

CHAPTER 248

DESIGN AND INSTALLATION OF SCOUR PROTECTION FOR THE ACOSTA BRIDGE

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ABSTRACT

The Acosta Bridge is located in a bend at a natural constriction of the tidally influenced St. Johns River. This natural constriction has resulted over time in scour of the river bottom resulting in present water depths up to 80 feet. The Acosta Bridge is presently being replaced with a new bridge. The existing bridge is located immediately adjacent to a railroad bridge and both bridges are on caisson foundations. Divers have reported that penetration of the foundations for one of these existing bridges is as little as two feet. Construction of the replacement bridge will increase the scour potential. Therefore, scour protection had to be provided not only for the replacement bridge but the two existing bridges. The scour protection for the existing bridges was completed in 1990. The replacement bridge is under construction and scour protection is being installed as the piers are constructed.

INTRODUCTION

The Acosta Bridge, as shown in Figure 1, is located in a bend of the St. Johns River at a natural constriction of the flow. This natural constriction has resulted in scour of the river bottom which is considerably deeper than at other sites in this part of the river. Another important aspect is the proximity of the existing Acosta Bridge piers to the piers of the railroad bridge. It is obvious that the proximity of the two sets of bridge piers in this tidal area creates local scour beyond that which would normally be encountered were there only one set of bridge piers. The bridge piers in the center of the river of the existing Acosta and railroad bridges and the new Acosta bridge are shown in Figure 2. It is noted that the bottom topography and the bend in the river causes the stream flow to be helical and therefore it is difficult to define the flows in this part of the river accurately.

The St. Johns River is very flat and the tidal prism extends over 100 miles upstream from the

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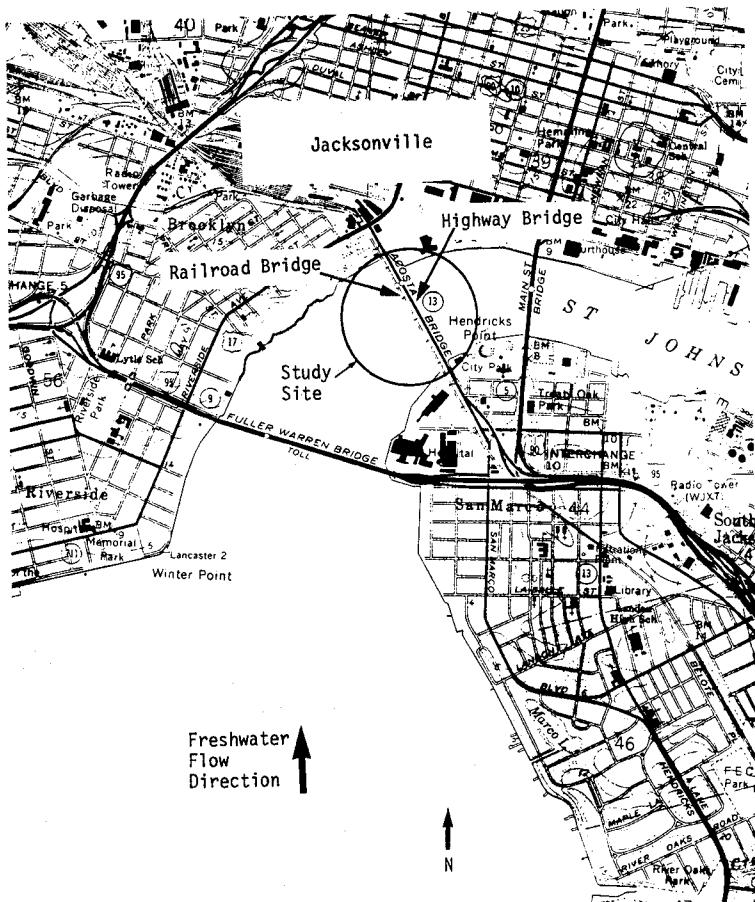


Figure 1. Location of the Acosta Bridge

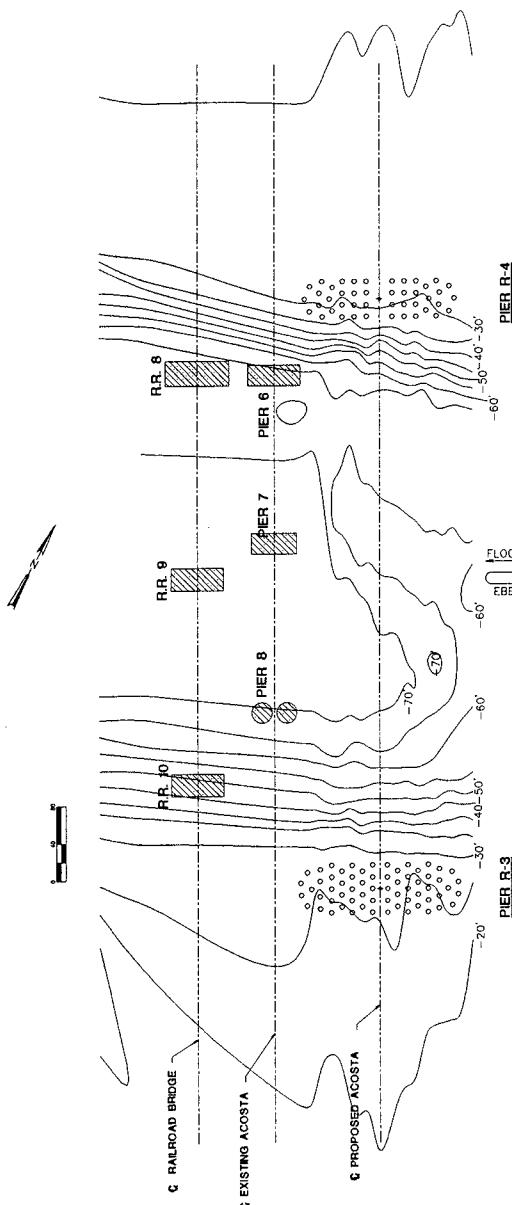


Figure 2. Plan View of the Acosta and Railroad Bridge Piers

bridges. The most severe storm conditions of record were during Hurricane Dora in September 1964. At that time there was an estimated flow of approximately 244,000 cfs downstream and 204,000 cfs upstream with a maximum stage at about elevation 5.2 MSL. The adjacent stream banks are at about elevation 6 MSL.

In the shallow water area of the site there is a sand layer varying in thickness from about 2 to 10 feet. This thin upper sand layer is highly erodible. The sand layer is underlain by a layer of lime rock varying in thickness from about 10 to 20 feet. Below the lime rock is marl that extends to great depth below the bottom of the channel. The marl erodes more easily than the lime rock. When the marl erodes it eventually leaves an overhang of lime rock which subsequently falls to reform a smooth channel slope. Figure 3 shows a survey that was made in 1924 and a recent survey of the area made in 1986. This figure shows that there has been approximately 20 feet of scour during this 62 year period. The largest amounts of scour occurred in the deeper parts of the river cross section. It also appears that geomorphologically the channel is migrating to outside of the bend in the river at the site. Similar scour has been observed at other bridges in the area.

ANALYSIS OF SCOUR

The scour which occurs in this part of the river can be considered as the cumulative effect of general scour and local scour. "General scour" results from a net reduction in the cross-sectional area of the river when additional bridge piers are added. The addition of obstructions or piers in this case results in an increase in the velocity of flow. This increased velocity in turn causes scour. The general trend is for erosion to continue until a stable channel is established. General scour usually increases with an increase in water depth according to Christensen and Bush (1971).

To determine general scour the procedure referenced in Christensen and Bush (1971) was followed. Dr. Christensen used this approach to provide the necessary general scour coefficient for the Acosta Bridge site which is shown in Figure 4. The existing Acosta Bridge as well as the range of pier widths considered during the preliminary design phase are also shown in Figure 4. To obtain the ultimate general scour the following relationship was used:

$$d_{gs} = c_{gs} (d^2)$$

where d_{gs} = depth of ultimate general scour in feet
 c_{gs} = coefficient of ultimate general scour from
Figure 4
 d = water depth in feet

The construction of additional piers in the river for the new Acosta Bridge will create general scour that will adversely impact the existing Acosta and railroad bridges unless proper precautions are taken. This is particularly true for the deep water piers located in the marl (Acosta Bridge Piers 6, 7, and 8 and railroad piers 8, 9 and 10). Assuming that the total sum of pier widths added is about 200 ft, the general scour coefficient from Figure 4 is .0028. For different water depths, Table 1 summarizes the estimated general ultimate scour, estimated scour after three years (the time expected for construction of the new bridge and removal of the old bridge) and the minimum present footing depth below the river bottom.

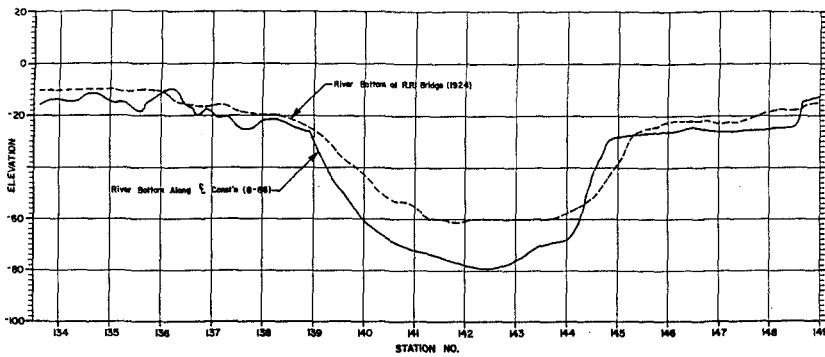


Figure 3. Profiles Across the St. Johns River in 1924 and 1986
at the Acosta Bridge

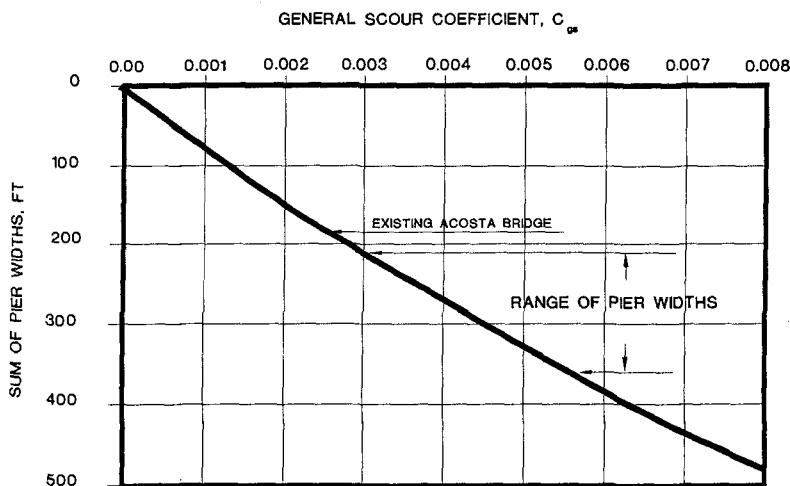


Figure 4. General Scour Coefficient for Acosta Bridge Site on
St. Johns River

TABLE 1
SCOUR SUMMARY FOR DEEPWATER PIERS IN MARL

| Pier Pier # | Average Width ft | Shape ft | Original Water Depth ft | Actual Scour ft | Estimated Ultimate Scour ft | Estimated Time To Ultimate Scour years |
|-------------|------------------|-------------|-------------------------|-----------------|-----------------------------|--|
| 6 | 12.0 | circular | 54.2 | 15.8 | 31.2 | 32,700 |
| 7 | 12.0 | circular | 60.0 | 26.0 | 32.8 | 330 |
| 8 | 12.0 | circular | 52.2 | 16.6 | 30.7 | 14,600 |
| 9 (RR) | 17.8 | rectangular | 61.5 | 23.3 | 55.5 | 448,100 |

The table shows that the estimated scour after three years is below the foundations for the Acosta piers 6 and 7 and railroad pier 9. These data predict likely pier failure for both bridges due to general scour alone if steps are not taken to protect the deep water piers. Similarly it can be shown that the construction of new foundations for the replacement bridge will cause local scour and most likely cause pier failure for both bridges if adequate steps are not taken for protection.

Addition of bridge piers in the cross-section creates a local obstruction to flow as well. The flow divides in front of the pier and the velocity increases as it flows around the pier. A system of vortices develop around the pier which are generally described as a horse-shoe vortex (Breusers, Nicollel and Shen, 1977). The combination of increased velocity plus the vortices form to create an environment for scour in the vicinity of the pier which is commonly termed "local scour". The local scour depth and the width to the affected area increases both with the width of the pier and with the depth of the water. It has been determined that the shape of the pier is also very important in determining the depth and extent of the local scour. Likewise the presence of other piers or structures have a very important role in local scour.

The total amount of scour is the sum of the general scour and local scour. In this analysis it was assumed that general scour is complete and that the local scour is superimposed for the ultimate conditions.

To determine local scour several procedures were considered. One procedure used a complete set of velocity profiles taken in 1962. These raw data taken by the USGS at the Main Street Bridge were analyzed to develop a velocity profile at the Acosta Bridge site. The Main Street Bridge is approximately one-half mile downstream from the Acosta Bridge. Based on all the analyses it was decided that the maximum flow during the 100-year storm would have an average velocity of 6.2 fps on both flood and ebb conditions.

Initially, it was decided that stone riprap should be used for general and local scour protection. The method of Isbash as reported in Brueser, Nicollel and Shen (1977), Blodgett and McConaughy (1983) and ASCE (1975) was used to calculate the minimum stone size. The formula was originally proposed by Isbash in 1936 for the construction of dams by dropping rock into a flowing stream. The size of the stone was then modified to take into account the slope of the bank and the curvature of the channel. The Isbash equation is frequently given in the following form:

$$W = \frac{4.1 \times 10^{-5} G_s V^6}{(G_s - 1)^3 \cos^3 \phi}$$

in which W = the weight of the stone in pounds

G_s = the specific gravity of the stone

V = velocity

ϕ = angle of the bank

Typical results with this approach yielded stone size for general scour protection on the flat slopes of 0.4 feet in diameter. On the steeper slope of 1.3h:1v, the required stone diameter increased to 1.5 ft. For local scour, required stone sizes varied from 1.2 ft in water depths of 30 ft to 4.5 ft in water depths of 80 ft. Considering a minimum protection of two layers of stone plus bedding stone the thickness of the bottom scour protection is such that in itself it will cause an increase in the general scour and possibly increase flooding in Jacksonville during design conditions.

PHYSICAL MODEL

Since there was not time to develop a full three dimensional tidal model a unidirectional movable bed model was done for this project by the Federal Highway Administration. The purpose of the model was to develop further confidence in the analytical results and to further understand the interrelationship of the pier structures on the local scour. Undistorted wooden scale models of the pier configurations were placed in a sump filled with sand within the flume. The model scale was restricted by the size of the flume. The scale of 1:50 was based on a maximum flume flow depth of about 1.25 ft and a river depth of 70 ft. The actual bathymetry in the river was not reproduced in the model. The appropriate model ratios are listed below:

| <u>Parameter</u> | <u>Ratio</u> |
|------------------|--------------|
| length | 50:1 |
| velocity | 7.1:1 |
| unit flow | 354:1 |
| riprap size | 50:1 |

Since the flume was only 6 ft wide the full river could not be modeled at any given time. The available sand at the laboratory was used as the movable bed material. However, no specific specifications were given to the sand to insure that it would quantitatively model the depth, time rate or extent of scour. The approach to the sump in the flume was plywood with sand glued to the surface to provide continuity of bottom roughness. There was no mechanism for recirculating sand therefore the bed shear stress, t_o , was kept near the critical shear stress value, t_c . For higher values of shear stress, sand would wash out of the sump. With an upstream supply of sand, the scour holes would fill as fast as scouring occurred once equilibrium was reached. The flow rate used in the experiments was determined from the minimum flow at which sand particles began to move under the maximum depth of flow. After the threshold flow was determined a pier was placed into the sand and the time for full development of the scour hole was measured.

Flow in the flume was unidirectional unlike the flow in the prototype. The model bridge piers

were therefore placed so that the flow traveled in the tidal flood direction. The bridge piers were also altered so they could be aligned with a flow approach direction of 15 degrees from normal to account for the bend in the St. Johns River at this location. Results from the model gave upstream and adjacent velocity profiles as well as the extent of scour. Results from these model tests showed that generally the maximum velocity by the bridge piers was approximately 1.4 times the approach velocity. The hydraulic model study also concluded that stone riprap with 1.5 ft diameter and a specific gravity of 2.65 would be satisfactory with a stability factor of 1.2 for local scour protection.

DESIGN

Since the St. Johns River is tidal at the Acosta site, scour protection design had to consider both upstream and downstream bridge piers. Initially riprap protection from general scour and local scour was considered. The size of stone was calculated using an approach velocity of 6.2 fps for the design conditions of a 100 year storm. These calculations indicated a stone size of approximately 4.0 feet. The steep side slopes of the channel which approached 1:1 would require even larger stone. The stone would need to be placed upon an appropriate filter which would be difficult to install considering the deep water, high currents, poor visibility and limited bridge clearance at the site.

Because of the large sizes of stone required for traditional riprap protection around the bridge piers it was decided that an alternative form of construction should be considered. The selected alternative was gabion wire baskets. These baskets when tied together form a blanket which holds smaller stone in place and which can have a filter integral to the installation. Individual gabion baskets can be wired together into large units to be placed on the bottom. These units can then in turn be laced (wired) to other units to create a continuous layer of protection across the bottom in the areas where local scour protection is required.

The final gabion design was developed based on Agostini et al. (1985). The structure included two layers of 9 inch mattresses. The baskets were filled with stone with the following gradation:

| <u>Weight</u> | <u>% Finer Than</u> |
|---------------|---------------------|
| 11 lb | 100 |
| 6.2 lb | 50 |
| 1.3 lb | 0 |

Filter fabric was in the bottom of the upper mattress layer. The layout for the existing Acosta and railroad bridges is shown in Figure 5. This layout will be connected to and become part of the scour protection for the new Acosta Bridge which is under construction. To minimize the effects of corrosion the wire mesh baskets were first galvanized and then coated with PVC. All tie wire was also galvanized and coated with PVC.

Two other bridges have also used similar techniques as alternatives to armor stone. The most recent was the Kalamazoo River Bridge in Michigan (personal communication with David Parsh of C-Way Construction, 1989). A very similar project was completed at the Vendee Bridge which crosses Loire River in Nantes, France. Although the conditions were not tidal on the Loire River, the combination of general and local scour posed a serious threat to the safety of the bridge (Officine MacCaferrri S.p.A., 1983). Soon after construction was completed in 1982 a 100-year flood occurred on the Loire River and the scour protection performed satisfactorily.

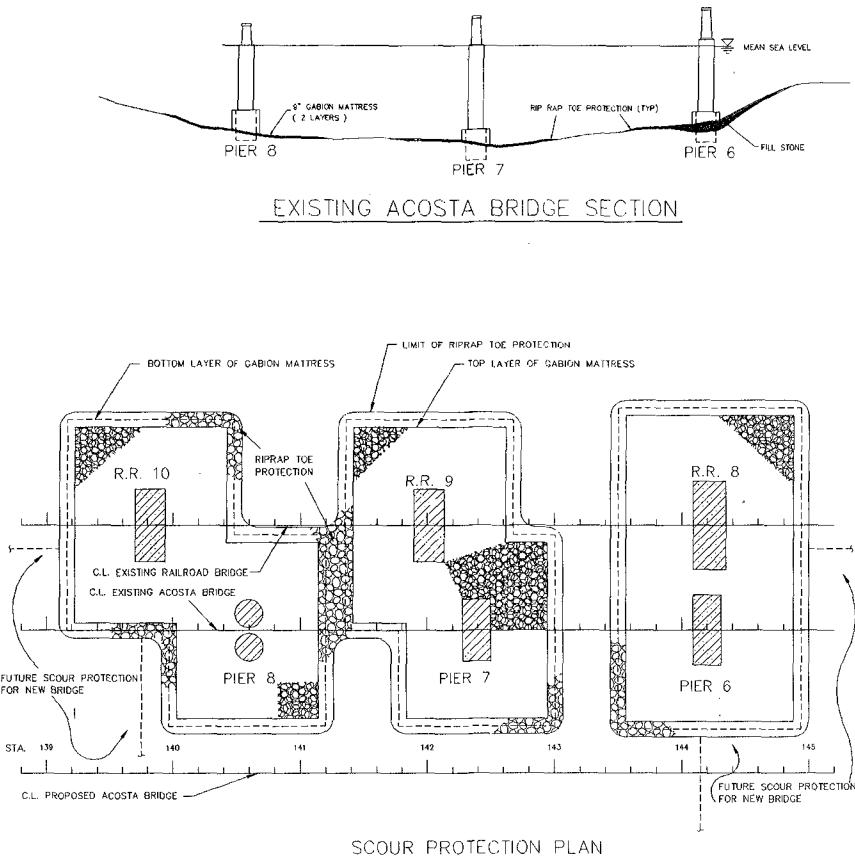


Figure 5. Plan of Scour Protection for Existing Acosta and Railroad Bridges

CONSTRUCTION

The individual mattresses of 6 feet by 18 feet were laced together on land and filled with stone on a barge before being placed. Special placement barges were fabricated by the Contractor to handle large sections of mattresses placed together to form a single unit 18 feet by 36 feet. Figure 6 shows the mattresses on the support barge and Figure 7 shows the special placement barge and the 18 ft by 36 ft unit being transferred from the support barge to the special placement barge. Note that the placement barge had to be partly submerged to maneuver and place the mattress assembly beneath the low railroad bridge. This was accomplished by transferring the assembly from the crane to the placement barge which was then winched by anchor cables to the proper location. In order to secure an adequate foundation for the mattresses side scan sonar and detailed bathymetric surveys were made to identify areas which were too steep to support the mattresses, to identify debris on the bottom which would have to be removed and to identify other obstructions which the mattresses would have to accommodate through construction or modification of design. In areas that were too steep for the mattresses to lay properly, stone fill was added to bring the slope up to at least 1v:1.5h and generally 1v:2.0h. Placement of the mattress assemblies and subsequent lacing underwater was made doubly difficult by the high tidal currents which although generally less than 2 feet per second occasionally exceeded 4 feet per second and the turbid water which limited visibility to a maximum of 4 feet and generally 12 inches with occasions of zero visibility. The placement was completed in August 1990 in time for construction of the new bridge piers.

SUMMARY

Scour protection was designed and installation completed for two existing bridges on the St. Johns River. Scour protection was designed to accommodate a 100 year design storm with a flood elevation of approximately 6.0 feet. This is the largest known tidal deep water installation for this type of protection. Coordination of the design and execution of the construction in adverse conditions was a challenge to all concerned.

REFERENCES

- Agostini, R., A. Conte, G. Malaguti and A. Papetti, "Flexible Linings in Reno Mattress and Gabions for Canals and Canalized Water Courses", MacCaferri Gabions, Inc., Williamsport, MD, 1985.
- ASCE, **Sedimentation**, edited by Vito A. Vanoni, Manuals and Reports on Engineering Practice -- No. 54, New York, 1975.
- Blodgett, J.C. and C.E. McConaughy, "Rock Riprap Design for Protection of Stream Channels near highway Structures: Volume 2 -- Evaluation of Riprap Design Procedures," Water Resources Investigations Report No. 86-4128, U.S. Geological Survey, 1986.
- Breusers, H.N.C., Nicolliet, G., Shen, H.W., "Local Scour Around Cylindrical Piers", **Journal of Hydraulic Research**, No. 3, IAHR, 1977.
- Christensen, B.A. and Bush, P.W., "Statistically Based Determination of Depth and Width Ratios

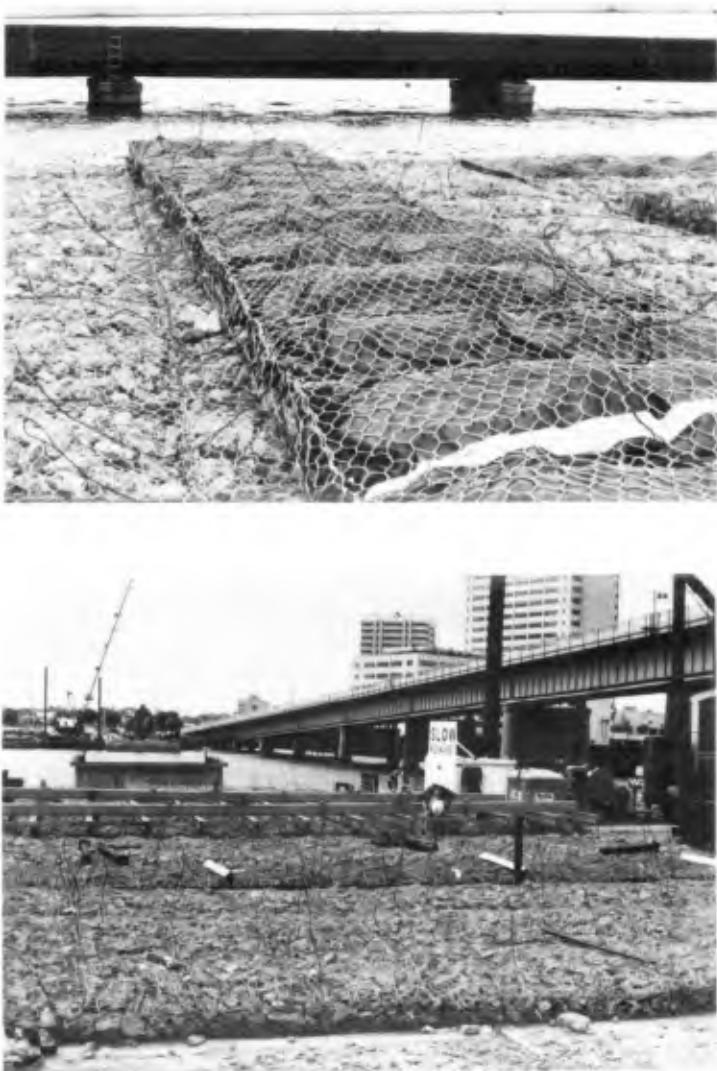


Figure 6. Gabion Mattresses on Supply Barge

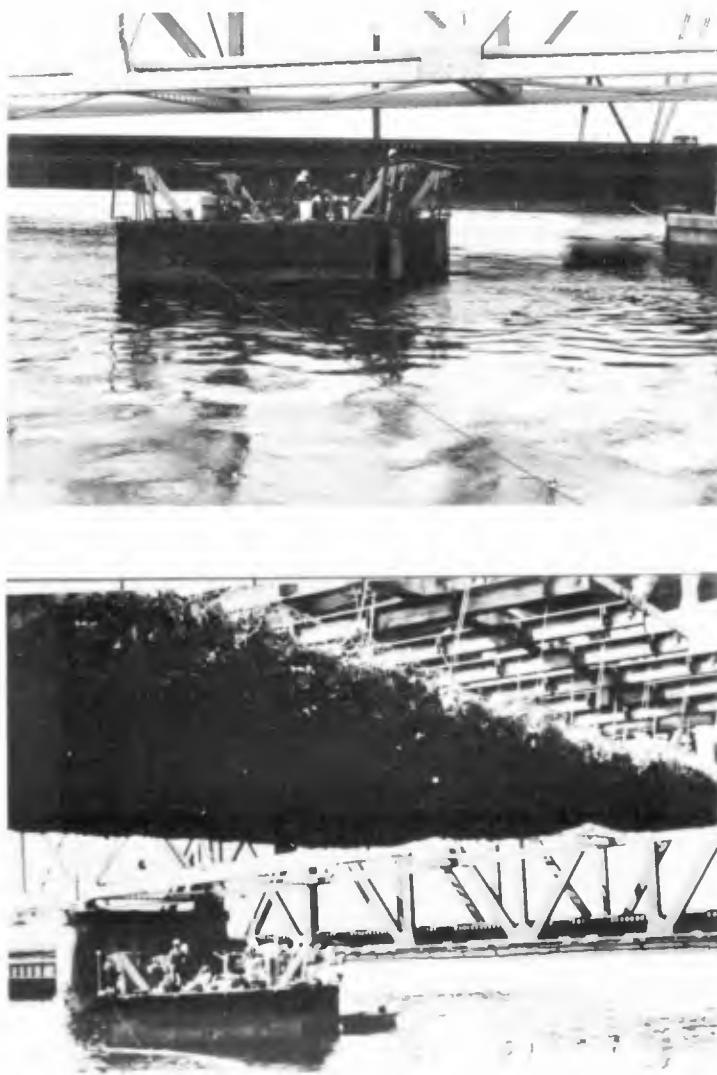


Figure 7. Mattress Assembly Being Lowered by Crane to Special Placement Barge. Note the Low Clearance of the Railroad Bridge in the Background.

in Alluvial Water Courses", **Proceedings of the First International Symposium on Stochastic Hydraulics**, Pittsburgh, ASCE, 1971.

GKY and Associates, Inc., "Lab Report for the Acosta Bridge Scour Study", Prepared for the Federal Highway Administration, McLean, VA, 1988.

Officine MacCaferrri S.p.A., "Protection of the Foundations of the Vendee Bridges Crossing The Loire River - Nantes", Brochure Published by MacCaferrri Gabions, Inc., Williamsport, MD, 1983.