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GEOMEMBRANES FOR COFFERDAMS
GEOMEMBRANES POUR LES BATARDEAUX
DICHTUNGSBAHNEN FÜR VORDÄMME

A few facts are discussed to suggest that Geomembranes can offer an appropriate solution to problems and conditions typical of cofferdams. After reviewing some design aspects of cofferdams incorporating a geomembrane, two examples, different for geometry and materials, are presented with their construction details and geomembrane characteristics.

Es wird dargestellt, dass Dichtungsbahnen klare und saubere Lösungsmoglichkeiten bieten für Vor-und Hilfsdämme. Zuerst weiden Bemessungsgrundsätze von Vordämmen mit Dichtungsbahnen diskutiert. An zwei Beispielen, mit unterschiedlicher geometrie und Materialien, weiden Eigenschaften des Dichtungsbahnen und Ausführungsdetails näher erläutert.

1 PECULIARITIES OF COFFERDAMS

Although structurally very similar to earth-rock dams, cofferdams differ from their sister structures in many respects. A first and obvious difference between cofferdams and dams stays in the lenght of their expected life. More important however are the conditions under which cofferdams are built and must operate. In most cases, the job timetable places cofferdam construction among the earliest operations to perform on the jobsite when borrows and quarries are not yet properly opened: this often results in a limited availability of materials. Even when the cofferdam forms a part of the main dam, lesser quality materials are assigned to the cofferdam and cofferdam zones construction is specified in a more tolerant way. Whenever the cofferdam is a temporary structure it becomes the obvious place where random or low grade materials find their place.

Often, start up delays and the inevitable difficulties of the early months of any field activity, leave a short time to built a cofferdam ahead the flood season. Cofferdams, actually work as flood control dams: the impoundments rates they must be able to withstand are normally high to very high in relation to the limited capacity of the lower part of the reservoir. Equally fast are draw-down rates. This represents a rather rough loading condition to the structure. Because grouting and drainage of cofferdam foundation is kept to a minimum (if not neglected) the cofferdam resources to face often demanding service conditions are seldom oversized.

Even when the above mentioned factors do not combine in the most unfavourable way, a cofferdam remains a structure posing a number of problems and requiring a sound design and a rughed construction.

2 POLYMER PRODUCTS AND CIVIL CONTRACTING INDUSTRY

Until recently civil construction, confident in its practice and long tradition, has been reluctant to consider new materials produced by other industries like industry of polymers. Yet geopolymers, in form of geotextiles, geonets, geogrids and geomembranes, once accepted, allowed substantial advances in civil construction in form of innovative solutions and better performance. There is no need to elaborate further on the reasons for a booming use of geopolymers in the civil contracting industry but one point is worth recalling.

The request for ever better quality, uniformity and performance of civil and geotechnical works has simply been transferred by designers and owners onto contractors. Limited or no consideration has been given to the inherent limits of many processes and practices of civil construction and of geotechnical construction in particular. Such a process resulted, more often than realized, in overdemanding specs and either in false promises or in unwarranted construction difficulties. Releaving traditional geotechnical materials and construction processes from overdemanding constraints and aiming rather at their 'quality x cost' optimum (in the sense of stopping short of processing and placement refinements requiring incremental costs exceeding the corresponding increase in quality / uniformity / performance) would certainly benefit the civil contracting industry. In this line of thinking, transferring, quality, uniformity and performance requirements to the new materials produced by the chemical industry and letting civil construction to work at his optimum 'quality x cost' level may be the best justification for introducing polymer materials in geotechnical structures and works. A geomembrane coupled to a random fill, where the embankment must provide support only and the key function of imperviousness is ensured by a high standard, imported material, will probably result in a more efficient and cheaper cofferdam than a convetional one.

Polymer products for geotechnical works were, in the last decade, improved substantially and extensively tested. Their reliability is now well established even in hostile conditions. Several test programs were performed to assess the capability of a thin membrane to resist substantial hydrostatic loads for long periods. Fig. 1 shows a 1.5 mm thick HYPALON geomembrane placed directly on a crushed basalt bedding with sharp, angular elements ranging from 25 to 37 mm. The geomembrane of the photograph is subjected to a water pressure of 1.0 MPa (10).

Fig. 1 A 1.5 mm thick CSM geomembrane placed over sharp basalt stones without the interposition of a geotextile under a 100 m water head.

It is difficult to imagine actual conditions rougher than the one assumed for this test yet water heads up to 40 m could be applied for indefinite times, without failure. Similarly, repeated sampling and checks made on some early applications of geomembranes, show that the original characteristics undergo moderate changes even when the membranes are directly exposed to the atmosphere and sunlight for long periods.

The amount of plasticizer present within the polymer at any time, governs the behaviour and performance of a geomembrane. There is a minimum plasticizer weight below which the product is no longer acceptable. The plasticizers lost at any given time can therefore be taken as the main indicator of a geomembrane actual quality and expected life. Fig. 2 shows the rate of plasticizer loss over a 10 years time for two PVC geomembranes installed under Mediterranean climate. Other tests conducted 6 and 9 years after installation on PVC used as exposed water-

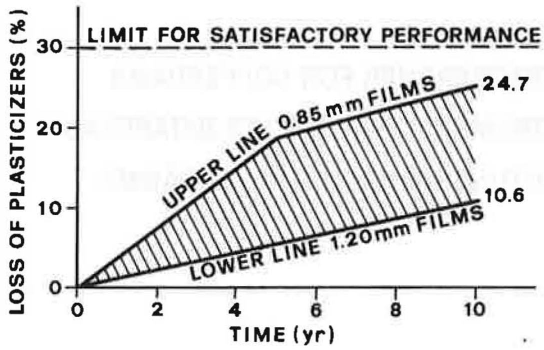

Fig. 2 Loss of plasticizers with time measured on exposed PVC geomembranes. Strain at failure reduces and Modulus increases slightly less, percentwise, than plasticizer loss (courtesy FLAG).

proofing element on two Italian dams at 2100 m a.s.l. in the Alps, showed tensile strenghts and failure strains practically unchanged. A certain degree of anisotropy (22%) and of surface hardening, were the only appreciable effects of 3 additional years of service.

3 SOLUTIONS FOR COFFERDAMS

The design of cofferdams incorporating a geomembrane as the only waterproofing element has several peculiar aspects. Typical solutions, developped for a number of these aspects will be revised and discussed.

Position of the geomembrane.

Two arrangements are possible in principle: a geomembrane set at, or near, the centre of the structure or a geomembrane placed on the upstream slope of the embankment.

The upstream solution is by far the most frequently adopted. An outstanding example of this solution is Nurek cofferdam where polyethylene film 1 mm thick, placed on the u/s face of the u/s shell, allowed an early partial impounding of the reservoir and starting power generation. Nurek's cofferdam top, shown in Fig. 3, retained for several years a water head of approximately 45 m.

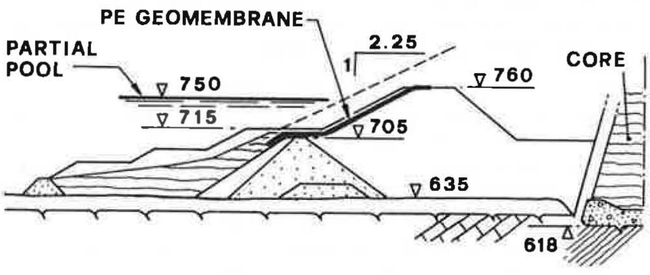

Fig. 3 The cofferdam for Nurek dam. A polyethylene geomembrane was used to waterproof the top 50 m of the structure. The lower portion of the cofferdam was built with conventional materials and with an inclined clay core placed over a gravel zone.

On the contrary, examples of the centre solution are scarce because placing a geomembrane in the middle of a fill is a slow and cumbersome operation. The Kara-su dike shown in Fig. 4 is an example of the centre solution. Mention must be made however of the fact that one of the highest dams incorporating a geomembrane (Atbashinskaya dam 76 m heigh, with 40 m of head retained by a geomembrane) is of the centre type.

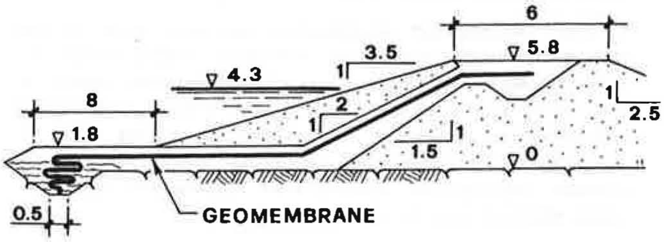

Fig. 4 The cofferdam on the Kara-su river, one of the few examples where the geomembrane was placed inside the fill.

Generally speaking, the u/s solution is simpler and therefore more appropriate for a temporary structure like a cofferdam.

Sequence of Filling - Waterproofing.
More important in defining the cross section and details of a cofferdam is the sequence of the filling and waterproofing operations. In many cases filling comes first and waterproofing is implemented on the nearly finished structure. There are however, situations asking for a structure made waterproof as construction progresses. There is no particular difficulty in meeting this condition as Fig. 8 shows. A stepped u/s face rather than a uniform slope usually helps the placement of the geomembrane in small incremental operations.

Slopes.
Slopes ranging from 1V/1.6H to 1V/2.5H are the most frequently adopted. Steeper slopes (up to the natural slope angle of the fill material) can be accepted if the face is stepped. Flatter slopes (1V/3H, or flatter) were used some time like in the case of Zolina (1V/4H). A 1V/2H slope is adeguate for most conditions.

Anchors.
Except on very flat slopes, some kind of anchoring is advisable for geomembranes placed on the u/s slope of cofferdams. Because cofferdams retain a water load only for a small fraction of their lifetime, a kind of ballast or tie downs may be required to avoid the geomembrane flapping (even a light wind may produce important lifting forces if the geomembrane is on the leeward slope of the cofferdam).

If the height of the cofferdam is limited, the anchoring along the crest trench may be enough but for structures exceeding 10 or 15 m in height, some intermediate fixity becomes desiderable. Precast concrete slippers, frequently adopted, usually result costly and difficult to place on the finished geomembrane. Anchor straps like the one shown in Fig. 5 can be a cheaper and more efficient solution. Anchor straps are placed as the fill is built and are designed using the methods of reinforced earth.

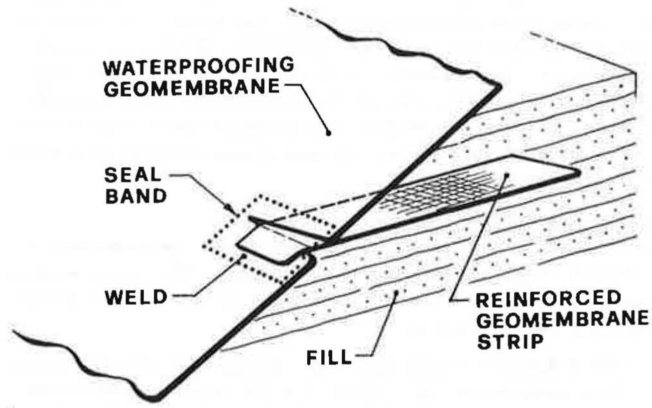

Fig. 5 Anchor obtained with an embedded strip of reinforced geomembrane (courtesy ISOMAT).

Seal along the periphery.
For permanent structures the geomembrane is connected to the foundation rock through a concrete plinth. Embedded steel, and clamp-down profiles are the accepted solution to provide a watertight connection. Folding back the geomembrane to isolate all clamps and bolts from a direct contact with water is a necessary and simple measure, yet often overlooked.

For cofferdams a simpler arrangement consisting in a clay filled trench where the membrane is inserted and loaded with a further clay plug, can be enough. Elaborate works in the riverbed are often impossible at the u/s toe of a cofferdam and the clay plug solution is often the only viable option. In designing the end folds of the geomembrane, care must be placed in adopting a simple geometry. The geomembrane should end with a horizontal lip so that the weight of the superimposed clay and the hidrostatic pressure will tend to close the contact between the membrane and the soil below.

Protection.
Within the upstream solution, there are two possible alternative: protecting the geomembrane with a soil rock cover (or else) or leaving the geomembrane exposed.

Protective layers, a common feature some years ago, are still preferred where the geomembrane must face extreme operating conditions (logs impact, ice, traffic, strong winds). The primary concern suggesting the adoption of protective covers is usually the integrity and durability of the geomembrane. Now the design lifetime of a cofferdam is usually less than 5 years and on the other side the durability of polymer films has been improved to such an extent (particularly for some type of materials) that the problem is no longer a mayor one. Protecting the geomembrane is necessary only when heavy impacts (or traffic) on vandalism are foreseen. In a large number of cases, the geomembrane can remain exposed. An exposed geomembrane allows the adoption of a steeper slope due to the fact that there is no longer the need for ensuring the stability of the soil-rock zone over the polymer surface.

Geotextile mat.
Depending on the type of support, it may be advisable

to place a geotextile between the fill and the geomembrane. Using a geotextile underlayer may allow more tolerant specifications for the fill materials which is usually convenient. The presence of a geotextile, though, makes stability and anchoring of the geomembrane more delicate. Combined geotextile-geomembrane product often reduce both types of difficulties and in many cases provide the most satisfactory solution.

Materials for the geomembrane.

A variety of polymer and polymer based geomembranes is offered today by the chemical industry. The most widely used, in connection with cofferdams pertain to the groups quickly revised below.

- PVC polyvinyl chlorides. The production of PVC films from plastisols (a liquid mix of resin, plasticizer, stabilizer and inorganic filler) with the 'spreading' process, allows obtaining thick membranes with limited delayed contraction. Production with the 'extrusion' process provides a stronger film of lesser dimensional stability. Extruded films seldom exceed the thickness of 1.5 mm. PVC geomembranes are easily welded at the site with hot air or hot point welding machines. The reliability of field welding makes pourposeless shop prefabrication of large sheet. The many brands of PVC geomembranes differ for the plasticizers and stabilizers used by the manifacturer and can provide, in accordance, different levels of service, up to excellence. Today PVC geomembranes rank among those of lower unit cost which makes the PVC option an attractive one for cofferdam.
- HDPE high density polyethylene. The hot deposition process started by Schlegel allows producing uniform films with thickness in excess of 2.5 mm and up to 10 m wide. The delayed contraction of HDPE is very small but the thermal expansion coefficient is appreciable. Its high mechanical resistance makes HDPE very suitable for use on the u/s slope of a cofferdam as an unprotected geomembrane. HDPE is stiff and field welding of adjacent rolls may become uneasy particularly at times of rapid temperature changes. Prefabrication is never done with HDPE films. Durability of HDPE is very high and largerly exceeds the need of a temporary structure. Like PVC, also HDPE is among geomembranes of lower unit cost.
- CSM Cloro sulphonated polyethylene, also known as Hypalon, is possibly one of the most durable geomembrane product. Calendering, is a normal production process which leaves substantial built in stresses in the material. This reduces the film's dimensional stability. Reinforcing fabrics (usually nylon grids) are frequently sanwiched between Hypalon sheets to alleviate this problem. Hypalon is a self-vulcanizing material and therefore it cannot stand long storage periods and becomes increasingly difficult to weld with age. Vulcanization is the best and normally used procedure for assembling Hypalon geomembranes in situ. In situ vulcanizing is however a cumbersome process making shop prefabrication of large sheet (up to 1000 or 2000 m2) a justified procedure. Hypalon stays on the high side of the cost range.
- CPE Clorinated Polyethylene, has many of the desiderable characteristics of Hypalon coupled to a lower susceptibility to aging and to an easier handling due to the fact that the material is not self-vulcanizing. CPE requires hot welding.
- IIR Isoprene Isobuthilene rubbers, also known as Butyl, is widely used and tested material. Butyls offer a remarcable resistance to aggressive environment but in some conditions may age appreciably. Certainly adequate for most cofferdam applications Butyl must be vulcanized for in situ assembling. Thus, like Hypalon, Butyl calls for shop prefabrication of large sheets.
- Bitumen impregnated Geotextiles are available on the market in several brands of different characteristics. A main drawback of this type of geomembrane stays in the fact that parallel strips are simply overlapped and connected by a film of bitumen, only. The lack of structural continuity and yielding joints makes all bitumen impregnated geotextiles inadequate whenever large strains must be expected.

4 LOCONE COFFERDAM

This cofferdam, shown in Fig. 6, is a homogeneous compacted fill built with well graded sand-gravel material obtained from the explotation of a nearby weathered conglomerate. The material was placed as quarried, in 0.8 m lifts, directly over the alluvial deposits present over the valley bottom after cleaning and a grading excavation 2 m deep. The alluvial foundation is up to 15 m thick and quite variable in nature and compressibility.

A cast in place diaphragm wall was used to waterproof the alluvium. The diaphragm penetrates a minimum of 2 m in on underlying marl formation.

The cofferdam is 13 m high and has a 4 m wide crest. The u/s slope was set at 2.5H/1V and an u/s scheme with unprotected geomembrane was adopted.

IIR Butyl Rubber 1.5 mm thick, produced by Pirelli was chosen as geomembrane material and it was decided to place the geomembrane directly over the fill. The membrane was placed in parallel, vertical continuos strips 1.4 m wide and up to 34.4 m long. Prefabrication or shop welding were not adopted and all seams were field work. A 909 m long crest required 650 strips and 18.9 Km of field seam. The overall facing area is 28 400 m2. An ave-

Fig. 6 Locone Cofferdam. Partial view of the structure completed.

rage of 600 m2 of finished geomembrane were placed dayly.

The anchoring along the crest was obtained with a concrete-filled trench while at the toe the geomembrane ties into a waterstop embedded in a concrete diaphragm cap. Where there is no diaphragm wall underneath, the geomembrane rolls over a concrete toe and into a concrete filled trench. Fig. 7 shows a detail of the connection between geomembrane and diaphragm wall.

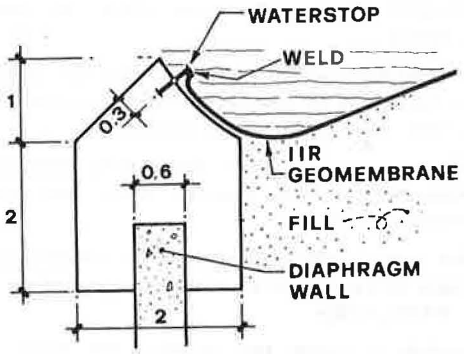

Fig. 7 Locone Cofferdam. Detail of the lower end of the geomembrane in presence of the diaphragm-wall.

The geomembrane was produced by coupling and successive vulcanization of two 0.75 mm films, to eliminate the local defects. Table 1 summarized the characteristics of the IIR geomembrane.

Tab. 1

Locone Cofferdam. Main Characteristics of the IIR Butyl - Rubber Geomembrane

Characteristics	Value	Unit
Mass per unit area	1.8	Kg/m2
Max. tensile stress	10	MPa
Strain at failure	600	%
Secant Modulus (1)	4	MPa
Hardness (Shore A)	62	-
Breaking Force in a tear test	45	N/mm
Dimensional stability	0.27	%
Resistance in a punch test	100	N

(1) at 300% strain

Welding was done mostly with hot bonding tape and vulcanizing press and locally with gum tape and primer COLLA 4000.

5 CHEW LARN COFFERDAM

Fig. 8 shows the cross section of the cofferdam studied for Chew Larn dam in Thailand. The cofferdam, 38 m high, had to become incorporated in the main dam.

The large overall volume of the cofferdam and the possibility of early floods suggested the placement of the waterproofing geomembrane as a parallel operation to the construction of the fill. Adopting an unprotected geomembrane was considered adequate. The result of these requirements was a stepped u/s face for the cofferdam, with steep slopes 1.4H/1V and 2 m wide berms every 5 m. The distance between berms resulted from the size of the sheets that could be prefabricated in the factory and conveniently transported and placed. Prefabricated sheets of 375 m2 were adopted thus limiting the in situ welds to every 25 m of berm lenght. Fig. 9 indicates the construction procedure allowing unrestricted filling activities above the membrane. Tunnel muck, 2 m thick in the horizontal plane, was the support of the geomembrane-geotextile facing. Removal of individual stones larger than 50 mm from the slope surface was specified. Below the muck, quarry run rock, mostly sandstone and quarzite, was used as compacted fill. CPE 2 mm thick was selected for the geomembrane. Between the geomembrane and the support a spum polyester geotextile of the 400 g/m2 gage was prescribed. The overall facing area is 19 200 m2 requiring 51 prefabricated sheets and 4 Km of field seams. Each prefabricated sheet is anchored at the top (i.e. along each berm) with 3 anchor strips similar to the one shown in Fig. 5. At the bottom, a clay filled trench was considered sufficient. The core of the precofferdam serves as toe seal in the centermost portion of the valley.

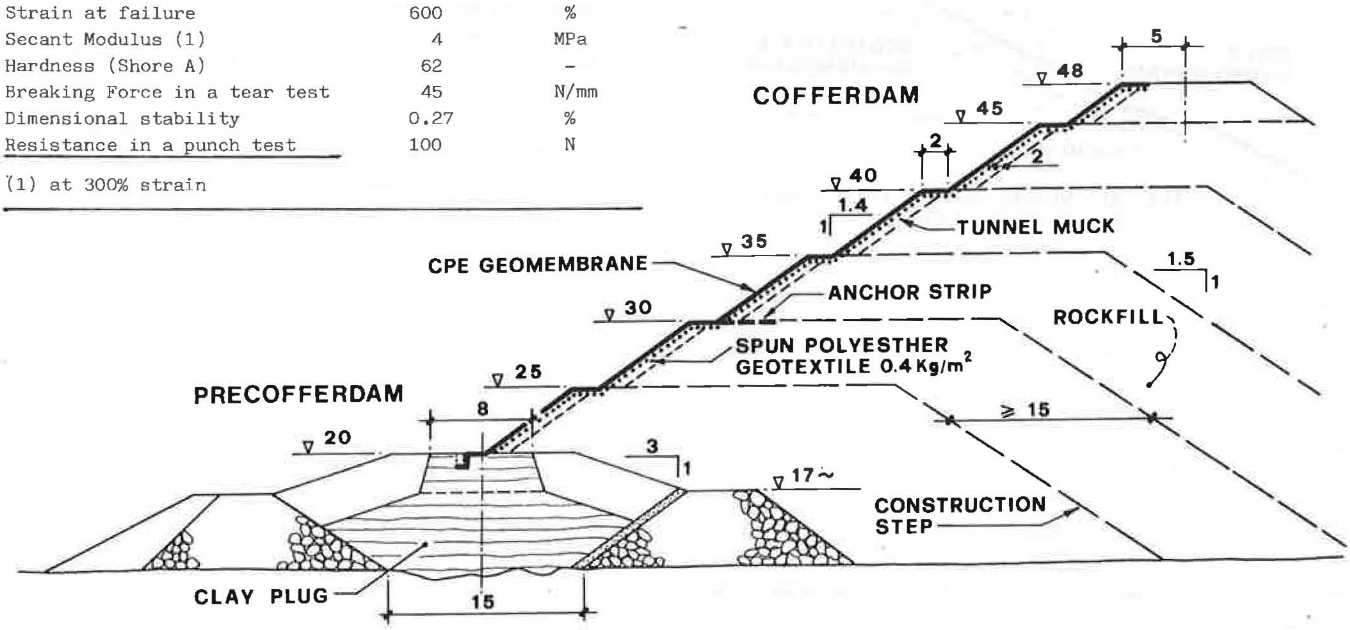

Fig. 8 Chew Larn Cofferdam. Mid river cross section showing the stepped u/s face for parallel filling and waterproofing.

Table 2 summarizes the characteristics of the CPE Geomembrane.

Tab. 2

Cofferdam for Chew Larn dam. Main Characteristics of the CPE Cloro Polyethylene Geomembrane.

Characteristics	Value	Unit
Mass per unit area	1.16	Kg/m2
Max. tensile Stress	17	MPa
Strain at failure	300	%
Secant Modulus (1)	12	MPa
Hardness (Shore A)	85	-
Breaking Force in a tear test	47	N/mm
Resistance in a punch test	210	N

(1) at 200% strain

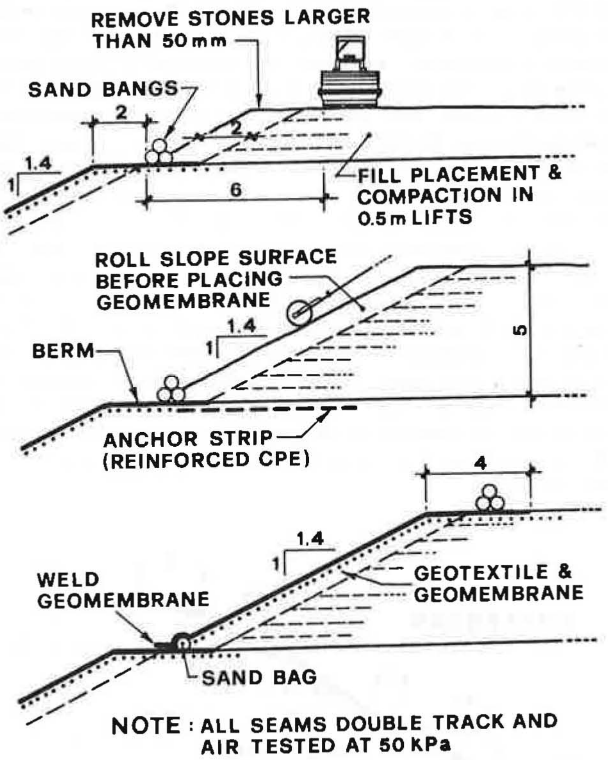

Fig. 9 Chew Larn Cofferdam. Setting anchor strips, filling, face rolling and geotextile + geomembrane placing sequence for parallel filling and waterproofing.

All field welds were specified as double track seams, made with the use of an automatic welding machine (with temperature-controlled speed), tested with compressed air.

Other examples of geomembranes used in connection with cofferdams are in increasing number. A progressively wider use of this type of solution will allow improving materials, design concepts and installation techniques while proving the suitability of geomembranes for medium size and eventually large dams.

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