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SAFETY INVESTMENTS IN HORCAJO DAM (SPAIN): A PROCESS INFORMED BY THE APPLICATION OF SPANCOLD GUIDELINES ON RISK ANALYSIS (*)

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1. INTRODUCTION

Hervás Dam is a RCC concrete gravity dam, 31.5 meters high, with an un-gated spillway and two-conduits bottom outlet, built in the late Eighties and founded partially on alluvium material. It is a key element of the water supply system to the downstream population (Hervás, located just a few kilometers downstream) and, though it certainly provides some degree of flood protection, it is only a secondary mission or collateral benefit.

Having already started a very important campaign to upgrade the monitoring system to today´s standards, as well as re-assessment of the geotechnical characteristics of the foundation, a complete risk informed process was started by the owner, Gobierno de Extremadura, the consultant on conservation, maintenance and operating support for the dam, PAYMACOTAS, and iPresas, a spin-off company from Universitat Politècnica de València (UPV) providing the overall risk framework.

The article summarizes the main findings of an overall process that, inspired by the application of the SPANCOLD Guidelines for Risk Analysis

(*)Investissements en sécurité dans le barrage de Horcajo (Espagne): un procédé établi grâce à l'application de directives SPANCOLD sur l'analyse de risques.

(SPANCOLD, 2012), is a first milestone in a journey towards risk informed dam safety governance.

2. FEATURES AND CURRENT STATE OF THE DAM

The dam is formed by four concrete gravity blocks, with a centrally located ungated spillway 30 meters long, whose discharge channel and stilling basin are also built in concrete. The bottom outlet, embedded within the concrete body of the dam, has two parallel conduits controlled by means of valves. “El Horcajo” dam has been classified as Hazard type A (the highest) due to the severe consequences in case of failure. Fig. 1 shows a view of the dam from downstream.

A significant part of the dam body, including all the central part and the left abutment were founded on an alluvial heterogeneous soil. This fact has raised concern on the integrity of the foundation and its potential for being eroded. To address such concern, during the first years of the dam operation (90s’) a series of foundation resistance improvements were performed and, since 2007, water pool level has been restricted to lower the risk of excessive leakage and and structural instability.

Once a working group was conformed including owner, regulator and external consultant personnel, and a site visit inspection performed there was a common understanding and consensus on the issues that seem not to comply with sufficient low risk according to modern safety standards (in a broad sense), namely foundation integrity and resistance. Moreover, some of the working group members expressed concern on sliding stability, the emergency preparedness, hydrologic adequacy of outlet work, the effectiveness of drainage and reliability of instrumentation and monitoring system.

Fig. 1
Dam view from downstream (photo taken during the inspection)
Vue frontale du barrage pendant une visite d’inspection

3. FAILURE MODES AND BASELINE RISK CHARACTERIZATION AND EVALUATION

After analyzing all available information, performing site visits and debating extensively on the current situation of the dam, the group proceeded with potential failure mode identification and analysis (Fig. 2). Five failure modes were found plausible, namely (1) Foundation erosion followed by an structural collapse, (2) Sliding along dam-foundation contact, (3) Sliding along a foundation discontinuity, (4) Overtopping and (5) Instability driven by stilling basin scour.

Fig. 2
Potential failure mode analysis sesion
Session d'identification de types de faille

Further on, a complete risk model was built in iPresas Calc[1] software, in order to be able to perform risk calculations on the basis of event tree generation. The model architecture links together the five failure modes with the loading conditions that trigger them and the consequences in case of failure and non failure. Once all required input data are provided and attached to the calculation scheme, annual probability of failure, societal and economical incremental risk were quantified.

Afterwards, in order to perform the risk evaluation, those estimates are plotted against existing tolerability guidelines on risk in such a manner that the justification for taking corrective actions may be more or less justified depending mainly on the expected fatalities and probability of failure. Figure 3 plots the current risk estimates for "El Horcajo" dam versus USBR (2011) tolerability guidelines. In addition, each of the failure modes have been plotted independently to understand the degree in which all of the are contributing to the overall risk.

[1] iPresas: Manual de usuario de iPresas Calc. http://www.ipresas.com, 2013.

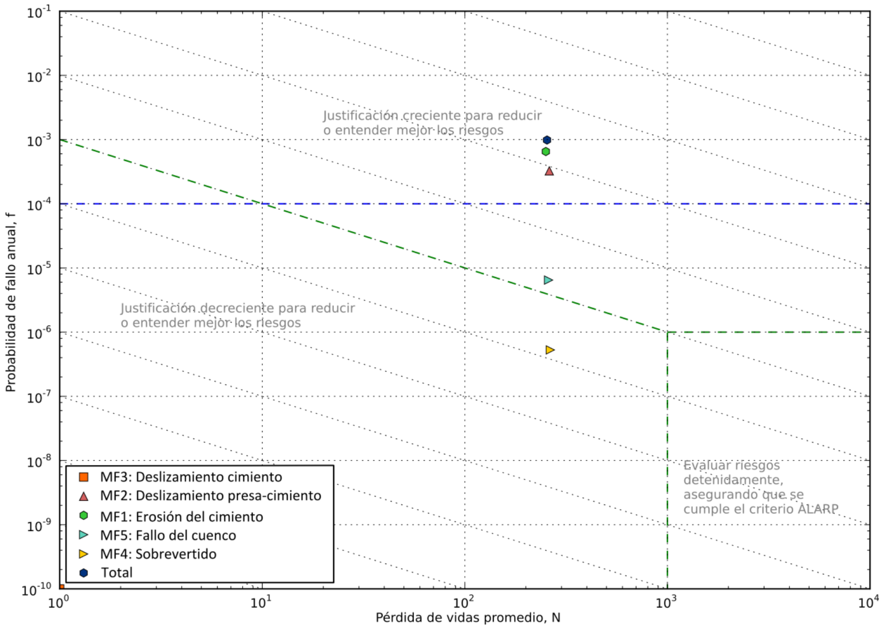

Fig.3
Current risk estimates plotted versus USBR (2011) tolerability guidelines
Evaluation de risque existant conformément à USBR (2011)

As can be inferred from Fig. 3, "El Horcajo" dam would not be aligned with a sufficiently low risk values, thus action is strongly supported to reduce such risk. Two main contributors to risk are (1) Foundation erosion followed by structural collapse and (2) Sliding along dam-foundation contact.

Before moving further into the type of actions to address the risk drivers, it was important to quantify the impact of uncertainty on the baseline risk estimates with focus on how it may inform different decisions.

Uncertainty analysis was performed on the hydrological inputs, system response estimates and consequences, with focus on the potential impact on decision making. The analysis was performed both for the BASE CASE and every studied alternative, as explained in next chapter.

4. EVALUATION OF ALTERNATIVES

The alternatives were first analyzed and later prioritized in accordance with the so called Equity Weighted Adjusted Cost per Statistical Life (EWACSLS), a risk indicator whose components and formulation are included in the Spancold Guidelines [1]. Namely, they were: (1) Emergency Action Plan implementation, (2) an Enhanced Emergency Action Plan implementation with focus on communication and education, (3) lowering of the spillway crest, (4) upgrading the monitoring system including new instrumentation devices, and (5) improving foundation impermeability.

Once EWACSLS is evaluated in each step and uncertainty analysis undertaken also at each of the prioritization steps, the recommended sequence both for the "best estimate case" and the "5% more conservative percentile case" of the Montecarlo simulations support a very similar sequence of decisions, as shown in Fig. 4.

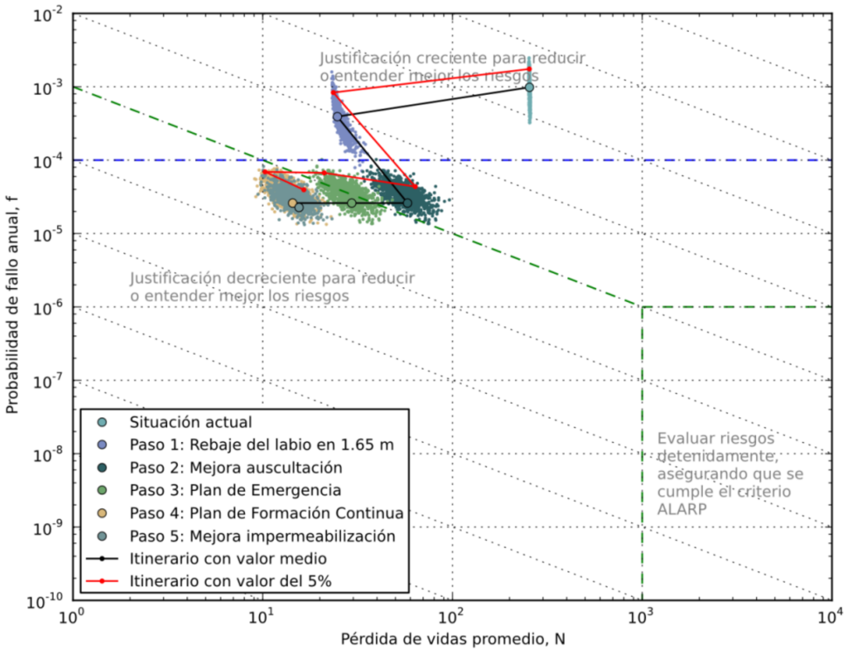

Fig. 4
Secuencia priorizada de alternativas de actuación
Séquence d'alternatives d'actuation priorisée

Three first alternatives identified in both itineraries in the same order are (1) lowering the spillway crest by 1.65 meters, (2) upgrading the monitoring system including new instrumentation devices and (3) Emergency Action Plan implementation, without questioning the suitability and utility of all the considered safety investments evaluated.

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SUMMARY

From the early stages of operation Horcajo Dam, the overall safety of the dam has been jeopardized by the fact of being partially founded on a non-sufficiently characterized, neither monitored, alluvium foundation, being this issue constantly referenced in every dam safety document written since then (safety reviews, emergency action plan and operating rules mainly).

The current risk baseline has been estimated and, in addition to those actions already taken, other complementary actions have been identified and evaluated in terms of several risk indicators. Such additional actions are, namely, the full implementation of an updated emergency action plan, reconstruction of the upstream impervious concrete monolith to reduce uplift, and a partial demolishing of the spillway to lower it to a set of different levels (alternatives).

The outcomes of the risk informed process are presented in this paper, showing how robust and transparent information has been developed to support decision-making in Hervás Dam safety upgrading, becoming a milestone in a journey to risk informed governance.

RÉSUMÉ

Dès les premières étapes de la mise en opération du barrage de Horcajo, la sécurité du barrage a été menacée du fait qu'il a été partiellement construit sur une fondation d'alluvions pas suffisamment qualifiée, ni contrôlée. Ce problème étant constamment référencé dans tous les documents écrits relatifs à la sécurité du barrage depuis lors (compte-rendus de visite de sécurité, plan d'action d'urgence et règles d'opération principalement).

La ligne base actuelle des risques a été estimée et en plus des actions déjà prises, d'autres actions complémentaires ont été identifiées et évaluées en terme de plusieurs indicateurs de risque. Ces actions supplémentaires sont, à savoir, la mise en œuvre complète d'un plan d'action d'urgence à jour, la reconstruction du béton monolithique imperméable en amont pour réduire le soulèvement et la démolition partielle du déversoir dans le but de le réduire à un guide de différents niveaux (alternatives).

Dams: El Horcajo Dam (Spain)
Key-words: benefits of dams, safety of dams, risk analysis
Mots-clés: bienfaits des barrages, securite des barrages, analyse de risque