Test Fills with Coarse Shell Materials for Göschenenalp Dam

Remblais d'Essai pour la Barrage de Göschenenalp

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Summary

In the autumn of 1955 large-scale field tests were carried out at the site of the future Göschenenalp Dam (Switzerland) in order to determine the most suitable placement method and the characteristics of the shell material. The tests have been carried out by the contractors under the supervision of Elektro-Watt, Electrical and Industrial Management Co., Ltd., Zürich, and the Laboratory for Hydraulics Research and Soil Mechanics at the Swiss Federal Institute of Technology, Zürich.

The maximum grain size was limited to approximately 1·0 ml. Altogether about 30,000 m³ of material was dumped in 9 test fills. The lift thickness, depending on the dumping height, varied from 1·5 to 5·0 m. Placement was moist, wet, sluiced and/or vibrated.

The tests show that even without artificial compaction it is possible to obtain very high dry densities averaging 2·25 t/m³ (with a specific gravity of 2·72) if all segregation is avoided at dumping. No noticeable increase of the dry density could be observed by sluicing or compacting with a big 15 ton vibrator. The average coefficient of permeability, determined by means of percolation tests, varied between 5×10^{-3} and 5×10^{-4} cm/sec.

Sommaire

En automne 1955, sur l'emplacement même du barrage en terre de Göschenenalp, des essais à grande échelle furent entrepris pour déterminer les méthodes de construction les plus appropriées et les caractéristiques mécaniques du matériau de la zone perméable.

Le matériau employé était un mélange de gros blocs et de gravier sableux (diamètre maximum: 1 m). 30.000 m³ de ce matériau furent répartis sur 9 champs d'essais. L'épaisseur des couches, fonction de la hauteur totale du remblai variait entre 1·50 et 5·0 m. 65 m³ de matériau furent extraits des remblais pour déterminer respectivement 15 poids volumétriques et 4 granulométries.

On obtient une densité seche de 2·25 t/m³ (pour un poids spécifique de 2·72 t/m³) même sans moyens artificiels de compactage si, lors de la mise des remblais, on effectue un mélange intime des matériaux. L'emploi d'un compacteur à plaque vibrante de 15 t n'augmente pas la densité seche d'une manière appréciable.

Introduction

Plans for the Göschenen hydro-power scheme (Switzerland) (Eggenberger, 1953) call for construction of a gravel-fill dam at Göschenenalp of 155 m maximum height, 540 m crest length and 8·3 million m³ embankment volume. Construction on the dam started in 1955 and its final design was carried out in the winter of 1955–56. Large-scale field tests were undertaken from 5 September to 24 November 1955 on the actual construction site in order to determine the properties of the shell material. These investigations and complementary laboratory shear tests (Zeller and Wullimann, 1957) permitted the evaluation of the strength characteristics required for the stability analyses.

Description of Material

The borrow pit for the proposed shell material is located at nearby rubble slopes. These comprise only slightly weathered recent deposits of granitic origin. Within the borrow pit the grain size distribution varies relatively little but extends from fine sand to blocks of up to several m³. All the material is angular to partly subangular. Fresh fills show an initial angle of repose of about 50 degrees, which in time and due to precipitation, snow melt, etc., flattens to about 40 degrees. The natural moisture content at depth is about 3 to 4 per cent as related to the complete grain size range.

Test Programme

The main features of the test programme are:

(a) All tests were performed on a 1:1 scale, i.e. material, equipment and procedures were exactly as they were envisaged for construction of the dam proper.

(b) The maximum rock size was limited to one m³.

(c) In order to evaluate the most appropriate placement method the following alternatives were studied:

- Placement in lifts of 1·5, 2·0, 3·0, 4·0, and 5·0 m
- Placement at natural moisture content.
- Placement with prior wetting of material.
- Sluicing.
- Compaction by hauling equipment during placement operations.
- Compaction by large size vibrators.

(d) The properties of the material determined were:

- Density.
- Moisture content.
- Permeability.
- Grain size distribution.

Tests Performed

Preparation of test site—Location and arrangement of the test fills is shown in Fig. 1. The fills had to be adapted to the sloping terrain, and for this reason the terraced arrangement shown in Fig. 2 proved the most suitable solution. Furthermore all the fills were laid out within the limits of the future dam so as to be incorporated into the final structure upon completion of the tests. In view of the 30,000 m³ placed this procedure afforded considerable saving compared with a test site away from the dam.

In determining the sizes for the various fills not only lift thickness and maximum rock size had to be considered but also the accuracy of measurement required for density determinations. Laboratory tests had already shown that for the material in question slight variations of porosity led to considerable changes in shear strength. The maximum allowable error in density determinations was therefore restricted to

Table 1
Principal data and characteristics of test fills
Données et caractéristiques principales des remblais expérimentaux

Test fill No.	*Fill dimensions* (m)	*Height of lift* (m)	*Placement*	*Compaction*	*Remarks*
1	17 × 17	2·0	Dumped moist	Hauling equipment and type M vibrator	
2	17 × 17	2·0	Dumped wet	Hauling equipment and type M vibrator	
2a	17 × 17	1·5	Dumped wet	Hauling equipment and type M vibrator	
3	19 × 19	3·0	Dumped wet	Hauling equipment and type M vibrator	
4	17 × 17	4·0	Dumped wet	Hauling equipment and type M vibrator	
5	19 × 19	5·0	Dumped wet	—	This fill not built
6	19 × 19	3·0	Sluiced	None	
7	17 × 17	4·0	Sluiced	None	
8	19 × 19	5·0	Sluiced	None	
9	17 × 17	twice 2·0	Dumped wet	Hauling equipment and type G vibrator	
10	19 × 19	twice 2·5	Dumped wet	Hauling equipment and type G vibrator	
11	17 × 17	twice 4·0	Sluiced	—	This fill not built

± 1 per cent. This also led to a minimum size of the density samples of 200 m³.

After excavation to grade, the surfaces of the terraces for the test fills were compacted by Euclid trucks loaded to 40 ton. Furthermore precise levellings of the completed terraces were taken.

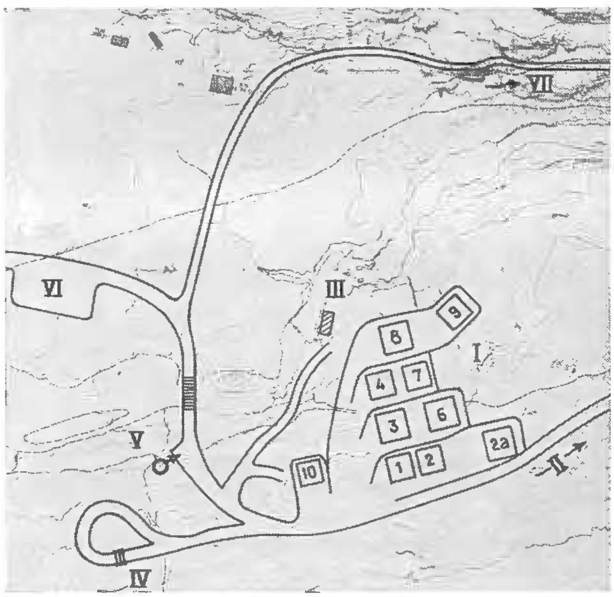

Fig. 1 Plan of test site

I Test fills; II To borrow pit; III Pumping plant; IV Weighbridge; V Wetting; VI Sieving; VII To field laboratory

Plan de situation des essais à grande échelle

I Remblais d'essai; II Vers la zone d'emprunt; III Station de pompage; IV Bascule; V Addition d'eau; VI Station de criblage; VII Vers le laboratoire de chantier

Placement and compaction of test fills—Principal data and characteristics of the various test fills are given in Table 1. Attention is called to the following observations:

Fill No. 1: Fig. 5 shows clearly how the material segregated upon dumping. The coarse rocks rolled down the slope, whereas the fines remained on top. Due to placing operations the surface of the fill also became so compact and silted up that rain water collected on it without draining off for days.

Fill No. 2: Prior to dumping, about 1 m³ of water was added to the material on the truck. Though at dumping much water flowed out ahead of the material, the latter slid from the truck as a compact mass and with little segregation. This was especially true when the truck drove up very close to the edge of the fill. The surface of the fill also remained rough and pervious. The observations made on fills No. 1 and 2 led to the discarding of dry dumping as unsuitable (Fig. 6).

Fills No. 3 and 4: With a 3 m lift no difference was observed as compared to the 2 m lift. On the other hand segregation increased at 4 m due to the longer rolling distance of the material down the slope.

Fill No. 5: As the result of the observations at fills Nos. 3 and 4 this fill was omitted.

Fill No. 2a: On the other hand a supplementary to fill No. 2 was built to check on the behaviour of the material when lift thickness and maximum rock size attain the same order of magnitude.

Fills Nos. 6, 7, and 8: For technical reasons as well as due to lack of time a sufficient pump capacity could not be obtained and the effect of sluicing therefore was not investigated

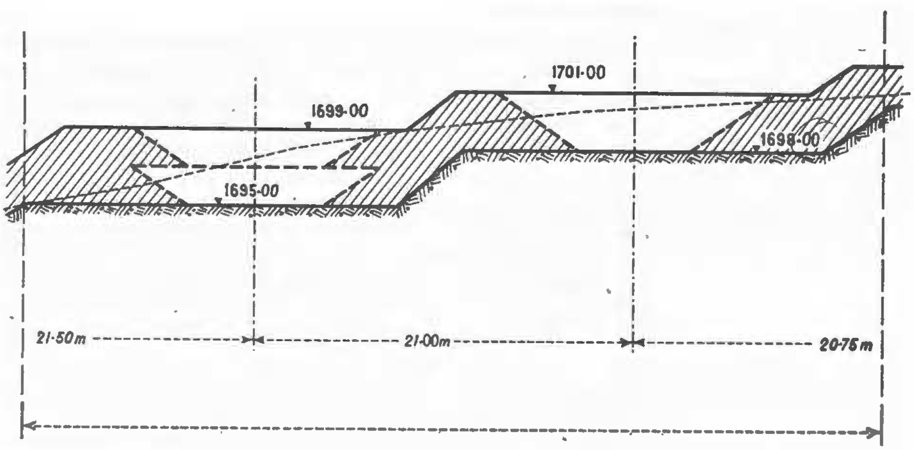

Fig. 2 Section through test fill with pits for density determination

Coupe d'un remblai d'essai avec le cône caractéristique pour la détermination du poids volumétrique properly. At dumping, about 0·3 m^3 of water was added to 1 m^3 of material: in order to obtain any compactive effect at least ten times as much water would have been necessary.

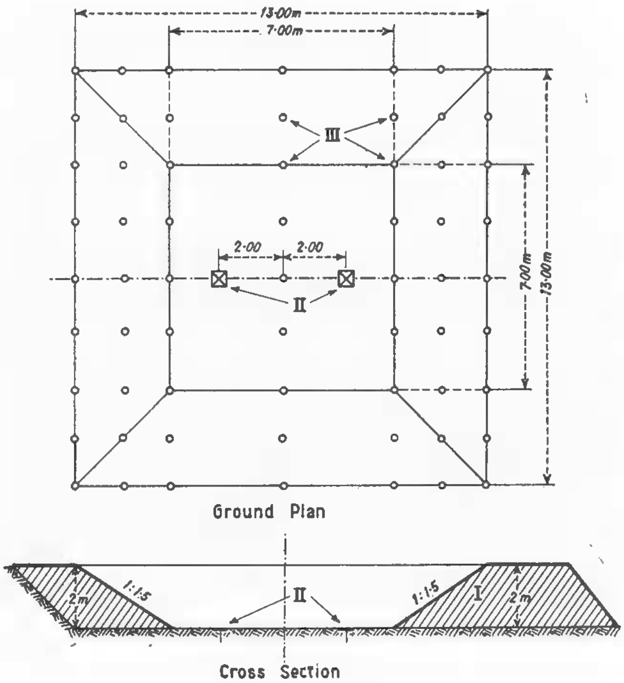

Fig. 3 Plan and section of test pit for density determination
I Fill; II Plates for settlement measurements; III Measuring points

Plan et coupe d'un cône pour la détermination du poids volumétrique
I Remblai; II Plaques pour la détermination des tassements; III Points de mesures

Fig. 4 General view of test fills. Foreground: sluicing operation. Middle ground: excavation of test pit for density determination

Vue d'ensemble sur les champs d'essais, au premier plan, installation pour un mélange optimum du matériau. Au milieu de la photo: extraction d'un cône de matériau pour la détermination du poids volumétrique

Finally, sluicing time was extended to a total of 5 minutes, so that 2·7 m^3 of water at a pressure of 4 to 5 atmospheres was used per m^3 of material.

Fill No. 9: To investigate the reciprocal influence of successive lifts on each other. Fill No. 9 was intended to be dumped in three 2 m lifts. Due to severe frost action only two lifts could be completed.

Fill No. 10: Each lift was compacted with a large 15 ton vibrator, 'Keller' Type G. The points of application of the vibrator were spaced at about 4 m centres.

Fig. 5 Marked segregation with 4·0 m lift

Forte dissociation causée par la mise en remblai de 4 m de hauteur

Fill No. 11: was not built, as the advent of winter weather stopped all construction activity. The fill was intended to comprise several sluiced lifts for study of the influence of aggregation within lower lifts by washed-through fines. Omission

Fig. 6 Test fill No. 2: dumping of wet material right on the edge of fill to reduce rolling distance (2·0 m lift)

Champ d'essai No. 2: Déversement du matériau humide directement sur la pente en évitant un trop grand chemin de roulement (hauteur du remblai 2·0 m)

of these tests, however, was of little importance as the sluicing equipment had proved insufficient.

Testing Procedures

Determination of density—At each fill test pits were excavated and the volume and weight of material excavated determined. Additional tests for permeability and in part also grain size distribution were performed. Figs. 2 and 3 show the shape of test pit excavations.

Densities due to compaction by hauling equipment only were computed from settlement measurements and final densities after vibration.

Excavation of the test pits was by backhoe shovel, which loaded the material into dumpers. The weight of material excavated was determined on these by axle weighing. The slopes of the pits were graded manually and their volumes determined by surveys.

Moisture contents were determined in the field laboratory on the fractions 0 to 100 mm (40 to 50 per cent of total) and in part 100 to 400 mm.

Table 2 gives the dimensions of the test pits at the various fills:

Table 2

Determination of density, dimension of pit

Determination de la densité, dimensions du trou

Fill No.	*Side length of pit* (m)	*Volume of pit* (m^3)	*Remarks*
1	13·0	203·55	Fills No. 4, 7 and 9 excavation of pits in two layers of 2 m each
2	13·0	221·21	
2a	13·0	206·07	
3	15·0	305·21	Fill No. 8, excavation of pit in two layers, the upper of 2 and the lower of 3 m
4	13·0	411·61	
5	—	—	
6	15·0	307·51	
7	13·0	371·27	Fill No. 10, excavation of pit in two layers of 2·5 m each
8	13·0/15·0	524·15	
9	13·0	401·05	
10	15·0	360·13	
11	—	—	

Determination of permeability—Since exploration of the borrow pits had led to the expectation of a considerable amount of fines also in the shell material, determination of permeability at the test fills became very important. To this end percolation tests were performed in ten small ponds of 0·5 m depth and 1 m^2 base area excavated at the various fills.

Determination of grain size distribution—In order to evaluate the actual grain size distribution complete sieve analyses from 0 to 1000 mm were performed. Accordingly the volume of each sample was 20 to 30 m^3. Specially resistant square mesh sieves were built for analysis of the fractions 100 to 200 mm, 200 to 400 mm and larger than 400 mm. A power shovel with gripping attachment was used for analysis of fractions from 100 to 1000 mm. Weighting was with the same scale as for density determinations. The fraction below 100 mm was analysed in the field laboratory.

Test Results

The test data presented in Table 3 for the Göschenenalp-material allow the following conclusions to be drawn:

Segregation—Dumping of moist material in 2 m lifts led to considerable segregation, with lifts over 3 m segregation became complete.

This effect was appreciably reduced by wetting the material on the trucks. Nevertheless it was absolutely necessary for the trucks to dump right on the edge of the fill so as to reduce the rolling distance of the material down the slope as much as possible.

Density—Densities attained were very high. With a specific gravity of 2·72 and a mean porosity of 17 to 18 per cent the dry density averaged 2·25 ton/m^3.

These high densities were already attained at dumping. No material increase of density could be obtained with the then available compaction equipment and an economically reasonable effort. In such coarse materials as these, sluicing affords an advantage only if used with very high pressures and accordingly large quantities of water.

No influence of the upper lifts on the densities in the lower ones was observed. Consolidation of the lifts is therefore to be expected only after application of much larger forces (strong interlocking of blocks).

Permeability—The permeabilities determined varied from 10^{-5} to 10^{-2} cm/sec. The shell of the dam will therefore comprise parts of very high and others of low permeability. Unfortunately the water supply was insufficient and no tests over an extended period of time could be performed in the areas of high permeability. Such tests would have shown whether the existing voids are just isolated pockets or if they form a communicating system. This detail would be of considerable interest in evaluating the behaviour of the dam in case of a sudden drawdown.

Grain size distribution—Four grain size analyses were performed. Their results are also given in Table 3. The samples were taken from wet dumped as well as from sluiced test fills. As the borrow pit extended over the entire slope

Table 3

Dry densities, permeabilities and grain size distributions (specific gravity of material 2·72)

Densité à sec, permeabilité et granulometrie (poids specific du matériel 2·72)

					Placement moisture		*Dry densities*					*Grain size distribution*			
Test fill No.	*Sequence of construction*	*Height of lift* m	*Segregation*	*Sample taken*	*Fraction 0–100 mm* %	*Total material (estimated)* %	*Dumped** t/m^3	*Compaction by hauling equipment* t/m^3	*Vibrated* t/m^3	*Vibrator type*†	*Permeability* 10^{-3} cm/sec	1 mm %	1–10 mm %	10–100 mm %	100–1000 mm %
1	1	2·0	Moderate to average	Entire lift height	7·03	3·3	2·21	2·21*	2·26	M	11–3				
2	2	2·0	Slight	Entire lift height	5·02	2·4	2·28	2·28*	2·28	M	5000–0·01				
2a	5	1·5	None	Entire lift height	5·02	2·4	2·37	2·37*	2·45	M		14	17	15	54
3	3	3·0	Moderate to average	Entire lift height	5·47	2·6	2·18	2·18*	2·22	M					
4	4	4·0	Average	Upper 2·0 m	7·18	3·4	2·47	2·47*	2·48	M	500‡				
				Lower 2·0 m	7·90	3·7	2·12	2·12*	2·13		500‡				
6	6	3·0	Moderate to average	Entire lift height	7·07	3·4	2·19	2·19	—			12	13	17	*ca.* 58
7	7	4·0	Average	Upper 2·0 m	7·07	3·4	2·22	2·22	—		74–100‡				
				Lower 2·0 m	5·75	2·7	2·01	2·01	—						
8	9	5·0	Considerable	Upper 2·0 m	6·79	3·2	2·26	2·26	—			12	14	36	38
				Lower 3·0 m	5·85	2·7	1·99	1·99	—			8	12	15	65
9	12	twice 2·0	Slight	Upper 2·0 m	7·65	3·5	2·26	2·26	—						
	11			Lower 2·0 m	6·73	3·1	2·26	2·26	—						
10	10	twice 2·5	Moderate	Upper 2·5 m	8·04	3·8	—	—	2·29	G	45–0·14				
	8			Lower 2·5 m	6·02	2·8	—	—	2·26	G					

* Values computed from measured settlements and final densities after vibration † M = Mammut Vibrator, 14 ton; G = Gigant Vibrator, 15 ton
‡ Large voids

width the grain size distribution varied within the fills. The fraction below 0·5 mm was about one-third smaller in the sluiced fills No. 6 and 8 than in the wet dumped fill No. 2a. This means that some fines were washed out and probably deposited in the lower parts of the fills.

At the sluiced 5 m high fill No. 8 the grain size distribution was determined in its upper as well as lower part. However, the effect of segregation heavily outweighed the effect of sluicing and washing-through in that the fines still prevailed on top and the coarse rocks at the bottom. This phenomenon was reflected also in the densities determined.

Conclusions in View of Göschenenalp Dam Construction

Due to the close co-operation of the contractors, contracting officers and soil testing staff progress on the test programme described was highly satisfactory. Among others the following specifications for placement operations have been worked out: (1) the maximum size of rocks shall not exceed 1 m^3—otherwise large variations in density and consequently in shear strength may result; (2) lift thickness shall be 2 m and not more than 3 m, in order to prevent segregation; (3) the material shall be dumped wet and right on the edge of the fill so as to limit its rolling distance down the slope; (4) no artificial compaction or sluicing is to be envisaged since the small improvement of densities possible does not justify the additional effort and expenditures.

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References

EGGENBERGER, W. (1953). The Goeschenenalp rock-fill dam project, Switzerland. *Proc. 3rd International Conference on Soil Mechanics and Foundation Engineering*, Vol. 3, p. 296

ZELLER, J. and WULLIMANN, R. (1957). Shear strength of the materials for the supporting shell of the Goeschenenalp dam, Switzerland. *Proc. 4th International Conference on Soil Mechanics and Foundation Engineering*, Vol. 2, p. 399