PERFORMANCE OF DAM AND FOUNDATION SYSTEM – CASE STUDY OF CONCRETE GRAVITY DAM OF SRINAGAR HYDROELECTRIC PROJECT, INDIA

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ABSTRACT

The 93m high Curved Concrete Gravity Dam of Srinagar Hydroelectric project is located near the Srinagar town on the Alaknanda River of Uttarakhand state. The project is a run-of-the-river scheme with an installed capacity of 330 MW. The dam crest length is 248m and consists of 08 nos. of Spillway-gates and has been designed to facilitate 26400m³/sec design flood. The dam and its adjoining structures have been founded on the inter-beds of Quartzites and Metabasic rocks of Garhwal groups of Precambrian age. The main dam-structure is curved in draft plan and consists of 15 blocks from the left abutment to the right abutment. Block no. 1 to 3 and 13 to 15 are non-overflow blocks, whereas block no. 4 to 12 are overflow spillway-blocks. These blocks transfer the dam-load vertically to the foundation and transversely to the abutment. The dam has been commissioned in the year 2015 and the project is operational.

Close surveillance and monitoring was carried out to understand the foundation and structural behaviour of the dam during its construction and the first filling of the reservoir. This paper presents an analysis of "Geotechnical Instrumentation Data" with a view to checking up behaviour and performance of the foundation and the dam body during its construction and the first filling of the reservoir.

Keywords *: Dam Foundation, Instrumentation & monitoring, structural behaviour, Reservoir filling.*

1. INTRODUCTION

The Concrete Gravity Dam of 330 MW Srinagar HEP is designed to impound a reservoir for diurnal storage for peaking purposes. The dam is expected to safely withstand the forces created by the impounded water, silt and earthquakes. It is therefore important to monitor and gather information to assess the performance and continued assurance of the safety of the dam during construction, first filling of the reservoir and during long the term service operations.

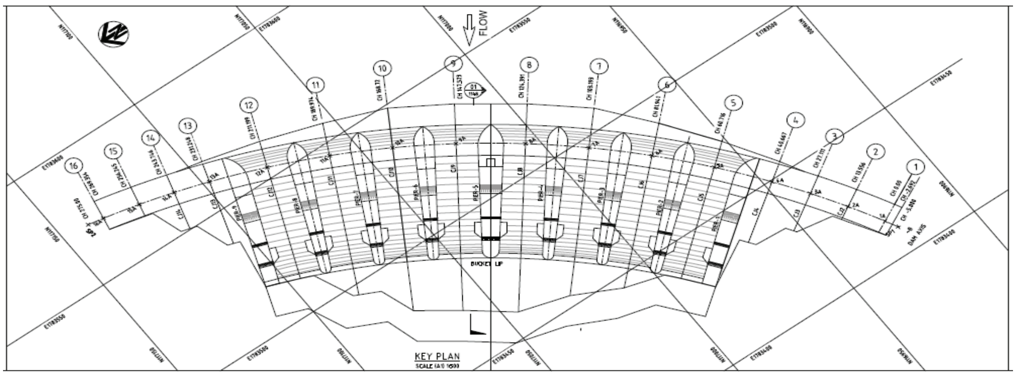


Figure 1 : Plan of Srinagar Concrete Gravity Dam

The structural behaviour and "foundation performance" of Srinagar Dam, during the first filling of the reservoir phase, was analysed using in-situ monitoring techniques.

A. B.

C. D.

E F

Figure 2 : Construction Phases of Srinagar Dam,

A. Excavation of Dam Pit, B. Concreting at Dam Foundation Blocks. C. Concreting of Dam Spillway during Monsoons season, D. After Monsoon season. E. Dam upstream face D. Dam downstream Face.

2. DAM FOUNDATION

The dam is founded on a complex folded-and-fractured sequence of Quartzite and Metabasic rocks of Garhwal Group. The trends of rock formation vary between N40E-S40W to N60E-S60W. Both the rock-units have undergone at least two generations of folding which are coaxial and plunging, at 70 degree to 85 degree in the northerly direction.

Detailed geological and geotechnical mapping of the dam foundation was carried out after reaching the foundation level. While carrying out geological mapping, the whole dam foundation was mapped with 1m grid marking at the exposed rock. All exposures was studied in detail, taking into consideration the record of the various geo-technical parameters along with the discontinuities that dissect the rock mass. The data was recorded and prepared on the international standards and utilized for geo- mechanical classification of the in- situ rocks. The weak zones/ seams and fissures of the dam foundation were treated with suitable measures and the entire dam foundation were consolidated with cement grouting.

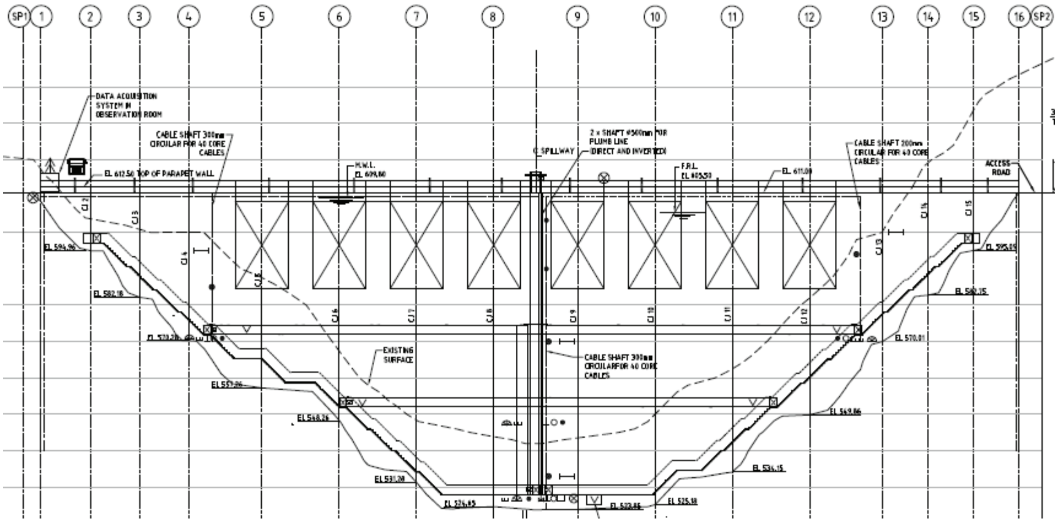


Figure 3 : Dam Instrumentation and monitoring section

3. DAM INSTRUMENTATION

A wide variety of geotechnical Instruments have been provided for in the dam body at the overflow (Block -8) and non-overflow sections (Block 4 & 12), in order to monitor the movement, pore pressure and uplift-pressure, water level and flow, seepage flow, temperature- gradient, movement of concrete joints, seismic events, stress and strain etc. Similarly the monitoring system of the Srinagar dam consists of several devices, which make it possible to measure, such as concrete and air temperature, reservoir water level, seepage and leakage, displacement of the dam and its foundation, joint movement, stress and strain in the and pressures.

4. MONITORING MECHANISM

The first filling of the reservoir is the most critical phase of a dam's life. Therefore, the data of the instruments installed at Gravity Dam were monitored in 3 shifts on daily basis to study the behaviour of the Dam and its Foundation system.

The instruments installed in the dam are mostly embedded in various groups of the respective blocks along with the ones installed on the surface. In the Overflow block -8, five groups of stress meter, strain meter, no stress-strain meter and pore-pressure meter have been installed at EL 526; and three groups of the same instruments were also installed at EL 547m. However, in the non-over flow block 4 & 12, three groups of stress meter, strain meter, no stress- strain meter and pore-pressure meters were installed at EL 570m.

5. MONITORING DURING CONSTRUCTION

The monitoring of the dam was started right from beginning of the dam construction. The dam monitoring was started with the installation of few Piezometer on the right and left abutments to measuring the ground water level upstream and downstream. The results of these measurements for checking the movement of ground water, during construction, were used for control to provide of a dry dam pit during excavation and concreting.

Figure 4 : Dam before Reservoir Filling

Figure 5 : Dam after Reservoir Filling

To monitor temperature changes in the concrete is very much crucial, keeping in view the risk of thermal cracking. For the purpose, 40 nos. of temperature gauges were installed at overflow and non-overflow blocks at different levels. The temperature of concrete at the time of placing was supposed to be in the range of +10 degree to +20 degree; and the growth rate of temperature in the concrete during hydration process was not to exceed the limit of $+40^0$. And the maximum temperature difference between poring and maximum growth temperature were recorded within 20^0.

6. PERFORMANCE OF DAM DURING FIRST FILLING OF RESERVOIR

The performance of the dam and its foundation system was examined on the interpretation of the dam instrumentation data of over flow section for reservoir level 590 to 603m. Holding time was also provided at every 1m increase of reservoir level in order to give the response-time to the structure and instruments. The response time of structure and foundation system was also recorded at each holding level.

6.1 Uplift Pressure

The uplift pressure-distribution, along the horizontal section through the dam, is assumed to vary linearly from full reservoir pressure at upstream heel to the tail water head at the downstream toe, provided the drains are not present. If drains are present, the recommended uplift pressure at the line of drains is equal to the hydrostatic pressure at the toe, plus 1/3rd of the difference between hydrostatic pressure at the toe and at the heel.

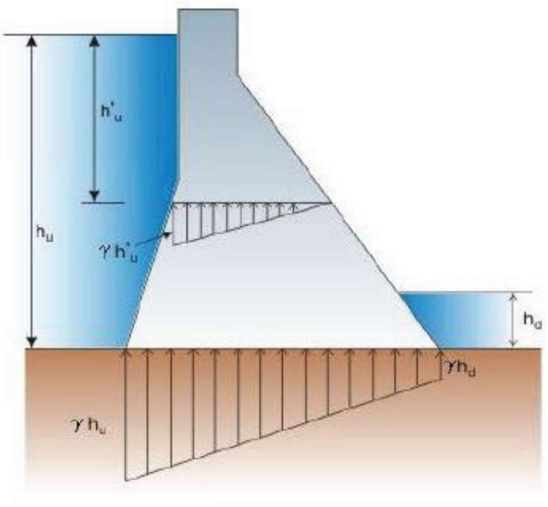


Fig. 6 : Uplift pressure without drain holes

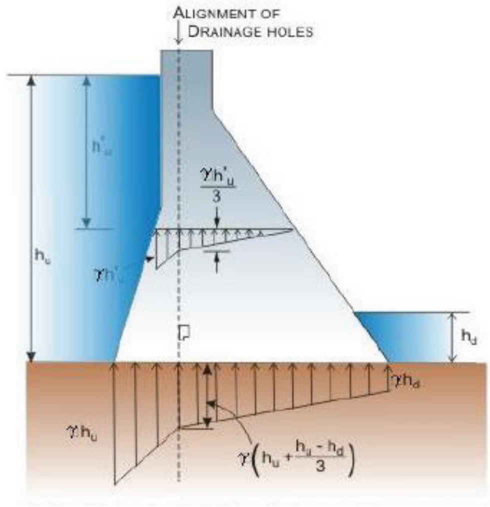


Fig. 7 : Uplift pressure with drain holes

Uplift-pressure at the dam foundation was analyzed with the changes in reservoir level from EL 590 to 603m. The minor increase in uplift-pressure between 0.2 to 0.23 kg/cm^2 was recorded near the drain-hole and the heel of the dam, and the uplift-pressure was found almost constant at the toe of the dam vis-à-vis the increased water level. This was because there were no changes in tail water level. As the seepage water from the drains was also found increasing, indicating effectiveness of drainage system of dam foundation

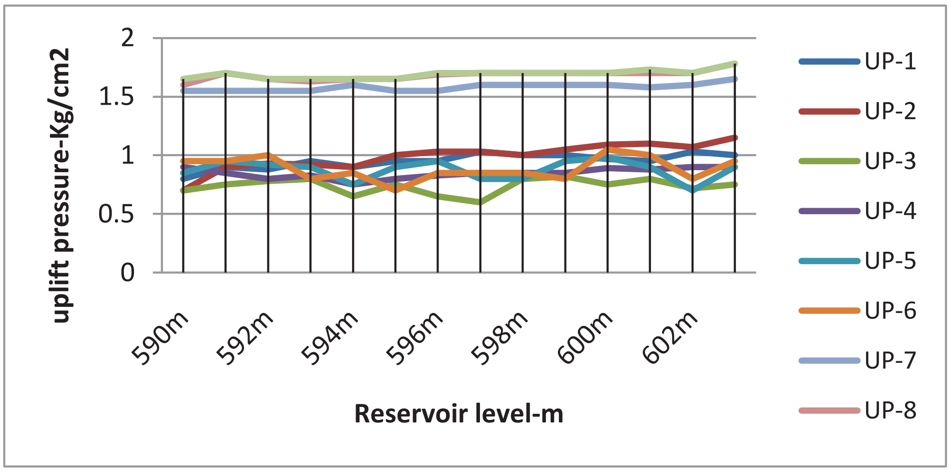


Fig. 8 : Uplift pressure at different reservoir level

Considering the above design-operating parameters with existing head water (EL 603m) and tail water level (El 550m), the uplift-pressure at downstream toe of the dam should not be more than 2.4 kg/cm^2. However the uplift-pressure near the drains should not be more than 4.1kg/cm^2 , when drains are functioning.

The increased uplift-pressure at, the Dam heel was recorded 0.2 to 0.23 kg/cm^2 and the Uplift-pressure increased at toe was recorded nil. However, recommended uplift-pressure at the heel for the existing reservoir level (603m) was 4.1kg/cm^2 and recommended uplift-pressure at the Toe for the existing tail water level (550m) was 2.4kg/cm^2. Therefore, the uplift pressure was found safe within the design limit.

6.2 Pore-Pressure

The response of pore-pressure, with variations in head water, and tail water was analyzed, and it was found that the pore pressure at upstream part of the dam body increased 1.3 kg/cm^2 with reservoir level variations from 590 to 593m; and no change in pore-pressure at downstream part of the dam was recorded with reservoir level changes.

Pore-pressure increase at upstream part was recorded 1.3 kg/cm^2. Maximum pore-pressure recorded at the heel of the dam 3.3 kg/cm^2, was found less than the differences of hydrostatic pressure of the toe and heel of the dam (5.3kg/cm^2). Response time of increased pore-pressure, with increasing reservoir level, was found 48 to 72 hrs. Pore-pressure within the dam body was found within the design limit.

6.3 Ground Water Level

The response of ground water level at both the abutments, due to change in reservoir water level, was analysed with the help of the standpipe piezometer data. It was found that the ground water level of the left abutment increased to 10.13m. However minor changes in the ground water level were recorded (0.4m) at the right abutment, with the increasing reservoir water level from 590 to 603m.

The status of all the drainage holes, below the El 603m at both the abutments, was analysed to correlate the existing ground water level with changes in drain hole flowing condition, and it was found that the drain-holes, started flowing with the increase in the water level.

The response of ground water level to the increased reservoir water level, was analysed; and it was found that the response of ground water level was slow at the right abutment, indicating less seepage at the right abutment from the reservoir. However, the response of ground water level was found fast at the left abutment indicating higher seepage rate at the left abutment from the reservoir compare to that of the right abutment.

In the above analysis, it was found that the seepage rate at the right abutment with the increasing reservoir level, was found very less compared to that of the left abutment. The response time of increased ground water level was found almost 10 to 12 hrs.

6.4 Seepage at Dam Foundation

Seepage from the dam body and dam foundation was recorded with the help of two seepage measuring devices installed at the dam gallery. The minor changes in seepage were recorded vis-a-vis the increasing reservoir level 590 to 603m at the right abutment. However, the seepage rate with increased reservoir level, was found on the higher side, at the left abutment. The maximum increased seepage, recorded was 688.2LPM, The total seepage at the dam gallery for the reservoir level EL 603m was recorded as1558.2LPM.

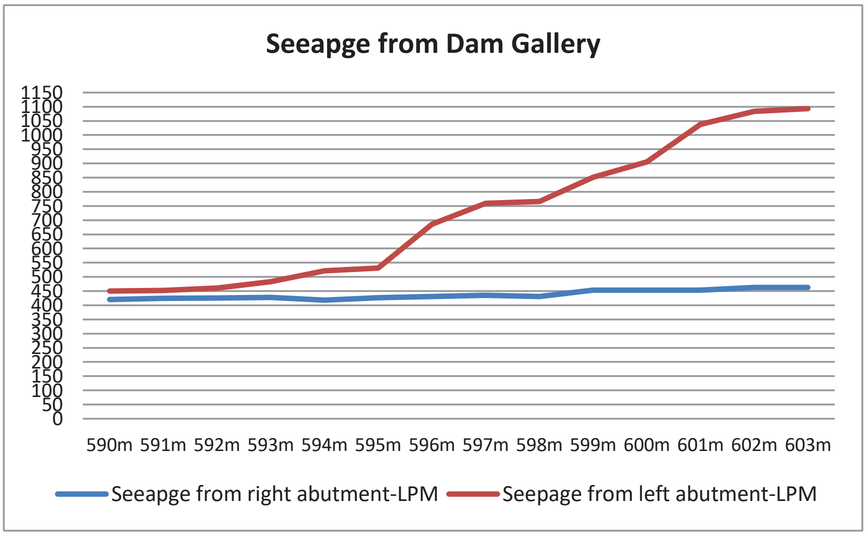


Fig. 9 : Seepage at Dam Gallery with reservoir level

The maximum share of seepage has been recorded from the foundation drain holes and porous drains provided in the dam body. Seepage from few block joints was also recorded at the dam gallery and the D/s face of the dam. The status of all the drainage holes below 603m was also checked and it was found that out of 42 drainage holes, 32 drainage holes were found in flowing condition.

6.5 Thermal Gradient

The distribution of temperature at the dam body and its correlation with the ambient air-temperature and reservoir water temperature, was analysed. Temperature of the dam body at the bottom level was found almost constant during the reservoir-level changes, only the temperature meter installed at 40m D/S of the dam axis showed the low temperature compared to other surrounding temperature meters. The reason for low temperature record indicated the seepage water flow. In this location, the recorded temperature was found matching with the river water temperature.

The temperature of the dam body at different levels was also checked and it was found that the d/s face of the dam is impacted mostly by solar radiation and air temperature. The recorded temperature above the tail water-level, matching with average daily air temperature, leads to non-uniform distribution of temperature along different levels. However, the recorded temperature below the tail-water level matched with the river water temperature.

The thermal gradient of the reservoir was checked, with the recorded temperature of the seepage-water from the porous drains at different levels in the dam gallery, and it was found that the temperature of the reservoir, increasing with depth, varied from reservoir level 603 to 528m, found almost 120c during winter season. However, during the summer, the temperature variation in reservoir level was recorded from 603 to 528m, found almost 1^{o}C. It was also observed that up to initial 10m depth, there were no major changes in reservoir temperature. This was due to impact of air temperature and inflow of water.

Considering the general trend of annual reservoir temperature, it was found that the temperature fluctuation was higher at the top surface (considering winter & summer air temperature), whereas, at the middle to bottom level, the temperature variation was minor.

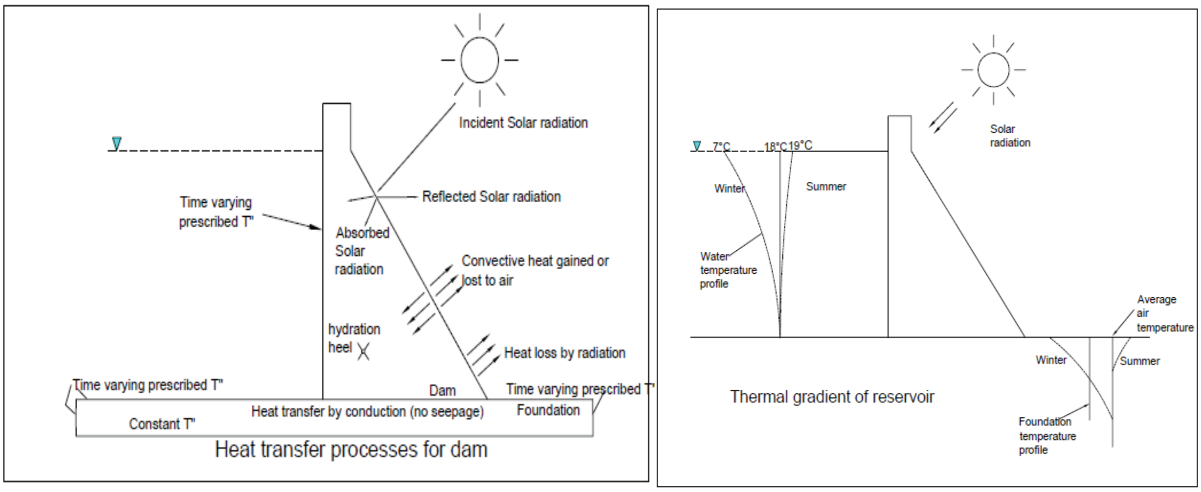


Fig. 10 : Thermal Gradient of Reservoir

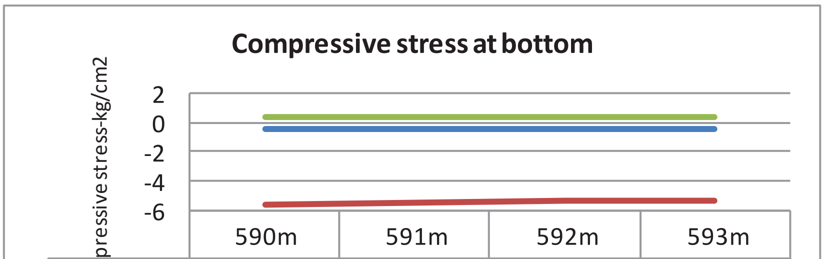
Air temperature difference on the analysis day was 10 to 23^{0}C. Reservoir temperature difference from EL 593 to 526m was recorded 13.2 to 17^{0}C. The dam body upstream faced temperature difference from EL 593 to 526m, recorded 13 to 17^{0}C. Maximum temperature at the dam core was recorded as 20^{0}C. The dam body downstream faced temperature difference above TWL (EL 592 to 550m), recorded 13 to 14^{0}C. and the dam body downstream faced temperature difference below TWL (EL 550 to 526m) recorded as 8 to 17^{0}C.

6.6 Compressive stresses at Dam Body

Stress meters have been installed at different levels of the dam to measure the compressive stress in the dam body. The stress at the overflow block no-8 was analyzed. The recorded compressive stress was found decreasing with the changes in reservoir level from 590 to 593m. The compressive stress at EL 526m and EL 547m was found decreasing by 0.2kg/cm^{2}.

As per the design operating parameters and IS6512-1984 the allowable working stress in any part of the structure should not exceed 70kg/cm^{2} (7N/mm^{2}). And as per USBR manual, the permissible compressive stress for normal loading condition should not be more than 5MPa (for M 15).

The change in compressive-stress correlated with changes in strain distribution pattern at the same location, and it was found that the strain at vertical and cross vertical direction (d/s) changed with reservoir level changes. The changes in strain pattern at the same location confirmed the redistribution of strain due to changes in the reservoir level. The recorded value of compressive stress at different levels was, again, found less than the permissible value.



	590m	591m	592m	593m
STM-1	-0.4	-0.4	-0.4	-0.4
STM-3	-5.6	-5.5	-5.4	-5.4
STM-4	0.4	0.4	0.4	0.4

Fig. 11 : L Thermal Gradient of Reservoir

Compressive stresses decreased by 0.2 to 0.3 kg/cm^2. The maximum compressive stress at the bottom (El 526) was recorded 5.6 kg/cm^2. Prescribed limit of compressive stress (M15 Concrete) was 50kg/cm^2 for the usual loading condition. One limit of compressive stress (M25 Concrete) was 83 kg/cm^2 for usual loading condition.

6.7 Strain Distribution at Dam Body

The Strain meters have been installed in groups to measure distribution of stress at the Dam body. The strain changes with the reservoir level changes. The nature of strain was observed "compressive" at the maximum locations. The maximum tensile strain at the dam heel with water level 590 to 603m was found 16.2 micro strain (3.13kg/cm^2). However, the maximum compressive strain was observed 12.2 micro strain (2.36 kg/cm^2).

The maximum tensile strain at the dam toe was observed 7.9 micro strain (1.52 kg/cm^2) corresponding with the reservoir level 590 to 603m. And maximum compressive strain at the dam toe was recorded 5.2 micro strain (1.0kg/cm^2).

The recorded strain at the dam toe and the dam-heel was found, less than the permissible limit of tensile stress-compressive strain for normal loading conditions. Both compressive and tensile stresses at the dam body were found within the design limit.

7. CONCLUSION

The response of uplift-pressure at the dam gallery was checked for reservoir level variations from 590 to 603m. The uplift pressure near the drain holes and D/s toe was found within permissible limits.

The response of GWL with the reservoir-level changes from 590 to 603m was checked. The GWL of the left abutment increased by 10.13m, and that of the right abutment increased only by 0.4m, indicating higher seepage rate at the left abutment from the reservoir compared to that of the right abutment. However, it was found that the drainage hole at EL 585.8m just 2m below the GWL was in flowing condition, indicating that the draining of seepage water continued from the abutment.

Total 42 drainage holes were found at the entire dam gallery from the left abutment to the right abutment. Except for the few holes, majority of drainage-holes at the lower levels were found in flowing condition. Few holes started flowing when the reservoir level was raised from 590 to 603m. The drainage holes of the right abutment recorded lesser flow compared to that of the left abutment. Drainage holes at the right abutment above EL 572.6m were still found dry, with the reservoir level raised from 590 to 602m, indicating less seepage from the right abutment. However, at the left abutment, the drainage holes up to EL 585.8m were found flowing from reservoir level 602m. The seepage at the dam gallery was recorded less and within the design limit. Low seepage in the gallery from the drain holes indicated effectiveness of curtain-grouting carried out below the dam foundation.

Seepage at the dam gallery through SMD was measured from the reservoir level 590m separately for both the abutments. It was found that to increase the reservoir level from 590 to 603m, 688.2LPM seepage increased at the dam gallery. The share of the seepage from the left abutment was found higher compared to that of the right abutment. The source of seepage at the gallery was traced from the foundation drainage holes. The CJ of dam blocks, under study formed drains and the concrete lift joints. The major contribution of seepage was recorded from the foundation drainage-holes; and at CJ no.4, approx. 150LPM seepage was recorded only from CJ-4 for reservoir level 603m. A total of 1558.2LPM seepage was recorded from reservoir level 603m.

The recorded strain at the dam toe and the dam heel was found less than the permissible limit of the tensile stress and compressive strain for normal loading condition.

The temperature of the dam body at different levels was also checked, and it was found that the d/s face of the dam was impacted mostly by solar radiation and air temperature. The recorded temperature above the tail-water level matched with the average daily air-temp, which led to a non-uniform distribution of temperature along the different levels. However, the recorded temperature below the tail-water level was found matching with the river water temperature.

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