Condition assessment of Government-owned dams in Finland

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SYNOPSIS. Some 480 dams in Finland are covered by dam safety legislation and of these, some 50 dams are government-owned. In spite of shortcomings and a few incidents there has been no complete dam failure in Finland affecting water storage dams that have a significant damage potential in case of failure. To unify the safety level of government-owned dams and to prioritise future maintenance work, the environment administration has decided to carry out condition assessments of dams that have a significant damage potential in case of failure.

INTRODUCTION

Finnish state-owned dams have been built over the last 40 years, and their history is still recent. Sufficient accurate data from different tests is available for many assessment aspects. The data consists of : soil investigations from the planning period, quality control tests from the period of construction, monitoring frost depth, phreatic surface level and seepage flow rate during the period of operation.

Nonetheless, some of the abovementioned data is inadequate or incomplete. Consequently, new testing, monitoring and supervision are necessary in order to obtain proper data for the condition assessment process.

DAM SAFETY IN FINLAND

In Finland, dams have been built mainly for flood control, hydroelectric power production, water supply, aquaculture and for storing waste that is detrimental to the health or to the environment. Most of Finland's dams were built after World War II. Regular monitoring of dam safety by the state-owned power companies began in 1962 and that of state-owned dams (the environment administration) in 1972.

The Act and Decree on Dam Safety were enacted in 1984 to improve the safety of all dams, waste dams included. In 1985, a Dam Safety Code of

Long-term benefits and performance of dams. Thomas Telford, London, 2004

Practice was issued to apply the statutory regulations as a practical guideline. This improved the maintenance situation considerably, due to the fact that a basic inspection had to be carried out and a safety monitoring programme created for each dam subject to the Dam Safety Act. The third revised Dam Safety Code of Practice was issued in 1997.

Some 480 of Finland's dams are covered by the legislation. Of these 85% are water storage dams and 15% waste dams. The experts calculate that in the event of an accident, 37 of the dams would endanger human life or health or cause considerable damage to the environment or property (so-called P dams). Most of the dams are embankment dams, and a few are concrete gravity dams. Concrete structures have been used for water regulating structures. Some dams are provided with an overflow structure for high flood situations.

Finland differs markedly from many other countries in topography, soil and climate. Finland is a rather flat country characterised by glacial formations. Typical features of the climate are the long, cold winters, the freezing of the soil and the spring thaw. The ground is seismically tranquil, and there are no earthquakes on a scale to threaten dams.

The emphasis of Finnish dam safety is on the prevention of dam accidents and on the effective reduction of hazards should it not be possible to prevent an accident. Careful design, construction and monitoring of dams and their appropriate maintenance play a key role in preventing dam damage. Long-term changes in conditions and the ageing of structures can be taken into account with regular safety monitoring. Rare exceptional physical conditions, human error or other causes (e.g. internal erosion) may, nonetheless, still lead to dam failure. The objective of the Finnish dam safety system is to restrict any damage that might be caused by dam failure and to prevent loss of human life in the event of an accident. To achieve this we must maintain our dams to a very high standard, have a regular monitoring and emergency action plans designed for P dams to activate the warning function, evacuation and rescuing of the downstream population.

REPAIR WORK ON STATE-OWNED EARTH DAMS

There are some 50 dams owned by the environment administration covered by the dam safety legislation. Eleven of these dams are class P dams (Fig. 1). The basic inspections and further inspections incorporated in the safety monitoring programmes revealed several shortcomings e.g. the following:

- the flood discharge capacity of some dams has been inadequate
- seepage problems

- wet areas and springs behind some dams
- inadequate freeboard against frost in some dam crests
- trees on the dam contrary to the code of practice
- drainage system does not work
- bedrock of some dams needed grouting
- facing of wet slopes needed repair work.

In spite of shortcomings and a few incidents there has been no complete dam failure in Finland affecting water storage dams that have a significant damage potential in case of failure. To unify the safety level of state-owned dams and to prioritise future maintenance work, the environment administration has decided to carry out the condition assessments of its P dams.

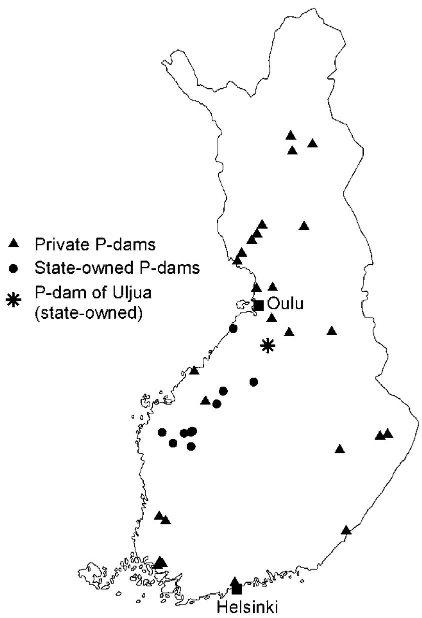

Figure 1: Location of P dams in Finland.

PRINCIPLES OF CONDITION ASSESSMENT

<u>Assessment data</u>

Finnish state-owned dams have been built over the last 40 years, and their history is still recent. Sufficient accurate data from different tests is available for many assessment aspects. This data consists of e.g.:

- soil investigations from the planning period

- quality control tests from the period of construction
- monitoring frost depth, phreatic surface level and seepage flow rate during operation.

Nonetheless, some of the abovementioned data is inadequate or incomplete. Consequently, new testing, monitoring and supervision are necessary in order to receive proper data for the condition assessment process.

An example of proper soil investigation data is presented in Fig. 2. Similar data on dam core permeability and density is available. Nevertheless, these accurate permeability test results do not contain anisotropy data from the core and subsoil. In order to assess the threat of piping, non-homogeneity as well as anisotropy should be taken into consideration.

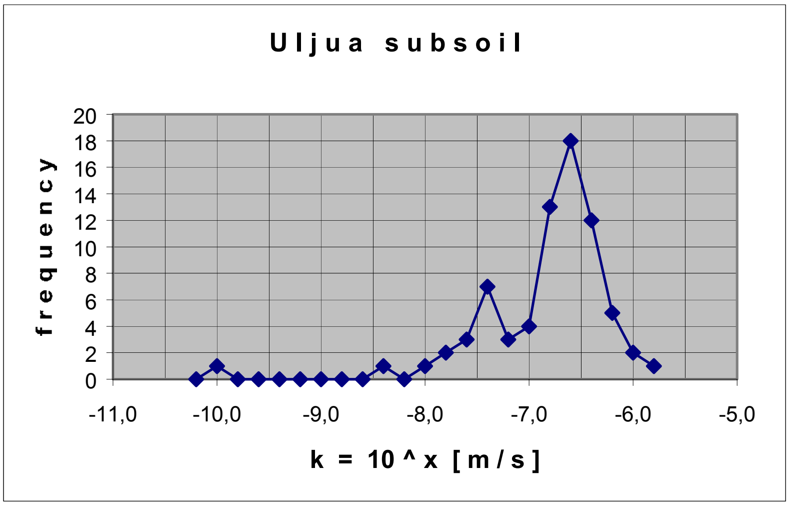

Figure 2: Coefficient of water permeability determined from Uljua subsoil moraine.

As an example, the main cross sections of Uljua dams are presented in Fig. 3. Such designs are typical for many Finnish state-owned dams. The wide core moraine dam construction seems to carry a shortcoming in the shape of poor filtering and drainage on the dry side of the dam. The technical failing of the rock fill dam construction seems to be a core that is too narrow and shallow with a weighted creep ratio that is too low. Both factors lead to an increased risk of piping either through the dam or the subsoil.

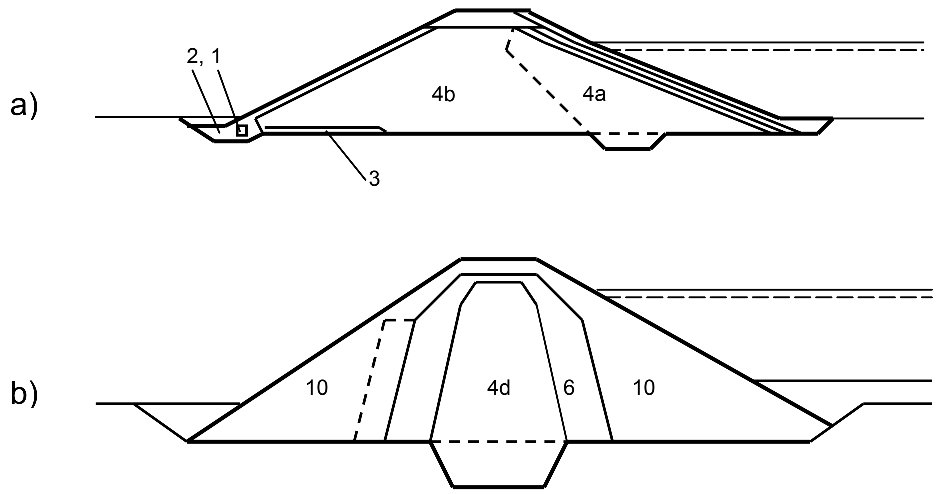

Figure 3: Uljua dams, typical cross sections. a) Arkkusaari 'homogeneous' or wide core moraine dam: 1 = 'stone drain', 2 = sand drainage layer, 3 = bottom drainage layer and filter, 4a and 4b = moraine cores. b) Tulisaari rock fill dam: 4d = moraine core, 6 = filter, 10 = supporting rock fill.

The data we use consists of technical data on one hand, and dam history on the other hand, especially failures. The knowledge of dam history is essential, because the dam itself is a full-scale test. Consequently, a lot of interest is focused on dam behaviour from the period of construction and first reservoir filling until the present. Typical dam incidents include:

- excessive seepage or possibly piping during the first reservoir filling, one in Uljua rock fill dam in the year 1970
- erosion of upstream rock fill blanket during operation
- piping in Uljua rock fill dam in the year 1990 during operation
- inadequate discharge of the drainage system, possibly due to thinness of the bottom filter and clogging of the subsurface drains.

<u>Assessment methods</u>

In order to be able to assess risks, a methodology had to be developed as well as technical criteria. It seems impossible to calculate actual probabilities, and yet the hazard and risk level of different phenomena have to be assessed and compared. Some tools applied or developed for these purposes are:

- application of the Fuller curve to determine the grain size distribution curve of the active portion of soil
- modification of the Foster and Fell filter criteria for practical activity; the principle is presented in Fig. 4

- utilisation of the principle of fuzzy logic; the principle is presented in Fig. 5; in fact Fig. 4 includes the concept of fuzzy logic as well.

Certain tools are considered necessary, because an individual engineering judgment alone may lead to inappropriate deviation in the assessment process. Besides, knowledge of the hazard and risk level is essential when drawing up the repair works schedule.

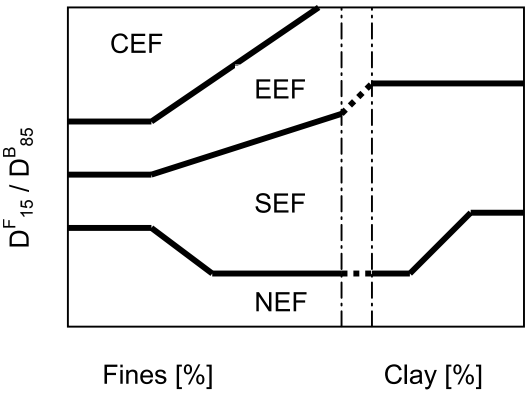

Figure 4: Principle of applied filter criteria chart. NEF = no erosion filter, SEF = some erosion filter, EEF = excessive erosion filter and CEF = continuous erosion filter. All percentages and grain sizes are calculated from corrected grain size distribution curves. D^F_{15} and D^B_{85} represent filter and base material grain size diameters, through which 15 and 85 % respectively, of the material will pass.

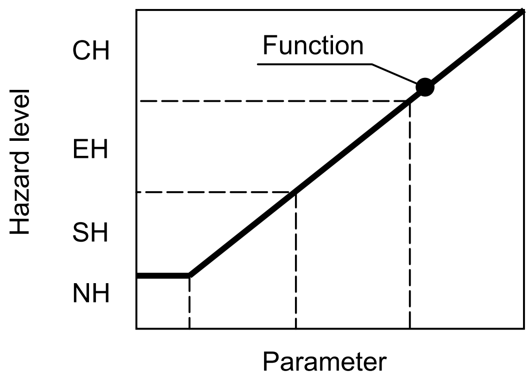

Figure 5: Principle of applied fuzzy logic, based loosely on the terminology used in Fig. 4. NH = negligible hazard, SH = some hazard, EH = excessive hazard, CH = catastrophic hazard.

The aspects to be assessed were classified into four main categories:
a) external erosion, including erosion induced by ice forces
b) internal erosion and subsurface drainage, including particularly:

- internal stability, self filtering and segregation of each layer
- filter criteria on the layer interfaces
- seepage in the dam moraine core, filters and subsoil
- frost action
- flow in pipelines, including clogging by ferruginous precipitation
- adjoining structures

c) slope and subsoil stability
d) additional aspects, including particularly:

- background ditch drainage
- vegetation effect
- supervision and monitoring
- maintenance
- emergency action facilities.

Based on preliminary results, internal erosion and subsurface drainage and additional aspects have major roles in the assessment process, while external erosion is merely a matter of engineering. Stability seems to be of minor interest.

Despite the fact that most aspects occur worldwide, there are certain special phenomena featured in Finnish dams. Apparently these phenomena are typical to a larger area, but they are reported rather seldom in literature. These phenomena are:

- frost action, especially formation of ice lenses, which lead to soil loosening and increasing piping threat
- ferruginous precipitation, apparently suspended hydrated iron oxide precipitation, which clogs the subsurface drainage system.

The result of the condition assessment process will be a document for each dam including presentation of:

- history
- current conditions
- hazard and risk classification
- recommendation for repair action.

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