Stability of Slopes in Earth Dams and Foundation Excavations

Stabilité des talus dans les barrages en terre et dans l'excavation des fondations

by Dr. K. L. Rao, M. Sc., Ph. D., M.I.C.E., M. I. Struct. E., M.I.E., Member (design and research) Central water and Power Commission, New Delhi

Summary

India is engaged on the construction of a large number of reservoirs to conserve water in its rivers which otherwise drains to sea wastefully in from four to six months. Earth dams are mainly employed for impounding reservoirs. There are earth dams in India built several centuries ago and still functioning. A study of the effect of time on slopes in ancient earth dams has been done by the author in order to bring out particular features that may be usefully incorporated in modern designs.

Examples of slope failures in two recently constructed earth dams are discussed. It is observed that if the outer part is made of freely draining gravelly soil and if the foundations are good, time has no effect on slopes. If the soil used on the outside is clayey, flattening and a tendency to slide in course of time are to be expected.

In excavation of foundations, soil slopes need be maintained only for a year or two. The slopes in excavations may be kept steep provided proper dewatering arrangements are made. Examples of excavations of foundations in Badua, Kotah and Sharavathy Projects now under construction are given by the author.

Sommaire

Pour conserver les eaux, qui autrement s'écouleraient inutilement vers la mer en 4 à 6 mois, l'Inde est engagée dans la construction d'un grand nombre de retenues dans lesquelles les barrages en terre sont en majorité. Il y a en Inde des barrages en terre construits depuis plusieurs siècles et qui fonctionnent encore.

Une étude de l'influence du temps sur les talus des anciens barrages est faite dans cette communication dans le but de faire ressortir des faits saillants dont on peut tenir compte dans les projets modernes.

L'auteur discute la rupture de talus dans deux barrages en terre récents. Il fait observer que si les revêtements extérieurs sont réalisés en sol graveleux à drainage libre, et si les fondations sont bonnes, le temps n'a pas d'action sur les talus. Si le sol utilisé à l'extérieur est argileux, il faut s'attendre à la longue à un applatissement et à une tendance au glissement.

Dans l'excavation des fondations, on ne doit maintenir les talus que pendant un an ou deux. Les talus peuvent être assez raides si on prend la précaution de rabattre la nappe. A l'appui, l'auteur donne l'exemple de l'excavation des fondations des barrages de Badua, Kotah et Sharavathy qui sont en construction

1. Introduction

As most of the rivers in South India carry water for only four to six months of the year, construction of earth dams to conserve water was resorted to in India from very early times. Many of these structures are still in service after several centuries.

Since 1947, there has been great activity of dam construction in India. Nearly 136 dams of more than fifty feet height have been undertaken. Of these, 81 per cent involve earth embankments either in the main portion or in the flanks.

A scientific study of the behaviour of slopes of ancient earth dams gives useful information with regard to the effect of time on stability of slopes. In the excavation of foundations of some of the masonry and earth dams, where time is not an important factor, it has been possible to use steep slopes by adopting stabilisation. These aspects have been discussed by the author.

2. Effect of time on slopes

Cross sections of some ancient earth dams still in service are shown in Figs. 1 and 2. These dams are located in South India. Pakhal Lake, Ramappa Lake and Lakhnawaram Lake embankments were constructed in the time of the kings of the Kakatiya dynasty in 1213 A.D. The reservoirs formed by these embankments have storage capacities of 3 400 m cft., 5 400 m cft. and 2 100 m cft. respectively and serve to irrigate thousands of acres. It is stated that in the 17th century when the Kakatiya kings failed to pay tribute and money to the then Delhi Emperor, Pakhal lake bank was breached by the enemy troops. This was subsequently restored and has been supplying coveted water for irrigation since.

The soils used in these embankments and the type of sections originally adopted are not known. General history indicates that the sections adopted were homogeneous built up of local materials. In practically all cases, the outer slopes and perhaps the entire structures are made up of gravelly soils generally red in colour. Arrangements have been made to obtain analyses of the soils used in these banks.

In Central India there are some very ancient tanks built over eight hundred years ago in the districts of Tikamgarh and Chhatarpur. Some of these tanks have top widths varying from 100 to 300 feet. The side slopes are very flat varying from 3:1 to 4:1 and even flatter.

The existing slopes of old embankments in South India are given in Table 1. The slopes to which these dams were originally built are not available, but the fact that existing slopes themselves are not flat indicates, that there has not been much change in them. A general study shows that in South India where earth dams were built up of gravelly soils, the slopes were originally steep being only 1·5:1 for heights of 30 to 40 feet. In the later period the slopes were made more than 2:1. Generally the top widths were very wide and downstreams slopes were flatter than upstream slopes.

In Central India where clayey soils appear to hove been used in the construction of embankments the slopes adopted were 4:1 and greater.

Fig. 3 shows sections of some recent earth dams built on modern concepts. The sections adopted are zonal. The top widths are small and the slopes generally vary from 2:1 to 4:1.

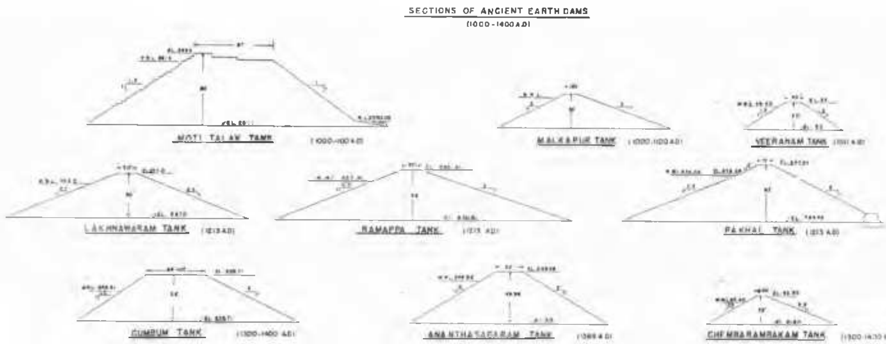


Fig. 1

A study of ancient structures is important as it will give very useful information on the behaviour of such structures with the passage of time and bring out particular features that may be usefully incorporated in the modern designs. The slopes of earth dams built in gravelly soil on the outside have not materially altered and remained quite stable through centuries. Earth dams under construction will be quite safe so long as the outer slopes are built up of pervious or semi pervious soils containing a predominant proportion of sand and pebble fractions. It appears that the stability and shear strength have increased with the passage of time where gravelly materials have been used on the outer slopes. Alternatively if the casing materials were clayey, there would have been reduction of shear strength due to their susceptibility to leaching out action, shrinkage and swelling due to alternate drying and wetting. Similarly the time may cause slow weathering of foundation material.

3. Failure of slopes

There have been slope failures in some of the earth dams built in the present century and two examples are discussed below.

The willingdon reservoir embankment, constructed in 1924, is an example of a structure which has been continuously giving trouble on account of slope failures. The section of the dam is shown in Fig. No. 4. The maximum height is 55 feet and the original upstream slope was 2 :1 and rear slope 3:1, the reservoir capacity being 2 600 m cft.

The reservoir was filled eight feet below top reservoir level immediately after completion and when the water in the reservoir began to fall, a slip in a length of 460 feet occurred. The movement was gradual till water level in the reservoir dropped by six feet but quicker when the reservoir was drained further.

The embankment was repaired to the original cross section; but this did not give satisfactory results. Later, piles were driven at the toe of the rebuilt revetment. Another slide occurred in 1935 in continuation of the earlier slip. The piles driven earlier were all pushed out.

In July, 1936, a length of about 110 feet was repaired by making the front slope 2:1 from top to M.W.L. and 3:1 from M.W.L. downward protected with rough stone masonry stone panels 10 feet. square with 1:6 cement mortar. Revetment was made to rest on a masonry toe wall 3 ft. square of rough stones in cement mortar in sections of 10 ft. length. The remaining length was repaired by providing a berm 10 feet wide and the revetment built to the original slope of 2:1 up to the top, all depressions being filled only with stones.

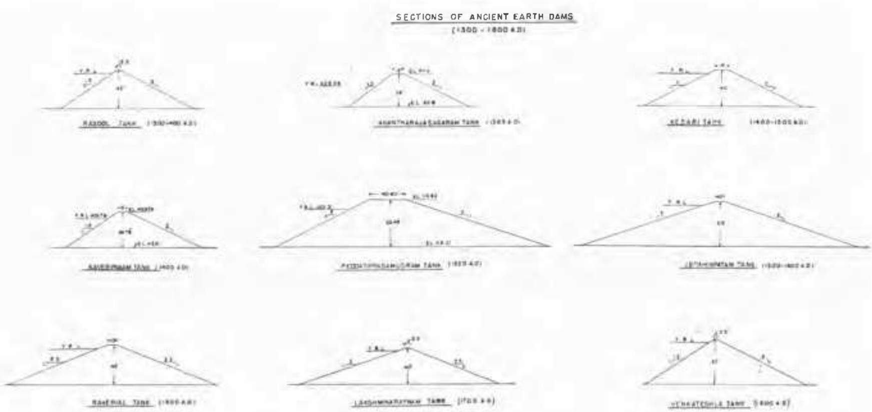
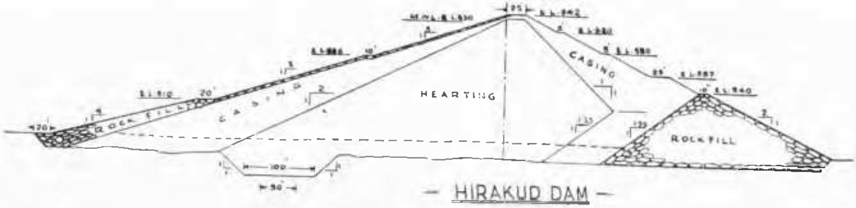
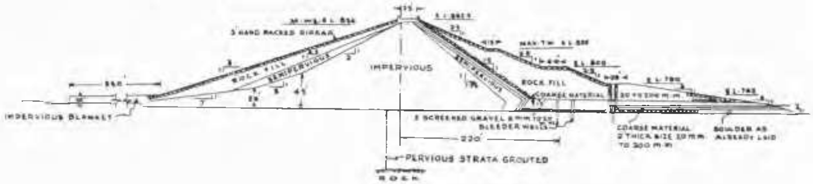


Fig. 2



— HIRAKUD DAM —



— KOTAH BARRAGE —

Fig. 3

WILLINGDON RESERVOIR

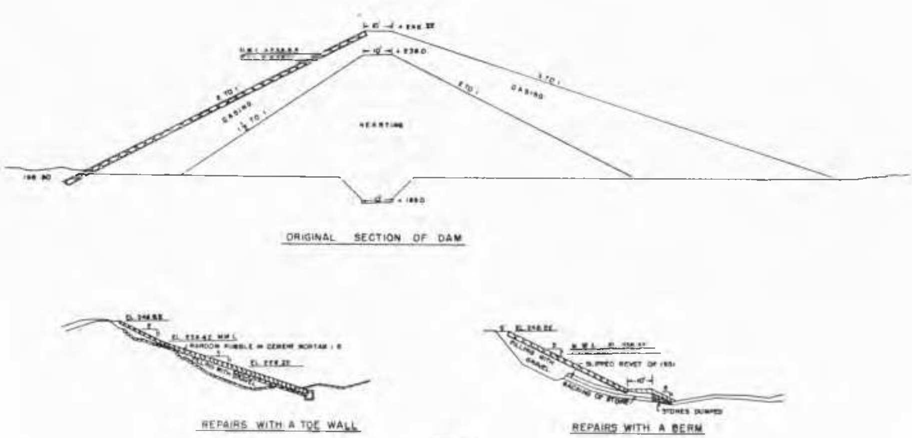


Fig. 4

Water was stored in November 1936 and when the water level was dropping, it was found that the length, where a masonry toe wall had been provided, showed slight movement and the revetment slabs cracked. However, the part where berms had been provided was quite satisfactory.

When the reservoir was refilled in November, 1937, and drained to 17 feet below the full tank level, further slips were observed. The gaps so caused were made up with stones.

A slip again occurred in 1939 when the water level was 28 feet below the full reservoir level. The same treatment i.e. provision of a berm 10 feet wide and 3 feet thick was given. The revetment was stopped at M.W.L. and portion above made up by filling with gravel in layers of 6 inches watered and rammed. This work was completed in July, 1939. The top of the revetment slipped in August, 1939. The revetment was repacked and the reservoir filled in october, 1939. After the reservoir had been drained, a movement 3 feet horizontal and 3 feet vertical at the worst affected portion was noticed in June 1940. This was restored in July, 1940; but again the revetment subsided. This was restored but again slipped.

There was slight movement in the bank between 1940 and 1941. It was decided to provide cement concrete 4 inches thick revetment above M.W.L. in addition to 2 or 3 rows of wave breakers. No further accident was reported till 1942. A new slip, however, occurred in August 1942 above the cement slabs. The slabs sank about 6 inches. The only remedial measure taken was further to strengthen the rear slope of the bund at 3:1 with gravel. No further serious accident has been reported since.

The apparent cause for frequent slips in this embankment is lack of proper distribution of materials in the construction of the embankment and poor compaction. It is noticeable that the slopes slipped whenever the reservoir was drained; thereby indicating that the soils used in the casing materials were of very poor quality liable to swelling and shrinkage and becoming unstable when water pressure was removed.

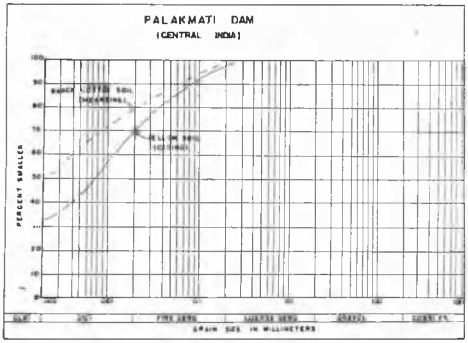


Fig. 5

The clayey material in the foundations on saturation became very weak and offered no resistance to the movement of the slide into the bed.

Another example of failure of a earth dam is afforded by that of the Palakmati Dam in Central India. This dam has a maximum height of 46 feet and was constructed in 1938. The upstream and downstream slopes vary from 2:1 to 3:1. The upstream slope was pitched with stones 1ft. thick. The section was built of a core of black cotton soil with heavy clay content and a casing of yellow soil with clay content up to 33 per cent. The grain size curves of the core and the casing material are given in Fig. 5.

On 26th June, 1953, a slide occurred for a length of 400 feet. Immediate repairs carried out consisted of filling up the gap with earth but this resulted in further movement of slide.

Trial pits made at the upstream and downstream toe revealed black cotton soil layer 3 feet thick followed by a layer of yellow clayey soil.

The slide occurred when the water level was falling from top reservoir level to about 16 feet below the top.

The slide was apparently due to the clay ey nature of the soil used in the casing and the predominantly clayey nature of the foundation.

The remedial measures adopted consisted of replacing the yellow clayey casing material by hill wash material and rock fill, flattening the upstream slope to 3:1 (Fig. 6).

A heavy rock toe taken to a depth of 10 feet was provided upstream to stabilise the slope. These repairs were completed in 1956 and no further slide has been reported after this date.

The persistent failures in the case of the Willingdon reservoir and failure of slopes years after construction in the case of the Palakmati dam show that it is difficult to deduce the time effect on slopes, as the failures may be due to several factors including the yielding of the foundations. In the above two examples, the failure of slopes was due to lack of drainage of clayey soil used in the casing.

To secure safety of earth structures for long periods it is, therefore, necessary to ensure proper treatment of foundations, use of freely draining materials in the shoulders and to provide adequate arrangement for drainage.

4. Slopes in foundation excavation

In the excavation of foundations for earth and masonry dams, slopes must be kept to the minimum to secure economy. A few difficult cases that have occurred recently are reviewed below.

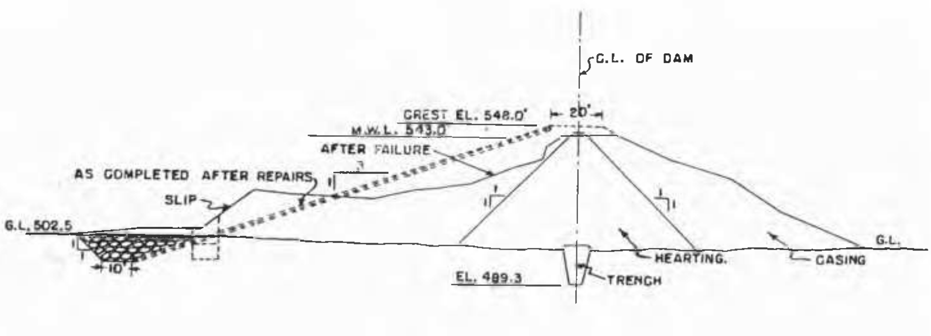
The Badua dam, an earth dam 132 feet high, is being built across the Badua river, the spillway being provided on the saddle. The overburden consists of sand varying in depths up to 52 feet in the river bed.

Sheet piling was not considered effective as a positive cut-off and it was decided to use a trench filled with clay. This meant open excavation in waterborne strata.

To lower the water table, eighteen tube-wells with 10 inches diameter filters were installed in the river bed upstream; another six were placed downstream of the cut-off, spaced 50 feet apart, and staggered over the whole width of 484 feet of the river.

In addition to those, ten diesel-operated pumps with a capacity of 1 1/2 cub. ft. per sec. were installed in the trench with from 200 to 300 feet long delivery pipes discharching water into lined channels or channels of steel sheet supported on suitably made tripod frames. In addition, ten electrically driven pumps were also installed in the wells with long delivery pipes at suitable places. Over and above these pumps there were four sump pumps of 1/4 cub. ft. per sec. capacity, each operated by compressed air.

Excavation was started in February 1959 with manual labour and the subsoil water table was lowered by eight diesel pumps (discharge 12 cub. ft. per sec). The width of the cut-off at the bottom was 20 feet. The consolidation of the



PALAKMATI DAM
(CENTRAL INDIA)

Fig. 6

soil fill was done by hand rammers or pneumatic tampers in 4-inch layers as sheep foot rollers could not operate in the small area available.

Later, electrically operated tube-wells in addition to the diesel pumps were installed (total discharge about 20 cub. ft. per sec.). and the water table was lowered about 24 feet below the bed of the river. The surface area thus opened out was about 120 feet wide and 100 feet long. All the tube wells in operation were installed around the area. The dewatering procedures were found to be very effective throughout the construction of the positive cut-off. With the dewatering arrangements it was possible to excavate with slopes of 45 degrees in sand to a depth of 50 feet or more.

The Kotah barrage, 122 feet high, is another example of an earth dam in a river bed with a spillway on the saddle. The bed of the River Chambal, consists of boulders mixed with pebbles and gravels down to a depth of 70 feet. The permeability of the foundation material was of the order of $1{\cdot}8 \times 10^{-1}$ cm per sec. In view of this a positive cut-off was difficult to excavate particularly as the work had to be done in one season. The progress of excavation was fairly satisfactory at the start but at great depth it was found impossible to make adequate dewatering arrangements. The cut-off could only be done for a length of 380 feet where the excavation to rock was down to 40 feet. Even in this length a pumping capacity of 80 cusecs had to be employed to dewater the foundations. A clay cement grout curtain with suitable overlap of cut-off was provided in the rest of the length where the depth of rock exceeded 40 feet. The slopes of excavation were 1 : 1.

Another interesting example of a foundation problems was encountered in the excavation for a masonry dam at Sharavathy in Mysore. This dam has a maximum height of 200 feet and forms a reservoir for a hydro-electric plant with an output of a million kilowatts. The investigations of foundation soil revealed the existence of light soils with a density as low as 82 lb. per cub. ft., and with moisture content ranging from 30 to 36 per cent. The annual rainfall in this area is 100 to 200 inches. Due to lateritic weathering, the rock minerals have been decomposed, Kaolin has been formed and silica and bases leached from them resulting in light soils. It was originally proposed to build an earth dam but due to the weak foundation soil it was decided to excavate to rock level and to construct a masonry dam on the rock.

The depth of rock varied from 50 to 60 feet below ground level. Diesel and electrically driven pumping sets were installed at several places to pump out the water. The entire excavation was done by manual labour. The slopes were generally 1:1 in steps of 3 feet × 3 feet. At a few places where slips were frequent, stone pitching was done to retain the slopes.

These examples show that where the slopes are to be maintained for only a short time, as in the excavation of foundations, steep slopes can be adopted provided that adequate dewatering arrangements are made and slopes are kept dry.

Conclusion

When earth structures are founded on stable foundations and are provided with good draining outside casing materials, the effect of time does not result in any deterioration of slopes. It is only in cases where clayey soils with high shrinkage and swelling properties are used exposed on the outside slopes, that there is a deterioration with time in slopes and frequent slips do result.

Where work has to be done, as in excavation lasting for a short time, steep slopes can be adopted resulting in economy of construction.

Acknowledgement

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Table 1

Data of some Ancient Earth Dams in South India

S. No.	*Name of tank*	*Year of construction*	*Length of Dam.*	*Max. height*	*Top width*	*Slide Slopes*
1	*2*	*3*	*4*	*5*	*6*	*5*
1.	Motitalav Tank	1 000-1 100 A. D.	13 200′	80′	47′ to 50′	U/s 1·75 : 1 D/s 1·4 : 1 to 5·6 : 1
2.	Malkapur Tank	1 000-1 100 A. D.	12 400′	38′	12′	U/s 2 : 1 D/s 3 : 1
3.	Veeranam Tank	1 011 A. D.	52 800′	30′	20′	U/s 1·5 : 1 D/s 1·5 : 1
4·	Pakhal Tank	1 213 A. D.	4 000′	63′	15′ to 40′	U/s 2 : 1 D/s 2 : 1
5.	Ramappa Tank	1 213 A. D.	2 000′	56′	20′	U/s 2·5 : 1 D/s 3·0 : 1
6.	Lakhnawaram Tank	1 213 A. D.	2 000′	50′	15′ to 20′	U/s 2·5 : 1 D/s 2·5 : 1
7.	Cumbum Tank	1 300-1 400 A.D.	1 000′ *main bank*	52′	66′ to 100′	U/s 1·5 : 1 D/s 2 : 1
8.	Ananthasagaram tank	1 300-1 400 A.D.		46·98′	30′	U/s 2 : 1 D/s 2 : 1
9.	Chembarambakam tank	1 300-1 400 A.D.	29 040′	32′	8′ to 10′	U/s 1·75 : 1 D/s 2 : 1
10.	Rasool tank	1 300-1 400 A.D.	4 200′	42′	2½′	U/s 1·5 : 1 D/s 2 : 1
11.	Anantharajasagaram tank	1 369 A. D.	14 000′	36′	12′	U/s 1·5 : 1 D/s 2 : 1
12·	Kesari tank	1 400-1 500 A. D.	5 000′	40′	15′	U/s 2 : 1 D/s 2 : 1
13.	Keveripakam tank	1 400 A. D.	23 760′	39·78′	9′	U/s ½ : 1 D/s 2 : 1
14.	Peddatippa Samudram tank	1 520 A. D.	4 150′	52·42′	40′ to 80′	U/s 2 : 1 D/s 3 : 1
15.	Ibrahimpatan tank	1 500-1 600 A. D.	7 920′	50′	10′	U/s 3 : 1 D/s 2 : 1
16.	Raverial tank	1 600 A. D.	5 700′	45′	10′	U/s 2·5 : 1 D/s 2·5 : 1
17.	Laksminarayan tank	1 700 A. D.	8 500′	40′	3½′	U/s 3 : 1 D/s 2·5 : 1
18.	Venkateswra tank	1 800 A. D.	3 000′	50′	2½′	U/s 1·5 : 1 D/s 2 : 1