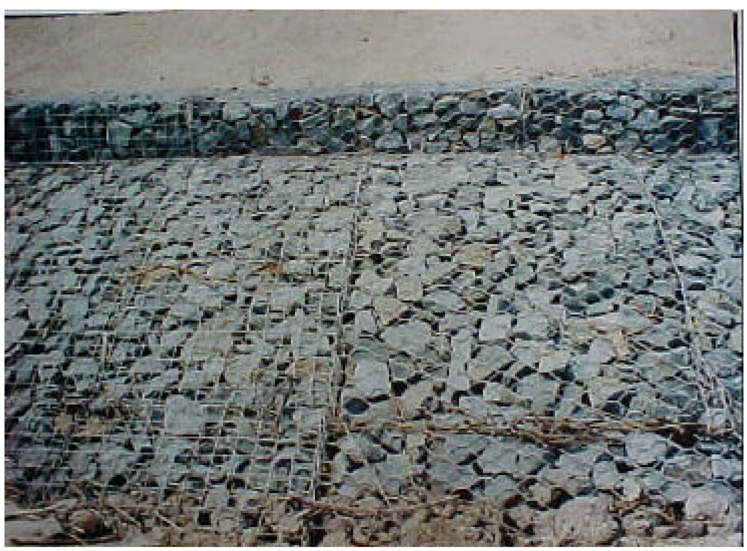
US Army Corps
of Engineers
Philadelphia District

Final Report

Analysis and Monitoring of
Double Twisted Wire and Welded Wire Gabions
Cape May Canal
Cape May, New Jersey

for

Chief, Engineering Division, North Atlantic Division



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•FOREWORD

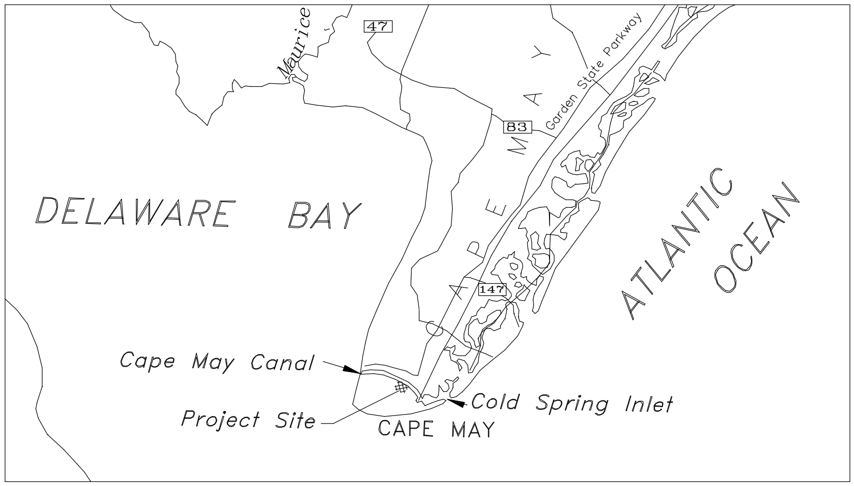
Gabion baskets are essentially steel wire containers divided into uniform compartments, filled with rock and fastened together to form a flexible, monolithic and permeable structure used for bank stabilization and other erosion control purposes. This report was drafted to document a comparison of installation and construction methods between welded wire mesh and double twisted mesh gabion baskets in the form of an erosion control revetment along the Cape May Canal in Cape May, New Jersey. The durability of both types of gabion baskets was also documented over a period of 3 years following initial construction of the Cape May project. This was completed in order to provide recommendations on factors such as optimal applications and to improve current construction methods relating to long term performance.

It should be noted that this report contains information based on observations, not laboratory testing. Specific observations listed in this report were documented to this particular site only and gabion performance and construction efficiency will vary with differing site environments and applications.

This study was initiated prior to the publication of ASTM A974-97, Standard Specification for Welded Wire Gabions and Gabion Mattresses, and ASTM A975-97, Standard Specification for Double-Twisted Hexagonal Mesh Gabions and Revetment Mattresses. In addition, this was the first gabion revetment constructed by the Philadelphia District using the welded wire gabions, therefore many aspects of construction of the welded wire gabions were as proposed by the manufacturer and contractor. Due to more experience using the double-twisted hexagonal mesh gabions (hereafter referred to as "twisted mesh" gabions), the District requirements for this type of gabion basket are much more defined in this report as well as in the original project specifications. Materials for both types of gabion baskets supplied for this project would currently conform to both ASTM A974 and 975

•INTRODUCTION

The Philadelphia District maintains the Cape May Canal as part of the New Jersey Intracoastal Waterway. The navigation channel links the Atlantic Ocean at Cold Spring Inlet in Cape May, New Jersey with the Delaware Bay at the southern tip of New Jersey. The canal is approximately 3.5 miles in length. The authorized channel depth is 10 feet; the tidal range is approximately 5 feet, in a saltwater environment. The presence of tidal currents and boat generated waves in the navigation channel has resulted in erosion of both shorelines along the canal. The primary method of erosion control used by the District on the canal has been gabion basket revetments. Riprap has also been used, but gabions were eventually selected due to lower costs. The first section of gabion revetment was constructed along the canal in 1982.



The Philadelphia District has specified all gabion basket materials on previous projects to be constructed of twisted mesh materials, primarily because of the lack of availability of alternate gabion material types, as well as the District's familiarity with the use and reliability of this type of gabion basket material. Since the use and availability of welded wire gabion baskets has continued to increase industry wide, the District, in cooperation with North Atlantic Division and funded by HQUSACE, initiated this study comparing the two types of baskets.

•PROJECT SUMMARY

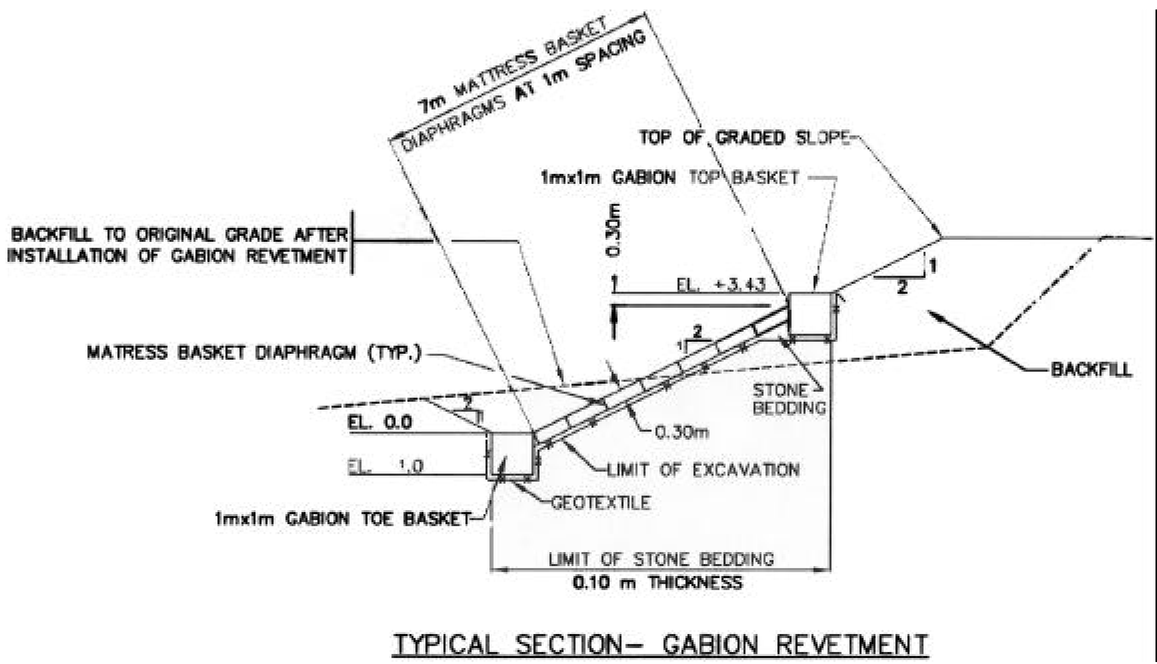
In 1996 the District awarded a contract to construct 705 meters (2300 feet) of gabion revetment using both twisted and welded wire gabions, which was completed in July 1997. The project, "Cape May Canal Bank Stabilization, Section V", provided an opportunity to complete an in-situ comparison of twisted mesh and welded wire mesh gabion baskets. Approximately one-half of the total revetment length was constructed of each type of gabion basket. The installation of each type was monitored during construction, and the condition of the gabion basket revetment was inspected for a period of three years hence. For the first year, the gabions were inspected quarterly. For the following two years, the gabions were inspected biannually.

The contractor for the project was Trevcon Incorporated, of Liberty Corner, New Jersey. The contract drawings and specifications for this project originally required the contractor to complete the gabion revetment using either twisted wire mesh gabions or welded wire mesh gabions. When the decision was made to conduct the comparison, the project was amended to require the Contractor to construct approximately half of the total length of the revetment with one type of gabion and half of the revetment with the other type. Since both types of gabions were constructed at the same location and by the same contractor, certain variables in comparing the two types were minimized, such as site conditions and quality of work. There were also several factors that could not be eliminated that affected the construction process such as weather (the contract extended from early winter to early summer), different numbers of available laborers on a given day, and the variability associated with different gabion manufacturers for the job. There are several different manufacturers for both types of gabion baskets and it should be noted that this study dealt with only two.

•PROJECT DESIGN

The site of the Cape May project is atypical as far as potential wear on the gabion revetment due to the proximity of a dredge material disposal area, as compared to the rest of the canal where gabion revetments are generally located along residential areas. The gabions for this project were subject to an increased potential for wear and damage since dredging operations into the disposal area have to bypass the revetment. The disposal area is also surrounded by sandy trails that attract dirt bikers and pedestrians. For this reason, as well as the brackish water, waves and tidal currents in the Canal, the site presents a very aggressive environment relative to potential gabion basket deterioration. Therefore the selected gabion mesh material was both galvanized (zinc coated) and poly-vinyl chloride (PVC) coated for both welded and twisted wire baskets.

The typical cross section of the gabion baskets was the same for both twisted and welded mesh materials (see figure below). This typical section included a 1 x 1 meter toe basket, a 1x1 meter top basket, and a 0.3 meter x 7 meter (roughly 1 foot thick x 23 feet long) mattress basket at a 1V:2H slope. This mattress was constructed of the same wire mesh dimensions and wire diameter as the square top baskets, and not to the lesser requirements for mesh and wire dimensions of "gabion mattresses" as defined by ASTM A974 –97 and A975-97. The reason for this requirement, as well as the on-slope configuration was the aggressive nature of the environment along the Canal as described above. The sloped baskets dissipate wave energy more efficiently than a vertical faced revetment constructed of stacked square or rectangular baskets. Gabion baskets were manufactured to metric dimensions; however, the properties of the mesh materials such as PVC coating and mesh opening sizes were standard gabion mesh materials readily available. The baskets were divided into compartments by diaphragms (vertical wire mesh panels). For ease of description, gabion dimensions are referred to in Metric units and rock size is referred to in English units throughout the report.



The above cross section is typical of almost all of the existing gabion revetments along the canal constructed under previous contracts.

•FOUNDATION PREPARATION

The ground preparation for both the twisted and welded wire gabions was the same. After clearing and grubbing of vegetation and trees was completed, excavation below the low water level was required to begin construction of the toe baskets. Excavated soil was placed as a built-up earthen cofferdam which progressed with the construction of the revetment along the canal. A series of pumps and hoses were used to maintain the water level within the excavated area. After excavation and/or backfilling was completed and soil compaction requirements were satisfied, non-woven geotextile was anchored in place, followed by a 4 inch layer of bedding stone.

•MATERIALS

Both types of gabion mesh consisted of galvanized steel wire with PVC coating. There is a difference in the process by which each type of mesh is manufactured, and in the types of fasteners designed by manufacturers to connect baskets together (any fasteners other than lacing wire are referenced as "alternative" in the following paragraphs). These were the primary items of interest in evaluating differences in construction procedures and long term performance. These differences in fasteners and materials are described in the following paragraphs. For additional information about welded wire mesh gabion materials, refer to ASTM A974. For information about double twisted wire gabion materials refer to ASTM A975. The Corps of Engineers Guide Specification Section 02371, "WIRE MESH GABIONS [AND MATTRESSES]" can also be used as a reference for both double twisted mesh and welded wire mesh gabions.

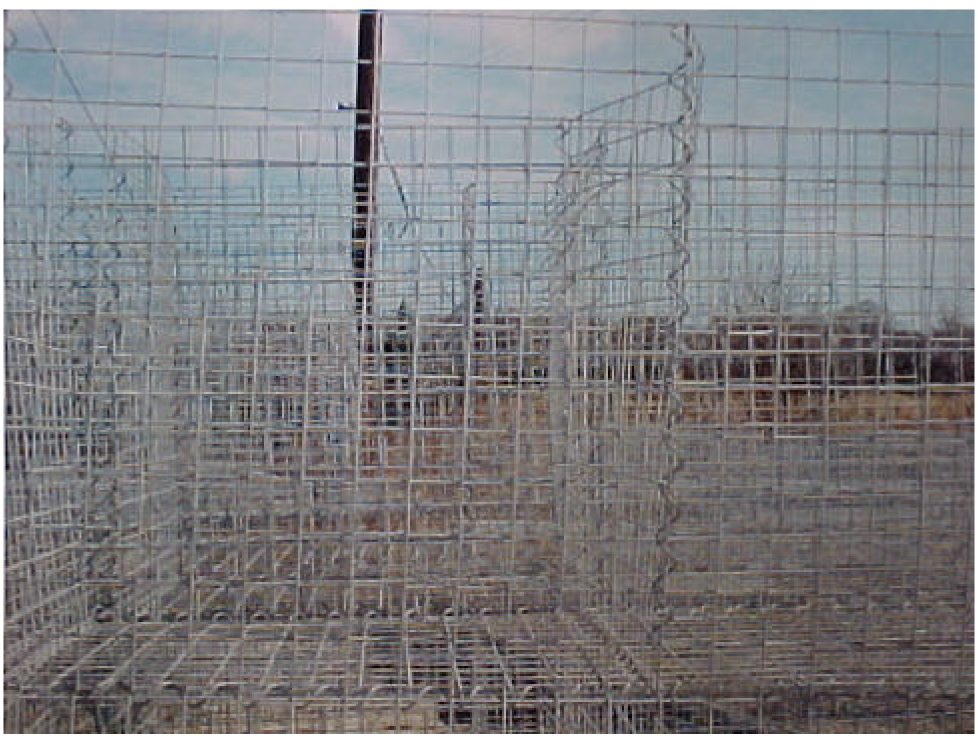
<u>Twisted Wire Mesh Gabions.</u> The steel wire used to fabricate the twisted mesh gabion material was coated with extruded PVC and then "double" twisted to form the mesh material. Diameter of the core wire, not including PVC coating was 2.7mm (0.106″). The diameter of the selvedge and reinforcing wire of the mesh was 3.4 mm (0.134″), not including PVC coating. PVC thickness was a nominal 0.50 mm (0.02″) per side. The dimensions of the mesh opening were 8.3cm x 11.4cm (3-1/4″ x 4-1/2″). The galvanized PVC coated lacing wire was 2.2mm (.087″) in diameter minus the coating thickness.

Assembled double twisted mesh gabion baskets, prior to placement

The twisted wire mesh gabions were delivered pre-cut and pre-assembled to the site. Top, toe, and mattress baskets were supplied with the sides, ends and diaphragms connected to the bottom face. Top and toe baskets were supplied in four-meter lengths, with the lids attached along one edge, and diaphragms at one meter spacing. Internal connecting wires were installed prior to filling procedures to prevent excessive bulging of the basket panels. The mattress baskets were supplied in 3-meter by 7 meter dimensions, and did not have pre-attached lids; roll out lids were provided. Mattress basket diaphragms were supplied at 1 meter spacing parallel to the canal and at 1.5 meter spacing perpendicular. Erection of the empty baskets involved unfolding and connecting the vertical adjacent edges.

Alternative fasteners proposed by the manufacturer and Contractor (other than lacing wire) were stainless steel locking wire fastener clips. The locking wire clips were used to assemble the individual empty baskets, however lacing wire was the primary method used to fasten the baskets together and to close the lids.

Welded Wire Mesh Gabions. The steel wire used to fabricate the welded wire mesh gabion material was first galvanized (zinc coated), then welded at right angles to form the mesh and then coated with fuse bonded PVC after primer application. Welding after galvanization is a common industry practice, although some wire gabions are available with mesh that is galvanized after welding. Diameter of the wire in the mesh, not including the PVC coating, was 2.7 mm (0.106″). PVC thickness was nominal 0.50 mm (0.02″) per side. The dimensions of the mesh opening were 7.6 cm x 7.6 cm (3″x3″). There are welded wire baskets available with different sized mesh openings, however the 3″x3″ mesh provides the largest cross-sectional opening area currently available.



Assembled welded wire mesh gabion baskets, prior to placement

The welded wire mesh gabions were delivered to the site in pre-cut panels and were pre-assembled. Top, toe, and mattress baskets were supplied with the sides, ends and diaphragms connected to the bottom face. Roll out welded wire mesh lids were provided for both square baskets and the mattress baskets. Top and toe baskets were supplied in four-meter lengths, mattress baskets in 2 meter by 7 meter dimensions. At the suggestion of the manufacturer, one end panel between adjacent baskets on the top and toe baskets was eliminated to reduce material cost and in the process facilitate use of the spiral binders. This was approved at the time but would not currently conform to requirements of ASTM A974-97, which requires that no end panels be removed due to concern that this would result in a lower shear resistance of the revetment as a monolithic structure. Redundant end panels were not removed from between the sloped mattress basket units. Internal connecting wires were installed prior to filling procedures to prevent excessive bulging of the basket panels.

Alternative fasteners proposed by the manufacturer and Contractor (other then lacing wire) were pre-formed spiral binders. The spiral binders are constructed of the same material as the lacing wire supplied; galvanized PVC coated steel wire 2.2mm (.087″) in diameter minus the coating thickness, twisted into a spiral with a 7.6 cm (3″) pitch. Spiral binders were used to assemble the individual empty baskets and for other applications as described in "Assembly and Fastening".

·GABION ROCK

The recommended grain size distribution for rock to fill both types of the gabion baskets was between 4″and 8″ in size. This distribution is based on mesh opening dimensions and thickness of the baskets. Obtaining consistent gradation quality in rock delivered to the site was difficult at times for this particular project and rock had to be consistently sorted by hand to remove any pieces that were too small while filling the baskets. Some shipments contained up to 17% rocks finer than 4″. Rocks that were larger then 8" were also encountered frequently. Possible improvements for obtaining more consistent gabion rock quality is discussed in the "Conclusions & Recommendations" section.

Assembled baskets were set in place, and interconnected with appropriate fastening materials prior to filling the baskets with rock. Placement of rock into the baskets was accomplished by a backhoe bucket. The one-meter baskets were filled with rock in three lifts. The slope baskets were filled using a single lift. Maximum height from which the stone was dropped was 1 meter (3'). Each lift was sorted and leveled by hand to provide interlocking and remove stones that were too small or too large. The twisted mesh baskets were overfilled about 1″-2″ above the top of the side panels. Welded wire gabions were filled such that a 1″ maximum gap was maintained between panel edges to be fastened together in order to facilitate use of the spiral binders. This generally resulted in a rock level even with the top of the basket side panels.

•ASSEMBLY AND FASTENING

<u>Twisted Wire Mesh Gabions</u>. The twisted mesh portion of the gabion revetment was constructed first; due to prior experience with the twisted mesh baskets it was easier to document as a baseline comparison to the welded wire baskets. The contract specifications required that individual twisted wire mesh gabion baskets be assembled, in place and connected together along all bottom and vertical edges prior to filling with rock

(see “Gabion Rock” section). The specifications required that only tie wire lacing be used to fasten adjacent basket units together and to close lids after the baskets were filled with rock. Fastener clips were permitted by the specifications to assemble side, end and diaphragm panels on individual empty baskets, but not for other connections. The restriction to the use of tie wire lacing to fasten adjacent baskets or to secure lids has been a requirement on past gabion projects the Philadelphia District has constructed. The clips used on previous gabion projects were too small to completely encircle three and four wires at a time without nicking and damaging the PVC coating. The clips were also not large enough to provide a consistently tight connection between the lids and side panels, since fastening the lid on a rock filled basket involves some pulling and tugging due to the practice of overfilling the twisted mesh baskets 1″ to 2″ with rock.

The contractor proposed to use stainless steel locking wire fastener clips specific to the gabions supplied by the manufacturer, initially to assemble individual empty baskets. It should be noted that the manufacturer’s submittal referred to these clips as “alternative fasteners”.

The contractor also wanted to use these clips to connect individual, adjacent gabion units together in the field before they were filled with rock, and as much as possible in fastening basket lids afterwards. Utilizing the clips was recommended by the manufacturer to expedite construction as opposed to using lacing wire to the extent required by the specifications. The start of project construction was in winter and the cold temperatures, although above freezing were enough to stiffen the lacing wire as well as the wire mesh, making the fastener clips a promising option.

The contractor was required to set up a test section approximately 24 feet in length so that the procedure and final product could be observed before use of the clips on other areas of the baskets would be approved. The locking wire fastener clips were larger in size than those used in past projects, and were installed with a pneumatic gun. The minimum required spacing of the clips for the empty baskets was four to six inches, which was roughly equivalent to the loop spacing required for the lacing wire.

The clips were first tested on the field fabrication of empty individual baskets. The clips worked well for this case and were approved to complete the assembly of the rest of the empty baskets.

The clips were then tested for connections involving both empty and rock filled adjacent baskets, and closure of lids on filled baskets. After comparing the baskets in the test section to those fastened only with lacing wire, it was determined that the clipped baskets were not as tightly fastened and there was a larger potential for damage to the PVC coating.

Closing a twisted mesh top basket lid with locking wire fastener clips

In addition, the following was observed in the test section:

•The lids on the baskets closed with clips were not connected as tightly to the diaphragms as were the lids fastened with tie wire lacing. This was because the clips were larger in size then the two wires involved in the connection, and consequently left it loose.

•For the case of the rock filled top and toe baskets, large gaps remained in some places between the outer edge of the basket lids and vertical front panels.

Connection along the edge of a top basket lid and side panel with locking wire fastener clips

•When two empty adjacent basket units were clipped together, the resulting joint consisted of four wires: two end panels and one side panel on each basket. Even empty it was difficult to pull the four wires close enough such that the gun clamps could grasp the wires completely and without damaging the PVC coating.

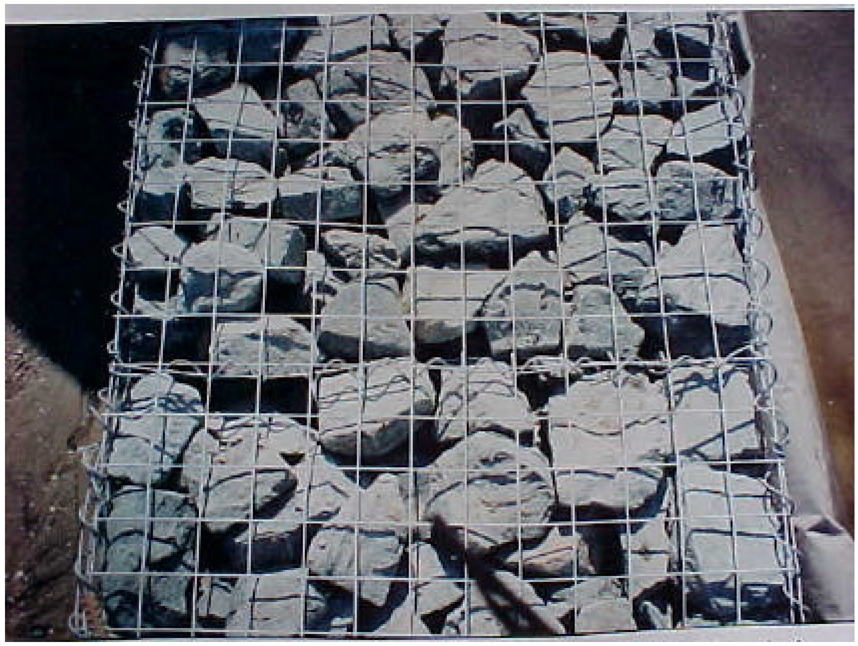
•The clips were a little easier to use when fastening the basket lids to the diaphragms and top edges of the end panels of the baskets. It was an easier process than the lacing since the workers could step on the lids to bring the wires in close contact, so that the gun could grasp the wires easily. However in many areas, the gabion rock in the filled baskets prevented the clamps of the gun from grasping the necessary wires, so the clips would not lock around the wires as required. This was a common occurrence where the top edge of the diaphragms was bent inwards away from the top of the basket from contact with the rock. Overfilling the baskets with rock 1″to 2″, a common practice to counteract rock settlement made it necessary to adjust the spacing of the clips to accommodate the rocks in the baskets. This resulted in inconsistent spacing of the clips.

•For the reasons listed above, it was almost impossible to use the fastener clips effectively or efficiently when fastening a closed top basket filled with gabion rock to an adjacent similar basket; and fastening a sloped mattress basket filled with rock to a top basket, also filled with rock.

In conclusion, it was determined that the efficient use of these fastener clips was limited, due mainly to their size and the limitations associated with use of the gun supplied with the clips. The gabion baskets fastened with lacing wire were clearly a more tightly knit structure. The strength of the clips when properly locked were not in question and the contractor was therefore permitted to use the fastener clips on the assembly of the empty individual baskets and also to fasten the diaphragms to the side panels of empty baskets. Lacing wire was used to construct the remainder of the twisted mesh gabion basket revetment.

<u>Welded Wire Mesh Gabions.</u> The contract specifications required that empty, individual baskets be assembled and fastened together using tie lacing wire, and/or spiral binders. Because of the District's unfamiliarity with the use of the welded wire gabions, the specifications did not place any limitations on the use of the spiral binders to fasten rock filled baskets. Welded wire baskets were essentially installed according to the manufacturer's recommendations.

Erection of vertical panels of individual, empty welded wire baskets were completed using spiral binders. Spiral binders were also used for most of the basket connections, with some exceptions as noted below. The spiral binders were twisted into each of the openings of the mesh, and the ends were turned under and crimped to lock them in place. Tie wire lacing was used for specific applications, also as noted below.



Welded wire mesh toe basket, prior to slope basket construction. Note the horizontal spiral binder connection between roll out lid and single diaphragm and along side panels. Geotextile fabric on right side of basket.

As per manufacturer's recommendations, spiral binders could be used as long as the gap between two adjacent edges to be fastened was less than 2.5cm (1 inch); otherwise, tie wire lacing would be required. This is due to the nature of the welded wire mesh, which is not easily stretched and pulled to fit. The contractor opted to use the spiral binders, and the baskets were filled with rock level with the top of the side panels and not overfilled, in order to facilitate their use.

The top, toe, and mattress baskets were placed empty and filled with gabion rock in the same procedure as the twisted mesh gabions (see "Gabion Rock" section). All connections along the edges and diaphragms of the top and toe baskets, including closure of the lids was accomplished using the spiral binders. Individual mattress baskets were fastened together empty using the spiral binders; the connection to the top and toe baskets was done with a combination of tie wire lacing and spiral binders. The roll out lids were fastened to the diaphragms of the mattress baskets using spirals, and to the two adjacent side panels using lacing wire (since the two side panels were already connected along their top edge with spiral binders). At the connection of the mattress end panels with the top and toe baskets, the 90 degree cut mattress side panel did not match up with the vertical square basket, resulting in a small angular gap. This gap was filled in using lacing wire woven between the mattress side panel and square basket panel.

When welded wire mesh baskets were filled with rock, the use of the spiral binders was limited to 2 wires per connection (2 mesh panels). The 3″ pitch of the spiral appears to function best with 2 or more wires when the baskets are empty.

•COST COMPARISON:

Materials:

The costs for the gabion basket materials supplied for this project were such that the unit cost for twisted mesh baskets was about 15% less in price, including all costs for lacing wire, fastener rings, and spiral binders. The welded wire baskets were supplied with one 1meter x1 meter end panel removed on every 1x1x4 meter long basket. This reduced the total material cost for the welded wire baskets but if all end panels were supplied (the twisted mesh baskets had both end panels included) the cost for the welded baskets would have been higher then as purchased for this project. The welded wire mesh gabions for this project were purchased from a manufacturer, the twisted mesh gabions from a distributor.

However, when costs from several different companies for both types of gabion baskets were compared, the costs obtained vary widely among distributors, especially for the welded wire mesh baskets. The lowest unit cost quoted for the welded wire mesh baskets from a manufacturer was about $10.00 less then the cost of the twisted mesh baskets also quoted from a manufacturer. With some shopping around, it seem that both types of gabions can be purchased for a similar cost.

Labor:

The amount of labor involved is more difficult to quantify, because (a) the construction of the toe, top and mattress baskets did not coincide, (b) there were some requirements for the twisted mesh basket construction that were relaxed for the welded wire basket construction and (c) the welded wire baskets were constructed in warmer weather which most likely did affect production (the wire was stiffer in the cold weather). The construction of the toe basket, for instance, was sometimes completed up to 200 feet ahead of the mattress baskets due to the distance along the work area to which the earthen cofferdam extended on a given day. The requirements that were relaxed between the two types of gabions include:

> (1) welded wire top and toe baskets were not overfilled 1″-2″ with rock so less effort was exerted in closing basket lids.
>
> (2) the number of end panels were reduced on the top and toe welded baskets making it simpler to use the spirals since the workers did not have to worry about two end panels lining up with each other exactly, or pulling away from each other under the forces associated with dropping rock into the baskets from a backhoe bucket.

The Contractor also experienced some delays in the delivery of the gabion rock that were not consistent between the two phases of the project. To obtain a reasonable estimate of the labor required, the installation of the 1 meter x 1meter square baskets were compared. The greatest quantity of gabion basket constructed on a single day is as follows:

Welded wire mesh = 40m (130 lf) of top or toe basket, 9 laborers working on the baskets, which is about equal to 14.5 lf per worker per day.

Twisted wire mesh =30m (100 lf) of top or toe basket, 7 laborers working on the baskets, which is about equal to 14.3 lf per worker per day.

This information was taken from quality control reports and daily construction logs. From these numbers, it would appear that the time required to construct the gabions is about equal for both types of baskets, considering the number of workers. However, when the workers and the contractor's field representative were asked, they stated a preference for the welded wire baskets, because less physical effort was required to assemble and to close lids on the welded baskets with the spiral binders. Fastening the lids with lacing wire was probably the most time consuming task involved in the gabion construction.

•MONITORING RESULTS

Damage or defects in the PVC coating of both types of gabions was monitored closely during construction and was the primary focus of the follow-up inspections. This is because the District has determined from previous gabion revetment projects that a major factor in the long term life and performance of properly installed gabions was protecting the PVC coating from damage. Damage or defects in the PVC coating allows moisture access to the galvanized wire, eventually leading to corrosion and breakage of the wire mesh and increases the risk that smaller stones will be lost from the baskets causing them to be partially filled. Corrosion also increases the possible effects of normal wear and tear on the revetment, such as pedestrian traffic and debris accumulation.

Following a period of three years of inspections, the following was documented on the condition of the gabions:

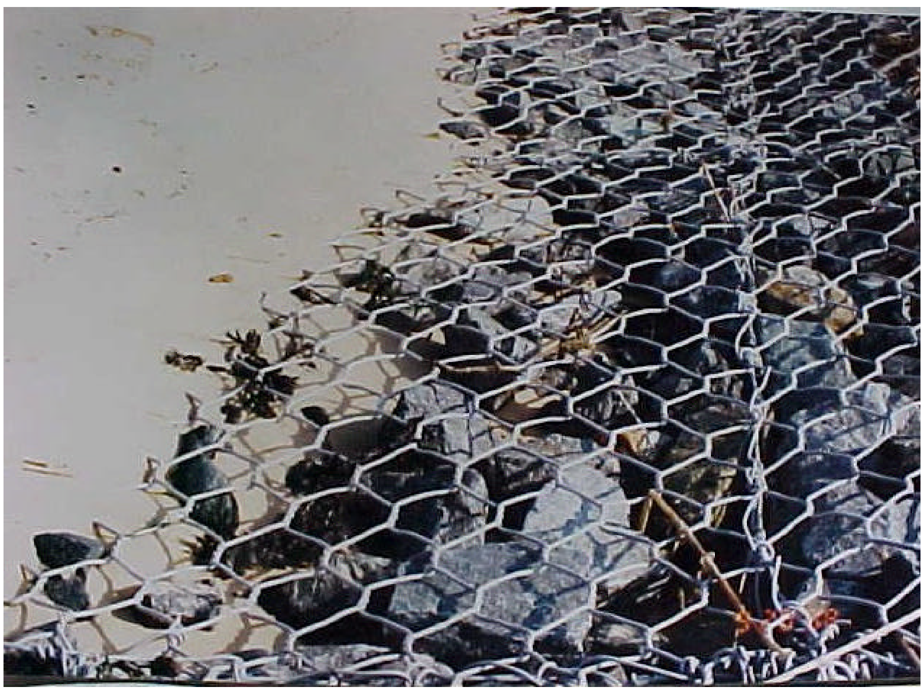
<u>Twisted Mesh Gabions</u>: The revetment as a whole was a very solid structure, and the overall condition was very good. The bottom one-half to one-third of the revetment (toe basket and part of the sloped baskets) was covered by sandy material from the canal and was not visible for inspection along its length until the final inspection. At the final inspection, a small section of baskets were excavated, but toe baskets were inaccessible due to water levels.

•The top selvedge wire of the diaphragms and end panels of the top baskets had slight damage in the form of small nicks and tears to the PVC coating. The wire beneath the damage was intact, however, with no visible corrosion. This damage probably occurred during placement of the gabion rock in the baskets in 3 lifts by the backhoe bucket. This damage to the PVC was not as evident on the top selvedge wire of the sloped mattress baskets. This was probably because the mattress baskets required 1 lift of rock and thus would have sustained less damage.

•Exposed gabion mesh material visually exhibited a tightness and slight thinning of the PVC coating at the location of the twist in the mesh. Brownish-tan discoloration of the PVC coating was noted (the original color of the PVC is gray). This discoloration did not appear to affect the integrity of the PVC coating. This was especially evident on the lids of the top baskets where pedestrian traffic was more common.

•Minor settlement of about 1″ of the rock along the profile of the top baskets was noted relative to the top edges of end panels which remained straighter due to the "double" lacing wire required by the specifications at the end panels of each individual top basket unit. The outer side panels of the square top basket facing the canal were slightly bulging outward relative to their immediate post construction condition, except at the location of the end panels of the top basket units.

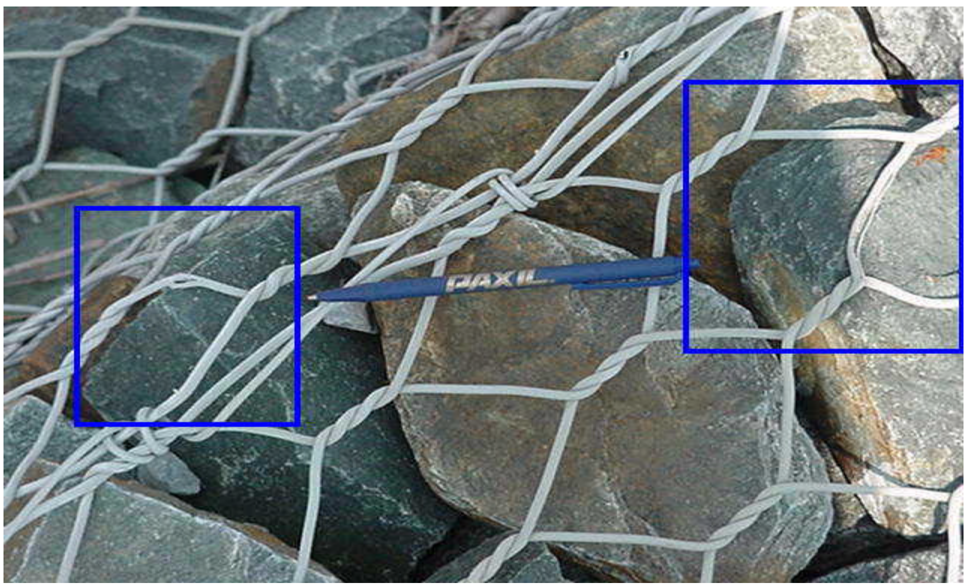
•Along the length of most of the revetment, the sloped mattress baskets below the high water line were noted to have voids up to 8″ deep in some areas between the mattress basket lids and the rock beneath.   Since this area is where the baskets were exposed to the effects of boat-generated waves and tidal currents, it appears that these forces exacerbated rock settlement resulting in more displacement of rock and the large voids. The presence of rocks that were smaller then 4″ (as dicussed in "Gabion Rock") also contributed to the voids.



Voids in the twisted mesh mattress basket in the wave zone resulting from displaced rock.

•In some localized areas, the practice of overfilling the baskets with rock beyond the recommended 2" resulted in breakage of the wire mesh over time, particularly in areas where the outer rock layer included rock(s) that were larger then 8″.

Break in twisted wire mesh top basket resulting from increased stress from protruding rock greater than 8” in size.



Damage to PVC coating on twisted mesh basket at location of angular rock face.

•The locking wire fastener clips made of stainless steel were in good condition with no evident surface corrosion, in areas both above and below the high water line. The PVC coating on the contact areas between the mesh and the clips was damaged.

•In localized areas where sharp or particularly angular rocks exerted pressure directly on portions of the mesh, the mesh was consequently deformed or stretched outward beyond the general shape of the baskets. This resulted in wire breakage and/or damage and splitting of the PVC coating on the top surface of the wire. This occurred primarily on the lids of the top baskets where contact with the baskets along specific areas that were located closest to the adjacent disposal area and access road were more likely. This occurred on average 4 times per 4 meter long by 1 meter wide top basket lid, and was also more common at the ends of the basket units on the selvedges. The same problems were not noted as frequently on the sloped mattress baskets where it was noted that the occurrence of angular edges of rock protruding above the general elevation of the lids were less than for the square top baskets, likely due in part to more rock settlement in the thicker top baskets. Where damage to the PVC coating was noted on the mattress basket lids, it was primarily on the bottom surface of the wire in contact with the angular face of rock.

•Breakage of wire was also noted to occur more frequently in areas where rock was displaced or had settled on the top basket lids, creating a void between mesh and rock. These voids appear to have caused these areas to be more vulnerable to damage from objects or people coming in contact with the mesh.

•In general, in areas where the PVC coating was damaged, the condition of the wire beneath was dependent on the location. Above the high water line corrosion was barely evident; in the tidal zone the corrosion was enough that the rust could be scraped off with little effort; in the area below the low water line the corrosion was minimal. The same was basically true of the condition of the PVC coating. The exposed portions above the sand backfill and water were brittle and discolored from ultraviolet damage. Below the sand and water line the PVC was more soft and pliable.

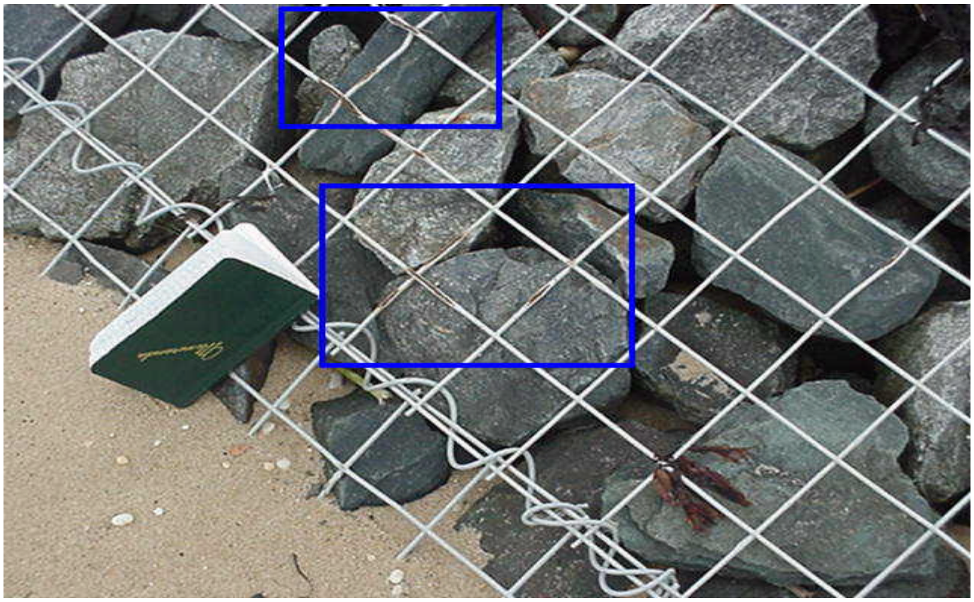
<u>Welded Wire Mesh Gabions</u>: The bottom one third of the revetment (toe basket and part of the sloped baskets) was covered by sandy material from the canal and was not visible for inspection along its length until the final inspection. At the final inspection, a small section of baskets were excavated, but toe baskets were inaccessible due to water levels. The revetment as a whole remains a solid structure, and the overall condition is good, but not as good as the condition of the twisted mesh baskets. This is due to the following:

•The top most wire of the side and end panels of the top baskets also had minor damage in the form of small nicks and tears to the PVC coating, similar to the twisted mesh baskets. This damage also appeared to be caused during placement of the rock in the baskets from the backhoe bucket as described for the twisted mesh baskets. Similar damage but occurring less frequently was also noted on the top edges of the end panels and diaphragms of the mattress baskets as described for the twisted mesh baskets.

•As with the twisted wire mesh baskets, along the length of most of the revetment the sloped mattress baskets below the high water line were noted to have voids up to 8″ deep in some areas between the mattress basket lids and the rock beneath. Since this area is where the baskets were exposed to the effects of boat-generated waves and tidal currents, it appears that these forces resulted in displacement of rock which increased rock settlement and aided the occurrence of the large voids. The presence of rocks that were smaller then 4″ (as discussed in “Gabion Rock”) also contributed to the voids, since it was noted that most rocks in this zone were on the large side of the allowable gradation.

•In general, the corrosion of the steel wire in areas where the PVC coating was damaged was the same as for the twisted mesh baskets. The exposed wire in the tidal zone was more corroded then on exposed wire above the high water line. The PVC coating overall was the same as well except that small black specks were common on the surface instead of the tan discoloration on the twisted mesh. The other exception was that the PVC coating was split at regular intervals on the lacing wire used on the welded wire mattress baskets in the area of the tidal zone, possibly due to a manufacturing defect. The exposed wire in this location was also badly corroded.

• In general, the factor that most affected the condition of the welded wire revetment was that in localized areas where sharp or particularly angular rocks exerted pressure directly on portions of the mesh, the mesh was consequently deformed or stretched upward beyond the general shape of the baskets. The result of this was that the PVC coating on the top wire surface was damaged and split, and in areas where obvious contact with the mesh from external loads and abrasion was noted the wires were frequently broken. This occurred primarily on the wires of the lid of the top basket and the mattress where the location of the revetment to the adjacent disposal area and access road made this more likely. This was a more frequent occurrence than compared to the twisted wire portion of the revetment, and on average occurred about 7 times per 4 meter long by 1 meter wide length of top basket lid. In addition, when the PVC coating was damaged and split, the size of the wire area exposed was generally larger. This tendency was more also common on the welded wire sloped mattress baskets than on the twisted mesh mattress baskets.



Typical splitting of PVC at location of angular rock on the welded wire baskets.

•The wire and PVC coating on the spiral binders (primarily along the outer edge of the lids of the top baskets with side panels closest to the canal) showed consistent damage. This occurred on approximately 50% of the spirals along this edge for the length of the top baskets. The exposed wire was minimally corroded. The spirals themselves were deformed from their original twisted shape, although still intact. This damage is probably due to the loads associated with pedestrian traffic and from work performed in and around the adjacent disposal area, since no such damage was evident on the vertical connections on the front of the baskets that were also fastened using spirals. This damage to the spiral binders was also noted on the diaphragms connected to the top basket lid but was not as prevalent, since the spiral binders there were generally connected closer to the lids then those on the outer edge of the top baskets. Spiral binders used on the mattress basket lids were generally in good condition, also because they are secured close to the lid mesh.

Damage to spiral binder on top basket.

•CONCLUSIONS & RECOMMENDATIONS

After 3 years of inspecting the condition of both the welded wire and twisted wire mesh gabion baskets, as well as documenting construction methods to install both types, the following was concluded:

Fasteners. The different types of alternative fasteners available and related procedures for assembling and interconnecting the baskets present the most obvious difference affecting construction methods. The primary concern regarding alternative fasteners is how each type of fastener invariably affects the PVC coating and how they can provide a tightly knit structure.

Twisted Mesh Gabion Baskets. Lacing wire remains the preferred method of connecting individual baskets together and for closing lids. Ring fasteners are generally acceptable for assembling individual empty baskets as well as fastening empty individual units together, but may not be acceptable for connecting baskets filled with rock or for closing lids unless their use is evaluated by means of a test section, due to product variability in the industry. One possible way to improve the accepted use of these clips is for the manufacturer to provide different sized clips for various connections. For example, a connection consisting of 2 wires would have small clips, a connection consisting of 3 wires would have larger clips, etc. However, it is not known if using various size clips would be feasible or economical, but is a possible improvement to look for in the future.

One area in which District specifications will be relaxed is in allowing the use of fastener clips along the top edge of adjacent empty mattress basket side panels. Previously it was required that the top edges of these panels be laced as well as lacing the roll out lids to the same edge (in effect, double lacing the top edge of these baskets), Lacing wire would only be required along the top edge when the lid is attached. The same does not apply to square baskets since they are greater in depth, each lid is separate, and lacing the top edge prior to rock placement protects this area more when rock is mechanically dropped then when clips are used for this purpose. Lacing wire was observed to generally provide tighter connections along the length of the panels to be fastened due to the practice of overfilling the twisted mesh baskets 1” to 2 “ and stretching the lids to close the baskets.

Other gabion projects since constructed under the jurisdiction of the Philadelphia District have been completed with materials supplied by several different twisted mesh gabion basket manufacturers. An issue that consistently arises when reviewing the District’s specification requirements for gabion construction is that the specifications differ from the recommended methods of installation issued by respective manufacturers. The primary difference is that the District’s position is that tie wire lacing is the most reliable method of fastening gabion baskets, while almost all manufacturers, in an effort to improve on the efficiency of assembling their products, recommend the use of various fastener clips.

The use of fasteners has been successfully substituted for lacing on other District projects since completion of construction for this project comparison. Fastener clips made of stainless steel called “hog rings” were used to pre-assemble twisted mesh baskets (these clips were manufactured by a different company than for the twisted mesh gabions for this project) and were different from the clips used on the twisted mesh baskets for this comparison. A ring was used at every mesh opening along the edges of the pre-constructed baskets. Damage to PVC coating was minimal upon observation of this procedure. In addition, rings were utilized along the lid to make the connections between the lid to the top edge of the baskets, the diaphragm to the lids, and the top of basket to bottom of basket edges of stacked baskets. Lacing was still required to secure adjacent ends of individual baskets. Simply stated, anywhere that 3 or more wires were present and a connection was required, the baskets were laced. It was observed in these projects that the fasteners provided a tight connection and quality control was improved due to ease of inspection, because the stainless steel rings were easy to identify against the gray colored PVC coating then compared to the similarly coated lacing wire.

PVC coating on the lacing wire could also be supplied in a different color or shade if cost is not an issue. This would improve the quality of visual inspection of the lacing and possibly improve the speed of the actual procedure since the lacing wire would be easier to distinguish from the mesh. This is an observation and it may not prove feasible in practice due to characteristics of the PVC coating, but would improve the installation speed when lacing wire is required.

A basic requirement for the use of any fastener clip for twisted mesh baskets should be that if manufacturer’s clips are approved and utilized, the maximum spacing should be four inches minimum through every mesh opening, not 4″ to 6″ as was originally required in the specifications for this projected. Any fastener clip should also provide a tight connection without damaging the PVC coating.

PVC material which can be applied in the field should be supplied with the delivery of any gabion mesh material where ring fasteners are to be used, since damage to the PVC is likely. Any tears or nicks in the PVC coating caused by installation procedures should be repaired prior to completion of work to help extend the overall life of the revetment.

A definite advantage to the use of the twisted mesh gabion baskets is the following:

(1) The twisted mesh gabion material allows the baskets to be overfilled, which in turn results in a tightly packed, very stable structure when factoring in future rock settlement, while remaining very flexible.

Some disadvantages to the use of the twisted mesh gabion baskets are the following:

(1) The variability across the industry that exists for supplying fastener clips complicates their use. Not all clips are equal in the ease of the process in which they can be used or in the tightness and integrity of the PVC coating of connections. Lacing the baskets (especially rock filled baskets) is a time consuming task, and when lacing overfilled baskets there is more physical effort required to pull and stretch the mesh to ensure a tight closure.

(2) The practice of overfilling the twisted mesh baskets with rock can cause damage to the PVC coating and wire breakage if the baskets are overfilled too much and excess stresses are placed on vulnerable areas, particularly those areas in contact with angular rocks and when subject to external loads or abrasion.

Welded Wire Gabion Baskets. Fastener rings are also available upon request from most manufacturers of the welded wire gabion baskets. Their use is not widespread since the spiral binders are more efficient, but they do exist, particularly for small projects. The above recommendations would also apply to these alternative fasteners, but the ring or clip spacing should be every 3″, or every mesh opening.

Spiral binders were observed to function well for assembling and connecting together individual empty baskets. Their use for connecting individual baskets filled with rock or for fastening lids should be approached with caution, although this is generally included in what their use is promoted for. The need to maintain a maximum 1″ gap between panel edges in order to install the spirals efficiently has some disadvantages, particularly when fastening lids to rock filled baskets:

(1) The need to maintain the maximum 1″ gap to efficiently use the spirals prevents the baskets from being overfilled 1″ to 2″, which is generally required when constructing twisted mesh baskets. This essentially means that welded wire baskets should be filled to the top of the side/end panel, not over or under filled. Some settlement always occurs on the lower rock layers from the weight of the rock placed above, as well as from other loads such as large debris or pedestrian traffic. In addition, on the Cape May project waves and tidal currents contributed to settlement by displacing rock that was not tightly packed into the baskets in the tidal zone. The restriction on overfilling the welded baskets 1″-2″ combined with the rock settlement results in extra space between the top layer of rock and the basket lids over time. This consequently can increase the tendency for damage to occur to the PVC coating. The mesh will tend to bend inwards towards the lower surface of the rock layer below and as a result in localized areas where angular rock exerts stress directly on a wire (or wires), the fuse bonded PVC coating may

split, exposing the wire beneath (see photo on pg. 15). If those areas in contact with angular rocks are also subject to enough external loads or abrasion, wire breakage has a tendency to occur.

(2) The welded baskets tend to contain slightly less rock by volume due to the need to maintain the 1″ gap between panel edges (as well as due to the level of effort in placing and handling rock on this project, which was determined to be sufficient at the time). Over time and when subject to large or repeated stresses such as waves or significant flows this may cause the revetment to be less stable overall when compared to gabion baskets that contain more rock by volume and therefore have more weight to the structure as a whole. However, this did not present such a problem on this project for the length of time the revetment was observed.

(3) The upper half of the spiral binders used on the top connection of lid and side panels on square baskets (not covered by other baskets or backfill) remain above the top of the basket lids since they retain their rounded shape. This leaves the spirals and PVC coating more vulnerable to damage from external loads or abrasion such as would result from pedestrian traffic.

To eliminate the disadvantages of using the spiral binders as discussed above on rock filled baskets, additional hand sorting and leveling of the rock as placed in layers is recommended. This is particularly necessary on the exposed outer layers of rock where eliminating sharp or angular rocks from contact with the wire mesh would reduce the chances for damage to occur to the PVC coating as described above. Hand placement would also increase the volume of rock that can be packed into the baskets as well as decrease the amount of expected rock settlement.

The potential for the spiral binders to become damaged as described above in paragraph #3 should be considered when evaluating potential locations to construct welded wire gabions. As an example, (in hindsight) due to the location of the revetment on this project adjacent to a dredged materials disposal area, use of spiral binders should have been limited to assemble empty baskets and for connections between individual empty basket units. Lacing wire remains the preferred method of fastening rock filled welded wire gabion baskets as well as twisted mesh baskets, especially for fastening lids (until stainless steel spiral binders become available). Providing the lacing wire with a different color PVC coating as mentioned in the twisted wire mesh gabion section would also be an improvement for welded wire gabions.

Another disadvantage to the welded wire baskets supplied for this project is that if the specifications would have required the lids to be laced on rock filled baskets, the roll out lids on top and toe baskets would have had an additional connection to be fastened in the field (along the land ward side of the lid to the side panels). The specifications could have accounted for this by requiring that the lids be delivered to the site connected in 4 meter long sections already pre-assembled along one edge to the rest of the individual baskets.

Welds. No problems were encountered on this project with the apparent shear strength or quality of the welds on the mesh for the welded wire gabions.

Some advantages of the welded wire baskets are the following:

(1) Additional choices of materials for the PVC coated and metallic coated welded wire mesh baskets as far as combinations of mesh opening sizes and wire gauge are available throughout the industry (disregarding additional cost). This in turn allows more flexibility in determining rock fill size distribution, or if rock sources are limited. It is possible to obtain PVC coated welded wire baskets with 11 gauge wire (which improves the stiffness and durability of the panels) while maintaining a cost slightly more expensive but still comparable to manufacturers' costs for 12 gauge twisted mesh baskets. This might possibly be the case where higher strength mesh is required due to expected loads or stresses. This would also improve the durability of the PVC coating on baskets subject to stresses incurred during construction and service life as described above. Conversely, this would reduce the flexibility of the whole structure which would have to be a consideration in evaluating other possible erosion control measures. Also, ASTM A-974-97 includes only standard size welded wire materials for gabion baskets.

(2) The spiral binders are very easy to use to assemble and connect empty baskets, require no tools to use and do not damage the PVC coating. Once in place, they are very simple to inspect for proper placement once it is verified that ends are crimped. If hand placement and leveling of rock placement is completed in such a way that voids are minimized, the outer layer of rock is relatively flat and the 1" gap between panel edges is satisfied, then use of the spiral binders is both faster to install and easier to inspect than lacing wire.

Gabion Rock. The factors of gabion rock that primarily affect the quality of the gabion baskets are the size distribution and the hand placement of the rocks inside the baskets.

The control of the gradation of rock fill is important in retaining the rock inside the baskets due to the mesh opening dimensions and for the need to minimize voids which increase the risk of settlement. Problems were encountered on this project in obtaining consistent rock gradation quality as discussed above in "Gabion Rock". Recommendations by gabion manufacturers and the contract specifications were very direct: the rock shall be between 4″ and 8″ in size. In the future, the following language will be included in District specification requirements for sizing rock fill in order to provide a more concise limit on what will be acceptable:

"Rock supplied as fill for the gabion baskets shall be such that no rock is retained on the 8″ sieve and minimal rock shall pass through the 4″ sieve (see table below). The 0 to 5 percent passing the 4″ sieve shall only include fines, sand, and quarry spalls incidental to mechanical handling and transport of the rock. Sizes of gabion rock shall be such that at the time the stone is mechanically dropped into the baskets an overall even distribution of stone sizes is achieved. Individual loads or parts of loads may be rejected if material does not meet the specifications."

Stone size	Stone size	% Passing
203 mm	8″	100
152 mm	6″	40-60
102 mm	4″	0-5

Sample gabion rock gradation

This requirement places more responsibility on the Contractor to perform sieve analyses on site if on inspection rock quality is not up to the specification requirements, which will result in an increase in construction costs. Due to the importance of limiting rock settlement in gabion baskets, in the future the District will reserve the right to require on-site rock screening by use of a grizzly if the Contractor has difficulty in obtaining the proper gradation from the quarry.

Hand leveling and sorting rock placed in each layer is also important for both welded wire and twisted wire baskets since it indirectly affects the durability of the PVC coating under stresses incurred from loads such as pedestrian traffic or large sized debris subject to movement from waves and currents.

The PVC coating is extruded onto the twisted wire before it is twisted to form the basket mesh. The PVC coating on the welded wire baskets is fuse bonded to the mesh after the mesh is welded. Both the fuse bonded and extruded PVC coated wire experience damage to the wire and coating in slightly different ways. Both types of mesh are subject to damage in localized areas where sharp or particularly angular rocks exert pressure directly on portions of the mesh where the mesh consequently deforms or stretches outward beyond the general shape of the baskets. These points where the rock protrudes too far are essentially points of increased stress and friction on the wire under loading conditions. The result of this is that the PVC coating on the top surface (and to a lesser extent, the bottom surface on the twisted mesh baskets) can become damaged and split, exposing wire to the elements. This appears to be more common for the welded wire mesh gabions since the PVC is bonded to the wire. This damage could be reduced significantly if more care is taken in hand leveling and sorting the rock to ensure that the top layer is composed of rock with the flattest face in contact with the mesh, and such that rock settlement will be minimized. The twisted mesh gabion baskets can also incur damage to the PVC coated wires if the baskets are overfilled too much and the lids have to be pulled and stretched in excess.

The outer faces of both types of square gabion baskets could also be supported by the use of plywood forms during the placement of rock in the baskets from mechanical equipment. This would help to prevent some bulging and additional stresses on the mesh material, make it easier to visualize the 1” to 2” overfilling of the rock in the twisted mesh baskets, as well as provide a neater appearance. Another method that may aid in reducing rock settlement is to distribute a mix of small stone such as a quarry blend or pea gravel throughout each hand sorted lift of rock in the square baskets. The smaller aggregate would fill in the voids in the rock and possibly prevent rock displacement and settlement. In warm climates, a mix of whatever material is excavated on site could also be used when freeze/thaw cycles are not a problem. Clearly, additional costs to incorporate the above recommendations should be considered against how long they may extend the useful life of the gabion baskets.

Summary. Based on observations made during the monitoring of this project, the welded wire and twisted mesh gabion baskets constructed for this comparison are nearly equal in function and performance. The amount of localized damage to the wire mesh and PVC coating described in the above paragraphs is not significant when considering the overall stability of both the twisted mesh and welded wire gabion revetments in this comparison. Most damage was noted on the top square baskets which were subject to a greater potential for wear relative to the rest of the revetment, due to their location adjacent to a Corps-owned dredge spoils disposal area and access road. Although this site presented a very aggressive environment, both portions of gabions are in good and stable condition.

The durability of both twisted mesh and welded wire gabion baskets could be improved by the recommendations above regarding rock placement and handling. It appears that this is more important when constructing welded wire gabions if the use of spiral binders is proposed to fasten lids on rock filled baskets.

Using spiral binders on welded wire mesh gabions as opposed to fastener clips on twisted mesh gabions to assemble and connect together empty baskets is comparable in time and effort. However, the spiral binders are easier to inspect than individual fastener clips that depend on a gun or other clamping tool to achieve proper closure, and may be loose or tight depending on the manufacturer and other factors. The spiral binders also do not cause damage to the PVC coating, which is a possibility with fastener clips. Conversely, spiral binders may not be as durable as fastener clips depending on the connection in which they are used and anticipated external loads.

The rate at which both types of gabion baskets can be constructed is similar, due to the following:

> (1) The spiral binders should be used with care when closing lids on rock filled welded wire baskets, for the reasons described previously in “Conclusions & Recommendations”. Since closing lids on rock filled baskets is generally a time consuming process, a trade off is essentially made between the length of time spent on ensuring quality control of rock placement procedures versus using the spiral binders or lacing wire. If it is desired to spend minimal time and effort on procedures for placement of rock, then using lacing wire on the welded wire baskets will result in a comparable length of time required for closing both types of filled baskets.

Cape May Canal project site prior to construction looking East

Completed gabion basket revetment, post-construction; showing the twisted wire mesh portion of the revetment from the same location.

Twisted mesh gabion revetment, 3 years post construction, facing east.

Completed gabion basket revetment, immediately post-construction; showing welded wire mesh portion of the revetment looking west. Access road and disposal area in background.

Welded wire gabion revetment 3 years post-construction, facing east

-GMG   06 June 2001