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Internal erosion in low plasticity cores of embankment dams

L'Érosion interne des barrages en remblai avec des matériaux peu plastiques

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ABSTRACT: Internal erosion is a major cause of failure in embankment dams, specifically, is the second common cause after overtopping. This phenomenon is strongly influenced by the behavior of clays, which are used as seepage control material for its low permeability. Due to the importance of this material, it is essential to set the limit parameters for using in this kind of structures.
In this sense at the Technical University of Madrid we are performing a research to assess the behavior of low plasticity clayey soils against internal erosion, which is precisely the reason for traditionally avoidance of its use in dam cores. First of all has been performed an exhaustive search of dam whose cores are made of low plasticity clayey soils. And secondly materials from two newly built dams in Spain have been submitted to erosion test. For this research has been used the "Modified Hole Erosion Test" (MHET), to which some improvements have been added.

1 INTRODUCTION

One of the identifying features of embankment dams is that they are constructed with materials from the reservoir environment. This conditioner is unrelated to the needs of regulation, detention or supplying the population, so it has been necessary to construct a large number of dams and ponds, adapting to the closest materials, which did not always comply with the usual canons.

For this reason, this line of research was born at the Universidad Politécnica de Madrid to find out which boundary materials can be used in the construction of embankment dams. Specifically, this research has as its object the study of plasticity and the uncertainties that its behavior presents facing the internal erosion, which is why these materials have traditionally been rejected.

The normal and traditional practice was usually limited to use materials with plasticity index highest or of the order of 15% (PI ≥ 15%), discarding the slightly plastic materials. As an example, the Spanish Technical Guide to Safety of Dams says that these materials have a greater risk against erosion due to their greater tendency to crack and to their greater permeability.

It must remember that other than overtopping, internal erosion and piping are the main causes of failures an incidents in embankment dams (Foster et al. 2002). There are numerous historical cases illustrating this statistic: Teton, Hyttejuvet or Wister among others. (ICOLD)

2 METHODOLOGY AND FIRST RESULTS

The intention is to provide a theoretical and experimental basis for the suitability of non-plastic materials as long as they fulfil with the same conditions of knowledge required for any other type of material in terms of resistance, deformability and alterability and provided they are accompanied by a suitable filter that avoid the migration of particles.

The design of this research contains two fundamental parts:

- Documentation of the use of low plasticity materials in the construction of embankment dams.
- To subject these materials to the own tests of the phenomenon of interior erosion.

2 .1 *Documentation*

It has been documented the dams whose nucleus have a plasticity index of less than 15%, and as far as possible, the behavior they have had until today. In the first stage the Spanish dams, see Table 1. And in a second phase, the search radius was extended to international dams, see Table 2.

Table 1. Spanish dams with low plasticity

Dam	Year	Height (m)	Capacity (hm3)	PI*
La Sotonera	1965	34	189	9 -22
Benínar	1982	87	68	8,5-(9,8)-16
Jerte	1985	42	58	(13)
Colomera	1990	65,5	42	8-25
Zufre	1991	64	168	2-(8,6)-16
Alpotrel	1992	24,5	49	(4)
Pajares	1994	73	35	9-(13)-21
Tórtoles de Esgueva	1995	27,5	1,8	4,5-(11)-23,5
Arenoso	2007	77	167	5-(9,65)-18
Siles	2012	55	30,5	7-(10,5)-18
Lasesa	Filling	45	10	(10)
Villalba de los Barros	Filling	45,5	106	(13)
Albagés	Work in progress	80	80	5,5-(7,5)-12

* Minimum value – (Average value) – Maximum value; (Average value)

Table 2 International dams with low plasticity

Dam	Country	Year	Height (m)	PI*
Vigario	Brazil	1951	33,5	3 – 17
Swift	EE.UU.	1958	156	(5)
Quebradona	Colombia	1958	27	(4)
Serre-Ponçón	France	1960	130	7-8,5
Miboro	Japan	1960	131	(5)
Tooma	Australia	1961	68	(3)

Dam	Country	Year	Height (m)	PI*
Trinity	U.S.	1962	164	(7)
Troneras	Colombia	1962	37	(9)
Shek Pik	Hong Kong	1963	55	(12)
Cougar	U.S.	1964	158	(10)
Gepatsch	Austria	1964	153	(10)
Kremasta	Greece	1965	165	(8)
Round Butte	U.S.	1965	130	(5)
Miraflores	Colombia	1965	55	(6)
Hyttejuvet	Norway	1965	93	(6)
Geeghi	Australia	1966	91	(4)
Greoux	France	1967	67	(10)
Oroville	U.S.	1968	230	(7)
LLyn Brianne	U.K.	1971	91	≤ 10
Mica	Canada	1973	244	(5)
Upper Blenheim-Gilboa	U.S.	1973	48	(4)
Ramganga	India	1974	128	< 10
Beas (Pong)	India	1974	133	8 - 12
Belmeke	Bulgaria	1974	88	8,4 – 13
Santa Rita	Colombia	1975	54	6 - 8
Andong	South Korea	1976	83	Nonplastic
Alvito	Portugal	1977	49	(10)
Chicoasén	Mexico	1980	206	12 - 20
Mokolo	South Africa	1980	55	2,3 – 13,6
Punchina cofferdam	Colombia	1980	45	(10,2)
Inamura	Japan	1981	88	(11,5)
Novo Panicharevo	Bulgaria	1983	20	13 –15
La Honda	Venezuela	1984	140	(13)
Odelouca	Portugal	2012	76	6 – 18

* Minimum value – (Average value) – Maximum value; (Average value).
**These features have been taken from the 25 International Congresses on Large Dams published by the International Commission On Large Dams (ICOLD)

2.2 *Experimental phase*

The Modified Hole Erosion Test, (MHET), has been taken as erosion test to experimentally support the use of low plasticity materials for construction of embankment core dams.

Figure 1 Photograph of the MHET, experimental device developed in the "Universidad Politécnica de Madrid", (UPM).

The original design is detailed on Wan and Fell (2004). This device has been modified and improved to assess the erosion characteristics of soils in cracks in embankment dams: critical shear stress, τ_c, and rate of erosion, ε_t, in order to establish the Erosion Rate Index, I_{HET}. This erosive mechanism of concentrated leaks is considered to be the most feasible, due to the greater tendency of slightly plastic soils to crack.

The equipment developed in the Geotechnical Laboratory of the UPM, is based on the original design and considering the possible scarcities that have been appearing in the specify literature. (Wahl, et al. 2008, Sam Lim 2008, Haghighi et al. 2013). The main improvement of the original design is the incorporation of a turbidimeter to instantly measure the eroded soil and consequently the evolution of the crack. Another relevant singularity is the use of a motorized valve for the monitorized control of flow rates and water head. (See Figure 1)

3 CONCLUSIONS

In view of the results obtained from an extensive bibliographic prospection and in the absence of a greater number of experimental data, the following preliminary conclusions can be drawn:

I. For the construction of embankment dams it is a widespread experience the use of materials sited near the reservoir, even if they have poor geotechnical properties, particularly with low plasticity values. There are examples on every continent, all over the world.
II. In reference to the magnitude of the dam, there is no maximum height to adhere to. Oroville 230 m or Mica 244 m
III. There are a dozen cases where the plasticity index of the impervious material is less than or equal to 5%. Even there is a case of a core dam made with a non-plastic material.

In conclusion, it can be pointed out that there is a fairly extensive body of information regarding the use of low-plastic materials in core dams, based on a satisfactory experience; This is important enough to confidently take it into account and support future similar actions.

On the other hand, a better understanding of the internal erosion process is needed based on experimentally well controlled laboratory tests.

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