ENGINEERING GEOLOGICAL EVALUATION OF THE MAJOR DAMS IN LOWER NARMADA VALLEY IN GUJARAT STATE

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Summary

1 The Deccan basalt is generally considered to be competent rocks for the dam foundation but experience has shown that basalt flows in the lower Narmada valley are posing problems of sliding, settlement and seepage. Roof falls and collapses have also been observed in the underground structures. Weak foundation media in the Deccan basalt flows include tuff, agglomerate, red bole, weathered rock seams and slaked rock zones besides shears and faults. The foundation problems at Narmada dam site are unique in this area due to the presence of infra-trappean sedimentaries brought by a river channel fault in juxtaposition with basalt.

2 Foundation treatment of sub-horizontal geological weak features at Narmada and Karjan dams, inter-alia, includes excavation of the drifts or open shear keys in the grid pattern along weak layers and back filling them with concrete to provide adequate resistance against sliding. As an alternative methods following modifications have been made in the design:

(i) Mild curvature was provided in the axis of the Narmada dam to mobilise shear resistance of all monoliths (dam blocks) together to ensure greater safety against sliding.

(ii) Flatter upstream batter was provided in the spillway blocks of Karjan dam to increase the vertical load for mobilising larger frictional resistance along the weak seams.

(iii) Stilling basin type of energy dissipater arrangement was adopted to provide passive resistance by protecting downstream rock from the scouring and also to check retrogression along weak geological features.

3.1 The Narmada and Karjan dams are traversed by 10 to 12m wide river channel faults but the nature of the fault zones and abutment rocks differ at both the sites. The Narmada fault zone is mostly unhealed (i.e. without hard filling or

cementing material). Rock mass of the fault zone as well as of abutment rocks (sedimentaries and basalt) are having different physico-engineering properties and belong to poor quality (RMR 11 to 33). Based on the rock mass evaluation and engineering analyses 34m deep reinforced concrete plug was provided to treat the Narmada river channel fault. On the other hand no treatment was provided to the Karjan dam river channel fault because it consists of fair quality rock mass (RMR 48) and it is nearly healed.

3.2 The Karjan dam blocks located on untreated fault have not shown any distress even after 14 years of completion and operation of the dam. Experience of the Narmada and Karjan dams has shown that major dams can be constructed on major faults with or without providing treatment depending on the proper assessment and evaluation of the rock mass conditions.

4.1 Treatment of weathered rock mass in the foundation of Narmada dam blocks was done by providing single layer or two-tier reinforced concrete mat depending on the nature of weathering and foundation topography.

4.2 Numerous weathered rock seams were encountered in the foundation of Karjan dam. It was not practicable to remove these seams form the foundation as they lie one over other at 3 to 10m intervals. No treatment was provided even to thick (2m) weathered rock seams having shallow rock cover (3 to 5m) from settlement consideration. It was thought that settlement, if any, would be completed during construction of the dam itself due to slow construction of the dam (i.e. slow loading of the foundation) under confined condition. This 60m high dam block has not shown any distress even after 14 years of operation of the dam. It indicates that weak layers can be left untreated from settlement consideration even in the foundation of large dams under confined condition.

4.1 Limestone exposed at Narmada dam site is of non-cavernous nature. The continuity of the permeable zones in the limestone is broken due to faulting and intrusion of basic dykes. Faults and dykes acted as natural seepage barriers. Treatment to high permeable local pockets/ zones was provided by grouting.

4.2 Conspicuous seepage was observed through weathered rock seams in the foundation of Karjan dam. Low pressure consolidation and curtain grouting was ineffective in treating the seams. Seepage was reduced appreciably by adopting high pressure (20kg/cm^2)-curtain grouting. It indicates that weathered rock seams can be treated from the seepage consideration by adopting high pressure grouting.

5. The Narmada and Karjan dams are located in the Son-Narmada-Tapi Rift Zone (seismic zone III of India) which is considered to be seismically active. Seismic events in and around project area are generally occurring below magnitude 3 except a few events between magnitude 4 and 4.5. Epicenters of about 85% earthquake occurring in the area fall on the southern side of the Narmada river mainly along and adjacent to Piplod fault which has already been considered in the aseismic design of dam. No activity along river channel faults, located at the dam bases, has been observed prior and during the present stage of construction of the Narmada dam (El. 85m till October 2000) and during and after completion and filling of the reservoir of Karjan dam. The horizontal seismic coefficient adopted for both the projects is 0.125g. Monitoring of the project sites is being done by a network of seismological observatories. No adverse effect of recent Bhuj (Kachchh) earthquake of 26 January 2001 of magnitude 6.9 (as per Indian Meteorological Department) has been noticed on Narmada and Karjan dams.

6.1 Major problem associated with excavation of the 58m high machine hall (powerhouse cavern) having shallow rock cover in jointed rock mass is that of *stress relief* due to low confining stress. Cracks aligned parallel to the longer axis of the machine hall are developed in the pressure shafts and bus galleries in the absence of adequate supports. This is analogous to the situation of excavating very steep slopes in hard but jointed rock masses resulting in the development of vertical tension cracks parallel to the walls.

6.2 Review of the design supports indicated that 6 to 7.5m long rock bolts initially installed in the walls of machine hall walls were too short. Thus, they could not restrain the deformation of the rock mass and failed to prevent the development of cracks in the walls. Rock mass has not acted as competent structural material after the installation of initial design supports. The remedial supports in the machine hall walls consisted of longer rock bolts (12m) and cables (10.5 to 32m) based on the experience of similar other projects.

7 Problems of rock falls and roof falls were experienced during the excavation of tunnels through dolerite rocks dissected by chlorite-coated joints, shears and slaked zones. About 50% rock bolts were noticed slipped in the slaked/ chloritized zone during tensioning. Failure occurred where removable blocks were present. Installation of pattern rock bolt supports in tunnel sections occupied by large removable rock blocks is questionable. Maximum collapses in the exit tunnel-1 occurred where tunnel is lying parallel to the Akkalbar fault and passing through chloritized and slaked dolerite rock. It would have been preferable to lay the tunnels crossing the fault rather than keeping them parallel to the fault zone and also to avoid slaked zones in the tunnel alignment. However, topography and economy were the governing factors for the layout of these tunnels. Therefore, rib supports were installed in the major part of tunnels. Introduction of rib supports besides providing positive supports removed the fear psychosis among the site staff for working inside the tunnels. The 'Observational Technique' adopted resulted in the timely modification of supports and thus safe execution of these tunnels.

8. Engineering geological study of the Narmada and Karjan dams has shown that large dams can be successfully constructed on weak foundations based on the proper geotechnical investigation and evaluation of each site.