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SINKHOLES IN EARTH DAM
KOTA BARRAGE [INDIA]

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ABSTRACT

Kota Barrage is the lowermost hydraulic structure amongst the series of four dams built across the river Chambal, a tributary of the river Yamuna in the Ganga Basin. It is situated near the Kota City, Rajasthan in India and is in operation since November, 1960. with an irrigation potential of 679 thousand ha in two adjoining states of Rajasthan and Madhya Pradesh. It comprises of a composite structure consisting of a 268.2m long earth and rockfill dam and a 304.8m long masonry spillway. the total length being 573.0m. The earth/rockfill dam abuts in the right against a hillock over which a very old Garh Complex exists and two fort walls intervened in between the spillway and the abutment have divided the dam into three distinct reaches having different foundation sub-strata. The spillway rests on hard quartzitic sand stone with high rock face in the left flank and is provided with 19-radial gates (12..2m x 12.2m each) and 2-under-sluices (2.7m x 3.3m) to discharge 21240 cumecs at MWL 260.9m. Heavy leakage of water through the bed rock crevices in the adjacent right abutment resting on hillock slope, wet spots on downstream edge alongwith repeated settlements and formation of sinkholes on top of the dam has led to a great concern about safety of the dam. Geo-technical investigations carried out recently revealed some lenses/zones with low density soilmass and higher permeability at places in the embankment.

KEY WORDS

Embankment and its geology. settlements/sinkholes, investigations/observations, remedial treatments and design criteria, etc.

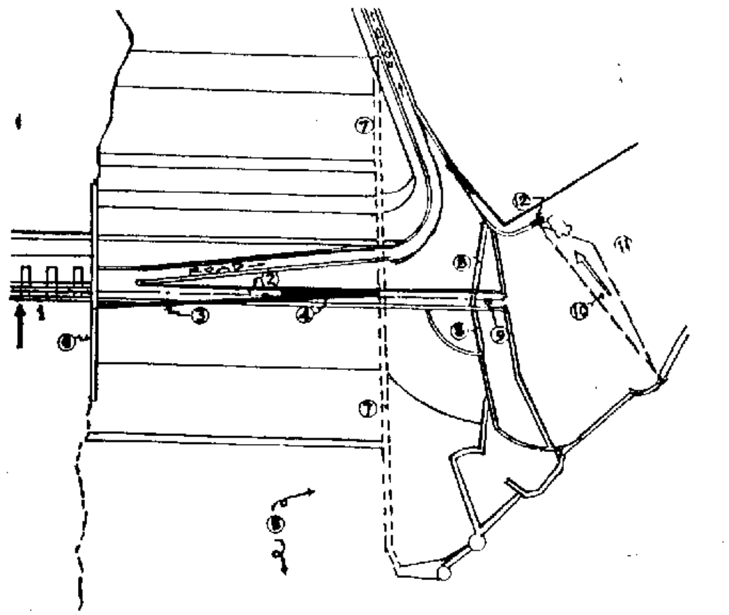
INTRODUCTION

Kota Barrage is the lowermost hydraulic structure amongst the series of four dams developed in the Chambal Valley for generation of power and irrigation. It is built across the main river, Chambal, a principal tributary of the river Yamuna in the Ganga Basin and is situated near Kota city, Rajasthan (India). The project was commissioned in November, 1960 to divert water into the canals for irrigating 679 thousand ha barren lands in two riparian States of Rajasthan and Madhya Pradesh and also to fulfil the water needs of Kota Thermal Power Plant and the Kota city.

Kota Barrage is a composite structure comprising of 268.2m long earth and rockfill dam and 304.8m long masonry spillway, the total length being 573.0m. The spillway is separated from the dam by a long cross retaining wall. It has 19 steel radial gates, each 12.2m x 12.2m size and 2 under-sluices (2.7m x 3.3m) to discharge 21240 cumecs. The spillway abuts against a vertical rock face in the left flank whereas the dam abuts in the right flank against the slope of a hillock overwhich a very aged Garh Palace exists. The general layout of the project is shown in Fig.1

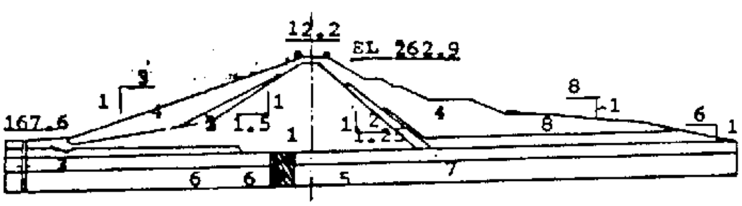
DAM EMBANKMENT

The dam has a maximum height of 37.3m with its top at EL. 262.9m. It consists of, in general, a zoned embankment with impervious core in centre, semi-pervious transition and shells of rockfill on either side as shown in Fig.2. The dam is intervened by two old fort walls called Lower Fort Wall and Upper Fort Wall which have divided the embankment in three distinct reaches(Fig 1). The Lower Fort Wall with about 6.0m base width at EL 219.9m and 4.3m top width at EL 241.2m intercepts the dam obliquely at Ch 182.9m whereas the Upper Fort Wall with its top at EL 260.6m in upstream and 258.9m in downstream intervenes the dam nearly at right angles to the dam axis at Ch.243.8m. At the junction of these walls, the core was laid after dismantling the walls for a short strip to accommodate the core.



1.Spillway
2.Embankment
3.Masonry Cut Off Wall
4.Clay Grout Curtain
5. Clay Blanket
6. Retaining Wall
7. Lower Fort Wall
8. Upper Fort Wall
9. Sink Hole.
10. Seepage Path
11 Garh Complex
12. Seepage Exit

Fig. 1 General Layout Plan Kota Barrage.



1. Impervious core
2. Semi-pervious Transition
3. Clay-Blanket
4. Rock shells
5. Sand and Boulder Strata
6 Clay-Grout Curtain
7. Clay-Tongue
8. Filter

Fig.2 Typical Embankment Section

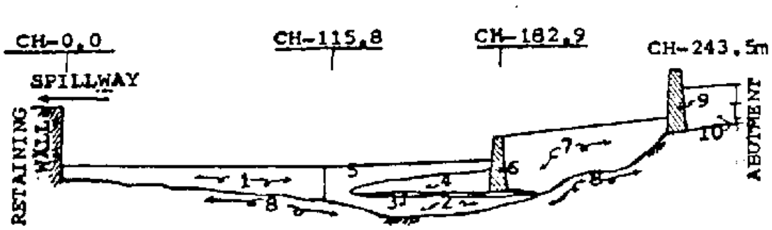
GEOLOGY AND PRE-CONSTRUCTION TREATMENT

The spillway rests entirely on hard quartzitic sandstone whereas the dam is founded on the old river bed of Chambal having different soil characteristics which have thereby necessitated different type of treatments. The dam between the Retaining wall and the Lower Fort Wall (Ch. 0.0 to Ch. 182.9m) rests partly on hard rock and partly on pervious strata comprising of silt, sand, gravel and boulders. An impervious clay-tongue of about 5m thick protruding into the river for a length of about 55m from the Lower Fort Wall and extending both upstream and downstream for a long distance is sandwiched in between two bouldery strata as shown in Fig3

From the Lower Fort Wall to the Upper Fort Wall (Ch. 182.9m to Ch. 243.8m), the dam rests on soil cover whose thickness varies from 24m to 6m in the right and which has been deposited during construction activities of the Garh Palace. Again, at the junction with the Upper Fort Wall, the dam has a step in the foundation with level at EL 240.8m on the left and EL 258.8m on the right of the wall. Beyond this wall, the dam rests on natural soil extending upto the dam end (Ch. 268.2m). Bed rock steeply rises from the river bed at EL 210.9m to the right abutment (Ch. 274.3m)at EL 249.5m.

A masonry wall, 12m depth in average, which rests on hard rock and has its top at EL 229.1m coupled with a 21m long masonry Cross Wall at Ch. 103.6m, is constructed from Ch. 0.0 to Ch. 115.8m to form a positive cut off. The river deposits in the area from the masonry wall to the toe of the clay tongue are excavated upto EL 216.4m whereas the deposits over the clay-tongue are excavated upto the Lower Fort Wall. The entire area is then backfilled with impervious clay upto the top of the cut off wall and grouted with Clay-Cement-Sodium Silicate grout and thereby formed an impervious water barrier(Fig3). In addition, a 3 m thick and 167.6m long upstream clay blanket, downstream filter drains, inverted filters and relief wells have also been provided in the deepest section (Ch 0.0 - Ch. 182.9m) of the embankment to further control the seepage through foundation or any possible soil erosion.

Due to the existence of thick clay cover, and low height of the dam from the Upper Fort Wall to the right abutment in particular, no special foundation treatment is provided beyond the Lower Fort Wall. However, as a preventive measure a semi-circular cut off trench of radius 10.7m and 4.5m in depth is provided at the junction of the core with the Lower Fort Wall to increase the seepage path. A 9m long masonry Key Wall resting on hard rock is also provided at the upstream junction of the core with the Upper Fort Wall. Here the core is extended in the upstream in the form of a quadrant of 30m radius as an additional preventive measure against seepage.



1. Masonry Cut-off Wall
2. Sand Boulders
3. Sand and Gravel
4. Clay Tongue
5. Clay Fill
6. Lower Fort Wall
7. Soil Deposits
8. Bed Rock
9. Upper Fort Wall
10. Natural Soil Deposits

Fig. 3 Geological Section of Dam Foundation

PROBLEM OF SETTLEMENTS / SINK HOLES

During initial filling of the reservoir to EL. 256.2m, some leakage of water emerged out from the Upper Fort Wall at downstream toe at EL. 247.2m. Some Water spots were also observed in the downstream edge in the vicinity of the Upper Fort Wall. With the increase of the pond level to EL. 259.7m and maintaining it almost constant, seepage started through the rock crevices in the Garh area at EL. 254.2m. Gradually it increased to 0.28 cumecs due to widening and washing off the seams in the rock with the passage of time. [Presently seepage is to the tune of about 0.23 cumecs with its water clear and free from suspended particles.] In 1968, the staircase from the top of the Upper Fort Wall to the approach road in downstream got damaged due to settlement. In 1983, a settlement was also observed in the rockfill slope at EL. 251.5 m. across Ch.246.9m.

Following a continuous downpour for three consecutive days (112mm rainfall was recorded), a sinkhole was observed on 20.7.89 on the downstream toe of the dam in the right flank followed by another sinkhole on 23.7.89 in the form of a crater on the top of the embankment at Ch.253.0m. These sinkholes were of about 1.8m to 2.4m in diameter and 1.8m in depth. Even after refilling the settlements with earth and boulders, a sinkhole reappeared on 08.11.89 at the same location **(Fig.4)**. This time, depth of sinkhole was about 2.7m. It was again refilled with earth and boulders. Another settlement was also observed on 23.5.90 at about 12m downstream from the dam axis across Ch. 254.5m. Thus repeated settlements/ sinkholes have led to a great concern for the safety of the dam.

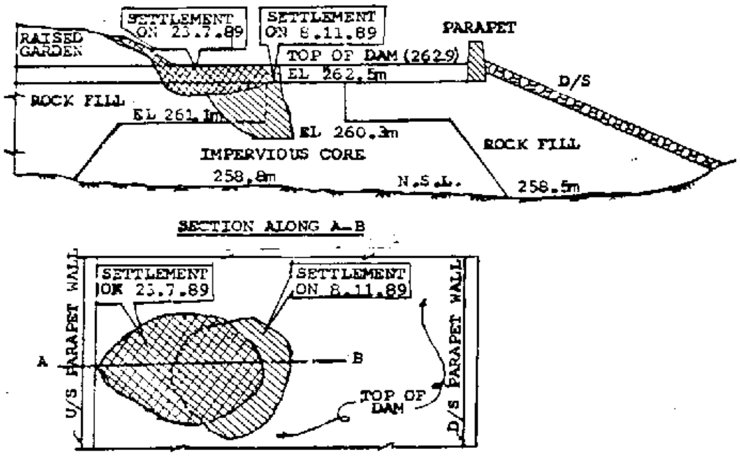


Fig. 4 Sinkholes at Ch. 253m. Kota Barrage

GEOTECHNICAL INVESTIGATIONS

In the year 1990, five boreholes were drilled in the right abutment in the Garh Complex to know about the geological conditions of the region. The investigations revealed that the depth of the overburden in the region varied from 4m to 9m and the overburden materials comprised of low density silty soil mixed with pieces of stones, bricks, etc. These drillings showed a very good to excellent core recovery (90% to 100%) of fresh, hard and massive sand stone, but bed rock was found highly fractured. Tracer studies carried out in these bore holes indicated that the seepage exit at EL 254.2m, was hydraulically connected to the reservoir **(Fig. 1)**.

Later in Feb.1992, a pit of about 2m dia was excavated at 1m upstream of the centreline of the embankment (Ch. 254.5m) to explore the pattern of movement of materials in the subsidence occurred during July/Nov, 1989. The pit was excavated from the top of the embankment at EL 262.9m down to EL 258.8m. Excavation revealed that the backfilled materials of the last settlement had moved towards the downstream and there was no evidence of 'piping' or seepage hole. However, a loose pocket was met at the bottom of the pit.

Twelve boreholes were further drilled for about 427m in total length at the selected locations (7 nos. in the embankment and 5 nos. in the Garh complex) to know more about the causes of sink holes/settlements. Fourteen Dynamic Cone Penetration Tests (DCPT) in addition to a number of in-situ and laboratory tests were also carried out. These tests indicated that the foundation overburden and the embankment materials together comprised of CI & CL types of soils, predominantly silt and clay particles in general, with moderate plasticity, density varying from 1.44 gm/cc to 2.15 gm/cc, moisture content of 9.6% to 25.5%. In-situ K values were found to be in order of 3.0 x 10^{-1} cm/s to

1 x 10 cm/s. Geo-technical investigations concluded that the embankment foundation was semi-pervious overlying the weathered bed rock. On the other hand, seeping of water through the old fort boundary wall forming the reservoir rim could not be ruled out. Also a few loose pockets in certain zones of the embankment might have been developed due to inadequate compaction and washing off fines and hence the related problems co-exist since filling of the reservoir.

PIEZOMETER OBSERVATIONS

To study the present behaviour of the dam body and also to check the effectiveness of the intended treatments, forty-three Porous - type Piezometers (23 Nos. in foundation and 20 Nos. in embankment) have been installed at various locations of the embankment as well as in leakage-prone region of the Garh Complex. In addition, twenty one Open-type Piezometers have also been installed inside the selective Sand Drains [see Design Criteria - Para-1] so as to ascertain their effectiveness.

Study of the piezometric levels revealed better effectiveness of the masonry cut-off wall than the existing clay-grout curtain. Water levels in the piezometers E_T-18 and E_T-4 (Fig. 5) were found to be much higher than those in the other piezometers in the same line. Both of these piezometers are located near the Lower Fort Wall. Possibility of hydro-fracturing at the contact of the interfaces of the wall with the embankment are also not unlikely and the same might have contributed to such higher piezometric levels. Similar phenomena were also observed in the vicinity of the Upper Fort Wall. These events confirmed the existence of the weak zones/lenses in the dam body which are directly connected to the reservoir. Again, incidences of sudden sinking of 3m deep sand filling inside a vertical Sand Drain at Ch. 249 m on 27.11.95 followed by another sinking of 0.7m on 28.11.98 in the same Drain contradicted against the soundness of the embankment body. Despite to these facts, seeping of water through the downstream toe of the embankment at Ch. 231m and Ch. 236m during injection of water inside the backfilling of the pit at sinkhole re-affirmed the existence of some paths which might have resulted in settlements/sinkholes due to ingress of rain water or otherwise flow of reservoir water through the dam body. Fig. 5 shows some piezometric water levels in the vicinity of sink hole at dam top.

REMEDIAL MEASURES

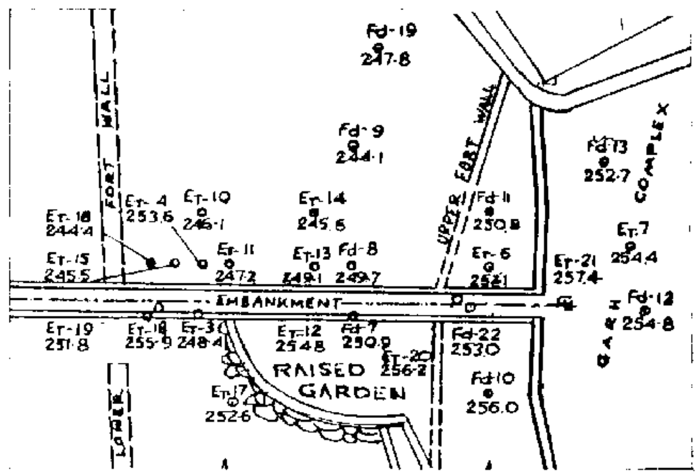
Some peripheral treatments like (i) Introduction of transition zone by sand - sluicing in the downstream between rockfill and the core from the Lower Fort Wall to the Upper Fort Wall, (ii) Proper drainage in the raised garden existing in the upstream junction with the Upper Fort Wall and also in the downstream slopes of the embankment and (iii) Black-carpeting of the dam were carried out.. Considering the results of the geo-technical investigations and piezometric observations, Central Water Commission has suggested the following treatments keeping in view the future safety of the dam :

I. Installation of Vertical Sand Filter Drains.

II. Installation of Cement-Grout Curtains.

III. Consolidation of Weak Zones / Interfaces of the Fort Walls.

IV. Contact grouting of the over-burden vis-à-vis bed rock plane.



F - Foundation Piezometer

E - Embankment Piezometer

Fig. 5 Piezometer Water Levels on 29.03.96

DESIGN CRITERIA

I. Installation of Vertical Sand Filter Drains:

The Sand Filter Drains comprise of two lines, 1m apart, with the upstream line at 3.2m downstream of the dam centre line. Installation of these lines of Sand Drains shall be accomplished by drilling 400 mm dia. holes at 2m c/c, staggered. The holes shall be drilled from the top of the embankment by **Bailor Boring Method** and shall be extended deep into the bed rock.

II. Installation of Cement - Grout Curtains :

The Cement Grout Curtains shall comprise of two lines, 2.5m apart with the upstream line at 0.7m downstream of dam centre line. An additional line of grout - curtain is also proposed from Ch. 225m to 290m which is more prone to seepage. Grout holes are proposed to be 38mm dia. with primary spacing of 6m , staggered , whereas the depth of curtain shall in general be extended deep into the bed rock where

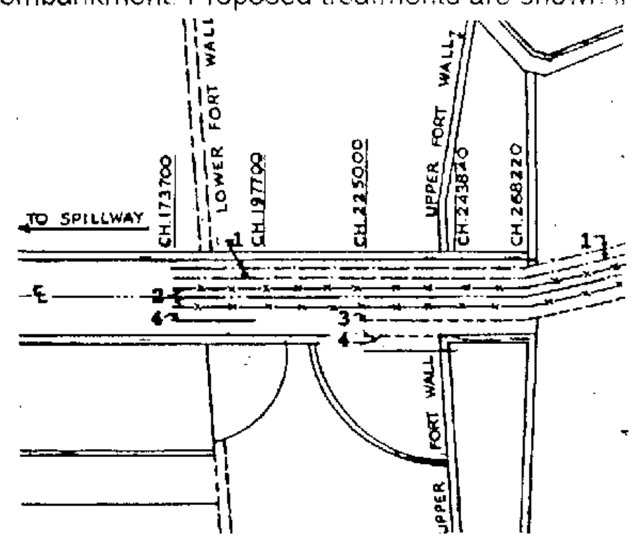
K ≤ 3 lugeon or
upto depth. D = H/2 whichever is less subject to a minimum of 3m below the rock-overburden contact plane and H = depth of water at the deepest section

III. Consolidation of the weak zones/lenses and the interfaces of the Fort Wall:

Consolidation of the weakzones/lenses prevailing in the body of the embankment and the interfaces of the Fort Walls intervening the dam body are suggested to carry out in the region of the embankment over the grout-curtains. Additional line of consolidation is also proposed from Ch. 225.0m to Ch.251.7m at 6.7 m u/s of the dam centre line. All such groutings are proposed to undertake with Clay-Cement-Sodium Silicate grout, injected through 75mm dia. holes with primary spacing of 6m , staggered , in average. Such grouting shall be extended from MWL (260.9m) to 3.0m below the bed rock plane.

IV. Contact Grouting of overburden / bedrock plane:

Similar to the consolidation grouting, contact grouting of the over-burden vis-a-vis bed rock plane is also suggested for a depth of 10m. starting from 5m above the bed rock plane. In all cases, grouting operations shall be carried out by drilling from the top of the embankment. Proposed treatments are shown in Fig. 6



1. Lines of Vertical Sand Filter Drains
2. Lines of Grout Curtain / Consolidation Grouting
3. Line of additional Consolidation Grouting
4. Lines of Contact Grouting

Fig.6 Layout Plan of Proposed Treatment

STATUS OF REMEDIAL WORK

Proposed treatment is taken up under World Bank assistance. Installation of 164 nos. Vertical Sand Filter Drains starting from Ch.173.9m to inside the Garh Complex have been completed in Feb.1996 and are functioning well as predicted. Other treatments are at present under bidding stage.

ACKNOWLEDGEMENTS

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iii)Vol -III - Specification for Sand Filter Drain Curtains
iv)Vol - VII -Specifications for Grout Curtain and Consolidation Grouting (Revised)