TAILINGS DAMS GEOTECHNICAL ENGINEERING : A REPORT OF TECHNICAL COMMITTEE TC-7

GEOTECHNIQUE DES BARRAGES EN RESIDUS : COMPTE RENDU DU COMITE TECHNIQUE - 7

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SYNOPSIS

This paper presents a summary of some of the findings on recent developments and future concerns in the field of Geotechnical Engineering applied to Tailings Dams, obtained as results of the activities of Technical Committee TC-7 on Tailings Dams, in the period 1990-1993. The environmental impact of tailings dams is one of the subjects which needs stronger contributions from geotechnical engineers, in the inmediate future in order to assure rational consideration and effective interaction with other aspects of design. Design for abandonment conditions needs further research to predict behaviour for long-term effects and to confront the loadings of extreme events.

1. PURPOSE AND SCOPE

This Report presents the conclusions of the works performed by Technical Committee N° 7 of the International Society of Soil Mechanics and Foundation Engineering, between its formation in May 1990 to December 1993.

The activities have been guided by the terms of reference of the Committee, which were:

1. To promote co-operation and exchange of information on design, construction and performance of tailings dams.
2. To participate in the IX Panamerican Conference of the ISSMFE, 1991.
3. To prepare a survey report on recent developments and future concerns with respect to tailings dams for presentation at the XIII ICSMFE in New Delhi.

This Report is based on the contributions of the members of the Committee who have actively participated in the different tasks which were planned to fulfill the terms of reference. These contributions are to be discussed by all members of the Committee and the results of such discussions plus other valuable comments should constitute the Final Report.

Because the scheme of the New Delhi Conference does not include the organization of parallel Sessions with presentation of papers, such as Technical Committee on Tailings Dams would require, to gather Committee members with interested practicioners and researchers, for an open discussion of the numerous topics covered, such discussion should be programed for a suitable opportunity in the very near future, before issuing the Final Report.

2. ACTIVITIES OF THE COMMITTE

Technical Committee on Tailings Dams was formed during 1990 after the invitation of President Morgenstern to the Chilean Group of the ISSMFE, in order to host the Committee , was accepted and J.H. Troncoso was appointed as Chairman. Active members of the Committee became:

R. Fell (Australia)
L.G. De Mello (Brazil)
C.B. Abadjiev (Bulgaria)
W.D. Liam Finn (Canada)
R.C. Lo (Canada)
J.H. Troncoso (Chile)
Wang Yuqing (China)
Y. Yamada (Japan)
R.V. Orozco (Mexico)
J. Velarde (Perú)
V. Perlea (Romania)
P.L. Ivanov (Rusia)
G.E. Blight (South Africa)
E. Smith (USA)
S.G. Vick (USA)

Six main topics were selected for analyses to be covered by an equivalent number of task groups as follows:

Topic 1	:	"Methods of Tailings Disposal and Resulting Properties in Tailings Deposits" (Abadjiev, Fell, Orozco).
Topic 2	:	"Design of Tailings Dams for Static Conditions" (Blight, De Mello).
Topic 3	:	"Design of Tailings Dams for Earthquake Conditions" (Lo, Finn, Troncoso).
Topic 4	:	"Seepage from Tailings Storages and Through Tailings Dams" (Fell, Smith, Velarde).
Topic 5	:	"Impact of Tailings Dams Failures" (Vick, Yamada).
Topic 6	:	"Rehabilitation of Tailings Deposits" (Ivanov, Perlea, Troncoso, Wang Yuqing).

To promote co-operation and exchange of information on design, construction and performance of tailings dams a questionaire was prepared and sent to all members and related groups. Main purpose of this request was to prepare improved data bases of behavior of tailings deposits under seismic loadings and other extreme events and to develop relationships between characteristics of dams, constructions methods, site conditions and age versus successful or unsatisfactory behaviors. Responses were received from China, Chile and Japan. Resistances of owners of facilities to provide information or lack of sufficient data were reported from some countries, while others requested more time to complete the information.

Meetings of members were held in Sidney, Australia (1990), Viña del Mar, Chile (1991), St. Louis, USA (1993). Participation in the IX Panamerican Conference on Soil Mechanics and Foundation Engineering (Viña del Mar, 1991) was accomplished successfully. The Committee organized the main session devoted to "Geotechincal Aspects of Tailings Dams" where thirteen papers were submitted by authors from Australia, Brazil, Canada, Chile, India, Japan, Mexico and the U.S.A.

An important event of the Committee was the International Seminar on "Seismic Design, Abandonment and Rehabilitation of Tailings Dams", held in El Cobre, Chile, on August 28, 1991, under the sponsorship of the Chilean Geotechnical Society and Compañía Minera Disputada de Las Condes. Seventy engineers, from 15 countries attended this meeting. El Cobre was selected as location of the Seminar because of the following technical reasons:

a) This was the site of the well known seismic failures of two El Cobre tailings deposits ("Viejo and "Nuevo"), which occurred during a Magnitude 7.5 earthquake on March 28, 1965. The ruins of these deposits and the efforts to rehabilitate them were inspected by the participants.
b) Three abandoned deposits, which have been succesfully vegetated with different types of trees and bushes to prevent erosion, were also visited.
c) The modern tailings dam El Cobre N° 4 was visited. This dam was being built by the downstream method, and it had been subjected to a dynamic analysis just before occurrence of a Magnitude 7.8 earthquake on March 3, 1985. The deformations of the dam validated very well the assumptions and methods used in the analyses. Dam N° 4 is a one hundred meter high dam instrumented with modern electric piezometers, and it was the first tailings dam in the world equiped with a seismic recording system capable to register simultaneously the earthquake motions and the dynamically induced pore water pressures.

The Seminar itself included nine lectures, presented by N.R. Morgenstern, S.G. Vick, G. Castro, W.D. Carrier, R.C. Lo, I. Towhata, R. Fell, M. Cohen and J.H. Troncoso, who covered the main topics of the works of the Committee. These lectures were edited in an Special Volume of the Proceedings of the IX Panamerican Conference.

3. RECENT DEVELOPMENTS

3.1 Design of Tailings Dams for Static Conditions

Blight and De Mello (1993), representatives of South Africa and Brazil national groups, have made the main contribution to this topic. The following points are raised from the many important aspects of design:

a) Environmental concern: no tailings disposal system design should be embarked on without an environmental impact study. The principal environmental concerns should be identified from the preliminary stages and advance together with all other aspects of design, so that information from one aspect could be used as input to all the others.
b) Reclamation of disposal areas and consolidation of muds: the rate of consolidation of tailings and their ultimate density are critical parameters for evaluating the time required to achieve reclamation of the disposal areas. The implementation of large strain non-linear consolidation theory (Shiffman and Carrier, 1990) allows for more accurate and detailed predictions of the behavior of fine wastes.
c) Control of erosion: to reduce erosional damage to the slopes of a tailings dams the slope lengths should be broken by the introduction of berms; dam crests and the edges of berms should be graded away from the edge and water must then be drained by pipes or similar surface drains. Slopes should be vegetated as soon as possible. Lost materials should be catched at the toe of the dam.
d) Contractant or dilatant behaviour under shear: the pore pressure generation characteristics of the tailings when sheared must be realistically established in order to carry out the stability analyses (Poulos, 1988). If the deposited tailings are expected to be contractant the consolidated undrained shear strength should be used, including, when appropriate, pore water pressures estimated by large strain consolidation theory.
e) Design as an ongoing process: the design of a tailings dam is not a once-off process but must be subject to continuous examination and confirmation. Periodic reviews should allow to optimize design by confirmation of variables such as: beach angles, actual stage curves, water balance, properties of deposited tailings, position of phreatic surface, safety of outer slopes of the dam.

3.2 Design of Tailings Dams for Earthquake Conditions

Lo, Finn and Troncoso were responsible of this topic as representatives of Canada and Chile national groups. As the same groups were also assigned the task to prepare guidelines for seismic design for ICOLD, their contributions have been integrated and they shall serve as bases for discussions and preparation of final documents in both institutions. Some of the many interesting recent developments in this subject are:

a) Relationships between earthquake characteristics and performance of tailings dams: Introduction of parameters such as the Earthquake Severity Index (Bureau et al, 1985) and correlations with crest settlements and horizontal movements (Lo and Klohn, 1992) permit more acurate predictions of seismic behaviour of dams.
b) In-situ tests to measure properties of foundation and tailings soils in natural structural state, undisturbed, subjected to real states of stress are presently available for better measurements of most important parameters: seismic cone penetration for low strain wave velocities (Finn et al 1989), penetration resistance at large energies (Yoshida et al, 1988; Sy and Campanella, 1992), cross-hole impact tests for high strain shear wave velocities (Troncoso et al, 1977).
c) Instruments to monitor the behavior of deposits, such as electric piezometers, multiple level settlement probes, inclinometers, have been greatly improved in recent years (Dunnicliff, 1988). Seismic instrumentation systems for simultaneous recordings of earthquake motions and induced pore pressures have been installed in tailings dams (Troncoso et al, 1990). These systems shall become useful tools to verify predictions of pore water pressures, and liquefaction potentials in tailings deposits.
d) Dynamic stability analyses permit to predict seismic deformations and residual displacements on the basis of staged approaches: steady-state strength analysis and finite-difference or finite-element dynamic methods combined with Newmark type of deformation analyses (Finn et al, 1990).

4. FUTURE CONCERNS

Tailings Dams Geotechnical Engineering is a discipline strongly connected to some of the newer and faster growing sciences such as soil dynamics and environmental engineering. Since design of more economic, safer and less pollutant deposits of tailings is a very important subject for the mining industry, research in this field should be strongly supported.

Some of the topics which require urgent attention are also very important for more general disciplines in geotechnical engineering, therefore the results of research shall be very positive for new developments in fields such as rheology, seismic strength, pollution, erosion, evaluation of risks of natural disasters and mitigation of effects.

A brief description of future concerns is summarized as follows:

a) Methodologies of Design for Abandonment of Tailings Dams need to be improved. This need arises from the fact that the period of time to be considered is indefinite since the deposit is decomissioned. Furthermore, it is not always possible to establish who is going to take care of the abandoned facilities after a mining operation closes. Therefore, maximum credible events in the cathegories of earthquakes, floods, avalanches, have to be considered. Such extreme events impose very large loadings and lead to lowest safety evaluations and to most pessimistic predictions of failures and consequences, in the present state of the art.

On the other hand, evolutions of the structures related to long terms effects of aging, consolidation, dessication and physico-chemical processes, which change the shear strength and the compressibility of tailings soils in the deposits, are not sufficiently known for practical use. Therefore, research efforts should be devoted in the next future to a better understanding of the evolution of soil properties with age, including physico-chemical changes and the effects of external events such as seismic loadings along the years.

b) Geotechnical Instrumentation for Abandonment Conditions needs improvements both in relation with the useful life of sensors and the recording procedures. The ambient conditions for sensors are generally more aggresive in tailings dams than in other soil deposits due to the chemical composition and the fine grain size of the tailings. Recording procedures with remote stations are very expensive but they could be improved using modern techniques to transmit the data from the dam to central stations. Monitoring of the evolution of the characteristics of the deposits is an important task which deserves attention to improve knowledge about long-term stability of soil structures.

c) Environmental impacts of tailings deposits have many aspects which need further research. The quality of water of natural streams are in some cases worse than effluent waters from tailings dams. Research is needed to classify the real effects of pollution in the environment, such as use of waters in irrigation and reclamation of the deposits for agricultural purposes.

The erosion and transportation of solid tailings by eolic and by liquid means require important research efforts starting with the development of tools to quantify the magnitude of the problems. May be the worst environmental aspects of tailings dams are first, the mere installation of the deposits in places where valuable lands are covered and left out of the use for production or recreational activities, and, second, the probability of catastrophic failures which depreciate the endangered adjacent areas.

Therefore, interdisciplinary investigations are necessary to study best ways to reclaim the lands, using for productive or recreational purposes the plateaus created by the tailings deposits.

d) Consequences of Flow Failures have to be evaluated for endangered areas located downstream. Vick (1991), Jeyapalan et al (1983) and Fread (1984) models are good to start with the analyses; however, better ways to represent the obstacles which cause dissipation of energy along the course of the flood have to be included, for better predictions of the height of wave and velocity of the flow. Such investigations should also include development of alarm system to alert the population and to evacuate the settlements which may be located inside the endagered areas, should a flow failure become enminent.

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This Report is only a brief sumary of the many contributions presented by individual members of the Technical Committee N° 7 as well as by interested specialists from National Groups. The author thanks all of them for their time and attention to the activities of the Committee. The Final Report shall include in detail the results of these collective efforts.

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