COMMISSION INTERNATIONALE
DES GRANDS BARRAGES

VINGT-CINQUIEME CONGRES
DES GRANDS BARRAGES
Stavanger, juin 2015

CONCRETE LINING OF THE CORE-FOUNDATION INTERFACE TO PREVENT INTERNAL EROSION: AN EFFICIENCY ASSESSMENT(*)

Alfredo GRANADOS
Assistant Professor, Ph.D., Universidad Politécnica de Madrid

Luis GARROTE
Professor, Ph.D., Universidad Politécnica de Madrid

Isabel GRANADOS
Associate Professor, Universidad Politécnica de Madrid

José Antonio REMESAL
Head of the Huelva Water Section, Environment and Water Agency of Andalucía

Spain

1. INTRODUCTION

The core-foundation interface of the embankment dams requires particular attention during design and construction, and specific surveillance during operation. A deficient treatment of this area may facilitate seepage along the interface and erosion of the core-base which, in turn, could lead to a major internal erosion process [1]. Several dam incidents and failures were initiated following this mechanism. For instance, an imperfect core-foundation treatment was one of the causes of the Teton Dam collapse in 1976 [2].

Therefore, it is clear that this surface requires specific study and treatment. Stripping, cleaning, removing unsuitable materials and shaping, are considered the minimum operations for preparing it [3]. In addition to this, a gallery beneath

---

(*) *Protection avec béton de l'interface noyau-fondation pour prévenir l'érosion interne: une analyse de l'efficacité* the core-base could be used. This gallery is an excellent safety element, as it provides a direct access to foundation, facilitating inspection and grouting during operation [4] [5]. Hence, despite its construction cost, is a usual arrange on impervious core dams. However, depending on the specific lithology and stratification, this option could be replaced by a concrete lining of the core-foundation interface. An option that could be advantageous when the following circumstances concur: the foundation is not erodible and no additional grouting treatment is predictable; and the excavation of the trench which houses the gallery would damage or decompress the rock, deteriorating the foundation conditions.

The risk of contact erosion at the core-foundation interface increases in those sites where the bed's strike is orthogonal to the dam axis. In such case seepage may flow along the joints eroding the clay particles of the core-base (Figure 1a).

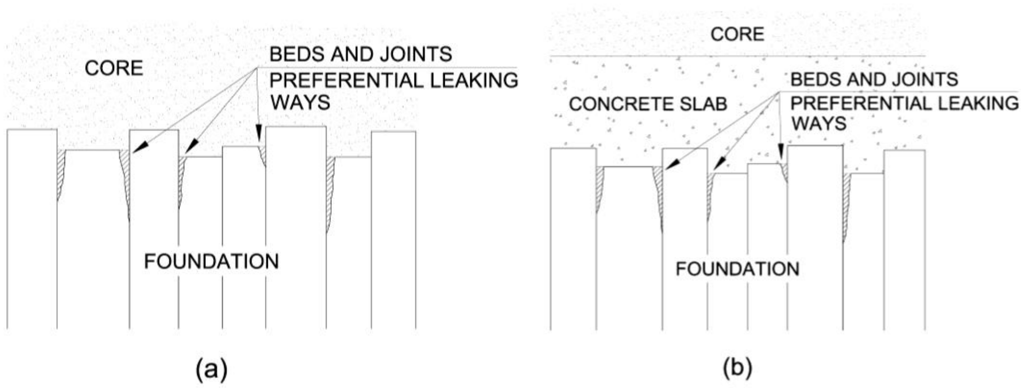

Fig. 1
Longitudinal sketch of an un-lined (a) and a lined (b) core-foundation.
Croquis longitudinale d'une noyau-fondation non-revête (a) et revête (b).

Internal erosion through the contact when these adverse geological conditions appear could be prevented by placing a concrete lining (Figure 1b). This concrete protection works as a barrier, separating the core particles from the beds and joints.

This measure, that could be a cost-effective alternative to galleries, was used to prevent internal erosion on Andévalo dam. It is a rockfill dam with a thin clay core, 80 m high and 1862 m long, with one of the largest Spanish reservoirs (1025 hm^3) [6]. Its construction was completed in 2002 and its first filling has been finished in 2013.

This paper presents that experience, describing the foundation characteristics, the design features and the performance assessment of the lining during the impoundment.

2. SITE GEOLOGY

The foundation rock of Andévalo dam is constituted by monotonous sequences of thin-to-medium bedded Devonian-Carbonian wackes and shales. The display of the beds and joints is sub-vertical following the river direction, orthogonal to the dam axis (Figure 2). This unfavourable orientation facilitates leakage along foundation, which could be decompressed in surface.

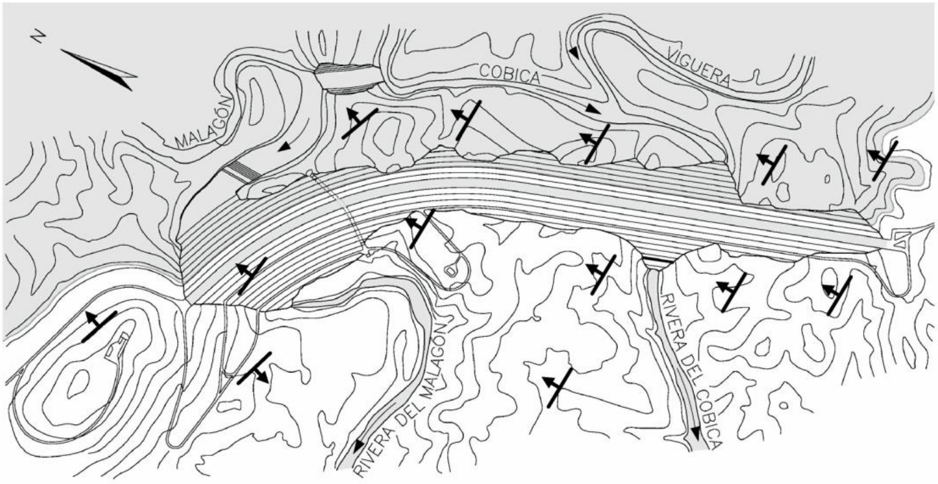

Fig. 2
Andévalo dam. Strike and dip of the beds at the dam site.
Andévalo barrage. Direction et pendage des strates.

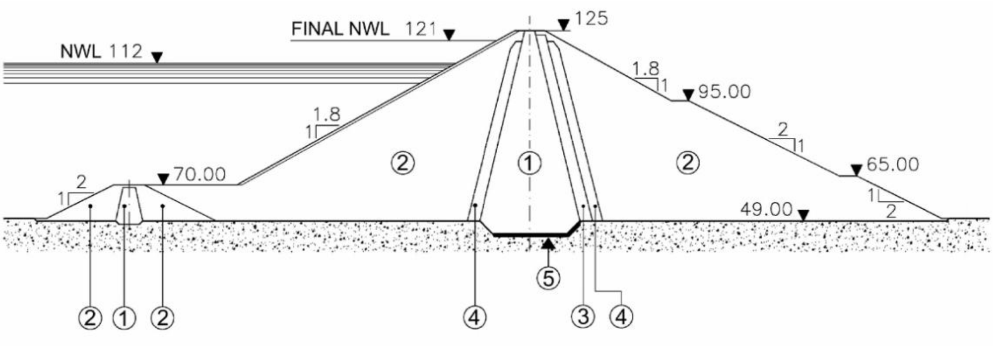

Fig. 3
Andévalo dam. Cross-section.
Andévalo barrage. Coupe.

1. Impervious core	*1. Noyau*
2. Rockfill	*2. Enrochement*
3. Filter	*3. Filtre*
4. Transition	*4. Transition*
5. Concrete lining	*5. Revêtement de béton*

Although the bedding planes are generally closed, as confirmed by the geological survey (the Lugeon Test that were carried out gave results between 1 and 3 LU), the core-foundation interface has been carefully treated. As explained above, the particular site geology increases the risk of contact erosion, since that preferential leaking ways may erode the clay particles at the core base initiating an internal erosion process. As the foundation was found impervious and future grouting was not predictable, and given that the excavation process of a trench for housing a gallery may deteriorate the rock; it was decided to use a concrete lining for preventing potential development of piping processes on the interface (Figure 3).

3. CORE-FOUNDATION TREATMENT AND MONITORING

The treatment was extended along the entire core base. The topsoil and weathered rock were excavated until suitable material was found. To that end the excavation depth varies between 1 and 7 m. Foundation treatment (Figure 4) was carried out following the next sequence:

- Shaping, cleaning and regularizing the surface with dental concrete.
- Installation of anchors: Φ25 mm steel bars, 3 m long, on a 5 x 5 m mesh.
- Construction of the concrete protection, which consisted in a 0.50 m thick concrete slab (minimum 0.30 m, depending on the surface shape), reinforced with a steel mesh 200 x 200 x 10 mm.
- Shotcrete protection of the downstream slope of the key trench (0.10 m thick).
- Blanket grouting of the core-base area, using the concrete slab as working platform. The main features of this process are:
  - The blanket was completed in two phases, both covering a 5 x 5 m mesh, being the holes of the second mesh drilled in the centres of the squares defined by primary ones. The depth of the holes is 10 m, except in those areas were the admission was significant. In such cases, the holes were re-grouted and the depth increased until 20 m.
  - Holes were grouted in two phases, each 5 m long, from down to top. Pressure for the first phase was of 6 kg/cm^2 and for the second phase was of 3 kg/cm^2.
  - Pilot holes, were drilled in the slab, at intermediate points with respect to the grouting holes, to control and prevent uplift pressures.
- Both the grout holes and the anchors were inclined, with the objective of intersecting a larger number of joints.

Internal erosion processes are difficult to detect. The protection against contact erosion considered this fact and included extensive instrumentation of piezometers both above an under the concrete lining, to assess its performance. The use of the piezometers has been combined with regular inspections of the downstream slope and seepage control.

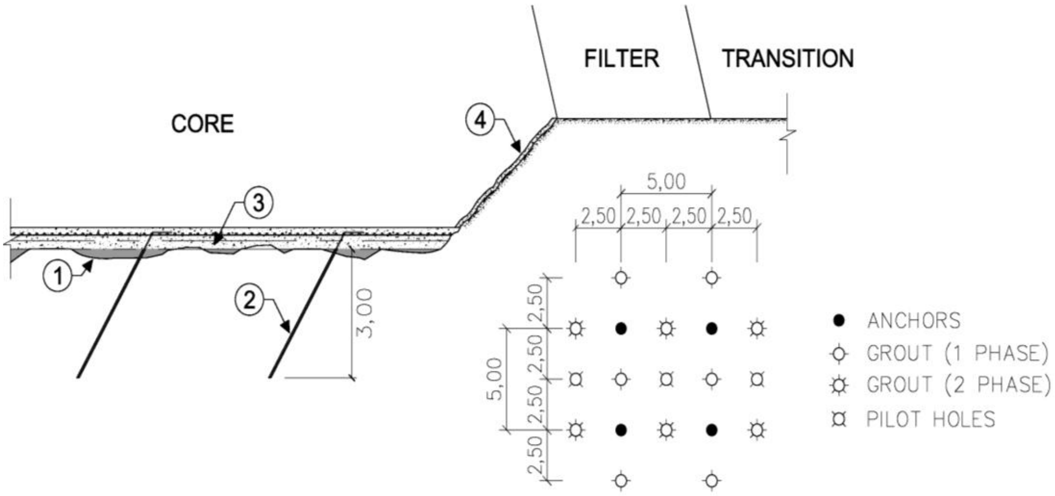

Fig. 4
Andévalo dam. Core-foundation lining
Andévalo dam. Revêtement de béton de l'interface noyau-fondation

1. Regularization with dental concrete	*1. Régularisation de l'excavation avec béton*
2. Anchors	*2. Ancres*
3. Reinforced concrete slab (0.5 m thick)	*3. Dalle de béton armé (0,5 m d'épaisseur)*
4. Shotcrete protection of the downstream slope	*4. Protection béton projeté de la pente en aval*

The core-foundation interface is widely monitored. The equipment is distributed in 39 cross-sections along the dam, which were spaced around 50 m. Each section is equipped with two lines of piezometers. Line 1 is located above the slab. It has three piezometers: at the upstream third, at the centre and at the downstream third. Pressure cells were also installed on line 1, in alternate cross-sections. Line 2 is located beneath the slab; it has also three piezometers with identical arrangement to that of the line 1.

4. PERFORMANCE DURING OPERATION

The lining of the core-foundation interface was expected to work as a barrier, separating seepage ways and clay particles; and so preventing contact erosion. This protective function has been analyzed with the monitoring equipment and the surveillance, during the impounding process (2002-2013).

Although pore pressure measurements are related to specific points of the dam and leakage may be located elsewhere, the extensive monitoring system for controlling this variable gives an accurate idea on how the lining performs. Figure

5 shows the evolution of the pore pressures in two sections, for the pair of piezometers located at the dam axis. It can be observed how the pore pressure follows the evolution of the reservoir level, with slight differences depending on the location of each apparatus. The general trend that is observed for most of the piezometers pairs is that pressures on the foundation have a faster response to changes in the reservoir level than those on the core-base. This effect suggests that the foundation permeability on the rock foundation is larger than that of the core-base.

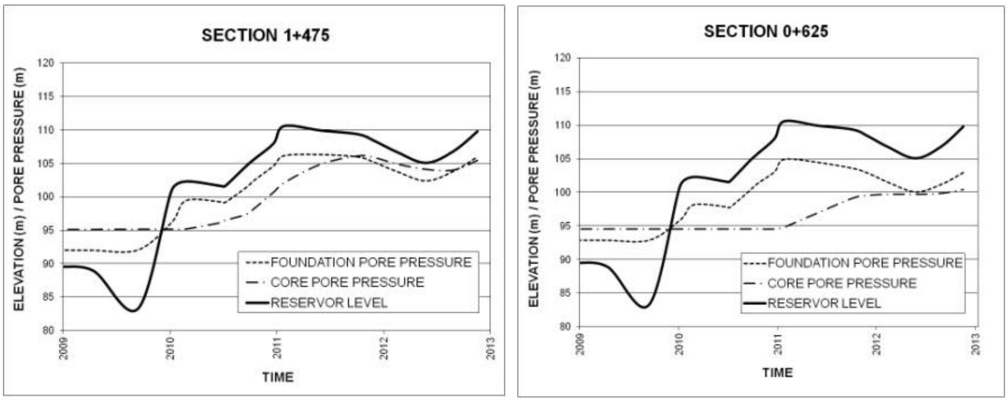

Fig. 5
Pore pressure evolution above and beneath the concrete slab.
Evolution de la pression interstitielle au-dessus et en dessous de la dalle.

The other facts that were monitored during impoundment (regular surveillance and seepage control) also indicate that the lining performance has been satisfactory. The regular inspection detected local springs at the downstream toe, in the more permeable areas. In those points v-notch weirs were installed to measure the leakage evolution. The leakage was small (between 0.6 and 1 l/s) and clean, with no evidence of clay removal; indicating the good performance of the interface lining.

5. CONCLUSIONS

The lining of the core-foundation interface with a concrete slab has been shown as an effective layout to prevent internal erosion in Andévalo dam. The analysis of the pore pressure evolution shows that the lining works as a barrier between seepage through foundation and the clay particles of the core-base.

This arrangement is particularly suitable for foundations with sub-vertical display of the rock joints, especially when the bed’s strike is orthogonal to the dam axis. That adverse layout may facilitate leakage trough the joints even in impervious formations, facilitating the development of contact erosion. In such cases the use of a concrete slab for lining the interface is a cost-effective alternative to the construction of an inspection gallery beneath the core.

The performance of the protection lining has been controlled with pairs of piezometers, located above and under the slab. That is to say, a line to control pore pressures development on the clay-slab contact and another to do it at the slab-foundation one.

Pore pressure on the core-slab line has a slower response to changes in reservoir level than the one on the foundation-slab interface. This behaviour, in which the pore pressure evolution of clay shows a significant inertia when following the reservoir level, is not that clear in the foundation. This is due to the different permeability of each one. This fact was expected for the site geology and clay characteristics of Andévalo dam.

The monitoring of the pore pressures has been complemented with regular inspections of the downstream slope and seepage control. Some springs were detected downstream the more permeable areas. The leakage was small and clean, with no traces of fine particles been dragged.

Therefore, the results of pore pressure monitoring, downstream surveillance and seepage control are indicating the good performance of the interface lining and its aptitude for preventing contact erosion.

REFERENCES

[1] ICOLD (2013), *Bulletin 164: Internal erosion of existing dams, levees and dikes, and their foundations. Volume 1: Internal erosion processes and engineering assessment*, Paris.

[2] Independent panel to review causes of Teton Dam failure (1976), *Failure of Teton Dam*, Idaho falls, Idaho.

[3] USBR (2012), *Design Standards 13: Embankment dams*. *Chapter 3: Surface treatment,* Denver, Colorado.

[4] SPANCOLD (2014), *Guía Técnica 2: Criterios para proyectos de presas y sus obras anejas. Tomo 2: Presas de materiales sueltos,* Madrid. (in Spanish)

[5] WEAVER K.D. & BRUCE D.A. (2007), *Dam foundation grouting*, ASCE Press, Reston, Virginia.

[6] LÓPEZ F., GRANADOS A., SANZ M. & ABADÍA F. (2004), *Andévalo enhances water resources management in the Chanza river basin*, Hydropower and Dams, 11(3):17-78.

SUMMARY

The core-foundation interface of the embankment dams requires specific attention during design, construction and operation. An inadequate treatment of this surface may facilitate leakage along the interface, and this may progress into contact erosion of the core-base. Several incidents and failures were initiated under that mechanism. The use of a gallery beneath the core for inspection and grouting is a usual arrangement to improve safety in this area. However depending on the geology, it may be cost-effective and equally safely to protect the core-foundation interface with a concrete lining, which works as a barrier that isolates the clay core particles from the potential under-seepage.

This arrangement has been used at Andévalo dam (one of the largest Spanish reservoirs). The protective concrete slab was widely monitored to control pore pressure evolution, with piezometers pairs located both above and beneath the lining. Control has been complemented with regular surveillance of the downstream slope and seepage measurements. This paper presents an assessment of the lining performance as a measure to prevent contact erosion, which has been excellent during the first 12 years of operation (including first impoundment from 2002 to 2013).

RÉSUMÉ

L'interface noyau-fondation des barrages en remblai nécessite une attention particulière lors de la conception, de la construction et de l'exploitation. Un traitement insuffisant de cette surface peut faciliter les fuites le long de l'interface, ce qui peut évoluer vers l'érosion du noyau à base de contact. Plusieurs incidents et ruptures ont été engagés en vertu de ce mécanisme. L'utilisation d'une galerie sous le noyau pour l'inspection et l'injection est une disposition habituelle pour améliorer la sécurité dans ce domaine. Toutefois, selon la géologie, il peut être rentable et aussi en toute sécurité protéger l'interface noyau-fondation avec un revêtement en béton, qui fonctionne comme une barrière qui isole les particules de noyau d'argile des fuites a le contact.

Cette disposition a été utilisée à Andévalo barrage (un des plus grands réservoirs d'Espagne). La dalle de béton de protection a été largement surveillée pour contrôler l'évolution de la pression interstitielle, avec piézomètres paires situées au-dessus et en dessous du revêtement. Contrôle a été complétée par surveillance régulière du recharge aval et mesures de l'infiltration. Cet article présente une évaluation de la performance du revêtement comme une mesure visant à prévenir l'érosion de contact, qui a fonctionner excellent au cours de ces 12 premières années d'exploitation (y compris la première mise en eau de 2002 à 2013).