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Question 75 d) :
contribution to the discussion by Dr Eng Giovanni Lombardi on

"DAM FAILURE AND THIRD-PARTY INSURANCE"

"RUPTURE DE BARRAGES ET RESPONSABILITE AUX TIERS"

Giovanni Lombardi
Dr Eng. Dr.h.c.
Lombardi Engineering Ltd.
Via R. Simen 19
CH 6648 Minusio-Locarno (Switzerland)

1. INTRODUCTION

Due to a number of reasons, there is presently an increasing demand for a more stringent liability of the dam's owners in case of damages of any type caused to any third party. The worst case is obviously that of the collapse of the dam and the consequent enormous impact that would take place downstream.
Following, the owners are often strongly required to subscribe a third-party liability insurance. So, discussions are presently ongoing on this point in Switzerland.

The principle of any insurance consists in :
– defining the extent of the possible damages caused by any event considered,
– defining the probability of occurrence for any one of the cases envisaged,
– computing the single risk in multiplying the damage by the corresponding probability of occurrence,
– summing up the single risks, and
– proposing the insurance premium in using an appropriate "factor of safety" to cover costs, overheads, and contingencies.

In the following only the case of collapse and its probability of occurrence will be dealt with.

2. STATISTICS ON DAM FAILURES

Ever since, ICOLD was interested in the statistics of dam failures. In doing so, great help was given to the progress of the art of dam engineering. Indeed, this action gave a significant contribution to the understanding of the causes and reasons of the failures and allowed to develop "strategies" in order to avoid such disasters or at least to reduce their frequency and their consequences. Actually, the ratio of failures to the number of dams built decreased dramatically along the lasts decades.

Very interesting in this respect is ICOLD-Bulletin Nr. 99.
Summarising it a lot, the main causes of failures can be reduced to the following ones :
– inadequate design,
– foundation weaknesses,
– inadequate materials,
– inadequate methods of construction,
– exceptional actions (floods, earthquakes),
– inadequate maintenance,
– appurtenant works (design, foundation, materials, construction, exceptional actions, main-tenance, operation).

It is very important to notice that no unidentified causes were ever mentioned.

In establishing such statistics, however, one suggests, even unwillingly, that any dam includes, to some extend, some inadequacy of the design, the foundations, the materials or the appurtenant works and that the dam is exposed, again to some extend, to exceptional actions, bad maintenance or faulty operation of the appurtenant works, and so on.

3.   INHERENTLY SAFE DAMS

However, there is a different way to look at the results of said statistics, as they are based on an extremely small and extremely inhomogeneous population of dams ; exactly dams which failed.
The following semantic comment is obvious. If the cause of a collapse can be, for example, a non-adequate foundation, this means conceptually that adequate foundations must exist. These foundations are exactly that ones which exclude the risk of collapse. Indeed, these studies hav-ing clearly identified the causes of the collapses occurred, they provide also the possibility to define the conditions for inherently safe dams.

These conditions are apparently fulfilled in the case of :
– correct design (no experimental dam),
– adequate foundations,
– adequate materials,
– correct methods of construction,
– exceptional events taken into consideration,
– adequate maintenance (especially preventive), including follow-up and monitoring
– adequate appurtenant works, and
– correctly defined operational modes,
in this context the "correct design" includes obviously an adequate factor of safety to cover the uncertainties on, or the dispersion of all the other parameters and to compensate for the limited precision of the computations.

Not considered are obviously "acts of good" which are thus not "acts of the engineer" as:
– a meteorite falling on the dam,
– military actions,
– sabotage,
– or human error in matter of operation,

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although some protection against a number of these acts is still possible and should be implemented.

Should a dam be declared safe, this does not mean it will stay so for any future time, but only as long as the conditions stated here above are fulfilled.

Therefore, the inherent safety of a dam must be confirmed and checked from time to time by :
– observation of a correct behaviour during a number of years,
– permanent monitoring (and interpretation) of the readings as well as
– frequent inspections to highlight any sign of ageing or weakness.

These actions are extremely important to detect immediately any deviation from a normal behaviour and to get enough time to take the required actions. In doing so, the residual risks can be significantly reduced or eliminated.

Indeed, at least the great majority of the dams which failed, were not correctly followed up in matter of monitoring, observation, interpretation of the readings or understanding of the warning signals. Nature is, in fact, kind enough to send signals in time before a failure occurs. You just need to pay them the necessary attention !

4. BOUNDED AND UNBOUNDED PROBABILITY DISTRIBUTION

The notion of "inherently by safe dam" may disturb those ones who are used to consider everything in term of a "Gaussian Normal Distribution" and are keen to see everywhere the infinite extension of the tails of such distributions of probability. This allows them to prove that everything is possible, even physically impossible facts. **Figure 1** is an example of such bold extrapolations.
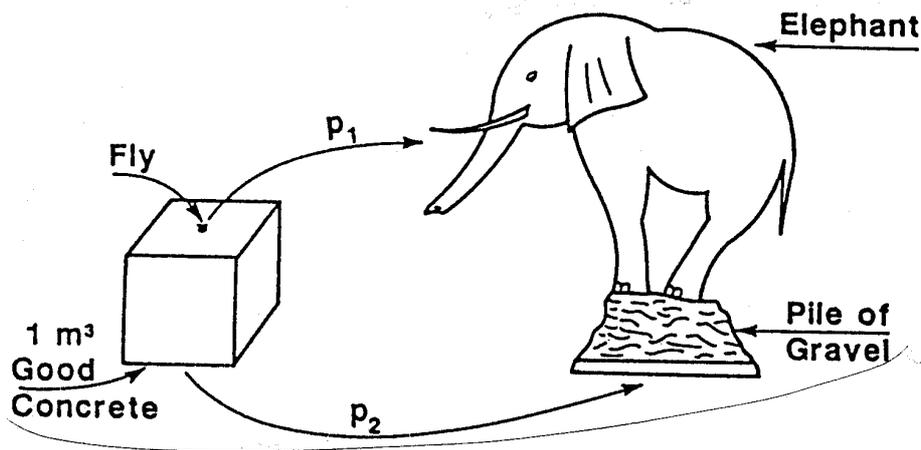

Fig. 1

The probability for a fly to crush a concrete block is obtained as product of the probability p_1 for the fly to be as heavy as an elephant by the probability p_2 for the concrete block to be as weak as a pile of gravel.

La probabilité qu'une mouche écrase un bloc de béton est le produit de la probabilité p_1 qu'elle soit aussi lourde qu'un éléphant par la probabilité p_2 que le bloc de béton soit aussi faible qu'un tas de gravier.

Said unbounded distributions may be very interesting for mathematicians and are also quite easy to handle, but have very little to do with engineering in the real world. At the best they may be useful, and are also often used, to study some variable in the vicinity of its average value; so for example concrete strengths.

The sound engineering judgement requires, at the contrary, that only bounded distributions are acceptable to explain any physical phenomenon, and should be used exclusively in assessing any kind of risks in our field.

Let consider the following very simple case of
– a gravity dam of moderate height,
– of excellent concrete,
– on excellent rock foundations, and
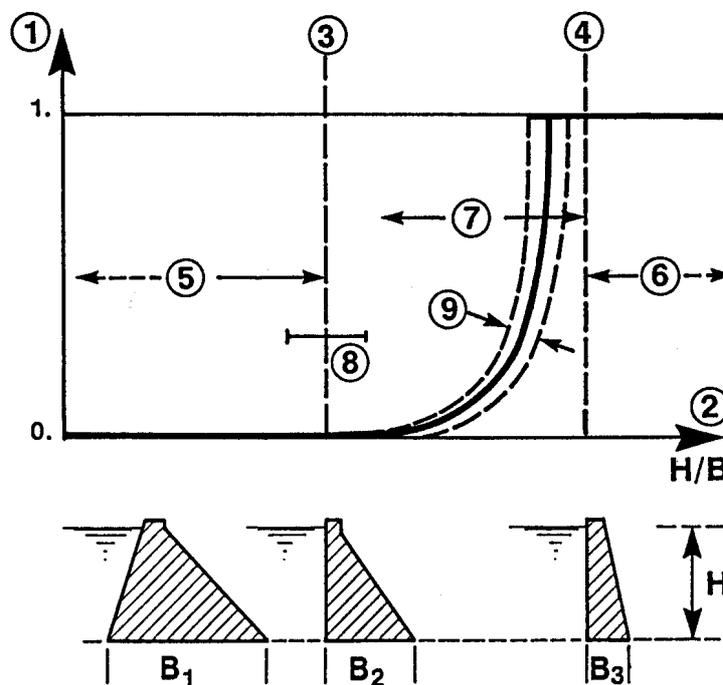– not subject to any earthquake nor to over-topping.

Fig. 2

Example of bounded probability distribution.
Toppling of a gravity dam ; moderate height, excellent concrete, excellent foundation, no overtopping, no earthquake.

Exemple de distribution bornée de probabilité
Renversement d'un barrage gravit ; hauteur modérée, béton excellent, fondation excellente, pas de déversement, pas de séisme.

1	Probability of toppling	*1*	*Probabilité de renversement*
2	Ratio height/base	*2*	*Rapport hauteur/base*
3	Lower bond	*3*	*Borne inférieure*
4	Upper bond	*4*	*Borne supérieure*
5	Inherently safe dams	*5*	*Barrages intrinsèquement sûrs*
6	Absolutely unsafe dams	*6*	*Barrages absolument non stables*
7	Unsafe dams	*7*	*Barrages à risque*
8	Usual dams	*8*	*Barrages usuels*
9	Fringes of uncertainties	*9*	*Franges d'incertitude*

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The only variable considered in this example is the ratio "dam height to base width", H/B, and its effect on the risk or probability of toppling. The only uncertainties are due to the uplift forces and the tensile strength of the contact surface between rock and concrete.

Surely a maximum value of said ratio exists, above which the dam will topple in any case, and there is also a minimum value below which the dam will never topple.

Between these two limits there is an increasing probability of rupture, as shown in **figure 2**.

Obviously the real problems are not uni-dimensional as the simple example discussed here above, but multi-dimensional. So fault tree theory and its methods can be used, but this makes sense only if based on bounded probability distributions. If not, one is just gambling with supposed infinite tails of assumed theoretical probability distributions.

Of course, all this does not mean that any dam is automatically "inherently safe".

In the real world, we have to do with a mix of "inherently safe dams", and of dams "presenting some risks".

5.   THE PROBLEMS OF INSURING DAMS

The wish to have the risks of a dam failure covered by an insurance may be well understood. But, there are quite a number of difficult problems to overcome.

The basis of any insurance is the evaluation of the probability of occurrence of a given event, in order to define the premium to be paid. If the concept of inherently safe is accepted for a given dam, the respective premium should be nil. One may easily understand, that this concept would hardly be agreed upon by any insurance company.

Also one should consider that by a kind of "natural selection" the weakest dams have already disappeared, as they failed, or were repaired. So the probability of rupture for the remaining dams is progressively decreasing at any accident. At the end of the day, only safe dams will have survived, so the premium will tend again to nil. How to introduce this fact into the computations is not easy to tell. Also quite difficult is the problem of the progressive ageing of the dams and of the increasing risks involved.

These considerations do not apply automatically to new dams, as according to the ICOLD statistics, the risks are steadily decreasing with the progress of the art and the experience gained by the study of the history of dam failures. So the premium should be progressively reduced in this case also. However, it is again not possible to tell exactly in which proportion this has to happen. Unavoidably, the statistics on failures are based on the "population" of dams built times ago.

Additionally, it is very difficult and risky to extrapolate any kind of estimated probability of rupture, if any, from one dam to another or from a country to another, or from a period of construction to the following one.

Furthermore, the influence of adequate, possibly preventive, maintenance, permanent follow-up and monitoring is extremely important for the overall safety but also quite difficult to be precisely evaluated and checked by the insurance company.

At the end, the problem results from the fact that the probability of collapse is extremely low, and in many cases equals zero, while the damages may be extremely high. As we know from

mathematics, the product of zero by infinite is not defined. To insure the risk of dam failure is thus approaching a kind of very risky and tricky lottery, which would and must invite the insurance companies to require a "safely" high premium. The "population" of dams in any single category is indeed too small to allow a meaningful management based on statistics.

In Switzerland, for example, the situation is as follows. The number of large dams is about 200 belonging to a great number of different public utilities and private owners.
No collapse was ever experienced and the dams have now proved to be safe for a substantial number of years. Inspections and monitoring are carried out very carefully and seriously.
The probability of rupture can thus be considered to equals zero or is at least to be extremely low. Even much lower is, of course, the probability of an unexpected sudden accident. For these reasons, the rational computation of a premium is practically impossible.

There are therefore a number of people, including myself, who are thinking that a different way should be followed than simply subscribing an insurance. A first path could be a self-insurance set up jointly by all the owners. A second way could be a kind of organisation - possibly steered by a pool of insurance companies -to which any owner would contribute with a certain amount of real warranties in order to create a special trust fund. In case of a disaster this organisation would operate as a clearing house to share out the damages.
Such a solution would generate very low costs for the owners. In lieu of paying a premium based on a lot of a priori assumptions and including a heavy overhead, the owners would have to pay only the actual, a posteriori defined, costs of the collapse. A possibility of cross-checking maintenance or monitoring among the owners could also be taken into consideration and could be very useful in reducing the risks.

No need to say that above thinking applies only to disasters, not to frequent small accidents related to the daily operation of the dams or the appurtenant works. In this case, covering of the third party risks by an insurance, as usually done, represents for sure the simplest solution.

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