ARMORFORM® ARTICULATING BLOCK MAT EROSION CONTROL SYSTEM

Final Report

Experimental Feature Project OR 89-05

Salmon Creek Bridge
Oakridge, Oregon

by

Eric W. Brooks, E.I.T.
Research Specialist, Research Unit

and

Liz Hunt, P.E.
Research Coordinator, Research Unit

Prepared for

Oregon Department of Transportation
Research Unit
Salem, Oregon 97310

and

Federal Highway Administration
Washington, D.C. 20590

May 1997

Technical Report Documentation Page

1. Report No. FHWA-OR-RD-97- 09	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ARMORFORM® Articulating Block Mat Erosion Control System Salmon Creek Bridge Oakridge, Oregon		5. Report Date May 1997
		6. Performing Organization Code
7. Author(s) E.W. Brooks and Liz Hunt		8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon Department of Transportation 2950 State Street Salem, Oregon 97310		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Experimental Features OR 89-05
12. Sponsoring Agency Name and Address Oregon Department of Transportation Administration Research Unit 2950 State Street Salem, OR 97310 and Federal Highway 400 Seventh Street SW Washington, D.C. 20590		13. Type of Report and Period Covered Final Report 1991-1996
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

ARMORFORM® Articulating Block Mat (ABM) was used as part of a bridge replacement project at the Salmon Creek Bridge abutments in the summer of 1991. ABM was selected to replace riprap which was continually being undermined by the erosion of the streambed. ABM was selected due to its ability to maintain its structure (articulate) and withstand erosion. The original design requiring the mat to be keyed into the bank could not be constructed according to the manufacturer due to product limitations. Therefore, contrary to the original design, the flanks of the mat were not embedded into the bank to protect against undermining from bank erosion.

The ABM did work well during the flood event in February of 1996. Although the northwest corner was undermined, the blockmat articulated and changed slope to partially fit the void. Because the bank erosion stopped near the edge, it appears that the ABM also retards embankment erosion. However, the gap was not filled completely which allowed the rushing water to flank the mat increasing the damage. Downstream, some of the blocks were torn away from the mat while others were uncovered in the toe trench. Since the riprap placed by maintenance to retard the erosion is end dumped rather than keyed into the channel bottom and bank, the stream will probably continue to flank the ABM.

Future designs subject to similar flow conditions should consider keying the upstream edge 10 ft (3 m) into the bank and burying the toe 8 ft (2.4 m) into the channel bottom. In addition, the design should include riprap to protect the flanks of the mat. The ideal situation would be to construct the mat as designed with the fan shaped ends. The ABM appears to be most suited for active streambeds susceptible to erosions with slopes steeper than 1.5H:1V (steeper than is reasonable to place riprap).

Future designs should also consider the configuration of the ABM blocks. Consideration should be given to configuring the blocks so that there is no vertical alignment offset versus staggering the blocks. Aligned rows of blocks would allow articulation in all directions.

17. Key Words EMBANKMENT, EROSION CONTROL, RIPRAP, SCOUR CONTROL		18. Distribution Statement Available through the Oregon Department of Transportation	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 28	22. Price

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

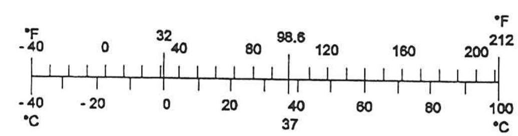
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

ACKNOWLEDGMENTS

The authors thank the following ODOT personnel for their help in gathering information: Kevin Groom, Dave Bryson, Chuck Godfrey, Paul Ferrigno, and Kaaren Hofmann. In addition, the authors thank Chris Dunn from FHWA for technical advice.

DISCLAIMER

This document is disseminated under the sponsorship of the Oregon Department of Transportation and the United States Department of Transportation in the interest of information exchange. The State of Oregon and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policies of the Oregon Department of Transportation or the United States Department of Transportation.

The State of Oregon and the United States Government do not endorse products of manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the object of this document.

This report does not constitute a standard, specification, or regulation.

ARMORFORM® ARTICULATING BLOCK MAT EROSION CONTROL SYSTEM

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The ARMORFORM® Articulating Block Mat (ABM) was constructed at the Salmon Creek Bridge abutments in the summer of 1991 as part of a bridge replacement project. The bridge is located on the east side of Oakridge, Oregon. The vicinity and location maps are shown in Figures 1.1 and 1.2, respectively. The construction of the ABM is detailed in a 1991 report. (*Scholl, 1991*) Subsequent performance is detailed in a 1993 report. (*Hunt, 1993*) This final report presents the ABM performance following a 17-year flood in February 1996.

In 1995, Nicolon stopped producing the textile grout bags for ARMORFORM® and other erosion control products. Donnelly Fabricators, Inc. bought the remaining Nicolon inventory. Donnelly has since sold most of the ARMORFORM® as of April 1997, however, they produce similar erosion control ABMs called TEXICON®. The TEXICON® ABM has some improved features including grout bags, which can be custom fit to irregular shaped installations. More details are available at (770) 339-0108.

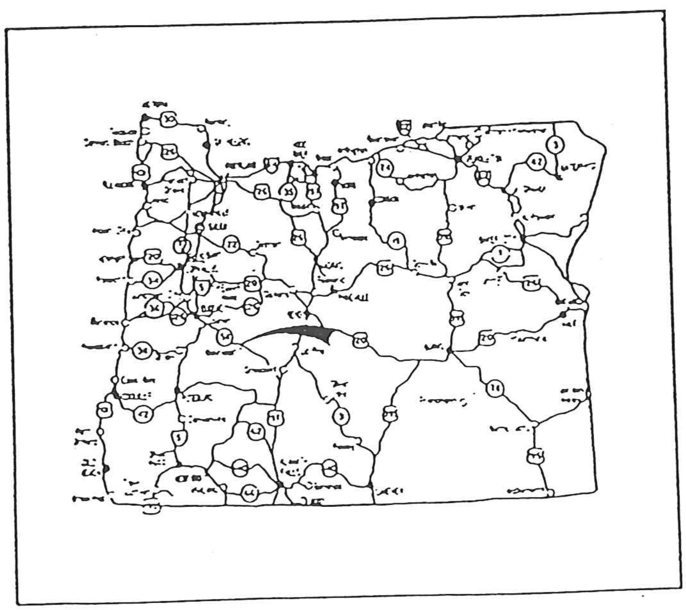


Figure 1.1: Vicinity Map.

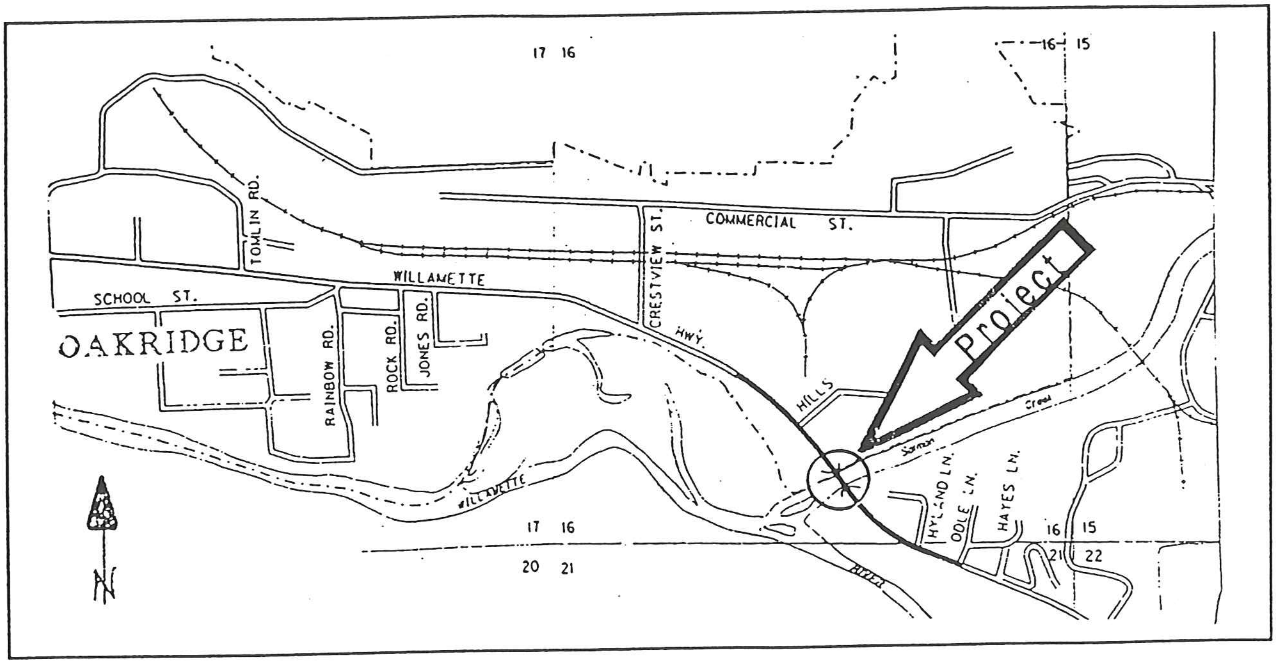


Figure 1.2: Location Map.

The ABM is a fabric formed concrete mat (see Figure 1.3). The system consists of closely spaced bags that are interconnected by grout ducts and flexible polyester cables. When the bags are filled with a cement rich concrete grout, it forms a solid mat, consisting of a series of connected blocks.

The blocks are aligned horizontally but staggered vertically which limits the ability of the mat to articulate diagonally. Because of this block configuration, it is easier for the mat to articulate along the axis which is parallel to the stream flow than to articulate along the axis which is normal to the stream flow. The mat also will not articulate until the grout ducts shear. A future design consideration is to configure the blocks so that there is no offset vertically. This would allow the mat to articulate in all directions.

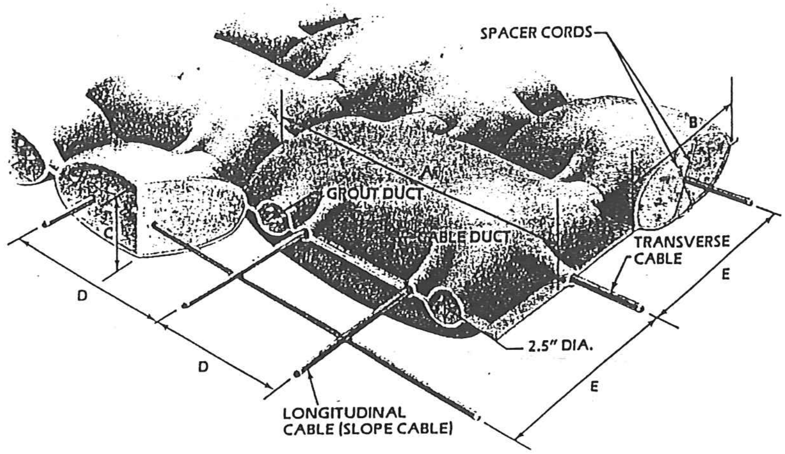


Figure 1.3: Cut away view of ABM formerly produced by Nicolon Corporation.

The mat was selected for the site to replace riprap that had a history of failure. Continuous degradation of the streambed undermined the riprap. Gravel bars in the channel diverted the flow direction to impinge directly on the riprap. Both of these conditions contributed to the riprap failure. The ABM was selected as an alternative to riprap since it is a structurally integrated system that maintains its ability to protect against erosion when undermined and it can withstand direct flow impingement.

The original ODOT design terminated the ABM by burying it 4 ft (1.2 m) into the channel banks. The design was modified, however, by the manufacturer due to the limitations of the product. That is, the fabric forms could not be terminated in a fan shaped pattern, as shown on the original ODOT plans (see Figure 1.4).

The construction report stated that the modification by the manufacturer could make the system less effective than the original design to control erosion from progressing by flanking around the end of the ABM. (*Scholl, 1991*) The original ODOT design and as-constructed drawings are included in the construction report. Prior to construction, the stream had washed out the west bank riprap upstream from the northwest corner of the ABM. The riprap was replaced to protect the leading edge of the ABM under a price agreement with the contractor. (*Hunt, 1993*) This same area eroded again during the February 1996 flood and has since been heavily riprapped.

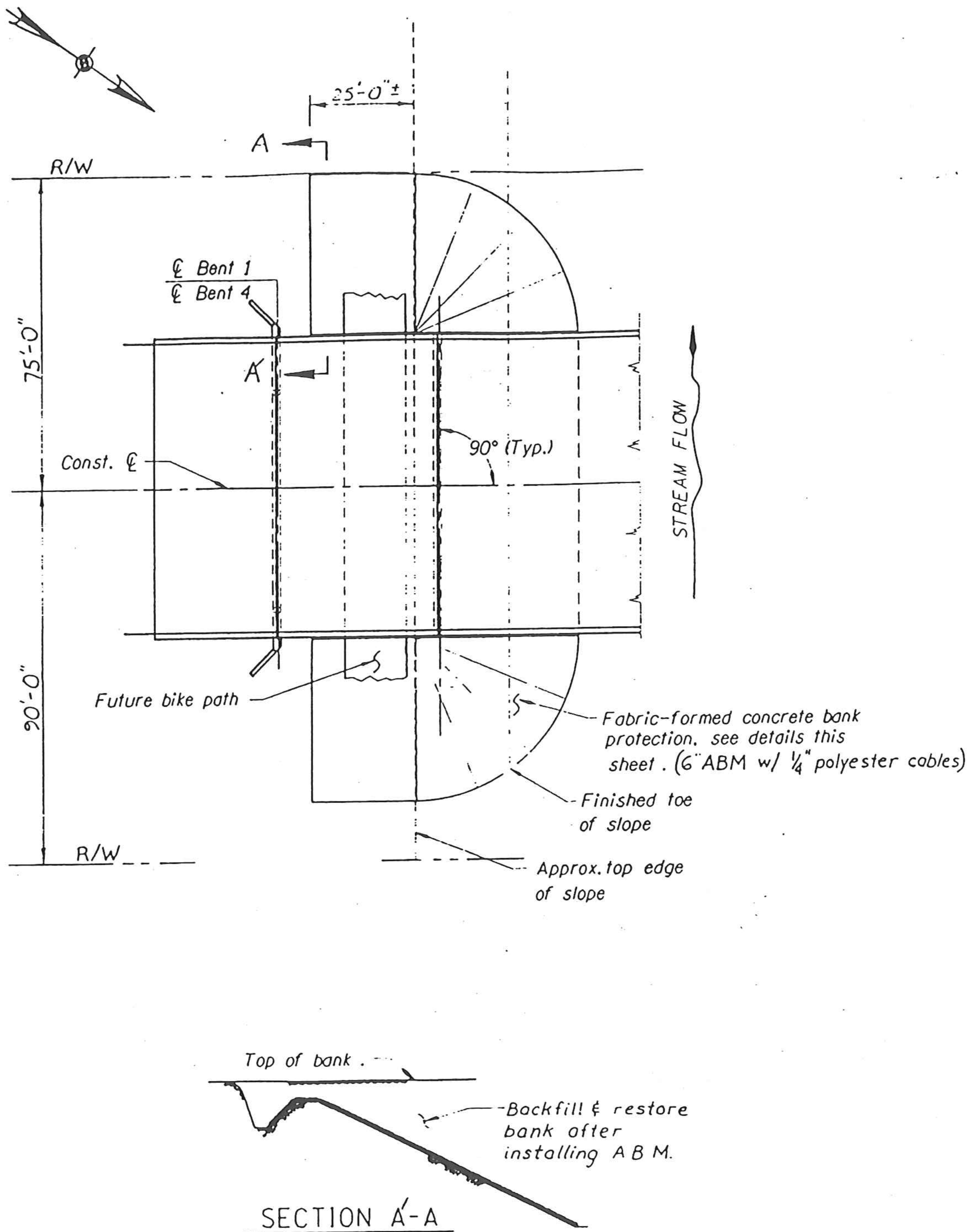


Figure 1.4 Original Fan-Shaped Design.

2.0 EVALUATION

Annual inspections have been made to the ABM site since the construction. The ABM had been evaluated for bank erosion control, maintenance and appearance. Flooding in February of 1996 produced the first major test.

2.1 EROSION

A flood event in February 1996 challenged the ABM as well as the standard riprap for bank erosion and scour. Both the riprap and the ABM had been affected by the high water, which was estimated as a 17-year event. The flood frequency was estimated from flows at nearby stream gages because the Salmon Creek gage was discontinued in 1991. Damage was confined to the upstream northwest corner, which has been a concern since construction.

A large island developed just upstream from the bridge. Chris Dunn, FHWA Regional Hydraulics Engineer, noted that islands in the Salmon Creek channel increase high water velocities due to narrowing the channel. The island upstream from the bridge also redirects the current into the bank in the area where the riprap was lost and the bank was eroded. (See Figures 2.1 and 2.2). An estimated 170 cubic yards (130 m^3) of bank and riprap had been washed out upstream from the northwest corner of the ABM. This hole extended about 38 ft (12 m) upstream from the edge of the ABM and gouged out the bank about 5.5 ft (1.7 m) (compare Figures 2.3 and 2.4). No other riprap damage was found.

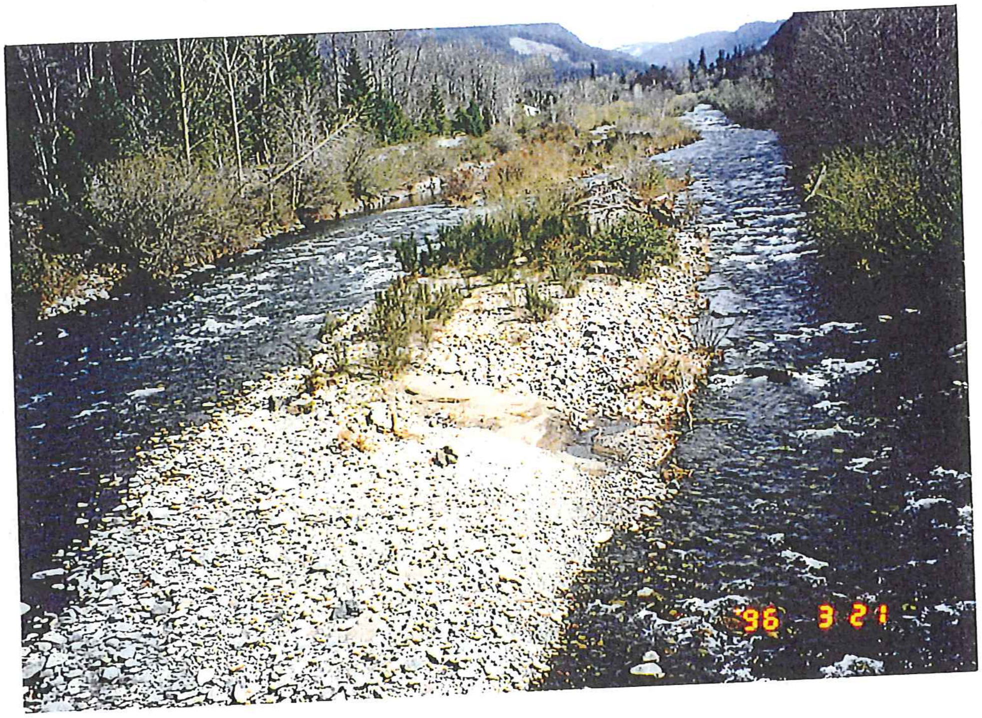


Figure 2.1: Large gravel island near bridge decreases the channel area.

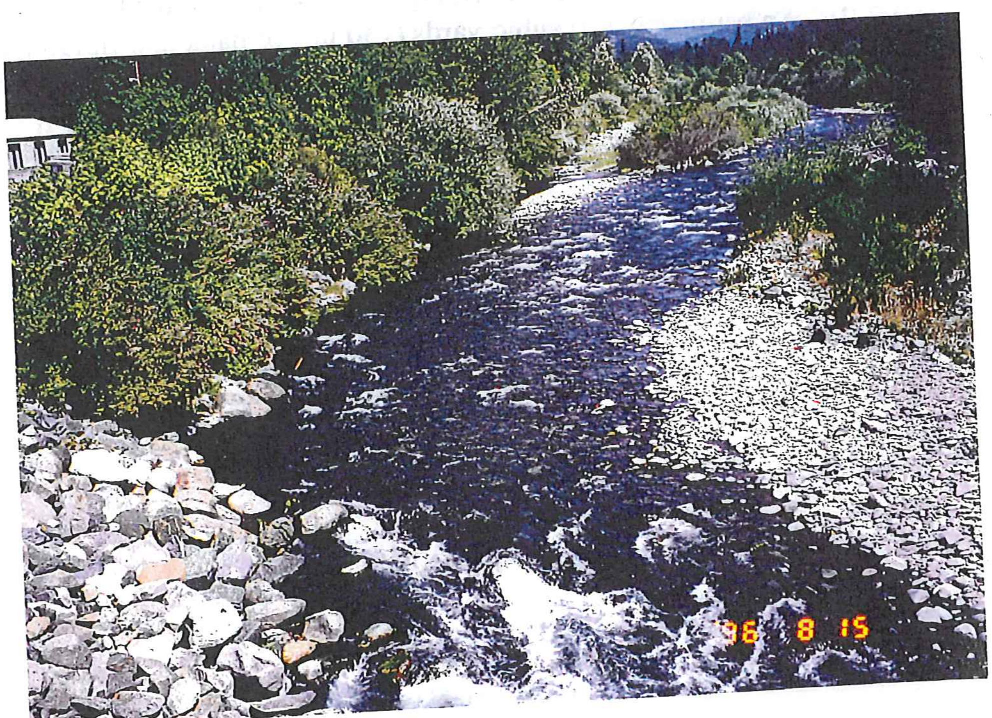


Figure 2.2: Gravel island directs current into northwest bank.

Figure 2.3: Northwest corner before flood, note the size of the riprap.

Figure 2.4: Northwest corner after flood, note the slope change of the ABM.

The bank erosion damage was repaired in late March. Larger boulders 400 lbs± (200 kg) were end-dumped to replace the washed out area of the bank. This riprap also covered the exposed northwest corner of the ABM. At the bottom of this fill, large elongated boulders were placed upstream from the washout at right angles. These "finger jetties" were placed to reduce the stream velocity next to the bank (see Figures 2.5 and 2.6).

2.2 ABM DAMAGE AND STREAMBED SCOUR

Damage to the ABM was confined to about 16 ft (5 m) of the northwest corner of the mat. The mat in the area of the large steel culvert pipe had changed slope (compare Figures 2.3 and 2.4). The slope was constructed on a 2H:1V and had dropped to almost vertical in some places. Although the ABM had been undermined on the north edge, it did articulate somewhat. The leading edge appeared to be stiff, however, leaving an opening for further undermining, causing several blocks to break free and plunge to the bottom of the streambed (see Figure 2.7).

Most of the break-away blocks came from the bottom of the ABM. This section had been buried under a gravel blanket at construction (see Figure 2.8). The gravel had been scoured away in two sections, each about 2 ft (0.6 m) long (see Figure 2.9). Some blocks were broken away from the polyester cable or were still held by one strand. Sections of the block mat fabric form were also noted swaying in the current near the bottom. For some blocks, the fabric was the only connection to the blockmat (see Figure 2.10). Three blocks which had broken free were found at the downstream end (southwest corner) of the ABM (see Figure 2.9). One block and two block fragments, still bound together by the polyester cable, were found about 66 ft (20 m) upstream from the northwest corner of the ABM. It is unknown how the blocks were transported.

The damage covered only about 5% of the entire system. The southwest side of the ABM had no visible damage (see Figure 2.11).

Figure 2.5: New riprap, note larger boulders in streambed near whitewater.

Figure 2.6: New riprap at northwest corner.

This page intentionally left blank.

Figure 2.7: Northwest corner of ABM, note undermined edge.

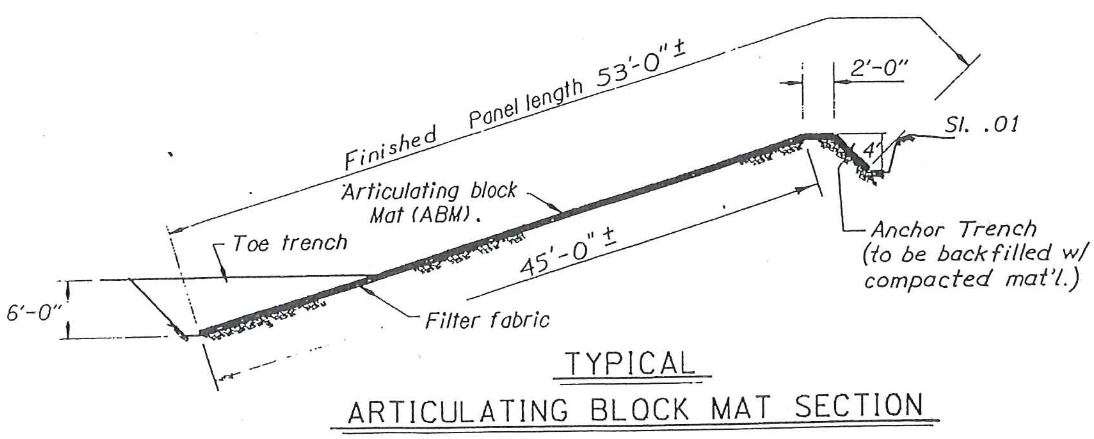


Figure 2.8: Detail of toe trench.

Figure 2.9: Exposed blocks after fill material in toe trench was scoured out.

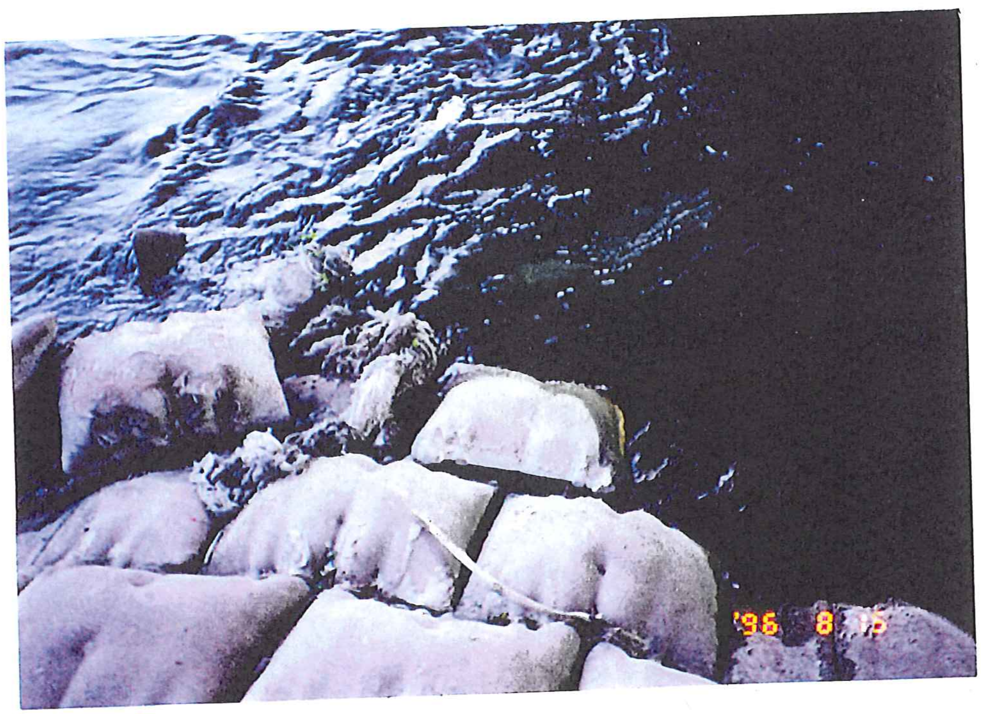


Figure 2.10: Blocks in damaged area are held only by fabric bag.

This page intentionally left blank.

2.3 AESTHETICS

Evaluating the aesthetic value of the ABM is difficult because it is a subjective quality. One opinion of the mat was that it was too white and uniform, so it did not blend in with the natural setting. Another opinion was that the mat looked nice and provided a finished look to the embankment. During the site visits, it was noted that the fabric enclosing the grout is slowing wearing away.

As the material degrades, the gray grout will be exposed which may appear more natural looking. An additional visual effect is the staining that occurs on blocks that are submerged during high water. As the water level recedes in the summer months, the blocks are exposed and appear several shades darker than the higher blocks. The very white blocks are under the bridge and are not visible to motorists. In fact most of the block mat is not visible to the motoring public because of a safety fence installed at the tops of the bridge rails (see Figure 2.12). Grass and other vegetation have started to sprout at the junctions of the blocks. Silt deposited from high water and run-off from the upper bank is furnishing nourishment for these plants. No plants grow under the bridge, where the sunlight is minimal.

Careful consideration of use should be given in areas of high foot traffic as the mat is slippery when wet making it hazardous to walk on.

Figure 2.11: Most of the west side was not damaged.

Figure 2.12: Motorist view of blockmat.

This page intentionally left blank.

3.0 MAINTENANCE

The riprap upstream from the northwest edge of the mat has been replaced twice since the 1991 bridge construction: in 1992 and 1996. The repair bill for the 1996 flood damage was $7,600. Had the ABM been constructed as designed, it still may have suffered some damage from toe scour and flanking.

No direct maintenance has been done on the ABM. The blocks, which broke free from the mat during the 1996 February flood, have not been replaced. Such repairs are possible but would be very costly according to the current manufacturer of the system. Repairing the lost blocks would include using a concrete drill to make holes for the polyester cable. The new bags could then be reconnected to the blockmat, and the holes grouted shut. If they were below water, a temporary dam would be needed. This would be very costly. The missing blocks could be replaced with riprap (750 lbs (340 kg)) at less cost.

This page intentionally left blank.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The original design considerations for this site included using riprap and the ABM to stabilize the slope. The alternatives were comparable in cost. The ABM was selected for use, however, because of its ability to articulate and protect against erosion. Unfortunately, since the mat could not be built as designed on the upstream side, that is not wrapped around to protect against flanking and undermining, maintenance has been required. As constructed, the mat is performing as expected. It was understood that the northwest corner was vulnerable.

The ABM did work well during the flood event in February of 1996. Although the northwest corner was undermined, the blockmat changed slope to fit the void. Because the bank washout stopped near the edge, it appears that the ABM also retards embankment erosion. However, the gap was not filled completely which allowed the rushing water to flank the mat increasing the damage. Downstream, some of the blocks were torn away from the mat while others were uncovered in the toe trench. Since the riprap placed by maintenance to retard the erosion is end dumped rather than keyed into the channel, the stream will probably continue to flank the ABM.

Future designs subject to similar flow conditions should consider keying the upstream edge 10 ft (3 m) into the bank and burying the toe 8 ft (2.4 m) into the channel bottom. In addition, the design should include riprap to protect the flanks of the mat. The ideal situation would be to construct the mat as designed with the fan shaped ends. The ABM appears to be most suited for active streambeds susceptible to erosion with slopes steeper than 1.5H:1V (steeper than is reasonable to place riprap).

Future designs should also consider the configuration of the ABM blocks. Consideration should be given to configuring the blocks so that there is no vertical alignment offset versus staggering the blocks. Aligned rows of blocks would allow articulation in all directions.

This page intentionally left blank.

5.0 REFERENCES

Hunt, Liz. *ARMORFORM® Articulating Block Mat Erosion Control System,* Salmon Creek Bridge, Oakridge, Oregon, Interim Report, Oregon Experimental Feature #OR89-05, Oregon Department of Transportation, Salem, Oregon, December 1993.

Scholl, L.G. *ARMORFORM® Articulating Block Mat Erosion Control System,* Salmon Creek Bridge, Oakridge, Oregon, Construction Report, Oregon Experimental Feature #OR89-05, Oregon Department of Transportation, Salem, Oregon, October 1991.

Scholl, L.G., and Bryson, D.W., *Hydraulics Report; Salmon Creek Bridge,* Oakridge, Oregon, Internal Report, Oregon State Highway Division, Salem, Oregon, 1988.