ARMORFORM® Articulating Block Mat
Erosion Control System
Salmon Creek Bridge; Oakridge, Oregon

Construction Report

OREGON EXPERIMENTAL FEATURE #OR89-05

by

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in cooperation with

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

October 1991

ACKNOWLEDGEMENT

The author wishes to acknowledge the roles played by the ODOT field personnel in inspecting construction, and photographing and reporting on the construction process. This work was performend by Bill Trissel under the direction of Larry Lindley, ODOT project manager.

INTRODUCTION

Erosion control can be a critically important element in assuring the long term structural integrity of a bridge. At the subject site, Salmon Creek Bridge - near Oakridge Oregon, the use of riprap for erosion control has a long term history of failure. In 1957 a major flood swept away the riprap protecting the bridge abutment and threatened to undermine the foundation of the earlier structure. This was only prevented by emergency action of the maintenance crew.

In 1958 the U. S. Army Corps of engineers constructed riprap revetments for a significant distance both upstream and downstream from the bridge. This project was intended to protect homes near the stream bank from serious progressing erosion. These revetments, however, confined and accelerated the flow and contributed to the tendency for the streambed to degrade. In the period of 30 years since the revetment construction, the streambed has apparently eroded six feet downward.* The stream degradation then caused the undermining and failure of the riprap that was intended to protect the stream banks in the vicinity of the bridge. Since then, the earlier bridge required periodic replacement of the riprap.

In 1986 the Corps of Engineers studied the problem of the failing revetments. A panel of State, local, and Corps officials decided that the revetments should not be reconstructed because the stream degradation had lowered the 100-year flood elevation below a level where it could cause significant damage. The 1986 study, however, failed to recognize that the original rationale for

*This assumes that the original streambed elevation after the 1958 project was the design elevation from the Corps of Engineers Plans.

constructing the revetments was not directly to prevent flooding, but rather to prevent homes from being undermined by erosion. This problem continues today, although no property is immediately threatened. The decision of the Corps and the panel not to reconstruct the revetments did, however, affect the design decisions of Oregon Department of Transportation (ODOT) engineers when designing the stream bank protection for the bridge.

DESIGN

When evaluating the need for stream bank protection at this site, the bridge designers recognized this long history of riprap failure and chose to use an ARMORFORM® Articulating Block Mat (ABM), because it is a structurally integrated system that maintains its ability to protect against erosion even when undermined. This system is produced by NICOLON Corporation of Norcross, Georgia.

An Articulating Block Mat (see Photos 1 and 2) is one particular type of fabric formed concrete. Fabric forms for concrete come in many different designs, but all have the same general concept in common. A strong synthetic fabric is sewn into a series of bags that are connected internally by grout ducts. These bags are then filled with a cement rich concrete grout. When set, the concrete then forms a solid mat, often made of a series of connected blocks. The mat does not usually depend on the fabric itself for strength. The particular design called "articulating block mat" (ABM) has two features that enable these blocks to articulate (or bend) within the mat while the mat remains structurally sound. First, the horizontal seams are continuous, allowing the blocks to bend downward by hinging along this seam line. Second, the individual blocks are connected internally by a series of flexible polyester cables which keep the individual blocks firmly connected, while allowing them to bend. Any undermining or internal erosion that may occur will then not be disastrous because the mat will shift to fill any voids. The design used at the Salmon Creek Bridge has rectangular blocks that, when filled with grout, weigh approximately 400 lbs. each. The nominal dimensions of each block are 19½" X 24". The entire mat is underlain by a geotextile filter fabric.

In the case of the Salmon Creek Bridge, to protect against further degradation of the stream, the streambed was excavated to allow the ABM to continue downward to an elevation 6 feet below the normal water level. Even in the unlikely event that the streambed degradation should continue below this elevation, the mat should articulate to fill any space left by the degrading stream.

In addition to the degradation problem, there was also a concern that erosion was progressing downstream toward the bridge along the west bank of the stream. Ordinary riprap would not have been sufficient to stop this flanking (or "sidemining") of the protection. The ABM, it was reasoned, could be wrapped around the abutment and buried in the stream bank to control the flanking problem. This concept was applied in the final ODOT design to all four corners of the bridge. This was illustrated in the plans as shown in Figure 1.

In choosing the ABM, the designers reasoned that, although the cost of the ABM system would be somewhat higher than that of normal riprap, it was worth the extra cost* to have the added assurance that it would continue to protect the bridge and stream bank for many years and during severe floods. While the long term solution to the erosion problem in the area would require additional bank protection further upstream from the bridge, ODOT does not have responsibility for problems outside of the State owned right-of-way. The ABM system, as designed, is believed to be the best way to protect the bridge for the long term without rebuilding the 1958 revetments outside of State right-of-way.

CONSTRUCTION

Design Modification

The concept of the original ODOT design (Figure 1) was modified somewhat as shown in Figure 2 when the shop drawings were made by Nicolon Corporation, for the subcontractor, Pacific Erosion. These drawings and the actual construction did not fully incorporate the concept of burying the ABM to full depth on two sides of the pier as shown in Section A′-A of Figure 1. Instead, the cross-section in the same area looks approximately as shown in Section B′-B of Figure 2. This modification took place because the fabric forms cannot be readily shaped as the ODOT design indicated. It is anticipated that this modification will make the system somewhat less effective than the original design in Figure 1 for controlling the tendency for erosion to progress by flanking around the end of the ABM. If erosion does progress, however, it will be a good test of the effectiveness of the ABM after it is undermined and begins to articulate.

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*See Appendix A for a cost analysis. This study concludes that functionally equivalent riprap would be more expensive than the ABM.

Construction Outline

Work Started:	6-18-91
Work Completed:	7-05-91
Prime Contractor:	Weaver Construction
Subcontractor:	Pacific Erosion
ODOT Project Manager:	Larry Lindley
ODOT Inspector:	Bill Trissell

ABM Installation Started: 6-26-91
Labor to fill fabric with grout: 5 days; crew of 4 men (285 man-hours)

Construction Problems and Solutions:

- All problems were relatively minor

Problem: In the original attempt to create a smooth surface for laying the fabric on, sand was placed over the native material. This was a problem because footprints readily disturbed the surface.
Solution: The native material (a gravelly sand) was used for the final surface by first clearing it of major rocks, then compacting it.

Problem: The difficulty of estimating where the toe of the finished slope should be.
Solution: Assume that the fabric contracts by 10% after filling with grout.

Problem: It was difficult to maintain straight lines along the horizontal seams when pumping grout. The easterly* slope (see Photo 2) was the worst problem because of lack of experience. The first attempt was to tie the upper edge of the fabric directly to the anchors on the bent while the grouting process proceeded upward from the bottom.
Solution: After the first experience with the easterly slope, the fabric was kept straight on the westerly slope by tying it to a series of #6 reinforcing bars.

Problem: Several of the bags were sewn such that the grout ducts connecting them to the other bags were blocked off. This occurred mostly in areas where the bags were cut during fabrication and were left only 1/2 the original size.
Solution: The bags were split and filled individually. This should not affect the strength or function of the ABM system, as its strength is derived from the internal cables tying the matrix of blocks together.

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* The terms "easterly" and "westerly" here refer to the direction of travel on the highway. Actually the "easterly" bank is on the southeast side of the stream and the "westerly" bank is on its northwest.

EVALUATION

The ABM is reasonably well constructed and appears to be an appropriate solution to the erosion problem at this location. As with any new or uncommon construction method or material, quality of construction improves with experience. It may be difficult, however, to maintain the advantage of the experience gained from this installation, as the next installation, if it occurs, will probably not take place for several years and it is unlikely that any of the same people will be involved.

As shown in Appendix A, contrary to the designers original estimates, the cost of the ABM is probably somewhat less than for the riprap alternative. A realistic cost comparison with a riprap alternative requires knowledge of the local price of riprap. This information was not available to the designers at the time of design. The best estimate as obtained by the construction inspector from a local contractor is \$32/ton for in-place riprap. The cost estimate also requires a knowledge of what constitutes a functionally equivalent design using riprap. Functional equivalence would probably mean that the riprap would have to be placed in "cutoff trenches" on all corners of the bridge to prevent erosion by "flanking", as well as extra riprap at the toes of the slopes for "toe trenches". Another basic design assumption is that the riprap alternative would require coverage of approximately the same area as the area covered by the ABM (2,390 yd^2). Also, according to the hydraulics report (Scholl and Bryson, 1988), the riprap would be placed 3 feet thick. In performing the estimate, it was necessary to assume a percentage of void space expected in the in-place riprap (15%), and the density of the rock (155 lb/ft^3). Based on these assumptions, the cost of riprap would be \$136,000 even before considering the riprap in the toe and cutoff trenches. With this extra material and excavation cost considered, the price for riprap could go to over $150,000 compared to the bid price for the ABM at $103,500. It is still questionable, even with these design assumptions, whether the two would be functionally equivalent. There is no known technology using riprap that actually ties the riprap together to make it function as a single structural unit.

The long term durability of the ABM may depend on one additional factor, its ability to drain readily if a sudden drawdown should occur after a flood. Whenever a relatively impermeable material is subjected to significant hydrostatic pressure from behind, as would occur in this case if water would not drain, there is a risk of failure. Although weep holes were not placed in the ABM material, the manufacturers technical representative, Mark Torre, states that it may be desireable to cut through the seams between blocks to assure that proper drainage occurs. It has been confirmed in the field that the seams can be easily cut with a knife. It is recommended that this be done at approximately five-foot intervals throughout the mat to add extra assurance that drainage will occur.

The bank erosion that is now visible on the west side of the upstream bank is the place to watch in the future. Photo 3 provides a "baseline" to compare with observations and photos of future erosion. The principal erosion problem can be seen on the right hand side of the photo. It is progressing in the direction of the newly installed ABM. The photo was taken from the easterly upstream side looking at the westerly side.

CONCLUSIONS

- The ARMORFORM® ABM system is constructable by inexperienced crews, and presents an attractive appearance.

- The ABM presents certain constraints that need to be considered in the design process. It cannot, for example, be readily shaped in a curved form as in the original ODOT design.

- In the future, designers should communicate with a manufacturer's representative when planning a curved design. This will assure that the ABM, as constructed, functions as the designer intended. In this case, the intent of the designer was that the ABM should extend around two sides of the pier at full depth. This was to protect against the laterally progressing erosion of the westerly stream bank. In the final product, this intent was not fully realized. Close communication with the manufacturer's representative could assure that the functional intent, if not the precise form of the design, is realized in future projects.

RECOMMENDATIONS

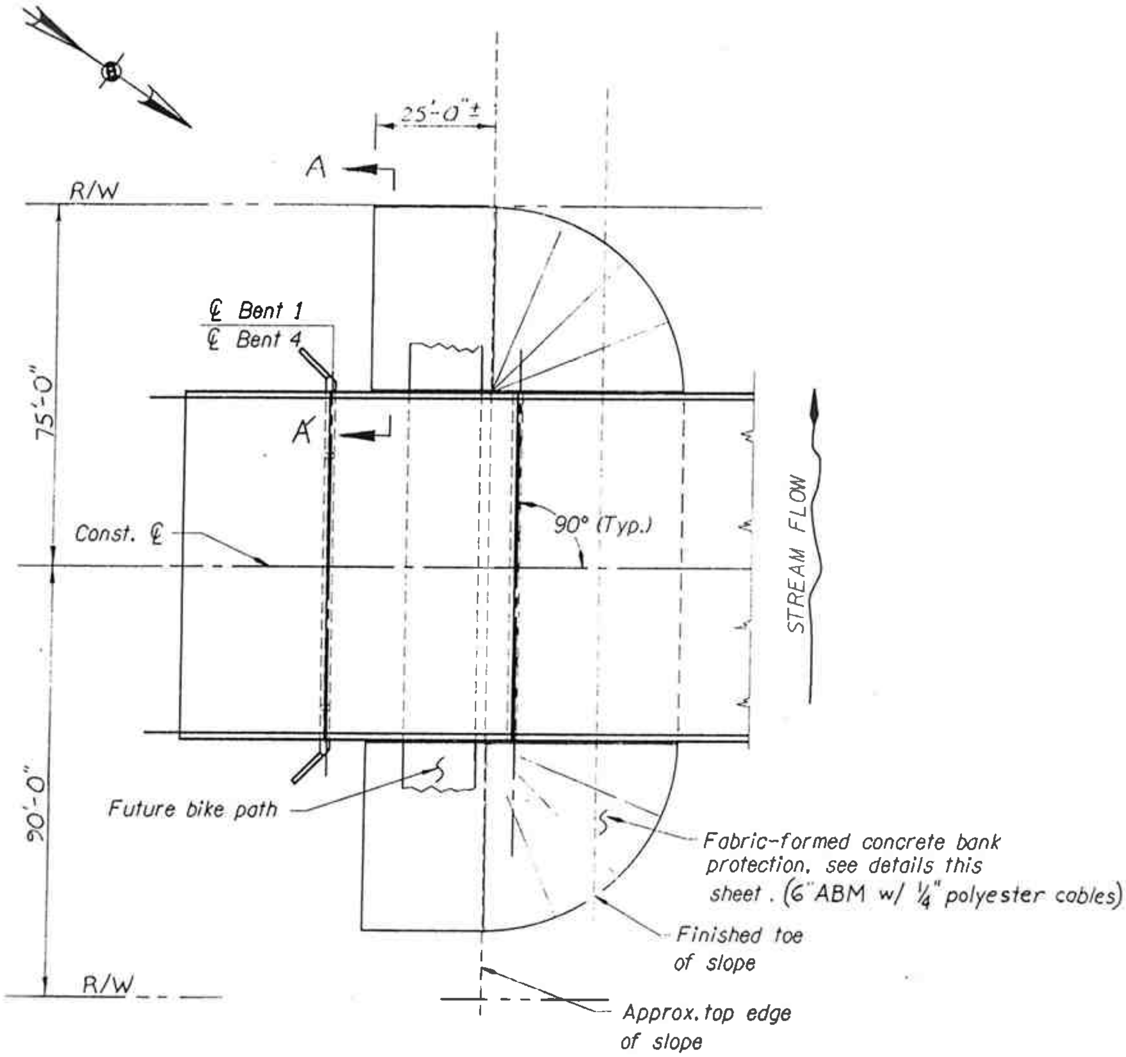
- Continue to monitor the performance of the ABM system for another 5 years as stated in the workplan. In particular, monitor the westerly bank on the upstream side to determine how effective it is as lateral erosion of the stream bank progresses.

- Although it is too early to conclude how long this protection will last, it appears that an ABM or a similar system is a reasonable and cost effective solution to erosion problems wherever high stream velocities or severe erosion potential exist. In such cases, serious consideration should be given during design, to ABM's or similar systems as an alternative to riprap.

- As with all forms of bank stabilization, it is essential that drainage be allowed. In this installation, it appears that excess grout is plugging the seams between the blocks in the ABM. These seams should be cut at five-foot intervals to assure that hydrostatic pressure does not build up if a sudden drawdown should occur after a flood.

REFERENCES

Scholl, L. G., and Bryson, D. W., 1988
<u>Hydraulics Report; Salmon Creek Bridge (Oakridge)</u>
internal report: Oregon State Highway Division, Salem, OR



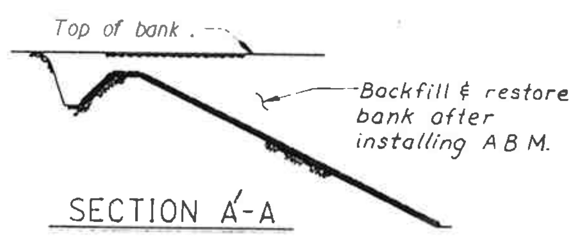
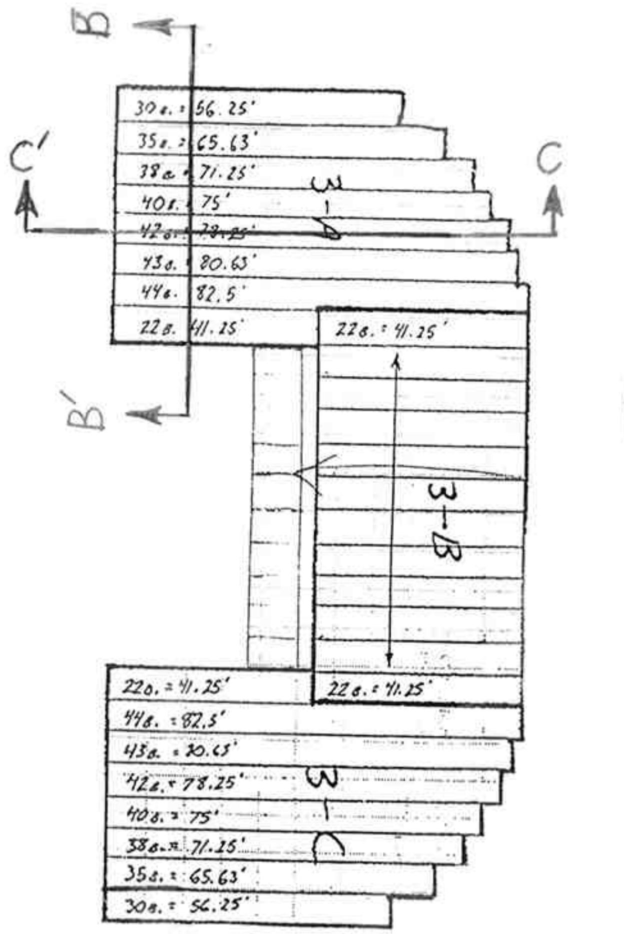
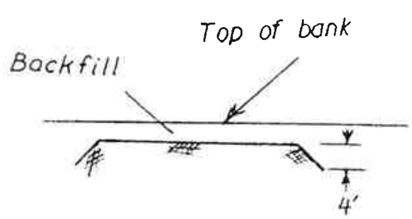
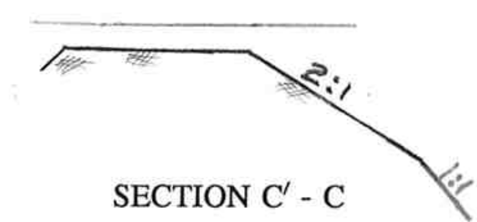


Figure 1
ODOT Design





SECTION B′-B



SECTION C′ - C

Figure 2
As Constructed

Appendix A

Determine weight and cost of riprap in place that would be equivalent to the ABM.

From shop drawings:

Area - Bent 2:	10,458 ft^2	
Area - Bent 3:	<u>11,048 ft^2</u>	
	21,500 ft^2	= 2,390 yd^2

Assume density of rock = 155 lbs/ft^3
or in yds: X 27 ft^3/yd^3 = 4,185 lbs/yd^3

Assume void content in riprap = 15%
Then bulk density = 0.85 X 4,185 lbs/yd^3 = 3,557 lbs/yd^3

Design says riprap is 3 ft thick
Therefore total wt = 2,390 yd^2 X 1 yd X 3,557 lb/yd^3 ≈ 8.6 X 10^6lb
or in tons: ÷ 2,000 lbs/ton ≈ 4,250 tons

Local contractor estimates cost = \$32.00/ton
Therefore cost = \$32/ton X 4,250 tons ≈ \$136,000

If ODOT estimate for riprap cost is used, cost = \$24.00/ton
In this case cost = \$24.00/ton X 4,250 tons ≈ \$102,000

Compare this to bid price of \$103,500

To obtain functional equivalence*, the cost of cutoff trenches and toe trenches must be added to the riprap cost estimate (see text under "Evaluation").

* It may not be possible to obtain <u>true</u> functional equivalence between riprap and an ABM system because riprap cannot be tied together to act as an integrated structural system.

PHOTO 1
ABM Appearance After Filling

PHOTO 2
Easterly Stream Bank During Construction