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UNCONVENTIONAL DESIGN IN DAM RAISING: SAR CHESHMEH TAILINGS DAM*

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1. INTRODUCTION

In 2006, at the 22nd ICOLD Congress in Barcelona, the same authors presented a new concept for construction of an impervious facing on new fill dams [1]. The concept was based on installing in the embankment itself, as it was being constructed, anchor "wings" of geomembrane material, secured to the dam by the ballasting action of the base/transition layer. The impervious facing for the dam was provided by a geomembrane liner, fastened to the dam by heat-welding it to the anchorage lines formed by the embedded geomembrane wings. This system allows constructing the dam while the upstream face can be formed with extruded porous concrete curbs, according to the now well established Ità method.

One of the technical advantages discussed in the paper was the capability of the waterproofing system to follow the settlements and differential movements of the dam during service maintaining imperviousness. Other advantages considered were the very short time required for completing the dam and its

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* *Projets non conventionnels de surélévation de barrages : le barrage de stériles miniers de Sar Cheshmeh*

impervious element, which would allow starting filling the reservoir even before completion of civil works.

In 2006, tree pioneer versions of the concept were presented. In 2008, two full field applications have been implemented: Kohrang dam and reservoir [3], whose behaviour is totally in line with expectations [4], and the Phase II raising of Sar Cheshmeh tailings dam in Iran.

2. THE RATIONALE OF THE SYSTEM

The concept is to provide imperviousness to the dam by a system that is totally deformable. According to established practice and to the findings of the new ICOLD bulletin on geomembranes [2], the material foreseen for both the anchor wings and the impervious liner is a PVC geocomposite formed by an impervious PVC geomembrane and an anti-puncture geotextile laminated to it during fabrication. This material, having > 200% elongation at break and very low modulus of elasticity, is highly flexible and deformable. The cross section of the dam has the following simple layering:

- Dam body
- Drainage layer
- Base/anchorage layer. This single layer forms the transition between the dam body and the watertight system, incorporates the anchorage system for the waterproofing liner, and can also be the drainage layer
- Waterproofing liner: a PVC geocomposite.

Figs. 1 and 2 reported here below, which are part of the paper cited above, outline the concept. Fig. 1 shows the anchor wings installed on the extruded curbs, Fig. 2 the placement of the impervious geomembrane liner on top of the parallel vertical anchorage lines formed by the wings.

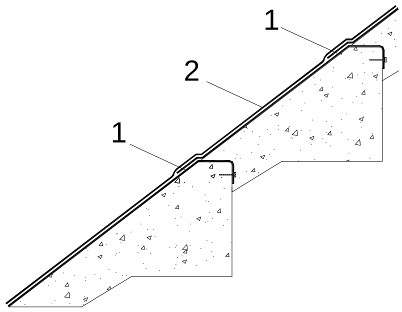

Fig. 1

The anchorage system for the PVC liner consists of PVC anchoring wings embedded in the base layer (curbs or stabilised gravel)

Le système d'ancrage du revêtement PVC consiste en « ailes » d'ancrage en PVC noyées dans la couche de forme (grave stabilisée ou bordures extrudées)

1. PVC anchoring wings	*« Ailes » d'ancrage en PVC*
2. PVC geocomposite	G*éocomposite PVC*

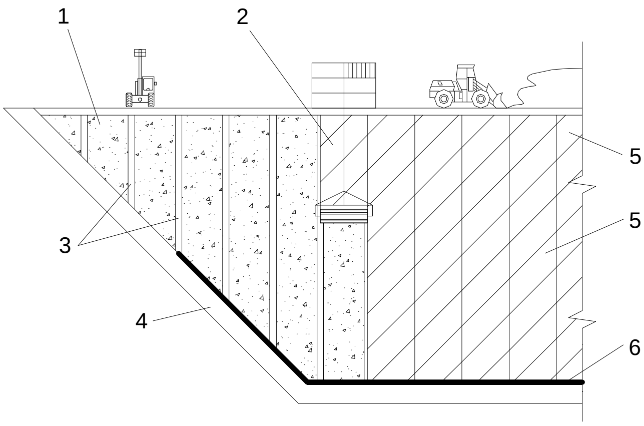

Fig. 2

The PVC waterproofing panels are anchored by heat welding to the PVC anchoring strips

Les panneaux d'imperméabilisation en PVC sont ancrés par soudure sur les bandes d'ancrage en PVC

1. Base layer (extruded curbs or stabilised gravel)	*1. Couche de forme (bordures extrudées ou grave stabilisée)*
2. PVC geomembrane panels	*2. Panneaux de géomembrane PVC*
3. PVC anchoring strips	*3. Bandes d'ancrage PVC*
4. Concrete plinth	*4. Plinthe béton*
5. Geomembrane panels welded to anchor wings	*5. Panneaux de géomembrane PVC soudés aux bandes d'ancrage*
6. Watertight perimeter seal	6. *Ancrage périmétral étanche*

3. RAISING OF SAR CHESHMEH TAILINGS DAM

Sar Cheshmeh, a large existing copper mine in central Iran, is owned and operated by National Iranian Copper Industries Company (NICICO), one of the largest copper mining operation in the world, and has an estimated ore reserve of about one billion tonnes.

3.1. THE EXISTING DAM AND THE RAISING

The existing tailings dam comprises a 70 m high embankment consisting of an inclined clay core and of an outer colluvial gravel shell. The upgrading project for tailings disposal and water management system carried out by NICICO includes strengthening and raising the Main Embankment and Saddle Dam No.1, to provide tailings storage for the remaining mine life. Design requires a 40 m high, 1000 m long downstream raise to the embankment, to be constructed in four stages. Maximum design earthquake is 0.8 g, temperatures at site, reported to vary from – 16℃ to + 38 ℃, were found to be si gnificantly higher.

The critical design case included up to 20 m of water ponding against the upstream face. The location of the clay core in the raised embankment is constrained by the existing inclined core. Iran is one of the more seismically active regions in the world, and with only hydrostatic loading, the un-drained shear strength of the clay was low and the resultant seismic factor of safety unacceptable.

Instead of clay, it was concluded that a cross-section consisting of a thin geomembrane sealing system on a rockfill embankment would be a more stable arrangement. Assessment and analysis of options was discussed. From a construction, performance and cost point of view an exposed geomembrane was preferred, and due to its superior mechanical and durability properties, a 3 mm thick PVC geocomposite represented the optimal geomembrane sealing system solution.

The designers, Australian Tailings Consultants and Middle East Water & Environment Joint Venture, have foreseen for Stage II B raising (from the existing crest at elevation 2175.5 m to elevation 2185 m) and Stage II C raising (from elevation 2185 m to elevation 2194 m) a zoned rockfill, with the upstream exposed PVC geocomposite system as the waterproofing component of the raise. Stages II B and II C will be followed by further Stage III and Stage IV raising, for a total of 39.5 m of heightening. SC Sembenelli Consulting developed the detailed design for the waterproofing system.

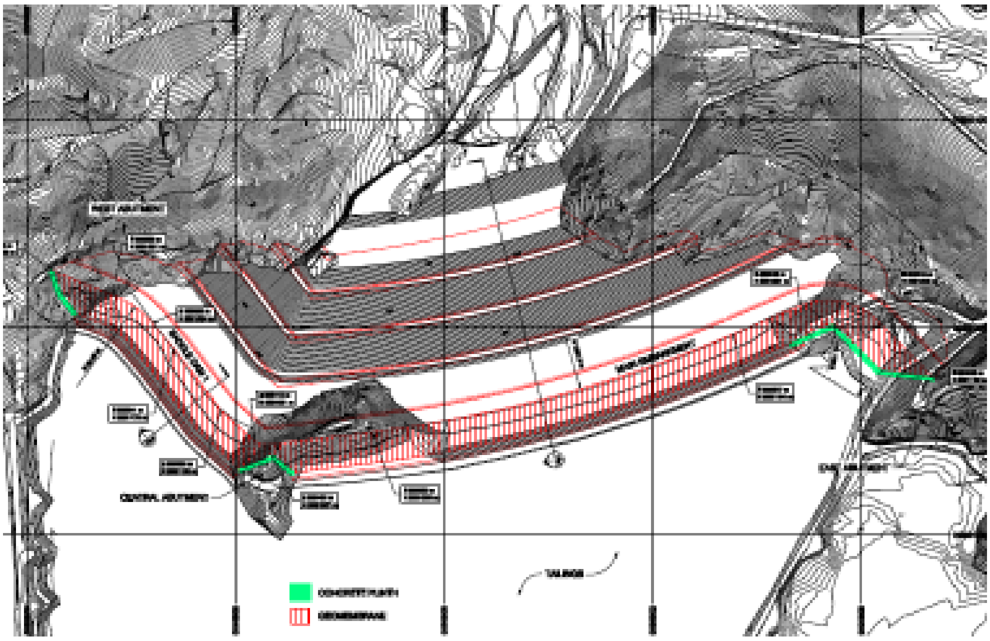

Fig. 3
Layout of Sar Cheshmeh dam raising
Schéma de la surélévation du barrage de Sar Cheshmeh

The exposed PVC geocomposite is anchored to the raised dam with the PVC anchor wings system described, which is a Carpi patent.

3.2. STAGE II B RAISING

Construction of Stage IIB raising started in October 2007 and was completed at the end of May 2008. Placement of the PVC geocomposite sheets started on May 30 2008; completion of waterproofing works of Stage II B was June 25, in only 27 days, for a total installed surface of 21000 m^2. Stage IIC raising will presumably be starting in July 2008 and be completed within the year 2008. Total length of the dam at Stage IIC will be 1000 m, total installed geocomposite for Stage IIC will be 18000 m^2.

3.2.1. Base/anchorage layer

The base layer is made with extruded porous concrete curbs, constructed integrally with the embankment rockfill, about 0.4 m high and having inclination 1.5 H:1 V. The curbs have interlock keys to avoid that as the embankment is being raised the curbs are laterally displaced by the pressure of the fill and by the horizontal stresses locked-in as result of compaction.

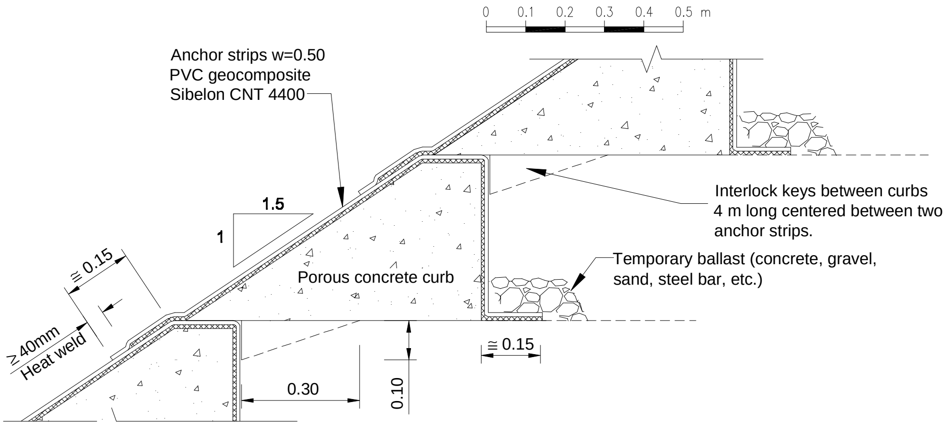

Fig. 4
Base layer and PVC anchor wings
Couche de forme et ailes d'ancrage PVC

The wings have been embedded in the porous concrete curbs during construction of Stage II B raising. Each PVC anchor wing, of the same material of the waterproofing liner, is about 0.5 m wide, and has a length adequate to allow on the upstream side overlapping of two superimposed wings, and on the downstream side placing the wing so that it can be secured to the dam by ballast (Fig. 6).

Figs. 5 and 6
Construction of curbs and embedding of PVC anchor wing
Construction des bordures extrudées et placement des ailes d'ancrage PVC

Superimposed wings have been welded at the overlapping at each curb (Figs. 7 and 8).


Figs. 7 and 8
Welding of superimposed PVC anchor wings
Soudage des ailes d'ancrage PVC superposées

Placing the anchor system for the PVC geocomposite liner proceeded at the same time of construction of the curbs. When placement of the curbs of Stage II B was completed also the anchorage system was completed. The welded anchor wings formed continuous vertical anchor strips at approximately 6.00 m spacing, securely fastened to the dam body by the permanent ballast provided by the compacted fill (Fig. 9 and 10). Placement of the waterproofing PVC geocomposite could start immediately after completion of the curbs. Positioning of anchoring strips was made under checking by surveyors, to adjust their spacing in function of the concavities and convexities, as the dam was not a straight line.


Figs. 9 and 10
At left, compaction of the fill to permanently anchor each PVC wing. Placement of PVC anchor strips at 6.00 m spacing was completed simultaneously with completion of the curbs
À gauche, compactage du remblai pour ancrage permanent de chaque aile d'ancrage. Le placement des bandes d'ancrage PVC à 6,00 m d'espacement a été achevé en même temps que l'achèvement des bordures extrudées

3.2.2. Placement and anchorage of the waterproofing liner

The waterproofing liner, Sibelon CNT 4400, is formed by a PVC geomembrane 3 mm thick laminated during fabrication to a 500 g/m^2 geotextile. Permanent face anchorage of the PVC geocomposite has been made by heat-welding it over the PVC anchor wings (Fig. 13).


Figs. 11 and 12

Immediately after completion of the curbs the PVC geocomposite sheets have been positioned over the PVC anchor strips

Immédiatement après l'achèvement des bordures, les lés de géocomposite PVC ont été mis en œuvre sur les bandes d'ancrage PVC

Adjoining PVC geocomposite sheets have then been watertight heat-welded, in order to construct a continuous watertight liner over the entire upstream face of the dam. Welds were executed mostly by manual welding machine and in part with automatic welding machine.


Figs. 13 and 14

At left, one PVC sheet is heat-welded to the PVC anchor strip to permanently anchor it to the dam body. At right the adjacent PVC sheet is overlapped on the one already anchored, and is watertight welded on it

À gauche, un lé de PVC est soudé à la bande d'ancrage PVC pour l'ancrer au corps du barrage. A droite, le lé de PVC adjacent est placé sur celui déjà soudé, pour y être soudé de façon étanche

3.2.3. Perimeter sealing

At the crest of the existing dam, when the installation of geomembrane system had been completed in a sufficiently wide section, the bottom perimeter anchorage of the PVC geocomposite has been made. The bottom anchorage keys the impervious geomembrane to the existing clay core in an excavated bottom trench (Fig. 15); to improve the contact of the PVC geocomposite with the existing clay core, a layer of GCL material was used, and the trench was then backfilled with clay. At the rocks abutments, at the location where the concrete plinth is constructed, the watertight seal has been of the mechanical tie-down type, designed to be watertight. The concrete is regularised with epoxy resin; the PVC geocomposite is anchored to the concrete with a 60 x 6 mm stainless steel batten strip placed on an EPDM gasket, and tied to the concrete with stainless steel anchor rods, 120 mm, embedded in chemical anchors placed in the concrete at 150 mm spacing.

At crest of Stage B II a mass concrete intermediate curb has been constructed. The top seal of Stage II B has been made anchoring the PVC geocomposite to the mass concrete intermediate curb with a 50 x 3 mm stainless steel batten strip, fastened to the concrete with stainless steel expansion anchors placed at 200 mm spacing (Fig. 18).


Figs. 15 and 16

Excavation of trench at existing dam crest to watertight connect the PVC geocomposite to the existing clay core

Excavation de la tranchée au couronnement du barrage existant, pour connecter de façon étanche le géocomposite PVC au noyau en argile existant


Figs. 17 and 18

At left the PVC geocomposite before bottom sealing in the trench and on the plinth. At right top seal of Stage II B on the top mass concrete curb

À gauche, le géocomposite PVC avant fixation étanche de fond au noyau en argile et à la plinthe. À droite, fixation supérieure du Stade II B sur la bordure en béton

3.3. STAGE II C RAISING

After the curbs and anchorage system of Stage C II are completed, the PVC geocomposite of Stage II C will be deployed from the crest at elevation 2194 m, will overlap the top anchorage of Stage II B at elevation 2185 m, and will be watertight welded to the PVC geocomposite of Stage II B. A cover strip of PVC geomembrane 3 mm thick will be watertight welded on the horizontal junction between the two geocomposites, to provide a watertight connection between the two Stages.

Top anchorage at Stage IIC will be made by positioning the PVC geocomposite in a trench excavated at crest, and by ballasting it with the mass concrete anchor beam that will be constructed at crest.

CONCLUSIONS

The system with anchorage system embedded in the dam as it is being constructed does not have the impact that traditional systems have on the construction schedule of the dam. Installation is quick and easy, so that just a few weeks are required to complete the whole facing system, after completion of the dam body.

The 4-years service behaviour of the first field application at Kohrang indicates a capability of following the deformation of the dam and of accommodating large differential movements without failing.

The field applications of this new design implemented up to date indicate that the system constitutes a viable and effective alternative to traditional upstream concrete facings and impervious cores.

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SUMMARY

An unconventional design for the waterproofing of embankment dams has been developed and has found full field application in the last few years. The design aims to avoid the problems that settlements and differential movements typical of this type of dams have caused to traditional waterproofing system, and to provide a system that can be constructed easily, quickly, and at low cost.

The system exploits the tensile properties of impervious flexible PVC geomembranes, to construct an upstream facing that has constant designed characteristics, and being highly deformable will not fail under high stresses due to movements. The impervious facing is an upstream exposed PVC geocomposite, its face anchorage system consists of wings of the same PVC material embedded in the base layer during construction of the dam. The permanent anchorage of the PVC geocomposite is made by heat-welding it to the PVC wings. Placement and anchorage of the PVC geocomposite, including the perimeter sealing, can be completed in matter of weeks after completion of the dam body.

The system has been successfully applied on a dam and reservoir in Iran in 2004. The paper discusses the latest application, the Stage II B and Stage II C raising of Sar Cheshmeh tailings dam in Iran. The system was adopted at Sar Cheshmeh because the location of the clay core in the raised embankment was constrained by the existing inclined core, and because under the site conditions a clay core would have an unacceptable seismic factor of safety. The designers concluded that a cross-section consisting of a thin geomembrane sealing system on a rockfill embankment would be a more stable arrangement, and from a construction, performance and cost point of view an exposed geomembrane was to be preferred, due to its superior mechanical and durability properties. The paper illustrate Stage II B waterproofing that is under way in these days.

RÉSUMÉ

Un concept non-conventionnel, développé pour l'étanchement des barrages en remblai, a trouvé des applications réelles ces dernières années. Le concept a pour but d'éviter les problèmes qui se sont produits avec les systèmes d'étanchement traditionnels, à cause des tassements et des mouvements différentiels typiques dans ce type de barrages, et de fournir un système pouvant être construit facilement, dans un délai très court et pour un coût peu élevé.

Ce système exploite les propriétés de résistance des géomembranes étanches souples en PVC pour construire un masque d'étanchéité amont aux caractéristiques prédéterminées et constantes qui, grâce à ses propriétés hautement déformables, ne va pas se rompre sous la contrainte élevée des mouvements. Le masque d'étanchéité est un géocomposite PVC apparent, son système d'ancrage sur la face amont est fait de bandes d'ancrage du même matériau PVC, noyées dans la couche de forme pendant la construction du barrage. L'ancrage permanent du géocomposite PVC est fait par soudage aux bandes PVC. La mise en place et l'ancrage du géocomposite PVC, y compris les fixations périmétrales, peuvent être effectués en quelques semaines après l'achèvement du barrage.

Le système a été appliqué avec succès sur un barrage et un réservoir en Iran. Le présent rapport traite de la dernière utilisation de ce système : les stades II B et II C de la surélévation du barrage de stériles miniers de Sar Cheshmeh, en Iran. Ce système a été employé à Sar Cheshmeh car l'inclinaison du noyau d'argile dans le barrage existant présentait trop de contraintes quant au positionnement du noyau d'argile de la partie surélevée. De plus, étant donné l'historique sismique du site, un noyau d'argile n'aurait pas rempli les exigences en termes de sécurité. Les concepteurs ont conclu qu'un dispositif d'étanchéité avec géomembrane mince sur un barrage en enrochement constituerait un aménagement plus stable et que, du point de vue de la construction, de la performance et des coûts, la géomembrane devait être choisie du fait des ses caractéristiques supérieures en termes de résistance mécanique et de durabilité. Le rapport illustre l'étanchement du Stade II B qui est encore en cours à ce jour.