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Dam break equivalent time for the peak flow calculation with classification objective

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ABSTRACT: The SMPDBK program of the National Weather Service of the United States, despite its limitations, is of great help in obtaining the dam classification as a function of dam break potential risk, with enough approximation and in general on the safe side. However, for certain ratios of dam height and reservoir volume, the direct application of this model can produce results on the non conservative side. This paper proposes a correction starting from the calculation of a dam break equivalent time, so the results of the peak flow are similar to those that would be obtained with the complete DAMBRK model application.

1 INTRODUCTION

In accordance with the Basic Rules of Civil Protection Planning Against of Flood Risk, its necessary to rank dams in accordance with the potential risk, for that the Spanish Environment Ministry has issued a Classification Guide (Technical Guide 1996). In this guide the criteria are unified and, among other methods, the use of the simplified program (SMPDBK) of the DAMBRK general model is recommended, as an initial working tool and as acceptable analysis of classification under certain conditions (Wetmore & Fread 1981). In any case, because of its easy use and due to the scarcely available information in the first phases of the analysis, its use is always recommended as a first approximation to the problem, giving generally results on the safe side (Penas; Berga & Rodríguez 1996).

From the obtained experience in its practical application in the dams of the North of Spain Hydrographic Confederation (SENER 1997) it has been detected that, for certain conditions of dam height and reservoir volume, the dam break peak flow analized with the SMPDBK does not produce always safe results when compared to analogous calculations made with the DAMBRK. In this paper these cases have been identified and a correction has been proposed that allows to maintain the program code, assuring dam break flow values analogous to those obtained by the use of the DAMBRK complete model.

From the analysis carried out it has been determined a dam break equivalent time *te* that together with the breach width constitute the input data to the SMPDBK model, extending in this way its applicability field and guaranteing that the category will not be infravalued in the potential risk classification.

Due to the great quantity of dams affected by this situation, it is hoped that the contribution made by the authors will be useful in the dam classification activities.

2 SIMPLIFIED DAMBRK METHOD OR SMPDBK MODEL

Fread developed a simplified formula for the dam break peak flow calculation, the same is incorporated into the National Weather Service (NWS) of the United States SMPDBK model (Wetmore & Fread 1981).

In this formula the breaking breach is assumed rectangular, defining the instantaneous flow through the breach from the known equation for a spillway:

$$Q = c \cdot b \cdot H^{1.5} \tag{1}$$

where b = breach width (m); H = water height above the breach (m); c = discharge coefficient and Q_b = flow through the breach (m^3/s). See figure 1.

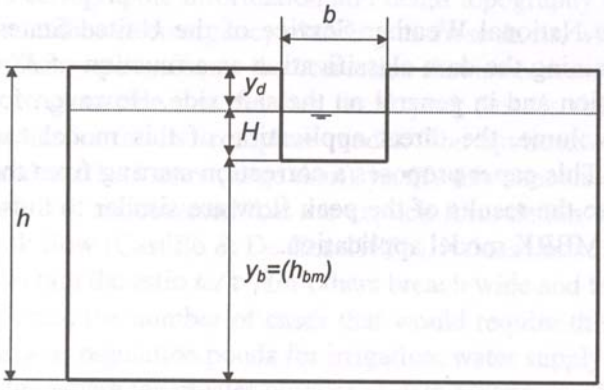

Figure 1.- Geometry of the instantaneous breach development for simplified calculation of the peak flow.

If the breach is developed in a finite time τ, and the reservoir surface is assumed constant during this time interval, the water volume that leaves the reservoir is given by instantaneous flow integral. This volume has to be equal to the product of the reservoir area A_s and the integral of the instantaneous level descent y_d accross the change in the reservoir level y_f, so that:

$$c \cdot b \cdot \int_0^{\tau} H^{1.5} dt = A_s \cdot \int^{y_f} dy_d \tag{2}$$

The evaluation of the instantaneous height on the breach can be expressed in terms of the instantaneous descent of the level $H = (h - y_b) - y_d$, where y_b is the instantaneous level of the breach bottom, reaching the h_{bm} value at the end of the process, and h is the dam height.

Replacing this expression in the last equation, an expression is obtained not integrated analytically. It has been proposed the instantaneous height on the breach to be calculated by the following expression (Wetmore & Fread 1981):

$$H = \frac{1}{\Gamma}(h - y_d) \tag{3}$$

where Γ is a dimensionaless empirical coefficient that defines the equivalent height on the breach that would produce the maximun breach flow. From the comparison between the calculated flows with this simplification and those obtained with the DAMBRK, they assumed that $\Gamma = 3$.

Replacing the expression (3) into the equation (2) and reordering, the expression for the maximun height on the breach is obtained:

$$H_{(max)} = h - y_f = \left\{ \frac{\dfrac{2 \cdot \Gamma \cdot As}{c \cdot b}}{\tau + \dfrac{2 \cdot \Gamma \cdot A_s}{c \cdot b \cdot \sqrt{h}}} \right\}^2 \qquad (4)$$

If in the equation of the outlet maximum breach flow (1), the failure time τ it is expressed in seconds, b and h in meters and A_s in square meters, and it is assumed that the maximun flow is reached at the moment when the breach has been completely developed, then the discharge coefficient will be $c = 1.7$ and the maximun flow would be:

$$Q_{(max)} = c \cdot b \cdot \left\{ \frac{\dfrac{2 \cdot \Gamma \cdot As}{c \cdot b}}{\tau + \dfrac{2 \cdot \Gamma \cdot A_s}{c \cdot b \cdot \sqrt{h}}} \right\}^3 \qquad (5)$$

3 COMPARISON OF RESULTS BETWEEN SMPDBK AND DAMBRK

In the dams classification study of the North of Spain Hydrographic Confederation (SENER 1997), it was observed that not always the maximum dam break flow obtained with the SMPDBK, was greater than that obtained with the DAMBRK complete model, leading the authors to analyse the causes in order to correct and to limit these inconsitencies in terms of practical application; that is, to continue using the SMPDBK model, without modifying the program.

A study was therefore undertaken with these programs of a group of cases whose reservoir surface varied between 2000 and 1000000 m^2 and dam heights between 4 and 30 m, for a width of breach of 45 m and a dam break time of 10 minutes, divided in two groups: reservoirs of constant surface area with the height (regulation ponds) and reservoirs with surface area increasing linearly with the height (reservoir shape similar to the normal situations).

As a result of this, the relation between the SMPDBK peak flow and the DAMBRK one were obtained (figures 2 and 3). From the observation of these figures it can be deduced that the SMPDBK method is not conservative compared with that of the DAMBRK for certain combinations of reservoir area and dam height (generally for small dams). In general terms, for the analysed conditions, the SMPDBK model obtains similar flows for reservoir of constant surface of over 500000 m^2 and for triangular reservoirs of over 100000 m^2.

Therefore the simplified hypothesis used in the SMPDBK, although give good results in general terms, are unsafe for small dams and in some cases for large dams; this circumstance could produce an infravaloration in the dam category classification.

The simplified hypothesis are three: constant width of breach, constant reservoir surface area and peak flow time equal to the breach development time.

These hypothesis are taken care of and corrected in the SMPDBK original method by means of a single parameter Γ (constant and independent of reservoir type), by which, using the estimated parameters of dam break time, breach width and reservoir area, good results are obtained for large dams and usual reservoir shapes.

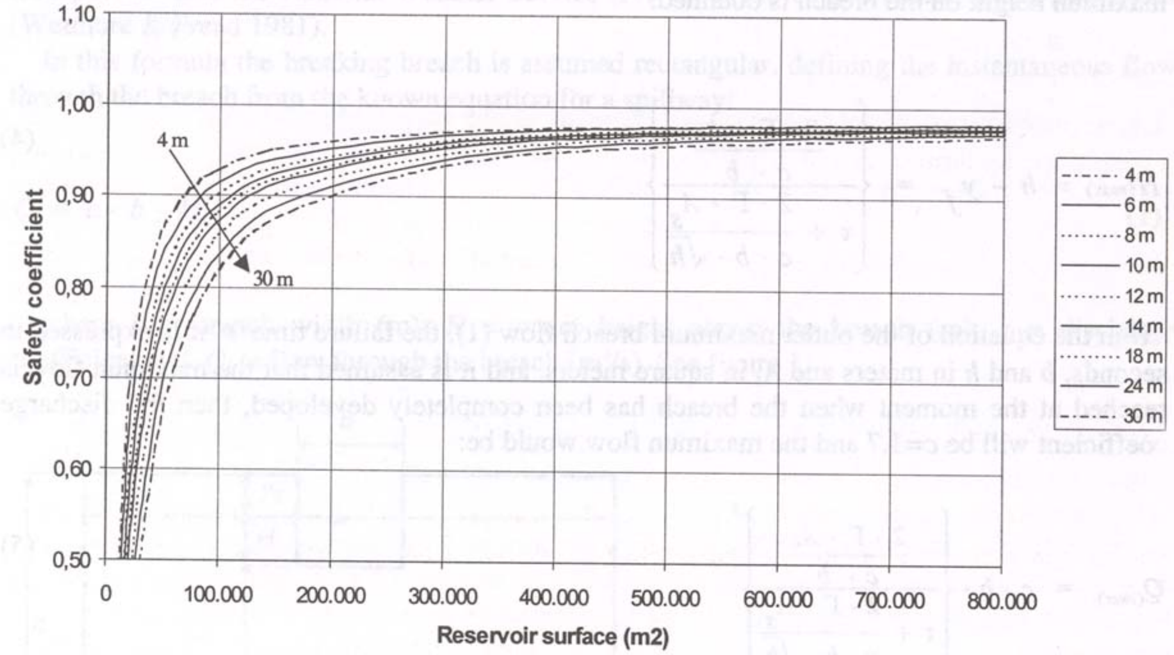

Figure 2. Flow ratio SMPDBK/DAMBRK for constant reservoir

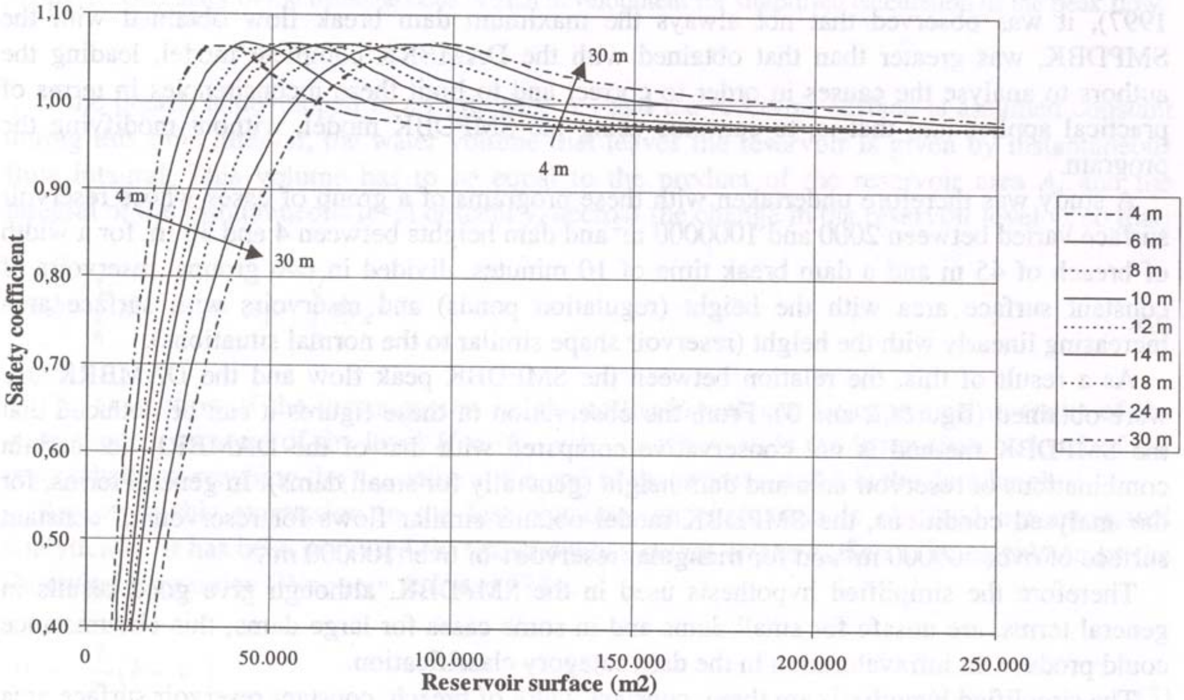

Figure 3. Flow ratio SMPDBK/DAMBRK for triangular reservoir

Figure 4 shows the Γ values for reservoirs with triangular variation, as a function of the reservoir area and dam height. It can be observed that for areas smaller than 60000 m^2, the Γ values exceed 3 in large height dams, while in small dams the Γ values are smaller reaching values lower than 3; the trend is inverted however below this zone with a tendency for Γ to reach 3, as the dam height increases.

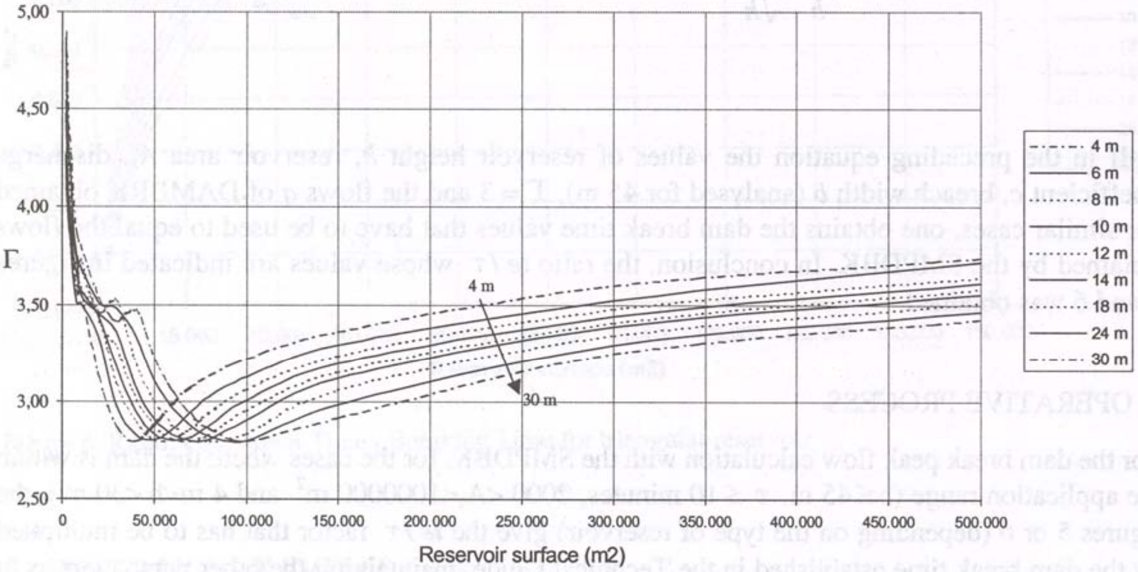

Figure 4. Γ values for traingular reservoir in function of the surface and height

4 ANALISED SOLUTIONS

Several possible solutions were analyzed with the purpose of maintaining the original code of the SMPDBK, by introducing adequate corrections in the basic parameters, dam break time and breach width (Castillo & De Cos 1997a, 1997b).

A first option consists in obtaining equivalent values for dam break time and breach width as an indirect method for modifying the parameter Γ so as to obtain with SMPDBK the same peak flow values as with DAMBRK. The method requires however a double group of graphics, which makes difficult its use.

A second way consists in utilising an equivalent breach width that makes the flows equal; this way has been abandoned because if the SMPBDK flow it is maximized with regards to the breach width, there are cases where the absolute maximun flow obtained is smaller than that obtained by DAMBRK, making this method unacceptable, aside losing any physical sense.

Finally, and after observing that the peak flow is not reached in every case at the same instant that the breach is completely developed, but is produced earlier (especially in those cases where DAMBRK flow is much higher than the SMPDBK one), it has been decided to define a “dam break equivalent time” that substituting to the parameter “breach development time” of the SMPDBK, obtains flows comparables to those of the DAMBRK.

5 DAM BREAK EQUIVALENT TIME FORMULATION FOR THE SMPDBK

Finding from equation (5) the τ value and renaming it as dam break equivalent time *te*, we obtain:

$$te = \frac{\left(\frac{b \cdot c \cdot \left(\frac{2 \cdot \Gamma \cdot A_s}{c} \right)^3 \cdot h^{3/2}}{q} \right)^{1/3} - \frac{2 \cdot \Gamma \cdot A_s}{c}}{b \cdot \sqrt{h}} \qquad (6)$$

If in the preceding equation the values of reservoir height h, reservoir area A_s, discharge coefficient c, breach width b (analysed for 45 m), $\Gamma = 3$ and the flows q of DAMBRK obtained for similar cases, one obtains the dam break time values that have to be used to equal the flows obtained by the SMPDBK. In conclusion, the ratio te / τ whose values are indicated in figures 5 and 6 was obtained.

6 OPERATIVE PROCESS

For the dam break peak flow calculation with the SMPDBK, for the cases where the dam is within the application range ($b \leq 45$ m, $\tau \leq 10$ minutes, $2000 < A_s < 1000000$ m^2 and 4 m$< h < 30$ m), the figures 5 or 6 (depending on the type of reservoir) give the te / τ factor that has to be multiplied by the dam break time established in the Technical Guide, maintaining the other parameters as in the general method. In a practice way, as a general rule, it is not necessary to make the correction for constant area reservoir of over 500000 m^2 and for triangular reservoirs of over 100000 m^2; that would suppose maximum deviations of about 5 %.

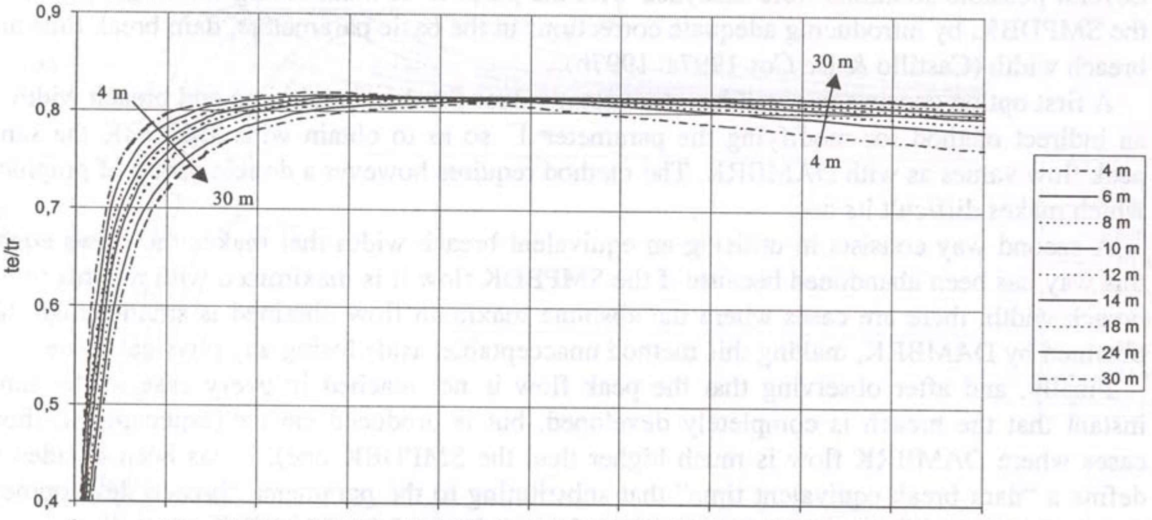

Figure 5. Ratio: Equivalente Time / Breaking Time for constant reservoir

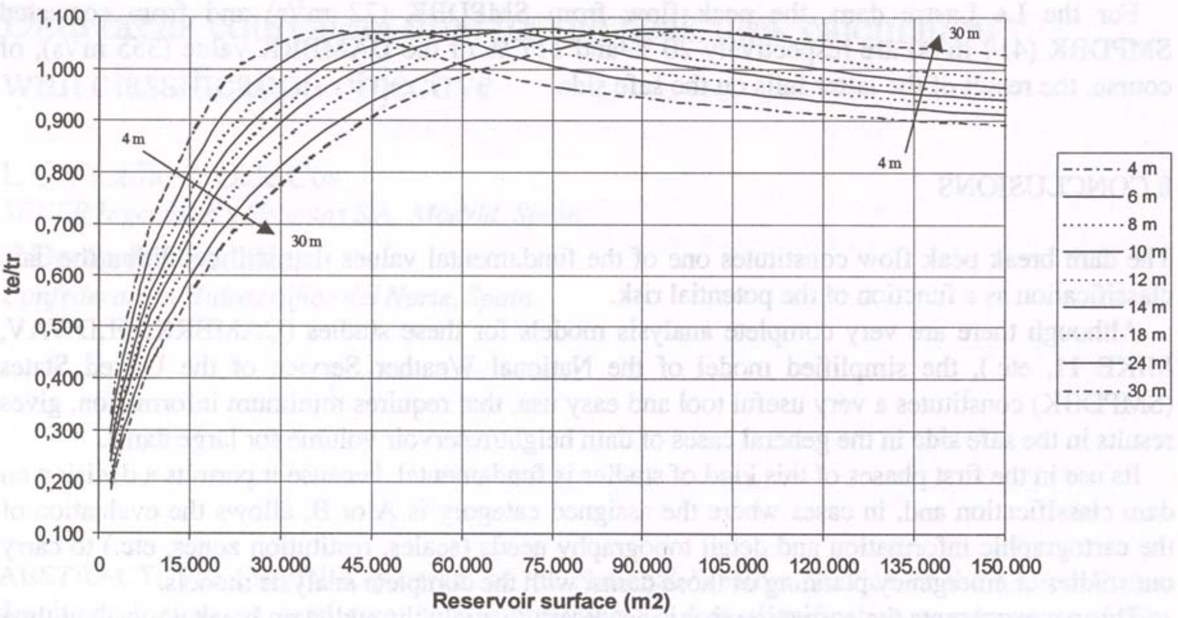

Figure 6. Ratio: Equivalent Time / Breaking Time for triangular reservoir

7 APPLICATION EXAMPLES

The principal characteristics and the obtained results of the dam break peak flow for the La Mortera and La Lastra dams are shown in table 1.

The ratios Equivalent Time/Breaking Time equal to 0.70 and 0.45 are obtained in figure 6 from the data of reservoir area and height.

Table 1. Dam break peak flow calculation with three methods: DAMBRK, SMPDBK, corrected SMPDBK

Dam and reservoir characteristics		La Mortera	La Lastra
Type		Gravity	Gravity
Crest length	(m)	91	83
Reservoir area	(m^2)	8400	9400
Dam height to the foundation	(m)	8.00	29.50
Analized reservoir height	(m)	4.00	24.60
Breach characteristics			
Break time	(minutes)	10	10
Breach width	(m)	45	45
Equivalent Time/ Breaking Time		0.70	0.45
Peak flows			
DAMBRK	(m^3/s)	53	355
SMPDBK	(m^3/s)	27	72
Corrected SMPDBK	(m^3/s)	52	414

It is found that for the La Mortera dam, the peak flow value obtained with the SMPDBK model (27 m^3/s) and the corrected SMPDBK model (52 m^3/s) are respectively 51 % and 98 % of the value obtained with DAMBRK (53 m^3/s).

For the La Lastra dam, the peak flow from SMPDBK (72 m^3/s) and from corrected SMPDBK (414 m^3/s) are respectively 20 % and 117 % of the DAMBRK value (355 m^3/s); of course, the result of the latter falls on the safe side.

8 CONCLUSIONS

The dam break peak flow constitutes one of the fundamental values that will condition the dam classification as a function of the potential risk.

Although there are very complete analysis models for these studies (DAMBRK, FLDWAV, MIKE 11, etc.), the simplified model of the National Weather Service of the United States (SMPDBK) constitutes a very useful tool and easy use, that requires minimum information, gives results in the safe side in the general cases of dam height/reservoir volume for large dams.

Its use in the first phases of this kind of studies is fundamental, because it permits a decision on dam classification and, in cases where the assigned category is A or B, allows the evaluation of the cartographic information and detail topography needs (scales, restitution zones, etc.) to carry out studies of emergency planning of those dams, with the complete analysis models.

This paper presents the correction that is necessary to apply through dam break equivalent time *te*, to guarantee that the dam break peak flow is similar to that wich would be obtained with the application of the complete model. The application examples presented for La Mortera (small dam) and La Lastra (large dam), justify this conclusion.

It was encountered that the explicit formulation of the breach wide that maximizes dam break peak flow (Castillo & De Cos 1997b), it does not constitute a general law. It would be convenient to obtain the ratio te/τ , for others breach wide and failure time.

Since the number of cases that would require this correction is very large, especially in small dams as regulation ponds for irrigation, water supply, mining ponds, etc., and since it is just in this range where the greater number of dam failures has been occurred due to the scarce resources that are being applied for their study, construction and maintenance (ICOLD 1995), the authors hope that the present contribution will be useful in the dam classification activities.

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