

SAFETY OF DAMS

ADDENDUM

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON SAFETY OF DAMS
COIMBRA/23-28 APRIL 1984

Safety of Dams

Edited by

J.LAGINHA SERAFIM

University of Coimbra, Portugal

ADDENDUM



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Foreword

The International Conference on Safety of Dams took place in Coimbra from 23 to 27 April 1984. The Conference attracted about two hundred participants and accompanying persons. Thirty one countries of the five continents were represented.

The Opening Ceremony was held on April 23, 1984 at the Auditorium of the University of Coimbra, at 11 a.m. and began with a performance by the "Orfeão Académico de Coimbra". The Technical Sessions were also held at the Auditorium.

The day of April 25 was devoted to a technical excursion to the Aguieira and Fronhas dams and to Mondego River Irrigation Scheme works.

The Closing Ceremony was held on April 27, 1984 at 4.30 p.m.

After the Conference, two technical excursions took place. The first one, a two day tour in Lisbon, included a visit to the L.N.E.C. (National Civil Engineering Laboratory). The second, apart from a visit to L.N.E.C., consisted of a bus tour, visiting several dams located on the Portuguese and Spanish stretches along the Tagus River (Pracana, Cedillo, Alcântara, Valdeobispo, Gabriel y Galan). This excursion ended in Madrid on May 2, 1984.

The editing of discussions held during the Conference is of the editor's responsibility. Texts are based on written versions left by the participants and on tape recordings. In many cases corrections were deemed necessary. Translations into English of the texts in Portuguese and Spanish were carried out under the editor's supervision. Regretfully, circumstances have not permitted the submission of all the texts for consideration by their authors.

Translation of Portuguese and Spanish texts were done by Lynn de Albuquerque.

Secretariate Services, typing of summaries, resumés and papers were done by Filomena Duarte, Elisabete Ramos, Elisa Pinto and Graciete Martins. Secretariate Services during the Conference were carried out by Filomena Duarte, Elisabete Ramos and Fernanda Maia.

Various members of the University of Coimbra and COBA, International Consultants, also greatly contributed to other tasks related to the organization of this Conference.

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Opening Session



Opening Session

Welcome addresses

J. LAGINHA SERAFIM

University of Coimbra, Portugal

Excellencies, Ladies and Gentlemen,

On behalf of the Organizing Committee of the International Conference on Safety of Dams, and myself, I have the honour of extending to all of you our sincere welcome. To His Excellency, the President of the Portuguese Republic, I should like to express our thanks for his having greatly honoured us with his personal representative's presence; an act which enhances the importance of this conference and adds to its prestige. We also owe much thanks to the representatives of the Ministers most concerned with dams and to the Ministers and Secretary of State for Cooperation, for having given of their time to assist and participate at this Inaugural Session and also for the material aid given. We should also like to mention here our grateful thanks to those sponsoring entities, both public and private, numbering 21 in all, that gave generous donations to this Conference. To our Iberian friends from the Hidroeléctrica Española and from Iberduero, many thanks for having made it possible for our participants to be able to visit their magnificent dams and installations. Also to the Directorate-General of Hydraulic Resources and to the EDP (Portuguese Electricity Authority) we extend our laudatory thanks for the excursion which we shall be making to the Aguieira Dam and the Mondego Valley and afterwards to the works in the Tagus Valley. We thank the Coimbra Municipal Council for their invaluable collaboration. More thanks for the support given by the International Commission on Large Dams, which I hail in the person of its Secretary-General. Similar thanks go to the Portuguese National Committee, which from the outstart has worked side by side with us in order that this International Conference (the first on the theme) be held. Finally, I should like to express my sincere thanks to the Rector of

this University for the support, aid and enthusiasm with which he greeted the idea and made it viable.

It is indeed an honour for us and the University to be able to greet here such a numerous and magnificent representation of dam specialists from all over the world. Twenty-seven countries are represented here, with five others although not present, having sent contributions. Similarly it is an honour for us, and also for the University of Coimbra, to be able to welcome here practically all Portuguese-speaking countries interested in dams.

The presence of these technicians and engineers from five continents from both sides of the Equator, is also a tribute to the Portuguese and to the desire in our country to see the consolidation and advancement of meetings such as this, of the interchange of human knowledge between peoples. To all present, many thanks for having come to Coimbra.

The idea of this meeting arose out of the fact of our belonging to two technical Committees on the International Commission on Large Dams, wherein it is our task to discuss and draw up considerations on the safety of dams, and on criteria for design, calculations and inspections. This has meant our having studied the statistics on accidents and their causes. Also this idea was the result of our having closely followed work on this theme which has been carried out in the principal countries of the world. We have sometimes had occasion to participate in meetings on the subject in Munich, Boston and other places.

The Conference will only deal with subjects related to the safety of dams. Dams should never collapse nor rupture. They should be eminently safe! Even more so than a plane or a car. In this case, those whose lives and property are placed at risk, have done nothing to run such a risk and seldom or never benefit from it. It is so-

ciety, the country, and continents in general, that need dams and they run little risk. However, despite the fact that dams should not collapse, some have ruptured and many times with catastrophic consequences. We could even say, of apocalyptic dimensions, since some of these tragedies have exacted too high a price of modest people, in the name of scientific, technical and economic progress. Happily, this rarely happens: the average is little more than a dam per year, since 1930. To be more specific: from 1930 to 1980, statistics indicate that 60 "large dams" have collapsed, i.e., 60 dams of over 15m high, since we are not talking here of small dams. From the middle of the last century up until 1930, 94 collapsed, which makes a total of 154. In 1980, however, 15,600 dams were in operation, not counting the Chinese, which are not included in the previous statistic. Since the number of dams has risen exponentially in the last decades and the number of ruptures has remained almost constant for a decade, this means that those dams more subject to collapse were old dams and those which were filled for the first time. In other words, those which had basic defects and faults or those which were due to serious human errors of supervision, control and operation. The most vulnerable were earth-fill dams, especially through overtopping due to insufficient or inadequately used spillways. A dam of over 100m in height has never collapsed, notwithstanding, that two dams each more than 300m in height are being built or completed, and dozens of others of over 200m are in service as well as thousands of over 100m high. These numbers prove that dams can be counted among structures, sources of energy, or organs of progress, of the most secure kind. It is a fact that all human works are hazard-prone. And the objective of engineers and scientists is not only to execute these works but above all, to minimize and make insignificant any risks. That is what we are here for. As a matter of interest, in Portugal, today, aside from a rock-fill dam under construction which was carried away by a flood, none of our dams of more than 15m have collapsed.

Dams are critical structures, in respect of present economies and societies. In other words, present civilization cannot do without these works. Humanity, especially since the Industrial Revolution, has grown and developed enormously and engineers have found a way to provide it with vital water, necessary food and indispensable electricity, with the building of larger and larger dams on rivers of ever-

growing importance. The supply of water to cities and megalopolises, the production of irrigation crops, in some cases in semi-deserts, in others of biannual and even in some cases triannual crops and navigation in the interior of continents, very often, is only made possible through dam-regulated rivers. Production of electrical energy would worsen and the annual and interannual storage of some would amount to little without large dams; without them the almost instantaneous availability of great electrical power would be nonviable. Dams, in many places, are the only means of alleviating the problems of droughts and floods. Dams create very pleasant scenery and environments, as can be seen in Paris and Boston, Brasilia and Pampulha (Belo Horizonte) in Brazil. They have contributed to the increased popularity of certain nautical sports, to tourism, to enriching wild life, etc. Even the deltas and estuaries at the mouth of great rivers have benefitted from dams made in their valleys. In brief, dams have transformed many countries and continue to transform others. Not a politician exists in the newly independent nations who does not wish to build dams; and not only is their own personal prestige, or that of their governments, in question; the people of those nations are also aware of the increased wealth such works will bring to them. It is not only the advanced and richer countries which have modern industry and rich agriculture but also those who have already dominated their rivers with dams and who utilize, totally or almost totally, their hydro resources.

All civilizations have built dams. The most ancient peoples constructed them; from the Persians, Babylonians and Egyptians to the American Indians and to the ancient Chinese. The greater part of these works were destroyed by natural elements, especially floods, or by man himself. Of those times, ruins or documents bear witness to their one-time existence. The Romans and Arabs were great dam builders, some of which are still in operation. Amongst the best examples of longevity and resistance can be counted some, close by, in Spain.

Already, in what we might term the scientific era, dams have sometimes played a decisive role in various sciences and techniques which are, today, human heritage. Merely as an example we can refer: in mathematics: the theory of orthogonal functions, those of complex variable, the series for the resolution of the problem of the theory of elasticity; the theory of similarity, the theories of structures, amongst which this "monument" to human intellectual

capacity—the "trial-load method", soil mechanics, without which we should not know how to build earth-fill dams, the hydraulics of porous matter and of drainage and dispelling of energy in spillways, the theory of consolidation of clays, the experimental analysis for strains and stresses and the theories of elastic structural models, the method of finite elements and other branches of the mechanics of materials and of hydraulics which could go on at great length without even going into detail.

We have seen, in the post-war era, i.e., in the past 40 years, the building and location of dams everywhere, all the world's large rivers, and some of which have been used to their total advantage: the Loire and the Garonne, the Po and the Tiber, the Rhône and the Rhine, the Ebro, the Minho, the Douro and the Tagus, the Missouri and the Tennessee, the Columbia and the Colorado, the Elbe and the Oder, the Vistula and Dnieper, the Don and the Volga, or that river of historic European division, the Danube. Other rivers also following the same lead, have large dams on their main beds and on their tributaries, such as of the Paraná and the São Francisco, the Nile and the Niger, the Yangtze and the Yellow, the Tigris and the Euphrates, the Guadiana and Guadalquivir, the Oueds Chelif and the Draa, the Zambezi, the Kunene and the Orange, the Ob and the Jenissei, the Ganges and the Hindu. Others which have been begun or are under consideration, are the Lena, the Amazon and its majestic tributaries: the Ucayali, the Marañon and the Napo, and the Pilcomayo, the Chabul and the Colorado in Argentina or on the other side of the Atlantic, the Congo, the Kwando and the Kubango, or in the Himalayas, the Martaban, the Mekong, the Salween and the Bramaputra, to speak of only four more great rivers of enormous potential in that region. Hundreds, if not thousands, of smaller rivers already have their dams and others, to a lesser extent, will have one in the more or less near future. This indication of the great amount which has been done in this sphere gives us a good idea of the colossal importance of safety in respect of the thousands of large dams built and the thousands to be built. Future dams cannot go much further than the present maximum height to which we have already referred, i.e., 300m. More will be built in the 100m height range. The orography of the earth's crust will be the determining factor. There will be few places where dams can reach the limit of 400m; perhaps only topographically viable in valleys such as those of Arun,

in the Himalayas, or of El Fraile of the Marañon, in the Andes.

We must bear in mind that of the most important problems, and also scientifically most interesting, of great feats of engineering (bridges or tankers, nuclear reactors or planes, offshore oil rigs or dams) are those of safety, which depend on how the methods of analysis and technical criteria are used and how much maintenance, supervision and management are carried out.

This Conference deals with three themes: the first refers to the past history of dams, i.e., to ruptures and incidents verified; within this theme we shall analyse cases, some to be related for the first time; causes will be appraised, some statistics will be analysed (from which many conclusions can be drawn) and probabilistic aspects, which the statistics show us in relation to ruptures and precarious functioning observed, will be submitted. There are 12 papers on this theme.

The second theme relates to present observations of the structural and hydraulic behaviour of dams: numerous reports from many countries will be analysed, sometimes using the most modern and sophisticated equipment, which, "per se", will be the subject of reports on an appropriate sub-theme, works and equipment (including automated and computerized) will be described, for the control of safety and also early warning systems, some of them supported by data processing. 27 papers have been presented on the four sub-themes. This, therefore, is the most adeptly-treated theme.

The third and last theme relates to the future: it is that of the control of safety, be it that of future projects or of the inspection of existing dams. Firstly, the new direction taken in respect of the criteria of a design for this purpose, or new criteria tried out in some countries, will be appraised, bearing in mind that the normal criterion based on coefficients of safety are not justified any more. Standards for design and inspection will subsequently be discussed then their logical and mathematical principles, including analysis of decision techniques, probabilistic methods in order to judge the reliability of the works and, finally, codes, regulations and legislation in force, or being studied, in some countries, to increase the safety and reliability of dams.

It is a long and important task for this Conference. We shall start on it this afternoon.

ADOLFO GONÇALVES

Ministry of Social Equipment, Lisbon, Portugal

Excellencies, Ladies and Gentlemen,

I am privileged, in my capacity as chairman of the Portuguese National Committee on Large Dams, to proffer a few words during this opening session of the International Conference on Safety of Dams, promoted and organised by the Science and Technological Faculty of Coimbra University, but sponsored by the International Commission and the Portuguese National Committee on Large Dams.

The importance of this Conference springs from its very theme and that importance is proved and reinforced by the interest it has aroused internationally and by the number and qualifications of the specialists participating from all over the world. The fact of its being held in Portugal is justified and signifies the high reputation that this country has attained in terms of dam techniques and hydraulic utilization.

In the 1940's, the first large dams built in Portugal were designed by foreign engineers, A. Coyne and A. Stucky (Castelo de Bode, Zezere River; Venda Nova, Rabagão River; Belver, Tagus River; Pracana, Ocreza River; Santa Luzia, Pampilhosa River). But the second generation of large Portuguese dams were entirely designed and built by Portuguese engineers and were significantly more developed (Cabril, Zezere River; Salamonde, Cavado River; Picote, Douro River).

We have thus created a truly Portuguese school in the area of dams and hydraulic utilization, not only in techniques and specialized organizations of which I should mention the planning, design and execution sector, the Directorate-General of Hydraulic Services (presently the Directorate-General of Hydraulic Resources and Utilization) and the Hydroelectric Companies of Zezere, Cavado and Douro (presently the state-owned Portuguese Electricity Authority); test and research

sector, the National Civil Engineering Laboratory; planning and design studies sector, some consulting offices, specializing in hydraulics and dams; in the construction sector, various large public works construction firms, and in the manufacturing and installation sector of hydro-mechanical and electro-mechanical equipment, and some national equipment industries.

These entities cover, and extremely well, not only national requirements but also external requests, since we are involved in works, in various countries, of an internationally recognized quality.

This situation arose, and was made possible, in our country, due to a great spurt in large hydraulic undertakings in the 1950's and 1960's but which dropped off in the 1970's up until the present.

This situation of a slow rhythm in hydraulic undertakings is generally attributed to the economic crisis which has hit many countries, including our own.

On the contrary, in my opinion, the economic crisis should be used to accelerate the execution of new hydraulic undertakings. In effect, part of this crisis is due to the balance of payments deficit which has been brought about by massive importations of energy and foodstuffs. Since the nation's only energy resource resides in its hydro-electrical potential and a significant increase in food products which could be increased in terms of irrigation and since we have at our disposal conditions and hydraulic utilization plans for multiple purposes, including irrigation and hydro-electricity, integrated in an optimized management of national hydro resources, it is obvious that top priority should be given to investments for such purposes. It is, in my opinion, the manner in which to overcome the crisis; take advantage of our natural resources and, to use our human and technological resources which are always the most valuable that any

country has at its disposal.

Given hydrological irregularities, the main objective in the planning of hydraulic undertakings must take into account the suitability of water availability, with all its seasonal and interannual irregularities in relation to the requirements of its many uses - irrigation, hydro-electrical energy, water supply to the population and industry, as well as flood control - with all its varied and irregular time demands.

That is why the fundamental organs for hydraulic undertakings are the regulating reservoirs created by dams. These are, therefore, an indispensable, essential structure, and implicitly of great responsibility, not only due to their high cost but also for their safety conditions, the lack of which implies serious loss of life and property hazards.

This, therefore, is one of the cases which the usual binomial, or economic-safety dilemma acutely places before the engineer.

In order to give suitable responses and solutions, notable technical progress has been made in the area of large dams during the last decades. This progress has only been made possible and incremented by an exchange of information and experience on a world level, which has been promoted by ICOLD.

A non-governmental organization, of great prestige founded in 1928, with the objective of promoting the development and propagation of large dam knowledge, by means of the exchange of the conception, study, design, construction, maintenance and exploration of large dams, ICOLD has carried out these objectives by means of its technical achievements, its triannual international congresses (the first in 1933 in Stockholm and the latest - the 14th - in 1982 in Rio de Janeiro), its annual executive meetings and its technical committees. The objectives of ICOLD have been fully achieved, through unprecedented and unparalleled activity in this sphere, to such an extent that one can state that information collected and divulged by its technical committees and reports, communications and debates at its congresses represent a complete panorama of technological progress made worldwide in the field of study, projects, construction and observance of large dam behaviour.

ICOLD has a present membership of more than 70 countries, through their respective National Committees.

Portugal prides itself on being a member of ICOLD since 1938, having formed its National Committee in 1946 and since then it has been one of its most active members,

ensuring participation of Portuguese delegations in all Executive Meetings and Congresses, presenting numerous reports and technical communications and represented on ten of its Technical Committees.

From this vast activity has resulted the honourable election of one of its members to top positions of this prestigious international organization: a vice president for the 1956-1958 period and the presidency through 1958-1961.

Safety of dams is a theme which, by its importance, has deserved attention from ICOLD as well as from Portuguese technicians of the CNPGB*.

I recall that at the 3rd ICOLD Congress (Stockholm, 1948) Portuguese technicians presented two papers on the methods of analysis (model tests and calculations) and results of surveillance of the first two important concrete dams built in Portugal (Emal, A. Stucky project and Santa Luzia, A. Coyne project).

At the 14th and latest Congress (Rio de Janeiro, 1982) there was a theme on "Safety of Dams in Service" on which three reports were presented by Portuguese engineers.

ICOLD recently published an important work on "Deterioration of Dams and Reservoirs", a theme closely allied to safety, and which is the subject of a report of the respective ICOLD Technical Committee, presided over by a Portuguese technician who succeeded another illustrious Portuguese engineer, Manuel Rocha, who by his dynamism and competence managed to congregate the collaboration of other national technicians on that work. A work which was lauded in his memory, by President Londe, in naming it the Rocha Committee.

It happens that dam safety has been the objective theme of works which fall within the scope of ICOLD and CNPGB. It is, therefore, only natural for it to have sponsored this Conference when asked to do so by the organizing body - the Science and Technological Faculty of Coimbra University.

I am very happy that this International Conference is taking place in Coimbra for various reasons - Coimbra and its famous University have been seats of historical and universal learning for many centuries. The University has in its Science and Technological Faculty a Professor who is a world renowned dam specialist. The city is bathed by the Mondego River, an entirely Portuguese river, on which the largest hydraulic works ever undertaken in this country is at an advanced stage.

*Portuguese National Committee on Large Dams.

A hydraulic undertaking of multiple purposes - hydro-electrical energy, irrigation, water supply to the population and industry, flood, solid transport and pollution control - with four different types of dams already built which the participants will have an opportunity of visiting.

J. COTILLON
ICOLD, Paris, France

Excellences, Messieurs, Chers Amis,

La sécurité a toujours été le premier souci des concepteurs et des exploitants de barrages. Au stade du projet, d'abord: il s'agit de concevoir un ouvrage qui présente toutes les garanties requises. Au stade de l'exploitation, ensuite: il faut s'assurer en permanence du bon comportement du barrage et, pour les barrages anciens, il convient de vérifier qu'ils présentent les mêmes garanties que celles exigées actuellement des ouvrages récents. Ce dernier domaine mobilise d'ailleurs de plus en plus, l'attention. Ce souci de la sécurité n'est pas passif. On ne se borne pas à vérifier ou à ausculter. De nombreuses interventions ont lieu, soit pour corriger des défauts, soit pour combattre le vieillissement. Le souci de la sécurité est donc un comportement éminemment actif. Mais l'exigence de sécurité pour les barrages, comme d'ailleurs dans tous les domaines de l'activité humaine, est maintenant plus grande qu'elle ne le fut jamais. Le succès de conférences sur la sécurité des barrages traduit bien ce souci. La présence parmi nous de plusieurs représentants des autorités gouvernementales témoigne de l'importance que ces autorités dans tous les pays, d'ailleurs, attachent à ce problème et de l'intérêt qu'elles veulent bien porter à nos travaux. C'est un encouragement précieux pour tous les ingénieurs de la Commission Internationale des Grands Barrages.

En Europe Occidentale, en ce printemps 1984, il y avait beaucoup de raisons pour tenir ici une telle Conférence. La première tient à la place qu'occupe le Portugal dans l'ingénierie des barrages. De grands noms ont illustré, ou illustrent encore, le rôle de premier plan que joue à cet égard votre pays. Que me soit permis de citer le regretté Professeur Manuel Rocha et, parmi les présents, le Professeur Laginha Serafim,

cheville-ouvrière de cette conférence. La seconde raison tient à l'activité du Comité National Portugais des Grands Barrages l'un des plus dynamiques de la Commission Internationale des Grands Barrages. Sous l'impulsion de son Président, l'ingénieur Adolfo Gonçalves, et grâce au Laboratoire National de Génie Civil, il prend une part active aux études que conduit notre Commission. La troisième raison est le rôle de phare que joue l'Université de Coimbra, l'une des plus anciennes et des plus célèbres d'Europe. Il n'est donc pas étonnant que la demande de parrainage de cette Conférence ait fait l'objet d'un vote unanime de la Commission Internationale des Grands Barrages en Septembre dernier, à Londres, lors de notre 51ème Réunion Executive. Je suis fier et heureux d'être aujourd'hui le porte-parole des soixante catorze pays-membres de notre Commission pour apporter un salut fraternel aux participants et à leurs hôtes et exprimer le vœu d'un échange fructueux de points de vue et d'informations durant cette Conférence. Obrigado!

E.VANMARCKE

Massachusetts Institute of Technology, USA

Excellencies, Ladies and Gentlemen,

I am much honoured by the request to offer a few words at the opening session of the Conference. The topic of this Conference is very timely: Safety of dams has received much attention throughout the world and much recent progress has been made in understanding and dealing with dam safety problems. For centuries, dams have provided mankind with essential benefits such as water supply, flood control, irrigation and hydro-electric power; they are an integral part of society's infrastructure. In the past few decades a number of major dam failures have increased public awareness of the potential hazards caused by dams. In today's risk conscious world dam failures are rated as one of the major low-probability-high-consequences events. As dams grow older they are quite often characterised by increased hazard potential, due to downstream development, increased risk due to structural deterioration or inadequate spillway capacity. Governments at all levels, as well as dam owners, have come to recognize and, in many cases, accept, responsibility in the area of dam safety. In many countries government agencies have been active in inventorying and inspecting dams in the interest of identifying the most hazardous structures, as well as identifying critical needs for repair and rehabilitation of existing structures.

The goal of preventive and remedial engineering is to reduce uncertainties, to minimize risk within economic constraints, recognizing that absolute safety remains always beyond reach. Many of the papers to be presented at this conference bear witness to the fact that the engineering community has made great strides in recent years in developing and implementing methods to quantify dam safety, including collecting and interpreting failures sta-

tistics, describing loads and resistances in probabilistic terms, evaluating risk-reduction effectiveness, offering remedial measures, improving safety-related instrumentation and developing better standards and criteria that will help engineers to make more optimal decisions concerning new or existing dams.

In conclusion, I would like to express my thanks to Professor Serafim for his splendid effort in organizing this Conference and also thank our Portuguese colleagues, especially those at the University of Coimbra, for the wonderful hospitality we have already experienced and look forward to enjoying during the remainder of this week.

Thank you.