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# GROUTING TECHNOLOGY FOR REHABILITATION OF TILLAR EARTHEN DAM.

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**ABSTRACT :** Over the last few decades grouting technology has grown into one of the disciplines in geotechnical engineering comprising mainly of foundation treatment of dams and other structures by strengthening or by making them impermeable and has become one of the main tool to rehabilitate the dams structurally. The present case study deals with structural rehabilitation of Tillar earthen dam which was constructed in 1987 but distress signals had started from the first impounding. Highly permeable strata having permeability to the tune of 0.36 x 10-1 cm/sec was existing between the bottom of Cut off Trench (COT) and foundation rock. From this zone water was permeating and causing danger to the stability of the dam. Grout curtain in the permeable zone, below COT bed and upto foundation rock by using the special technique namely Tube-a-Manchatte Grouting was used to reduce the permeability from 10-1 cm/sec to 10-5 cm/sec and also to provide grout curtain in foundation rock upto 7 m depth.

## 1.0 INTRODUCTION.

The invention of pressure grouting is credited to a FrenchEngineer Mr. Charlies Berigny. In 1802 while repairing a masonry wall in Port City of Dieppe by pumping a suspension of clay and lime in the wall he named this process as “ INJECTION PROCESS”. The first cement grout has been used by one Mr. Marc Brunel in the year 1838. Between 1880 to 1905 in Belguim & France cement grouting was increasingly used to control water inflow from fissures, water bearing rock strata, encountered during shaft sinking for coal mines. By middle of 20th Century grouting which was known as an art has become a systematic science. Over the last two decades grouting has grown into one of the disciplines of Geo-technical Engineering and became one of the major tool for foundation treatment of dams and other hydraulic structures and to Rehabilitate the dams structurally.

## 2.0 DAM REHABILITATION.

As far as Rehabilitation of dams are concerned such dams having inadequacies, send signal of distress either at (I) 1st impounding or (2) Due to aging or (3) due to in-adequacies in design.

Dam Rehabilitation is considered for (a) Hydrological rehabilitation or (b) Structural rehabilitation.

The present case study deals with the structural rehabilitation only. Tillar Earthen dam was constructed in 1987 and trouble started from 1st impounding of reservoir in August 1987 itself.

## 3.0 STATISTICS OF TILLAR DAM.

Tillar dam is 2.2 Km. long Earthen Dam with a maximum height of 23.47 m and crosses 6valleys deepest being valley No. IV. This dam is located 88 Km. from Ujjain in Shajapur Distt. of M.P., India. The earthen dam was practically completed in 1987 and constructed out of ML soil with riprap on the U/S face. The foundation rock is Basalt. Cut off trench in earthen dam valley No. IV has been kept at H/2 depth, thus leaving a gap of 2 to 4 M. between COT bed and foundation rock and no curtain grouting below COT was done.

## 4.0 OBSERVATIONS OF DISTRESS.

In Sept. 1987 when water was impounded, on downstream side, there appeared the sheet flow of water. Total such seepage was measured with the help of v-notches to 2 cusecs. The natural ground from toe of the dam on downstream side had become slushy. Conspicuous boiling was also seen at two places in the valley on d/s.

side at RD 1200 m. It was suspected that piping may start and dam may collapse.

4.10 Causes of distress.

(1) Detailed investigations for the dam foundation were not done to completely delineate the permeable stratas and other vulnerable zones before construction of dam was taken up in hand.

(2) Geological report, after getting the drill holes logged by the Geologist was not obtained and designed C.O.T. bed level was not approved by the Geologist.

(3) No water loss tests in the holes drilled were carried out, during investigation stages.

(4) In view of the fact that the earthen dam was crossing six valley, the restricting of the C.O.T. to the depth of H/2 was not desirable.

(5) Highly permeable strata having permeability ot the tune of 0.36 x 10-1 cm/sec were existing between the bottom of C.O.T. and foundation rock. From this zone water was permeating and causing danger to the stability of the dam. This high permeability zone below C.O.T. is shown in Fig. 1. In short it was a classic case of providing depth of C.O.T. upto H/2 depth and not bothering to check up the depth of bed rock and quality of strata below C.O.T. bed.

## 5.0 REMEDIAL MEASURES.

(1) Loading the downstream toe of the dam in the slushy area by providing 1 m thick inverted filter in 15 to 30 m width from the toe of dam.

(2) Relief wells surrounded byfillers in the D/S area near the toe of dam to dissipate the inside built up pressure.

(3) To provide grout curtain in the permeable zone below C.O.T. bed and uptofoundation rock by Tube-A-Manchatte (TAM) grouting to reduce the permeability from 10-1 cm/sec to 10-5 cm/sec.

(4) To provide grout curtain in foundation rock upto 7 m depth.

## 6.0 TAM GROUTING TECHNIQUE OR GROUTING THROUGH TUBES WITH SLEEVES.

TAM Grouting Technique is a grouting method using " tube-a-manchatte " (TAM) for allowing repetitive injection of grout material by stages into the ground having collapsible nature.

This Technique consists of following components as shown in Fig. 2

(1) TAM casing pipe of 40 mm diameter perforated at every 30 cm c/c.

(2) Rubber sleeves cover with perforation on TAM casing pipe.

(3) TAM casing is lowered in 100 mm hole.

(4) Sheath grouting is done around TAM casing in the hole.

(5) A double packer is lowered and fixed on both sides of rubber sleeve inside the TAM casing.

(6) A grout of cement bentonite is pumped through packer, sheath is cracked and grout spreads in the surrounding strata to make it impervious.

(7) Same process is done on other sleeves.

## 7.0 IDENTIFICATION OF GROUT MATERIAL AND MIX DESIGN OF GROUT.

Various points governing the selection of grouting materials are as follows.

(1) Grain size distribution of strata to be grouted.
(2) Grain size of grouting material
(3) Viscosity of grout.
(4) Resistance to corrosion of grout.

Following table given in Indian Standard 4999 (1991), explains that cement has to be used as grout material. For alluvial grouting to make the cement grout as colloidal, bentonite is required to be added. Hence combination of cement-bentonite is tentatively selected as grouting materials.

| Grout | Material Grouted | Finest Size that can be grouted Mm | Permeabilty |
|---|---|---|---|
| Cement | Fissuress | 0-10 | K>1 cm/sec. |
| | Loose sand | $D_{10}$=0.5 | |
| | Dense sand | $D_{10}$=1.4 | |
| | Soil | $D_{10}$=0.75 to 1 | |
| Caly | Soil | $D_{10}$=0.2 | $K>10^{-1}$cm/sec |
| Silicates | Soil | $D_{10}$=0.1 | $10^{-1}>K>1^{-3}$cm/sec |
| Chemical | Soil | $D_{10}$=0.1 | $>K>10^{-3}$ cm/sec |

Grout material particles should not be more than 1/10th of D-10 size of soil strata to be grouted. The criteria D85/D15 < 1/20 is also in use. These criteria should be used as guide only, especially when grain size distribution is irregular and gaps are present in the grading.

### 7.10 Final Selection of Grout Materials.

There are two criterias for grain size in selection of grout material.

(1) For D85 value of grout material and D15 value of material/strata to be grouted, it is generally considered that D85/D15 < 1/20. Particle size of D85 of bentonite is 0.002 mm, whereas, D15 of soil at RD 1411.50 m from RL 422.50 m to 421.50 m was found as 1.35 mm hence D85/D15 = 0.051/ 1.35 < 1/20. Thus criteria is satisfied.

(2) Particle size of grout material should not be more than 1/10th of D-10 size of soil strata to be grouted is the second criteria.

In this case D-10 is 1.35 mm

And $1/10^{th}$ of 1.35 mm = 1.35/10 = 0.135 mm > Particle size of grout material i.e. cement 0.051 mm

(Cement particle size < 0.051 mm)

Hence, Cement – Bentonite grout material satisfies both the criteria.

## 8.0 MIX DESIGN OF GROUT.

It is essential to establish a field laboratory at site and extensive experiments are to be conducted by using various combination of mixes and different proportion of cement bentonite and water. Following equipment are needed for field laboratory.

- Triple beam balance accuracy 0.1 gm.
- 1000 cc, 500 cc & 100 cc corning glass measuring cylinders (2 each)
- Corning glass beakers and glass rods.
- Laboratory type stirrer with cone and baffles.
- Marsh cone 4 nos. (1 for Lab and 3 for the Field).
- Stainless steel container of 2-3 liters capacity.

Bentonite from Kutch area of Gujrat State in India only has been used for this work because of its good quality and comparative consistency in quality.

A test plot of 15 m length is selected and grout of various proportion of cement bentonite and water are tried and pumped through the sleeves to find out the acceptability of grout at the lowest pressure.

The proportion of cement bentonite and water was controlled in such a way that bleeding is restricted to less than 5 %. Three consistencies of grout, thinner, medium and thick grout were designed in the field laboratory and are designated as A, B and C grout. The proportions of these components are mentioned below :

| | Cement | Bentonite | Water | Viscosity Marsh Cone |
|---|---|---|---|---|
| Best combination (A) | 1 | 1.2 | 15 (Thin) | 30 seconds |
| (B) | 1 | 0.9 | 10 (Medium) | 32 seconds |
| (C) | 1 | 0.7 | 8 (Thick) | 34 seconds |

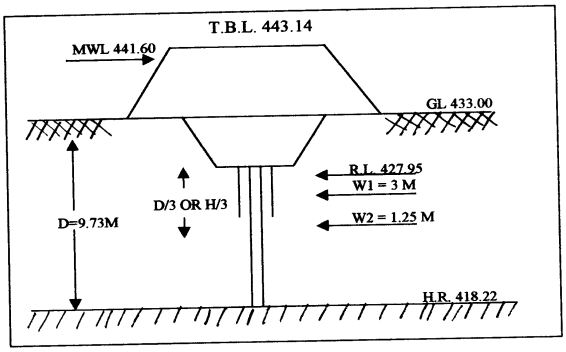
## 9.0 DESIGN OF GROUT CURTAIN.

For alluvium/pervious soils, multiple rows of holes for grouting is necessary for effective curtain against the seepages barrier which shall have long life for narrow width of grout curtain. There looms large danger of curtain being eroded due to leaching and natural erosion owing to constant flow of water. Width of grout curtain is very important paramater for long term performance of grout curtain.

DESIGN OF WIDTH OF GROUT CURTAIN.

Curtain width has been chosen as per Indian Standard 11293 (part I) – 1985 Para 2.3.1. The curtain width at the core contact should match the core base. Usually H/3 is provided.

Typical cross section – RD 1425 M.




Curtain width at core contact : W! = H/3 TO H/5 = 8.6/3 W1 = 2.86, Say = 3.00 M.

Hence, to achieve 3 M width of grout curtain (W1) we may consider 2 rows of grout holes.

The main curtain should extend up to roof or impervious stratum. The width should be reduced from the width core contact to the main curtain width.

The curtain width at core contact (W1) = 3M should be reduced to width W2. For economical grouting the main curtain grout i.e. W2 should have a width of 1/7th head, which works out to 8.60/7 = 1.25 M. But in case of Tillar dam there is a sand gravel horizon lying between R.L. 418 to 422 M. just above igneous formation. In this tuype of strata minimum width has been kept uniform as 3 M from bottom of C.O.T. to impervious hard rock. The curtain width W1 is therefore, adopted same i.e. 3 M.

Hence, three rows at 1.5 M centre to centre and each holes in a row shall be 3 M C/C apart, in staggered manner in each row shall serve the purpose.

10 DETAILS OF EXECUTION OF GROUTING PLAN.

The execution of this grouting plan can be divided into following main operations :

(1) Drilling holes to provide TAM casing pipes.

(2) Drilling and conventional grouting (curtain grout) in the foundation rock upto 7 M depth.

(3) TAM casing to lower down in drill holes.

(4) Sheath grouting of TAM casing.

(5) Installation of piezo-meters.

(6) TAM grouting.

10.10 <u>Drilling holes to provide TAM casing pipes.</u>

(1) From top of dam, 100 mm diameter hole is drilled at the desired location by rotary-cum-percussive drilling rigs to the full depth of alluvium and 0.5 M in rock.

(2) M.S. casing of 80 mm is lowered in the hole immediately.

10.20 <u>Drilling and conventional grouting (Grout Curtain) in foundation rock – 7 M depth.</u>

(1) Through 80 mm casing pipe, a grout curtain is being provided in the foundation rock upto 7 M depth. For this 51 mm bore hole is drilled through 80 mm casing pipe in the foundation rock by percussion drilling rig. After drilling, hole is washed thoroughly with jet of air and water.

(2) Pre-grout water test is taken in 7 M depth hole by providing single packer in the rock.

(3) After water test, through the same single packer, conventional grouting is done by using neat cement slurry. Thus a grout curtain below C.O.T. in the rock foundations is completed upto a depth of 7 M.

10.30 <u>TAM casing.</u>

TAM casing consists of 40 mm M.S. pipe (Tube) which is cut to length of 1.5 M each. At every 30 cm interval 10 mm drill hole – 4 Nos. are done on the periphery of TAM casing in the whole length. Rubber sleeve (manchettee) of 40 mm inner diameter and 100 mm length is then slipped on the casing pipe so as to cover 4 Nos. of small drill holes at every 30 cm. in the entire length of casing pipe. This TAM casing fitted with rubber sleeve is pre-determined in length in such a way that it extends 0.5 M in foundation rock and 1 M above the COT bed. Above this level 40 mm dia M.S. ordinary casing, is screwed to TAM casing and the whole outfit is lowered in the 80 mm casing pipe.

10.40 Sheath grouting of TAM casing.

Sheath grout is a mixture of cement water and bentonite prepared in a high velocity concrete mixers. The proportion of sheathgrout is kept in such a way that its compressive strength is around 2 tons/M2. Sheath grout is pumped in the bore hole (through 80 mm casing pipe) through a 20mm dia. pipe lowered in the bottom of the hole and grout is let out at the bottom. Simultaneously 80 mm casing pipe is lifted and taken out of bore hole. This sheath grout surrounds the 40 mm TAM casing pipe and fills annular space between TAM casing and inner side of 100 mm hole. Hole is filled by grout upto the top. After 24 hours whatever sheath grout has settled in the hole, has been refilled upto the top.

10.50 Installation of piezometers.

The four piezometer lines have been installed at various RD's with 6 piezometer in each line i.e. 2 Nos. piezometer on upstream of grout curtain and 4 Nos. piezometer on the D/S of grout curtain, in all 24 Nos. piezometer were installed prior to start of TAM grouting. Type of piezometer installed were porous tube type.

10.60 TAM grouting.

The details of various components of this grouting system are as under :

(1) High speed mixers for mixing of cement and bentonite with water. High velocity mixers known as colcrete mixers are used. It is imperative to use these mixers to make the grout colloidal with practically no bleeding (lees than 5 %)..

(2) Double Drum Agitator : From colloidal mixer, grout is taken to double drum agitator. They are basically spedal mixer run by compressed air motor or electrically operated motor.

(3) Electrically operated double cylinder pumps have been used to pump the grout in the hole. These pumps are reciprocating, piston type, capable of producing 50 Kg/cm2 pressure and having a pumping capacity of 100 to 300 Lit./Minute liquid in the hole.

10.70 Process of grouting.

The grout pattern and design of grout curtain has already been dealt with earlier. A pre-determined quantity of grout is required to be injected through each sleeve. The quantity of grout is calculated on the basis of 60% of soil volume covered by each sleeve. Here in present case it comes to 810 Lit. of grout, required to be pumped through each sleeve. Generally, alternate holes are taken up for grouting in both the outer rows first. A double packer is lowered in the hole and is installed in such a way that rubber sleeve is located in the center of double packer. Grouting is done first in the lowest sleeve of the hole and after completion it is done upward, sleeve by sleeve, lifting the packer from lower sleeve to the one above.

While grouting, first of all sheath has to be cracked by high pressure grouting. Some times high pressure upto 24 Kg/cm2 has been used to crack the sheath. Once the sheath has cracked grouting pressure drops down immediately. However, once sheath has cracked, grouting pressure should be raised slowly to keep the constant intake of grout in the hole. Pressure more than 5 Kg/cm2 at gauge is not advisable, to avoid any hydraulic fracture of the strata.

Once holes of outer rows are completed for length of 30 M, central row holes have been grouted by adopting similar process for entire distressed length of the dam.

11.0 REVIEW OF POST GROUT RESULTS.

Post grout permeability.

(1) For finding out the post grout permeability in the reach from RD 1140 M to 1500 M, eight No. bore holes were drilled by using diamond drilling machine. These bore holes were done at RD 1170

M, 1201.5 M, 1365 M, 1410 M, 1440 M, 1455 M, 1470 M & 1494 M.

(2) Precautions were taken that bore holes were drilled not earlier than 28 days of completion of grouting in the area.

(3) Permeability test were taken at every 0.5 M depth in critical strata and 1.0 M depth in other strata. The results were computed in cm/sec.

(4) It may be observed that permeability of entire reach from RD 1140 M to 1500 M has been reduced from 10-1 cm/sec. to less than 10-5 cm/sec. These permeability result were obtained by performing cement bentonite grouting in the soil strata, without using the silicate grouts.

## 12.0 PIEZOMETRIC OBSERVATIONS – POST GROUT.

As already discussed four piezometer lines have been installed at RD 1155 M, 1185 M, 1335 M and 1485 M, with 6 piezometers in each line i.e. 2 piezometers on upstream of grout curtain and 4 piezometers on the downstream of grout curtain. Pre-grouting piezometric observation were made regularly and recorded. To study the behaviour of piezometers, pre grout mean hydraulic gradient is drawn from the reading of piezometer.

It is essential to extend the hydraulic gradient line upto 90 M downstream of curtain by linear interpolation of hydraulic gradient line from the readings of four piezometers installed in downstream. The mean hydraulic gradient line is to be drawn on the sheet. It was observed that the drop of head across the curtain was 88.85% at RD 1155 M, 76.39% at RD 1135 M, 80.38% at RD 1335 M and 88.44% at RD 1485 M of the differential head indicated bythe difference in piezometer level at 15 M upstream of centre line of curtain and 90 M downstream of the centre line of curtain. It may be observed that drop of head across the curtain formed is more than 80% practically in entire length of grouted zone from RD 1140 M to 1500 M. Cross-section of one piezometer line showing various location of 6 Nos. of piezometer and its hydraulic gradient is shown in Fig. 3.

## 13.0 AUTHORS CONCLUSIONS AND RECOMMENDATIONS.

(1) The permeability of the critical strata reduced from 10-1 cm/sec. to lesss than 10-5 cm/sec by TAM grouting technique, using cement bentonite as a grouting material.

(2) No silicate grout was required to be used as second phase of TAM grouting for this particular dam. However silicate grout may be used in other projects, depending on grain size analysis of strata.

(3) The seepage through body/foundation of dam has reduced from pre-grout seepage of 2 cusecs to practically nil.

(4) It is very important to install piezometeric lines at every 100 M. c/c across the axis of the dam and each piezometric line should have 6 Nos. piezometers, 2 on the upstream and 4 on the down steam side to the grout curtain before grouting plan is embarked on.

(5) The drop of hydraulic gradient across the grout curtain is more than 80 % of the differential head, measured at 90 M from the grout curtains.

<u>References.</u>

Indian Standard – 4999 (1991) , Indian Standard 11293 (Part-1) – 1985

Observation and reports of Dam Review panel, Govt. of M.P, India on Tillar Dam.

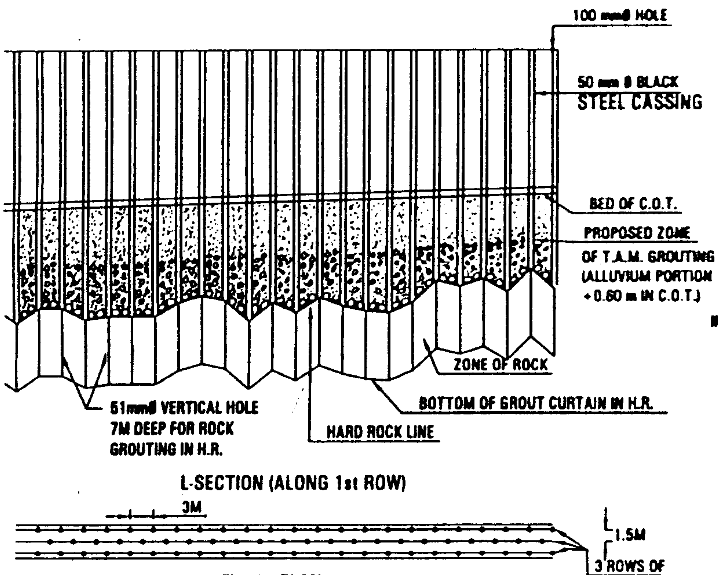



Fig.-1 PLAN

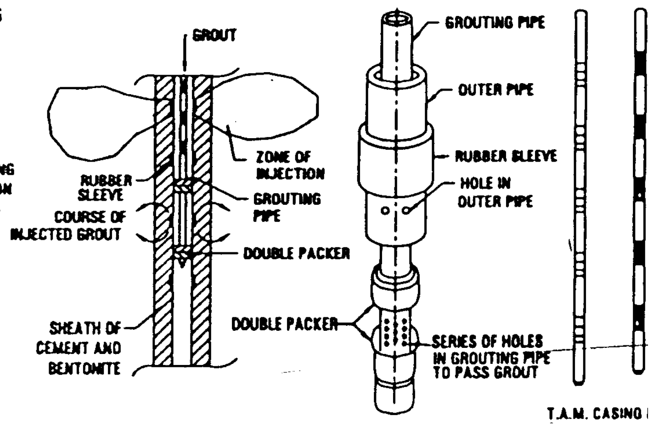



Fig.-2

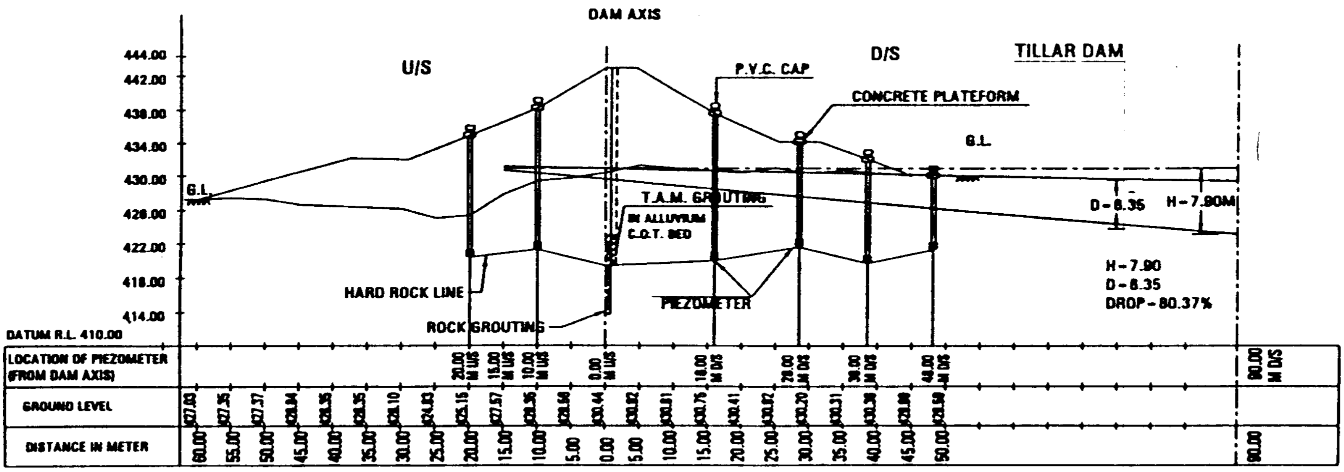



Fig.-3 CROSS SECTION AT R.D. 1335M