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Geo-Engineering Problems in the Spillway Foundations and Their Treatment at Guhai Reservoir Project in Gujarat, India

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SYNOPSIS: During the initial stage of construction of a 23 m high composite dam across the Guhai river, the downstream dipping sedimentary rock sequence of conglomerate, sandstone and shale resting unconformably over quartzite and schist was encountered as a suprise during the excavation of the foundation. Besides, an 8 to 8.5 m wide major fault zone along with three minor faults running across the dam axis were also noticed. Extensive subsurface investigations to study the nature and characteristics of sedimentary rocks, fault zones, etc. met with in the foundations were undertaken concurrently with the construction activity. As a result, the construction schedule was greatly affected.

The paper discusses the detailed evaluation of the geological flaws by thorough investigation and foundation treatment evolved to safeguard the structure.

INTRODUCTION

Guhai Reservoir Project located about 90 km NE of Ahmedabad city in Gujarat State of India is under construction since 1980 and on completion it would create irrigation facilities to 7111 hectares of land of Sabarkantha district.

The project includes the construction of a composite dam across the Guhai river. The construction of a 23 m high zoned earth dam on the left bank is in progress and the river section is kept open till the construction of a 34.57 m high spillway and N.O.F. structures located on the right side of the river, is over. When completed, the dam will impound 62.34 Mm^3 of water at F.R.L. 173 m. Based on the hydrological study, an 88.72 m long spillway has been provided to negotiate the designed discharge of 4384.92 m^3/s through six radial gates of 6.09 x 9.14 m size.

Geological setting at the dam site is intricate and had played a pivotal role in effecting modifications in design and layout of the project. At the project site, quartzite interbedded with schist belonging to Delhi System is seen intruded by quartz porphyry of post Delhi age. Except the left and right abutment rocky hills, the entire area of the main dam including the river channel is covered with alluvium and sand.

It was only during the construction stage that a sedimentary rock sequence (Cretaceous ?) with a low downstream dip resting unconformably over the Delhi formation and affected by an 8 to 8.5 m wide steep angle fault zone running across the dam axis, was noticed in the foundation. The unconformity is marked by the presence of conglomerate predominantly consisting of pebbles of quartzite and occasional quartz. Unusual geological setting could not be detected during the investigation stage due to the absence of exposures of sedimentary rocks around the dam site and inadequate subsurface exploratory data. Detailed investigations divulged the occurrence of conglomerate, sandstone and shale beds with a low downstream dip associated with clay filled bedding joints and fault zones. Geological setting posed the integrated problems of sliding, settlement as well as seepage and led to the modification in design of masonry dam and proper treatment to weak features encountered.

INVESTIGATIONS

The project was conceived as back as 1954. The details of the core drilling done are given in table 1.

TABLE 1. Details of Core Drilling

Period	No. of holes Drilled	Depth Drilled (m)
1958	2	21.59
1971-72	8	149.34
1980-81	6	143.47
1981-82	23	554.20
1982-83	19	727.23
1983-84	4	71.20
	62	1667.03

GEOLOGY OF MASONRY DAM FOUNDATIONS

The spillway with a non overflow section on the right side has been located hugging the right bank. At the dam site, igneous, metamorphic and sedimentary rocks are met with. The rocks encountered in the masonry dam foundations are quartzite and schist of Delhi System intruded by quartz porphyry of post Delhi age. During the initial stage of construction, when the foundations of the spillway were being excavated an unanticipated sedimentary rock sequence was observed which lies uncomformably over quartzites and schists. The unconformity is marked by the presence of conglomerate (Fig. 1). The description of rock types is given hereunder.

Quartzite and Schist

Quartzite and schist occur as alternate bands. Quartzite bands vary in thickness from 1 to 2 m whereas schist occurs as thin bands having thickness of 5 to 30 cm. These bands strike in N20°-40°E - S20°-40°W direction with downstream dips varying from 45° to 50° towards S50°-70°E direction.

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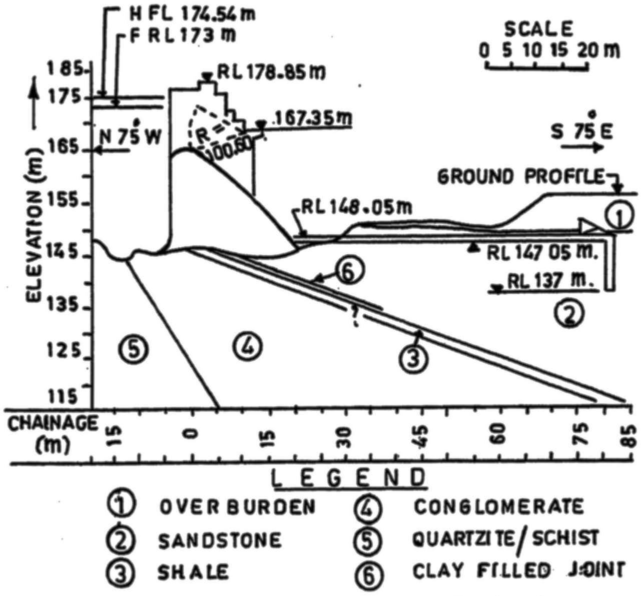

FIG.1: GEOLOGICAL CROSS SECTION

Quartzite is fresh, hard and resistant while schist is comparatively soft. These beds are intruded by quartz porphyry which is not met with in the masonry dam foundations.

Conglomerate

Conglomerate marks the unconformity between metamorphics below and sedimentaries above. Conglomerate seems to have been deposited over the pre-eroded surface of quartzite and schist. It mainly consists of rounded pebbles and gravels of quartzite and at times of quartz having 25 to 40 cm size. The matrix is siliceous. Thin ferrugenous coating is seen along the boundaries of pebbles and gravels. The matrix of conglomerte is somewhat weakened in the close proximity of the faults. Pebbles are sharply cut along the sets of joints developed sympathetic to the faults. At the foundation level and even below it, conglomerate is fresh and hard. The thickness of conglomerate amplifies towards the downstream being more than 45 m at 70 m downstream as compared to 15 m at the dam axis.

Sandstone

Sandstone is fresh and sparsely jointed. However, a few 0.5 to 1.5 cm thick low downstream dipping clay filled bedding joints are observed within sandstone. The interface of sandstone and conglomerate is also marked by the presence of clay at a few spots. Sandstone associated with thin shale beds and lenticular beds of conglomerate is seen deposited over conglomerate. Dip of these beds varies from 25° to 30° towards the downstream.

GEO-ENGINEERING PROBLEMS

During the course of investigation and foundation excavation, certain geo-engineering problems cropped up which stalled the progress of work for a considerable period.

Since the sedimentary rock sequence could be seen only in the river bed during excavation of the foundations, a thorough subsurface investigation became imperative to assess its nature, characteristics, extent, etc. more so because of conglomerate as it is normally known for its pervious and incompetent nature. Extensive subsurface exploration was, therefore, undertaken concurrently with the construction activities (Fig. 2). The exploration revealed the following.

(i) Thin clay beds associated with sandstone and at the interface of conglomerate and sandstone having low downstream dip of 25°.

(ii) Occurrence of conglomerate which was apprehended for its weak and pervious nature.

(iii) One major and three minor faults running across the dam axis with steep to vertical dips (Table 2).

(iv) Discovery of palaeo river channel occupied by 30 to 33 m thick sand between Ch. 630 and 730 m (Fig. 3).

TABLE 2. Details of Faults

Location (m)	Attitude		Width at foundation level (m)	Description of the material
	Strike	Dip		
Ch. 835 (Monolith 2)	N75°W-S75°E	80° on either side to vertical	0.1 to 0.5	Clay with sheared rock pieces
Ch. 861 (Monoliths 3 and 4)	N65°W-S65°E	75° due S25°W	0.2 to 1.0	Predominantly clay with rock pieces
Ch. 871.5 to 880 (Monolith 5)	N75°W-S75°E	80° due N15°E	8.0 to 8.5	4.0 m thick yellow clay and 2.4 to 4.4 m thick zone of sheared conglomerate
Ch. 921 to 922 (Monolith 8-Right NOF)	E-W	80° due North	0.3 to 1.5	Gougy material with crushed rock pieces

INFLUENCE OF GEOLOGY ON LAYOUT AND DESIGN

In view of the integrated effects of the geological flaws, the following modifications in design and layout of the spillway were warranted for its better performance.

Three alternative spillway locations were studied besides the one originally contemplated between Ch. 806.52 and 895.24 m. This study revealed that from all considerations the original spillway location was suitable, hence finally accepted.

At the finally selected spillway location, the sloping cum horizontal apron has been designed and provided instead of roller bucket. This design would shift the scour much away from the toe. Moreover, deeper excavation through rock is avoided which has provided adequate safety against sliding along clay/shale beds.

Earlier five spillway gates of 14.93 x 10.67 m were proposed.

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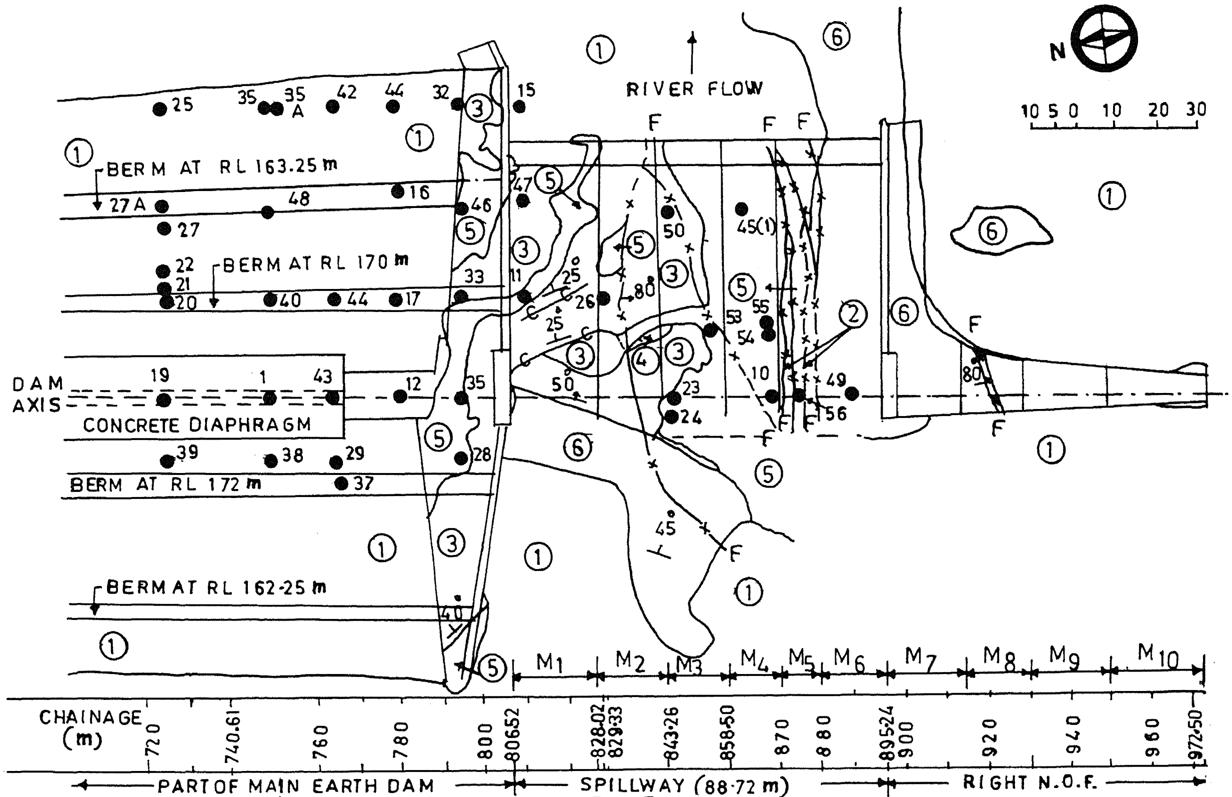
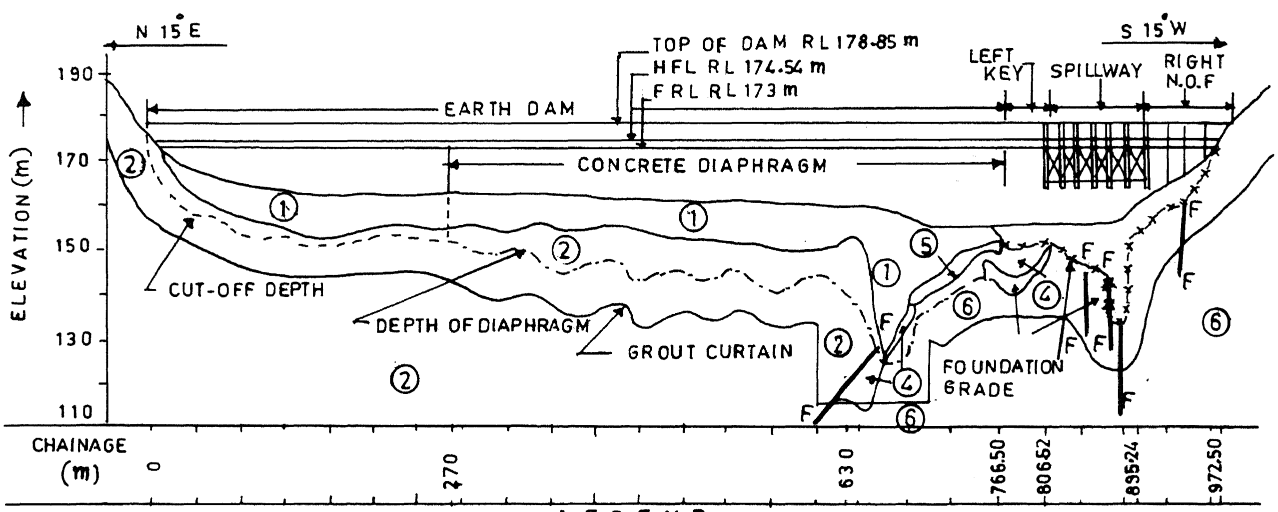


LEGEND

1 OVERBURDEN	4 SHALE
2 BASIC INTRUSION	5 CONGLOMERATE
3 SANDSTONE	6 QUARTZITE/SCHIST
F —x— F FAULT	—C— CLAY FILLED JOINT
● DRILL HOLE	

FIG. 2 GEOLOGICAL MAP OF MASONRY DAM



LEGEND

1 OVERBURDEN	4 SANDSTONE	7 BASIC INTRUSION
2 QUARTZ PORPHYRY	5 SHALE	F/F FAULT
3 CONGLOMERATE	6 QUARTZITE/SCHIST	

SCALE
METRE
10
0 40

FIG.3 GEOLOGICAL SECTION ALONG DAM ALIGNMENT

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Apprehending the weak nature of conglomerate, the number and size of the gates were modified to six of 12.5x8.23 m which reduced the discharge intensity from 76.18 $m^3/s/m$ to 58.53 $m^3/s/m$.

Earlier a separate monolith for the major fault zone had been designed to avoid any differential settlement but later on contraction joints between monoliths 4 and 5 and that between 5 and 6 have been eliminated to have a bridging effect.

PHYSICAL CHARACTERISTICS OF FOUNDATION ROCKS

Physical characteristics of the rocks encountered in the masonry dam foundations have been evaluated for their anticipated behaviour after impounding of the reservoir. The details are enumerated in table 3.

TABLE 3. Physical Characteristics of Rocks

Rock Type	Conglomerate	Sandstone	Quartzite
Specific Gravity	2.5 to 2.7	2.62 to 2.73	2.71
% Water Absorption	0.064 to 0.73	0.26 to 2.13	0.21
Compressive Strength (Wet) (MPa)	65.36 to 147.70	28.56 to 171.44	71.64
% Core Recovery	47 to 100	52 to 100	50 to 100
Penetration Rate (m/hour)	0.30	0.40	0.24
Permeability (Lugeon)	1 to 60	1 to 57	1 to 66

Physical characteristics of conglomerate fairly match with those described by F.P. Pettijohn for ortho quartzitic conglomerate (oligomict). Such conglomerates normally belong to Lower Cambrian age. It is possible to deduce from the above that conglomerate formation occurring at the project site must have been formed during the early geological time (Delhi formation ?) and has attained thorough induration and compaction.

Moreover, the data given in table 3 indicate that the properties of conglomerate, sandstone and quartzite are quite comparable. Thin shale beds occurring within the sandstone are soft to moderately hard in nature.

FOUNDATION TREATMENTS

In view of the foregoing foundation problems, the following curative measures to safeguard the structure have been evolved.

Treatment to the Low Downstream Dipping Clay Bed and Clay Filled Bedding Joints

Low angle (25° to 30°) downstream dipping clay filled bedding joints/shale beds in sandstone were encountered in the spillway monolith 1 and in a part of monolith 2. The mechanical analysis and shear parameters of clay were determined in the laboratory to carry out the stability analysis of monoliths 1 and 2 (Table 4).

TABLE 4. Mechanical Analysis and Shear Parameters of Clay

Location (m)	Grain Size Analysis (%)				Box Shear		Trixial Shear	
	Gravel	Sand	Silt	Clay	C (MPa)	ϕ	C (MPa)	ϕ
Ch. 828 to 829, down - stream 10	05	38	35	22	0.015	21°	0.02	22°

The stability analysis for monolith 1 was carried out on the low dipping clay filled joints taking into consideration the shear parameters C=0 and ϕ = 20°. The values of the sliding and shear friction factors obtained after considering the passive resistance available from the downstream side rock ledge are acceptable.

Treatment to Conglomerate

Conglomerate was apprehended for its weak and permeable nature. Laboratory test results of conglomerate and sandstone samples indicated that the minimum compressive strength in saturated condition is 65.36 and 28.56 MPa respectively which is about 29 times higher than the maximum stress of 0.98 MPa that will be developed after the completion of the spillway. Thus, their relative deformability would also be similarly less in the light of the maximum stress considered in design of the structure.

Usually, the value of bond between good rock and masonry is considered as 0.686 MPa, but due to weak nature of rock this value is considered as 0.49 MPa. Thereby, the values of shear friction factor for all conditions of loading are satisfied. Moreover, to achieve better bond with the foundation rock where conglomerate is exposed a 50 cm thick bottom layer of M 20 (20 N/mm^2) strength concrete has been provided and masonry work was started when concrete was green. Some bond stones have also been inserted in the bottom concrete to have proper bond with masonry. This treatment has been provided in monoliths 3 and 4. Adequate curtain and consolidation grouting has been done to minimise the seepage and to further improve the modulus of deformation of foundation rocks including conglomerate.

Treatment to Fault Zones

(a) The foundations of the spillway monoliths 2 to 5 and 8 are traversed by four steep angle faults (Table 2).

Before finalising the treatment, an in-depth geological investigation of the fault zone in monolith 5 by sinking two inclined and one vertical drill holes to ascertain its thickness, nature of the material, etc. were undertaken. Data obtained from these drill holes indicated that (i) the width of the clay zone below RL 115.85 m reduced and (ii) the fault zone narrowed down at depth and towards the downstream.

Of these faults, those met with in the monoliths 2 to 4 and 8 were minor ones and were given the usual dental treatment. While excavating the trench along the fault zone in monoliths 3 and 4 for dental treatment from 7 to 13 m downstream, the width of the fault gouge increased to 2.1 m as against 0.3 to 1.0 m observed in the rest of the area. Further, the condition of conglomerate constituting the foundations of these monoliths beyond 7 m downstream is also somewhat weakened due to effect of faulting. Keeping in view the above conditions, a concrete plug of M 20 strength was provided in the fault zone trench and due to the increase in the width of the fault zone from 7 to

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13 m downstream, a 1 m thick concrete raft spanning the entire block has been provided to guard against any local differential settlement.

(b) Fault zone encountered in monolith 5 being a major one, elaborate treatment was considered imperative. Because of an 8 to 8.5 m wide fault zone traversing across the dam axis, a separate monolith had been provided. By adopting the Shasta formula for the plug treatment, the depth of excavation worked out to 6 m from the general foundation level at RL 143.5 m. Accordingly, the fault zone material was excavated down to RL 137 m where it was revealed that the clayey gauge was the decomposed product of basic intrusive along the fault zone. The excavated trench has been plugged with M 15 (15 N/mm^2) strength concrete. To transfer the load to the competent shoulders, arch shaped concrete has been done. Hammock reinforcement of 32 mm diameter deformed bars placed at 30 cm both ways has been provided to take care against any settlement. This has been extended upto RL 143.5 m. Above this and upto RL 146 m concreting is done (Fig. 4).

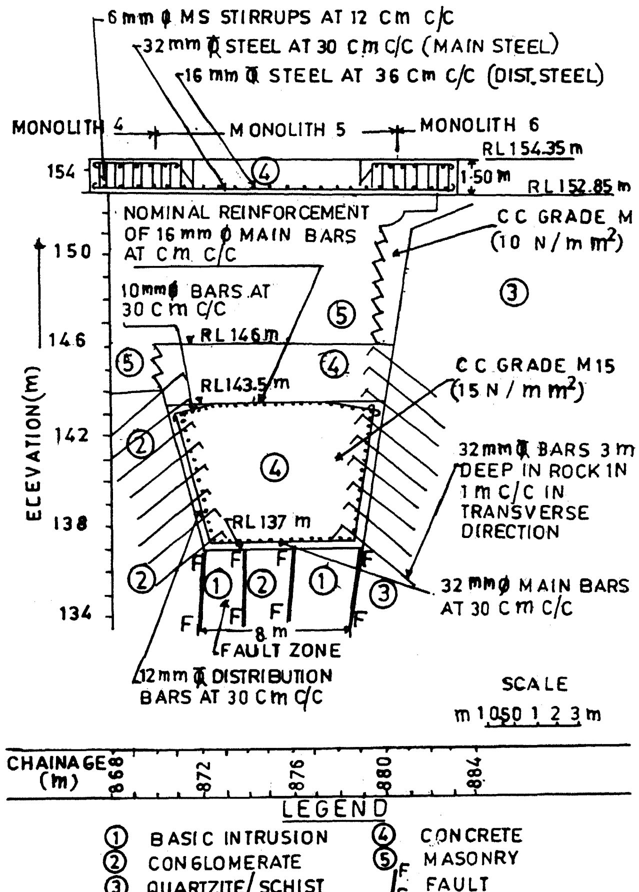

FIG.4: FAULT ZONE TREATMENT IN MONOLITH 5

The left shoulder of the fault zone trench is formed by conglomerate whereas the right one is made up of competent quartzite interbedded with thin schist bands. The sides of the trench were roughened to have proper bond between the concrete and the rock. Contact grouting has also been done to take care against shrinkage, etc.

Plasticity index of the gauge material was more than 15 hence piping is not apprehended. However, to have adequate path of percolation through the fault zone, a 5 m wide upstream cut-off to a depth of 3 m (RL 134 m) below the bed of the trench has been provided. To achieve the desired path of percolation, the plug treatment was extended upto 36 m downstream. The bottom of the trench from 30 to 36 m downstream was kept at RL 139.5 m to avoid dewatering problem (Fig. 5).

Since the horizontal apron beyond the fault zone concrete was to rest on comparatively softer strata, differential settlement was likely. To obviate this possibility, a longitudinal joint with water stop arrangement has been provided in the apron portion of monolith 5 itself.

At the final excavation level of the trench, conglomerate in 2 m width occurred in the central portion of the foundation. It is bounded on both sides by basic rock intrusion of 2 and 3 m width. Basic intrusive rock is highly weathered while conglomerate is slightly weathered and jointed due to the effect of faulting. The contacts between basic intrusion/conglomerate and basic intrusion/quartzite and schist are marked by the presence of a thin layer of clay.

The spillway monoliths 4 to 6 posed unique problems because of - (i) differential foundation levels in monolith 4 (RL 144 m), monolith 5 (RL 137 m) and monolith 6 (RL 152 m), (ii) coincidence of pier location exactly over the contact of monoliths 5 and 6 and (iii) FEM analysis indicated differential settlement of 1.75 cm of the fault zone material at RL 137 m.

Considering these points, R.C.C. slab beam above the fault zone in monolith 5 had been designed and constructed. This raft is 1.5 m thick and provided between RL 152.85 and 154.35 m and has been extended by 2.75 m on either side of the monoliths 4 and 6, thereby affording an adequate bearing to the raft on either side of monolith 5. All the three monoliths have been combined to reduce the load intensity on the foundation rocks (Fig. 4 and 5).

CONCLUSION

For safe and sound design as also timely execution of any irrigation project, thorough prognostications are imperative.

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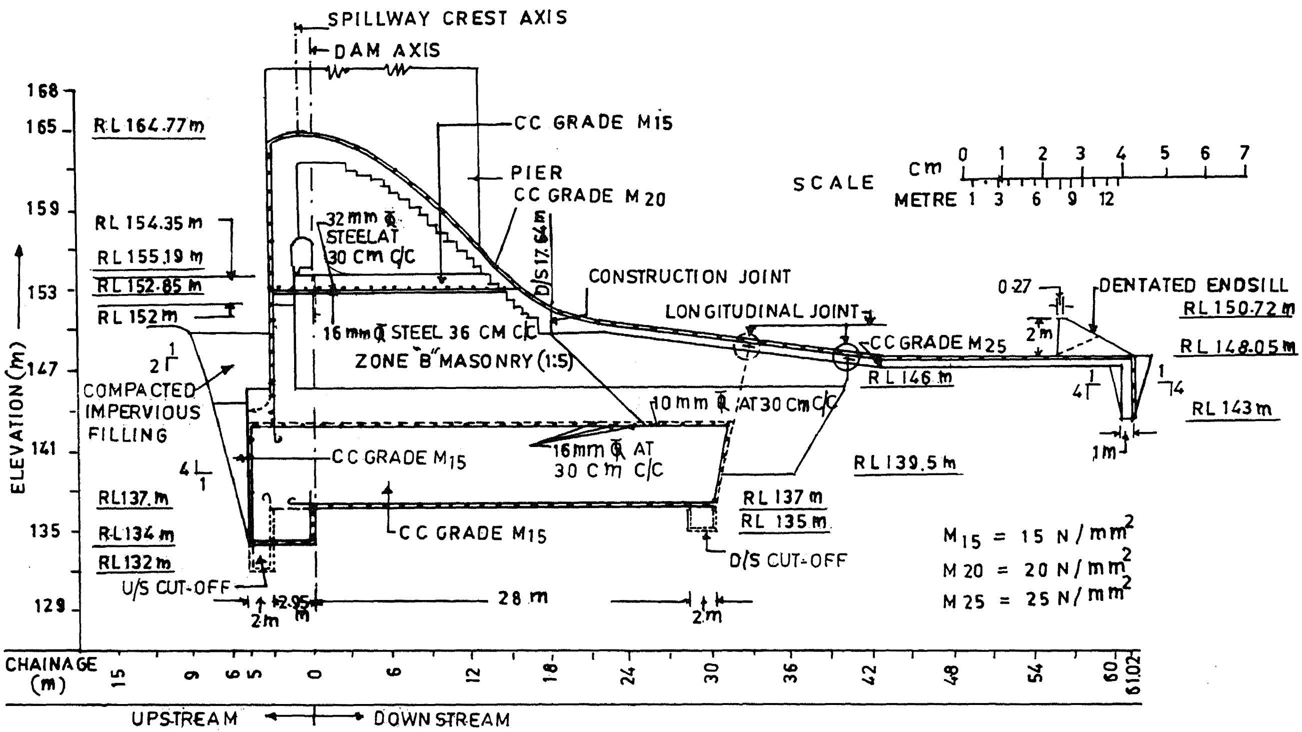

FIG. 5 SECTION OF FAULT ZONE TREATMENT IN MONOLITH 5

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