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INVESTIGATION OF DEBRIS AND SAFETY BOOM ALTERNATIVES FOR BUREAU OF RECLAMATION USE

February 1992

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16. ABSTRACT

Bureau of Reclamation projects make extensive use of debris and safety booms constructed from large diameter timber boom sticks. The service life of these boom sticks varies from 10 to 20 years, depending on their use, timber quality, timber species, and environmental factors. Recent difficulties in obtaining replacement boom sticks and the high cost of available replacements prompted an investigation into the possible use of manmade materials. This investigation consisted of a literature review, site visit to the Grand Coulee Project, and establishing contacts with other water resources organizations in the Western United States who have experience in the use of manmade materials for debris and safety booms. Several promising boom types were identified, including log-type booms constructed from steel pipe or polyethylene culvert sections, or cabled float lines using floats constructed from a variety of durable plastics.

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by

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INTRODUCTION

Debris control facilities are a common feature of many Bureau of Reclamation (Reclamation) projects. Often, the first line of defense in the debris control system is a boom designed to retain floating debris before it reaches the trashracks or screens. In addition, booms have been used to prevent public access to spillways, intakes, and other hazardous areas of water resources projects. Traditionally, these booms have been constructed from large logs, and are similar to the designs used for the control of commercial timber floated downriver to processing locations. Thus, the term *log booms* has been applied to most similar structures. In this report, booms intended for the control of debris will be referred to by the general term *debris booms*. Booms that are intended to prevent public access to hazardous areas will be referred to as *safety booms*.

The most common construction material for booms on Reclamation projects has been timber. Timber has been favored in the past due to its wide availability and simplicity of construction and handling. The type of wood used generally depends on local availability. Sizes of boom sticks vary with the application and locale, but are usually in the range of 12 to 24 inches in diameter and 20 to 40 ft long.

Recently, concerns have been raised over the use of timber for debris and safety booms, due to limited durability, limited availability, and increasing replacement cost. In general, boom sticks used in low stress applications, such as safety barriers, can be expected to last about 20 years, while sticks used for heavy debris control may last only 10 years. In addition, the cost of timber has risen rapidly in recent years. Environmental concerns about the harvesting of old growth timber have reduced the supply of available timber for large boom sticks, and the limited supply is highly sought by the lumber industry. Faced with this combination of problems, Reclamation projects are now seeking alternatives to the traditional timber boom stick.

A research program was established to identify alternatives to timber boom sticks and to assess the suitability of those alternatives for use on Reclamation projects. The program was conducted in conjunction with WATER (Water Technology and Environmental Research) Program NM022, Research and Development for Better Trash Screening and Cleaning Devices. The work thus far has consisted of a literature search, an informal survey of current Reclamation and non-Reclamation practice, and a site visit to the Grand Coulee Project.

CONCLUSIONS

- The study identified several alternative designs and materials for safety and debris booms. Based on the experiences of Reclamation and other agencies, many of these alternatives have the potential for improved performance, greater durability, and reduced operation and maintenance costs when compared to the timber booms presently used.

- Some alternative safety boom designs have lower initial costs than the timber booms presently being used. Despite the high and rising cost of timber, none of the debris boom alternatives identified thus far have lower initial costs. Thus, reduction of operation and maintenance costs and extended lifespan will have to be considered to make these alternatives economical.

- Promising safety barrier designs which have been identified include cable barriers with buoys or floats, and modified debris boom-type barriers constructed from manmade materials. Possible shell materials for safety barriers include steel, aluminum, polyethylene, fiberglass, and a variety of durable plastics. Flotation may be provided by polyurethane or polystyrene foam.

- The most promising alternatives identified for use in debris deflection or debris retention are pipe booms with foam flotation, such as the steel booms used by PG&E (Pacific Gas and Electric Company). Several other debris boom designs, such as net booms and fence booms also may be useful for specialized applications.

- The implementation of alternate boom designs should be encouraged at sites experiencing problems with existing debris control or safety systems. The performance, durability, and operation and maintenance requirements of these alternatives should be monitored closely to provide data which may be used to further refine future designs.

LITERATURE SEARCH

A literature search was conducted to identify information on traditional debris and safety boom designs, and designs utilizing manmade materials. The literature search included keyword searches of major engineering data bases. Information on debris booms was obtained from several sources, many related to the commercial pulpwood industry. The literature search revealed very little information on safety booms. The majority of information on safety booms was obtained by informal contacts with water resource organizations in the western United States, and is discussed in the section titled *Current Practice*. Similarly, the literature search turned up little information on the use of manmade materials for either debris or safety booms. Again, information obtained from contacts with other water resource organizations is included in the *Current Practice* section.

Safety Booms

A search of the available literature revealed little specific information on the design or selection of safety booms. The majority of safety booms on Reclamation projects are modifications of typical debris boom designs.

The most useful information obtained in the literature search is a collection of safety guidelines published by the FERC (Federal Energy Regulatory Commission) (1990), for use by their Division of Dam Safety and Inspections. The FERC is responsible for licensing of non-Federal hydropower projects, and in this capacity reviews safety programs for projects under its jurisdiction. The publication described above identifies typical hazards encountered at hydropower projects, the operations that can contribute to safety hazards, and the devices and programs that may be used to reduce or eliminate such hazards. Some of the hazards identified for which safety booms are applicable are spillways, intakes, tailrace areas, and low head and diversion dams. The operations that may contribute most to hazardous conditions are peaking power operations and remote-controlled facilities. Any of these hazards may be encountered at Reclamation hydropower facilities or pumping plants, or on water distribution systems.

A typical public safety program may include any or all of the following items: an education and public information program; visual and audible warning devices; physical restraining devices; escape devices; and operating procedures that improve public safety. Safety booms may address several of these issues by providing visual warning, physical restraint, and an escape mechanism. The FERC makes no distinction among the various types of possible safety booms, stating that:

> "Any type of barrier, such as trash booms, debris deflector booms, log booms, and specially designed barriers that have been placed upstream of dams may be considered a satisfactory boat restraining barrier."

The FERC does suggest that existing barriers can be made more effective by increasing their visibility through the use of nighttime lighting and colored floats. International orange, or an alternating pattern of international orange and white, is preferred. In addition, specially designed floats which minimize debris accumulation will improve the effectiveness of safety barriers.

Debris Booms

Much of the available literature on debris booms focuses on the control and containment of commercial pulpwood products in transit to processing locations. Both in the pulpwood industry and in Reclamation applications, two primary types of debris booms are used. *Glance booms* are used to guide or deflect debris away from an undesirable area, or into a designated collection area, while *retention booms* are used to hold debris in a collection area until it may be disposed of. Debris retention booms may also be used in the active collection of debris from lakes and reservoirs, although this is not common at Reclamation projects.

Debris Boom Configurations. - An excellent summary of various floating debris control techniques is provided in a two-volume report by Perham (1987; 1988). The second volume presents 16 different configurations of booms that are in use or have been described in the literature. The simplest design is a string of single logs connected by a chain, ring, and toggle. This design is typical of the log booms in use at Reclamation projects, and may be used for either deflection or retention of debris. In this design, the boom sticks and connections carry the tensile load in the boom. A modification of this design is to attach boom sticks to a continuous wire rope that carries the tensile load.

Variations of glance boom designs are numerous; several are presented by Perham (1988). Glance booms are generally provided with an upstream smooth face to facilitate the sliding of debris along the boom. The upstream face may be vertical or tipped slightly back to keep debris from slipping under the boom. Some designs also have a horizontal lip at the bottom of the upstream face. The lip reduces the undertow at the upstream face of the boom, thus reducing the amount of debris escaping below the boom. Glance booms can be anchored to one shore and then maintained in place in the current with fins or rudders, or may be anchored at intermediate points along their length using pilings or submerged anchors.

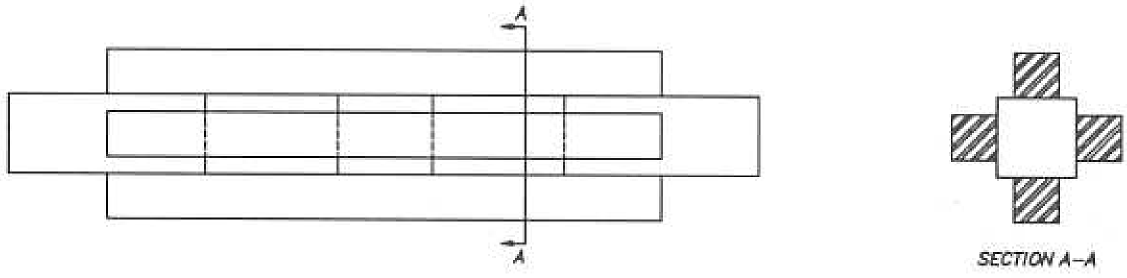

Figure 1. - Core (Bathurst) boom stick used to retain heavy debris loads.

Kennedy and Lazier (1965) describe a number of additional boom types, many of which were tested in subsequent hydraulic model tests. For retention of extremely heavy debris loads, deep booms built up from sawn lumber may be used. One specialized deep boom design is the core boom, or Bathurst boom, shown in figure 1. This boom combines large depth with relatively light weight due to the hollow core.

Another boom design intended for control of extremely heavy debris loads is the cable, or net boom. This boom consists of a net of two or three cables and cross ties hung from a flotation member that may be timber or any other suitable material. The main advantage of such a boom is its extremely high strength. Intermediate anchors required for typical timber booms can usually be eliminated due to the high tensile strength of the cable. The greatest disadvantage may be the difficulty of cleaning the boom.

Flat booms are constructed from sawn lumber and are designed to provide pedestrian access to the debris or pulpwood jam. Model tests by Kennedy and Lazier (1965), described below, showed that these booms have a relatively low debris retention capacity. However, their performance can be improved by installing fenceposts along the upstream edge which extend below the bottom of the boom section. The fenceposts may also be extended above the top surface of the boom in areas where wind and waves tend to wash debris over the boom. Such booms are generally referred to as fence booms.

The literature contains few references to debris boom designs using manmade materials. One conceptual design presented by Perham (1988) consists of concrete box sections filled with polystyrene and clipped to a load-carrying wire rope. This design also incorporates scrap tires as bumpers between the flotation members. This design has never been constructed.

Shawinigan Consultants (1982) conducted a survey of hydropower industry practice in Canada, the United States, and Europe, to determine the most prevalent boom types. The survey showed that Canadian utilities use timber booms almost exclusively. Timber booms are also the most common in the United States, but steel pipe booms with interior foam flotation were also used by several organizations. In following up on references made by Creager and Justin (1950) to locations using timber and steel pipe booms, the survey found that the steel booms were still in service, while many of the locations using timber booms were in the process of switching to steel pipe booms.

Design Forces. - The major forces acting on retention and glance booms are water friction drag, wind friction drag, water form drag, shore reactions, and the reactions of piers or anchors. Additional forces to be considered are wind form drag, gravitational force components along the water surface slope, and impact forces. Wind form drag is generally negligible in comparison with wind friction drag, due to the low projected height of the log jam. Impact forces may sometimes be significant, such as for ice booms that are required to retain large sheets of ice which have broken free and move downstream as a single unit. Shawinigan Consultants (1982) summarized the various equations and techniques which have been proposed for estimating these forces for debris and ice retention booms.

The most significant loading on a debris retention boom comes from the friction drag of water against the underside of the log jam. Kennedy (1957), using data from field measurements and hydraulic model tests of pulpwood jams, presented a nomograph that can be used to estimate the sum of the water friction, water form drag, and gravitational forces. The water friction drag was estimated from the von Karman/Prandtl equation. The final result is dependent on the length and depth of the jam, the depth of flow, and the Froude number. Techniques for estimating the length, depth, and roughness of the jam for 4-ft-long pulpwood sticks were presented for use with the nomograph. Estimation of these quantities requires knowledge of the flow velocity below the jam, and the total quantity of pulpwood contained in the jam. The nomograph was found to give reasonable agreement with forces measured in the field. No evidence was found in the literature of any extension of this technique for use with other sizes and types of debris.

Kennedy (1962) presented techniques for estimating the wind friction drag and the forces exerted by the shore and piers. At locations where water levels may rise and fall significantly, the shore reactions should be neglected in determining the design load for the boom; a rising water level may lift the jam off of the shore, thereby temporarily transferring load to the boom.

Once the forces acting on the boom are determined, the tensile load in the boom and connections may be estimated by assuming a deflected shape for the boom under load. This shape is generally assumed to be parabolic.

Boom Performance. - The most extensive laboratory tests of comparative debris boom performance were commissioned by the Canadian Electrical Association (Kennedy and Lazier, 1965). Scale model hydraulic laboratory tests were conducted to compare various designs of debris retention and debris deflection booms. In addition, Kennedy (1965) reported on tests that examined the performance of retention booms subjected to waves.

Debris boom designs tested at a 1:20 scale by Kennedy and Lazier (1965) included:

- 8-, 20-, and 28-in-diameter round booms
- Flat booms made up of one to three sawn lumber sections 1 ft on a side
- Several designs of deep booms with depths of 18 to 36 in
- Fence booms with fence depths of 33 in
- Net booms with depths ranging from 40 to 60 in

Scale models of 8-in-diameter by 4-ft-long pulpwood logs were introduced into the flume, and after the jam had stabilized, the percentage of logs which had passed the boom was determined. The results were presented as the percentage of logs lost as a function of the stream velocity in the model. Three major service ratings were developed: severe, where the velocity of the current is 3.0 to 4.5 ft/s; heavy, where the velocity is 1.5 to 3.0 ft/s; and light, where the velocity is less than 1.5 ft/s. Each boom design was assigned one of the service ratings.

The various net boom designs were by far the most effective, with all but one assigned a severe service rating. One deep boom design also received a severe service rating. Booms assigned the heavy rating included the various designs of deep booms and fence booms, and one of the net boom designs. The 3-ft-wide flat boom and the 18- and 28-in-diameter round booms were also assigned a heavy service rating. The 2- and 1-ft-wide booms and the 8-in-diameter round boom were the least effective booms, receiving only a light service rating.

These tests also confirmed that once a large jam has formed, the boom has little effect on the retention capability and is only relied upon for strength in holding the jam. When a large jam was established in the model, and more logs were subsequently added, the percentage of logs lost decreased with each addition of logs. This may be explained by observing the process of jam formation in a flume with plexiglas walls. The first logs to arrive at the boom collect in a single layer at the water surface. As more logs accumulate behind the boom, the water drag on the debris increases until the layer buckles and the jam becomes deeper. A few loose logs near the front of the jam may be lost at this point, but most logs will be held securely in a tangled jam. Subsequent logs reaching the head of the jam are likely to become lodged in the fabric of the jam before they reach the boom itself. Thus, the jam takes over the job of retaining debris, while the boom is only required to hold the jam in place (Kennedy, 1965).

Kennedy and Lazier (1965) also conducted similar tests of glance booms, measuring the percentage of logs that escaped past the glance boom at various angles of incidence and flow velocities. The booms tested were similar to a flat boom with a prototype section size of 15 by 48 in. These booms were tested with and without a horizontal lip installed below the water surface on the upstream face of the boom. The addition of the horizontal lip reduced the undertow near the face of the boom (fig. 2) and thus reduced the amount of debris that escaped under the boom. The tests evaluated the effectiveness of various lip widths and depths. The tests showed that increasing the depth and width of the lip improved the performance of the boom in nearly all cases. The disadvantage of a deep, wide lip is that a large overturning moment will be developed that may cause the boom stick to tilt or overturn. An outrigger may be required to maintain the stability of the boom stick.

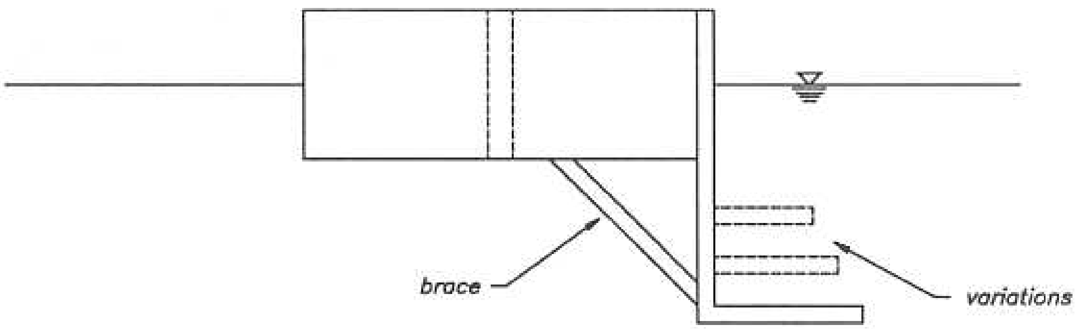

Figure 2. - Typical glance boom with horizontal lip.

Kennedy (1965) also conducted a series of laboratory tests to evaluate the performance of retention booms subjected to wave motion. The most effective boom types were a modified core boom, and specialized net booms. The modified core boom consisted of a central flotation member surrounded by stringers which extended to the end of the boom. This boom offers a large barrier both above and below the water surface. Extending the stringers to the end of the boom greatly reduced the loss of timber over and under the boom near the connections. The performance of the net boom designs in waves was quite sensitive to the stiffness of the net cables; soft cables were required to allow the boom to effectively follow the water surface.

These tests also showed that the specific gravity of the boom sticks and their resulting natural oscillation frequency had a significant effect on the results. The natural oscillation period of an independently floating boom stick can be calculated from (Kennedy, 1965):

$$T=2\pi\sqrt{\frac{W}{g\gamma A}}$$

where:

T	=	period of vertical oscillation
g	=	acceleration of gravity
W	=	weight of boom stick
γ	=	unit weight of water
A	=	cross sectional area of the stick at the water line

The natural oscillation period should be much shorter than the wave period so that the boom will easily follow the water surface. This effect was observed in the wave tests.

CURRENT PRACTICE

Currently, the most common boom used on Reclamation projects is a simple string of round timber boom sticks. These booms are used for debris diversion, debris retention, and safety barriers, with little variation. Reclamation projects have also had some experience with safety booms and safety barriers constructed from manmade materials. Other organizations have experience with manmade materials in debris applications.

Timber Booms

Reclamation and others have a large body of experience in the use of timber for boom sticks. The durability of timber boom sticks based on this experience is estimated at 10 years for high stress applications such as debris retention, and 20 years in low stress applications such as safety barriers. The greatest factor affecting the durability of timber is waterlogging. There are several detrimental effects of waterlogging. First, as logs become waterlogged and float lower in the water, they are less visible and less effective as safety barriers. Also, low floating logs are less effective for debris applications because wind and waves can more easily push debris over the top of the logs. Also, the increase in the weight of the boom stick causes the natural oscillation period to increase. This further decreases the effectiveness of the boom in waves. Finally, as the logs become waterlogged and begin to deteriorate, their strength decreases. Failures generally occur by splitting out of the ends of the logs at the holes where connecting hardware is attached.

Some relief from waterlogging problems can be obtained by periodically removing the logs from service and allowing them to dry. However, this often increases the chance of failures by splitting, because the wood tends to crack as it dries. This may be an effective remedy in cases where the timber is not relied upon for strength, such as in booms with a steel cable that carries the tensile load. Treatment of timbers with products such as creosote or penta is generally not feasible because the specific gravity of the treated timbers is too high, and the timbers sink or float very low in the water.

Timber Safety Booms. - A typical example of the timber safety booms encountered on most Reclamation projects can be seen at the Grand Coulee Project. The standard boom stick is an untreated 14- to 24-in-diameter spruce or fir log, about 33 ft in length. Holes are drilled through each end and the logs are connected end-to-end with chains and toggles to form long strings. To improve the durability of the connection, plate steel flanges are installed around the holes. This boom stick design is shown in figure 3.

On the Grand Coulee Project, a mile-long timber boom spans Roosevelt Lake, about 1/2 mile upstream of Grand Coulee Dam. This boom originally was a double string of boom sticks and provided debris control to protect the overflow spillway and power and pumping plant intakes. Presently, the boom contains only one string of logs and is intended to prevent public access to the spillway and intake areas. Debris control on the project is now provided by timber booms at China Bar and Kettle River on the upstream end of Lake Roosevelt.

Several disadvantages of this boom for safety applications are readily apparent. Older boom sticks from the debris booms at the upstream end of the lake are often salvaged for use in the safety boom, and consequently, the majority of boom sticks are badly waterlogged and float very low in the water. This increases the potential for boaters to cross the boom. The boom sticks are also difficult to see in low light conditions, partially due to their deep submergence, and partially due to their dark color. The poor visibility of the boom could present a hazard to boaters not familiar with the location of the boom. The most visible parts of the boom are the large orange floats used to support the weight of cables leading to anchors submerged deep in the reservoir.

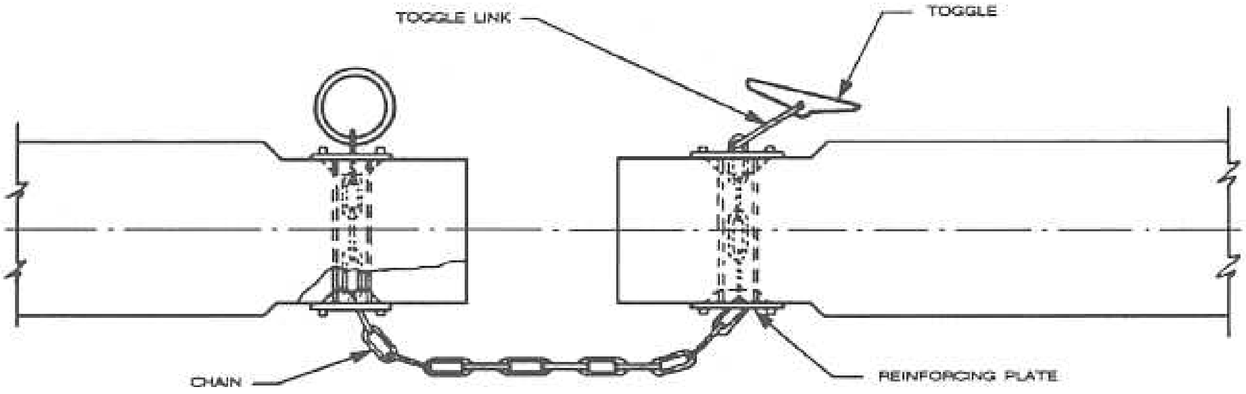

Figure 3. - Connection scheme for the standard debris and safety boom design used at Grand Coulee Dam, China Bar, and Kettle River on the Grand Coulee Project. Boom sticks are 14 to 24 inches in diameter and 33 ft long.

Finally, the cost of the timber used for this safety boom is increasing rapidly. The cost of a 33-ft boom stick, complete with connecting hardware, was about $500 in 1990. The cost increases about 8 percent per year. In safety applications, these booms can be expected to last about 20 years.

Timber Debris Booms. - In addition to safety applications, timber boom sticks are also used extensively on Reclamation projects as glance and debris retention booms. The effectiveness of timber booms in these applications is generally quite good, although boom failures often occur as the result of timber deterioration, connection failures, or anchor failures. At sites with heavy debris loads or large waves, double or triple strings are used to achieve good performance. The greatest disadvantage of the timber booms in debris applications is their high cost and limited durability.

An excellent example of glance and retention booms on Reclamation projects is the China Bar debris facility on the Grand Coulee Project. A debris control facility has been constructed on the Columbia River just upstream of Roosevelt Lake. The facility is downstream of a sweeping left turn in the river, so that debris naturally accumulates on the right side of the channel. A mile-long glance boom made up of three independent, parallel boom strings guides the debris into a holding area at China Bar. Boom sticks in the glance boom are essentially the same design as the safety boom at Grand Coulee Dam, described above. The glance boom does not have any of the special glance boom features described earlier, such as smooth facing or a submerged lip on the upstream edge.

In the holding area, a double-string timber retention boom holds the debris in place. Boom sticks in the retention boom are also of the same design as the glance boom and the Grand Coulee Dam safety boom. When water levels fall in early spring before snowmelt runoff, the debris is piled and burned.

In calm waters, the operation of a debris boom may be relatively trouble-free. However, in heavy currents, or under heavy debris loads, operation and maintenance procedures are important factors to be considered in comparing boom designs. Untangling of debris, reconnecting boom sections after failures, repositioning of anchors, and replacing deteriorating boom sections are common maintenance operations. In heavy currents, these operations can be quite dangerous. Boom sticks must be designed for easy handling to make these operations as safe and simple as possible. One advantage of the timber booms is that they are easily handled. The debris contractor at China Bar uses a tugboat to maintain the booms.

Pike poles and log tongs are used to handle and grab the logs, and the contractor can easily cross the boom with the tugboat without damaging the boom.

The triple-string glance boom at China Bar has been the subject of some experimentation in the past. As the boom is presently configured, the failure of one boom or connection causes the loss of a full span between anchor locations. To prevent this type of failure, the boom sticks were attached to a cable which ran the length of the glance boom. This modification was unsuccessful, however, because when the boom strings crossed, the cables cut through the chain connecting hardware and cables for adjacent boom strings. Without the cable installed, boom strings still become crossed, but the connections rarely line up with one another and there is no problem with connection failures by cutting.

The second major debris control boom on Roosevelt Lake is located at the mouth of the Kettle River. This boom originally spanned the mouth of the river, and included a gate section which allowed public access upriver. The gate was a continual maintenance problem, because the gate was often left open, thus releasing debris into the reservoir. The boom was modified in 1989 to provide a permanently open navigation channel through the boom. Two holding areas were constructed, one corresponding to high reservoir levels, the other corresponding to low reservoir levels. The main holding area was lined with a second string of boom sticks. A single string of boom sticks was installed as a glance boom to divert debris out of the main flow of the river. This design performed successfully for small debris loads, but in May 1990, flows and debris loads in the Kettle River reached extremely high levels. A combination of anchor and boom stick failures occurred in the glance boom. The presence of the liner boom prevented the loss of debris into the reservoir.

Manmade Materials

Safety booms. - One common safety boom used on Reclamation projects is a cabled float system used to protect small areas. These booms consist of round or elliptical floats with a hard plastic shell, filled with flotation material, and spaced along a cable at about 25-ft intervals. The floats are usually constructed from international orange materials, or a combination of white and orange. These booms are intended for short spans, less than about 400 ft according to one manufacturer, although longer spans are possible with special designs. Examples of these types of booms can be seen at Banks Lake Feeder Canal on the Grand Coulee Project, Mt. Elbert Forebay Reservoir, or the tailrace of Davis Dam. One disadvantage of this type of safety boom is that floating debris can become entangled in the cable.

To reduce problems with debris, the floats can be replaced by buoys that hold the cable above the water surface. This also makes the cable easily accessible to boaters in distress. One commercially available design uses a fiberglass shell for the hull of the buoy and polyurethane foam as a flotation material. The hull of the pontoon is similar to a double-hulled boat, and is designed to have minimal drag in the current. Warning signs are installed on the deck of the floats. The hull may also be designed so that swimmers or boaters in distress can climb onto the buoy to await rescue. The WWP (Washington Water Power Company), Spokane, WA, has installed these types of boat safety cables at several locations with good success.

A recent development for safety booms is the use of foam-filled polyethylene pipe for the construction of boom sticks. A commercially available system has recently been installed at Stagecoach Dam, CO, (Reclamation Small Projects Program). The boom sticks are constructed from international orange corrugated polyethylene culvert pipe. Tensile load is carried by a wood 4x4 which runs the length of the boom stick. The interior of the polyethylene culvert is filled with expanded polystyrene foam. This type of float could also be used as the flotation member for a net boom used for debris retention. The commercial purchase price for this type of boom ranges from about $280 for a 12-in-diameter, 20-ft-long boom stick, to $700 for a 24-in-diameter stick. The boom at Stagecoach Dam has been in service for about 2 years, and has performed satisfactorily.

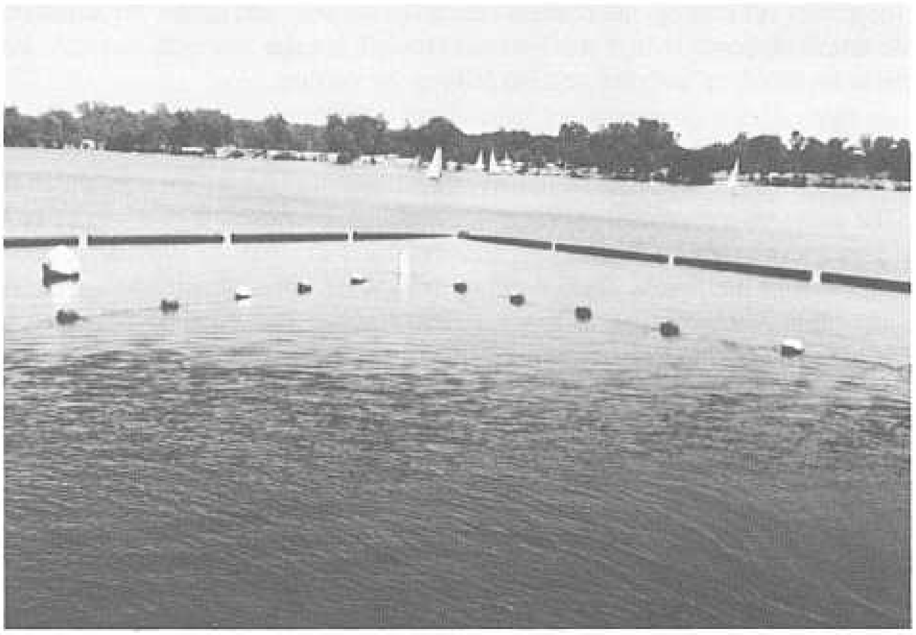

Figure 4. - Cabled buoy safety line (foreground) and the new safety boom at Nimbus Dam. The new boom is constructed from recycled plastic.

An example of both of these types of safety booms is shown in figure 4. These booms are installed at Nimbus Dam, CA, on the CVP (Central Valley Project). The set of cabled floats was the original safety boom around the power intakes, but was considered unacceptable because sailboaters and swimmers used the line as a resting point, despite its close proximity to the intakes. The newly installed boom, constructed from recycled plastic, was purchased commercially. This boom is quite similar to the polyethylene booms described above. Installation was performed by Reclamation personnel.

The Shasta Office of the CVP has operated three safety booms built from 18-in-diameter aluminum pipe filled with polyurethane foam. The booms are not painted, but are easily visible due to the brightness of the aluminum pipe. Two booms are located at the intakes to the Lewiston Fish Hatchery, and one boom protects the morning glory spillway at Whiskeytown Dam. These booms have been in service for 5 to 10 years. The only significant problems during this time have been with the boom at Whiskeytown. The long fetch of the reservoir produces very large waves which have caused fatigue failures of chain and cable connecting hardware. Problems have been reduced by using swivels in the chain connections.

The California Department of Water Resources has operated a hybrid timber and metal pipe safety boom at Oroville Dam since about 1963. This boom is constructed primarily from 12- to 16-in-diameter surplus pipe filled with styrofoam for flotation. Connections between boom sticks are made with pins and shackles. The pins are tack welded in place so that they cannot be removed by vandals. Tensile load is carried by a steel cable, to which each boom stick is attached. The reservoir level fluctuations at this location are quite large, which leaves the ends of the boom string on shore during much of the year. To eliminate damage to the metal booms by wave action pounding the booms against shoreline rocks, timber boom sticks are used near the shore.

Debris booms. - One unique synthetic boom design used for debris control is located at Chief Joseph Dam on the Columbia River, operated by the U.S. Army COE (Corps of Engineers). This design consists of surplus 6-ft-diameter by 12-ft-long steel Navy buoys connected by clamps and shackles to a load-carrying wire rope (Perham, 1988). Each float is partially filled with concrete ballast, and has timber bumpers attached at 45° above, 45° below, and at the waterline, on the upstream side of the boom. Scrap automobile tires are used as bumpers between each float. The remainder of the float is hollow. The exterior of the floats is painted with a vinyl paint. This boom has been in place for about 13 years, and has performed satisfactorily during that time. Debris loads at this site are usually light, as the site is only about 60 miles downstream of Grand Coulee Dam, with little debris from intervening tributaries.

PG&E, San Francisco, CA, has used steel pipe booms in debris and safety applications since the late 1950's. The standard boom design consists of a 10-gauge, 16-in outside diameter welded steel pipe with styrofoam inserts to provide flotation. The styrofoam is unbalanced to provide a righting moment for the boom stick. The interior of the boom is coated with coal tar epoxy, but the exterior is left bare, since the abrasive action of debris would remove any coating. Connections between booms are made using galvanized shackles, angles and steel plate members. The pin for each shackle is tack welded at field assembly to prevent vandals from disconnecting the boom. Prior to 1975, a number of different connection details were used, each of which experienced fatigue failure in the steel angles where they were bent and welded to the pipe walls. This connection detail was modified successfully in 1975 (fig. 5).

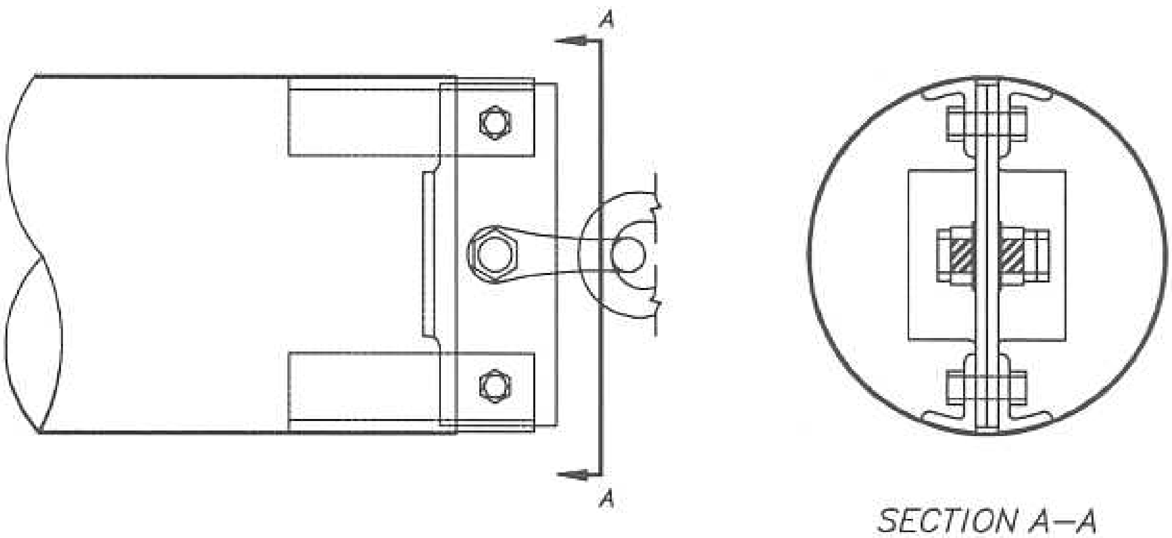

Figure 5. - Connection details for steel pipe debris booms used by PG&E.

PG&E incorporates several practical features into their boom design. Although 20- and 30-ft booms are used primarily, 10-ft booms are used near shore so that as the water level falls, a long boom is not required to span a large distance at the water's edge. This reduces the amount of debris passing under the boom near shore. PG&E also includes a "weak link" in each boom string which is designed to fail first. This allows the boom failure to be controlled so that the free ends of the boom do not enter spillway areas.

One recent installation of steel pipe booms by PG&E was at Salt Springs Dam in 1986. The approximate cost of materials and construction at that time was $1,000 for a 16-in-diameter, 20-ft-long boom stick.

Reclamation engineers have recently designed a steel pipe boom for debris control at Shasta Dam, to protect the proposed Shasta Temperature Control Device. This boom is to be constructed from 24-in-diameter, 16-gauge corrugated steel pipe, filled with polystyrene or polyurethane foam. Connections will be made using a modification of the chain and toggle hardware used for timber booms at other Reclamation projects. Initial engineer's cost estimates for this design indicate a cost of about $3,000 for each 20-ft boom stick, about half of which is associated with the flotation material.

The WWP has also had experience with the use of steel pipe booms for safety and debris applications. Their designs have generally consisted of two steel pipe pontoons side by side, connected by a truss structure. A wood platform can then be built over the truss, so that workers may walk out onto the boom. Model tests (Kennedy and Lazier, 1965) did not demonstrate any particular debris retention advantage for flat booms over single stick round booms. However, there may be some advantage in heavy winds, as Kennedy (1965) showed that double strings of single sticks (floating independently) were more effective at retaining debris in waves than were single strings.

ALTERNATIVES FOR RECLAMATION USE

Safety Barriers

The alternative safety barrier designs which have been identified can be categorized as follows:

- Traditional debris boom designs using boom sticks made from timber
- Traditional debris boom designs using manmade materials
- Cable barriers with buoys or floats.

Many variations are possible depending on connection details, material selection, and buoy configuration.

The safety guidelines of the FERC state that any barrier may be considered an adequate boat restraining barrier. However, the experience of the Grand Coulee Project indicates that boaters and fishermen often cross traditional timber booms that the FERC would consider adequate. Despite this experience, traditional debris boom-type barriers provide a more substantial barrier than cable-type systems and also have greater visibility. Thus, debris boom-type barriers should be considered for protection of areas where there is imminent danger of death or serious injury to persons passing the boom. These booms should be highly visible and present the greatest physical barrier that is reasonably possible.

Many of the safety barrier systems identified by this study are available commercially and could be easily implemented at Reclamation projects. As discussed above, several projects have already installed commercially available systems or have designed and built systems of their own.

Debris Booms

Alternatives that have been identified for use in debris deflection or debris retention include:

- Presently used timber booms
- Pipe booms filled with styrofoam or other flotation material

- Specialized booms built up from sawn lumber, such as deep booms, core booms, flat booms, or fence booms
- Net booms using any of a variety of flotation members

Net booms and other specialized designs are required only for extremely heavy debris loads or other specialized applications. Reclamation projects have experienced good performance of the present timber booms, and have not required the extra retention capacity of these designs. Thus, the alternatives most likely to be used at Reclamation projects in place of timber booms are pipe booms.

The boom at Chief Joseph Dam constructed from salvaged Navy buoys, and the steel pipe booms used by PG&E have both been successful designs and could be readily applied to Reclamation projects with a high expectance of success.

Manmade Materials

Manmade materials that may be used for the exterior shell of boom sticks, pontoons, floats, or buoys include steel, aluminum, polyethylene, and fiberglass. Flotation may be provided by polyurethane or polystyrene foam.

The durability of the various materials which could be used in safety barriers or debris booms will be affected by their susceptibility to waterlogging, weathering processes, biological attack, and abrasion. Special coatings, manufacturing procedures, or maintenance operations may minimize these problems. For instance, booms or buoys could be specially designed to allow for the replacement of flotation materials when necessary.

The durability of various possible materials will be influenced by widely varying environmental conditions. Portions of most debris or safety booms will be submerged permanently, although some booms may also be left on dry ground for portions of the year. Temperatures may vary from subfreezing to over 120 °F in the direct summer sun. Corrosive influences will vary widely depending on location, soil types, and water quality. Debris booms will be subjected to abrasion by trees, brush, and possibly ice.

Fiberglass. - No examples were found in the literature in which fiberglass pipe was used for debris or safety booms. Fiberglass has been used in the commercial manufacture of pontoons for cabled buoy safety lines. The chief advantages of fiberglass are its tensile strength and resistance to weathering. However, fiberglass is more expensive than many competing materials, and also is subject to impact damage that limits its usefulness in debris applications.

Polyethylene. - Polyethylene has many advantages including low specific gravity, low cost, good resistance to weathering, and colorability. Polyethylene is one of the least expensive polymers. The greatest threat to long-term durability of polyethylene is UV (ultraviolet) light. However, polyethylene can be formulated to be very resistant to UV light damage by the addition of UV absorbers that also determine the final color of the material. The two most UV resistant formulations are colored black and safety orange. The safety orange coloring is ideal for safety booms.

Steel. - The greatest advantages of steel for the construction of booms are its resistance to impact and abrasion damage, structural strength, and workability/weldability. Disadvantages to consider include high unit weight, high cost, and susceptibility to corrosion damage. Corrosion protection options for steel include painting, coating with coal tar epoxy, galvanizing, cathodic protection, or impressed current protection systems. Reclamation experience with steel trashrack bars has shown that specialized corrosion protection systems are often uneconomical. Trashrack bars are generally overdesigned to allow for expected corrosion during the service life of the structure.

Aluminum. - Aluminum has many of the same advantages and disadvantages as steel for the construction of booms. One significant advantage of aluminum relative to steel is its lighter weight. Aluminum costs more than steel, and cannot be easily welded in the field. Corrosion of aluminum may be more or less severe than steel depending on environmental conditions. Galvanic corrosion may be a problem if steel or other dissimilar metals are used for connecting hardware.

Polystyrene foam. - Polystyrene foam is often used for flotation applications because of its excellent resistance to water absorption. It is also resistant to damage from UV light. It must be premanufactured, cut to size with a hot wire, and then forced into the pipe shell. Polystyrene has been used successfully in a number of commercially available booms, pontoons, and buoys. Unit weights of polystyrene foam vary from 0.7 to 3.0 lb/ft^3.

Polyurethane foam. - Polyurethane is less expensive than polystyrene, but does not have any UV resistance. Protection from UV light damage must be provided by encasing the polyurethane foam in a shell material. Polyurethane is a closed-cell product and therefore has adequate resistance to water absorption, but less than polystyrene. It can be manufactured in blocks that are fit into the pipe shell, or it may also be frothed directly into the pipe. Polyurethane is available in a wide range of unit weights from 1 to 20 lb/ft^3 or greater.

BIBLIOGRAPHY

Creager, W. P., and J. D. Justin, *Hydroelectric Power*, John Wiley and Sons, New York, 1950.

Federal Energy Regulatory Commission, *Public Safety at Hydropower Plants*, Division of Dam Safety and Inspections, March 1990.

Kennedy, R. J., *Forces Involved in Pulpwood Holding Grounds I: Transverse Holding Grounds Without Piers*, Technical Report No. 43, Pulp and Paper Research Institute of Canada, Montreal, Québec, 1957.

Kennedy, R. J., *Manual of Forces Calculation for Pulpwood Holding Grounds*, Technical Report No. 293, Pulp and Paper Research Institute of Canada, Montreal, Québec, 1962.

Kennedy, R. J., "An Evaluation of the Performance of Booms Subjected to Wave Motion," *The Water Transportation of Pulpwood II. The Protection of Pulpwood Holding Grounds*, Pulp and Paper Research Institute of Canada, Montreal, Québec, 1965.

Kennedy, R. J., and S. S. Lazier, "Booms," *The Water Transportation of Pulpwood III. Structures*, Pulp and Paper Research Institute of Canada, Montreal, Québec, 1965.

Perham, R. E., "Some Economic Benefits of Ice Booms," Proceedings of the Second International Symposium on Cold Regions Engineering, Fairbanks, AK, August 12-14, 1976.

Perham, R. E., "Floating Debris Control Systems for Hydroelectric Plant Intakes," *The REMR Bulletin*, U.S. Army Corps of Engineers, Vol. 3, No. 2, September 1986.

Perham, R. E., *Floating Debris Control; A Literature Review*, U.S. Army Corps of Engineers, Technical Report, REMR-HY-2, June 1987.

Perham, R. E., *Elements of Floating-Debris Control Systems*, U.S. Army Corps of Engineers, Technical Report, REMR-HY-3, September 1988.

Shawinigan Consultants, Inc., *Analysis of Procedures Used in the Design of Log and Trash Booms to Protect Hydro Electric Intakes*, prepared for the Canadian Electrical Association, Montreal, Québec, November 1982.

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