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Indra Prakash

Geological Survey of India, Gandhinagar (Gujarat), India

A. B. Vyas

Central Design Organization, Gandhinagar, India

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GEOTECHNICAL PROBLEMS AND TREATMENT OF WEATHERED ROCK SEAMS OCCURRING IN THE FOUNDATION OF KARJAN DAM, WESTERN INDIA

Indra Prakash
Geological Survey of India
Sector-10A
Gandhinagar (Gujarat) -382043
INDIA

A.B.Vyas
Central Design Organisation
Dr. Jivraj Mehta Bhavan
Gandhinagar (Gujarat)
INDIA

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ABSTRACT

The Karjan dam is located on the Deccan Basalt flows of Cretaceous - Eocene age in the Narmada valley in Gujarat state. A characteristic feature of the basalt flows in this area is conspicuous presence of a number of sub-horizontal weathered rock seams posing the foundation problems of settlement, sliding and seepage. Concrete shear keys have been provided to increase the sliding stability of dam blocks besides other remedial measures. Additional curtain grouting has been done after completion of the dam to reduce seepage.

KEYWORDS

Karjan dam, Weathered rock seams, Settlement, Sliding, Shear friction factor, Concrete shear keys, Seepage.

INTRODUCTION

The 100m high and 903m long masonry-cum-concrete gravity Karjan dam has been constructed across the narrow gorge of the Karjan River, a tributary of Narmada River in the year 1986 for mainly irrigation (Fig. 1). Detail surface and sub-surface geological investigations have been carried out in the area besides rock mechanics studies. A number of sub-horizontally disposed weathered rock seams were detected and precisely delineated during construction stage investigations by 69 bore holes aggregating to 1100m length. Geotechnical problems emanating from the presence of these seams in the foundation of entire dam needed careful assessment and evaluation of the foundation rocks for providing adequate remedial measures.

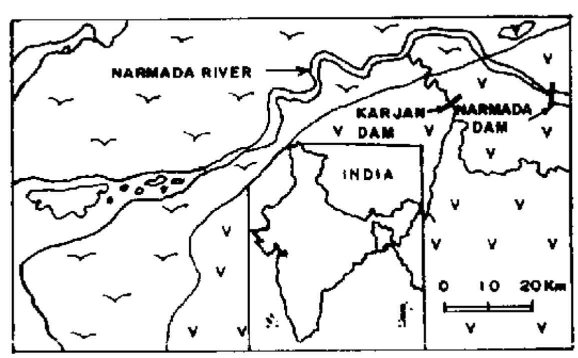

Fig.1 Location plan of Karjan Dam

GEOLOGY OF THE DAM SITE

The area is occupied by "Aa" and "Pahoehoe" type of the Deccan basalt flows of Cretaceous-Eocene age. The "Aa" flows are characterised by fine grained or porphyritic dense basalt towards the base becoming amygdular or tuffaceous at the top. These flows are exposed on the abutments. In the river section, "Pahoehoe" type basalt characterised by wrinkled (ropy) and vesicular top, and pipe amygdules at the base is exposed. Persistent sets of joints, shears and faults in the area trend in N-S to NNE-SSW and also in NW-SE directions (Prakash, 1990).

A characteristic feature in this area is the presence of weathered rock seams at 4 to 10m intervals, developed along interfaces of flows and sub-horizontal joints (Fig. 2).

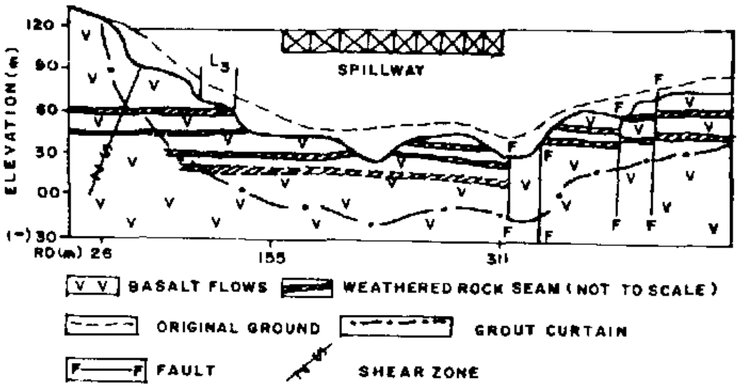

Fig. 2 Longitudinal geological section of part of the dam showing disposition of weathered rock seams.

NATURE OF WEATHERED ROCK SEAMS

The weathered rock seams consist of a zone of highly to completely weathered basalt varying in thickness from 1cm to 2m, developed along flow contacts and also along sub-horizontal open joints due to percolation of seepage water. The presence of slickensided surface and gougey material, and displacement of the vertical shear zones along seams clearly indicated shearing and lateral movement resulting in the formation of potential weak planes for sliding.

In-situ shear tests conducted on the seams indicated the value of angle of internal friction "ϕ"= 22° to 26° and the value of cohesion "C" = 0.

GEOTECHNICAL PROBLEMS DUE TO WEATHERED ROCK SEAMS AND THEIR REMEDIAL MEASURES

The weathered rock seams posed the problem of settlement, sliding and seepage. Treatment of these weak features depended on the thickness, properties of seam material, strike and dip of the seams and their precise disposition below the foundations.

Settlement

Weathered seams in general are of pinching and swelling nature, and wavy disposition posing no serious problem of settlement/differential settlement of dam blocks except in the foundation of left non-overflow block-L3 where minimum thickness of the seam was 0.5m and maximum 2m and rock cover was also less than 5m (Fig. 2). Part foundation of the block near block-L3/L4 joint was free from the seam (Mehta and Prakash, 1990). On engineering analyses and judgement except consolidation grouting no other treatment was considered necessary and this 60m high block has not shown any distress even after ten years of completion of the dam.

Sliding

Weathered rock seams occurring in the foundations of dam blocks have low shear parameters ("C" = 0, "ϕ" = 22° to 26°). These seams were considered as potential planes for sliding (Prakash, 1990). Based on the stability analyses concrete shear keys were provided in the foundation of all spillway blocks and in the foundations of right non-overflow blocks R1-A, R1-B and R2 besides other following remedial measures considered/provided to achieve required shear friction factor :

Curvature in the alignment of the dam. A mild upstream curvature in the alignment of the dam was initially considered for mobilising greater resistance against sliding. On the basis of geological analyses abutment rocks were not found suitable for arch action as they are dissected by steeply dipping shears, joints and faults aligned almost parallel to the probable direction of thrust in case of curved axis. These abutment rocks are also traversed by sub-horizontal weathered rock seams (Fig. 3).

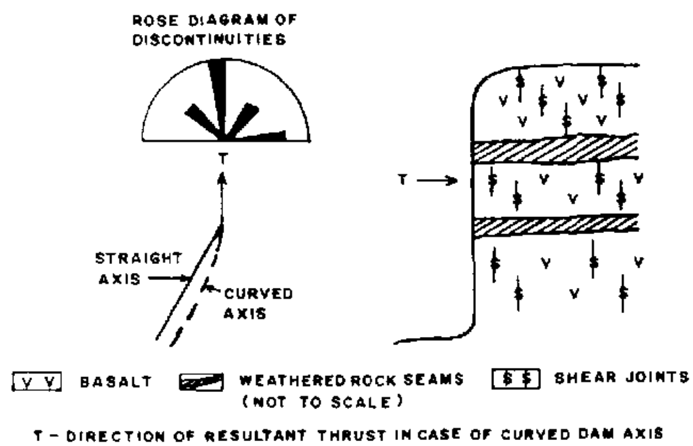

Fig. 3 Critical geological abutment conditions.

Change in the design of dam blocks. The spillway section was provided with a flatter upstream batter of 1:2 below El.75m instead of the original 1:15 below El.85.70m to increase the stability against sliding of blocks by taking advantage of additional weight of concrete and water on the upstream face.

Provision of concrete shear keys. Remedial measures like flattening of the upstream batter, roughening of the foundation base for greater friction, combining two or more blocks together in the stability analysis did improve the factors of safety against sliding but they were not adequate to yield the required minimum values of the sliding factor or the shear friction factor (Parmar and Vyas, 1983). Therefore, open or underground concrete shear keys (plugs) were provided in all the spillway blocks and also in three right non-overflow blocks depending on the various stages of construction to achieve required sliding factor (F1 = 1.5) and shear friction factor (F2 = 3.0).

Treatment to shallow seams overlain by 3 to 5m good basalt rock cover was provided by excavating trenches and back filling them with concrete. For the deeper seams and where the blocks were already partly constructed, drifts were excavated from the approaches through shafts located in the apron area and back filled with concrete without affecting normal concreting work (Fig. 4).

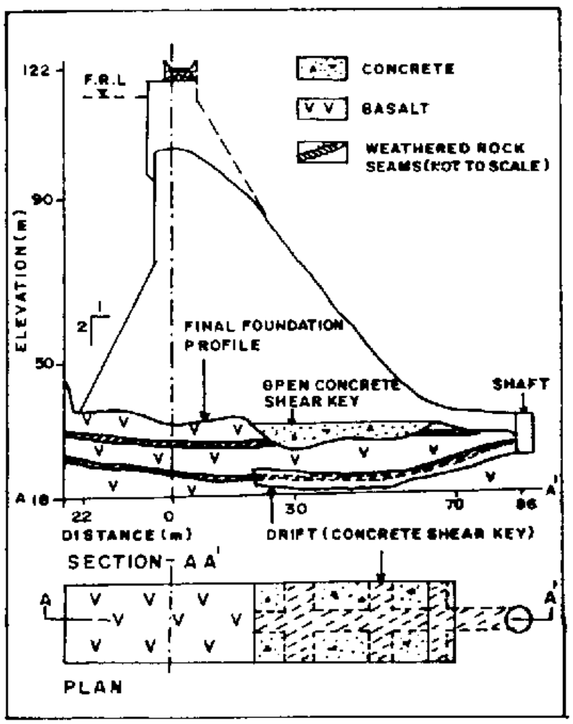

Fig. 4 Typical section and plan of spillway block showing foundation treatment of weathered rock seams.

Selection of stilling basin type energy dissipator. Basalt rocks in the downstream of spillway blocks are underlain by weathered rock seams and are blocky in nature, dissected by joints, shears and faults. Based on the geological evaluation of the rock mass and model studies of various alternative choices, a sloping apron-cum-stilling basin type of the energy dissipator was provided to check retrogression along weak geological features and to increase the passive resistance in the downstream by protecting downstream rock from the scouring. Deepest anticipated scour level in case of roller bucket, ski-jump and stilling basin was at El.12m, 14m and 33m, respectively. So far, no problem of scouring has been observed in the downstream area.

SEEPAGE

Conspicuous seepage was observed through weathered rock seams during the excavation of shafts and drifts in the foundations of spillway blocks (Mehta and Prakash, 1990). Nearly all the drill holes during pre-construction stage investigations recorded high permeability (upto 75 Lugeons). To reduce the permeability of rock foundation initial curtain grouting was done in four stages with 5, 10, 15 and 20 kg/cm^2 pressures, gradually increasing with depth when the reservoir level was at minimum. Depth of curtain grouting in spillway section varies from 42 to 60m. It was observed in five spillway blocks that post grouting seepage was more than 100 litres/minute. It clearly indicated ineffectiveness of initial curtain grouting. Therefore, to reduce the seepage additional curtain grouting was done with uniform high pressure of 20 kg/cm^2, after filling of the reservoir upto El.78m, to seal remaining gaps/permeable windows in the grout curtain. Seepage has reduced in general by about 70 to 90% after providing additional curtain grouting (Fig. 5).

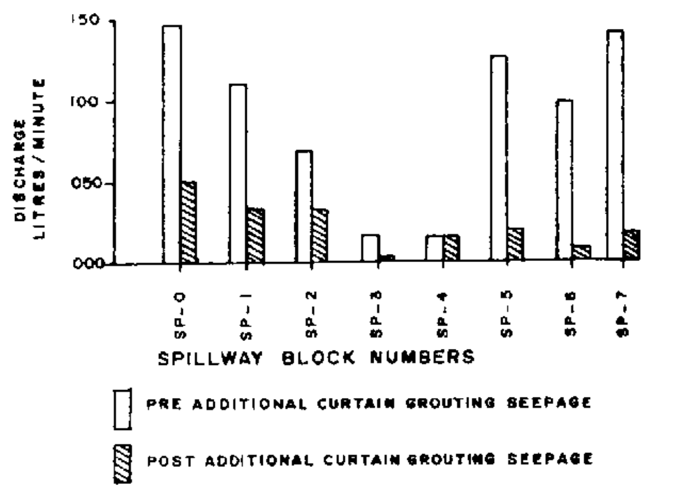

Fig. 5 Pre- and post-additional curtain grouting seepage observed through foundation drainage holes in spillway blocks.

CONCLUSION

Weathered rock seams occurring in the foundation of Karjan dam have posed mainly problems of sliding and seepage. Experience has shown that even untreated thick (2m), moderate to highly weathered rock seam overlain by shallow jointed basalt rock cover (3 to 5m) has not caused any foundation settlement problem probably due to its confined condition and slow loading/construction of the dam.

Analyses of weathered rock seams have shown that they are potential planes for sliding. Concrete shear keys were provided to act against sliding wherever the required shear friction factor was not available, especially in the spillway blocks. Flattening of the upstream batter of spillway blocks has also been done to increase the sliding stability. Stilling basin type of energy dissipator arrangement has been provided to increase the passive resistance against sliding and also to prevent retrogression along weak features.

Conspicuous seepage was observed through weathered rock seams during excavation of the foundation and even after initial curtain grouting as such type of features are pathways for ground water movement. Therefore, additional curtain grouting with uniform high pressure has been done to effectively grout the seams and to seal remaining permeable windows in the grout curtain. Now, seepage has reduced appreciably.

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