DAM CONSTRUCTION IN SALT FORMATIONS

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ABSTRACT

Dam Construction is a key task for the safety of the Gorleben repository. In order to seal a filled disposal field from the part in operation and to minimize radionuclide migration during the post-operating time a dam is to be developed and tested under certain accident conditions i.e., mainly the intrusion of brines and natural gas from either side of the dam. The development of this dam is subject of an extensive engineering project. This report summarizes the goals, problems, concepts, and first results of these systematical project studies. By analysing and characterizing special design criteria under site-specific aspects the major development priorities are investigated. First results will be presented concerning concrete based materials and their property changes due to the corrosive behavior of brines at elevated temperatures. Based on these investigations, pilot dams will be built and tested to prove their efficiency.

INTRODUCTION AND OBJECTIVES

The Federal Republic of Germany's program goal for the disposal of heat producing radioactive waste (HLW) is the construction of a repository in the salt dome of Gorleben. First of all an exploratory mine will be developed using two shafts as shown in Fig. 1. After sinking the shafts to a depth of 840 m an exploration level will be driven about 30 m above the actual disposal level. This disposal level of the mine will be developed after the suitability of the salt dome for disposal of radioactive waste has been proved.

Starting from these exploration drifts the salt dome will be explored by horizontal and inclined holes of long distance (about 1 mile as a maximum) reaching to the so called water warning line of the salt dome. The inner area, where the radioactive waste is to be disposed later on, will be bypassed by exploration drifts. Emplacement will be performed by starting from the border of the mine, whereby the operating sequence is directed toward the shafts. By this procedure the repository is completely developed before the first radioactive waste will be disposed of and comprehensive knowledge concerning any potentially existing source of danger in the salt dome will be available.

But taking thermal stresses due to HLW into account, failure of the natural barrier during the operating time of the mine cannot fully be ruled out.

Although inflow of brines into accessible mine openings is very improbable, a dam will be built in order to seal the flooded part of the mine in case this event occurs. While one part of the openings can be kept operational, the one beyond the dam has to be abandoned.

Inflow of brines into already filled and abandoned areas of the repository during the operating phase is also very unlikely. Though, if this occurs, these areas are not available for any direct observation or control and effective counter measures will be impossible. Therefore, dams which close the backfilled and abandoned openings at least prevent an uncontrolled flow-off of brines into the operating parts of the mine.

During exploratory drilling from the surface small amounts of hydrocarbon condensate were met in the inner part of the dome which become gaseous after relieving the pressure.

Thus the possibility of an inflow of natural gas and hydrocarbon condensate respectively into abandoned or still operating parts of the mine may not be totally ruled out, considering the influence of thermal stresses caused by HLW. While hydrocarbons leaking into the operating part of the repository may be run off by the ventilation they might build up pressure in the backfilled openings closed by the dams.

Obviously, dams are important parts of the safety concept for the Gorleben repository

- that compensates for possible defects of the natural barrier and

- allows for remedial action.

During the operating time of the repository the engineering barrier system will consist of the following components:

- Backfilling of remaining void volumes of the disposal rooms

- plugging and sealing of boreholes filled with HLW

- Closing the room-entries by a defined flow-restraining seal, eventually enriched with radionuclide getters

- backfilling of all drifts in the mine

- sealing of disposal areas by pressure-resistant dams.

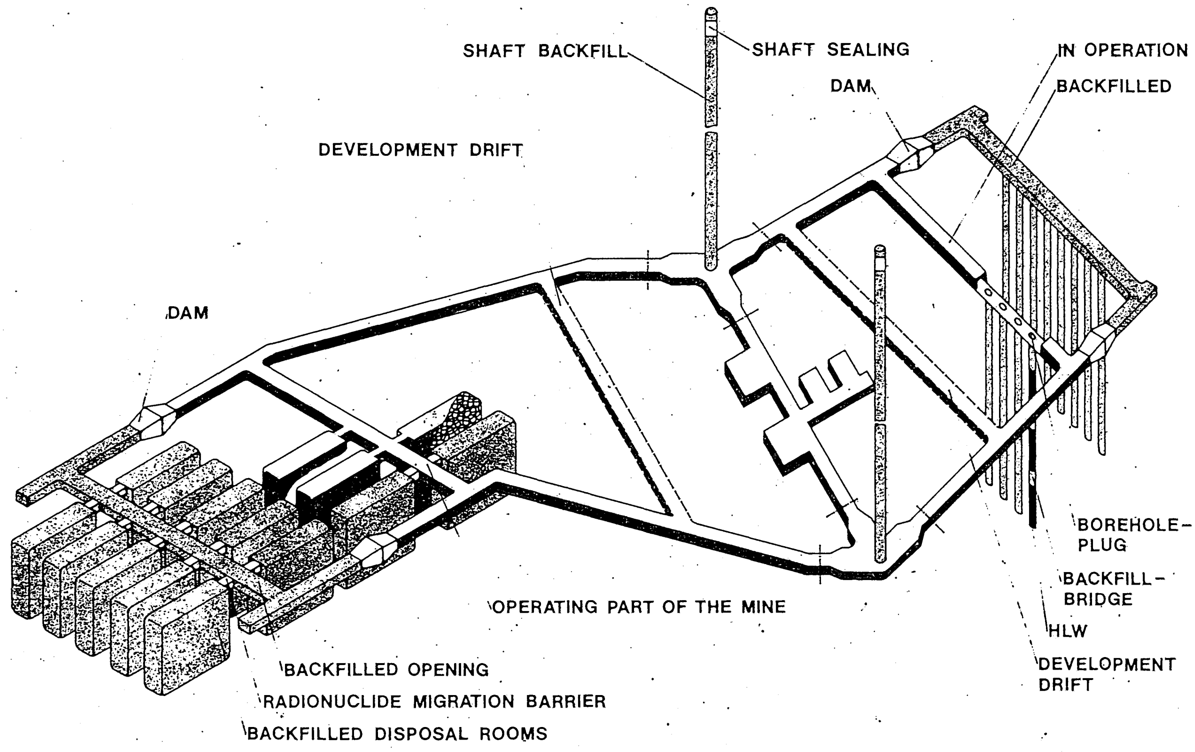

Fig. 1. Engineered Barrier System of the Repository in the Salt Dome of Gorleben.

These measures increase the operating reliability as well as the long-term safety of the repository by creating conditions that are to exclude the possibility of undue radionuclide concentrations in the biosphere.

These dams offer the chance to segment the repository in different compartments and thus segmenting the radionuclide inventory.

In the case of a defect of the natural barrier it is quite likely that only the radionuclide inventory of one compartment will be released with the ensuing reduced consequences for the biosphere.

According to the present state of knowledge concerning the inflow of brine into the repository, long-term safety calculations show that the following radionuclide concentrations would reach the surface after being pressed out of the repository by convergency (see Table I):

TABLE I

Radiation Exposure at the Surface after an assumed Defect of the Natural Barrier.

radio-nuclide	radiation exposure (rem/a)
C 14	2.1 E-2
Tc 99	2.9 E-2
I 129	6.4 E-3
Np 237	3.5 E-2

Segmenting the radionuclide inventory in, for instance, 5 segments would reduce the consequences for the biosphere by approximately a factor of 5.

As a consequence the dams have to comply with the following requirements:

- In case of inflow of brines or hydrocarbons the dam should be able to withstand a depth - dependent hydrostatic pressure - of about 11 MPa.
- Therefore, the dam is to be designed so as to prevent leakage on the air-side during the operating phase. Gaseous hydrocarbons should not exceed a concentration of 0.1 % in the ventilation of the operating part of the mine.
- After a least 25 years (after construction) the penetrability for liquids should be less than 0.5 l/min.
- Materials for dam construction have to be fairly resistant against the highly corrosive Gorlebenspecific brines.
- Materials for dam construction have to be thermally stable to endure temperatures of about 70° C during the first 25 years.
- The dam has to be designed to withstand the load from either side.

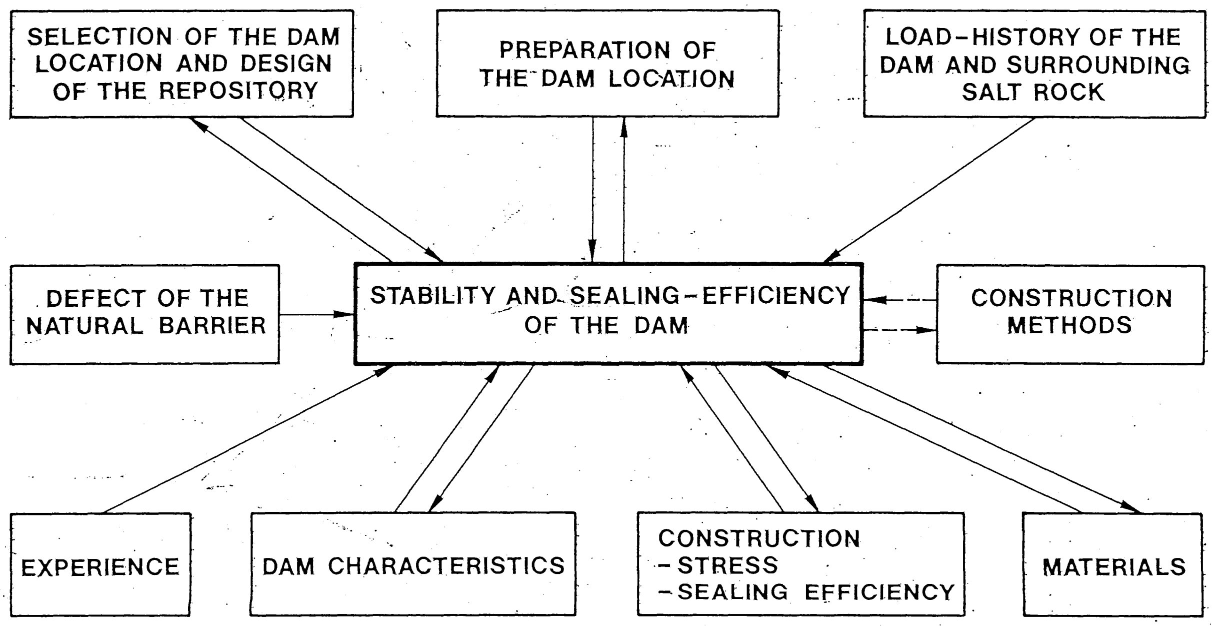

Fig. 2. Dam Construction - a Complex Interacting System.

CONCEPTION FOR THE ENGINEERING PROJECT

General Experiences and Consequences

The construction of dams as an engineered barrier against danger of brine inflow appears to be an old problem in salt mining. There were some successful constructions and also many failures in the past - but neither systematic investigations nor analysis of the failure causes were performed up to about 10 years ago. First comprehensive concepts for dam construction in salt formations showing systematic approaches to solutions were presented by SITZ and FÖRSTER (2) and by the German potash and rock salt industries in the middle of the 1970's (3).

The problem of successful dam construction in salt formations is only soluble if the complex interaction of the following components is understood (see Fig. 2):

- Experience in dam construction projects,
- analysis of the consequences of a defect natural barrier,
- thermomechanical behavior of the surrounding rock salt,
- materials for dam construction,
- dam characteristics, i.e., shape, dimensions, etc.,
- construction methods.

This system has to be optimized.

Finite-Element Calculations

Calculations concerning the thermomechanical behavior of the surrounding rock salt formations, shape design and stress aspects of the dam as well as interaction between dam and salt formation will be performed by the numerical Finite-Element-Method. The ANSALT FEM-program was designed especially for calculations of thermomechanical processes in HLW disposal in salt formations by the BGR (Bundesanstalt für Geowissenschaften und Rohstoffe (German Geological Office)).

The selection of suitable types of dams results from quantification of the following criteria:

- Transfer of stress into the salt formation, avoiding tensile stress to rule out the risk of failure of the rock salt and dam abutment (considering a hydrostatic pressure of about 11 MPa).
- Resulting deformations of the surrounding visco-elastic rock salt.
- Possible design variations to reduce undue stress in the dam and salt formation.
- Possibility for the combination of different materials, p. ex. polymeres for improved hydraulic and mechanical bonds between dam and salt formation.
- Possibility to achieve effective sealing to meet the requirements mentioned above.
- Economical construction.

In principal the following dam shapes are the most promising to suit the criteria (see Fig.3):

- Friction dams,
- prism-shaped dams,
- multiple joggled dams,
- multiple truncated-cone shaped dams.

The calculations to be carried *out will* mainly take into consideration the following aspects:

- Gorleben site-specific requirements, i.e., hydrostatic pressure, thermomechanical behavior of the rock salt formation, and temperature rise caused by the radioactive waste,
- shape and dimensions of the dam for a tensional as well as form closed transfer of load to the salt formation,
- interactions between dam and salt formation by variation of some important mechanical properties of the materials intending to decide whether "soft" or "hard" material meets the stress requirements best,
- load history (under consideration of time-dependancy: convergency, pressure of brine, and temperature).

Materials for Dam Construction

The laboratory tests of materials for dam construction under site-specific aspects started with several cements that were tested after being stored in a saturated NaCl-solution and a Gorleben-specific brine, respectively. After 28 days temperatures were raised to 70° C. The following physical properties were measured as functions of time (up to 360 days):

- compressive strength
- corrosion resistance
- volume constancy
- temperature stability
- setting behavior.

The results of these cement investigations are demonstrated for the compressive strength in Fig. 4-9 being representative for the comparison of the cements. The graphs show the influence of water as well as saturated NaCl-solution added as mixing water and saturated NaCl-solution as well as Gorleben-specific brine as storing media.

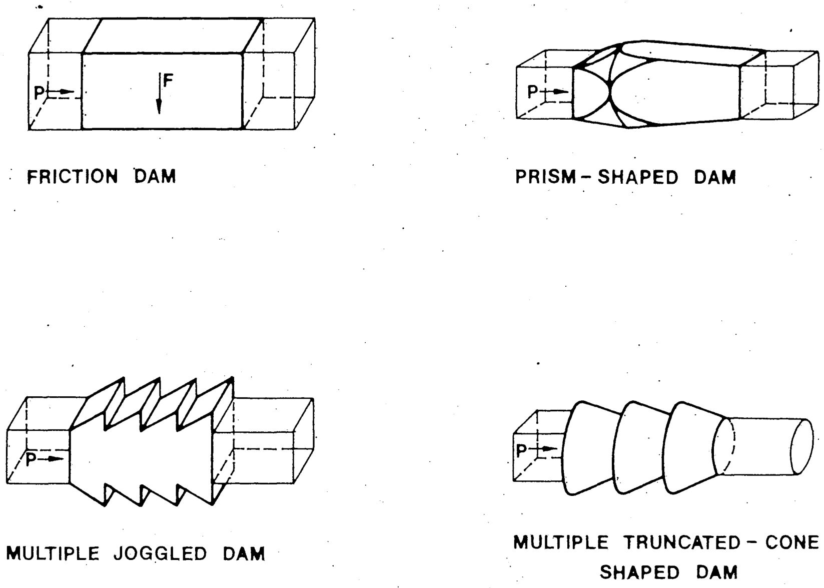

Fig. 3. Dam Types for the Construction in Salt Formations.

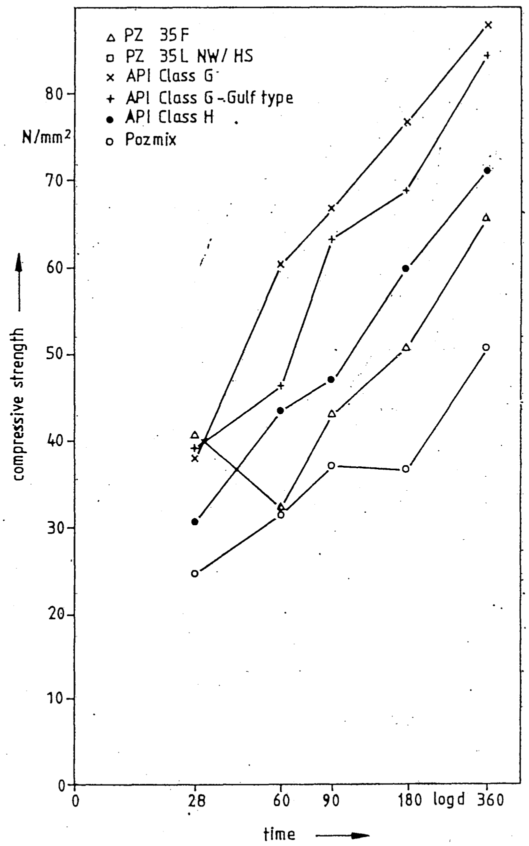

Fig. 4. Influence of Storage in NaCl-Solution at 70° C on the Compressive Strength of Cements (Mixing Water: H_2O).

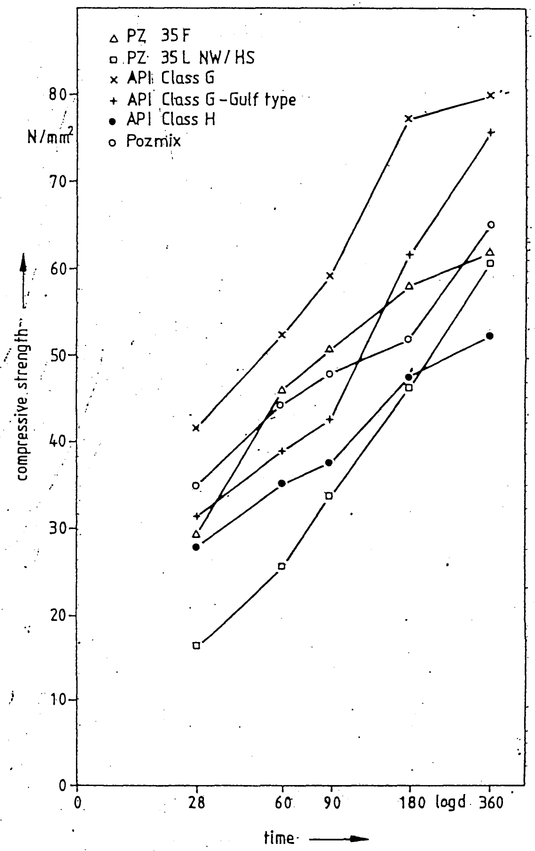

Fig. 5. Influence of Storage in NaCl-Solution at 70° C on the Compressive Strength of Cements (Mixing Water: NaCl-Solution).

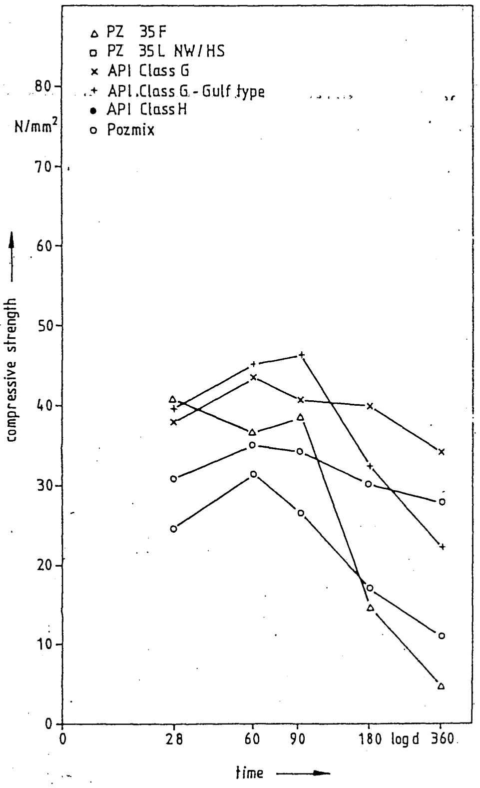

Fig. 6. Influence of Storage in Gorleben-specific brine at 70° C on the Compressive Strength of Cements (Mixing Water: H_2O).

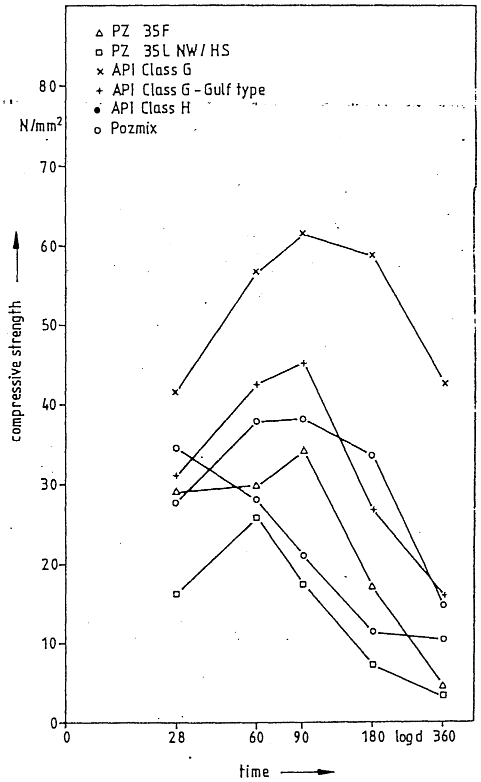

Fig. 7. Influence of Storage in Gorleben-specific brine at 70° C on the Compressive Strength of Cements (Mixing Water: NaCl-Solution).

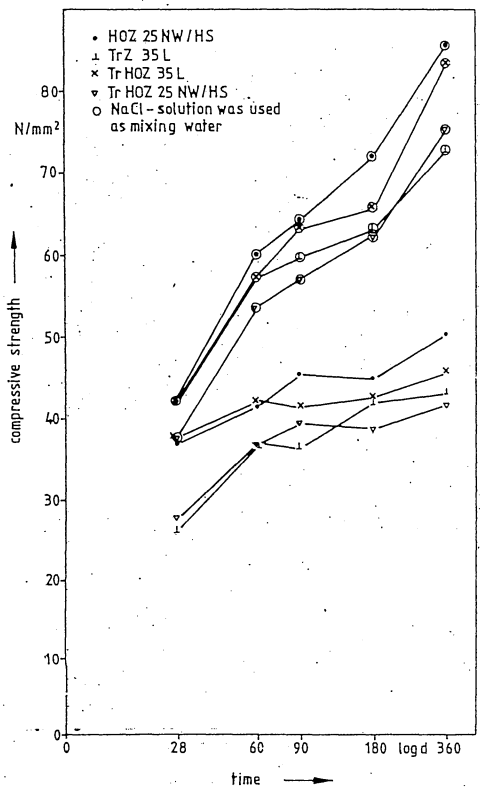

Fig. 8. Influence of Storage in NaCl-Solution at 70° C on the Compressive Strength of Cements.

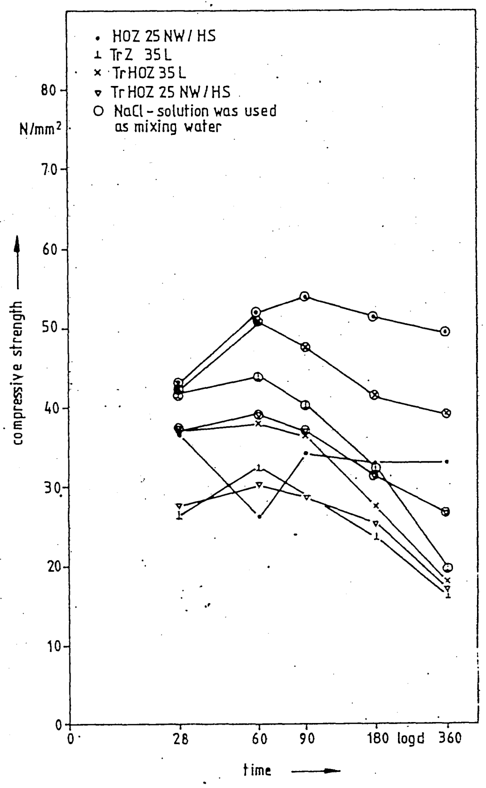

Fig. 9. Influence of Storage in Gorleben-specific Brine at 70° C on the Compressive Strength of Cements.

Based upon these results the following cements were selected as most promising for further tests with hard rock (Gabbro) or crushed salt as aggregates for concrete.

HOZ 25 NW/HS (blast furnace cement)
TrZ 35 L (trass cement)
API Class G
API Class G, Gulf type.

For all concrete saturated NaCl-Solution is used as mixing water. If these types of concrete turn out to suit the requirements, their setting behavior will be investigated in situ. Boreholes will be filled with defined concrete plugs where the mechanical and hydraulic bond between concrete and salt formation can be tested.

For special applications such as improved mechanical bonding or as sealing material, the addition of polymeres as well as pure polymeres might prove successful, even though not much experience exists concerning these materials under specific conditions.

CONCLUSION

Up till now, available experience was collected and analyzed:

- a possible risk assessment was performed,
- criteria and requirements for the dam construction were established,
- the construction of dams in salt formations by application of numerical calculation methods was proved,
- suitable cements were tested and selected,
- investigations on different types of concrete were started,
- from the large variety of possible dam shapes four types were selected for further detailed investigations.

Comprehensive, final results of the entire engineering project "Dam Construction in Salt Formations" will be available in about one year. Based on these investigations pilot dams will be probably be built and tested to prove their efficiency.

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