Longterm Behaviour of a Dam in a Period of 108 Years

Comportement d'une Digue durant une Periode de 108 Ans

A. WACKERNAGEL Gruner SA, Basel/Switzerland

SYNOPSIS A dam constructed 108 years ago for the water supply of the city of Basle and having ever served its purpose is investigated with respect to safety. The construction materials are lake deposits. At the time of construction the safety of the dam is believed to have been close to unity. As creep has occurred during the life time the present safety factor is estimated to be near 1.14. It may be concluded that in the course of time the safety will increase. Regular checking of the deformation by measurements is, however, advisable.

CONSTRUCTION OF THE DAM AND OPERATION

The public water supply for the city of Basle, Switzerland, was started in the year 1866 and consisted of a number of springs in the hills of the Jura range, which were conducted to the city by a pipe line. To safeguard an even water supply of the springs, a reservoir of some 100'000 m^3 was constructed in the year 1871. From there the springs are fed by infiltration.

The reservoir is formed by an earth dam having a height of 9.0 m. The upstream slope has an inclination of 1:3 and the downstream slope an inclination near 1:2.4. The length of the crest is 75 m. On the left abutment an open channel spillway having a capacity of 8.0 m^3/sec is provided. The intake is formed by two steel pipes Ø 500 mm through the base of the dam (Fig. 1).

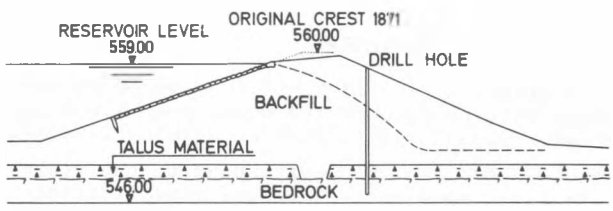

FIG.1 CROSS SECTION OF DAM 1978

About the construction of the dam no detailed records are available. The drawings would indicate an impervious core and pervious outer sections. This could, however, not be verified. The cross section is more or less homogeneous. The backfill was started early in the year 1871 by a contractor. It was planned to be completed by the end of June 1871. However, in June 1871, following heavy rains, a flood occurred and breached the nearly completed dam. After this incident, construction was resumed and the dam was completed in November 1871. The filling of the reservoir was accomplished in steps in March 1872 and was checked weekly by experts. When the reservoir was full it was found to be "completely impervious".

The dam has been serving its purpose ever since completion. Today it is, however, only of minor importance for the city water supply. The dam is said to have been overtopped repeatedly by rainstorms. The last time it was overtopped in summer 1975 by some 0.20 m without heavy damage, the total discharge of the flood being some 15.0 m^3/sec.

INVESTIGATION OF CONSTRUCTION MATERIALS

In the year 1977 the federal authorities asked for a check whether the dam did satisfy the regulations with respect to freeboard, crest width and spillway capacity. The freeboard was to be 1.50 m above maximum storage level, the crest width at least 3.0 m, the spillway capacity to be increased to 30.0 m^3/sec.

To get information regarding the safety of the dam itself, an investigation was carried out in the year 1979. Two drill holes were executed on the downstream slope. Against expectation of coarse-grained materials in the outer dam sections the drill holes disclosed that the dam consisted of a material which could be identified as a lake deposit probably borrowed from a drained lake downstram of the dam site. It can be classified as a silty clay with low to high plasticity (CH,CL). Small lenses of peat, remnants of plants, wood and shells are interspersed. The material is saturated and of soft to very soft consistency. The dam is resting on a layer of talus material containing debris of limestone with some clay binder having a thickness of 1.3 m to 1.6 m. This layer can be classified as a silty to clayey gravel (GM,GC). Below the bed-

rock is met which is a dense lime stone in nearly horizontal layers with steep fissures filled with clay.

It may be assumed, as shown on the design drawings, that an impervious cutoff trench reaches through the talus to the surface of the bedrock. While drilling a waterlevel was met at a depth of 2.75 m to 3.80 m. This water level subsided to a stable level further down when the drill holes entered the talus materials.

The characteristics of 6 samples taken from the backfill material are the following:

Water content w:

27.5% - 50.0%, mean 35.7%

Liquid limit w_l:

40.8% - 57.2%, mean 49.8%

Plastic limit w_p:

23.0% - 31.6%, mean 25.4%

Consistency Index I_c:

0.28 - 0.64, mean 0.52

Dry density γ_d:

1.11 - 1.51t/m³, mean 1.32t/m³

Colloidal fraction < 0.002 mm:

10.4 - 34.5%, mean 22.8%

The grain size distribution of the backfill materials and the talus materials are shown in Fig. 2.

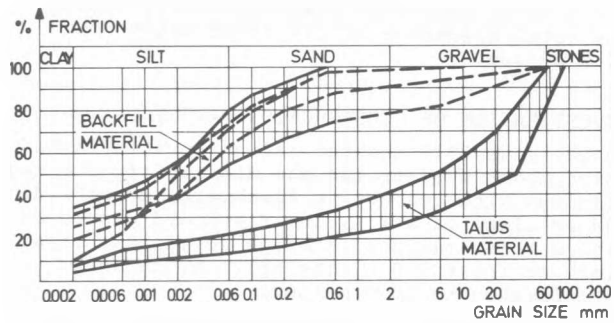

FIG.2 GRAIN SIZE DISTRIBUTION OF MATERIALS

The shear strength characteristics of four samples were determined by direct shear test and are the following.

Peak effective shear strength

$c' = 0.0 - 2.0 t/m^2$, $\varphi' = 21.3° - 28.0°$,
mean $c' = 0.95 t/m^2$, $\varphi' = 25.5°$

Residual effective shear strength

$c'_r = 0.0 - 1.4 t/m^2$, $\varphi'_r = 15.1° - 23.7°$,
mean $c'_r = 0.70 t/m^2$, $\varphi'_r = 20.2°$

SETTLEMENT OBSERVATIONS AND SETTLEMENT CHARACTERISTICS

During the life of the dam considerable settlements occurred. The magnitude of the settlements can be deduced from available records. Originally, the dam was constructed having a freeboard of 1.0 m. By the year 1918 the crest had settled 600 mm at the maximum section and was then heightened to the original level. By the year 1978 the crest had settled by another 450 mm, thus the average settlement within recent times being 7.5mm/year. It is, however, a retarded movement.

The total settlement of the dam since construction is amounting to 1050 mm which is 12% of the height of the dam (Fig. 3).

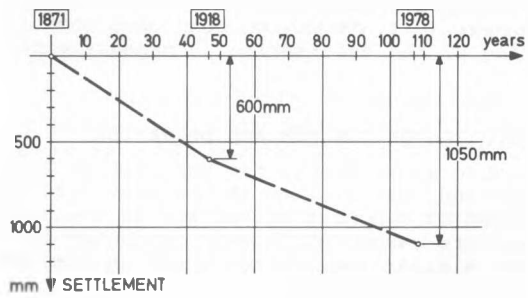

FIG.3 SETTLEMENT OF DAM CREST

The settlement to be expected from results of oedometer tests are not more than 470 mm. From this it may be concluded that the observed settlements of the dam crest are partly due to creep. From the results of oedometer tests it appears further that the present degree of consolidation of the dam is between 60% and 80%. Therefore, settlements will continue.

STABILITY OF EMBANKMENT

If a safety factor of F = 1.0 is supposed the stability analysis of the downstream slope indicates for $\varphi' = 0$ a cohesion of $c' = 2.1 t/m^2$.

This case $\varphi' = 0$ would correspond to the state just after construction before consolidation had started. The cohesion of $c' = 2.1 t/m^2$ would indicate very soft consistency of the construction materials used.

In order to determine the actual stability of the dam it is to be considered that in addition to consolidation the creep is being observed. Therefore as plastic displacements have occured the residual shear characteristics are to be used. By applying the mean values $c'_r = 0.7 t/m^2$ and $\varphi' = 20.2°$ and considering the pore water pressures due to consolidation and seepage the present factor of safety is estimated to be equal to F = 1.14. If allowance is made for the fluctuation of the characteristics the safety factor is still close to unity.

CONCLUSIONS

The behaviour and the safety of a dam after a life-time of 108 years has been checked by classical methods of soil mechanics.

Settlement of the crest is more than to be expected from consolidation theory. Therefore, plastic displacement is to be supposed. It is, however, a retarded movement. For judging the stability the residual shear strength is to be applied. It appears that some slight cohesion is acting besides the friction. When the dam was constructed the safety factor war close to unity. Although consolidation has occurred the present safety factor may be considered to be only slightly above unity.

The dam has served its purpose ever since construction. As the movements are retarded, the safety of the dam will increase as time goes on. The behaviour will have to be checked by regular surveys.

REFERENCES

Skempton A.W. "Long Term Stability of Clay Slopes". Geotechnique 14, 1964.

Skempton A.W., Hutchinson J. "Stability of natural Slopes and Embankment Foundations". State-of-the Art Report. Proceedings 7th International Conference on Soil Mechanics, Mexico 1969.

Hauber L., Wackernagel A. "Baugrund und Fundationsprobleme in der Region Basel", Schweizerische Bauzeitung, Heft 36, September 1977.

Morgenstern N., Blight G.E., Janbu N., Resendiz D., "Slopes and Excavations". State-of-the Art Report. Proceedings 9th International Conference on Soil Mechanics, Tokyo 1977.