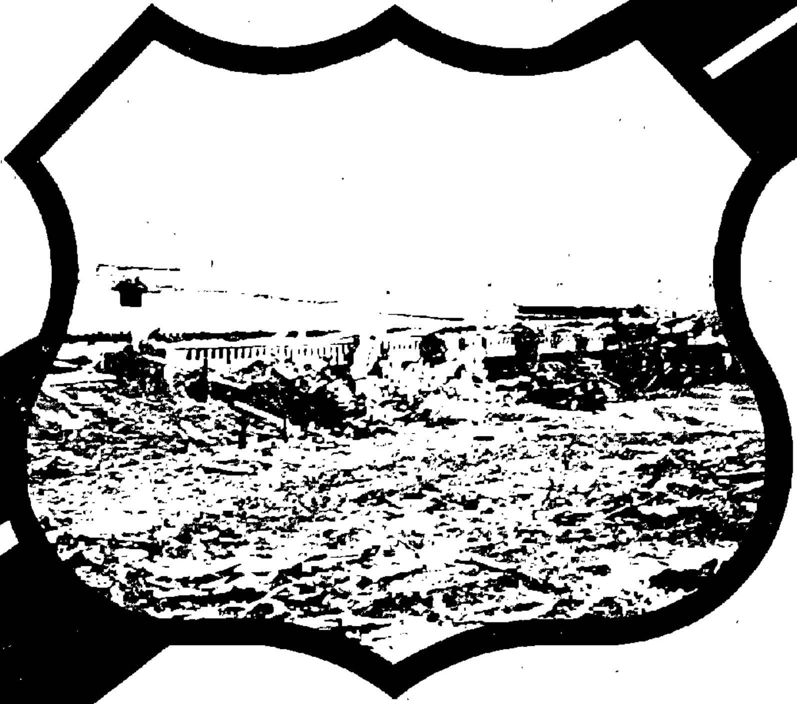
Report No. FHWA-RD-79-62

PB80-162100

DEBRIS PROBLEMS IN THE RIVER ENVIRONMENT

March 1979

Final Report



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DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Environmental Design & Control Division
Washington, D.C. 20590

FOREWORD

This report describes debris hazards posed to highway bridges during floods and includes an examination of measures to reduce these hazards. It will be of interest to highway engineers working in the river environment.

Research in highway drainage and stream crossing design is included in the Federally Coordinated Program of Highway Research and Development in Project 5H "Protection of the Highway System from Hazards Attributed to Flooding." Dr. Roy E. Trent is the Project Manager and Mr. Stephen A. Gilje is the Contract Manager.

This research was conducted through the Small Business Administration under the 8(a) contracting program for small minority businesses.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each FHWA regional office, division office, and State highway agency. Direct distribution is being made to the division offices.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

Technical Report Documentation Page

1. Report No.
FHWA-RD-79-62

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Debris Problems in the River Environment

5. Report Date
March 1979

6. Performing Organization Code

8. Performing Organization Report No.

7. Author(s)
Fred F.M. Chang and Hsieh Wen Shen

9. Performing Organization Name and Address
Tye Engineering
9614 Jomar Drive
Fairfax, Virginia 22080

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DOT-FH-11-9274

13. Type of Report and Period Covered
Final Report
June 1977 to March 1979

12. Sponsoring Agency Name and Address
Office of Research and Development
Federal Highway Administration
U.S. Department of Transportation
Washington, D.C. 20590

14. Sponsoring Agency Code
E0446

15. Supplementary Notes

FHWA Contract Manager - Stephen A. Gilje (HRS-42)

16. Abstract

Debris causes hydraulic problems at highway bridges nationwide. The problems are the greatest in the Pacific Northwest and the upper and lower Mississippi River Valley. Debris hazards are local and infrequent phenomena often associated with large floods. Most bridge destruction is due to accumulation against bridge components. Debris may partially or totally block waterways and create adverse hydraulic conditions that erode pier foundations and bridge abutments and do other structural damage. Many debris problems exist in forested areas with active logging operations. Bridges on streams where stream slopes are mild or moderate, in contrast to headwater streams, are more vunerable to debris related hazards. Debris hazards occur more frequently in unstable streams where bank erosion is active. Countermeasures presently used by highway agencies include: (1) sufficient freeboard, (2) proper pier spacing, (3) solid piers, (4) debris deflectors, (5) special superstructure designs, (6) flood relief structures, and (7) regular and emergency removal of debris at bridge crossings. Most debris transported in floods does not travel a great distance and was observable locally along the streambanks upstream from the bridge prior to the flood. Rather than in congregations, debris moves as individual logs in a non-random path concentrating in the thalweg of the stream. Therefore, methods for evaluating its abundance and for mitigating its hazard are deemed feasible.

17. Key Words
Debris
Bridge Failure
Open Channel Flow
Stream Erosion
Scour

18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
71

22. Price

m DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

Appreciation is due to those highway departments and other government agencies who furnished the data pertaining to debris hazards. The state highway departments of Louisiana, Virginia, Pennsylvania, Tennessee, Texas, Illinois, New York, California, and Oregon, in particular, merit special recognition for their enthusiastic cooperation, without which this study would not have been possible. The authors are especially indebted to William Jacks and Al Dunn, both of Louisiana, R. W. Schwartz, W. T. Reams, Joseph McCabe and Calvin Boles, all of Virginia, Ming Tsai of Pennsylvania, Ronald Green of Tennessee, Samuel Fox of Texas, Danial Ghere of Illinois, and R. L. Hollenbeck of New York for their assistance in compiling the data.

Special thanks is extended to Stephen Gilje of the Federal Highway Administration, Office of Research, for continuing support, critical review of the report and for the constructive comments. Also, the assistance provided by Sterling Jones, Bill Barbour, and Michael Smith is fully appreciated, as are the support and suggestions offered by Lester Herr and Frank Johnson.

The authors also wish to acknowledge the help of Henry Froehlich of Oregon State University, Sam MacNab of the Oregon Department of Highways, and Guy Muncarti of the California Department of Highways.

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I. INTRODUCTION

Debris can be defined as material that is not generally transported in large amounts during normal stream flow. Thus, excessive vegetation, ice, man-made materials and even rocks can be considered debris. The potential hazards caused by debris have been experienced for a long time. Extensive research on ice problems has been pursued by the Task Committee on Hydromechanics of Ice of the ASCE and the U.S. Army Corps of Engineers. In contrast to a concentrated effort on the ice problem, less work has been directed toward the problems related to vegetative debris, although evidence indicates that many bridge failures are attributable to this type of debris accumulation. This report focuses only on the hazards of vegetative debris to highway bridges.

Vegetative debris causes many problems. For example, in Nelson County, Virginia, a flood caused severe damage in August 1969, much of which was due to heavy vegetative debris loads. The Virginia State Government reported, "Massive landslides occurred which swept tons of soil, boulders, and thousands of trees into streams. Logs and debris jammed against bridges and water overflowed and damaged the bridges. At least 91 bridges were damaged, resulting primarily from the great amount of debris that was washed downstream." A New Zealand Soil Conservation and River Control Council report [1] states, "Flood damage can be serious, particularly to roads, bridges, and railways. Whenever the rivers in flood had their catchment in forest country, large quantities of fallen timber were swept down the hillsides, reaching the bridges at the height of the flood and causing enormous damage." O'Donnell [2] in observing bridge damage in Pennsylvania and New York due to Hurricane Agnes in June 1972 concluded that the most obvious case of damage was waterborne debris that struck the bridges and collected on the superstructures and piers. The damage was largely attributable to the force of the impacting debris and the pressure of the flowing water on the lodged debris. In Colorado in June of 1965, a series of showers and thunderstorms produced an unusually high discharge in the Bijou Creek [3]. Water heavily loaded with debris swept across the flood plain and knocked down three bridges. The destruction of the three bridges occurred when the debris accumulating on the structures sent the already high water higher until the structures finally gave way. There are many other reports illustrating that the hazards of floating debris in the river environment cannot be ignored.

Forest service and land management agencies have been exploring logging techniques that may reduce the supply of debris. Highway agencies have taken actions to avert debris problems at culverts and are using several devices to prevent debris from clogging the inlets of small drainage structures [4]. Only a few countermeasures have been applied to highway bridges, however, and these efforts are extremely limited as compared to the scale of the problems reported. Although serious debris accumulations recur frequently in many places, the problem has not received much attention, and no in-depth work has been completed in this area. From this seeming contradiction, many questions can be posed: Do highway agencies think the debris problem is not significant? Is the debris problem considered not within the province of highway activities? Is the debris problem too difficult to deal with? Answers to these questions can be gleaned only from an in-depth examination of the problem. Unfortunately, data are very scarce, although typical structural failures of comparably large bridges have been reported [5]. Even in those few reports on bride failures which exist, the facts are often described very briefly and the causes of the failures are seldom stated explicitly.

Opinions of highway bridge engineers on debris problems are often diverse. Some bridge engineers insist that the occurrence of debris problems is so infrequent that it needs no special attention. When it does occur, the scale is so enormous that no practical solution except on-site emergency cleaning of accumulated debris can be possible. Nevertheless, a great number of highway engineers recognize the constant threat of debris problems in debris-prone streams; however, the significance of the problem has not been clearly identified.

Opinions among highway maintenance engineers are quite different. An assistance maintenance engineer of the Washington Department of Highways stated that during high water he had to constantly watch for debris problems at about 100 bridges in a Western Washington District alone. A bridge maintenance engineer of the Louisiana Department of Highways shares the attitude that debris accumulation against bridges is a severe problem in his state and that more effort should be expended to minimize the hazard. Granted, these two states may represent areas of the country with very special debris potential, but similar problems exist elsewhere.

The Office of Research, Federal Highway Administration, as a result of data accumulated in a statistical study on the causes and costs of bridge failures [6] felt a need for an investigation on debris, in order to obtain a quantitative overview of the hazards to highway bridges. Thus, this study was initiated to examine the magnitude of organic debris problems and the significant factors related to the potential of debris hazards. An additional objective was to investigate the effectiveness of countermeasures used against debris hazards and to determine if any additional work is needed to limit debris-oriented bridge losses.

II. LITERATURE REVIEW

Because logging operations in the river environment cause part of the problem, forest services and other related organizations have expended a considerable effort to mitigate problems in headwater streams. This work is concentrated mainly on reducing the sources of organic debris caused by logging.

A. Sources and Volume of Organic Debris

Swanson and Lienkaepmper [7] asserted that principal mechanisms of debris input to streams are: blowdown of whole trees, tops and major limbs by strong winds, debris slides, debris avalanches, deep-seated mass movements from adjacent hillslopes, undercutting of stream banks with resulting falling timber, and yarding operations. A dominant source of debris in coastal Alaska was found by Bishop and Stevens [8] to be from mass wasting of logs and from debris avalanches. They advocated that efficient forest land management requires identification of slide-prone areas and then establishing tree cutting patterns which result in minimal disturbance. Fredriksen [9] concurred with Swanson in stressing that landslides into streams are a major contributor of debris and added that forest roads are an accelerating factor to the occurrence of landslides. Bishop and Stevens [8] recognized that tree disease is another factor contributing to an increase in log debris.

In normal timbering practices, a large amount of unused wood residue remains in harvested areas. This material sooner or later gets into streams. In an attempt to minimize residue reaching streams, forest agencies have established some regulations regarding forest management and practices. The Field Guide to Oregon Forest Practice Rules [10], for example, provides a guideline in Section 24-645, "Treatment of Waste Material,"

> "Debris, overburden and other waste material associated with harvesting shall be left or placed in such a location as to prevent their entry by erosion, high water or other means into waters of the state."

Froehlich [11] concluded in his study that different logging methods, especially at the tree-felling stage, can produce substantial differences in the resultant debris loads. Directional felling uphill with a tree-pulling system was found effective in reducing the quantity of material reaching streams. Buffer strips maintained along streams were also found effective debris barriers even when they were not continuous or of large widths. Froehlich [11] in studying 17 channels on the west side of the Cascades found that the natural accumulation of organic debris within a 10-meter side strip centered on the stream channel averaged about 4 tons of debris per 10 meters of channel. The debris in the stream varied greatly from 0.1 to 3 tons per 10 meters of channel, with the amount dependent on the type of trees, soil condition, precipitation, time after the last natural calamity, hill slopes, etc.

B. Debris Accumulation and Movement in Headwater Streams

Heede [12] stated that log jams across Fool Creek and Deadhorse Creek in Oregon accumulated gravel and thus formed steps along the channels. Step length decreased with increasing channel gradient. The cumulative height of steps formed by logs and gravel bars nearly offset the total fall of Deadhorse Creek and approached 75 percent of the fall of Fool Creek.

Debris is transported through stream channels either by floatation during high water or by transport in debris torrents (large volumes of organic debris, mud, gravel and water which catastrophically "sluice out" channels) [9]. The ability of a stream to float debris depends both on the size of the free-flowing part of the water course and the size of debris. In larger rivers, nearly all organic material entering the river can be floated and transported downstream. Very large debris can be transported through small channels only in debris torrents [13]. Debris torrents may be triggered by the breakup of debris jams in a channel, the collapse of a road fill in a channel way or by a slide entering the channel from the adjacent hillslope.

C. Effect of Debris on Watersheds

Debris influences bank stability, channel slope [12], channel roughness [9], the balance of sediment transport in the stream, and lateral migration. A debris accumulation may cause a stream to by-pass a jam and cut a new channel. When channels continue to flow through massive debris accumulations, streamflow may be forced downward below the surface of the debris throughout much of the year. In areas of active creep and earth flows, lateral stream cutting may undermine banks and trigger hill slope failure and accelerate sediment supply to the channel [8].

D. Channel Cleanup

Channel cleaning can be accomplished manually or mechanically. The cost of hand-cleaning was estimated by 20 Western Oregon logging managers to range from $300 to $1,500 per 100 meters. Froehlich [11], in a study of hand-cleaning of two streams, found a difference in costs when cleaning was done by a special crew as compared to a regular logging crew. The special crew cleaned a 393-meter reach of channel with 35 percent side-slopes, removing 4.5 tons per 100 meters. Total cost, including tools, labor, and administration was $84 per 100 meters. The logging crew, cleaning 540 meters of stream, removed 1.5 tons of debris per 100 meters at a cost of $110 per 100 meters. These results suggest that the costs of stream-cleaning are approximately $180 per ton of debris per 100 meters.

As for mechanical cleaning, Holderman [15] recommended that the heavy equipment for cleaning should be set up along the side of the stream, rather than in it, wherever access is available. During the operation, care should be taken to minimize disturbance of streambanks. Large debris imbedded in the bank should not be removed. A crawler type crane equipped with a long boom and grapples has been found economical and effective. The operation creates very little stream disturbance. Rubber-tired skidders with cable winches joined traditional crawler equipment with caterpillars and shovels as a tool for removing larger woody material from streams. Blasting and burning still have limited application and should be coupled with other physical methods. For example, hand work will probably always be the only suitable means to clean smaller debris from stream channels. Various cable yarding systems are receiving greater use. In certain terrain, even helicopters and balloons have been employed to protect streams and other natural resources. A Lewis donkey winch [16] may be used to gather timber residue at inaccessible locations.

For cleaning streams in Jackson State Forest, Fort Bragg, California, Tilley [17] estimated the cost of the operation of a machine consisting of a rubber-tired skidder equipped with an 8-meter tower and a double drum winching system at $90 per linear meter of streambed. This figure excludes the costs of additional equipment such as a loader and of transportation expenses for the machine.

E. Practices of Highway Agencies Related to Debris

In contrast to the exhaustive efforts of forest management agencies to reduce the sources of debris in headwater streams, only a minor effort has been made by highway agencies in preventing debris hazards at bridge crossings. This is brought to light by examining state highway design manuals. A hydraulic (or drainage) manual is generally provided in every state for highway engineers to design hydraulic structures. Hydraulic structures must be designed in accordance with the guidelines and specifications given in these manuals. The manuals generally vary from state to state, mainly because of the climatological and geometric differences. Of all the manuals reviewed, only 20 states include some discussion on debris-related subjects. These are presented mostly in the section on survey and planning. Most of these sections read something like the following:

> "The presence of debris at the bridge site must be noted for the design of a new bridge. If the problem is serious, remedial measures of some kind should be considered."

Substantial progress has been made by some states on specific remedial measures for protecting culvert inlets by employing the Hydraulic Engineering Circular No. 9 [4]. No specific measures for bridge crossings have been presented in any manual. Nevertheless, a freeboard of 0.6 to 1.0 meter has been recommended for all new bridges. Freeboard is used as a precautionary allowance for water and floating debris to pass under the bridge without incident at high stage flow. For heavy drift, a higher freeboard is advised. In some areas where debris is a recurring problem, the nature and condition of debris must be studied, and the findings should be included in the bridge survey report. The Hydraulics Manual of the Texas Highway Department, for instance, states:

> "For stream crossings, the probable nature, size, and the volume of drift should be noted in order to determine the amount of freeboard that will be required for the proposed structure. Ordinarily it is the practice of the Texas Highway Department that 0.6 m clearance is added to the calculated highwater elevation and the bottom of the bridge to provide for passage of drift."

III. TYPES OF DEBRIS HAZARDS TO BRIDGES

According to the mode of destruction, debris hazards can be grouped into three categories: (1) destruction induced by debris accumulation, (2) destruction due to direct impact and drag force, and (3) other miscellaneous hazards.

(1) Destruction Induced by Debris Accumulation:

Debris accumulation causes the most frequent bridge damage by far. Any obstacle in a water course may catch floating debris. When a piece of debris is firmly trapped by the obstacle, it starts in turn to trap other on-coming debris. Debris volume often grows exponentially and soon reaches an enormous size which blocks the waterway opening. Accumulated debris deflects the water in all directions, drastically changing the flow pattern and creating unexpected adverse flow conditions.

Debris may totally or partially block waterway openings, depending on bridge size and geometry and the amount of debris loading in the stream. Total blockage occurs more often at bridges with shorter spans and lower decks. When this occurs, the water seeks its way either to the sides or over the top of the bridge, washing away the abutment fill and the highway approaches. In some cases the flow pushes the deck downstream when the rising water exerts sufficient pressure to dislodge the deck off the piers. During a flood in 1975, a reinforced concrete bridge over Big Bear Creek in Lycoming, Pennsylvania, was lost, costing $281,610 for replacement. The bridge was 15 meters long, but clearance from the riverbed was only 2.3 meters. Debris totally blocked the waterway opening, and the water rose 0.2 meters above the deck. The flow washed the approaches away and severely damaged the substructures as shown in Figure 1.

A 23-meter timber bridge on the Brockliss Slough in Minden, Nevada, received major damage to the superstructure, substructure and road approaches when drift choked the narrow clearance of only 1.4 meters from the riverbed, causing the water to overtop the bridge.

For a bridge across wider streams, such an occurrence is rare because more space is available for passage of debris and water. Debris generally is transported in a non-random manner across the channel. It concentrates along the main flow and, consequently, the accumulation of debris often starts at piers located there. When the accumulated debris becomes sizeable, the main flow will be forced to deviate from the normal route, creating a strong lateral flow across the river toward the adjacent piers at some angle. This type of rampant flow may critically scour the pier foundations. In many instances, the lateral flow strikes the embankment, eroding away the embankment fill. This type of destruction is frequently observed in the field; often its damage is comparable to that resulting from total blockage.

A steel bridge on the Rockfish River in Nelson County, Virginia, built in 1969, was damaged by debris during the Hurricane Agnes flood in 1969. The bridge was composed of six 21-meter spans with a clearance from the streambed

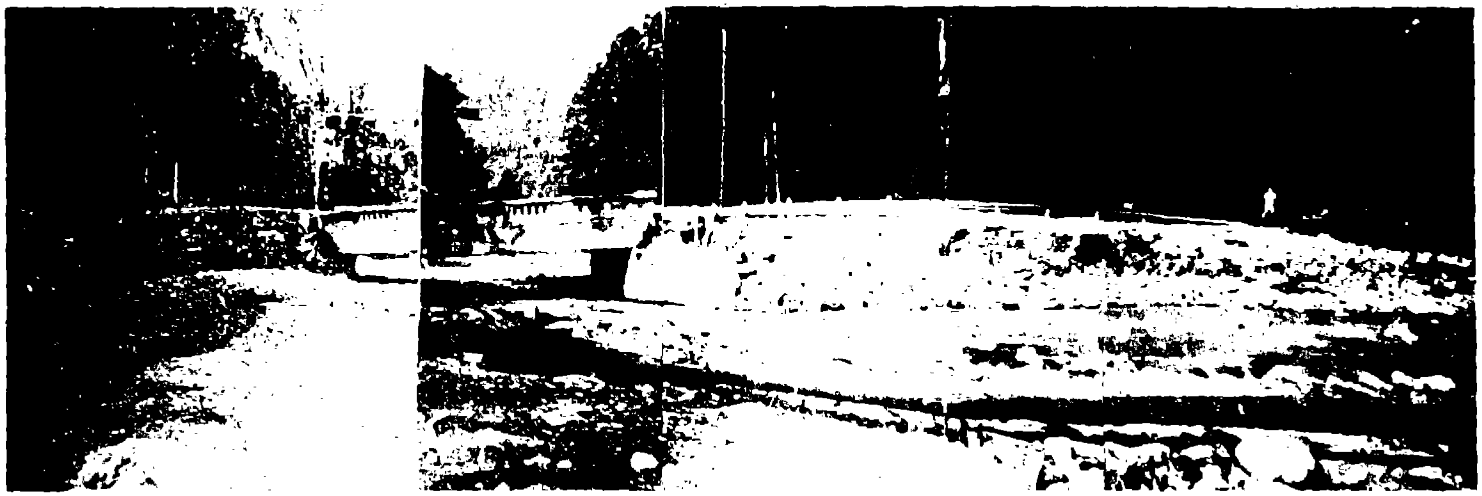

Figure 1 A Bridge on Big Bear Creek, Lycoming County, Pennsylvania, after Destruction.

of 6.1 meters. During the flood, three spans were completely blocked with debris forcing water under the other three spans. Resulting flow conditions caused two piers to be severely undermined. Although only minor damage to the superstructure was reported, the substructure received damage costing $40,000.

During a 1975 flood, a 35-meter concrete beam bridge on the Burch Creek in Pittsylvania, Virginia, was damaged because debris blocked the waterway opening under the center span of the three-span bridge. Water was forced under the end spans, and both abutments were undermined to the point where the footings were exposed one meter above the streambed.

Debris accumulations around a pier may pose a problem when the flow is intensified on the pier foundation soils. A bridge over McCraney Creek in Pike County, Illinois, composed of two 15-meter spans supported with a rectangular pier at the center of the stream was subjected to this type of damage. During a flood in 1973, debris accumulated around the pier in large amounts. The diving flow near the pier was intensified and scour caused settlement of the pier as shown in Figure 2. Since the bridge was located at a bend, lateral erosion of the channel created a destructive flow condition which further intensified scour at the pier. As with most bridge failures, this demonstrates that no stream hazard usually operates alone. However, debris often plays an important if not the main role in the destruction of bridges.

Partial blockage of the waterway may raise the stage to the bridge deck, leading to a collection of floating debris along the entire length of the bridge. Water is then compelled to flow downward under the deck, impinging on the riverbed and pier foundations. As the water is forced down, some debris may be pulled down and freely passes under the deck. However, some debris may be trapped between the deck and the streambed and thus forms a screen to trap additional debris. When this happens in streams with heavy debris loading, the opening under the deck can be totally blocked. For a high-deck bridge this is not likely to happen; however, the erosion of the riverbed by the intense underflow will persist and the safety of the bridge will be jeopardized.

A 72-meter steel beam bridge over the Tye River in Nelson County, Virginia, was lost during a flood in 1969. The bridge was composed of three equal spans supported by two piers, each with two columns. The flood with an estimated recurrence interval of 250 years sent the water stage up to the bridge deck and trapped floating debris across the bridge. The flow then dived down and struck the riverbed and the pier foundations. As additional debris accumulated, the flow intensified and scoured the foundations to the point where the piers could no longer hold the weight of the bridge. Both piers collapsed, dropping all three spans into the river.

(2) Destruction Due to Impact and Drag Forces of Debris:

Pier damage resulting from either impact or drag forces of the debris is not common for massive solid piers. However, for open-pile bents or thin solid piers, some damage was observed. A large log may generate a substantial impact force; however, it does not cause serious damage to solid piers unless the log strikes the pier at some critical angle, concentrating its force in a small area. Open-pile bents are more vulnerable to such an acute impact force.

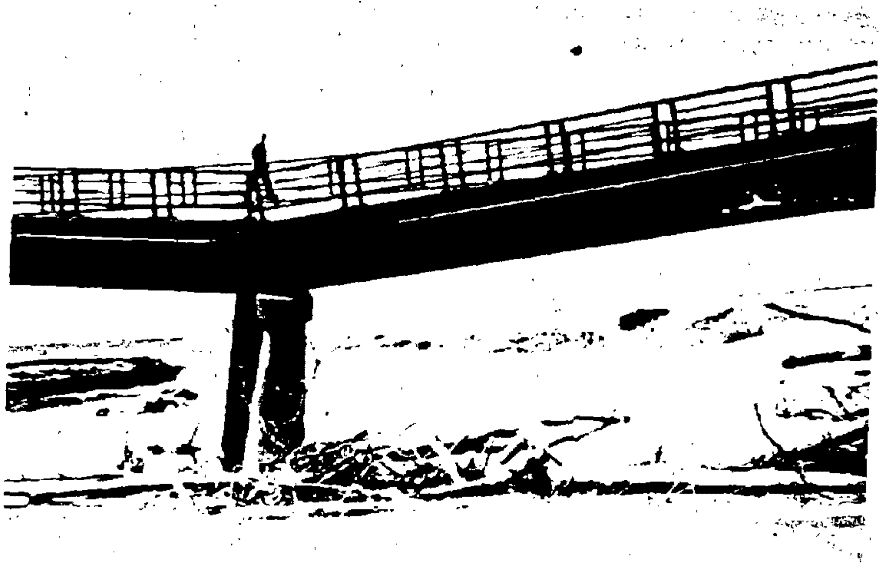

Figure 2 A Bridge on McCraney Creek, Pike County, Illinois

Figure 3 A Bridge on the Bayou Plaquemine, Acadia County, Louisiana

A 41-meter timber bridge across the Bayou Plaquemine in Acadia County, Louisiana, is built on treated timber trestles. During a flood in 1977, one timber pile was broken, as shown in Figure 3, probably due to the impact force of debris. This pier damage cost the state $2,000. For economical reasons, timber open-pile bents have been used often in Louisiana, and thus this type of destruction has been observed frequently in this state. Open-pile bents below a bridge over the Bayou Macon and a bridge over the Tensas Bayou were reported requiring yearly repair of damage caused by debris impact.

Drag force, as distinguished from impact force, is based on the length of impact time of the debris on bridge components and is proportional to the size of accumulation and to the square of the flow velocity. When the size becomes extremely bulky, the drag force may exert a sufficient force to ultimately damage bridge components. Destruction of this kind is infrequent for low stage flow because seldom is debris massive enough to exert enough drag force to bring about damage. Although a few such cases were claimed to exist by some highway engineers, the damage was more likely caused by the impact force rather than by the drag force. A long log wedged one end between two open-pile bents may develop a sufficient force to break the bents when a large quantity of debris is accumulated at the other end to create a torque. At any rate, whether damage was in fact due to the impact force or the drag force cannot be determined easily from a post-flood inspection.

Substructural damage due to the impact force of debris is not always on piers alone. An abutment, though usually massive in size, may also be subject to some debris damage. For example, the abutment of a bridge over the Eel River in California was punctured by a log. The bridge was built in 1911, and perhaps the abutment concrete had been aged and became brittle, thus could not resist a concentrated impact force exerted by the log.

For a high-stage flow, when the water rises above the deck, the drag force of debris plays an important role in the destruction of the bridge deck, particularly for a bridge with truss superstructure. When water loaded with debris reaches the deck, the truss acts as a large screen stretched across the river to trap debris, forming a solid wall of debris and damming up the water. As the water pressure exceeds the ultimate resisting capacity of the bridge, destruction is apparent. Many truss bridges in Pennsylvania were destroyed in this way in 1972, when Hurricane Agnes swept across the state. A 330-meter steel truss bridge on the Susquehanna River near Wyoming, Pennsylvania, was destroyed during the 1972 flood. Debris accumulated on the truss about 1.5 meters high above the deck and dammed water upstream. When the resulting drag force of the debris became sufficiently large, it pushed two spans off the piers. A 244-meter steel truss bridge located about 5 miles downstream was destroyed by debris also. In this case debris included mobil homes, steel drums, and houses in addition to normal vegetative debris. Although the pier noses were loaded with debris, they suffered only minor damage. A 241-meter steel truss bridge on the Chemung River near Bradford, Pennsylvania, was washed out by debris. A steel truss bridge nearby on the Susquehanna River met with the same fate when timber debris accumulated on the deck. The water overtopped the bridge and washed out five spans, costing $1.5 million for replacement.

Many truss bridges in Southwestern Virginia suffered similar destruction during the spring flood of 1977. The trusses of a bridge across the Powell River in Lee County, a bridge on the same river in Wise County, and a bridge on the Russell Fork River in Dickenson County were all washed out by debris when water reached above the decks.

Bridges with heavy concrete decks have been reported less prone to such incidents because of their heavy weight which can resist substantial drag forces from the debris. Four concrete bridges near Austin, Texas, were overtopped during the August flood of 1978. Even though a large amount of debris accumulated on the bridges, all four survived with no apparent damage.

(3) Miscellaneous Debris Problems:

There are other minor types of damage associated with debris. In Louisiana, it was reported that the accumulated debris at a bridge from a past flood caught fire during low water and damaged the concrete piers and timber pilings, costing the state $15,000. Large debris, logs and trees may scar paint on bridge decks when they rub vigorously against the structure during high stage flow. Such damage was reported in Virginia; however, no apparent structural damage occured, and the cost of repainting was found to be minimal. This type of damage is apparently more of an expensive nuisance than a true hazard.

IV. SURVEY OF DEBRIS HAZARDS TO BRIDGES

For a preliminary survey, a memorandum was sent to the Federal Highway Administration Regional Offices, asking the following questions:

In any State or States in your Region:

1. Does floating debris cause bridge or stream crossing maintenance problems?
2. Have any measures been utilized to alleviate debris problems or have any studies been made on debris accumulation?
3. Have there been any design or maintenance guidelines developed to counter debris accumulation problems?

These questions were posed in a very broad and general sense; thus the replies were quite general also, reflecting only the respondents' immediate reactions. The responses are presented in Appendix A and are briefly summarized in Table 1.

Table 1 Summary of Responses to Debris-Related Questions

Question Number	Number of States		Remarks
	Yes	No	
1	42	2	Major Problems - 4 States Moderate Problems - 25 States Minor Problems - 13 States
2a	39	5	Countermeasures - Sufficient freeboard, longer span, solid pier, proper location of pier, removal of debris.
2b	2	42	Both research projects on case-by-case basis only.
3	0	44	No specific guidelines pertaining to maintenance practices.

It is apparent that floating debris poses a problem of varying degree and dimension: four states recognized it as serious while 25 states classified it as of moderate magnitude. In Figure 4, the geographic distribution of debris problems is shown, indicating that the Pacific Northwest and the upper and lower Mississippi River Valley experience serious debris problems.

Although five states indicated no countermeasures to alleviate the debris problem, a freeboard of 0.6 meters or more above the maximum design water surface is ordinarily required for a new bridge to pass floating debris freely under the deck. Other countermeasures commonly in practice are regular and emergency on-site removal of debris and regular inspection of bridges. Other

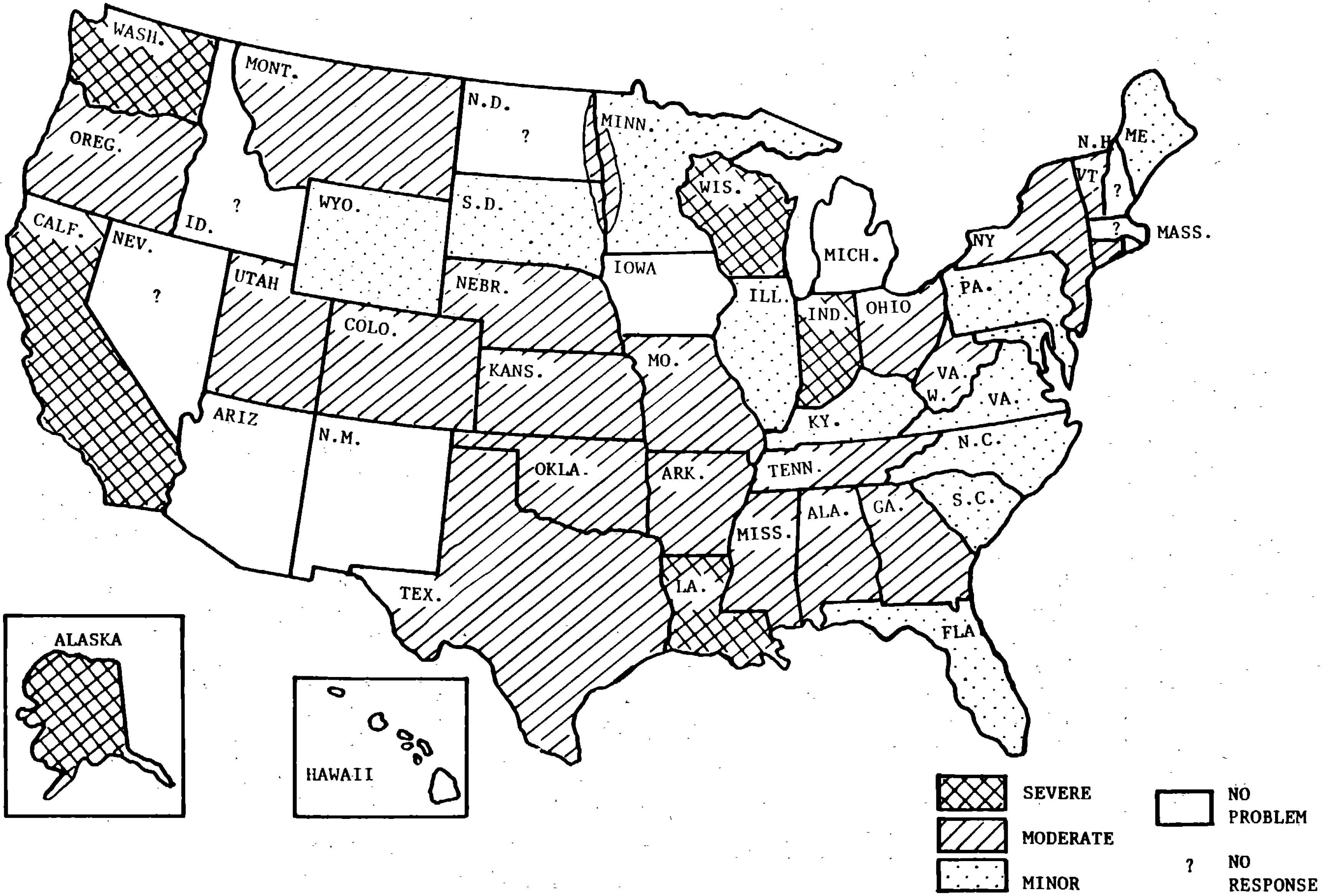

FIGURE 4 DEGREE OF DEBRIS PROBLEMS IN THE RIVER ENVIRONMENT

practices utilized by state agencies include designs with solid, round-nosed piers, longer bridge spans, and the selection of proper pier location to avoid debris accumulation. Only two states (California and Tennessee) conducted research studies on a case-to-case basis. Most states have no specific maintenance guidelines for debris, but maintenance engineers are obligated to supervise the removal of debris from bridges during or immediately after every flood.

The fact that states realize debris problems exist but have not applied many countermeasures nor conducted much research is puzzling. From a careful review of the states' responses, many possible explanations are conjectured. Among these, the following diversified and contradictory explanations emerge: (1) it is felt that the costs of debris damage to bridges are not high enough to justify new research, (2) debris problems are local and infrequent phenomena, (3) the existing countermeasures are considered to be adequate in serving the purposes, and thus no further research is needed to improve the situation, and (4) the problem is so complex and the volume of debris involved so bulky that no effective measures, except on-site cleaning, could be possible.

Based on the preliminary survey, several State Highway Departments, Forest Services, and the U.S. Geological Survey were visited to gather additional information pertaining to debris hazards to highway bridges. Included are frequency and costs of debris damage to highway bridges and case histories of bridge damage that was considered attributable to floating debris. The information on the items listed in Appendix B was obtained on a voluntary basis from the above mentioned agencies through verbal communication or completion of a form (given in the appendix) if they preferred to do so. Most agencies were quite cooperative and filled out the form in as much detail as possible. However, some items, such as characteristics of flood, river and basin characteristics, were generally not readily available, and an additional effort was required to obtain some pertinent estimations. Some agencies preferred not to supply the additional information while others responded favorably.

While admitting the difficulty in pinpointing the exact cause of a bridge failure attributed to debris, highway agencies and others were able to supply a total of 62 case histories of bridge failures involving debris. Although in general the information supplied lacks preciseness, the data outline essentials and present a quantitative overview of the debris problem. The frequency and the estimated costs of debris-related bridge damage for the last ten years were furnished by the Highway Departments in California and Oregon. They are presented in Tables 2 and 3. These states have similar debris problems, yet the frequency of incidents appears to vary widely from one state to the other. While only five cases of bridge damage were reported in the last ten years in California, Oregon experienced 58 cases. Among the districts in Oregon, a similar pattern is observed: District 13 in the Northeast experienced 20 cases of debris-related bridge damage in contrast to none in the Western Districts 5, 7, 9 and 10 for the last ten years. This is understandable if the terrain and climates of these areas are compared.

The 62 case histories provided by state highway personnel are concisely tabulated in Appendix C. In the following section, a closer examination and analysis of the data will be presented.

Table 2 Bridge Damage Due to Organic Debris in California (1969 - 1978)

District	No. of Bridges Damaged by Organic Debris	No. of Bridges Requiring Special Maintenance	No. of Bridges Requiring Emergency Maintenance	Cost of Debris-Related Bridge Maintenance
1	2	6	6	$130,000
2	1	-	-	$190,000
4	0	0	0	0
5	2	2	0	$10,000

Table 3 Bridge Damage Due to Organic Debris in Oregon (1969 - 1978)

District	No. of Bridges Damaged by Organic Debris	No. of Bridges Requiring Special Maintenance	No. of Bridges Requiring Emergency Maintenance	Cost of Debris-Related Bridge Maintenance
1	10	10	10	$150,000
2	2	7	4	$40,000
3	4	20	2	$100,000
4	6	12	6	$300,000
5	None	6	None	None
6	6	10	3	$100,000
7	None	10	10	$40,000
8	6	-	-	-
9	None	None	None	Minimal
10	None	None	None	None
11	1	-	1	$30,000
12	1	7	2	$20,000
13	20	14	5	$100,000
14	2	2	2	$500

V. A STATISTICAL ANALYSIS OF DEBRIS HAZARDS TO BRIDGES

This statistical analysis, like all others, is only as accurate as the data it describes. In the case of debris, the accuracy is considerably limited. This stems from the fact that the causes of bridge failures are interrelated and often indistinguishable; thus collection of accurate data pertaining to bridge failures attributable to debris is extremely difficult.

Few states have files on debris damage which clearly elucidate the true nature of the problem and frequency of occurrence. The occurrence of debris-related damage is directly related to floods of high stage and thus infrequent recurrence intervals, although exceptions to this general tendency have been noted in this research. When a debris accumulation of considerable importance occurs, actions are reactionary, aimed at quickly mitigating the problem at hand, with secondary concern for the causative agents. Usually maintenance crews are called out to solve the problem, and hydraulic engineers are not available to describe in detail debris conditions because they are busy assessing other flood hazards. Thus, most of the information used in this analysis is drawn from determinations following the flood and are biased to locations where impressive or unmistakable debris damage has been experienced. Unfortunately, this type of data rules out controls or sites where considerable debris approached the bridge, posed a potential problem, but for whatever reason caused no damage. Nonetheless, the findings do provide a quantifiable overview of general debris problems occuring nationwide.

Some additional general comments are in order before proceeding with the findings. Because documentation of debris damage in general is poor, documentation of hazards prior to 1969 (at which time there was a general increase in environmental awareness) is dismal. In fact, of 62 documented cases tabulated in Appendix C, only six were obtainable for debris damage prior to 1969. The lack of evidence of damage due to debris prior to 1969 is a data collection deficiency and does not imply that older bridges were built better than newer designs or that there were fewer problems in the past. It does, however, indicate that the information used is current and applicable to the type of bridge problems that have occurred recently. Many of the findings simply reiterate concepts an engineer with experience or basic common sense would consider obvious. They are presented here not as truisms but rather to reaffirm general beliefs or because situations which deviate from these concepts were also found, and these exceptions are noteworthy.

The following represent general attitudes toward debris hazards:

1. Debris damage is associated with either catastrophic or unusual types of floods. Most debris damage occurs during large floods; however, about 80 percent of sites had damage due to a flood of recurrence interval equal to or less than 100 years. It should be noted that with current requirements, highways must now be designed taking the effect of a 100-year flood into account. Floods of this frequency are no longer considered beyond the realm of highway design consideration.

Four cases of bridge destruction occurred during minor or medium floods. A 125-meter bridge over the Obion River in Tennessee (Case 4*) was destroyed by debris accumulation during a minor flood of 5-year recurrence interval. The official report of the bridge failure filed by the Tennessee Department of Highways in cooperation with the U.S. Geological Survey stated that "A large amount of drift lodged on the two main piers resulting in a reduced waterway opening and a consequent increase in velocity. The drift probably also caused large-scale eddies which increased the amount of scour." The increase of flow in the main channel was attributed also to the blockage of the overflow section; it was obvious that debris contributed to the destruction.

This example apparently disclosed an important characteristic of bridge destruction due to debris, in that the destruction of bridges is not necessarily always associated with an extreme flood. When a sufficiently large quantity of debris accumulates at a portion of the bridge where it will then direct the entire flow to concentrate elsewhere, portions of the bridge will be exposed to an intensive flow comparable to that of a much larger flood.

2. Longer bridge spans are less subject to debris hazards. With a larger space for the flow and debris to pass through, the chance of debris lodging against the bridge will be reduced. Even if a portion of the bridge is blocked with debris, the water may flow through the other portion of the bridge without creating destructive flow conditions. The data clearly show this point. The number of bridges destroyed decreases with increasing bridge length.

3. High bridges are less prone to debris hazards. This appears to be obvious, and the data confirms this logical and longstanding belief. For the cases studied, only six bridges with a clearance from the riverbed of over 7.5 meters encountered debris problems, and no incident was observed for bridges with more than 15-meter clearances. Because this factor is so important to the debris problem, serious consideration should be given to raising bridges on streams where debris is abundant. An in-depth discussion of freeboard and debris is presented in Section VII of this report.

4. Different pier types affect debris accumulation potential. There is little doubt that bridge substructures offering minimum obstruction will be less prone to debris accumulation than those where obvious obstructions exist. Therefore, in debris-prone streams, engineers have provided designs which do take into consideration their environment. Multiple-column piers probably create a better chance for debris accumulation and thus hazards. However, the data shows very little difference between the two types of piers: 25 against 26, of incidents incurred with bridges with multiple-column piers against bridges with solid piers.

5. Different types of vegetative debris pose varying degrees of hazard. Of 36 cases in which the typical length of debris was given in 33 cases the observed typical length of debris exceeded 1.5 meters. Longer debris has a greater chance of being trapped on bridge components and in turn trapping other debris. In South Florida, large amounts of floating hyacinth often cause maintenance problems, but because of this plant's flexibility, the problem has never been of such scale that it has brought substantial damage to bridges.

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*Refer to Case 4 in Appendix C.

6. Bridges in mountainous areas near the source of debris are more prone to damage than those on milder slopes. The data contradicts this statement. Only 12 cases of debris-related destructions occurred in the steep streams of mountainous areas as compared with 48 cases in milder and moderate streams. Explanations for this phenomenon at first seem difficult; however, there are a few things worth pointing out. The number of bridges over steep mountain streams is generally less than for bridges across moderate streams; therefore, the occurrence of debris hazards in mountain streams are similarly less frequent. Mountain valley streams are usually cut deeper into the surrounding terrain, and thus the clearance from water surface to bridge deck is often larger, with a corresponding reduction in potential debris hazard. On the other hand, because of the shallower and wider configuration of mild streams, the clearance of bridges in these streams is commonly much less, creating an unfavorable condition for passing debris during high-stage flow. Also mountain streams are usually smaller, therefore the chance for floating debris is less. In addition, the fluctuation of the stage due to change in discharge is larger in milder streams, with the effect that the stage will rise and close-in the clearance faster with an increase in flow at bridges in milder streams. The stream power is higher and the flow more turbulent in steeper streams, thus further reducing the chance of debris lodging against bridge components.

7. Bridges in streams running through heavily forested basins are most prone to debris hazards, and land use has an important role in the potential for debris hazards. A review of the 25 cases, in which the basin characteristics were described, reaffirms that forests serve as the primary source of debris. In all but one case, the forested area exceeded 50 percent of the total watershed. Logging operations definitely present a negative impact on the debris-related hazard to bridges: in 19 of 25 areas, logging operations were active. Strip mining within the drainage basin and gravel mining from stream beds inevitably increased land as well as bank erosion and disturbed the stability of the channel; all these are conditions that favor the presence of more debris in the streams. Eight such cases were found in the data. A bridge over the Amite River in St. Helena, Louisiana, has constantly suffered debris problems. There, one half of the drainage basin is used for mining and the other half for logging operations. As a result, changes in the river flow pattern have been quite frequent, and bank erosion is severe. Obviously, a substantial amount of trees from along the banks have been brought into the river as bank erosion progressed. These trees pose a serious threat to the bridges downstream as they are floated and transported by floods.

8. Streams with unstable banks and moderate vegetation cover provide a continuing source of hazardous debris. Of the 51 cases where the bank materials have been specified, 26 bank materials are erosive and 20 are semi-erosive. Only five bank materials were found not to be erosive.

Vegetation cover on the banks has an interesting impact on the debris problem. Where vegetation cover is dense and the bank well secured against erosion, only minor amounts of debris are available. On the other hand, where vegetation cover is scarce, the supply of trees and bushes is not abundant enough to create a hazard, even if erosion of the banks is severe and progresses inland. This implies that the debris hazard is less in streams with banks having either very dense vegetation or little vegetation. The analysis of 41 cases where the quantity of vegetation was specified proves this point. While a total of 28 debris-related bridge damages were observed in streams with banks with moderate vegetation, only 8 cases were recorded for streams with densely covered banks. It is also interesting to find that only 5 cases of bridge damage were incurred in streams with bare banks.

The stability of streams is here termed very loosely, based on the rate of change in the river configuration. A stable stream is defined as a stream undergoing very slow changes over a long period of time, while the change is greater for an unstable stream. It is generally accepted that a relationship exists between the stability of a stream and debris hazards. However, no apparent pattern was detected in this data. The frequency of debris-related damage incurred in the unstable streams was only slightly higher than those in the stable streams: 19 cases in the unstable streams, 17 cases in semi-stable streams, and 15 cases in stable streams.

The discussions above are summarized in Table 4.

Table 4 Summary of Debris Hazards to Highway Bridges

Item	Description	No. of Cases
1	Recurrence Interval of Flood:	
	Longer than 100 years	7
	50 to 100 years	23
	Less than 50 years	4
2	Length of Bridge:	
	Longer than 150 meters (500 ft)	10
	75 to 150 meters (250 to 500 ft)	14
	Less than 75 meters (250 ft)	38
3	Bridge Deck Clearance from Riverbed:	
	7.6 to 15.2 meters (25 to 50 ft)	6
	4.6 to 7.6 meters (15 to 25 ft)	14
	Less than 4.6 meters (15 ft)	12
4	Type of Pier:	
	No pier	6
	Solid pier	26
	Multiple column pier	25
5	Typical Debris Length:	
	Shorter than 1.6 meters (5 ft)	3
	Longer than 1.6 meters (5 ft)	33
6	Slope of Channel:	
	Steep	12
	Mild	48
7	Basin Characteristics:	
	Forested area less than 50% of basin	1
	Forested area more than 50% of basin:	
	with active logging operation	19
	without logging operation	5
8	Stream Characteristics:	
	Bank Materials:	
	erodible	26
	semi-erodible	20
	non-erodible	5
	Bank Vegetation Cover:	
	dense	8
	moderate	28
	scarce	5
	Stream Stability:	
	unstable	19
	semi-stable	17
	stable	15

VI. SOME OBSERVATIONS ON FLOATING DEBRIS IN RIVERS

Bridge damage inflicted by floating debris is mostly due to the accumulation of debris directly against the structures, which partially or totally blocks the waterway openings. To avoid such occurrences and to minimize damage, the phenomenon of debris accumulation should be closely observed and examined. However, because of diverse attitudes among highway engineers on the degree of its importance as related to the safety and maintenance of bridges, only a limited number of observations by field engineers are available. Their observations will be briefly summarized here for reference.

1. Floating debris is composed mostly of old plants and trees that are scattered along stream channel banks and on channel bars for 10 or more years [7]. Only a landslide or a large bank encavement will bring fresh plants and trees into the stream. Even during the catastrophic flood of 1969 in Nelson County, Virginia, where many landslides were reported, only about 50 percent of the floating debris was found to be fresh.

2. Seldom was debris observed floating in large masses or congregations in a large river. Even massive debris conglomerates brought into the stream all at once due to land avalanches or sudden bank slumping untangled and then floated freely. Perhaps the turbulence inherent in high-velocity flow is vigorous enough to separate the entangled debris. The axes of logs usually line up with the flow direction. Ideas of deflecting debris away from waterway structures have been repeatedly brought up among highway engineers; however, these ideas have not been applied because of the misconception regarding debris floating patterns. It has been generally believed that debris floats in massive congregations and that deflecting debris is very difficult. On the contrary, debris floats in dispersed patterns as shown in Figure 5, and therefore methods of debris deflection should be feasible.

3. In fairly straight streams, floating debris tends to move in the thalweg at the rising stage of a flood and outward to the banks at the receding stage. The reason is not clear, but it could be that the direction of secondary flow changes as the flood moves from the rising to the falling stage. For a channel with a large curvature, floating debris tends toward the outside of the curve regardless of whether the flood is rising or falling. Because the pattern of debris movement can be estimated, it is possible to guide debris through the opening of the bridge downstream. If necessary, a part of the debris may be trapped at several selected locations upstream, and thus the amount of debris lodging on the bridge can be reduced.

4. The rate of accumulation is largely dependent on the concentration of debris and the magnitude of the flood. According to some engineers, for a normal flood, it may take about two to four hours for debris to accumulate to a massive volume where it will pose an actual threat to a bridge. On the other hand, heavy concentrations of debris resulting from landslides, catastrophic floods, or dam breaks, may accumulate so fast that emergency removal of debris

Figure 5 Drifting Pattern of Floating Debris.

from the bridge cannot be accomplished in time. A 91-meter concrete girder bridge over the Henry's Fork River near Rexburg, Idaho, was lost when the Teton Dam ruptured. Large masses of debris carried in the rampant flow were trapped on the open-pile bents and blocked the waterway opening. As a result, the water rose above the deck and more debris was trapped on the superstructure. Because of its heavy concentration, the emergency attempts to remove the debris could not cope with the enormous amount that accumulated rapidly on the bridge components.

5. A great deal of debris usually enters the river during the first big flood of the season. When there are long periods between floods, debris problems can be expected to be greater.

VII. COUNTERMEASURES

Countermeasures now in use may be divided into two groups: (A) forest management and practices at headwater streams, and (B) highway practices at bridge crossings.

A. Forest Management and Practices

Since this is usually not the concern of highway agencies, only a very brief discussion will be included in this report. A detailed discussion on the subject can be found in various publications of forest agencies [10,14,15]. Because of concern that debris produced from logging industries will cause damage downstream, forest agencies have undertaken considerable effort to minimize debris. The countermeasures include reducing the sources of debris, preventing debris from entering streams, and cleaning debris from stream channels.

Although costly, the best method for minimizing the source of debris is cable-assisted felling of trees. This can reduce debris in the form of broken limbs added to streams by about 30 percent from that produced by conventional felling. Stabilization of adjacent hillslopes and streambanks is also essential to prevent landslides and erosion that send large quantities of trees and debris into streams.

Efforts are made to keep tops, broken chunks, limbs and logs out of the stream. Buffer strips 5 to 10 meters wide provide an adequate degree of protection to prevent logging residue from entering the streams. They were found to be effective even when they were not continuous or of large widths. In cutting trees on steep slopes, it is suggested that the stumps should be left high to trap logs and residue rolling downhill from above.

In order to avoid accumulation of debris along the channel, streambeds should be cleaned often without disturbing the balance of the ecological system and keeping channel changes to an absolute minimum. Manual or cable-assisted removal of logs from the stream is generally employed.

B. Highway Practices

Freeboard is recommended mainly as a safety precaution against high water that reaches above the maximum design stage. Floating debris is an aspect involved in the consideration of freeboard. However, in the current determination of freeboard, the conditions of debris and flow characteristics have not been properly considered. Often the arbitrary value of 0.6 meter has been assigned, regardless of debris loading in the stream. Where the source of floating debris is remote, freeboard is less important, but for a bridge over a stream with high potential for floating debris, a careful selection of the freeboard is required.

Rise in stage (or the elevation of flood waters) due to an increase in discharge varies with stream slope, roughness, and geometry of the channel; therefore, it is apparent that the rise in the stage would be different in two streams having different characteristics. The stage-discharge relationship and the discharge-recurrence interval relationship for most rivers in the United States are available. Therefore, investigating the pattern of stage fluctuation of the rivers for floods of various magnitudes is not difficult. If a bridge is designed based on the hydraulic condition of a 50-year flood and if consideration of the safety of the bridge against damage from a 100-year flood is desired, then the freeboard should be determined through a comparison of the stages of the 50-year and the 100-year floods. Increasing freeboard will decrease the probability of debris hazards to a certain degree; however, the cost of construction may increase depending on the geometry of the river crossing and the bridge. If increasing freeboard is costly and undesirable, another alternative, such as design of a lower bridge but with accommodation for the 100-year flood over the bridge, may be considered. In either case, a cost-risk analysis becomes very important.

The risk of partial or total blockage of the waterway opening in times of flooding upstream is important. Flooding downstream will increase when the bridge cannot hold the pressure created by the high water behind it and finally collapses, releasing a large quantity of water at one time. The damage could be disasterous. Lower freeboard may save some construction costs, but the subsequent cost for maintenance and repair must be considered. There are other indirect costs due to the temporary discontinuation of road service while debris is removed and damage repaired. All these factors need to be considered in the cost-risk analysis for the determination of proper freeboard. Details on this procedure are given in a series of reports prepared by the Water Resources Engineers [18].

Since any obstacle in the flow tends to catch debris, pier spacing ought to be greater in streams heavily loaded with debris. In critical cases, a pier should not be placed in the main flow. In the actual determination of pier spacing and span lengths of a bridge, however, the total cost of the bridge in relation to the pier spacing should be carefully studied. The total cost of the bridge generally rises with increasing pier spacing and span length.

It is generally accepted that solid piers with smooth edges be used in streams with an appreciable amount of debris. Column piers with solid web walls resist debris entrapment better than column bents without web walls. For a bridge crossing over the Cache Creek near Madison, California, where two bridges run parallel, web walls were constructed between the piers of the two bridges to prevent lodging of drift. The engineers are satisfied with the performance of the installation.

Where open-pile bents are used, timber or metal cribs as shown in Figure 6 are installed in some States to encase the bents and prevent debris from lodging between them. The effectiveness, however, is largely dependent on the size of the mesh. Cribs with large mesh create a favorable condition to trap debris and may pose problems. Debris hazards to a bridge over the Pigeon Roost Creek near Lewisburg, Mississippi (Case 62) have been frequent and persistent. The first bridge was built in 1950, supported with open-pile bents encased in timber sheathing. The bridge suffered from debris-related damage in 1968 and

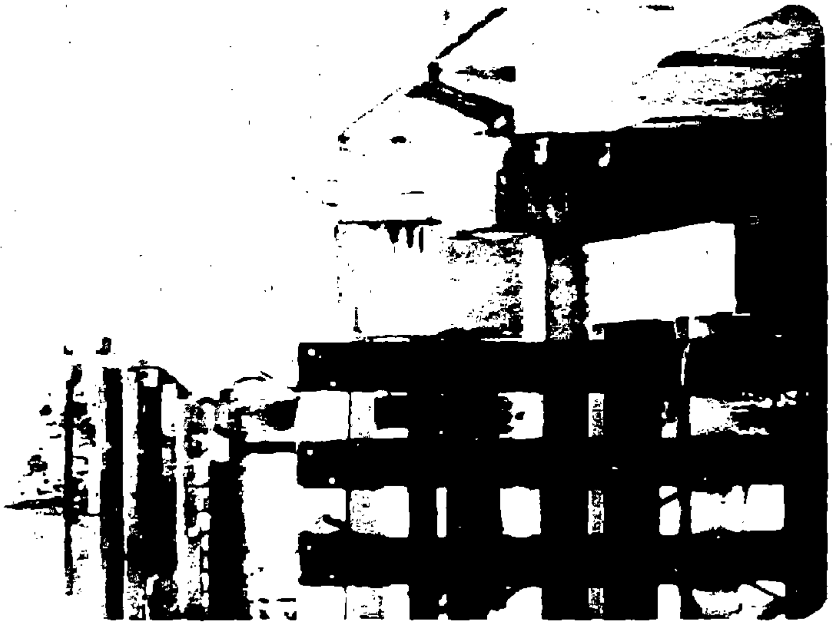


Figure 6 Bridge Piers with Timber Sheathings.

Figure 7 A Bridge on the Pigeon Roost Creek, Lewisburg, Mississippi, after Failure.

1969. In 1973, the bridge was completely destroyed, apparently partially due to debris accumulation on the piers as shown in Figure 7. Whether timber sheathing helped to deflect some debris or not is difficult to determine. Concrete sheathing was used for the new bridge built in 1973. The upstream pile in each bent was slightly slanted in hope that it would serve to deflect debris. The effectiveness of the whole arrangement has not yet been verified; however, it is generally expected to perform better than the earlier timber sheathing.

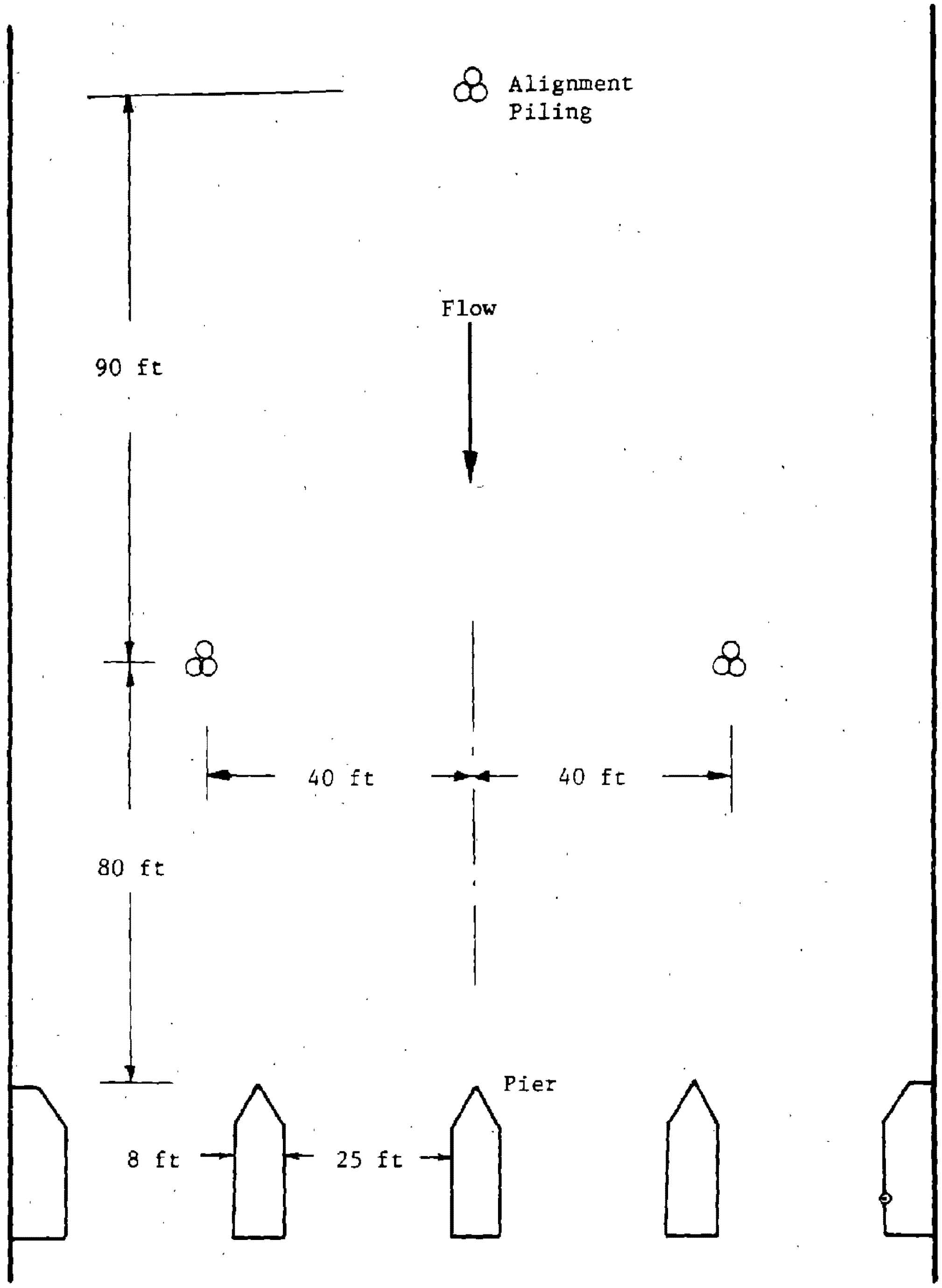
Debris deflectors are placed upstream of piers to divert and guide debris through bridge openings. The U.S. Army Corps of Engineers used this scheme to solve debris problems at the Chena River Flood Control Dam in Alaska. A group of three pilings were placed well in front of the piers as shown in Figure 8 to align logs coming downstream with axes parallel to the flow. The logs were to pass through the openings without incident. After successful laboratory tests in straight flumes, tests were conducted in a model alluvial channel [19]. Unfortunately, the tests were inconclusive because a change in the channel configuration forced the flow to concentrate on one side of the channel, and two of the pilings were no longer in the flow of the channel. In many cases the model logs were aligned with the flow and passed through the structure. However, in some instances, the model logs would form jams around the pilings.

For a bridge over the Homochitto River in Mississippi, a debris deflector, as shown in Figure 9, was placed directly in front of each pier. Approaching debris was to ride up onto the deflector before reaching the pier. As it is pushed by the flow and slides up the ridge of the deflector, it should then be pushed aside and be returned into the main flow downstream. Although this mechanism was claimed by some engineers to function as anticipated, more observations and research are needed to support this claim. This deflector, like the one recommended by the U.S. Army Corps of Engineers, is highly directional: its effectiveness is largely controlled by the direction of stream flow. With a change in flow direction, the deflector could fail to work and in some cases actually worsen the situation.

A fin debris deflector was built in 1976 on the center pier of a bridge over the South Fork of Rock Creek in Clatsop County, Oregon. A 7.5-meter long reinforced concrete retaining wall is stretched out from the center pier and runs parallel to the flow. The debris fin is to align logs coming downstream so that their length is parallel to the flow, to enable them to pass under the bridge without incident. It is still too early to tell whether the debris fin functions as expected.

Where debris hazards persist and the chance of floods overtopping bridges is high, consequences of overtopping can be considered in the design. Bridges with thin decks and low railings can withstand extreme floods even in a submerged condition. Care should be exercised to properly design the connection between deck and pier so that it will not entrap debris.

Where ample space is available and where design geometries do not otherwise preclude their use, flood relief sections (generally at the ends of the bridge) should be provided to relieve excess flow and debris. If part of the flow can be diverted through the relief structure, the bridge may be saved from destruction. The relief section may be eroded and need reconstruction; however, the cost of repairing these structures would be much less than the cost of repairing the bridge itself.



1 ft = 3.05 m

Figure 8 Debris Deflector at the Chena River Flood Control Intake Structure, Alaska.

Figure 9 Debris Deflector on a Bridge Across the Homochitto River, Mississippi.

Although no specific guidelines have been given for highway maintenance practices, regular inspections and cleaning, coupled with emergency removal of debris at bridges has been the general maintenance practice among the state highway agencies. In coping with persistent debris problems in Louisiana, the highway maintenance engineer has suggested the following directives regarding debris removal:

> "In case of high water -- at all bridges known to have drift problems -- (1) maintenance crews should be sent out with proper equipment to start removing drift as it starts building up, and (2) all debris removed should be cut up, loaded and hauled off."

At a glance, debris-related maintenance practices appear to be adequate, but, because of the general lack of funding, state highway maintenance engineers realize the inadequacy in the services. In some instances, debris is hastily picked up from upstream of the problem bridges only to be disposed of directly downstream, ignoring the consequences to the bridges below. Debris still clinging to, and scattered around, bridges for a long time are frequently observed in the field, a reflection of the shortage of maintenance funds.

Debris has been found to be composed mostly of dead trees, travelling downstream very slowly in an alternating sequence of drifting and resting. Debris floats during the rising stage of a flood, drifts downstream generally in the mainflow where the velocity is high, and during the falling stage moves toward the banks, where it is deposited. A long rest period, sometimes of many years, follows. Because of this, an estimate of the volume of debris becomes possible. Aerial surveys or direct counting of debris along stream banks may reveal a reasonable estimate of the volume of debris available for floatation in times of flood. Debris usually does not travel great distances during a single flow event; therefore, an analysis of the debris in the watershed only needs to be done for a few miles upstream of the bridge. Only when an apparent change in watershed characteristics is noted upstream, should the analysis be extended beyond this distance. From this analysis, the potential of debris hazards can be predicted, and the proper measures may be taken in time to alleviate the problems.

By removing large or potentially dangerous debris from streams during low flow, a major disaster may be avoided. Debris can also be dealt with during floods. Since debris moves outward at river bends, trapping and removing debris from selected, convenient locations can be considered. Where ample space is available, a trap basin may be provided in a stream to collect a large amount of debris. The costs of performing such services and of constructing traps should be closely investigated in terms of the advantages that may be gained from their operation.

VIII. SUMMARY

1. Although the role of floating debris in bridge destruction is mostly indirect and the extent of the involvement varies, it is certain that debris poses hazards to highway bridges. Debris hazards are local and infrequent phenomena often associated with larger floods. However, in regions where debris problems exist, they occur repeatedly. Without proper countermeasures, damage to bridges is likely to continue.

2. Most bridge destruction inflicted by debris is due to the accumulation of debris against bridge components. Debris may partially or totally block waterways and create adverse hydraulic conditions that erode pier foundations and embankments. Destruction due to the impact force of vegetable debris is found to be minimal.

3. More debris problems exist in forested areas with active logging operations. Bridges on streams where the channel slope is mild or moderate, in contrast to headwater streams, are more vulnerable to debris-related destruction.

4. Debris hazards occur more frequently in streams with erodible banks. Where vegetation cover on the banks is either very dense or scarce, debris supplies seem to be less, and the number of debris-related bridge destructions is reduced. As for the stability of streams in relation to the debris problem, the study indicates a slightly higher number of incidents occurred in unstable streams.

5. The countermeasures now in use by highway agencies are:

(a) Sufficient freeboard, generally 0.6 meters above the design flood level, to ensure free passage for water and floating debris,

(b) Proper pier spacing and location to provide an adequate waterway to pass debris,

(c) Solid piers where debris loading is heavy,

(d) Debris deflectors where debris may otherwise lodge on piers,

(e) Special superstructure designs, such as thin decks, to prevent accumulation of debris on the structure when the flood stage rises above the deck,

(f) Flood relief sections to relieve debris and excess water through the sections, and

(g) Regular and emergency removal of debris at bridge crossings.

IX. RECOMMENDATIONS FOR FURTHER STUDIES

Although debris problems are generally local and infrequent, they are highly persistent in nature, and often destruction comes in an enormous scale. Therefore, debris problems should not be totally ignored, particularly in debris-loaded streams. Highway engineers must recognize the existence of the problem, quickly identify the trouble areas, and seek economical solutions that best fit the circumstances.

The following further studies are recommended:

1. Development of Debris Deflectors

Some debris deflectors have been used by highway agencies and the U.S. Army Corps of Engineers. The deflectors are either directly attached to piers or located at some distance upstream. Deflectors attached to piers have some disadvantages. Since the deflector is rigidly fastened to the pier, hydraulically it acts as a portion of the pier and tends to form deeper scour, particularly for the flow approaching at an angle. Another shortcoming is that the function of the deflector will be crippled once debris has accumulated on the deflector. A more useful deflector consists of a group of piles properly arranged some distance upstream of the bridge. However, this device is highly directional; with a change in flow direction, the deflector may no longer function as expected and may create undesirable effects. These deflectors can be greatly improved if the flow direction in the stream can be stabilized by some auxiliary structures such as spur dikes which confine and stabilize the flow in a certain direction.

In developing these types of debris deflector systems, more research is required. The flow patterns around structures are complex and cannot be easily predicted based on instinctive feelings or experiences. Therefore, in the determination of proper location and configuration of deflector piles or spur dikes, physical modeling is encouraged to assure the proper functioning of each component at various water stages. Also, the size of debris has to be taken into consideration in the selection of the spacing of deflector piles to avoid debris being trapped between two piles.

2. Development of Debris Traps and Trap Basins

In forest management practices, buffer strips and debris traps have been found to be effective in trapping debris. However, in highway practices, this technique has not yet been explored for fear that the trap may not be able to hold debris for sufficiently long times in swift flow, particularly when trapped debris grows into an enormous size. Another reason is that highway agencies have no jurisdiction over the entire reach of streams, and thus the cleaning of trapped debris may cause some problems. Nonetheless, in light of advanced construction techniques and materials, it is believed that sturdy debris traps can be built at a reasonable cost. A group of pilings tightly bundled together and properly arranged in the likely path of debris is suggested.

Since debris generally moves outward at a stream bend, the traps should be placed there. The exact location of the traps needs to be carefully studied in light of stream stability and cost effectiveness. In a narrow stream, trapping a large volume of debris should be avoided; a large mass of debris may choke the stream and cause undesirable effects. Several small traps along the stream, at a location easily reachable by the maintenance crew, would be a satisfactory arrangement. Such traps, to remain fully effective, must be properly maintained and cleaned periodically.

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APPENDIX A

RESPONSES OF STATES TO DEBRIS-RELATED QUESTIONS

The following questions were asked:

1. Does floating debris cause bridge or stream crossing maintenance problems?
2. Have any measures been utilized to alleviate debris problems or have any studies been made on debris accumulation?
3. Have there been any design or maintenance guidelines developed to counter debris accumulation problems?

RESPONSES OF THE STATES TO QUESTIONS STATED IN THE PREVIOUS PAGE

Question No. State	1	2	3
Alabama	Yes	Sufficient openings are provided for bridges to pass debris.	No
Alaska			
Arizona	No	No	No
Arkansas	Land clearings and logging activities supply the sources of debris.	Removal of debris from streams. Channel training.	Removal of debris in the maintenance manual.
California	Very serious. Bridge embankment failures directly attributed to it.	Studies for indivisual structures. Funneling debris through opening. Usage of solid piers.	Longer span, higher freeboard, debris deflector, fenders, and fins.
Colorado	Some maintenance problem	Provide sufficient freeboard.	No
Connecticut	Maintenance problems. Undermining of piers due to debris by restricting waterway.	No study	2-ft freeboard. Recommend round nosed piers.
Delaware	Minor problem	No study Removal of debris.	Debris grates for culverts.
Florida	No major problem. Only in South Florida, large amounts of floating Hyacinth.	Control of the growth of Hyacinth.	3-ft freeboard. No, except in No.2 answer.
Georgia	Yes	No	No
Hawaii	No	No	No
Idaho			

ft = 3.05 m

RESPONSES OF THE STATES TO QUESTIONS STATED IN THE PREVIOUS PAGE

Question No. / State	1	2	3
Illinois	Some maintenance problem in limited areas.	Debris racks for culverts. Proper location of piers.	2-ft freeboard.
Indiana	Long-standing problems. Waterway blockage and some scour; not much bridge damage	Removal of debris. Piers are kept out of normal channel. Solid wall pier is recommended.	3-ft freeboard.
Iowa	Not significant.	No.	No.
Kansas	Some problems. Increase scour depth at pier foundation.	Web-wallpier is adviced. Utility lines must be installed downstream.	3-ft freeboard.
Kentucky	Some problems but not to the extent that need special effort.	Piers must be out of mainflow.	No.
Louisiana	Suffer damages on state bridges. Debris increases scour depth.	Removal of debris during build-up. Deflection pile with cribbing to deflect drift.	Increase span. Hydraulic booms and poles to push drift under bridge.
Maine	Some ice problems also.	Freeboad, longer span, and improved pier shape have been considered.	
Maryland	No problem except during severe storms.	Freeboard.	No.
Massachusetts			
Michigan	Some maintenance problem	Smooth pier nose.	
Minnesota	Only in the Red River, does debris present big problem.	Proper pier shape. Removal of debris.	3-ft freeboard. Pile bents must be avoided.
Mississippi	In some instance, debris caused structural damage	None other than commonly used design procedures.	No.
Missouri	Some maintenance problem Older open-pile-bent bridges collect debris.	Channel control to align floe with piers. Remove debris during flood.	High deck design. Piers should be out of main channel.

1 ft = 3.05 m

RESPONSES OF THE STATES TO QUESTIONS STATED IN THE PREVIOUS PAGE

Question NO. / State	1	2	3
Montana	Maintenance problems.	Freeboard.	No.
Nebraska	Maintenance problems	Removal of debris. No study.	
New Hampshire			
New Jersey	Some maintenance problem at high stage flow.	Inspection of bridges and removal of debris have been practiced.	No.
New Mexico	No significant problems. Maintenance crew watch problem bridges in flood	Use solid piers at least 25-40 ft apart where debris is expected.	
New York	Some problems	No formal study. Design of drainage opening based on debris ratings.	2-ft freeboard above 50-year flood.
North Carolina	Some minor problems	Longer span. Removal of debris. No study.	No except answered in No. 2 question.
North Dakota			
Ohio	Long-standing problem, but not much damage. Some maintenance problem	Solid wall piers.	3-ft freeboard.
Oklahoma	Maintenance problems.	No study. Sufficient freeboard. Removal of debris.	No.
Oregon	Maintenance problems.	Measures(not specified) have been taken to alleviate debris problem	No guidelines.
Pennsylvania	No problem under normal condition.	No.	Round nosed pier. Freeboard.
Rhode Island			
Nevada			

1 ft = 3.05 m

RESPONSES OF THE STATES TO QUESTIONS STATED IN THE PREVIOUS PAGE

Question No. State	1	2	3
South Carolina	Minor problems in some restricted waterways. Edgefield County.	Removal of debris. Longer spans.	No.
South Dakota	Limited extent.	Freeboard.	No.
Tennessee	Debris problems exist. Two bridge failures due to debris in recent yrs.	Research: project-by-project bases. Longer spans.	Bridge inspection program. Additional freeboard.
Texas	In some areas, debris presents maintenance problems.	Sufficient freeboard that gives more opening for floating debris.	No.
Utah	Maintenance problems.	Sufficient freeboard.	No.
Vermont	Yes.	Just started to put trash rack for culverts	
Virginia	No problem except in severe storms.	Sufficient freeboard.	
Washington	Any pier will catch debris that blocks water way and increases scour.	Debris removal. Proper location of piers	For large debris, impact force must be estimated.
West Virginia	No problem except in severe storms.	Sufficient freeboard.	No.
Wisconsin	Big problem.	Debris deflector.	No.
Wyoming	Limited extent.	Freeboard.	No.

APPENDIX B

FORM FOR DEBRIS HAZARD SURVEY

The form given in the following two pages was used to collect the data for the debris hazard survey.

APPENDIX B

PRELIMINARY SURVEY OF
DEBRIS HAZARDS AT BRIDGE CROSSINGS

Data Provided by R. W. Schwartz
VDH&T, Lynchburg, Va.

Date: 8-9-77

I SITE LOCATION OF DEBRIS DAMAGE:

State: VA ; County: Nelson ; Rt. 29(6)
Stream crossed: Rockfish ; ___ mi from At Woods Mill

II BRIDGE DESCRIPTION:

Year Built; 1966 ; Type; 6-Comp.Steel Beam Spans, 2 Col. Concrete Piers on
Length: 406 ft ; Minimum Span Length: 68 ft Piles and shelf Abutments
Clearances: from Riverbed: 20 ft ; from Highest Water Mark: 2 ft over deck
Pier: ☐ Single; ☐ Double; ☒ Multiple; ☒ with Web; ☐ without Web

III DAMAGE ATTRIBUTED TO DEBRIS:

Date of Occurrence: 8/20/19 69
Bridge Components Damaged:

Damage at \ Degree of Damage	Major	Some	Minor	Estimated Cost
Super Structure			X	$10,000
Substructure	X			15,000
Approaches	X			15,000

IV CHARACTERISTICS OF DEBRIS:

Type: ☒ Timber; ☐ Ice; ☐ Others: __________
Size: Typical Length: ☐ Less than 5 ft; ☐ 5-10 ft; ☒ Over 10 ft
Typical Width: ☒ Less than 5 ft; ☐ 5-10 ft; ☐ Over 10 ft

V DESCRIPTION OF DAMAGE (Attach Photographs and Sketches if available)

Effect on	Super Structure		Substructure		Approaches	
	Major	Minor	Major	Minor	Major	Minor
Debris Accumulation on	X		X		X	
Debris Impact on	X		X		X	

Add narrative description of damages:

Three of six spans completely blocked with debris forcing water under other three spans and undermining two piers, slab riprap one abutment footing debris heavily scarred paint on structural steel.

---

1 ft = 3.05 m

APPENDIX B (Continued)

Virginia
Rt. 6, #1123
Nelson County

PRELIMINARY SURVEY OF

DEBRIS HAZARDS AT BRIDGE CROSSINGS
(continued)

VI CHARACTERISTICS OF FLOOD ASSOCIATED WITH THE DEBRIS DAMAGE:
Discharge: 71,000 cfs
Recurrence Interval: 250 year Rt. 634

VII STREAM CHARACTERISTICS:
Bed Material: Silt 5 %; Sand 20 %; Cobbles 10 %; Boulders 65 %
Streambed Slope: ☐ Mild; ☒ Moderate; ☐ Steep
Bank Material: Erodible; XX Semi-erodible; Non-erodible
Vegitation along Banks: ☐ Thick; ☒ Some; ☐ Sparce
Stability of Stream Channel; ☐ Instable; X☒ Semi-stable; ☐ Stable
River Improvement: ☐ Reservoir; ☐ Channel Training; ☐ Others None

VIII BASIN CHARACTERISTICS:
Land Use: Forest 70 %; Agriculture 30 %; Urban Area ___ %
Lumbering Operations: ☐ Very Active; ☒ Active; ☐ None
Landslides : ☐ Often; ☒ Sometimes; ☐ None
Extensive August, 1969

APPENDIX C
CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. Descriptions	1	2	3
Location:			
State	New York	New York	New York
County	Allegany	Allegany	Chemung
Highway No.	Village Road	31	17
Stream	Genesee River	Genesee River	Newton Creek
Bridge Description:			
Year Built	1900	1935	1954
Type	Truss	Through Truss	I-Beam
Length(ft;m)	138(45)	150(49)	210(69)
Clearance From Bed	--	16(5.3)	12.5(4.1)
Pier Type	Single	Single	Double
Damage:			
Date	June, 1972	June, 1972	June, 1972
Superstructure	None	Major	--
Substructure	Minor	Major	--
Approaches	Minor	Major	--
Debris:			
Typical Length	Less than 5 ft(1.6m)	Less than 5ft(1.6m)	Less than 5ft(1.6m)
Typical Width	"	"	"
Accumulation on			
Superstructure	Some	Plenty	--
Substructure	Some	Plenty	Some
Approaches	--	Plenty	--
Impact Damage on			
Superstructure	--	--	--
Substructure	Some	--	--
Recurrence Interval of Flood(years):	--	100	50
Stream Characteristics:			
Slope	Mild	Mild	Moderate
Bed Materials	Silt(70%);Sand(30%)	Silt(70%);Sand(30%)	Silt(60%);Sand(25%)
Bank Materials	Semi-erodible	Erodible	Semi-erodible
Vegetation on Banks	Scarce	Some	Some
Stream Stability	Semi-stable	Instable	Stable
Basin Characteristics:			
Land Uses			
Forest(%)	--	65	50
Agriculture(%)	--	25	35
Urban(%)	--	10	15
Logging Operation	None	None	None
Landslides	Sometimes	Sometimes	None
Remarks	Max. flood discharge beyond the capacity of gage.	Bridge replacement cost $745,621. Flood discharge higher than the Max. previous discharge.	Debris: old bridge from upstream.

CASES OF DEBRIS HAZARDS TO BRIDGES

Descriptions \ Case No.	4	5	6
Location:			
State	Tennessee	Tennessee	Pennsylvania
County	Dyer	Hardin	Lycoming
Highway No.	5-8005	142	LR-291
Stream	Obion River	Owl Creek	Big Bear
Bridge Description:			
Year Built	1959	1930	1932
Type	--	--	Reinforced Conc. T
Length(ft;m)	380(125)	205(67)	45(15)
Clearance From Bed	--	20(6.6)	7(2.3)
Pier Type	--	Multiple piers	None
Damage:			
Date	1/14/1974	3/4/1977	9/26/1975
Superstructure	Major	Major	Moderate
Substructure	Major	Major	Major
Approaches	--	--	Major
Debris:			
Typical Length	--	--	5-10 ft(1.6-3.2 m)
Typical Width	--	--	Less than 5ft(1.6m)
Accumulation on			
Superstructure	--	--	Some
Substructure	Plenty	Plenty	Plenty
Approaches	--	--	Plenty
Impact Damage on			
Superstructure	--	--	Minor
Substructure	--	--	Major
Recurrence Interval of Flood(years):	5	--	75
Stream Characteristics:			
Slope	--	--	Moderate
Bed Materials	Erodible	Erodible	Sand(40%);Cobble(35%)
Bank Materials	--	--	Semi-erodible
Vegetation on Banks	--	--	Thick
Stream Stability	--	--	Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)	--	--	100
Agriculture(%)	--	--	0
Urban(%)	--	--	0
Logging Operation	None	None	Very active
Landslides	None	None	None
Remarks	Report filed by the Highway Department & USGS clearly stated that debris was one of the factors for excessive scouring at pier foundations.	Upstream bridge with solid piers survived because less debris accumulations.	Debris blocked water way opening,causing a built up of water. Replacement cost $281,610. Water mark:0.7ft (0.2 m) on beam.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. Descriptions	7	8	9
Location:			
State	Pennsylvania	Pennsylvania	Pennsylvania
County	Bradford	Wyoming	Wyoming
Highway No.	8066	LR 11, TR 309	LR 65041
Stream	Chemung River	Susquehanna River	Susquehanna River
Bridge Description:			
Year Built	1900	1900	1900
Type	Through Steel Truss	Steel Truss	Steel Truss
Length(ft;m)	793(241)	800(244)	1081(330)
Clearance From Bed	20(6.1)	27(8.2)	33(10)
Pier Type	Single	Single	Single
Damage:			
Date	6/23/1972	6/23/1972	6/23/1972
Superstructure	Major	Major	Major
Substructure	Minor	Minor	Major
Approaches	None	Minor	Minor
Debris:			
Typical Length	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)
Typical Width	--	""	--
Accumulation on			
Superstructure	--	--	Plenty
Substructure	--	Plenty	Some
Approaches	--	Some	Some
Impact Damage on			
Superstructure	Major	Major	Major
Substructure	Minor	--	Minor
Recurrence Interval of Flood(years):	300	300	300
Stream Characteristics:			
Slope	Moderate	Mild	Mild
Bed Materials	Cobble(50%);Boulder (30%)	Cobble(50%);Boulder (30%)	Cobble(50%);Boulder (30%)
Bank Materials	Erodible	Non-erodible	Semi-erodible
Vegetation on Banks	Scarce	Some	Some
Stream Stability	Semi-stable	Stable	Stable
Basin Characteristics:			
Land Uses			
Forest(%)	90	90	90
Agriculture(%)	9	9	9
Urban(%)	1	1	1
Logging Operation	Active	Active	Active
Landslides	None	None	None
Remarks	All spans washedout by debris. Peplacement cost: $1,000,000. Water overtopped.	Debris: timber,mobil homes, steel drums, parts of homes. Floating debris impact with steel truss caused damage; nose of piers were loaded with debris. Cost of damage:$2,700,000. Water overtopped.	Debris pushed 2 spans off. The two other spans were filled with debris about 5-ft(1.5m) above floor Cost of damage: $1,300,000 Water overtopped.

Case No. Descriptions	10	11	12
Location:			
State	Pennsylvania	Pennsylvania	Illinois
County	Bradford	Westmoreland	Pike
Highway No.	8077	64229	US 36
Stream	Susquehanna River	Jacobs Creek	McCraney Creek
Bridge Description:			
Year Built	1900	--	1932
Type	Steel Deck Truss	R.C. Slab	R.C. Deck Girder
Length(ft;m)	1405(431)	17(5.2)	100(31)
Clearance From Bed	21(6.4)	6(1.8)	20(6.1)
Pier Type	--	None	Single
Damage:			
Date	6/23/1972	6/25/1972	4/21/1973
Superstructure	Major	Minor	Major
Substructure	Minor	Minor	Major
Approaches	None	Major	Minor
Debris:			
Typical Length	Over 10 ft(3.1m)	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)
Typical Width	--	Less than 5ft(1.5 m)	"
Accumulation on			
Superstructure	--	Plenty	None
Substructure	--	Plenty	Plenty
Approaches	--	Plenty	None
Impact Damage on			
Superstructure	Major	Minor	Minor
Substructure	Minor	Minor	Minor
Recurrence Interval of Flood(years):	300	50	100
Stream Characteristics:			
Slope	Mild	Steep	Moderate,Steep
Bed Materials	Cobble(50%);Boulder (30%)	Cobble(50%);Boulder (30%)	Sand and Cobbles
Bank Materials	Non-erodible	Erodible	Erodible
Vegetation on Banks	Some	Some	Some
Stream Stability	Stable	Instable	Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)	90	90	80
Agriculture(%)	9	10	20
Urban(%)	1	0	0
Logging Operation	Active	None	Active
Landslides	None	None	None
Remarks	Five spans washedout by timber debris impact. Replacement cost: $1,500,000. Water overtopped.	Channel was choked for 1/4 mile(400 m), 8 ft(2.4 m) depth with cobbles and boulders. Cost of damage: $11,000. Water overtopped.	Debris at center pier increased scour depth under the foundation and piling causing settlement of the pier. Cost of damage: $90,000.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. Descriptions	13	14	15
Location:			
State	Virginia	Virginia	Virginia
County	Halifax	Compbell	Nelson
Highway No.	658	633	639
Stream	Dan River	Seneca Creek	Tye River
Bridge Description:			
Year Built	1963	1965	1963
Type	Steel Beam	Steel Beam	Steel Beam
Length(ft;m)	321(98)	206(63)	235(72)
Clearance From Bed	24(7.3)	15(4.6)	24(7.3)
Pier Type	Multiple	Double	Double without Web
Damage:			
Date	--	6/21/1972	8/20/1969
Superstructure	Minor	Minor	Major
Substructure	Some	Minor	Major
Approaches	Some	Minor	Major
Debris:			
Typical Length	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)
Typical Width	Less than 5ft(1.5m)	Less than 5ft(1.5m)	Less than 5ft(1.5m)
Accumulation on			
Superstructure	Plenty	Plenty	Plenty
Substructure	Plenty	Plenty	Plenty
Approaches	Some	Some	Plenty
Impact Damage on			
Superstructure	Minor	Major	Major
Substructure	Minor	Minor	Minor
Recurrence Interval of Flood(years):	50	50	250
Stream Characteristics:			
Slope	Mild	Moderate	Moderate
Bed Materials	Silt(20%);Sand(60%)	Cobble(60%);Boulder (20%)	Sand and Cobbles
Bank Materials	Erodible	Semi-erodible	Semi-erodible
Vegetation on Banks	Some	Thick	Some
Stream Stability	Instable	Semi-stable	Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)	60	70	70
Agriculture(%)	30	30	30
Urban(%)	10	0	0
Logging Operation	None	Active	Active
Landslides	None	None	Sometimes(extensive)
Remarks	Debris scarred paint on steel beams. One abutment undermined and piling exposed. Cost of damage: $15,000. Water overtopped.	Debris scarred paint on steel beams, blocked approximately 50% of hydraulic opening. Cost of damage: $7,000. Water overtopped.	Both piers collapsed If they were web-walls or solid piers, probably would not have collapsed. Replacement cost: $145,000. Water overtopped.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. Descriptions	16	17	18
Location:			
State	Virginia	Virginia	Virginia
County	Nelson	Nelson	Pittsylvania
Highway No.	29 (6)	623	729
Stream	Rockfish	Rockfish	Burch Creek
Bridge Description:			
Year Built	1966	1971	1962
Type	Steel Beam	Steel Beam	Concrete T-Beam
Length(ft;m)	406(124)	158(48)	115(35)
Clearance From Bed	20(6.1)	20(6.1)	11(3.4)
Pier Type	Multiple with Web	Multiple with Web	Multiple without Web
Damage:			
Date	8/19/1969	6/21/1972	3/30/1975
Superstructure	Minor	Minor	Minor
Substructure	Major	Some	Major
Approaches	Major	Major	Some
Debris:			
Typical Length	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)
Typical Width	Less than 5ft(1.5m)	Less than 5 ft(1.5m)	Less than 5ft(1.5m)
Accumulation on			
Superstructure	Plenty	Plenty	Some
Substructure	Plenty	Plenty	Plenty
Approaches	Plenty	Some	Some
Impact Damage on			
Superstructure	Major	Minor	Minor
Substructure	Major	Minor	Major
Recurrence Interval of Flood(years):	250	250	--
Stream Characteristics:			
Slope	Moderate	Moderate	Mild
Bed Materials	Sand(20%);Boulder(	Sand(20%);Boulder(	Silt, Sand, Cobbles
Bank Materials	Semi-erodible 65%)	Non-erodible 65%)	ERodible
Vegetation on Banks	Some	Some	Thick
Stream Stability	Semi-stable	Semi-stable	Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)	70	70	60
Agriculture(%)	30	30	40
Urban(%)	0	0	0
Logging Operation	Active	Active	Active
Landslides	Sometimes	Sometimes	None
Remarks	Three of six spans completely blocked with debris forcing water under other 3 spans and undermining two piers. Cost of damage: $40,000. Water overtopped.	Tree scarred paint on beams. Partially blocked channel. Cost of damage: $18,000. Water overtopped.	Debris partially blocked opening at piers forcing water under end spans resulting in undermining of both abutments. Cost of damage: $12,000.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. Descriptions	19	20	21
Location:			
State	Virginia	Virginia	Virginia
County	Nelson	Lee	Buchanan
Highway No.	626	654	617
Stream	Tye River	Powell River	Levisa River
Bridge Description:			
Year Built	1969	1935	1925
Type	Steel Beam	Steel Truss	Truss
Length(ft;m)	387(118)	252(77)	154(47)
Clearance From Bed	30(10)	36(11)	23(7)
Pier Type	Multiple with Web	Double	None
Damage:			
Date	8/20/1969	4/3/1977	4/3/1977
Superstructure	Major	Major	Some
Substructure	Major	Minor	None
Approaches	Major	Minor	None
Debris:			
Typical Length	Over 10 ft(3.1 m)	5-10 ft(1.5-3.1 m)	5-10 ft(1.5-3.1 m)
Typical Width	Less than 5ft(1.5m)	Less than 5ft(1.5m)	5-10 ft(1.5-3.1 m)
Accumulation on			
Superstructure	Plenty	Plenty	Plenty
Substructure	Plenty	Plenty	--
Approaches	Plenty	Some	--
Impact Damage on			
Superstructure	Major	Major	Major
Substructure	Minor	Minor	--
Recurrence Interval of Flood(years):	--	100	100
Stream Characteristics:			
Slope	Moderate	Mild	Moderate
Bed Materials	Cobble(50%);Boulder	Silt, Sand, Cobbles	Silt, Sand, Cobbles
Bank Materials	Semi-erodible (25%)	Semi-erodible	Semi-erodible
Vegetation on Banks	Some	Some	Some
Stream Stability	Semi-stable	Stable	Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)	70	45	60
Agriculture(%)	20	40	5+30(Strip Mining)
Urban(%)	2	15	5
Logging Operation	Active	None(but Strip Mining)	Some
Landslides	Sometimes	Rarely	Rarely
Remarks	High water and debris swept three spans away, overturned 2 piers. Cost of damage: $120,000. Water overtopped.	Debris consisted of trees and trash. Bridge was washed out. Cost of damage: $271,000.	Debris consisted of trees, trash, mobil homes, cars, and storage tanks.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. Descriptions	22	23	24
Location:			
State	Virginia	Virginia	Virginia
County	Wise	Scott	Dickenson
Highway No.	605	619	685
Stream	Powell River	Clinch River	Russell Fk. River
Bridge Description:			
Year Built	1927	1949	1954
Type	Truss with Steel Beam	Steel Beam	Through Truss
Length(ft;m)	210(64)	120(37)	154(47)
Clearance From Bed	22(6.7)	11(3.4)	24(7.3)
Pier Type	Double	Single with Web	None
Damage:			
Date	4/3/1977	4/3/1977	4/3/1977
Superstructure	Major	Major	Major
Substructure	Major	Major	Minor
Approaches	Minor	Major	Minor
Debris:			
Typical Length	Over 10 ft(3.1 m)	5-10 ft(1.5-3.1 m)	Over 5 ft(1.5 m)
Typical Width	5-10 ft(1.5-3.1 m)	Less than 5ft(1.5m)	5-10 ft(1.5-3.1 m)
Accumulation on			
Superstructure	Plenty	Some	Plenty
Substructure	Plenty	Plenty	Some
Approaches	Some	Some	Some
Impact Damage on			
Superstructure	Major	Minor	Major
Substructure	Minor	Major	Minor
Recurrence Interval of Flood(years):	100	100	100
Stream Characteristics:			
Slope	Moderate	Moderate	Moderate
Bed Materials	Silt(20%);Cobble(75%)	Sand(10%);Cobble(80%)	Silt, Sand, Cobbles
Bank Materials	Semi-erodible	Erodible	Semi-erodible
Vegetation on Banks	Some	Thick	Thick
Stream Stability	Stable	Instable	Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)	50	90	55
Agriculture(%)	10+30(Strip Mining)	10	10+30(Strip Mining)
Urban(%)	10	0	5
Logging Operation	None	Minor	Some
Landslides	Sometimes	None	Occasionally
Remarks	Bridge completely destroyed by debris consisted of trees and vehicles. Cost of damage:$262,000. Water reached to the bottom of the deck.	Scour caused failure Debris consisted of trees and trash. Cost of damage: $ 159,000.	Truss span washedout Debris: trees and vehicles. Cost of damage: $200,000. Water reached to the bottom of the deck.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. Descriptions	25	26	27
Location:			
State	South Dakota	South Dakota	South Dakota
County	Pennington	Pennington	Laurance
Highway No.	US 79	--	--
Stream	Box Elder Creek	Cleghorn	Spearfish
Bridge Description:			
Year Built	1939	1965	1949
Type	Continuous Concrete	Continuous Concrete	I-Beam
Length(ft;m)	386(118)	60(18)	107(32)
Clearance From Bed	9(2.7)	--	5(1.5)
Pier Type	Double with Web	None	--
Damage:			
Date	6/13/1971	--	--
Superstructure	Major	Major	Some
Substructure	Major	Major	Major
Approaches	Major	Major	Some
Debris:			
Typical Length	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)
Typical Width	Over 10 ft(3.1 m)	Less than 5ft(1.5m)	Less than 5ft(1.5m)
Accumulation on			
Superstructure	Plenty	plenty	Plenty
Substructure	" "	" "	" "
Approaches	" "	" "	" "
Impact Damage on			
Superstructure	Major	Major	Major
Substructure	Major	Major	Major
Recurrence Interval of Flood(years):	100	100	100
Stream Characteristics:			
Slope	Moderate	Steep	Moderate
Bed Materials	Cobble(90%);Boulder (10%)	Cobble(70%);Boulder (30%)	Sand(30%);Cobble(80%)
Bank Materials	--	Erodible	Erodible
Vegetation on Banks	Some	Some	Some
Stream Stability	Instable	Instable	Instable
Basin Characteristics:			
Land Uses			
Forest(%)	90	95	60
Agriculture(%)	8	4	30
Urban(%)	2	1	10
Logging Operation	Active	Active	Active
Landslides	None	None	None
Remarks	Cost of damage: $300,000. Water overtopped.	Cost of damage: $80,000 Water overtopped.	Water overtopped.

CASES OF DEBRIS HAZARDS TO BRIDGES

Descriptions / Case No.	28	29	30
Location:			
State	South Dakota	South Dakota	Louisiana
County	Pennington	Pennington	Acadia
Highway No.	US 79	I-90	LA 97
Stream	Rapid Creek	Box Elder Creek	B. Nezpigve
Bridge Description:			
Year Built	1930	1959	1937
Type	Cont. Concrete Slab	Cont. Concrete Slab	Plate Girder
Length(ft;m)	119(36)	306(93)	218(67)
Clearance From Bed	13(4)	--	--
Pier Type	Double	Multiple without Web	Double
Damage:			
Date	6/9/1972	6/9/1972	1954
Superstructure	Major	Major	None
Substructure	Major	Major	Some
Approaches	None	None	None
Debris:			
Typical Length	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)	Over 10 ft(3.1 m)
Typical Width	Less than 5ft(1.5m)	Less than 5ft(1.5m)	Over 10 ft(3.1 m)
Accumulation on			
Superstructure	Plenty	Plenty	None
Substructure	Plenty	Plenty	Plenty
Approaches	None	None	None
Impact Damage on			
Superstructure	Major	Major	None
Substructure	Major	Major	Minor
Recurrence Interval of Flood(years):	100	100	
Stream Characteristics:			
Slope	Moderate	Steep	Moderate
Bed Materials	Silt(20%);Cobble(80%)	Cobble(80%);Boulder(20%)	--
Bank Materials	Erodible	ERodible	Semi-erodible
Vegetation on Banks	Thick	Some	Thick
Stream Stability	Unstable	Unstable	Stable
Basin Characteristics:			
Land Uses			
Forest(%)	90	95	--
Agriculture(%)	0	3	--
Urban(%)	10	2	--
Logging Operation	Active	Active	Active
Landslides	None	None	None
Remarks	Water reached to the bottom of the deck.	Water overtopped. Debris consisted of trees, rocks and cobbles.	Accumulated debris from previous flood caught fire damaging concrete piers and timber piling. Cost of Damage: $15,000.

CASES OF DEBRIS HAZARDS TO BRIDGES

Descriptions / Case No.	31	32	33
Location:			
State	Louisiana	Louisiana	Louisiana
County	Acadia	Lafayette	St. Landry
Highway No.	LA 59	Bayou Parkway	SR 93
Stream	B. Plaqumiue	Coulesmine	B. Bourbeau
Bridge Description:			
Year Built	1950	--	--
Type	Treated Timber Tres.	Precast Concrete Slab	Conc. Flat Slab
Length(ft;m)	135(41)	114(35)	180(55)
Clearance From Bed	23(7)	31(9.5)	--
Pier Type	Open pile Bents	Open Pile Bents	Open Pile Bents
Damage:			
Date	April, 1977	--	--
Superstructure	None	None	None
Substructure	Major	None	None
Approaches	None	Some	None
Debris:			
Typical Length	Over 10 ft(3.1 m)	--	Over 10 ft(3.1 m)
Typical Width	Over 10 ft(3.1 m)	--	Over 10 ft(3.1 m)
Accumulation on			
Superstructure	Some	None	--
Substructure	Plenty	Some	--
Approaches	None	None	--
Impact Damage on			
Superstructure	Minor	None	--
Substructure	Major	Minor	--
Recurrence Interval of Flood(years):	--	--	--
Stream Characteristics:			
Slope	Steep	Steep	Moderate
Bed Materials	--	--	--
Bank Materials	Semi-erodible	Erodible	Semi-erodible
Vegetation on Banks	Scarce	Scarce	Some
Stream Stability	Stable	Semi-stable	Stable
Basin Characteristics:			
Land Uses			
Forest(%)	--	--	--
Agriculture(%)	--	--	--
Urban(%)	--	--	--
Logging Operation	None	--	None
Landslides	None	--	None
Remarks	Channel was dredged at highwater. Debris broke piles. Cost of repair: $2,000.	Debris accumulation on bridge forced water to erode canal slope.	Eroded the embankment slope under structure.

CASES OF DEBRIS HAZARDS TO BRIDGES

Descriptions \ Case No.	34	35	36
Location:			
State	Louisiana	Louisiana	Louisiana
County	St. Martin	St. Landry	18
Highway No.	3083	358	585
Stream	B. Alexander	B. Plag. Brule	Bayou Mason
Bridge Description:			
Year Built	1965	1958	1953
Type	Treated Timber Tres.	Treated Timber Tres.	Treated Timber Tres.
Length(ft;m)	240(73)	97(30)	219(67)
Clearance From Bed	32(9.8)	14(4.3)	30(9.2)
Pier Type	Open Pile Bents	Open Pile Bents	Open pile Bents
Damage:			
Date			Yearly
Superstructure			None
Substructure			Minor
Approaches			None
Debris:			
Typical Length	5-10 ft(1.5-3.1 m)	5-10 ft(1.5-3.1 m)	Over 10 ft(3.1 m)
Typical Width	5-10 ft(1.5-3.1 m)	5-10 ft(1.5-3.1 m)	Over 10 ft(3.1 m)
Accumulation on			
Superstructure	--	None	None
Substructure	--	Some	Plenty
Approaches	--	None	None
Impact Damage on			
Superstructure	--	None	None
Substructure	--	Minor	Major
Recurrence Interval of Flood(years):	--	--	--
Stream Characteristics:			
Slope	Moderate	--	Steep
Bed Materials	--	--	Silt(90%);Sand(10%)
Bank Materials	Semi-erodible	--	Semi-erodible
Vegetation on Banks	Some	Some	Some
Stream Stability	--	Semi-stable	Stable
Basin Characteristics:			
Land Uses			
Forest(%)	--	--	0
Agriculture(%)	--	--	100
Urban(%)	--	--	0
Logging Operation	Active	None	None
Landslides	None	Sometimes	Sometimes
Remarks	Debris is removed at least once a year.	Debris and drift cause erosion on canal slope.	Sway bracing, sash bracing and timber piling have some damage due to pulling drift.

Case No. Descriptions	37	38	39
Location:			
State	Louisiana	Louisiana	Louisiana
County	18	18	St. Helena
Highway No.	580		LA 37
Stream	Tensas Bayou		Amite River
Bridge Description:			
Year Built	1958	Nine other bridges are reported to have the similar debris problem as in Case 37.	1955
Type	Treated Timber Tres.		Concrete I-Beam
Length(ft;m)	134(41)		380(116)
Clearance From Bed	19(5.8)		49(15)
Pier Type	Open Pile Bents		Open Pile Bents
Damage:			
Date	Yearly		4/17/1977, 8/5/1977
Superstructure	None		Minor
Substructure	Minor		Major
Approaches	None		None
Debris:			
Typical Length	Over 10 ft(3.1 m)		5-10 ft(1.5-3.1 m)
Typical Width	Over 10 ft(3.1 m)		Less than 5ft(1.5m)
Accumulation on			
Superstructure	None		None
Substructure	Plenty		Plenty
Approaches	None		None
Impact Damage on			
Superstructure	None		Minor
Substructure	Major		Major
Recurrence Interval of Flood(years):			2 ?
Stream Characteristics:			
Slope	Steep		Mild
Bed Materials	Silt(90%);Sand(10%)		Sand(90%);Cobble(10%)
Bank Materials	Erodible		Erodible
Vegetation on Banks	Thick		Some
Stream Stability	Semi-stable		Unstable
Basin Characteristics:			
Land Uses			
Forest(%)	0		50
Agriculture(%)	100		50(Mining)
Urban(%)	0		
Logging Operation	None		Active
Landslides	Often		--
Remarks	Some damage to bracings and pilings due to pulling drift.	Scour around pile bents from the first flood caused settlement;additional steel piles were driven for support. During the later flood, drift piled up causing the structure to bow approximately six inches(0.15m) out of alignment. Cost of damage: $250,000.	

CASES OF DEBRIS HAZARDS TO BRIDGES

Descriptions \ Case No.	40	41	42
Location:			
State	Louisiana	Louisiana	Alaska
County	Livingston	Allen	Matanuska
Highway No.	US 190	LA 26	SR 1
Stream	Amite River	Whisky Chitto Creek	Moose Creek
Bridge Description:			
Year Built	1932	1975	--
Type	STNITR	COPCSS	Steel Girder
Length(ft;m)	1453(442)	7790(2370)	180(55)
Clearance From Bed	--	20(6.1)	--
Pier Type	Single	Double	Single
Damage:		No damage from drift Drift is removed twice a year at annual cost of $1,500.	
Date	4/17/1977		8/10/1972
Superstructure	None		None
Substructure	Some		Major
Approaches	None		Major
Debris:			
Typical Length	Over 5 ft(1.5 m)	Over 5 ft(1.5 m)	
Typical Width			
Accumulation on			
Superstructure	None		
Substructure	Plenty		
Approaches	None		
Impact Damage on			
Superstructure			
Substructure			
Recurrence Interval of Flood(years):			
Stream Characteristics:			
Slope	Mild	Moderate to Steep	Moderate
Bed Materials	Sand(90%);Cobble(10%)	Silt(15%);Sand(85%)	Sand and Gravel
Bank Materials	Erodible	Erodible	Erodible
Vegetation on Banks	Thick	Some	
Stream Stability	Semi-stable	Unstable	
Basin Characteristics:			
Land Uses			
Forest(%)		75	
Agriculture(%)	Mostly Mining	25	
Urban(%)		0	
Logging Operation		Active	
Landslides		Sometimes	
Remarks	During flood, drift built up causing severe scour. Pier foundation was exposed 12 ft(3.7 m)	Debris diverted flow from normal path to erode embankment.	Debris blocked openings under two end spans. Water then concentrated at center with high velocity causing excessive scour.

Case No. Descriptions	43	44	45
Location:			
State	Arkansas	Mississippi	Missouri
County or Town	Batesville	Rosetta	Clearmont
Highway No.	SR 25	SR 33	SR C
Stream	Pfeiffer Creek	Homochitto River	Nodaway River
Bridge Description:			
Year Built	--	1963	1948
Type	Concrete Slab	Concrete Slab	I-Beam
Length(ft;m)	175 (53)	603(184)	415(126)
Clearance From Bed	--	--	--
Pier Type	Double	Timber Piles with Debris Crib.	Single Solid Pier
Damage:			
Date	1975	1955, 1957-1964	1950--1956
Superstructure			
Substructure			
Approaches			
Debris:			
Typical Length			
Typical Width			
Accumulation on			
Superstructure			
Substructure			
Approaches			
Impact Damage on			
Superstructure			
Substructure			
Recurrence Interval of Flood(years):			
Stream Characteristics:			
Slope	Moderate	Moderate	Moderate
Bed Materials	Alluvial, Gravel	Alluvial, Sand	Alluvial, Sand-Silt
Bank Materials	Erodible	Erodible	Erodible
Vegetation on Banks	--	--	--
Stream Stability	Degradation	Unstable	Unstable
Basin Characteristics:			
Land Uses			
Forest(%)	Mining of gravel near bridge		
Agriculture(%)			
Urban(%)			
Logging Operation	Active		
Landslides	--		
Remarks	Accumulation of drift at one end of bridge concentrated flow at piers near opposite end, causing a pier to settle.	Failure of timber pile is attributed to the impact of abundant drift during floods.	Recurrent problem with accumulation of drift at bridge.

CASES OF DEBRIS HAZARDS TO BRIDGES

Descriptions / Case No.	46	47	48
Location:			
State	Canada	Washington	Washington
County or Town	Saskatchewan	Darrington	Mt. Baker
Highway No.	PH 26	Snoqualmie National Forest, Sauk River	Snoqualmie National Forest, Boulder Cr.
Stream			
Bridge Description:			
Year Built	1971	--	1933
Type	Prestressed Conc. Girder	Log Stringer	Steel Pratt Truss
Length(ft;m)	267(81)	135 (41)	220 (67)
Clearance From Bed	--	--	--
Pier Type	Solid Single Pier	Solid Single Pier	None
Damage:			
Date	1974	1975	1974--1975
Superstructure	None	None	None
Substructure	Minor	Major	None
Approaches	Major	Some	Major
Debris:			
Typical Length		--	
Typical Width		--	
Accumulation on			
Superstructure		None	
Substructure		Plenty	
Approaches		Some	
Impact Damage on			
Superstructure		--	
Substructure		--	
Recurrence Interval of Flood(years):	50	13	30
Stream Characteristics:			
Slope	Mild	Steep	Steep
Bed Materials	Alluvial, Sand	Cobble & Boulder	Gravel, Boulder,Sand
Bank Materials	ERodible	Non-erodible	--
Vegetation on Banks	50% Coverage	--	
Stream Stability	Unstable	Stable	Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)			
Agriculture(%)			
Urban(%)			
Logging Operation			Active
Landslides			Frequent
Remarks	Local scour in bridge waterway, attributed to debris lodged against pier.	Log jam formed at the left side of the bridge and diverted flow toward timber pile bent, causing bridge to subside. Log jam was not attributed to low clearance but to the location of bridge on a bend.	Logs and debris diverted the flow against the right abutment, and the abutment was undermined.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. / Descriptions	49	50	51
Location:			
State	Washington	Washington	Wyoming
County or Town	Marysville	Toppenish	Douglas
Highway No.	--	US 97	I-25
Stream	Steamboat Slough	Satus Creek	Box Elder Creek
Bridge Description:			
Year Built	1967	1942	1958
Type	Concrete Deck	Steel I-Beam	Concrete Deck
Length(ft;m)	1025(313)	133(41)	1550 (465)
Clearance From Bed	--	--	--
Pier Type	Four Round Piers	Two Round Open Piers	Two Round Open Piers
Damage:			
Date	1975	1974	1970
Superstructure	None	None	None
Substructure	Major	None	Major
Approaches	None	Major	Some
Debris:			
Typical Length		Over 10 ft(3.1 m)	
Typical Width			
Accumulation on			
Superstructure	None	None	Drift against Pier No. 2 alone.
Substructure	Plenty	Plenty	
Approaches	None	None	
Impact Damage on			
Superstructure			
Substructure			
Recurrence Interval of Flood(years):	--	100	50
Stream Characteristics:			
Slope	Mild	Moderate	Moderate
Bed Materials	Sand, Silt	Alluvial, Gravel	Alluvial, Gravel
Bank Materials	Erosive	Silt-clay	Silt-clay
Vegetation on Banks	--	--	--
Stream Stability			Semi-stable
Basin Characteristics:			
Land Uses			
Forest(%)			
Agriculture(%)			
Urban(%)			
Logging Operation			
Landslides			
Remarks	Scours at several piers were associated with large accumulation of logs. Timber piles installed upstream of the piers were also partly destroyed.	Debris accumulated at the left of the bridge. The right abutment was undermined and the end span collapsed. Cost of repairs: $12,300.	Pier 2 was undermined, attributed, at least in part, to debris. Web were installed between piers as a countermeasure against debris accumulation.

Case No. Descriptions	52	53	54
Location:			
State	California	California	California
County or City	Madison	Sierra	Fernbridge
Highway No.	I- 505	SR- 49	SR- 01
Stream	Cache Creek	Salmon Creek	Eel River
Bridge Description:			
Year Built	1959	1925	1911
Type	Concrete Box Girder	Concrete Box Girder	Continuous T-girder
Length(ft;m)	599(183)	252 (77)	2,405(733)
Clearance From Bed	--	--	--
Pier Type	Solid Rectangular P.	--	Massive Concrete
Damage:			
Date	--	--	12/'55, 2/'60, 12/'64
Superstructure	None	--	--
Substructure	Some	Major	Some
Approaches	Some	Major	Major
Debris:			
Typical Length			
Typical Width			
Accumulation on			
Superstructure	None	--	--
Substructure	Bulky	Bulky	Some
Approaches	None	--	Some
Impact Damage on			
Superstructure	None	--	--
Substructure	None	Impact by boulders	Some
Recurrence Interval of Flood(years):	--	--	See Remarks
Stream Characteristics:			
Slope	Moderate	Steep	Moderate
Bed Materials	Sand -Gravel	Boulder,Cobble,Gravel	Sand
Bank Materials	Silt, Sand	Boulder	--
Vegetation on Banks	--	--	--
Stream Stability	General degradation	Stable	Unstable
Basin Characteristics:			
Land Uses			
Forest(%)	Gravel Mining		
Agriculture(%)			
Urban(%)			
Logging Operation			
Landslides			
Remarks	Drift caused obstruction to flow. Webs placed between piers of parallel bridges to prevent lodging of drift.	Bents were damaged by impact of boulders and accumulation of debris to cause the channel to shift. New bridge(1964) has a freeboard of 8ft(2.4m) and the min. span length of 35ft(11 m).	Log drift punched a hole through abutment 8. Flows overtopped,1955. 1960 flood(10 yr. RI). 1964 flood, the largest since 1911.

Case No. Descriptions	55	56	57
Location:			
State	Nevada	Nevada	Pennsylvania
County or City	Minden	Gardnerville	Morgantown
Highway No.	SR- 88	SR- 56	SR- 10
Stream	Brockliss Slough	E. Fork Carson River	Conestoga Creek
Bridge Description:			
Year Built	1935	1936	1929
Type	Timber	Concrete	Concrete T-beam
Length(ft;m)	75(23)	103 (32)	80(24)
Clearance From Bed	4.5(1.4)	--	11 (3.4)
Pier Type	Timber pile bents	Solid Concrete	Sharp-nosed solid C.
Damage:			
Date	12/3 /1950	12/ 1955	1972
Superstructure	Major	Major	--
Substructure	Major	Major	--
Approaches	Major	--	Major
Debris:			
Typical Length			
Typical Width			
Accumulation on			
Superstructure			
Substructure			
Approaches			
Impact Damage on			
Superstructure			
Substructure			
Recurrence Interval of Flood(years):	--	100	100
Stream Characteristics:			
Slope	Mild	Moderate	Moderate
Bed Materials	Sand	Gravel	Sand
Bank Materials	Silt- Sand	Gravel	Silt- Clay
Vegetation on Banks	Some	--	Some
Stream Stability	Unstable	Semi- stable	Unstable
Basin Characteristics:			
Land Uses			
Forest(%)			
Agriculture(%)			
Urban(%)			
Logging Operation			
Landslides			
Remarks	A large amount of drift was collected at bridge due to inadequate clearance.	Logs and debris piled up near right-bank abutment, causing excess scour at piers. A new bridge with an additional span increased waterway to prevent lodging of debris.	Debris clogged right span, causing channel to shift to left. The left abutment was scoured until the bridge collapsed.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. / Descriptions	58	59	60
Location:			
State	Pennsylvania	Oklahoma	Arkansas
County or City	Orangeville	Calvin	Clover Bend
Highway No.	SR-487	US-75 & US-270	SR-228
Stream	Fishing Creek	Canadian River	Big Running Water Cr.
Bridge Description:			
Year Built	1973	1966	1962
Type	Concrete I-beam	Pres. Conc. Steel B.	Concrete Box Girder
Length(ft;m)	240 (73)	1,260(384)	125 (38)
Clearance From Bed	--	--	--
Pier Type	Round-nosed, Solid P.	Dual columne, Webbed	Three piers
Damage:			
Date	1975	5/21/ 1976	3/1975
Superstructure	None	Major	None
Substructure	Some	Major	Major
Approaches	None	None	None
Debris:			
Typical Length			
Typical Width			
Accumulation on			
Superstructure	--	--	None
Substructure	--	--	Massive
Approaches	--	--	None
Impact Damage on			
Superstructure	--	--	None
Substructure	--	--	None
Recurrence Interval of Flood(years):			
Stream Characteristics:			
Slope	Moderate	Moderate	Moderate
Bed Materials	Gravel	Sand	Silt, Clay, Sand
Bank Materials	Gravel	--	Silt- Sand
Vegetation on Banks	Some	--	Dense
Stream Stability	Unstable	Semi-stable	Stable
Basin Characteristics:			
Land Uses			
Forest(%)			
Agriculture(%)			
Urban(%)			
Logging Operation			
Landslides			
Remarks	General scour near the middle of channel and local scour at pier 1 was attributed to debris pileup at the bridge in that area.	No specific flood was associated with the failure. Logs were found lodged on the steel piling about 20ft(6m) below the normal streambed.	Accumulation of drift caused extensive scour and subsequent bridge damage.

CASES OF DEBRIS HAZARDS TO BRIDGES

Case No. / Descriptions	61	62	62(continued)
Location:			
State	Idaho	Mississippi	
County or City	Rexburg	Lewisburg	
Highway No.	SR-88	SR-305	
Stream	Henry's Fork	Pigeon Roost Creek	
Bridge Description:			
Year Built	1960	1950	
Type	Concrete Girder	Pres. Concrete Beam	
Length(ft;m)	297 (91)	352(107)	
Clearance From Bed	--	--	
Pier Type	Multiple Piles	Steel Piles encased in timber sheeting	
Damage:			
Date	6/1976	4/10/ 1969	4/19/1973
Superstructure	None	Major	
Substructure	Major	Major	Complete Failure
Approaches	Major	None	
Debris:			A new bridge was built in 1973 with the following protective measures: 1. Steel pile bents were encased in concrete sheathing to protect against lodging of drift.
Typical Length			
Typical Width			
Accumulation on			
Superstructure	Massive		
Substructure	Massive		
Approaches			
Impact Damage on			
Superstructure			
Substructure			
Recurrence Interval of Flood(years):			2.The upstream pile
Stream Characteristics:			in a bent with a batter of 3/4 to 12 vertical was placed to act as a drift deflector
Slope	Mild	Mild	
Bed Materials	Sand	Sand	
Bank Materials	Silt- Sand	Silt- Clay	
Vegetation on Banks	--	None	
Stream Stability	Stable	Channelization	
Basin Characteristics:			3.The bridge spans were increased from 24ft(8m) to a minimum of 80ft(24m) to reduce the chance for debris lodging.
Land Uses			
Forest(%)			
Agriculture(%)			
Urban(%)			
Logging Operation			
Landslides			
Remarks	Flooding due to failure of Teton Dam overtopped the bridge. Debris caught on pile bents and built up water. Attempts to remove the debris failed.	In 1968, nose piles were constructed to deflect drift,and timber sheathing was used to encase the pile bents to prevent lodging of debris.	

APPENDIX D

MINUTES OF THE SEMINAR ON DEBRIS PROBLEMS IN THE RIVER ENVIRONMENT

Date: Thursday, June 22, 1978

Place: Transport Building, Room 5503
U.S. Department of Transportation

Program: 1. Debris Hazards to Highway Bridges
by Fred Chang, Professor, University of The District of Columbia, and H. W. Shen, Professor, Colorado State University

As the material presented by these authors was a summary of this report, it will not be repeated here.

2. Forest Management to Reduce the Sources of Debris
by Henry A. Froehlich, Professor, Oregon State University

Floatable debris in and near stream channels in forested watersheds is very common. Landslides were found to be the main cause of tree debris entering small headwater streams during floods, and bank-cutting caused countless trees to be uprooted and fall into the streams. Generally in Oregon, small floating debris is a small portion of the total.

Debris accumulates at the constriction of a flow pass. Culverts will be often plugged by debris, causing the water to overtop the roadway, thus eroding road fills. Constrictions placed upstream of bridges on the other hand may serve as debris traps for protection of the bridges. The trapped debris may be stored on the stream banks.

To minimize the debris problem, efforts should be made to reduce the floatable material in the watercourse. This includes reducing fallen trees entering streams, removal of concentrations of debris, burning dry trees and anchoring debris. Stopping debris before it enters the stream can be accomplished by buffer strips along stream channels. In many instances, buffer strips have been found effective in reducing the debris loading. However, in removing debris loading from areas where it has been naturally high, the buffer strip has been found less effective. Burning seems to have limited success in reducing debris. However, logs should be completely dry for burning to be effective. A major portion of burnt trees was found remaining six years after burning. Therefore, this technique has not been generally recommended.

Directing falling trees has been found successful in reducing debris. Cable should be tied to trees about 13 to 27 meters above ground and the tree should be pulled uphill in the direction opposite the stream. Although it is highly effective, the cost is high.

Mechanical removal of debris is most common. In most cases there is at least a short-term decrease in debris concentration. However, heavy equipment should be used carefully without disturbing the natural condition of the stream. Few instances of utilizing manpower and chain saws for extensive channel clearance have been recorded. There is an obvious limitation for manual cleaning on how far or high the debris may be moved by hand. Where no place exists to move debris, or where it is inaccessible, efforts have been made to anchor the debris in place by barriers cabled together and tied to trees or stumps. These barriers may be constructed of several rows of posts about 1.5 meters apart at right angles to drainage. In some instances debris racks have been used successfully in smaller streams. Their effectiveness in larger streams with high-velocity flow has been debated among engineers.

To solve debris problems at bridges, the maintenance problem should be solved first. The responsibility of the maintenance crew should be spelled out exactly. The entire maintenance program must be well planned and executed.

3. Bridge Maintenance Practices Related to Debris

by Al J. Dunn, Bridge Maintenance Engineer, Louisiana Department of Highways

The extent and quality of maintenance practices is generally controlled by the amount of available funds and political maneuvering. Practically no river in Louisiana is free from debris problems. Yet, because of limited funds, maintenance has not been too effective. When debris accumulation is not bulky, often no action is taken to clear the debris. In one case, debris build-up at a bridge was ignored until it finally jeopardized the safety of the bridge. Then the scour around a pier became so deep that the State had to spend about $150,000 to repair the foundation.

Debris often chokes one side of a bridge opening, forcing all flow to the other side, cutting embankments and causing channel changes. In a river flowing along the border of Louisiana and Texas, rip-rap and jetties have been constructed on the Texas side to protect banks. As a result, bank cutting on the Louisiana side became severe and debris loading in the river increased, costing Louisiana about $40,000 per year for maintenance.

Open-pile bents are vulnerable to debris impact. Much damage inflicted by debris impact has been observed in Louisiana. On the average, the State has to spend about $10,00 to $20,000 to repair each damage. Drag force exerted by debris on the bridge deck sometimes may become large enough to shift the deck. On one occasion, the bridge deck was pushed by debris 0.2 meters off the center line of the bridge.

Open-pile bents of a bridge on Willow Creek, Louisiana, are encased with timber sheathing to prevent debris from lodging on the bents. So far, the performance of the sheathing has been satisfactory.

Debris accumulation at a pier may extend downward as deep as five meters below the water surface. As the water is constricted and sluices down, the bed materials will be severely eroded, causing serious damage to the pier foundation.

Sand and gravel mining in five streams in Louisiana have increased channel changes and bank erosion, and, as a result, added considerably to the debris in the streams. Because of channelization of the Homochitto River, the flow has been eroding the riverbed as well as the banks and bringing more debris into the river. Frequent damage to bridges along the river is partially attributable to debris. Debris deflectors were used but were found not to perform as expected.

Due to the shortage of maintenance crews, debris accumulating upstream of bridges is often hauled out and then immediately dumped downstream, ignoring the consequences to downstream bridges. Time and money are the controlling factors for better maintenance.

☆U.S. GOVERNMENT PRINTING OFFICE: 1979 O—629-850/2409 REGION 3-1

FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C 20590.