	0.0090	-0.0156	-0.0172	-0.0176
0.4280	0.0080	0.0088	0.0088	-0.0158	-0.0164	-0.0166
0.4900	0.0108	0.0116	0.0114	-0.0190	-0.0192	-0.0192
0.4940	0.0090	0.0100	0.0104	-0.0206	-0.0208	-0.0218
0.5160	0.0108	0.0092	0.0114	-0.0222	-0.0222	-0.0226
0.5620	0.0122	0.0132	0.0130	-0.0226	-0.0236	-0.0240

Pt 7 Dynamic m.	Pt 8 Dynamic m.	Pt 9 Dynamic m.	Pt 10 Dynamic m.	Pt 11 Dynamic m.	Pt 12 Dynamic m.
-0.0006	-0.0010	-0.0010	-0.0012	0.0002	0.0012
-0.0020	-0.0024	-0.0022	-0.0020	-0.0002	-0.0004
-0.0028	-0.0032	-0.0028	-0.0026	-0.0010	-0.0010
-0.0030	-0.0032	-0.0032	-0.0028	-0.0012	-0.0014
-0.0036	-0.0038	-0.0044	-0.0032	-0.0016	-0.0020
-0.0042	-0.0044	-0.0050	-0.0040	-0.0024	-0.0024
-0.0080	-0.0088	-0.0090	-0.0076	-0.0058	-0.0062
-0.0052	-0.0054	-0.0056	-0.0046	-0.0028	-0.0030
-0.0058	-0.0066	-0.0068	-0.0052	-0.0036	-0.0038
-0.0118	-0.0126	-0.0142	-0.0104	-0.0088	-0.0096
-0.0122	-0.0132	-0.0140	-0.0110	-0.0090	-0.0094
-0.0164	-0.0178	-0.0172	-0.0144	-0.0128	-0.0128
-0.0158	-0.0174	-0.0190	-0.0146	-0.0126	-0.0126
-0.0196	-0.0196	-0.0210	-0.0178	-0.0166	
-0.0212	-0.0218	-0.0232	-0.0192	-0.0182	
-0.0214	-0.0226	-0.0238	-0.0202	-0.0186	
-0.0242	-0.0252	-0.0264	-0.0224	-0.0206	

JP02P Test Results

Velocity	Pt. 1 Dynamic m	Pt. 2 Dynamic m	Pt. 3 Dynamic m	Pt. 4 Dynamic m	Pt. 5 Dynamic m	Pt. 6 Dynamic m	Pt. 7 Dynamic m
0.0920	0.0030	0.0030	0.0034	-0.0002	-0.0004	-0.0004	-0.0004
0.1420	0.0040	0.0034	0.0042	-0.0010	-0.0010	-0.0010	-0.0008
0.1620	0.0044	0.0040	0.0048	-0.0012	-0.0014	-0.0014	-0.0014
0.2040	0.0046	0.0042	0.0050	-0.0020	-0.0020	-0.0020	-0.0024
0.2280	0.0048	0.0046	0.0052	-0.0028	-0.0030	-0.0030	-0.0030
0.2500	0.0048	0.0052	0.0052	-0.0046	-0.0044	-0.0046	-0.0052
0.3300	0.0064	0.0068	0.0072	-0.0068	-0.0068	-0.0070	-0.0072
0.3700	0.0078	0.0080	0.0084	-0.0104	-0.0110	-0.0116	-0.0124
0.4260	0.0092	0.0094	0.0102	-0.0134	-0.0140	-0.0144	-0.0140
0.4720	0.0114	0.0116	0.0126	-0.0168	-0.0178	-0.0178	-0.0180
0.5700	0.0144	0.0134	0.0156	-0.0210	-0.0222	-0.0230	-0.0228

Pt. 8 Dynamic m	Pt. 9 Dynamic m	Pt. 10 Dynamic m	Pt. 11 Dynamic m	Pt. 12 Dynamic m
0.0002	0.0002	0.0008	0.0004	0.0010
-0.0004	-0.0006	0.0002	0.0002	0.0006
-0.0010	-0.0010	0.0002	-0.0002	0.0002
-0.0016	-0.0018	-0.0006	-0.0008	-0.0004
-0.0022	-0.0024	-0.0010	-0.0010	-0.0006
-0.0046	-0.0048	-0.0032	-0.0030	-0.0026
-0.0058	-0.0064	-0.0046	-0.0046	-0.0042
-0.0108	-0.0108	-0.0082	-0.0078	-0.0074
-0.0126	-0.0132	-0.0102	-0.0096	-0.0092
-0.0158	-0.0164	-0.0120	-0.0118	-0.0116
-0.0206	-0.0216	-0.0156	-0.0154	-0.0152

Appendix C : Oscillation Velocity Test Results

Safety Boom Test Results

L/D	First Anchoring System		Second Anchoring System	
	SB01	SB02	SB01	SB02
1.00	0.93	0.93	N.A.	N.A.
1.50	0.93	0.93	0.84	0.84
2.00	0.93	0.93	0.81	0.81
2.50	0.90	0.90	0.79	0.79
3.00	0.87	0.87	0.78	0.78
3.50	0.85	0.85	0.76	0.76
4.00	0.84	0.84	0.73	0.73
4.50	N.A.	N.A.	N.A.	N.A.
5.00	N.A.	N.A.	N.A.	N.A.

All velocities are in m/s.

Appendix D : Expert System Approach to Testing Ice Boom Sticks Code Listing

1. Final System Code Listing

Knowledge Base ***scale.kbs***

```
RUNTIME;
ENDOFF;
ACTIONS
DISPLAY "

                Welcome to the Expert System entitled:

            EXPERT SYSTEM APPROACH TO TESTING ICE BOOMS


    This knowledge base is used to compile a testing program that can be
implemented by the user based on the prototype ice boom stick and flow
conditions as well as equipment available in the hydraulics lab.


                DEVELOPED BY : David C. Poole

                Press any key to continue~"
CLS
DISPLAY "
    The first segment of the expert system will attempt to calculate the
scale required to build your model so that it can be tested in the hydraulics
laboratory. The factors affecting the scale to be used are:

    1) Capabilities of the hydraulics laboratory
    2) Physical dimensions of the ice boom stick
    3) Prototype anchoring system of the ice boom stick
    4) Prototype flow conditions (ie. velocity, depth of water )

    The expert system is now going to ask you questions about the afore-
mentioned factors.


                Press any key to continue~"
CLS
WHILEKNOWN scale_flag
    RESET scale
    RESET display_scale
    RESET scale_flag
    FIND scale
    FIND scale_flag
END
WHILEKNOWN velocity_flag
  FIND velocity_flag
  RESET velocity_flag
END;

RULE 1

IF      length<1000 AND
```

```
          width<1000 AND
          depth<1000 AND
          velocity<25 AND
          height_front_face<5 AND
          height_back_face<5 AND
          space_between_sticks<10
THEN        BCALL c:\vp\project\batch\dimen,""
          SHIP c:\vp\project\text\dimen,length
          SHIP c:\vp\project\text\dimen,width
          SHIP c:\vp\project\text\dimen,depth
          SHIP c:\vp\project\text\dimen,velocity
          SHIP c:\vp\project\text\dimen,height_front_face
          SHIP c:\vp\project\text\dimen,height_back_face
          SHIP c:\vp\project\text\dimen,space_between_sticks
          CALL c:\vp\project\fortran\scale_2,""
          RECEIVE c:\vp\project\text\scale,scale1
          scale=(scale1)
          aspect=(length/width)
BECAUSE "The dimensions of the prototype are necessary to calculate the
scale of the model";

RULE 2

IF        scale>10
THEN        scale_flag=UNKNOWN
DISPLAY"    The length scale calculated is too large. The reasons could be one
of the following:

          1) Inadequate pumping capacity and/or
          2) Inadequate size for the flume

     These areas must be addressed before any testing can commemce.~"
BECAUSE "If the scale is greater than 10, then viscous forces will dominate
which is not the case in the prototype. Therefore, the scale must be less
than 10.";

RULE 3

IF        scale<=10
THEN        scale_flag=yes
          FIND display_scale;

RULE 4

IF        scale<=10
THEN        display_scale=(scale1)
          FORMAT display_scale, 6.3
DISPLAY "The length scale calculated for the ice boom stick prototype chosen:

               = {display_scale}.
~"
          FIND calculation_mass;

RULE 5
```

```
IF       scale_chosen<=10 AND
         mass_prototype<10000
THEN        BCALL c:\vp\project\batch\weight,""
         SHIP c:\vp\project\text\scalem,scale_chosen
         SHIP c:\vp\project\text\scalem,mass_prototype
         CLROFF
         CALL c:\vp\project\fortran\weight,""
         CLRON
         calculation_mass=yes
         CLS
         FIND model_dimensions
BECAUSE "The scale chosen must be rounded up because otherwise, the model
will be too big for the flume. Rounding it up ensures that the model is
smaller than the optimal scale size.";

RULE 6

IF       calculation_mass=yes
THEN        RECEIVE c:\vp\project\text\plex,thick1
         plex_thick=yes
         display_thick=(thick1);

RULE 7

IF       calculation_mass=yes
THEN        RECEIVE c:\vp\project\text\weight,mass
         model_mass=yes
         display_mass=(mass);

RULE 8

IF       scale_chosen<=10
THEN        velocity_scale=(@sqrt(scale_chosen))
BECAUSE "The velocity scale is equal to the square root of the length
scale because the dominant force acting on the model is gravity. Therefore,
the Froude Number must be the same for the model and prototype.";

RULE 8b

IF       aspect<6
THEN        space_display=3_dimensional
         FIND space_model
BECAUSE " The aspect ratio determines whether the boom stick acts two
dimensionally or three-dimensionally. If the aspect ratio is less than
6, then edge effects on the sides of the boom stick dominate and the
prototype behaves three-dimensionally. If the aspect ratio is greater than
6, then the prototype behaves two-dimensionally. The aspect ratio determines
the length of the model to be used.";


RULE 8c

IF       space_display=3_dimensional
THEN        space_model=(space_between_sticks/scale_chosen)
```

```
          depth_ratio=(depth/height_front_face)
          FIND depth_flume;

RULE 8d

IF        depth_ratio>=6
THEN        depth_flume=0.714
BECAUSE "The depth ratio is greater than 6, so there are no boundary effects
caused by the flume floor. Therefore, the depth of water can be set to
maximum depth possible in the flume.";

RULE 8e

IF        depth_ratio<6
THEN        depth_flume=(depth_ratio*front_model)
BECAUSE "The depth ratio is less than 6 so the prototype is influenced by
the bottom of the flow section. Therefore, this ratio must be maintained in
the lab. Therefore, the depth of water in the flume is calculated based on
the height of the front face of the model";

RULE 8d

IF        aspect>=6
THEN        space_display=2_dimensional
          FIND space_model;

RULE 8e

IF        space_display=2_dimensional
THEN        space_model=not_required
          depth_ratio=(depth/height_front_face)
          FIND depth_flume;

RULE 8f

IF        depth_ratio>=6
THEN        depth_flume=0.714
BECAUSE "The depth ratio is greater than 6, so there are no boundary effects
caused by the flume floor. Therefore, the depth of water can be set to
maximum depth possible in the flume.";


RULE 8g

IF        depth_ratio<6
THEN        depth_flume=(depth_ratio*front_model)
BECAUSE "The depth ratio is less than 6 so the prototype is influenced by
the bottom of the flow section. Therefore, this ratio must be maintained in
the lab. Therefore, the depth of water in the flume is calculated based on
the height of the front face of the model";

RULE 8

IF        aspect>=6 AND
```

```
        anchor_type=1
THEN        length_model=0.914
        width_model=(width/scale_chosen)
        front_model=(height_front_face/scale_chosen)
        back_face=(height_back_face/scale_chosen)
        model_dimensions=yes
        FIND plex_thick
        FIND display_thick
        FIND model_mass
        FIND display_mass
        FORMAT display_mass, 5.3
CLS
DISPLAY "
The dimensions of the ice boom model are as follows:

                    length = {length_model} m.
                     width = {width_model} m.
     height of front face = {front_model} m.
     height of back face  = {back_face} m.
 . thickness of plexiglass = {display_thick} m.
                    weight = {display_mass} kg.
~"

  CLS
  DISPLAY "    The next phase of this knowledge base is to compile the
testing program for the ice boom. The factor which effects the testing
program to be used by the user is:

         - Equipment available in the hydraulics lab.

~"
CLS
DISPLAY" One moment please while expert system compiles testing program"
  WKS velocity_meter,A2,c:\vp\project\database\equip
  WKS data_acquisition,B2,c:\vp\project\database\equip
  WKS pressure_transducer,C2,c:\vp\project\database\equip
  WKS load_cell,D2,c:\vp\project\database\equip
  WKS video_measure,E2,c:\vp\project\database\equip
  WKS video_analysis,F2,c:\vp\project\database\equip
  CLS
  DISPLAY "      The following testing program can be implemented:

"
;

RULE 9

IF        aspect>=6 AND
        anchor_type=2
THEN        length_model=0.9
        width_model=(width/scale_chosen)
        front_model=(height_front_face/scale_chosen)
        back_face=(height_back_face/scale_chosen)
        model_dimensions=yes
```

```
        FIND plex_thick
        FIND display_thick
        FIND model_mass
        FIND display_mass
        FORMAT display_mass, 5.3
CLS
DISPLAY "
The dimensions of the ice boom model are as follows:

                    length = {length_model} m.
                     width = {width_model} m.
     height of front face = {front_model} m.
     height of back face  = {back_face} m.
   thickness of plexiglass = {display_thick} m.
                    weight = {display_mass} kg.
~"

  CLS
  DISPLAY "   The next phase of this knowledge base is to compile the
testing program for the ice boom. The factor which effects the testing
program to be used by the user is:

        - Equipment available in the hydraulics lab.

~"
CLS
  DISPLAY "   One moment please while expert system compiles testing program"
  WKS velocity_meter,A2,c:\vp\project\database\equip
  WKS data_acquisition,B2,c:\vp\project\database\equip
  WKS pressure_transducer,C2,c:\vp\project\database\equip
  WKS load_cell,D2,c:\vp\project\database\equip
  WKS video_measure,E2,c:\vp\project\database\equip
  WKS video_analysis,F2,c:\vp\project\database\equip
  CLS
  DISPLAY "     The following testing program can be implemented:

"
;

RULE 10

IF      aspect<6 AND
        anchor_type=1
THEN      length_model=((length+space_between_sticks)/scale_chosen)
        width_model=(width/scale_chosen)
        front_model=(height_front_face/scale_chosen)
        back_face=(height_back_face/scale_chosen)
        model_dimensions=yes
        FIND plex_thick
        FIND display_thick
        FIND model_mass
        FIND display_mass
        FORMAT display_mass, 5.3
CLS
```

```
DISPLAY "
The dimensions of the ice boom model are as follows:

                  length = {length_model} m.
                   width = {width_model} m.
     height of front face = {front_model} m.
     height of back face  = {back_face} m.
  thickness of plexiglass = {display_thick} m.
                  weight = {display_mass} kg.
~"

 · CLS
   DISPLAY "    The next phase of this knowledge base is to compile the
testing program for the ice boom. The factor which effects the testing
program to be used by the user is:

         - Equipment available in the hydraulics lab.

~"
CLS
   DISPLAY "    One moment please while expert system compiles testing program"
   WKS velocity_meter,A2,c:\vp\project\database\equip
   WKS data_acquisition,B2,c:\vp\project\database\equip
   WKS pressure_transducer,C2,c:\vp\project\database\equip
   WKS load_cell,D2,c:\vp\project\database\equip
   WKS video_measure,E2,c:\vp\project\database\equip
   WKS video_analysis,F2,c:\vp\project\database\equip
   CLS
   DISPLAY "     The following testing program can be implemented:

"
;

RULE 11

IF        aspect<6 AND
          anchor_type=2
THEN         length_model=((length+space_between_sticks)/scale_chosen)
          width_model=(width/scale_chosen)
          front_model=(height_front_face/scale_chosen)
          back_face=(height_back_face/scale_chosen)
          model_dimensions=yes
          FIND plex_thick
          FIND display_thick
          FIND model_mass
          FIND display_mass
          FORMAT display_mass, 5.3
CLS
DISPLAY "
The dimensions of the ice boom model are as follows:

                  length = {length_model} m.
                   width = {width_model} m.
     height of front face = {front_model} m.
```

```
      height of back face  = {back_face} m.
   thickness of plexiglass = {display_thick} m.
                   weight = {display_mass} kg.
~"
   CLS
   DISPLAY "   The next phase of this knowledge base is to compile the
testing program for the ice boom. The factor which effects the testing
program to be used by the user is:

         - Equipment available in the hydraulics lab.

~"
CLS
   DISPLAY "   One moment please while expert system compiles testing program"
   WKS velocity_meter,A2,c:\vp\project\database\equip
   WKS data_acquisition,B2,c:\vp\project\database\equip
   WKS pressure_transducer,C2,c:\vp\project\database\equip
   WKS load_cell,D2,c:\vp\project\database\equip
   WKS video_measure,E2,c:\vp\project\database\equip
   WKS video_analysis,F2,c:\vp\project\database\equip
   CLS
   DISPLAY "      The following testing program can be implemented:

"
;


RULE VELOCITY_1

IF        velocity_meter=propeller AND
          data_acquisition=no
THEN      velocity_measure=average;

RULE VELOCITY_2

IF        velocity_meter=propeller AND
          data_acquisition=yes
THEN      velocity_measure=average;

RULE VELOCITY_3

IF        velocity_meter=pitot_tube AND
          data_acquisition=no AND
          pressure_transducer=no
THEN      velocity_measure=average;

RULE VELOCITY_4

IF        velocity_meter=pitot_tube AND
          data_acquisition=no AND
          pressure_transducer=yes
THEN      velocity_measure=average;

RULE VELOCITY_5
```

```
IF      velocity_meter=pitot_tube AND
        data_acquisition=yes AND
        pressure_transducer=yes
THEN       velocity_measure=real_time;

RULE VELOCITY_6

IF      velocity_meter=pitot_tube AND
        data_acquisition=yes AND
        pressure_transducer=no
THEN       velocity_measure=average;

RULE VELOCITY_7

IF      velocity_meter=acoustic AND
        data_acquisition=yes
THEN       velocity_measure=real_time;

RULE VELOCITY_8

IF      velocity_meter=acoustic AND
        data_acquisition=no
THEN       velocity_measure=no;

RULE VELOCITY_9

IF      velocity_meter=doppler_laser AND
        data_acquisition=yes
THEN       velocity_measure=real_time;

RULE VELOCITY_10

IF      velocity_meter=doppler_laser AND
        data_acquisition=no
THEN       velocity_measure=no;

RULE LOAD_CELL_1

IF      load_cell=yes AND
        data_acquisition=yes
THEN       load_measure=real_time;

RULE LOAD_CELL_2

IF      load_cell=yes AND
        data_acquisition=no
THEN       load_measure=average;

RULE LOAD_CELL_3

IF      load_cell=no AND
        data_acquisition=no OR
        data_acquisition=yes
THEN       load_measure=no;
```

```
RULE VIDEO_1

IF      video_measure=camera AND
        video_analysis=physical OR
        video_analysis=computer
THEN      video=average;

RULE VIDEO_2

IF      video_measure=video_tape AND
        video_analysis=computer
THEN      video=real_time;

RULE VIDEO_3

IF      video_measure=video_tape OR
        video_measure=camera AND
        video_analysis=physical
THEN      video=average;

RULE VIDEO_4

IF      video_measure=no AND
        video_analysis=no OR
        video_analysis=computer OR
        video_analysis=physical
THEN      video=no;

RULE VELOCITY_FLAG_1

IF      velocity_meter=no
THEN      velocity_flag=UNKNOWN
DISPLAY"   No testing can be accomplished because the hydraulics lab does not have
the equipment to measure velocity. Arrangements should be made to purchase a
velocity meter in order to carry out the tests~";

RULE VELOCITY_FLAG_2

IF      velocity_meter<>no
THEN      velocity_flag=YES
  FIND test1
  FIND test2
  FIND test3
  FIND test4
  DISPLAY"
    Now the expert system is going to link up to next portion
of the knowledge base which deals with enquiries that the user might have
about testing procedures, construction methods for model building and
instructions on how to use equipment available in the lab


              Press any key to continue!~"
SAVEFACTS c:\vp\project\submerge
CHAIN c:\vp\project\test;
```

```
RULE TEST1_1

IF       velocity_measure=real_time AND
         video=real_time
THEN     test1=real_time
DISPLAY" - The real-time study of the relationship between velocity and ice
  boom position"
ELSE
         test1=average
DISPLAY" - The average time study of the relationship between velocity and ice
  boom position";


RULE TEST2_1

IF       velocity_measure=real_time AND
         load_measure=real_time
THEN     test2=real_time
DISPLAY" - The real-time study of the relationship between velocity and
  hydrodynamic forces"
ELSE
         test2=average
DISPLAY" - The average time study of the relationship between velocity and
  hydrodynamic forces";

RULE TEST3_1

IF       velocity_measure=real_time AND
         video=real_time
THEN     test3=real_time
DISPLAY" - The real-time study of the flow field around the ice boom"
ELSE
         test3=average
DISPLAY" - The average time study of the flow field around the ice boom";


RULE TEST4_1

IF       velocity_measure=real_time OR
         velocity_measure=average
THEN     test4=yes
DISPLAY" - The velocity at which the ice boom submerges";



ASK length: "What is the length of the ice boom stick (m)?";
ASK width:  "What is the width of the ice boom stick (m)?";
ASK depth: "What is the depth of water at the proposed location (m)?";
ASK velocity: "What is the velocity at the location (m/s)?";
ASK height_front_face: "What is the height of the front face (m)?";
ASK height_back_face: "What is the height of the back face (m)?";
ASK space_between_sticks: "What is the space between the boom sticks?";
ASK scale_chosen: "
```

```
     Since the scale calculated is less than or equal to 10, your model can
be built. However, the scale used for building your model must be at least
equal to the calculated scale. The best way is to round up the calculated
scale to the nearest whole number.

     Therefore, what scale are you going to use for building your model?";
ASK mass_prototype: "What is the weight of the prototype in kg.?";
ASK anchor_type :


"What type of anchoring system is proposed for the ice boom?
          1) anchored by a main cable
          2) connected in series





ANCHORED BY MAIN CABLE - ice boom is connected to a main cable running across
        the entire expanse of the river or forebay.

CONNECTED IN SERIES - ice boom sticks are connected to each other and the ends
        of each boom stick.
";
CHOICES anchor_type: 1,2;
```

Knowledge Base *test.kbs*

```
RUNTIME;
ENDOFF;
ACTIONS
DISPLAY "     Welcome to the portion of the expert system entitled:



                    TEST CONSULTATION PHASE


     This portion of the expert system will consult the user on how to
implement the testing program formulated in the previous knowledge base.





                    Press any key to continue~"
CLS
LOADFACTS c:\vp\project\submerge
FIND velocity_scale
FIND space_display
CLS
WHILEKNOWN subject
```

```
    CLS
    RESET subject_material
    RESET subject
DISPLAY "The knowledge base contains information on the following subjects:


1) TEST EQUIPMENT - description of the equipment available to be used by the
        user in the hydraulics lab and instructions on how to use them
        for various test.

2) TEST PROCEDURES - description of objective and instructions for each test
        that was compiled in the previous knowledge base. Guides the user
        in the successful implementation of the testing program.

3) CONSTRUCTION PROCEDURES - description of constructions techniques
        necessary to construct the user's model as well a guidelines in
        the installation of the testing apparatus in the flume for the
        model.

"
   FIND subject
END
CLS;


RULE 1

IF       test1=real_time
THEN       display_test1=yes
DISPLAY " 1) The real time study of the relationship between velocity and the ice
   boom position";

RULE 2

IF       test1=average
THEN       display_test1=yes
DISPLAY " 1) The average time study of the relationship between velocity and the
   ice boom position";

RULE 3

IF       test2=real_time
THEN       display_test2=yes
DISPLAY " 2) The real time study of the relationship between velocity and the
   hydrodynamic forces";

RULE 4

IF       test2=average
THEN       display_test2=yes
DISPLAY " 2) The average time study of the relationship between velocity and the
   hydrodynamic forces";

RULE 5
```

```
IF      test3=average
THEN      display_test3=yes
DISPLAY " 3) The average time study of the flow field around the ice boom";

RULE 6

IF      test3=real_time
THEN      display_test3=yes
DISPLAY " 3) The real time study of the flow field around the ice boom";

RULE 7

IF      test4=yes
THEN      display_test4=yes
DISPLAY " 4) The analysis of the velocity at which the ice boom submerges~";

RULE 8

IF      scale_chosen<=10
THEN      velocity_scale=(@sqrt(scale_chosen))
BECAUSE "The velocity scale is equal to the square root of the length
scale because the dominant force acting on the model is gravity. Therefore,
the Froude Number must be the same for the model and prototype.";

RULE 8b

IF      aspect<6
THEN      space_display=3_dimensional
        FIND space_model
BECAUSE " The aspect ratio determines whether the boom stick acts two
dimensionally or three-dimensionally. If the aspect ratio is less than
6, then edge effects on the sides of the boom stick dominate and the
prototype behaves three-dimensionally. If the aspect ratio is greater than
6, then the prototype behaves two-dimensionally. The aspect ratio determines
the length of the model to be used.";

RULE 8c

IF      space_display=3_dimensional
THEN      space_model=(space_between_sticks/scale_chosen)
        depth_ratio=(depth/height_front_face)
        FIND depth_flume;

RULE 8d

IF      depth_ratio>=6
THEN      depth_flume=0.714
BECAUSE "The depth ratio is greater than 6, so there are no boundary effects
caused by the flume floor. Therefore, the depth of water can be set to
maximum depth possible in the flume.";

RULE 8e

IF      depth_ratio<6
```

```
THEN      depth_flume=(depth_ratio*front_model)
BECAUSE "The depth ratio is less than 6 so the prototype is influenced by
the bottom of the flow section. Therefore, this ratio must be maintained in
the lab. Therefore, the depth of water in the flume is calculated based on
the height of the front face of the model";

RULE 8d

IF       aspect>=6
THEN      space_display=2_dimensional
         FIND space_model;

RULE 8e

IF       space_display=2_dimensional
THEN      space_model=not_required
         depth_ratio=(depth/height_front_face)
         FIND depth_flume;

RULE 8f

IF       depth_ratio>=6
THEN      depth_flume=0.714
BECAUSE "The depth ratio is greater than 6, so there are no boundary effects
caused by the flume floor. Therefore, the depth of water can be set to
maximum depth possible in the flume.";


RULE 8g

IF       depth_ratio<6
THEN      depth_flume=(depth_ratio*front_model)
BECAUSE "The depth ratio is less than 6 so the prototype is influenced by
the bottom of the flow section. Therefore, this ratio must be maintained in
the lab. Therefore, the depth of water in the flume is calculated based on
the height of the front face of the model";


RULE 9

IF       subject_material=1
THEN      subject=equipment
     WHILEKNOWN equipment
     CLS
     DISPLAY " The following equipment is available to be used:

          1) Velocity meter - {velocity_meter}
          2) Data Acquisition system - {data_acquisition}
          3) Pressure Transducers - {pressure_transducer}
          4) Load Cell - {load_cell}
          5) Visual Measurement Device - {video_measure}
          6) Visual Data Acquisition system - {video_analysis}
"
          RESET lab_equipment
```

```
          RESET equipment
          FIND equipment
     END;


RULE 11

IF        lab_equipment=1
THEN        equipment=displayed
          RESET velocity_description
          FIND velocity_description;


RULE 12

IF        velocity_meter=propeller AND
          data_acquisition=no
THEN        velocity_description=propeller_manual
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 13

IF        velocity_meter=acoustic AND
          data_acquisition=no
THEN        velocity_description=acoustic_unavailable
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 14

IF        velocity_meter=acoustic AND
          data_acquisition=yes
THEN        velocity_description=acoustic
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 15

IF        velocity_meter=doppler_laser AND
          data_acquisition=no
THEN        velocity_description=doppler_unavailable
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;



RULE 16

IF        velocity_meter=doppler_laser AND
          data_acquisition=yes
THEN        velocity_description=doppler
CLS
```

```
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 17

IF        velocity_meter=pitot_tube AND
          data_acquisition=no AND
          pressure_transducer=no
THEN      velocity_description=pitot_nodata_nopressure
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 18

IF        velocity_meter=pitot_tube AND
          data_acquisition=no AND
          pressure_transducer=yes
THEN      velocity_description=pitot_nodata_pressure
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 19

IF        velocity_meter=pitot_tube AND
          data_acquisition=yes AND
          pressure_transducer=yes
THEN      velocity_description=pitot_data_pressure
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 20

IF        velocity_meter=pitot_tube AND
          data_acquisition=yes AND
          pressure_transducer=no
THEN      velocity_description=pitot_data_nopressure
CLS
SHOWTEXT c:\vp\project\text\equipmd,velocity_description;

RULE 21

IF        lab_equipment=2
THEN      equipment=displayed
.         RESET data_description
          FIND data_description;



RULE 22

IF        data_acquisition=no
THEN      data_description=data_not_available
CLS
SHOWTEXT c:\vp\project\text\equipmd,data_description;
```

```
RULE 23

IF      data_acquisition=yes
THEN      data_description=data_available
CLS
SHOWTEXT c:\vp\project\text\equipmd,data_description;

RULE 24

IF      lab_equipment=3
THEN      equipment=displayed
        RESET pressure_description
        FIND pressure_description;


RULE 25

IF      pressure_transducer=no
THEN      pressure_description=pressure_not_available
CLS
SHOWTEXT c:\vp\project\text\equipmd,pressure_description;


RULE 26

IF      pressure_transducer=yes
THEN      pressure_description=pressure
CLS
SHOWTEXT c:\vp\project\text\equipmd,pressure_description;

RULE 27

IF      lab_equipment=4
THEN      equipment=displayed
        RESET load_cell_description
        FIND load_cell_description;


RULE 28

IF      load_cell=yes AND
        data_acquisition=no
THEN      load_cell_description=load_cell_manual
CLS
SHOWTEXT c:\vp\project\text\equipmd,load_cell_description;


RULE 29

IF      load_cell=yes AND
        data_acquisition=yes
THEN      load_cell_description=load_cell_real_time
CLS
```

```
SHOWTEXT c:\vp\project\text\equipmd,load_cell_description;


RULE 30

IF        load_cell=no AND
          data_acquisition=no OR
          data_acquisition=yes
THEN      load_cell_description=load_cell_unavailable
CLS
SHOWTEXT c:\vp\project\text\equipmd,load_cell_description;

RULE 31

IF        lab_equipment=5
THEN      equipment=displayed
          RESET video_measure_description
          FIND video_measure_description;


RULE 32

IF        video_measure=camera
THEN      video_measure_description=video_camera
CLS
SHOWTEXT c:\vp\project\text\equipmd,video_measure_description;

RULE 33

IF        video_measure=video_tape
THEN      video_measure_description=video_tape
CLS
SHOWTEXT c:\vp\project\text\equipmd,video_measure_description;

RULE 34

IF        lab_equipment=6
THEN      equipment=displayed
          RESET video_analysis_description
          FIND video_analysis_description;


RULE 35

IF        video_analysis=physical AND
          video_measure=camera
THEN      video_analysis_description=video_camera_manual
CLS
SHOWTEXT c:\vp\project\text\equipmd,video_analysis_description;

RULE 36

IF        video_analysis=computer AND
          video_measure=camera
```

```
THEN      video_analysis_description=video_camera_computer
CLS
SHOWTEXT c:\vp\project\text\equipmd,video_analysis_description;

RULE 37

IF        video_analysis=physical AND
          video_measure=video_tape
THEN      video_analysis_description=video_tape_manual
CLS
SHOWTEXT c:\vp\project\text\equipmd,video_analysis_description;


RULE 38

IF        video_analysis=computer AND
          video_measure=video_tape
THEN      video_analysis_description=video_tape_computer
CLS
SHOWTEXT c:\vp\project\text\equipmd,video_analysis_description;

RULE 39

IF        subject_material=2
THEN      subject=test
    WHILEKNOWN test_program
CLS
DISPLAY " The following tests can be implemented:

"
          RESET display_test1
          RESET display_test2
          RESET display_test3
          RESET display_test4
          FIND display_test1
          FIND display_test2
          FIND display_test3
          FIND display_test4
          RESET test_procedure
          RESET test_program
          FIND test_program
    END;


RULE 40

IF        test_procedure=1
THEN      test_program=displayed
          RESET test1_description
          FIND test1_description;

RULE 41

IF        test1=average
```

```
THEN      test1_description=test1_average
CLS
SHOWTEXT c:\vp\project\text\testmd,test1_description;

RULE 42

IF        test1=real_time
THEN      test1_description=test1_real_time
CLS
SHOWTEXT c:\vp\project\text\testmd,test1_description;

RULE 43

IF        test_procedure=2
THEN      test_program=displayed
          RESET test2_description
          FIND test2_description;

RULE 44

IF        test2=average
THEN      test2_description=test2_average
CLS
SHOWTEXT c:\vp\project\text\testmd,test2_description;

RULE 45

IF        test2=real_time
THEN      test2_description=test2_real_time
CLS
SHOWTEXT c:\vp\project\text\testmd,test2_description;

RULE 46

IF        test_procedure=3
THEN      test_program=displayed
          RESET test3_description
          FIND test3_description;

RULE 47

IF        test3=average
THEN      test3_description=test3_average
CLS
SHOWTEXT c:\vp\project\text\testmd,test3_description;

RULE 48

IF        test3=real_time
THEN      test3_description=test3_real_time
CLS
SHOWTEXT c:\vp\project\text\testmd,test3_description;

RULE 49
```

```
IF       test_procedure=4
THEN       test_program=displayed
         RESET test4_description
         FIND test4_description;

RULE 50

IF       test4=average
THEN       test4_description=test4_procedure
CLS
SHOWTEXT c:\vp\project\text\testmd,test4_description;

RULE 51

IF       subject_material=3
THEN       subject=construction
WHILEKNOWN construction_query
CLS
DISPLAY "
This is the Construction and Installation portion of the knowledge base.
The purpose of this portion of the knowledge base is to quide you in the
construction and installation of your ice boom model. You have a choice of
one of the following subjects:

         1) CONSTRUCTION OF MODEL      2) INSTALLATION OF MODEL

"
         RESET construction_query
         RESET construction_description
         FIND construction_query
    END;

RULE 52

IF       construction_description=construction
THEN       construction_query=yes
CLS
DISPLAY"    The size of the model to be constructed and the associated scale
factors are as follows:

                        length = {length_model} m.
                         width = {width_model} m.
          height of front face = {front_model} m.
           height of back face = {back_face} m.
                        weight = {display_mass} kg.
      thickness of plexiglass = {display_thick} m.
                  length scale = {scale_chosen}
                velocity scale = {velocity_scale}
space between ice boom models = {space_model}
      depth of water in flume = {depth_flume} m.
~"
FIND construction_file;

RULE 53
```

```
IF       anchor_type=1
THEN       construction_file=main_cable
CLS
SHOWTEXT c:\vp\project\text\constmd, construction_file;

RULE 54

IF       construction_description=installation
THEN       construction_query=yes
         FIND installation_file_page1;

RULE 55

IF       aspect>=6 AND
         anchor_type=1
THEN       installation_file_page1=2_dimensional_main_page1
CLS
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page1
         FIND installation_file_page2;
RULE 56

IF       aspect>=6 AND
         anchor_type=1
THEN       installation_file_page2=yes
         CLROFF
         CALL c:\sketch\sketch,"icemain"
         installation_file_page3=2_dimensional_main_page3
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page3;

RULE 57

IF       aspect>=6 AND
         anchor_type=2
THEN       installation_file_page1=2_dimensional_series_page1
CLS
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page1
         FIND installation_file_page2;

RULE 58

IF       aspect>=6 AND
         anchor_type=2
THEN       installation_file_page2=yes
         CLROFF
         CALL c:\sketch\sketch,"iceseris"
         installation_file_page3=2_dimensional_series_page3
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page3;

RULE 59

IF       anchor_type=2
THEN       construction_file=connected_series
CLS
SHOWTEXT c:\vp\project\text\constmd, construction_file;
```

```
RULE 60

IF      aspect<6 AND
        anchor_type=1
THEN       installation_file_page1=3_dimensional_main_page1
CLS
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page1
        FIND installation_file_page2;
RULE 56

IF      aspect<6 AND
        anchor_type=1
THEN       installation_file_page2=yes
        CLROFF
        CALL c:\sketch\sketch,"icemain"
        installation_file_page3=3_dimensional_main_page3
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page3;

RULE 57

IF      aspect<6 AND
        anchor_type=2
THEN       installation_file_page1=3_dimensional_series_page1
CLS
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page1
        FIND installation_file_page2;

RULE 58

IF      aspect>=6 AND
        anchor_type=2
THEN       installation_file_page2=yes
        CLROFF
        CALL c:\sketch\sketch,"iceseris"
        installation_file_page3=3_dimensional_series_page3
SHOWTEXT c:\vp\project\text\instalmd, installation_file_page3;

ASK subject_material: " Which subject would you like to inquire about?
";
CHOICES subject_material : 1,2,3,QUIT;
ASK lab_equipment : "Which piece of equipment do you want to know about?";
CHOICES lab_equipment: 1,2,3,4,5,6,quit;
ASK equipment_description: "

Do you want a description of any equipment in the lab?";
CHOICES equipment_description : yes,no;
ASK test_procedure: "



Which testing program do you want to know about?. Enter number corresponding
to test program displayed or type 0 to quit
```

```
";
ASK construction_description : "What subject do you require information on";
CHOICES construction_description: CONSTRUCTION, INSTALLATION, QUIT;
```

FORTRAN PROGRAM *SCALE_2.EXE*

```
C    THIS PROGRAM WILL CALCULATE THE SCALE FOR THE ICE BOOM STICK
C    MODEL BASED ON THE PHYSICAL PARAMETERS OF THE MODEL AND
C    PHYSICAL LIMITATIONS OF THE LAB.
C
C
      REAL LENGTH, WIDTH, DEPTH, VEL, HFF, HBF, SPACE,
     +DEPTHB, VELMAX, SCALEV, SCALEH, SCALE, ASPECT
C
C    READING THE FILE PRODUCED FROM EXPERT SYSTEMS
C
      OPEN(1, FILE='c:\vp\project\text\DIMEN')
      OPEN(2, FILE='c:\vp\project\text\SCALE')
C
C    READING THE FILE
C
      DO 11 N=1,7
        IF(N.EQ.1) THEN
          READ(1,*) LENGTH
        END IF
        IF (N.EQ.2) THEN
          READ(1,*) WIDTH
        END IF
        IF (N.EQ.3) THEN
          READ(1,*) DEPTH
        END IF
        IF (N.EQ.4) THEN
          READ(1,*) VEL
        END IF
        IF (N.EQ.5) THEN
          READ(1,*) HFF
        END IF
        IF (N.EQ.6) THEN
          READ(1,*) HBF
        END IF
        IF (N.EQ.7) THEN
          READ(1,*) SPACE
        END IF
   11 CONTINUE
C
C CALCULATING SCALE
C
      DEPTHB=DEPTH/HFF
      VELMAX=0.144
      DEPMAX=0.762
      ASPECT=LENGTH/WIDTH
      WIDTHF=0.914
```

```
C
C ICE BOOM STICK IS TWO DIMENSIONAL PROBLEM IF ASPECT GREATER THAN 6
C
   IF (ASPECT .GE. 6) THEN
     SCALEV=(VEL/VELMAX)**2
     IF (DEPTHB .GT. 10) THEN
       SCALEH=10*HFF/DEPMAX
       DEPTHB=10
     ELSE
       SCALEH=DEPTHB*HFF/DEPMAX
     END IF
     IF (SCALEH .GT. SCALEV) THEN
       SCALE=SCALEH
     ELSE
       SCALE=SCALEV
     END IF
     IF (SCALE .GT. 10) THEN
       IF (SCALEV .GT. SCALEH) THEN
         SCALEV=SCALEH
         VELMAX=0.5/SCALEV**0.5
         DEPMAX=0.1/(0.914*VELMAX)
         SCALEH=DEPTHB*HFF/DEPMAX
       ELSE
         SCALEH=SCALEV
         DEPMAX=DEPTHB*HFF/SCALEH
         VELMAX=0.1/(0.914*DEPMAX)
         SCALEV=(VEL/VELMAX)**2
       END IF
       IF (SCALEH .GT. SCALEV) THEN
         SCALE=SCALEH
       ELSE
         SCALE=SCALEV
       END IF
     END IF
   END IF
C
C TWO DIMENSIONAL PROBLEM
C
   IF (ASPECT .LT. 6) THEN
     SCALEV=(VEL/VELMAX)**2
     SCALEW=(LENGTH+SPACE)/WIDTHF
     IF (DEPTHB .GT. 10) THEN
       SCALEH=10*HFF/DEPMAX
       DEPTHB=10
     ELSE
       SCALEH=DEPTHB*HFF/DEPMAX
     END IF
     IF (SCALEH .GT. SCALEV) THEN
       SCALE=SCALEH
     ELSE
       SCALE=SCALEV
     END IF
     IF (SCALEW .GT. SCALE) THEN
       SCALE=SCALEW
```

```
    END IF
    IF (SCALE .GT. 10) THEN
      IF (SCALEV .GT. SCALEW) THEN
        IF (SCALEW .GT. SCALEH) THEN
          SCALEV=SCALEW
          VELMAX=0.5/SCALEV**0.5
          DEPMAX=0.1/(WIDTHF*VELMAX)
          SCALEH=DEPTHB*HFF/DEPMAX
        ELSE
          SCALEV=SCALEH
          VELMAX=0.5/SCALEV**0.5
          DEPMAX=0.1/(WIDTHF*VELMAX)
          SCALEH=DEPTHB*HFF/DEPMAX
        END IF
      END IF
      IF (SCALEH .GT. SCALEW) THEN
        IF (SCALEW .GT. SCALEV) THEN
          SCALEH=SCALEW
          DEPMAX=DEPTHB*HFF/SCALEH
          SCALEV=0.1/(WIDTHF*DEPMAX)
        ELSE
          SCALEH=SCALEV
          DEPMAX=DEPTHB*HFF/SCALEH
          SCALEV=0.1/(WIDTHF*DEPMAX)
        END IF
      END IF
      IF (SCALEW .GT. SCALEH) THEN
        IF (SCALEH .GT. SCALEV) THEN
          SCALEW=SCALEH
          VELMAX=VEL/SCALEW**0.5
          DEPMAX=0.1/(WIDTHF*VELMAX)
          SCALEH=DEPTHB*HFF/DEPMAX
        ELSE
          SCALEW=SCALEV
          VELMAX=VEL/SCALEW**0.5
          DEPMAX=0.1/(WIDTHF*VELMAX)
          SCALEH=DEPTHB*HFF/DEPMAX
        END IF
      END IF
      IF (SCALEH .GT. SCALEV) THEN
        SCALE=SCALEH
      ELSE
        SCALE=SCALEV
      END IF
      IF (SCALEW .GT. SCALE) THEN
        SCALE=SCALEW
      END IF
    END IF
  END IF
  WRITE (2,7) SCALE
7 FORMAT(F6.2)
  END
```

FORTRAN PROGRAM *WEIGHT.EXE*

```
C    THIS PROGRAM WILL CALCULATE THE WEIGHT OF THE MODEL BASED ON THE
C    SCALE CHOSEN, THE WEIGHT OF THE PROTOTYPE AND THE ASPECT RATIO.
C
C
      REAL LENGTH, WIDTH, DEPTH, VEL, HFF, HBF, SPACE, SCALE, THICK,
     + MASSM, MASMOD, MASPRO
C
C    READING THE FILES PRODUCED FROM THE EXPERT SYSTEM
C
      OPEN(1, FILE='c:\vp\project\text\DIMEN')
      OPEN(2, FILE='c:\vp\project\text\SCALEM')
      OPEN(3, FILE='c:\vp\project\text\PLEX')
      OPEN(4, FILE='c:\vp\project\text\WEIGHT')
C
C
      DO 11 N=1,7
      IF (N .EQ. 1) THEN
        READ(1,*) LENGTH
      END IF
      IF (N .EQ. 2) THEN
        READ(1,*) WIDTH
      END IF
      IF (N .EQ. 3) THEN
        READ(1,*) DEPTH
      END IF
      IF (N .EQ. 4) THEN
        READ(1,*) VEL
      END IF
      IF (N .EQ. 5) THEN
        READ(1,*) HFF
      END IF
      IF (N .EQ. 6) THEN
        READ(1,*) HBF
      END IF
      IF (N .EQ. 7) THEN
        READ(1,*) SPACE
      END IF
   11 CONTINUE
      DO 12 M=1,2
      IF (M .EQ. 1) THEN
        READ(2,*) SCALE
      END IF
      IF (M .EQ. 2) THEN
        READ(2,*) MASPRO
      END IF
   12 CONTINUE
C
C    CALCULATING ASPECT RATIO
C
      ASPECT=LENGTH/WIDTH
C
```

```
C     TESTING ASPECT RATIO TO SEE IF ICE BOOM STICK IS 2 OR 3 DIMENSIONAL
C
      THICK=0.00635/2
      IF (ASPECT .GE. 6) THEN
        MASMOD=MASPRO/LENGTH*0.914/SCALE**2
 10     MASSM=0.914*1185.15*(WIDTH/SCALE*THICK+(((HFF-HBF)/SCALE)**2 +
     +        (WIDTH/SCALE)**2)**.5*THICK+(HBF/SCALE-2*THICK)*THICK +
     +        (HFF/SCALE-2*THICK)*THICK)+(2*((WIDTH/SCALE-2*THICK)*
     +        ((HFF/SCALE-2*THICK)+(HBF/SCALE-2*THICK))/2))*1185.15*
     +        THICK
        IF (MASSM .LT. MASMOD) THEN
          THICK=THICK+0.00635/2
          GOTO 10
        END IF
        IF (MASSM .GT. MASMOD) THEN
          THICK=THICK-0.00635/2
          MASSM=0.914*1185.15*(WIDTH/SCALE*THICK+(((HFF-HBF)/SCALE)**2 +
     +        (WIDTH/SCALE)**2)**.5*THICK+(HBF/SCALE-2*THICK)*THICK +
     +        (HFF/SCALE-2*THICK)*THICK)+(2*((WIDTH/SCALE-2*THICK)*
     +        ((HFF/SCALE-2*THICK)+(HBF/SCALE-2*THICK))/2))*1185.15*
     +        THICK
        END IF
      ELSE
        MASMOD=MASPRO/SCALE**3
 20     MASSM=LENGTH*1185.15*(WIDTH/SCALE*THICK+(((HFF-HBF)/SCALE)**2 +
     +        (WIDTH/SCALE)**2)**.5*THICK+(HBF/SCALE-2*THICK)*THICK +
     +        (HFF/SCALE-2*THICK)*THICK)+(2*((WIDTH/SCALE-2*THICK)*
     +        ((HFF/SCALE-2*THICK)+(HBF/SCALE-2*THICK))/2))*1185.15*
     +        THICK
        IF (MASSM .LT. MASMOD) THEN
          THICK=THICK+0.00635/2
          GOTO 20
        END IF
      END IF
      DO 5 P=1,2
      IF (P .EQ. 1) THEN
        WRITE (3,7) THICK
      END IF
      IF (P .EQ. 2) THEN
        WRITE (4,7) MASSM
      END IF
    7 FORMAT (F6.4)
    5 CONTINUE
      END
```

Due to the size of the indexed test files, they will not be included in the appendices. Refer to the files on disk to view them.

Sample Executions

Here is a listing of inputs for a sample execution of the system.

Length of model = 10 m.
Width of model = 1.0 m.
Depth of water = 50 m.
Velocity of water = 0.5 m/s.
Height of front face of boom stick = 0.1 m.
Height of back face of boom stick = 0.05 m.
space between boom sticks = 1.5 m.

To change the testing program, edit the spreadsheet file **equip.wks**. Here is a list of options for each type of equipment.

Velocity Meter	**Data Acquisition**	**Load Cell**	**Video Measure**	**Video Analysis**
propeller	yes	yes	camera	physical
pitot_tube	no	no	video_tape	computer
acoustic				
doppler_laser				