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Scour at bridges due to debris Accumalation: A Review

SCOUR AT BRIDGES DUE TO DEBRIS ACCUMULATION: A REVIEW

Jean-Louis BRIAUD[1], Hamn-Ching CHEN[2], Kuang-An CHANG[3], Xingnian CHEN[4], Seung Jae OH[4]

ABSTRACT

Ten percent of all bridges over rivers in the USA are subjected to debris scour. This debris is principally made of tree trunks and other types of vegetation. The debris accumulates at bridges, mostly around piers; this increases the effective size of the pier and leads to a larger scour hole around the pier. Predicting such an increase in scour depth is still very difficult because the research ahs been limited. This article presents the results of a review of the existing knowledge on this topic. It addresses three topics: How much debris comes down rivers? How much debris accumulates at bridges? How deep will the debris scour be?

INTRODUCTION

The problem of debris scour is serious throughout the world (Figs. 1 to 4). Debris, in particular tree trunks, accumulates at bridges and creates a larger obstacle to the flow. The water needs to compensate for that decrease in flow area and erodes the river bottom: this is debris scour. In the USA, it is estimated that about 10% of all bridges over water are subjected to debris scour. This number comes from the database developed by Dave Mueller at the USGS (http://ky.water.usgs.gov/Bridge_Scour/BSDMS/). Indeed in this 507 bridge case histories database, 49 are classified as having debris problems. Doheny (1993) also indicates that for 876 highway bridges surveyed in Maryland, the number of bridges with debris blockage was 120 or 13.7%. Other countries have similar problems as was exposed at the First International Conference on Scour of Foundations organized at Texas A&M University in November 2002 (http://tti.tamu.edu/conferences/scour). This article is a review of the existing knowledge on debris scour. It addresses the following topics. 1. How much debris comes down the rivers? 2. How much of the debris coming down the river accumulates at bridges and what is the shape of the accumulation? 3. Knowing the quantity and shape of the debris, how deep will the scour hole be? 4. Common practice for debris scour calculations. 5. Case histories are then listed and discussed.

Fig. 1 – Example 1 (From Beucler, 2003)

Fig. 2 – Example 2 (From Diehl, 1997)

1. Professor and Holder of the Buchanan Chair, Dpt. of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, USA, (briaud@tamu.edu).
2. Professor, Dpt. of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, USA.
3. Assistant Professor, Dpt. of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, USA.
4. Graduate Student, Dpt. of Civil Engineering, Texas A&M University, College Station, Texas, 77843-3136, USA.

Fig. 3 – Example 3 (From Benn, 2003)

Fig. 4 – Example 4 (Diehl, 1997)

HOW MUCH DEBRIS COMES DOWN RIVERS?

Debris can be classified and HEC-9 (Reihsen and Harrison, 1971) presents such a classification. The most common debris is vegetation (tree trunks and limbs) and ice (in the Northern parts of the country). Ice debris scour is studied at CRREL (Cold Region Research Engineering Laboratory) by Leonard Zabilansky including a case history (monitoring a bridge) and flume tests. Trees falling into rivers represent the most common source of debris however. The debris in rivers is either fresh debris or old debris, but old debris represents the majority. Indeed Chang and Shen (1979) state that floating debris are composed mostly of old plants and trees that are scattered along stream channel banks and on channel bars for 10 or more years. 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 (Chang and Shen, 1979).

The factors influencing the loading of debris into the river (Keller, Tally, 1979, Hogan, 1987) include geology, valley slope, bank erosion, landslide activity, wind-throw, channel width, channel sinuosity, discharge, upstream drainage area, and floatation from upstream. The events leading to tree collapse can be chronic or episodic. Chronic mechanisms include the regular introduction of wood as a result of natural tree mortality or gradual bank undercutting. These processes tend to add small amounts of wood at frequent intervals. In contrast, episodic inputs, including catastrophic wind-throw, fire or severe flood, occur infrequently but can add large amounts of wood to the channel network. The zone which contributes most of the debris is located within 30 m of the river bank (Fetherston et al., 1995).

To quantify debris, Downs and Simon (2001) presented steps to get the necessary input data in the model. **1**. Delineate plots on either bank of the river stretching from the waters edge. **2**. Within each plot measure all trees with a diameter greater than 0.05m at breast height. **3**. Estimate tree height using an angular reading from a known horizontal distance. **4**. Calculate the average tree diameter and tree height. **5**. Calculate the average density of trees in the survey area. Various correlations have been attempted on the basis of local databases. Bilby and Ward (1989) developed such correlations for streams in Western Washington (Fig. 5)**.** Robinson and Beshta (1990) for streams in Southern Alaska also attempted correlations (Fig. 6).

Nakamura and Swanson (1993) observed the interaction between woody debris and channel morphology at mountain streams in Western Oregon and presented the results in tabular form. Braudrick et al. (1997) observed that there were essentially three types of debris transport in rivers (Fig. 7): 1. un-congested transport, 2. congested transport, 3. semi-congested transport.

HOW MUCH DEBRIS ACCUMULATES AT BRIDGES?

Diehl (1997) points out that most debris accumulations form at the water surface as a raft. Logs and smaller pieces of debris accrete to the upstream edge of the raft. The accumulation can grow toward the river bed through accretion of logs on the underside of the raft as they are washed under it by the plunging flow at the upstream edge. Alternatively, the raft can

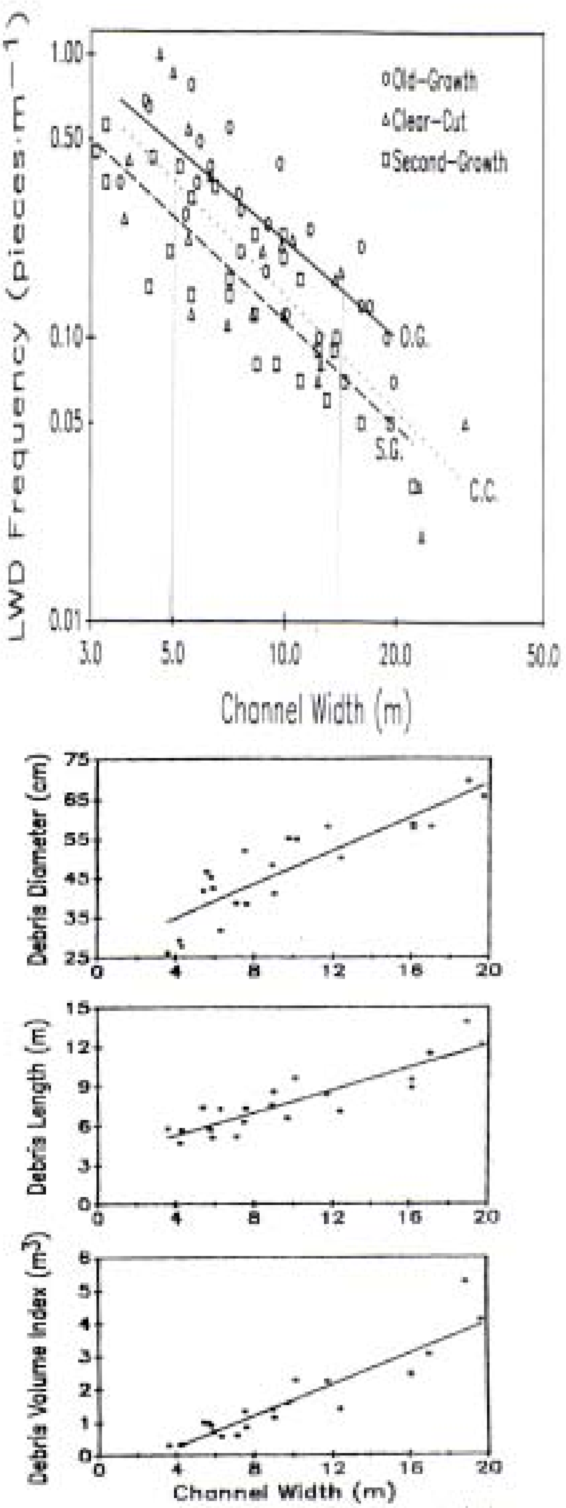

Fig. 5 – Observations from Bilby and Ward (1989) for Streams in Western Washington. (LWD = Large Woody Debris. Frequency = Number of Debris Pieces Divided by the Length of River Containing Those Debris Pieces, Debris Volume Index = Volume of the Debris Piece, L x $\pi D^2/4$)

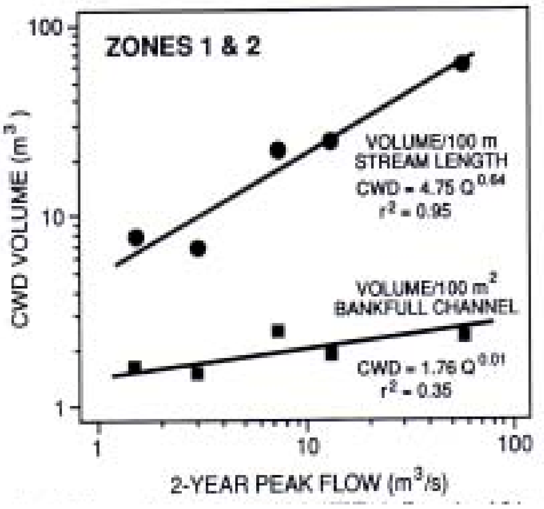

Fig. 6–Observations from Robinson and Beshta (1990) for Streams in Southern Alaska (CWD = Coarse Woody Debris)

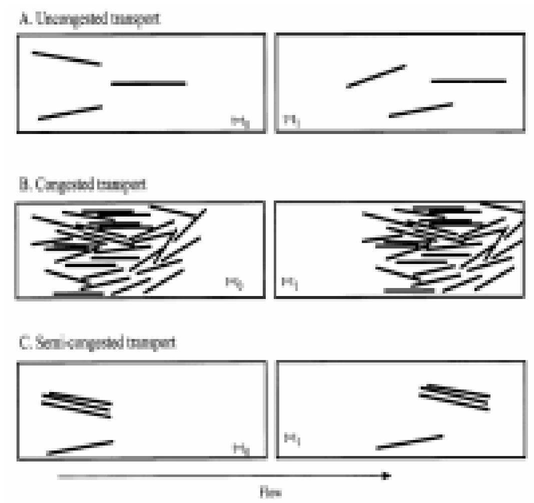

Fig. 7–Debris Transport (Braudrick et al., 1997)

forces on the raft exceed its compressive strength (Kennedy,1962). Most observed debris accumulations fall into two classes: single-pier accumulations (Fig. 4) and span blockages (Fig. 1).

Diehl and Bryan (1993) found that debris jams contained 23 percent of the total debris volume found in the river. Most of the rest of the debris occurred along short reaches of relatively unstable channel.

The shape and size of the accumulation depends on a number of factors. Accumulations may be irregular, but most large accumulations are similar in shape. In the process of formation, logs are added parallel to the upstream edge of the raft. Accumulation is often with a curved upstream edge, and with the upstream nose of the raft near the thalweg. Single-pier accumulations often take on a form roughly resembling the inverted half-cone shape implied by New Zealand's design criteria (Dongol, 1989). The depth of a blockage is limited by the depth of flow. Debris accumulations can extend up to the maximum flood stage even after the flood recedes. The maximum vertical extent of drift observed is about 12 m, but a larger vertical extent of debris seems possible (Diehl, 1997). The maximum width of the common types of debris accumulation is determined by the length of the longest pieces of drift. The width of the channel influences the length of drift delivered to the bridge, and therefore helps to determine accumulation potential and characteristics (Diehl, 1997).

The factors affecting debris accumulation at bridges include: properties of the debris, flow conditions (velocity and depth), channel characteristics, bridge geometry (pier placement, type of pier, span). The properties of the debris refer to the rate of decay of the woody debris; this rate varies within the range of 1% to 3% of mass per year; this means that woody debris can persist for years in the river environment. Many have worked on this problem including Keller and Tally (1979) , Harmon et al. (1986); Andrus et al. (1988), Murphy and Koski (1989); Gippel et al. (1992), Ward and Aumen (1986); Golladay and Webster (1988), Hauer (1989), Sedell et al. (1988). The length of the longest pieces of drift determines the maximum width of the common types of drift accumulation. Throughout much of the United States, the maximum sturdy-log length is 24 m, and may be as long as about 45 m in parts of northern California and the Pacific Northwest.

As shown by Lyn et al. (2003) high flow velocities carry a lot of debris but low flow depths are most favorable to accumulation. The channel width plays an important role in debris accumulation by controlling the maximum size of log that can transported. Correlation work by Diehl and Bryan (1993) and by Diehl (1997) shows the relationship between debris width and channel width (Figs. 8, 9, and 10). With regard to pier placement, Diehl also observes that among 3,581 selected bridges in Tennessee, those with one pier in the channel were several times more likely to have single-pier drift accumulations than bridges with two piers on the banks and none in the channel. The river geometry (a bend for example) also influences the judicious location of the pier to minimize debris accumulation. The type of pier also affects debris. Multiple column piers and piers with exposed pile caps and piles accumulate debris more than single column piers. The span length needs to be compared with the longest log length for the area. A method to estimate the potential for debris accumulation has been devised by Diehl (1997). It consists of two convenient flow charts based on the concept of the design log length and envelopes recommended for design shown below. Methods for estimating a maximum drift-accumulation size for use in bridge design have been recommended for Australia and New Zealand, but not for the United States (American Association of State Highway and Transportation Officials, 1989). Australian design practice assumes that the potential width of drift at a pier is equal to the average

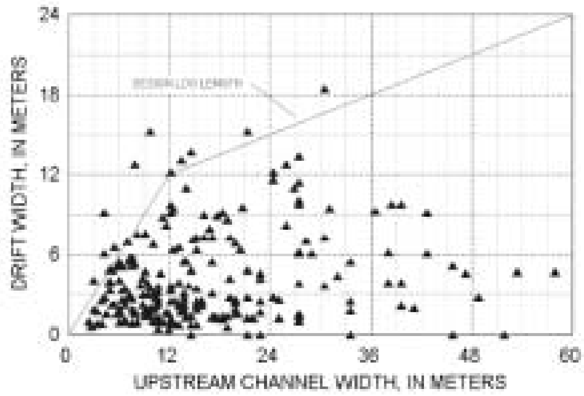

Fig. 8 - Indiana Data (Diehl, 1997)

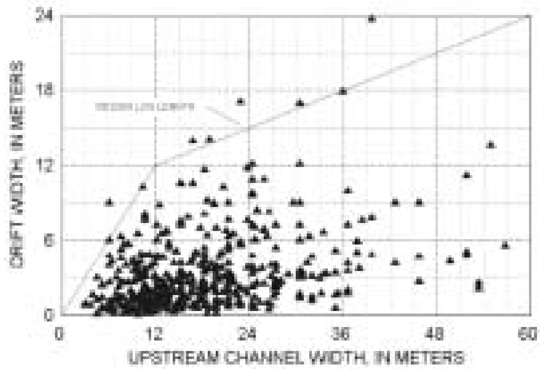

Fig. 9 - Tennessee Data (Diehl, 1997)

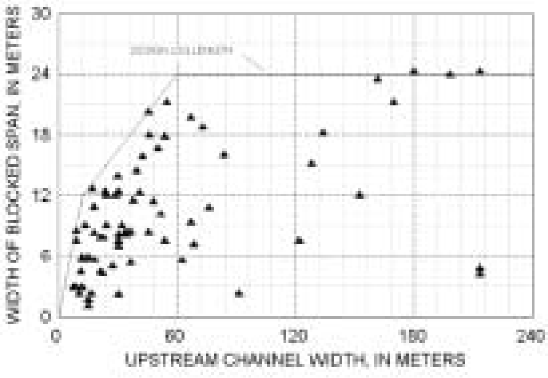

Fig. 10 - Pacific Northwest Data (Diehl, 1997)

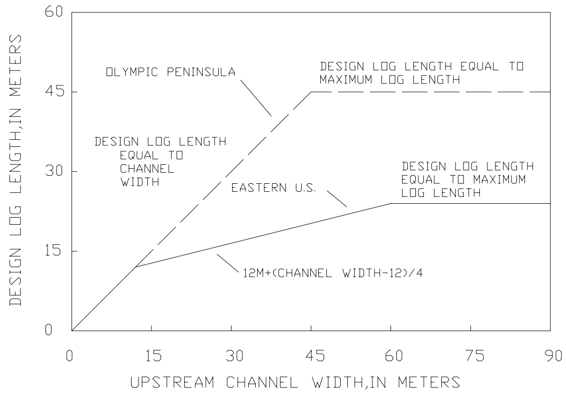

Fig. 11 - Design Chart (Diehl, 1997)

of the adjacent span lengths, up to a maximum of 20 m, and that the minimum assumed vertical depth is 1.2 m (National Association of Australian State Road Authorities, 1976; Wellwood and Fenwick, 1990). The potential width of drift on a submerged bridge superstructure is assumed to be the length of the superstructure. In developed river basins, the assumed minimum potential vertical depth of a drift accumulation is 1.2 m greater than the vertical extent of the submerged superstructure (typically, from low steel to the top of the parapet). The assumed maximum potential vertical depth is 3 m, unless local information indicates that it should be greater. New Zealand's design practice is similar to Australian design practice. A draft design specification states that the potential drift accumulation at a pier can be assumed to be triangular in cross section perpendicular to the approaching flow .The triangle's greatest width (at the water surface) is half the sum of the adjacent span lengths up to a maximum of 15 m. The triangle extends vertically downward along the pier nose to a depth equal to half the total water depth or 3 m, whichever is less (Fig. 12). Diehl (1997) found in his study that the maximum width and depth of drift accumulations exceeded the values used in design in Australia and New Zealand.

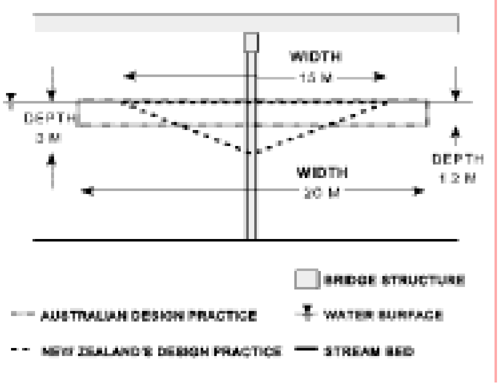

Fig. 12 - Vertical Cross Section of Assumed Maximum Drift Accumulations on Single Piers. (Diehl, 1997)

HOW DEEP WILL THE DEBRIS SCOUR BE?

Once the debris size has been established, then the additional depth of scour created by the debris needs to be estimated. Two methods presently exist in the literature; the HEC-18 Appendix method and the Melville-Dongol method. The HEC-18 Appendix method is quite conservative in that it takes the width of the debris as the pier width (Fig. 13). In another words it assumes that the debris width is constant and extends all the way down to the bottom of the river. Then the regular equations of HEC-18 are used with the new dimensions.

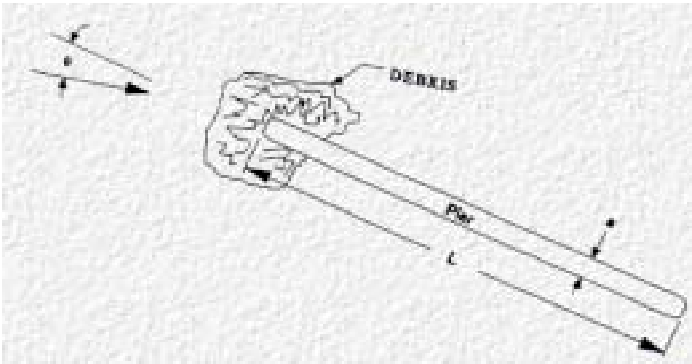

Fig. 13 - HEC-18 Approach (Richardson and Davis (2001)

The Melville Dongol method (1992) was developed from flume tests done at the University of Auckland. For piers without debris, they give:

$$\frac{d_s}{D_e} = 1.872\left(\frac{y}{D_e}\right)^{0.255} \quad (y/D_e < 2.6)$$

$$\frac{d_s}{D_e} = 2.4 \quad (y/D_e > 2.6)$$

Where, d_s is the total scour depth (pier plus debris), D_e is the equivalent pier diameter, and y is water depth. The equivalent pier diameter is calculated by using an equivalent area concept as follows; the effective diameter of the pier with debris accumulation, D_e is given by

$$D_e = \frac{T_d^* D_d + (y - T_d^*)D}{y}$$

where, T_d^* is effective thickness of debris and $T_d^* = 0.52T_d$. The factor 0.52 was determined by evaluating the limits of T_d and D_d / D for the hypothetical case where D is assumed to be zero and the debris is assumed to extend to the base of the scour hole. The diagram indicates that the calculated scour depth for piers with debris accumulation given by the design curve is always more than the measured values.

Other factors such as clear water scour, relative flow depth, bed sediment size, pier shape and approach flow alignment are included using modification factors

$$\frac{d_s}{D} = K_I K_y K_d K_\sigma K_s K_\alpha$$

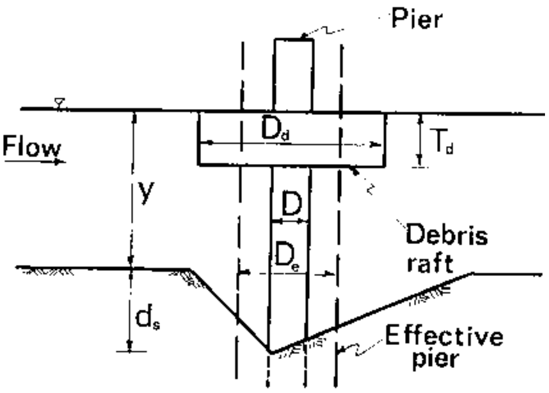

Fig. 14 - Melville and Dongol Method (1992)

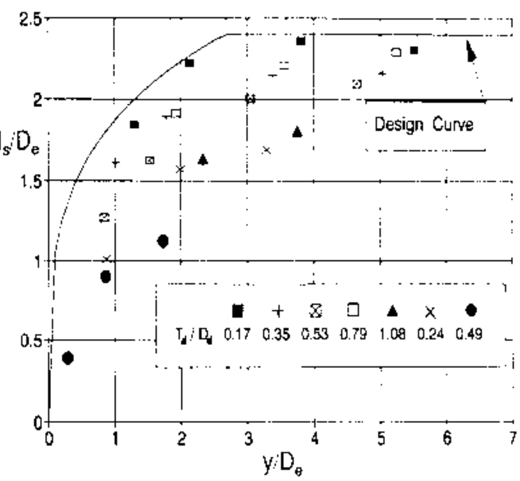

Fig. 15- Melville and Dongol Curve (1992)

where

K_I	Flow intensity factor	K_d	Sediment size factor
K_y	Flow depth factor	K_s	Pier shape factor
K_σ	Sediment gradation factor	K_α	Pier alignment factor

Additional contributions to the prediction of debris scour have been made by Manga and Kirchner (2000) on the shear stress on the river bottom due to the existence of debris around a pier and by Wallerstein and Thorne (1995, 1996, 1997).

CONCLUSIONS

A review of existing knowledge on debris scour at bridge piers was presented. The questions addressed were: How much debris comes down rivers? How much debris accumulates at bridges? How deep will the debris scour be? The answers to those questions found in existing knowledge remain vague. The guidelines in Australia and in New Zealand seem to be the most advanced.

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