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Silt Curtains to Control Sediment Movement on Construction Sites

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Silt Curtains to Control Sediment Movement on Construction Sites

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Abstract:

Environmental concerns regarding the introduction of sediments to rivers and lakes have risen in recent years. These concerns require that the state-of-the-art be defined with respect to floating silt curtains surrounding underwater construction.

Proper design, installation, and maintenance are needed in order to ensure a curtain's proper functioning.

A simple mathematical model is presented which allows the total force acting on a silt curtain to be calculated. This model can be used to estimate anchoring loads thus indicating the feasibility of using a curtain in a particular location. In general, when currents exceed approximately 0.3 m/s (1 ft/s), the anchoring loads become excessive and the curtain becomes prone to catastrophic failure.

A model study has provided additional information detailing when a curtain will lift off the bottom allowing silt laden water to escape. The upper limit of velocity which will prevent lifting depends directly on the weighting used, the shape of the enclosure, and the presence or lack of piles supporting the curtain. The currents tolerated for lifting are lower than the current limits for mooring. Based on field experience and the model tests, it is not realistic that free floating silt curtains can be used when the velocity in the constriction is in excess of 0.15 m/s (0.5 ft/s).

To ensure the effective use of silt curtains, it is imperative that proper field studies be carried out at the proposed location. This will ascertain the feasibility of a curtain and allow its proper design.

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Silt Curtains to Control Sediment Movement on Construction Sites

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ABSTRACT

Environmental concerns regarding the introduction of sediments to rivers and lakes have risen during recent years. With these concerns, a need to define the state-of-the-art with respect to floating silt curtains surrounding underwater construction exists.

The purpose of silt curtains is to contain sediments which are brought into suspension in marine construction operations. Floating silt curtains are meant to contain turbidity (i.e. not filter). They have been used in dredging operations, bridge construction projects, and for spill-box effluent sediment control. A possible future use is for channelling turbidity to a "safe" zone where turbidity will not have a detrimental effect on the environment.

Proper design, installation, and maintenance are needed in order to ensure a curtain's proper functioning. A simple mathematical model is presented which allows the calculation of the total force acting on a silt curtain. This model can be used to estimate anchoring loads, which may in turn indicate the feasibility of using a curtain in a particular location. In general, when currents exceed approximately 0.3 m/s (1 ft/s), the anchoring loads become excessive and the curtain becomes prone to catastrophic failure.

A model study has provided some additional information as to when a curtain will lift off the bottom, thereby allowing silt laden water to escape. The upper limit on velocity to prevent lifting depends directly on the weighting used, the shape of the enclosure, and the presence or lack of piles supporting the curtain. The currents which can be tolerated with regard to lifting are lower than the current limits for mooring. Based on field experience and the model tests, it is not realistic that free floating silt curtains can be used when the velocity in the constriction is in excess of 0.15 m/s (0.5 ft/s or 0.3 knots).

To ensure the effective use of silt curtains, it is imperative that proper field studies be carried out at the proposed location. This will ascertain the feasibility of a curtain and its proper design.

It is recommended that the work be extended to enlarge the data base through model studies; to improve the mathematical model to include a prediction when lifting will occur; and to carry out field work to verify these models.

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1. INTRODUCTION

Public awareness of the detrimental effects of adding many substances to the natural environment has increased dramatically during the last two decades and governments have passed laws and set up special agencies to prevent degradation of the environment. The Ontario Government has enacted the Ontario Water Resources Act (RSO 1980, Ch. 361) and the Ontario Environmental Protection Act (RSO 1980, Ch. 141) to control the discharge of undesirable substances. One form of contamination is the transport of sediments into lakes and rivers. There are many sources of sediments, for instance, farming operations, logging, urban and highway construction, and mining operations.

This report deals with one specific source of sediments, namely, sediments put into suspension through underwater construction. The Ministry of Transportation of Ontario (MTO) in its road construction and reconstruction operations is frequently faced with having to disturb natural channels or lake beds when removing soft material prior to placing fill for roadbeds and bridge abutments. In such situations, if the construction site is an area where the introduction of sediments is undesirable, floating silt curtains may be used to contain the sediments in an enclosure, where the sediments can settle to the bottom rather than be carried into a lake or stream.

The use of silt curtains was first reported by Gerner (1971). His paper describes what was referred to as the "Florida Diaper". It was a jury rigged silt barrier made of canvas and attached to posts driven into the bottom of the Indian River in Eastern Florida. This is a low gradient river but silt from a dredging operation was found to cloud the water up to three miles from the dredging operation. This barrier was found to be very efficient in controlling dredge-induced silt pollution. Since then, the use of silt curtains has spread. As noted above, there are many possible applications for silt curtains but it has become apparent that curtains are only effective, and indeed possible, for a very limited range of conditions.

Difficulties with the use of silt curtains can be divided into two categories: hydraulic and material problems. The hydraulic problems are due to the river or water-body characteristics. Problems encountered with the curtains were due to high currents, strong wave and tidal action, and fluctuating water levels. High winds also proved to be a problem. (Johanson, 1976)

With regard to the curtains themselves, difficulties included rapid deterioration of the fabric and marine growth on the fabric (Ekey, 1970), damage by boat traffic and marine animals, silt build-up on the skirt pulling the barrier under the water, flotation failure or inadequate flotation, parting of the fabric seams (Johanson, 1976), inadequate weighting, improper weighting due to rough sea-bed (McLuckie, 1981), and build-up of sediment in shallow water resulting in prolonged intermittent turbidity as it was subjected to constant agitation (Gerner, 1971).

2. LITERATURE REVIEW OF SILT CURTAINS

2.1 Background

Silt curtains have been in use for the past two decades. For example, in the Indian River, Florida, curtains were used during a dredge and fill operation (Gerner, 1971; Better Roads Association, 1970; Ekey, 1970). In the Oklawaha River and the Riveria Beach, Florida, they were used for spillbox effluent sediment control (Johanson, 1976).

In Ontario, the effective use of silt curtains was documented for the construction of the approaches to a bridge at Vernon Lake Narrows near Huntsville (McLuckie, 1981), the approaches for the Norris Whitney on Highway 14 (Jones, 1983), and for the construction of a cooling water intake at the Lennox power generating station in the Bay of Quinte (Ontario Hydro, 1972). However, for a number of installations, problems ranging from minor to the complete loss of the silt curtain were experienced. Because of the potential benefit of the low cost silt curtains, the U.S. Army Corps of Engineers sponsored a study of the use of silt curtains (Barnard, 1978). The Corps' findings are summarised in their report as follows:

> "The dispersion of near-surface turbidity can be controlled, to a certain extent, by placing a silt curtain downstream or around certain types of dredging/disposal operations. Under quiescent current conditions (less than 5 cm/s) turbidity levels in the water column outside the curtain may be reduced by as much as 80 to 90%; however, the effectiveness of silt curtains decreases with increasing current velocity. Silt curtains are not recommended where currents exceed 50 cm/s (1 knot)."

Other authors also indicate that floating silt curtains are effective in controlling turbidity in velocities of up to 0.26 m/s (0.5 knots) (Gerner, 1971; Ekey, 1970; Johanson, 1976A, 1976B; Brown, 1978; Barnard, 1978).

At least one company specialises in the manufacture of silt curtains (American Marine, undated). They provide a description of three products: Stillwaterscreen, Fastwaterscreen, and Center Tension screen. The first is intended for applications where there is no current and the area is sheltered from wind. The second is designed for use in areas where there may be some small currents and/or wind and waves. The Center Tension screen is designed for applications where considerable currents are possible.

It is noteworthy that American Marine considers currents of 0.5 to 1.0 m/s (1 to 2 knots) considerable. For such applications they manufacture a screen made of nylon, which is very tear resistant and very stretchy, allowing stress redistribution in the material when point loads are imposed. While these high strength curtains may be used in special cases, they cost substantially more than the "Fabrene" curtains which have been used in Ontario.

While the Barnard (1978) report did refer to model studies as part of the research programme, no information was found in the literature. The U.S. Army Corps of Engineers at the Vicksburg Waterways Experiment Station provided an assurance that the Barnard report provided all the relevant information and that this information is current (Montgomery, 1988). Christopher and Holtz (1985) in "Geotextile Engineering Manual", base their recommended use of silt curtains on Barnard's report.

From past experience, several design requirements and considerations can be summarised. These include the fabric properties, the geometry of the curtain, and the site characteristics.

Selection of a geotextile fabric for a silt curtain application depends on several criteria. The fabric Effective Opening Size (EOS) depends on the predicted suspended solids (SS) characteristics. The strength of the geotextile (tensile, grab) depends on the perceived installation stresses and the stresses induced by the site environment in which it will be placed, such as hydraulic pressure and marine life (McLuckie, 1981). Duration of the construction dictates the life span requirement of the curtain. This indicates whether untreated fabric can be used (Better Roads, as above, 1970) (Note: most fabric in use for these applications are synthetic) and whether maintenance is required. It should be noted that silt curtains are meant to contain and not filter silt (Roberts, 1988).

There are several options with respect to curtain geometry that can be considered. Three typical configurations are: closed (anchored to shore, or of an elliptical or circular shape), open (semi-circular), or a maze (two or more parallel curtains with an aperture between them). The maze curtain is ineffective as turbid water directly flows through the aperture between the curtains. This type has been used in areas of considerable boat traffic. When the curtain needs to be moved frequently, the open configuration has often been used. However, this geometry requires large curtain lengths in order to reduce end losses. The most effective shape is the closed one which has been effectively used for containing overflows from weirs, standpipes, and settling ponds. (Johanson, 1976)

Controversy exists regarding the need for a curtain that extends all the way to the bed of the water-body. A closed configuration which extends the depth of the water has no pressure relief. Th s, the stresses induced on the curtain may become critical and induce a failure. A partial depth curtain would allow excess pressure to escape beneath the curtain. Any sediment that escapes beneath would be coarser material which would settle relatively quickly thus having little detrimental effect (Johanson, 1976). Presently, there does not appear to be a consensus on the required design depth for silt curtains but Barnard (1978) provides a detailed set of recommendations for the design and installation of silt curtains based on an evaluation of silt curtain performance under various field conditions. These recommendations are already incorporated in the MTO Drainage Manual, Chapter F. (Ministry of Transportation of Ontario, 1985)

Barnard (1978) also concluded that improper and/or inadequate mooring systems typically contribute to silt curtain ineffectiveness and failure. Figure 1 shows the recommended mooring system. However, in this figure or in the remaining literature on silt curtains, there is no mention of scope, the amount of mooring line required as a function of anchoring depth. In the boating world, it is a widely accepted practice to have a 3:1 scope for chain and at least 5:1 for rope anchor rodes. This means, as an example, if the depth is 3 meters (9 ft), at least 15 meters (45 ft) of rope anchor rode is required. The recommended scope for rope is actually 7:1. This is to ensure that the anchor rode pulls the anchor parallel to the bottom, causing it to dig deeper with increasing load. Failure to provide proper scope will nearly always cause the anchor to break out of the bottom and merely slide along. Certain anchors, such as Danforth type anchors are known to "sail" without touching the bottom when a load is applied without proper scope.

Other silt curtain designs allow excess pressure to escape. By flaring the curtain (slant in the direction of the current), excess pressure can easily be released underneath and sediment cannot accumulate on the skirt. Also, slack can be provided in the curtain (Ekey, 1970); and in the case of a silt curtain extending across a current in a stream or river, it can be installed in a concave shape facing the current direction (Johanson, 1976). The hydrostatic pressures on silt curtains depend on the site characteristics.

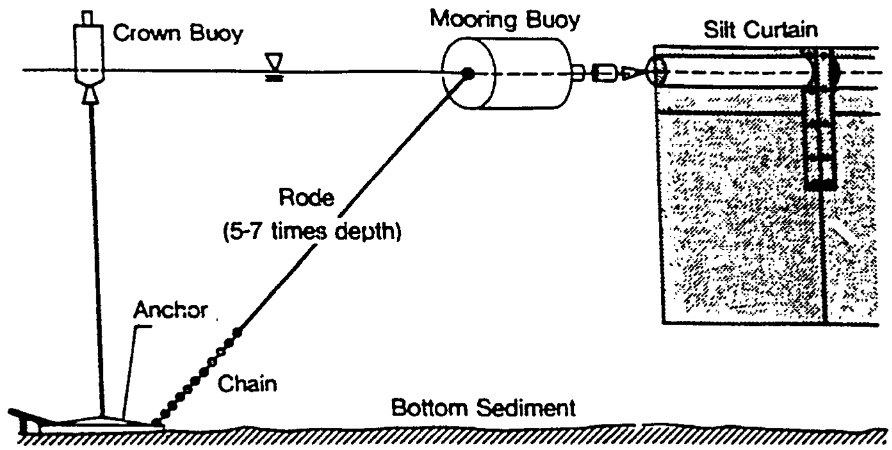


Figure 1 - Recommended mooring system for silt curtains (Barnard, 1978)

2.2 Recommended Silt Curtain Design

The site characteristics where the curtain is to be employed plays a major role in the design requirements of the floating barrier. Current velocity, tidal and wave action will dictate the amount and type of flotation and anchoring devices required. The conformity of the bed will indicate the type of anchoring to use, whether it be intermittent weights or a continuous ballast such as a chain. The expected hydrostatic pressure on the curtain may indicate the need for reinforcement with steel cable. Also, geotextile requirements are dictated by the hydraulic loads and the site environment such as aquatic plants, algae, animals, chemicals, and temperature (freeze/thaw action) (Johanson, 1976B).

Other design requirements include triple sewn or heat sealed seams (Gerner, 1971), and a suitable maintenance programme to ensure that no formidable gaps exist (considered a failure as much turbidity can escape through a relatively small gap).

2.3 Applications of Silt Curtains

Several applications exist for floating silt curtains. For dredging, silt curtains can reflect turbid clouds back towards the cutter and thus towards the influence of the suction system. For this type of application, it is important that the curtain extends to the very bottom of the waterbody as the majority of the turbid cloud generated by the dredging operation moves along the sea-bed (Herbich, 1984). In river applications, an additional silt curtain can be strung across the river at a downstream location. Another important consideration for the use of silt curtains is channelling turbid water to a "safe" section of the waterway where the environmental effects are not detrimental (Ekey, 1970). Silt curtains can also be used in highway applications such as around bank operations or bridge construction. It should be noted that except for dredging, silt curtains are only temporary measures and permanent methods to prevent erosion or infiltration of sediments into the water-body must be implemented near the end of any construction project.

2.4 Summary

In spite of the recommendations for the use of silt curtains provided in the literature, curtains are still contemplated and used in inappropriate situations. For instance, the original design for the curtain on Contract 88-11 at Matchedash Bay was wholly inadequate. The currents through the narrow bridge opening into the Bay were 0.5 to 1.0 m/s (1 to 2 knots) and periodically reversed. Currents of this magnitude were not anticipated prior to the installation, and point to the need for field data prior to construction. However, even if the current data had been available, there is little information available to help the designer in evaluating the effectiveness of a curtain in situations with currents.

Currents may not always be present and the curtain may work effectively most of the time. The problem then is what happens to the curtain when currents do occur even occasionally. It would be very desirable if the curtains were able to withstand the currents without being torn out completely. Construction could be halted for a period and continue when the currents subside. Information is needed to allow a curtain to be designed in such a way that it would work effectively in low currents, would not be destroyed when some currents are encountered, and can be recovered when construction is completed. The remainder of this report will attempt to provide a better understanding of hydraulic aspects of silt curtains.

3. ANALYSIS OF SILT CURTAINS

3.1 Theory

A silt curtain, when installed in a river, can be considered as a sudden contraction. As such it is a straight forward application of hydraulic principles to calculate the overall forces acting on the curtain. Since only low velocities have to be considered, the flow will be sub-critical. As suggested by Eichert (1970), for this type of flow the energy equation is applied first to determine the head loss for flow through the constriction. This provides the difference in water elevation between the upstream and downstream side of the curtain. Next, these water levels are used in the momentum equation. This yields the total force acting on the curtain.

Figure 2 is a schematic of three silt curtain configurations blocking flow in a channel. The geometries are kept very simple to keep the configuration within shapes for which loss coefficients are known. However, the rectangular shape (a) and the bevelled shapes (b & c) roughly provide the worst and best shapes of installed curtains respectively.

In Figure 2, a rectangular channel is assumed with w the width of the channel, d the depth of the channel, L the length of the contraction, and C_c the coefficient of contraction. For the energy equation, standard loss coefficients can be used (Streeter and Wiley, 1981). For case (a), the entrance loss coefficient $C_i = 0.5$ and the exit loss coefficient $C_o = 1.0$. For case (b) C_i and C_o are 0.1 and 0.2 respectively. The relative values of the loss coefficients may also be obtained from Chow (1959) but note that his definitions of the loss coefficients are different.

The Energy (Bernoulli) Equation for the contractions is written as:

$$d_1 - d_2 + \frac{1}{2g} [V_2^2 + C_i(V_1 - V_c)^2 + C_o(V_c - V_2)^2 + S_f L - V_1^2] \qquad (1)$$

The subscripts 1, 2, and c refer to sections 1, 2 (upstream and downstream) and the contraction, respectively. V is the mean channel velocity and is given by:

$$V_1 = Q/(d_1\, w) \qquad V_2 = Q/(d_2\, w) \qquad V_c = Q/(d_c\, w_c) \qquad (2)$$

where w_c is the width of the contraction and is given by:

$$w_c = C_c w \tag{3}$$

S_f is the slope of the energy grade line through the contraction and can be calculated with the Manning formula. The length of the contraction is L, as shown on Figure 2.

Equation 1 gives the upstream depth as a function of the downstream depth and the flow through the contraction. The downstream depth and the flow are required to calculate the upstream depth.

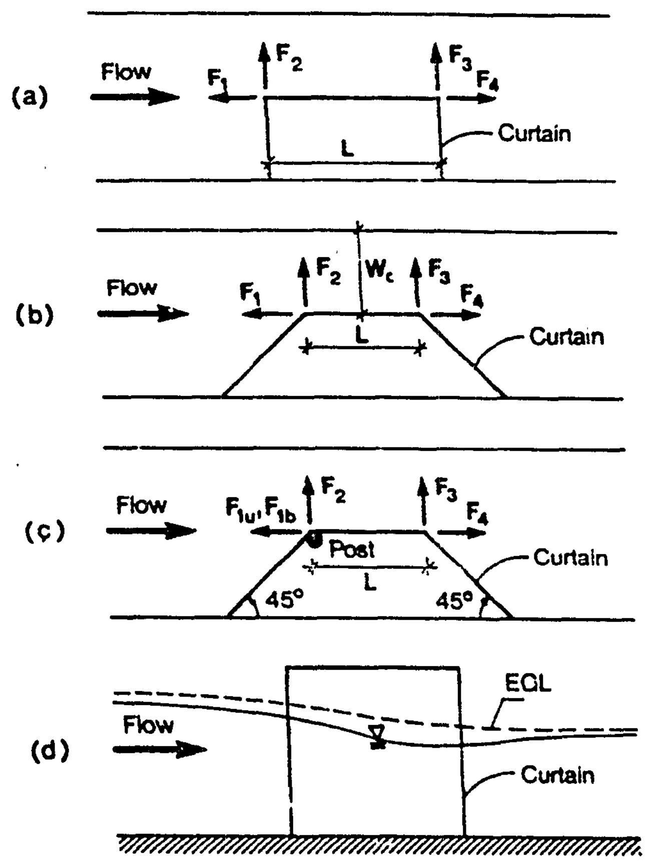


Figure 2 - Schematic of silt curtain layout

Next, the total force acting on the barrier can be calculated:

$$F = (0.5\ \gamma\ d_1^2\ w + \rho\ Q\ V_1) - (0.5\ \gamma\ d_2^2\ w + \rho\ Q\ V_2) \qquad (4)$$

where γ is the weight density of water and ρ is the mass density of water. In equations 1 and 4, the energy and momentum coefficients are ignored as their values are unknown and their effect on the outcome is likely to be small.

As an example, Figure 3 is a plot of the total force on a silt curtain in a channel 30.5 m (100 ft) wide, 3.05 m (10 ft) deep, 61 m (200 ft) long, with a rectangular curtain extending across 50% of the width of the channel. The vertical axis gives the total downstream force as a function of the velocity in the contraction. The figure serves to illustrate the magnitude of the total force.

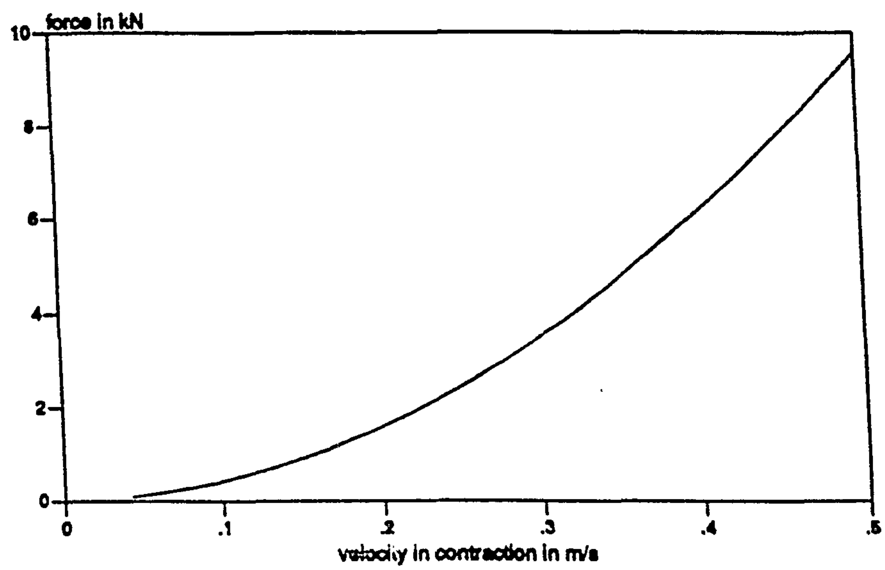


Figure 3 - Example of total force as a function of velocity

3.2 Modelling Silt Curtains

To verify the mathematical model and to obtain some insight into the hydraulic behaviour of silt curtains, a physical model of a silt curtain was constructed in the Hydraulics Laboratory at the University of Waterloo. The model consisted of a rectangular tank .60 m (2 ft) deep and 1.8 m (6 ft) wide, and 7.3 m (24 ft) long. The tank was connected to a constant head recirculating system with a flow capacity of approximately 0.1 cms (3.5 cfs). The flow was measured with a

V-notch weir. The forces were measured with spring scales having a maximum capacity of 250 grams (0.5 lb). Figure 4 is a photograph of the experimental setup.

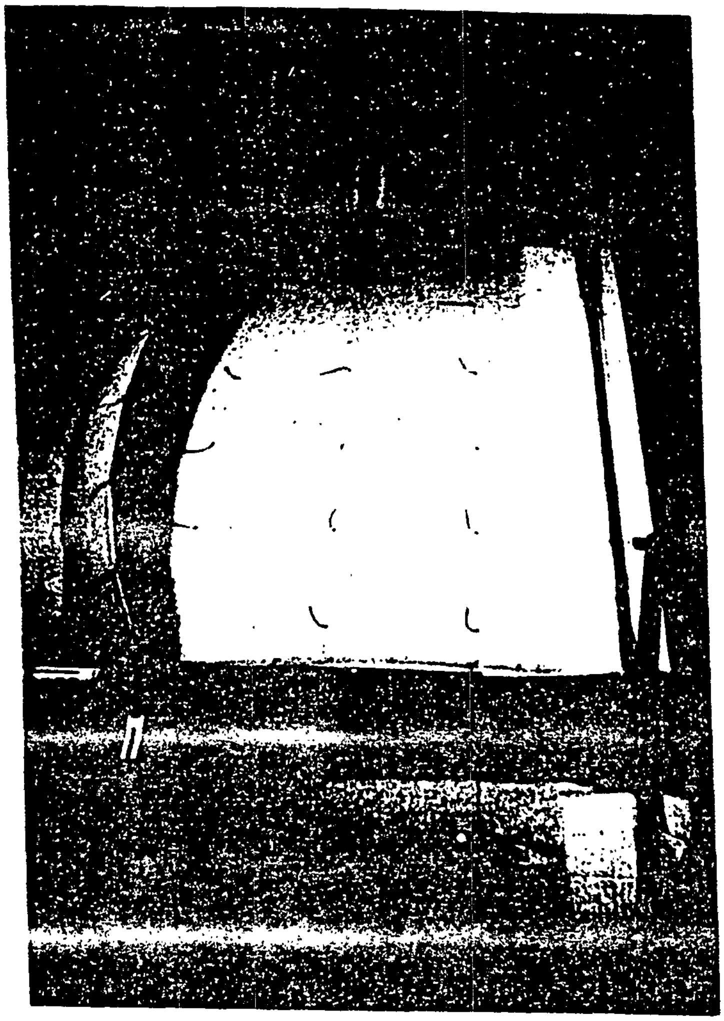


Figure 4 - Silt curtain model

For models involving free surface flow, the Froude modelling criterion is normally followed. Standard fluid mechanics textbooks provide a description of this technique. If the geometric scale is given as:

$$\lambda = \frac{\text{prototype length}}{\text{model length}} \tag{5}$$

then measured forces in the model are scaled up by λ^3, velocities are scaled up by $\lambda^{1/2}$, and the flow is scaled by $\lambda^{5/2}$. For instance, if the prototype to model ratio is 10 to 1, then model forces are scaled by 1000, the velocity is scaled up by 3.16, and the flow is scaled up by 316.

3.3 Experimental Programme

A total of 12 experiments were performed to compare the mathematical and physical models. The different configurations are listed in Table 1.

The conventional curtain has floats along the top and weights along the bottom. Often, the curtain height is the maximum depth expected along the planned location of the curtain plus approximately 10%. This causes the excess material to lie on the bottom of the river or lake which usually results in sediments piling on the lost curtain. When this occurs, it is difficult to recover the curtain when construction is completed or to move it to another location. It is nearly equally as impractical to tailor the curtain exactly to the bottom contours as the exact location of the curtain is not always known prior to its installation.

To prevent the accumulation of sediments on the curtain, a model curtain with two sets of flotation was manufactured. Figure 5 is a cross-section of the curtain. The lower float is attached below the water surface and serves to keep the lower portion of the curtain stretched vertically, but it does not have enough buoyancy to lift the chain. In fact, it should only have enough flotation to support the material below it. The top flotation supports the top section of the curtain and should have enough buoyancy to prevent overtopping and to support any downward pull due to anchors. Table 1 indicates the type of curtain by the number of floats used.

For each experiment, the curtain was installed as noted in Figure 2 and Table 1. The initial flow was set to approximately 6.2 ℓ/s (0.22 cfs) which resulted in a contraction velocity of approximately 0.02 m/s (0.065 ft/s). The flow was increased incrementally until the curtain was completely raised from the bottom as shown in Figure 6. Photographs were taken and the forces on each of the spring balances noted for each flow. Also, the size of the gap between the curtain and the bottom was noted in experiments c and i through ℓ.

Table 1 - Silt Curtain Experimental Programme

Experiment	Layout (Fig. #)	Depth d_2 mm (inches)	Curtain depth mm (inches)	Chain weight g/m (lbs/ft)	Type: Number of floats
a	2 a	280 (11)	305 (12)	39 (0.026)	1
b	2 a	280 (11)	305 (12)	39 (0.026)	1
c	2 a	457 (18)	508 (20)	33 (0.022)	1
d	2 a	457 (18)	508 (20)	39 (0.026)	1
e	2 a	457 (18)	508 (20)	65 (0.044)	1
f	2 a	457 (18)	508 (20)	79 (0.053)	1
g	2 a	381 (15)	508 (20)	79 (0.053)	2
h	2 b	457 (18)	508 (20)	33 (0.022)	1
i	2 b	457 (18)	508 (20)	65 (0.044)	1
j	2 b	381 (15)	508 (20)	33 (0.022)	2
k	2 b	381 (15)	508 (20)	79 (0.053)	2
ℓ	2 c	457 (18)	508 (20)	39 (0.026)	1 + post

3.4 Experimental Results

All the data measured in the laboratory was entered into a spreadsheet along with the mathematical model. The results for each experiment are plotted in Figures 7a through 7ℓ. This allows a direct comparison of the measured forces with the computed forces for each contraction velocity, depth and curtain layout. The square symbols show the net downstream force measured on the model curtain while the lines show the corresponding computed or theoretical force. On each Figure 7b through 7k, the contraction velocity where the curtain first lifted from the bottom is noted with an arrow. The experiments plotted in 7a and 7ℓ were for cases where the experiments were stopped before the curtain lifted.

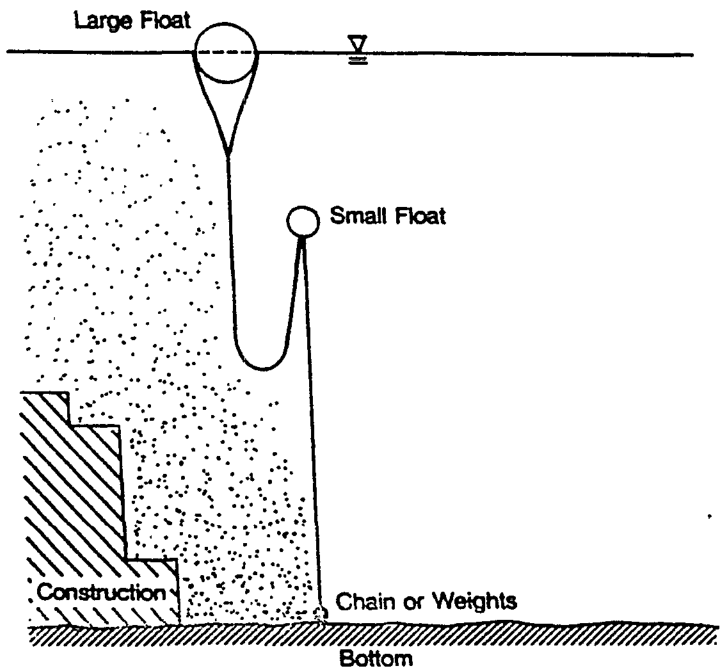


Figure 5 - Cross section of a 2-float curtain

Most experimental points fall close to the theoretical points. Since the mathematical model used to create the plot in Figure 3 was identical to the model used for Figure 7, the model can be used to estimate the total force that has to be contended with in an actual setup. Figure 3 shows that this total force is 3.6 kN (800 lbs) for a velocity in the constriction of approximately 0.3 m/s (1 ft/s). Since the channel modelled in Figure 3 is only 30.5 m (100 ft) wide, which is rather small, it can readily be understood that silt curtains supported only by floats and anchored at the corners are not a practical solution to silt containment in water flowing at velocities higher than 0.3 m/s (1 ft/sec) with respect to anchoring forces.

In most of the plots in Figure 7, the measured points fall close to the computed points at the lower end of the scale. However, at higher contraction velocities, the measured points are generally above the theoretical points. This happens when the curtain lifts at the upstream side and the downstream section of the curtain begins to act like a giant scoop. Such a situation is shown in Figure 6, which is a photograph of a model curtain with a large gap between the weighted bottom of the curtain and the channel floor. The effect of the lifting of the curtain on the overall downstream force is substantial. Before the curtain lifts at the upstream end, the curtain geometry adjusts itself to a streamlined shape with a low drag (or loss) coefficient. When the curtain lifts at the upstream side, the downstream part acts like a parachute, with a resultant high drag (or loss) coefficient. Hence the increase in force on the curtain.

In each of the plots, the contraction velocity at which the curtain begins to lift is noted by a vertical arrow. In experiment *1*, no lifting occurred and the lifting velocity was assumed to be the highest contraction velocity of the experiment. Experiment *1* was carried out to determine the effect of a rigid corner at the upstream end of the curtain. Figure 8 is a photograph of a model curtain with a vertical post inserted at the upstream corner. In this setup, scales were attached both to the bottom and the top of the post (Figure 2c). The advantage of the setup is that it leaves a contractor more room to work inside the enclosure or it allows a smaller enclosure for the same amount of working space. The post eliminates the tendency for the upstream corner of the curtain to become submerged under the downward load imposed by the anchor line, reduces the load on the upstream anchor, and prevents the downstream displacement of the bottom of the curtain.

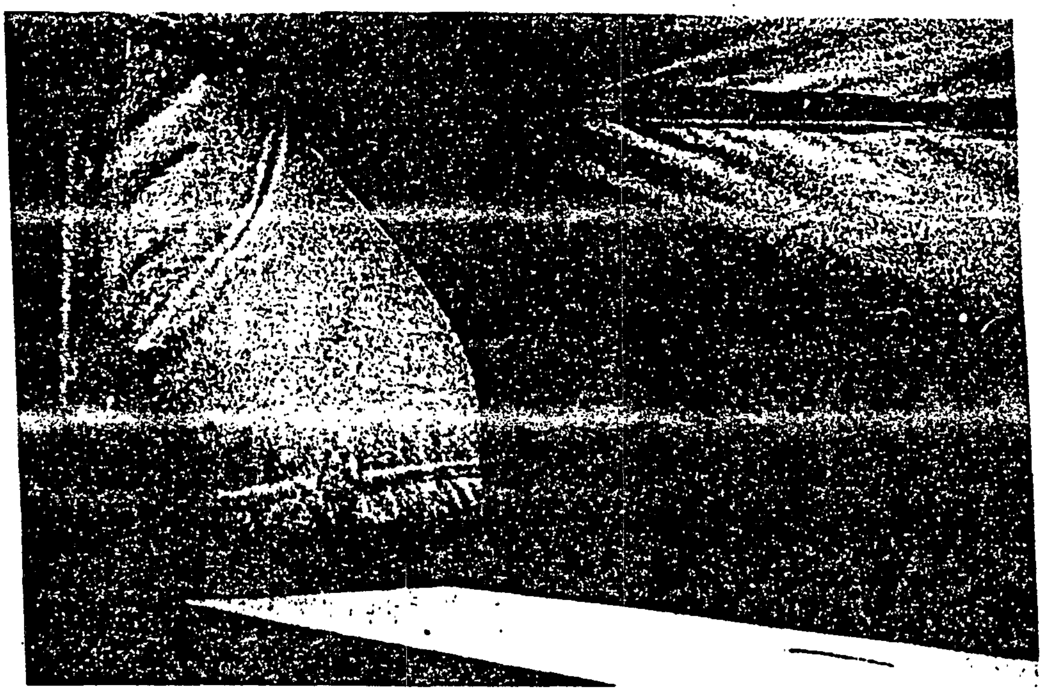
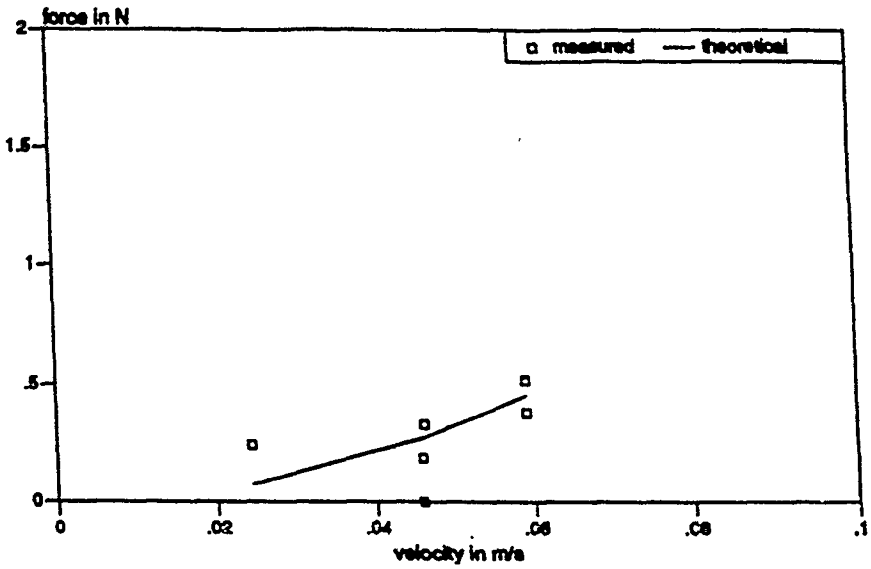


Figure 6 - Curtain which has lifted from the bottom

a) 305 mm curtain, tube floats, 39 g/m



b) 305 mm curtain, 6.4 mm floats, 39 g/m

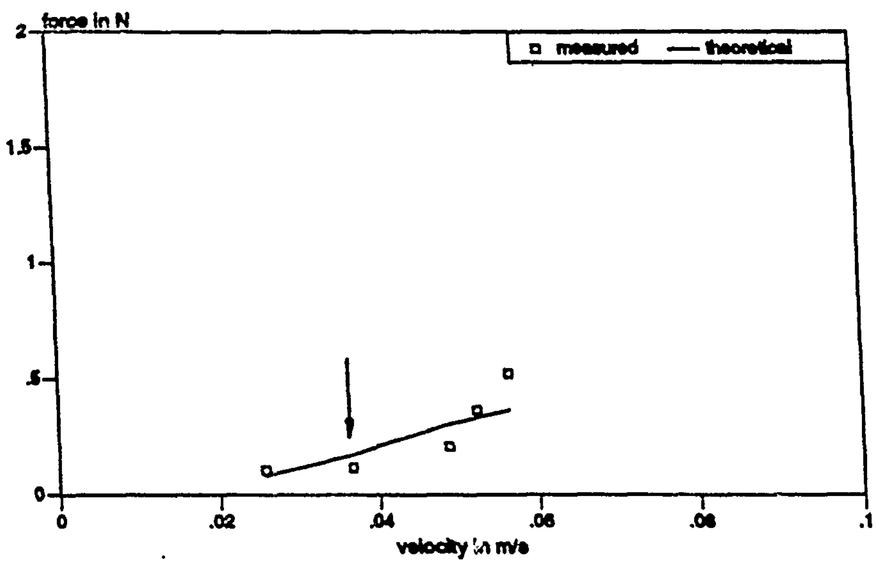
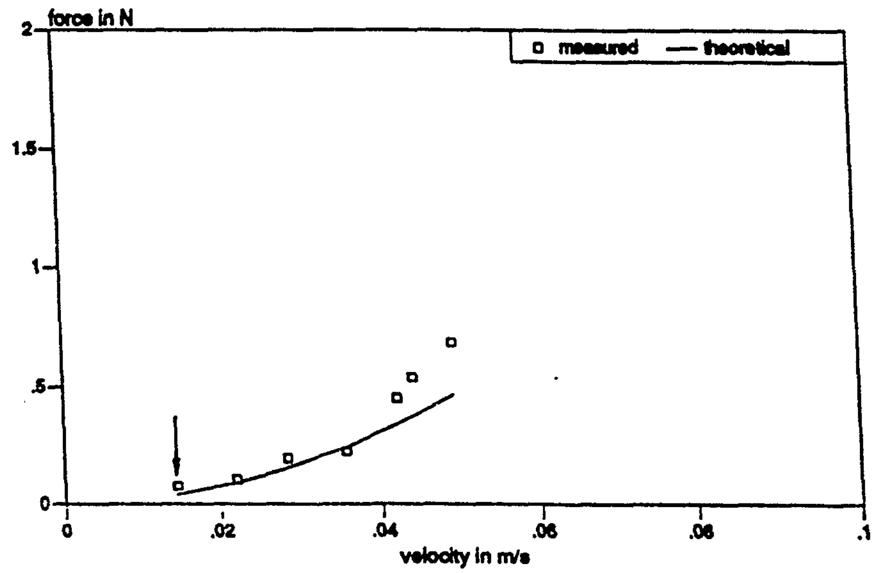


Figure 7 - Plots of force as a function of contraction velocity (model)

c) 508 mm curtain, 13 mm floats, 33 g/m



d) 508 mm curtain, 13 mm floats, 39 g/m

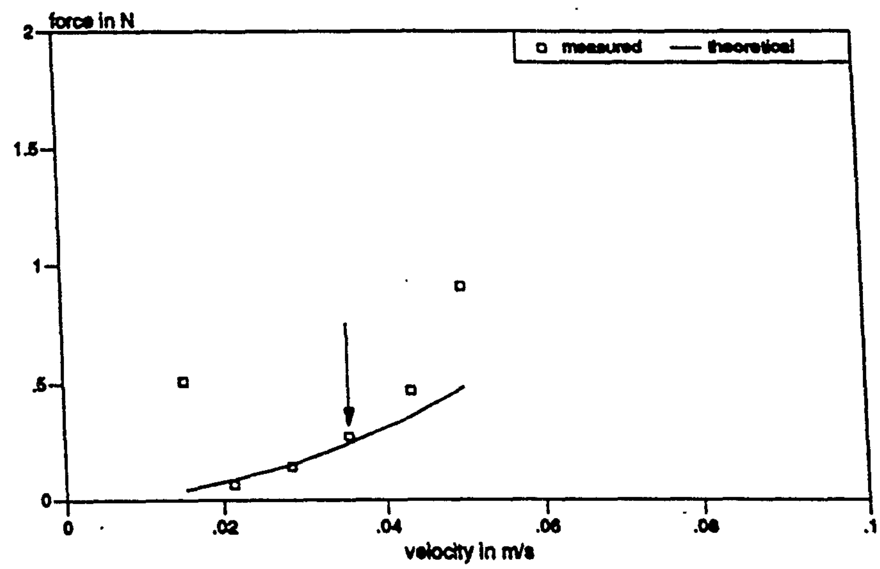
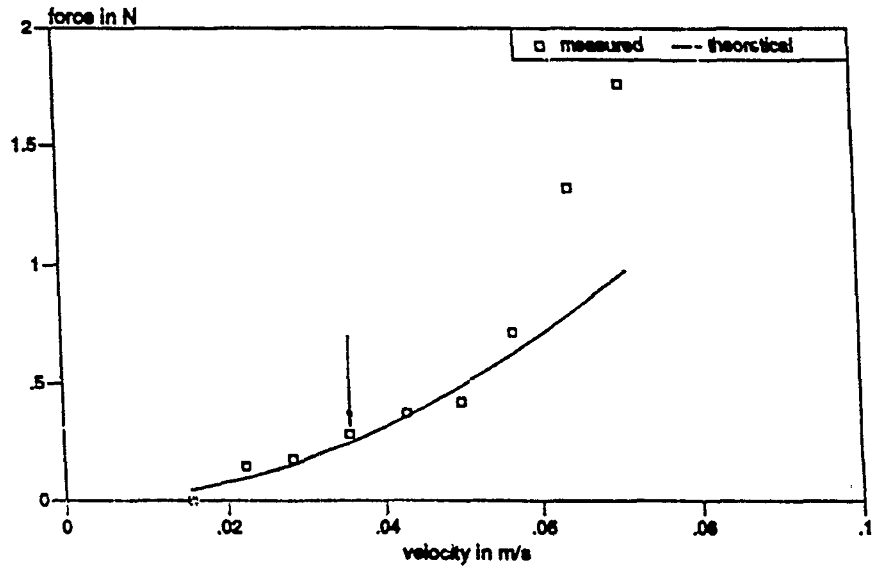


Figure 7 - Plots of force as a function of contraction velocity (model) (Cont.d)

e) 508 mm curtain, 13 mm floats, 65 g/m



f) 508 mm curtain, 13 mm floats, 79 g/m

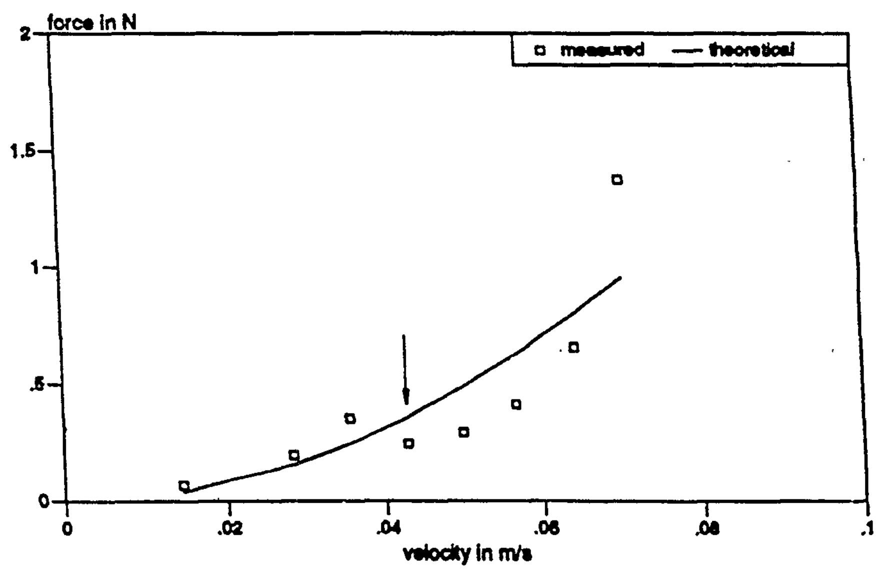
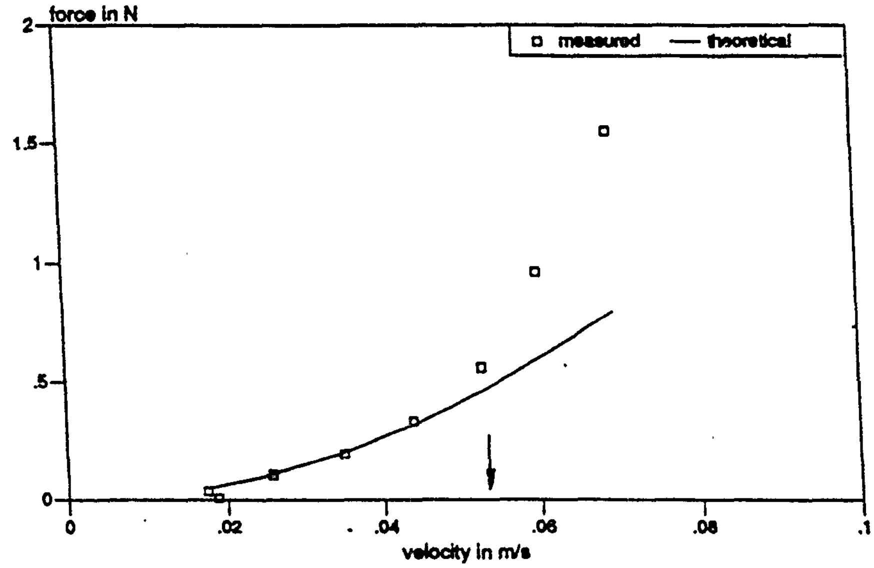


Figure 7 - Plots of force as a function of contraction velocity (model) (Cont.d)

g) 508 mm curtain, 2 floats, 79 g/m



h) 508 mm curtain, 13 mm floats, 33 g/m

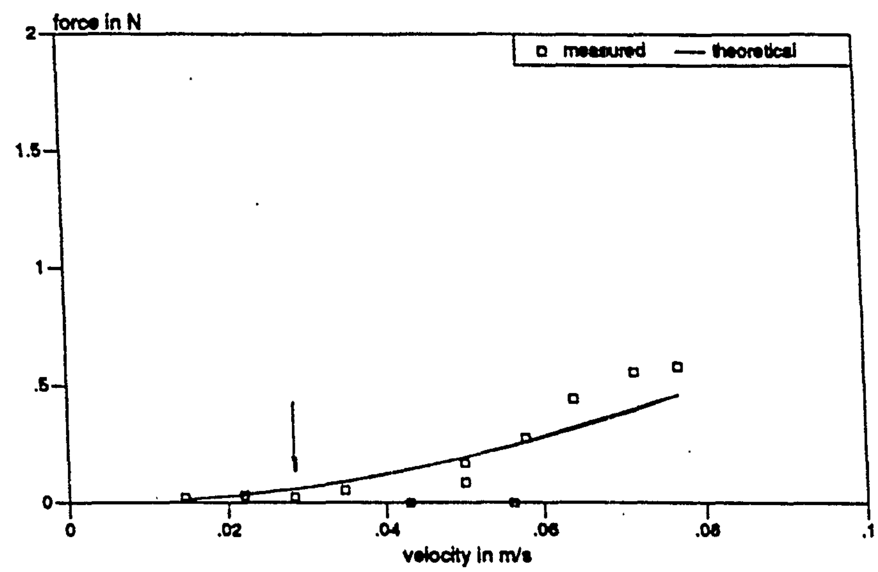


Figure 7 - Plots of force as a function of contraction velocity (model) (Cont.d)

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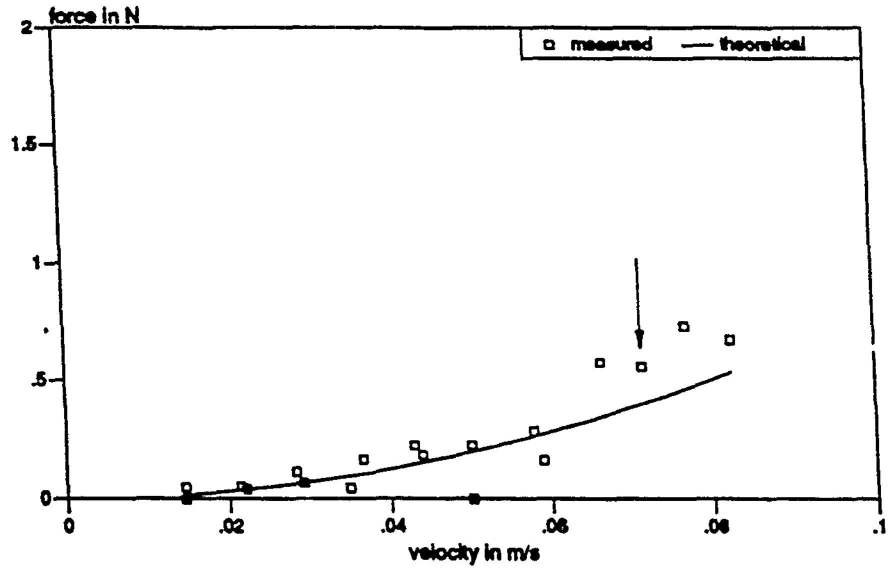
i) 508 mm curtain, 13 mm floats, 65 g/m



j) 508 mm curtain, 2 floats, 33 g/m

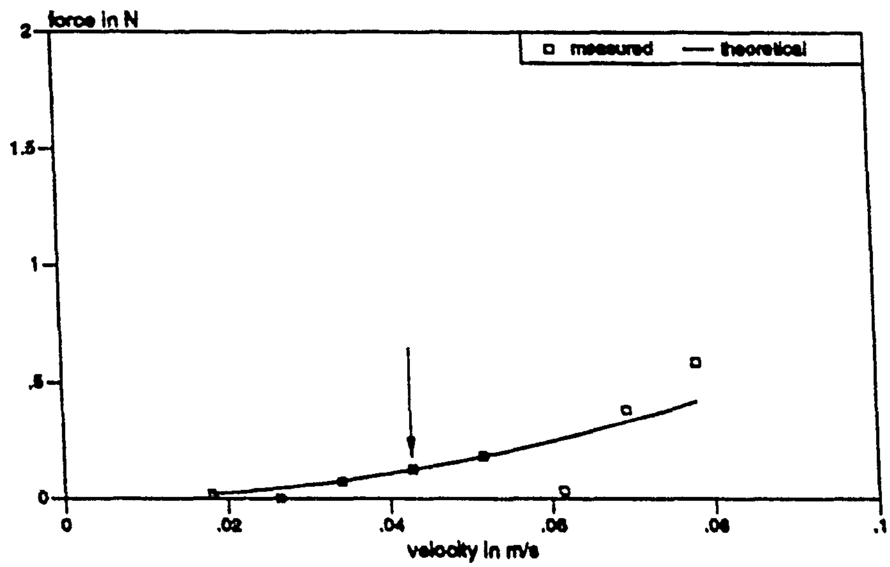
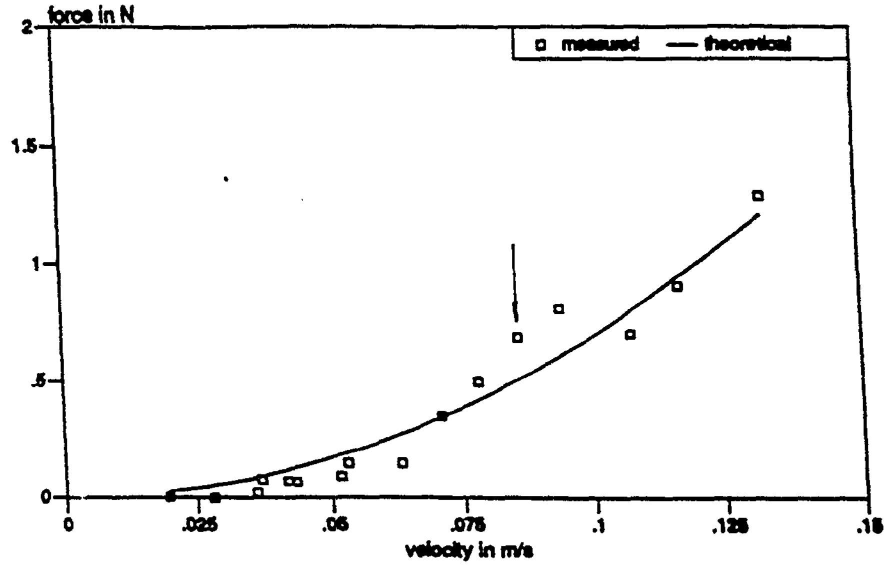


Figure 7 - Plots of force as a function of contraction velocity (model) (Cont'd)

k) 508 mm curtain, 2 floats, 79 g/m



l) 508 mm curtain, 13 mm floats, 39 g/m, post

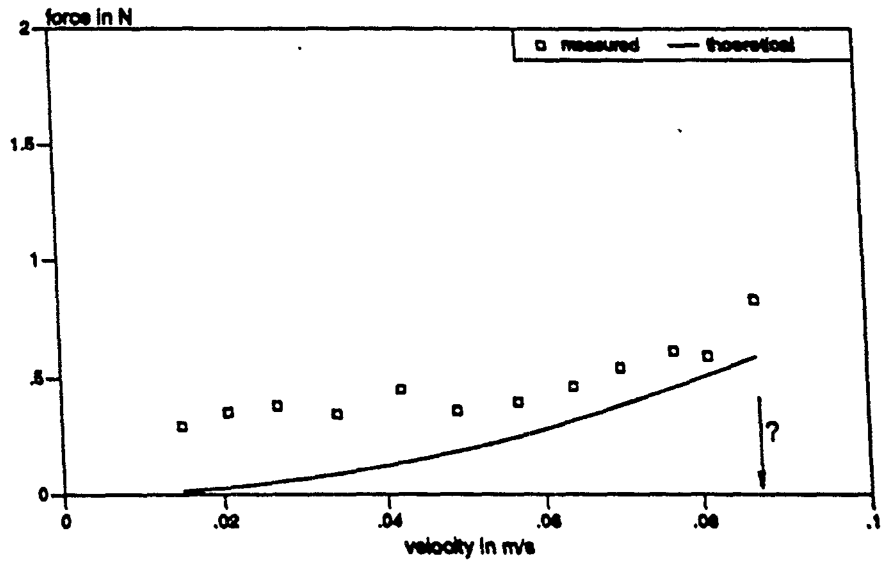


Figure 7 - Plots of force as a function of contraction velocity (model) (Cont'd)

However, the post also prevents the curtain from adjusting its shape to the current, thereby reducing its drag coefficient. This results in forces greater than the theoretical forces and greater than the forces measured on an unconstrained curtain. Figures 7h and 7i can be directly compared to Figure 7ℓ for the experimental points where lifting did not occur. For these points, the flow depth and the curtain shape were the same and the chain weight had no effect. The measured forces for the curtain with the post (Figure 7ℓ were substantially greater than the curtain without the post (Figures 7h and 7i).

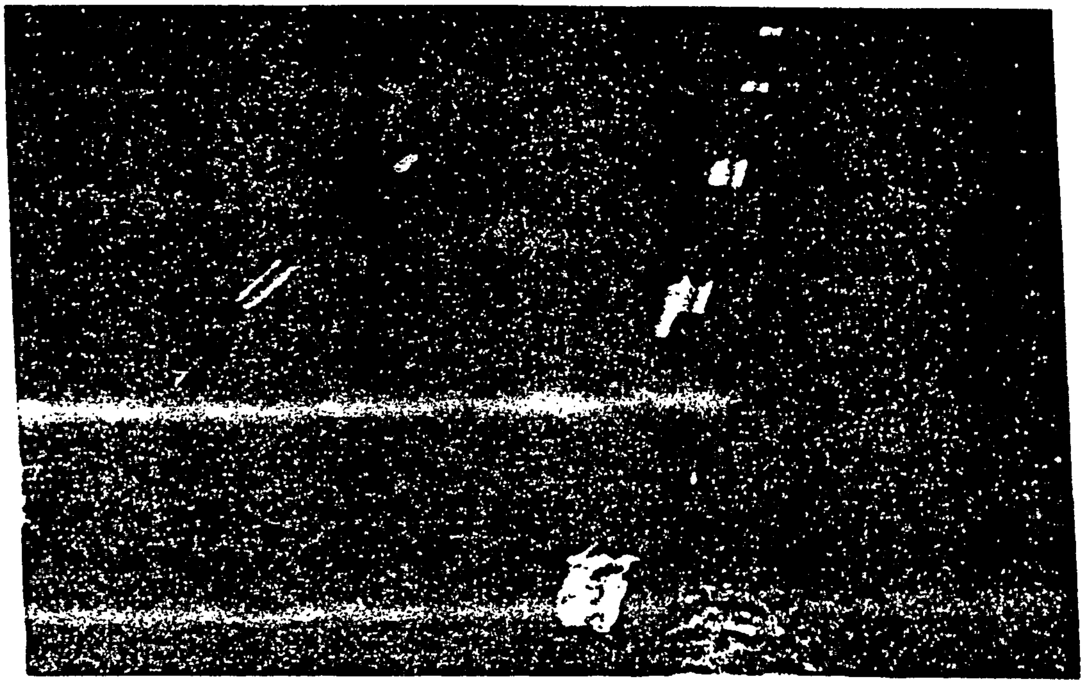


Figure 8 - Curtain supported by a corner post

Figure 9 gives the velocity in the contraction when the curtain first lifted, for each of the curtains modelled, as a function of the chain weighting down the skirt. The experiments (a-ℓ) are marked with each of the points on the graph and refer to the designation given in the first column of Table 1. The shape of the curtain is noted with each point - either 90° or 45°.

It was not possible to model the chain weight very well. In a 10 to 1 prototype to model ratio, the weight of the chain in the model should be 1/100ths of the prototyp hain weight. Thus if a 9.5 mm (3/8 in) chain having a weight of 1.5 kg/m (1 lb/ft) is used in the field, the model's chain should weigh 15 g/m (0.01 lbs/ft). The lightest chain used in the experiment was 33 g/m (0.022 lbs/ft), which would be correct for a 6.2 to 1 prototype to model ratio. However, Figure 9 does illustrate the effect of chain weight and curtain layout on the velocity of flow in the contraction when the curtain first begins to lift, thereby reducing its effectiveness in containing the silt laden water.

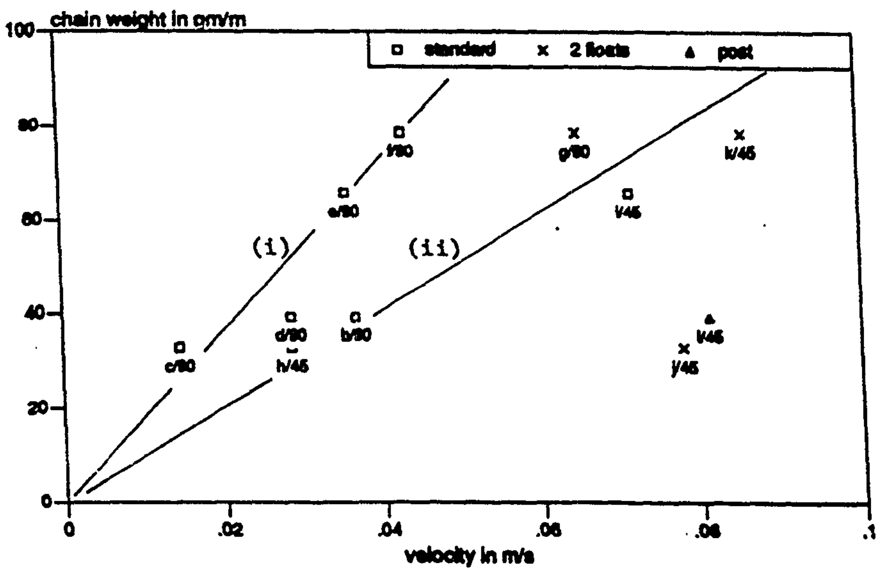


Figure 9 - Initiation of lifting

Figure 9 also serves to illustrate a number of additional points. Since the chain weight per unit length is given along the vertical axis, a set of points along a horizontal line allows a direct comparison of other curtain characteristics. First, and most important, an angle of approximately 45^{0} of the curtain to the flow roughly doubles the velocity when the curtain first lifts for a given chain weight with a standard curtain, i.e., one float. The insertion of a post at the upstream corner at least doubles the lifting velocity. In the experiment with the corner post, the curtain did not lift at all before the experiment was halted. Figure 9 does not show that the insertion of a post and the angling of the curtain to the flow have a multiplicative effect, i.e. using both a post and angling the curtain does not increase the lifting velocity by a factor of four. It may do so, but tests were not carried out to ascertain this possibility.

Experiments b and d compare the lifting velocity as a function of the height of the curtain, with the chain weight the same. Keeping in mind that there are only two points on the graph, it shows that the lifting velocity is higher for a smaller depth. The lifting velocity is reduced by about 25% for a 63% increase in flow depth.

Finally, the figure shows that the use of two floats, one at the surface and one submerged, as shown in Figure 5, also increased the lifting velocity. The effect appears more pronounced for the lighter chain weight. While this configuration was tried with the intent to simply keep the excess skirt from lying on the bottom where the bottom elevation varies, and thus keep sediments from accumulating on the skirt, it also appears to have value in terms of keeping the curtain from lifting. The loading on the anchors is also reduced because of the ability of the curtain to take on a low drag shape. However, because much of the curtain material is unconstrained, more room is required for its installation.

3.5 Discussion and Summary of the Experimental Work

A total of 12 different curtain configurations were tested in the Hydraulics Laboratory at the University of Waterloo. Obviously, the number of combinations of layout, weighting and float sizing is unlimited and many more experiments could be run before more confidence can be had in the conclusions. However, the two lines drawn on Figure 9 show the lifting velocity, which is the velocity in the contraction when the curtain first begins to lift, is linearly related to the chain weight in the bottom sleeve. Line (i) is derived from experiments c, e, and f, for which only the chain weight differed. Similarly, line (ii) is fitted (by eye) to experiments h and i.

The lines can be used to extrapolate downward to determine the lifting velocity if the chain had been modelled properly in a 10:1 model, i.e., a model chain weight of 15 g/m (0.01 lbs/ft). The diagram indicates that the lifting velocities would be roughly 8 and 16 mm/s (0.025 and 0.05 ft/s) for the rectangular and angled shape, respectively. For the prototype, this would mean a constriction velocity of only .025 and .05 m/s (0.08 and 0.16 ft/s or 0.05 and 0.1 knots), respectively. These numbers are obviously very small but they agree very well with Barnard's (1978) recommendations as noted in Section 2.1. It points out the need for heavier chain (or double chain), the need to angle the curtain to the flow, and the use of posts at the upstream corner. It also illustrates that free floating curtains have a very limited range of applicability.

American Marine Inc. (undated) contends that it is seldom practical to extend a curtain below 3 to 3.6 m (10 to 12 ft), even in deep water, in currents of one knot. Based on the model studies for this research, a one knot upper limit for the application of a free floating curtain seems optimistic. However, the use of a post or double floats, as shown by experiments ℓ and j respectively, or the use of a centre tension cable as suggested by American Marine Inc., can extend the range of application. A lifting velocity of 0.075 m/s (0.25 ft/s) in the model (Figure 9) represents a lifting velocity of .25 m/s (0.8 ft/s or 0.5 knots) in a 10 times prototype.

4. CONCLUSIONS

During the past two decades, silt curtain applications have prevented silt-laden water from directly contaminating surrounding water bodies. However, many cases exist where catastrophic failure occurred. These failures could have been avoided by ensuring proper design, installation, and maintenance. A search of the literature did not reveal very much quantitative information to aid in the design of silt curtains. There was no mathematical model to determine whether a silt curtain of given dimensions, chain weight, and flotation size would be adequate in a particular application.

This study has provided a simple mathematical model which can estimate the overall forces acting on a curtain, and it has provided some general indication on the relative effect of shape and weighting. The experience of practitioners, as stated in the literature, and as related in personal contacts, is born out in this study. It is not realistic that free floating silt curtains can be used when the velocity in the constriction created is in excess of .15 m/s (0.5 ft/s or 0.3 knots). In fact, this velocity is above that indicated by the model study.

In view of the very severe constraints on the use of silt curtains imposed by hydraulic (and wind) loading on silt curtains, it is obvious that the site for a proposed silt curtain should be carefully monitored prior to the design and installation of a curtain under similar anticipated meteorological conditions. Also, an investigation of the river or lake bottom should provide data on which to base anchoring specifications. Such pre-engineering surveys are essential if silt curtains are to be used successfully.

5. RECOMMENDATIONS

5.1 Recommendations for the Design of Silt Curtains

The foregoing analysis points to an upper limit to the velocity of flow in a constriction caused by a free floating curtain of .15 m/s (0.5 ft/s or 0.3 knots). This points out the need for a thorough field study prior to the design and installation of a silt barrier. Velocities and water levels should be monitored at the proposed site to obtain a representative period of flow history to allow a proper assessment of the feasibility of installing a silt curtain at the site.

The design of a silt curtain is of a very technical nature.. It is recommended that silt curtains be designed by engineers conversant with fluid mechanics and hydraulic principles. The curtains should be designed for the specific conditions expected at a proposed curtain location. The mathematical model and the graphs provided in this report may be used as a guide, keeping in mind the approximate nature of the model involved.

5.2 Recommendations for Further Research

As noted above, the findings of this study confirmed much of what has been written about silt curtains. Still, many questions remain. A mathematical model to indicate in more detail how a curtain will behave under specific site conditions is needed. A simple model providing only the overall force acting on a curtain was developed as a result of this study. It was validated by a number of experiments. The model was tested for a very limited range of conditions and for very simple geometries. This model is an important first step towards the development of a more detailed model in that it shows the feasibility of applying hydraulic and mathematical models for the determination of hydraulic forces on the curtain. It is recommended that this study be extended in the following ways:

1. Carry out additional experiments to test a greater number of combinations of curtain layout, flotation size, weighting, anchoring, and contraction ratios.

2. Improve the experimental setup to measure additional forces, for instance at the attachment points on the banks.

3. Extend the mathematical model to include irregular cross-sections.

4. Develop a mathematical model to predict when a curtain will begin to lift.

5. Verify the mathematical models with direct observation of silt curtain performance in the field. In the past, measurements have been made of turbidity inside and outside the curtains. No data seems to exist on the degree of lifting or anchoring forces.

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