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Synthetic Fabrics as a Concrete Forming Device

Tissu synthétique utilisé comme système de moulage du béton

Since the advent of concrete as a construction material, engineers and contractors have been restricted in its use by the rigid forms of steel and wood required to contain the concrete until its initial set. In the early 1960's another man-made material, synthetic fabric was pioneered as a flexible forming system for concrete placement thus greatly expanding the potential uses of concrete. Furthermore, the relatively low cost of the synthetic fabrics has resulted in more economical concrete placement costs. This paper will trace the nearly 20 years of synthetic fabrics as a forming system covering its history, fabric development, design and installation criteria and significant case histories in the following areas.

1. Mattresses for slope protec tection.
2. Pile Jacketing.
3. Tubes and bags for underwat er concrete placement
4. Columns through mines and limestone cavities.
5. Miscellaneous uses.

Depuis le béton soit utilisé dans la construction sont les ingénieurs et entrepreneurs limités par la nécessité de retenir le béton fluide dans des moules rigides de bois et d'acier jusqu'à sa prise initiale. Au début des 1960's est apparu un nouveau matériel fabriqué de main, le tissu synthétique, qui s'est introduit comme système flexible de moulage du béton, élargeant le rôle potential du béton à la fois que le coût assez bas du textile synthétique a mené à un coût plus économique de la mise en place du béton. Le présent rapport racontera l'histoire de vingt ans du tissu synthétique utilisé comme système de moulage du béton, sa développement, des critères pour le dessin et l'installation aussitôt que des dossiers importants dans les domaines suivantes:

1. Matelas pour protection de pente.
2. Enveloppement du pieu.
3. Tubes de mise en place du béton sous marin.
4. Colonnes à travers des mines et cavernes calcaires.
5. Usages divers.

INTRODUCTION

The first U.S. patent for utilizing fabric as a forming system was issued in 1906 to Robert Cummings of Beaver, Pennsylvania for building concrete piles. A pipe was driven in the ground, a sleeve of pervious coarse bagging was inserted into the pipe, concrete was poured into the sleeve-lined pipe, and the pipe withdrawn. In the early 1920's a Norwegian, John Store, developed a flexible fabric form for the placement of concrete in a subaqueous environment. In addition, the 1926 Danish book of inventions described a method using fabrics for casting large underwater concrete foundation blocks for the purpose of constructing bulkheads and wharfs.(1) So even though fabrics as a concrete forming system was recognized as a viable technique at about the same time that concrete was coming into use as a construction material, fabric as a forming system had limited use prior to the early 1960's when a new generation of synthetic fibers were introduced. The superior strength and performance qualities of the woven petroleum based yarns resulted in a great expansion of fabric formed applications in the area of construction. In the ensuing years, many patents were issued; so much so that, of the many uses of fabrics in construction, the use as a form is the most heavily patented.(2)

1.0 MATTRESSES FOR SLOPE PROTECTION

With the availability of the new generation of high strength synthetic fibers, attention was concentrated on the development of a dual-walled fabric envelope into which concrete could be placed for utilization in erosion control applications. Prior to 1970 numerous methods were suggested to join the fabric layers, for example, H.F.J. Hillen of the Netherlands, suggested using nails and washers. Other methods tried were sewing, gluing, thermoplastic adhesion, weaving and the utilization of integral spacer cords. Actual field applications have proven that weaving and/or integral spacer cords provide the most economical and strongest method of joining two layers of fabric.

With the weaving method, the two layers of fabric are joined intermittantly through the mechanical function of the weaving loom. The current method of joining fabric by the weaving process is by joining the layers together in a grid pattern. These 4.4 cm. (1.75 in.) circular joining points are spaced on 12.7, 20 or 25 cm. (5, 8, or 10 in.) centers and control the maximum thickness of the concrete inflated mats.

With the integral spacer cord method the two layers of fabric are interconnected by spacer cords. The length of the spacer cords may be adjusted during the weaving process to produce a fabric form of desired thickness. Within each square yard of fabric the spacer cords provide a minimum of 178 kN. (20 tons) of tensile strength, and in some cases exceed 333 kN. (37.5 tons). For the relief of hydrostatic pressure, non-corrosive weep hole assemblies may be placed in the fabric prior to concrete placement, at desired locations.

Where slopes are not subjected to continuous heavy flows and/or where environmental conditions or aesthetics dictate, an alternate fabric formed revetment mat may be utilized. This form work consists of interconnected tubes of concrete, the diameter of which may be varied according to the application. The areas between the interconnected concrete tubes provide a means for the placement of soil and ground cover and vegetation. This results in an aesthetically pleasing armourment.

1.1 Concrete Design

As the space between the two fabric layers may be as close as 7.6 cm. (3 in.), with internal cords at 7.6 cm. (3 in.) spacings and has to be pumped in place, a very fine-grained fluid concrete has been mainly utilized. A typical mix may be as follows:

Typical Mix:

6 - 10	Sacks Cement 2.5 kg. (94 lbs./sack)
68 - 115 kg. (50 - 150 lbs.)	Flyash (when available)
1,000 - 1,200 kg. (2,200 - 2,650 lbs.)	Sand (depends on FM)
180 - 225 litres	Water (48 - 60 gal.)
4 - 12%	Air (Depending on Geographical Area)

Some fabrics for the mattresses are specifically designed to allow the water in the mix to bleed through the fabric without allowing the cement to escape thus causing a lowering of the water cement ratio and an increase in compressive strength. (3)

1.2 Design, Construction and Cost Criteria

The revetment should be sized using the same criteria as established for conventional cast-in-place slabs. Based on experience in navigation canals carrying heavy traffic, the thrust and waves caused by ships is of particular importance in the design and dimensioning. As a guide for sizing mats thickness, the following is suggested:

a) Inland waterways, such as canals and rivers: 1.91 - 2.87 kPa (40 - 60 lbs./sq. ft.)

b) Costal areas and inland water with strong current and wave action: 2.87 - 7.18 kPa (60 - 150 lbs./sq. ft.)

Actual case histories show that reventment mats 9 cm. (3.5 in.) thick have been subjected to velocities between 4.6 and 5.5 m./sec. (15 and 18 ft./sec.) and those 60 cm. (24 in.) thick have withstood typhoon forces. Where hydraulic energy is a design consideration, the "n" value as used in the Manning formular will range between 0.014 and 0.030, depending on the type mattress.

Revetment Mats provide protection to stable earth slopes and surfaces which are subject to erosion by water. They may be placed on a horizontal or on gradients up to 1:1. Steeper gradients have been successfully completed but are not recommended. Mats should not be used on unstable slopes or where conditions of excess deformation is anticipated.

Most installations have the mat toed in a minimum of 0.3 m. (1 ft.) into a trench at the crown and bottom of the slope to prevent underscour. In subaqueous installation the bottom trench may not be utilized if the mat is taken 1 m. (3 ft.) below known scour.

The cost of an installed mat is subject to many factors, some of which are, project size, water conditions, local labor conditions and concrete prices. At the current time a 10 cm. (4 in.) reventment mat installed will range from between $16.00 to $21.50 per sq. m. excluding site preparation.

1.3 Case Histories

Johnstown, Pennsylvania

The Johnstown area first obtained flood notoriety when the South Fork Dam broke on May 31, 1889, killing over 3,000 people. The next major flood to hit the Johnstown area was the one-in-two-hundred year storm in the winter of 1936 and the peak maximum discharge of the Conemaugh River at Pennsylvania Electric's Seward Station was estimated to be 2,500 cms. (90,000 cfs.). When Pennsylvania Electric Company's engineers were designing a new dike to surround Flyash Pond No. 2, they wanted to make sure that the dikes were not only strong enough to take the force of any future flood waters, but also higher than the two past major storms.

The river side of the dike was designed to have a 2 in 1 slope and the face of the dike was designed to be protected by a 20 cm. (8 in.) filter point Fabriform® revetment mat with the top of the revetment mat toed into the dike at the height of the 1936 flood at this location. Also, in order to prevent undercutting of the dike, the Fabriform was designed to have a 0.6 m. (2 ft.) toe into original ground at the bottom of the dike. The Fabriform revetment mat was approximately 305 m. (1,000 ft.) long and covered just under 3,530 m2 (38,000 s.f.) of the surface area of the dike.

After the mattress was installed, an additional 1.5 m. (5 ft.) was added to the dike as an additional safety factor.

On July 20, 1977, heavy rains inundated the Johnstown area causing floods of a greater magnitude than the 1889 and 1936 flood. At the Seward Station site, waters were 1.5 m. (5 ft.) higher than the 1936 storm and the peak discharge was over 2,750 cms. (97,000 cfs.) equivalent to a one in 250 year storm. The town of Robindale, situated between Flyash Disposal Pond No. 2 and the Seward Station, was completely wiped out; with the Seward Station inundated with over 6.1 m. (20 ft.) of water.

Although scour of the upper unprotected dike above the mattress took place, the mattress completely protected the dike and prevented the large quantities of flyash in the pond from polluting areas downstream. Except for some minor damage caused by heavy debris in the flood waters scraping the mattress, the mattress itself was unscathed.

New York, New York

LaGuardia International Airport is built largely upon landfill and is protected from the adjacent shoreline by a sheet pile bulkhead. During initial construction, the toe of the bulkhead was covered with an asphalt-topped earthen berm to prevent erosion and underscour.

In late 1980, after years of damage from heavy wave action, the entire shoreline was littered with large and heavy debris which had penetrated the asphalt-topped berm and exposed the unstable earthen substrate. This condition subjected the sheet pile bulkhead to rapid underscour and potential failure during storms, which would result in flooding and damage of adjacent runways.

As a means of permanently protecting the bulkhead from erosion and underscour, the Port Authority specified an 20 cm. (8 in.) thick revetment mat to be placed along 800 m. (2,600 ft.) of the bulkhead.

After removal of the large amount of accumulated debris, the erosion-damaged slope was backfilled to provide an even surface for the revetment mat. The Hydro-lining fabric formwork was shipped to the site in preassembled panels of 279 m2 (3,000 s.f.) in area. These panels were positioned on the prepared slope and joined together using a portable sewing machine. Using a 19 m3 (25 c.y.) per hour concrete pump, the grout slurry was pumped into the fabric until it had inflated to its full predetermined thickness.

In order to relieve groundwater pressure which could lift and crack the mat, weep holes were placed in the mat on 2 m. (6 ft.) centers. The project required in excess of 4,645 m2 (50,000 s.f.) of revetment mat and was completed in November, 1980. The revetment mat was installed without interfering with flight schedules, and the finished product provides a attractive, permanent protection for the bulkhead and adjacent runways.

2.0 JACKET PILING

Up until the 1960's the main method of repairing deterioration of wood, concrete or steel piles in a marine environment was to attach metal half-shells together around the section to be repaired and connecting this to a cumbersome bottom form prior to filling the annular space with concrete. The use of fabric forms offers a viable and economical alternative method.(4)

After the pile is cleaned, reinforcing steel installed, a pre-cut fabric sheet fitted with a heavy industrial zipper is wrapped around the pile by a diver. The fabric form is zippered in place and clamped below the bottom of the zone of the pile to be repaired and the top is supported off the marine structure or clamped above the splash zone. Through hoses installed to the bottom of the repair, fine grained concrete is injected thus filling the annular space with a minimum of 7.6 cm. (3 in.) of concrete. Due to the flexibility of the fabric forms and despite the internal spacers, care must be exercised in fast moving water so that the jacket of fluid concrete is kept uniform around the pile until initial set. Also, as sewing of the zipper to the fabric restricts the normal 10% fabric expansion at that location, stitching on the opposite side of the jacket is recommended in order to avoid a "banana" shaped jacket.

The light weight, ease of installation and low cost of the fabric forms resulting from this system nearly always are more economical than other forming systems. However, these repairs are still highly labor intensified, always made by divers and dockworkers whose rates will fluctuate by a factor of at least ten depending on whether the job is performed non-union or union, and the idiosyncrocies of the local labor agreement. This coupled with many other variables such as number of piles to be repaired, depth and velocity of the water at the site, diameter of jackets, amount of cleaning required, amount of reinforcing steel needed, etc. makes it almost impossible to give even a budget cost figure for pile jacketing except on a job by job basis. Experience has shown that minimum cost start at $150/m.

2.1 Case History

Since the mid-sixties many piles have been repaired by this system in water depths up to 18 m. (60 ft.). However the following case history is the largest diameter on record to the authors' knowledge. After approximately 50 years of exposure to the Pacific Ocean environment, the steel forms on the 2.5 m. (8 ft.) diameter caissons supporting a pier for the exportation of copper ingots had badly corroded and revealed deteriorating concrete at Andes Cooper Mining Company, Chanacal, Chile.

The rehabilitation design called for a 30 cm. (1 ft.) cover of reinforced concrete encasement utilizing a fabric form. The concrete encasement extended from the top of the caisson to the ocean floor, a length of between 7.7 m. and 8.6 m. (25 and 30 ft.). After removal of all unsuitable material and marine growth, reinforcing steel was attached to the caisson along with non-corrosive spacing devices. A fabric form 3.1 m. (10 ft.) in diameter was then placed around these elements and zipped closed, suspended from the pier and banded tightly to the caisson slightly below the ocean bottom. Concrete injection pipes were installed in the bottom of the form and were slowly withdrawn as the fabric form filled with high strength fine aggregate concrete. Steel bands were used to provide temporary support to the fabric during pumping and were subsequently removed.

3.0 TUBES/BAGS FOR UNDERWATER CONCRETE PLACEMENT

Since the availability of high strength synthetic fibers it has been possible to construct large bags and/or tubes to cast large concrete elements in place in a subaqueous environment. These concrete elements have been used to protect shorelines against heavy wave action, repair scour of bridge piers and abutments, structural repairs, construct breakwaters and groins, pipelines cradles/saddles, etc. (2,4,5,6,7,8). These fabric formed elements are an economical alternate to the conventional methods of large riprap and/or massive precast concrete elements.

3.1 Design and Installation Criteria

When utilizing large tubes/bags for shoreline protection, close attention must be given to protecting against toe scour and undermining of the underlying soil.

Until the concrete sets, the fluid mass of concrete could roll out of position endangering divers working with them. Therefore, the fabric tubes/bags may be anchored and held in proper alignment with steel stakes which may be removed after the concrete has set. To insure proper alignment when stacking the tubes/bags, the joints should be staggered. A temporary supporting device such as angles may be used to prevent the tubes/bags from rolling. Straps and/or grommets may also be used. The tubes and bags may be doweled together with reinforcing steel by inserting one end of a reinforcing steel bar through the fabric and into the fresh concrete, the other end is threaded into the next tube/bag prior to concrete placement. The maximum thickness a tube/bag may be filled is limited by its width. For all practical installations the height should not exceed 60% of the width. The length of tubes/bags have no maximum, however, those of 3.1 m. (10 ft.) are most popular, with tubes as long as 27.5 m. (90 ft.), to heights of 1 m. (3 ft.) and widths of 1.85 m. (6 ft.) being installed in over 12.4 m. (40 ft.) of water.

Placement of the concrete into the tubes/bags is accomplished by means of a concrete pump. The pump hose is "inserted into" the inlet valve (self sealing or manually tied) and filled with a sand/cement mortar. The mix design being within the same range as that utilized in the mattresses and described earlier. Pea gravel may be added to the mix to lower the material cost providing pumping conditions are tolerable.

3.2 Cost

The tubes/bags material will range in cost between $3.25 and $7.50/sq.m ($0.30 and $0.70/sq. ft.) depending on the material used which is dictated by the size of the tubes/bags.

4.0 COLUMNS THROUGH ABANDONED MINES AND LIMESTONE CAVITIES

Many parts of the earth are underlined by abandoned mines or limestone cavities whose subsistence could cause major failures to structures situated over them. The cost of grouting or backfilling these abnormalities is high and often indeterminate. One alternative is to form columns through the cavities on a grid pattern to support the roof of the cavity and prevent failure during the life of the structure. The technique involves drilling 12.6 cm. to 15 cm. (5 to 6 in.) diameter holes through the cavity and a minimum of 1 m. (3 ft.) below the floor, then to snake down the hole a fabric tube having an inflated diameter of between 0.6 and 1.2 m. (2 and 4 ft.). A steel pipe is used within the tube for stiffness and to inject the grout. When the fabric tube is into the drill hole below the floor, the grout pipe is slowly extracted as grout is injected. Care has to be exercised as not to rupture the tube with too high a hydraulic pressure and a multilift filling operation can be utilized.

4.2 Case History

A fossil electric generating plant in South Carolina is supported mainly on caissons extending through the overburden into limestone rock. The limestone is subject to cavitation and extensive grouting has been performed in the cavities beneath the caisson. A limestone reclaim pit was to have a deep foundation extending to the top of the rock. In order to prevent future settlement, while avoiding the large and indeterminate cost of cement grouting, it was elected to form 1 m. (3 ft.) diameter concrete columns through the cavity in the limestone. In the 6.1 m. by 10.4 m. (20 ft. by 34 ft.) area, 14 holes were drilled and the height of the cavity varied from zero to 4.3 m. (13.9 ft.) with the roof of the cavity at approximately 18.2 m. (60 ft.) from the surface. In order to test the continuity of the columns, the fabric was wrapped around a closed-end PVC pipe. After the fine-grained concrete inflated the tube to the 1 m. (3 ft.) diameter, geophysical sonic velocity probes were performed and verified that 1 m. (3 ft.) diameter tubes had been formed.

5.0 MISCELLANEOUS USES

5.1 Off Shore Pipeline Installation Cradles

In order to speed up installation of offshore pipelines, fabric tubes have been designed to be attached to the leading edge of the pipeline. After being inflated with fast-setting concrete, these serve as cradles for support of the pipe until the trench under the rest of the pipe is being backfilled thus freeing up the surface support equipment sooner and resulting in a more economical installation.

5.2 Cylinder Pile Closures

In order to form continuous walls in aqueous environments, large diameter cylinder piles have been installed, but the forming of the uneven vertical closures has been an expensive operation. Fabrics sewn on the job to accurately conform to the configuration developed in the pile placement operation and to meet the varying requirements of the project can be economically installed, reinforced and inflated with concrete.

5.3 "Safe" Riprap

An alternate design for an offshore circulating water system for a nuclear power plant called for the pipe to be buried in a trench in the ocean floor. The Nuclear Regulatory Agency was concerned that conventional riprap used as protective backfill would harbor marine life which could be exposed to contamination. Therefore, the design called for concrete inflated fabric tubes to be placed over the backfill and installed so that the convex-concave edges of the tubes would allow flexibility without allowing intrusion by marine life.

5.4 Scour Protection for Offshore Structures and Pipelines

The research platform "TVORDSEE" compared the advantages for scour protection of nylon woven mats filled with grout to artificial seaweed, sandbag clusters in nylon netting and pre-cast concrete slabs hinged to the edge of the platform. The mats weighing 3.5 kn/m2 proved relatively economical and offered a high degree of scour protection.

5.5 Raising of Earthen Dikes

When it is required to raise earthen dikes, one technique is to use fabric tubes inflated with concrete. A narrow trench can be dug in the top of the dike for positive cutoff and a single tube, or pyramid of tubes with vertical dowels, used to conform to the project requirements.

6. FUTURE DEVELOPMENTS

The use of synthetic fabrics as a concrete forming device has unlimited potential. One natural extension of its utilization is in the installation, repair and maintenance of offshore structures and related subsea installations. (8) With continued development of stronger synthetic fibers, special sewing/fabricating techniques and specialized installation contractors, some of the following applications become practical: a) Pipeline perimeter lining - continuous or rip joined; b) Protective domes for subsea installation; c) Repairs to pipeline protective coatings; d) Sleeve Grouting - electrical conduits/cables; e) Repairs to damaged structural nodes; and, f) Pipeline support and relining of large diameter corroded or damaged underground sewer lines.

7. DEVELOPMENT OF SYNTHETIC FABRIC AS A CONCRETE FORMING SYSTEM

Woven fabric of nylon, polyester and polypropylene have been used almost exclusively for the predescribed applications. Polypropylene being a byproduct from production of petroleum product is more available and economical and less subject to continuing cost escalation then nylon.

For economic reasons non-woven fabrics have been experimented with, but either poor aesthetic appearance, too low textile strength, non-uniform strength in different directions, inadequate connection capabilities, etc. have effected their more widespread use. Current weaving technology allows different yarns to be utilized in the warp and weft directions if so desired. Most forming fabric uses have been with yarns between 840 and 2,000 denier, however, deniers as low as 500 and as high as 3,200 have been used. The yarns utilized to produce fabric forming should be ultra violet stabilized to increase the longevity of the fabric form.

8. CONCLUSIONS:

This heavily patented field has resulted in only a small number of construction firms having installation experience; only a few suppliers of fabric materials and most regrettably little funding for basic research, thus the lack of interest in the academic community in this area. Consequently, to date there has been a limited number of technical publications and reports on using synthetic fabrics as a forming system with most emphasizing the case history approach. However, the flexibility of the fabric forming system will continue to inspire the imagination of the engineers and contractors to use fabrics as a tension form and solve many future problems economically.

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