14 Aug 2008, 4:30pm - 6:00pm

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6th International Conference on
Case Histories in Geotechnical Engineering, Arlington, VA, August 11-16, 2008

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ABSTRACT

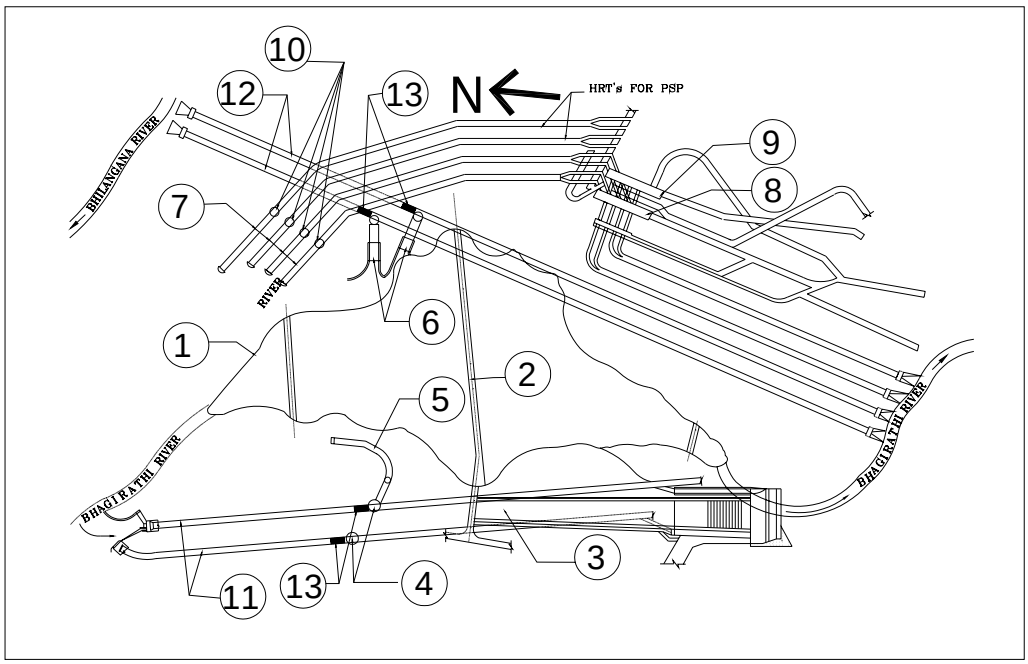
Initial Filling of reservoirs in dams, particularly the embankment type, is a very important phase as unusual behaviour / accidents of many dams have been reported during this period. A regular observation / analysis of quantum of seepage vis-à-vis the reservoir level is a significant activity so that any serious development inside the body of dam and foundation / abutments rocks are revealed in advance and remedial measures are taken up timely to prevent catastrophic failures. At Tehri, a 260.5m high earth & rockfill dam has been constructed across river Bhagirathi, a tributary of mighty river Ganga in India. Seepage discharge data of first two years of Initial Filling of Tehri reservoir has been analysed, which has led to a few important conclusions. The Analysis of Seepage data for the Initial Filling of Tehri reservoir is presented in the paper.

INTRODUCTION

Tehri dam is the highest earth & rockfill dam in India which has been constructed across river Bhagirathi, a tributary of mighty river Ganga which originates from Gaumukh glacier in Himalayas. Tehri dam project has been conceived on river Bhagirathi in order to even out the temporal variation of rainfall in the region. The project site is located in a unique seismo-tectonic set-up and therefore impressed upon the choice of an earth and rockfill dam. Construction of main dam & appurtenant structures was completed in Sept'05 and subsequently, the last diversion tunnel of the project (T-2) was plugged in accordance with the specified closure sequence. Filling of the Tehri reservoir was started in Oct'05, and it is planned to be completed in a total period of 3 seasons. Second year filling of reservoir commenced in June'07 and it has also been completed successfully. Initial phase of filling of reservoirs behind the dams, particularly the embankment type, is very important as unusual behaviour / accidents of many dams have been reported during this period only. At Tehri dam, a regular observation / analysis of quantum of seepage through the body of dam and its foundation vis-à-vis the reservoir level is being done so that any serious development inside the dam and foundation are revealed in advance and remedial measures are taken up timely. In this paper an analysis of seepage data observed during the first filling of Tehri reservoir, for the period upto 30th Sept'07, and the conclusions drawn there from are discussed.

THE PROJECT

Tehri project is a multipurpose project providing benefits of Irrigation, Drinking water supply and production of hydropower etc. The project comprises of an earth & rockfill dam of 260.5 m height at Tehri on River Bhagirathi at 1.5 km downstream of its confluence with River Bhilangana. It is having a spillway system to bypass the surplus water during monsoon and high floods. The spillway system comprises of a chute spillway having 3 bays of 10.5m each on right bank, and four shaft spillways, two each on left and right bank constructed by joining vertical shafts with the existing 4 Nos. diversion tunnels. An intermediate level outlet on the right bank has been constructed by joining a horizontal tunnel with vertical shaft. There are four headrace tunnels and an underground powerhouse on the left bank to accommodate four conventional power-generating units of 250 MW each (i.e. total installed capacity as 1000 MW). The layout of Tehri dam project is given in Fig. 1.



(1) Dam Boundary
(2) Dam Crest
(3) Chute Spillway
(4) Right Bank Shaft Spillways
(5) Intermediate Level Outlet
(6) Left Bank Shaft Spillways
(7) Head Race Tunnels (2 for HPP & 2 for PSP)
(8) Machine Hall of HPP
(9) Transformer Hall (Common for HPP & PSP)
(10) Maintenance Gate Shafts
(11) Right Bank Diversion Tunnels
(12) Left Bank Diversion Tunnels
(13) Concrete Plugs

Fig. 1. General Layout Plan

GEOLOGY AT DAM SITE

The rock formations at the dam site comprise phyllites of Chandpur formation. These are in general, banded in appearance, the bands being constituted of argillaceous and arenaceous materials. On the basis of extent of argillaceous and arenaceous materials, varying magnitude of tectonic deformations suffered by them and on the basis of geo-mechanical properties, the rocks in the area have been broadly grouped into 3 grades, namely Phyllite Grade-I (PQM & PQT), Phyllite Grade-II (QP), and Phyllite Grade –III or Sheared Phyllite (SP). The thickness of overburden in the river section at dam site was of the order of 10 to 15 m. Geological plan of the dam area is shown in Fig. 2.

The foliation of the phyllites exposed in the Tehri gorge generally strike N 55˚ W – S 55˚ E to N 80˚ W -S 80˚ E with a dip of 35˚ to 67˚ in South –Westerly (d/s) direction. The rocks at the dam site are traversed by numerous major and minor shears classified as diagonal (D) and longitudinal (L) shears. The L –shears more or less, coincide with bedding / foliation traces and dip in southern quadrant, whereas D-shears dip in northern quadrant. In the main dam core area, major L-shears (L6 & L7) traverse the foundation at different levels on either abutment. No major D- shear has been exposed in core portion. Eight prominent sets of joints occurring in the area were observed to be open in weathered rock mass and generally tight at the depth, down to which stripping has been done.

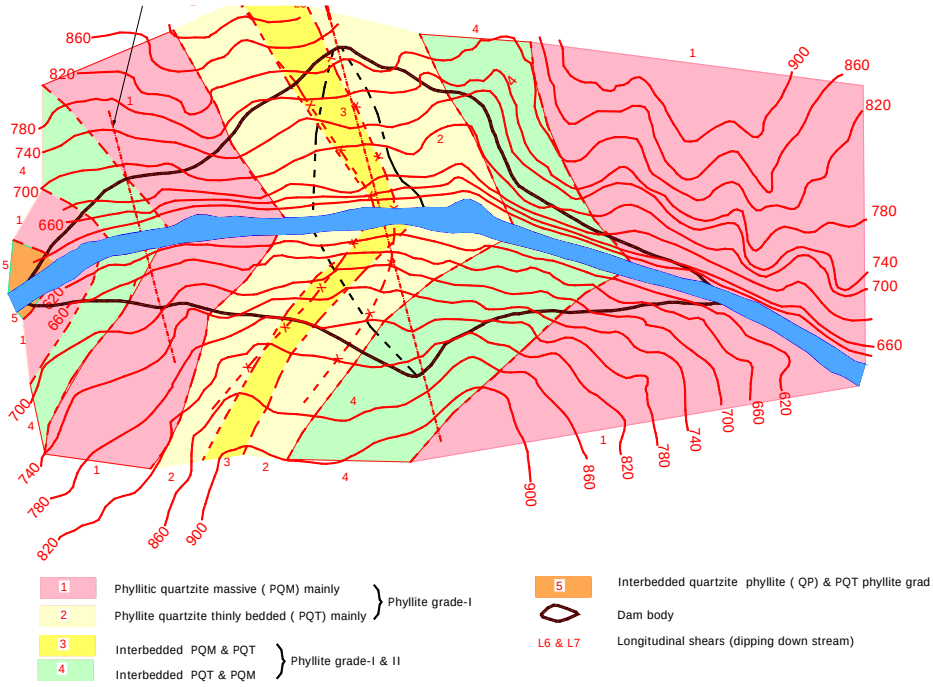
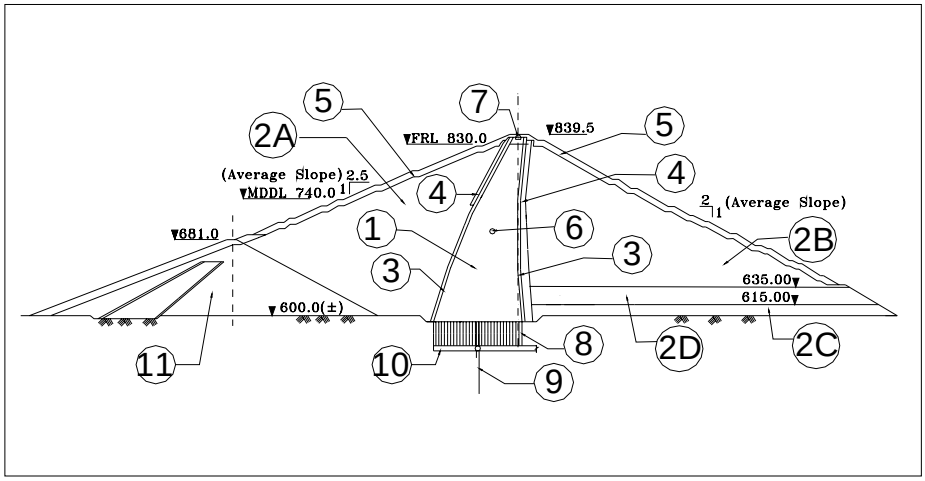


Fig.2. Geological Plan of Dam Site Area

DAM

Tehri dam is a 260.5 m high earth & rockfill dam having u/s and d/s slopes as 2.5 H :1V and 2.0 H:1V respectively. The general elevation of the river bed in the dam area is 600m. The crest level of the dam is 839.5m, full reservoir level is 830m and dead storage level is 740m. A very liberal freeboard of 9.5m has been provided above full reservoir level (FRL). The crest of dam is 25.5 m wide in central portion, which has been flared to 30.5 m near abutments. The dam section is composed of central impervious core, transition zones on both u/s and d/s of core (filter zones), pervious shell zones and riprap. Typical section of Tehri Dam is shown in Fig. 3.



(1)	Impervious Clay Core	(5)	Riprap
(2A)	Upstream Shell	(6)	Inspection Gallery at El. 725 m (+/-)
(2B)	Downstream Shell	(7)	Inspection Gallery at El. 835 m (+/-)
(2C)	Processed Shell	(8)	Consolidation Grouting
(2D)	Processed Shell	(9)	Grout Curtain
(3)	Fine Filter	(10)	Underground Grouting Gallery
(4)	Coarse Filter	(11)	Coffer Dam

Fig. 3. Typical Section of Tehri Dam

As the deposits of clayey soils were available in the vicinity of dam site, it was found suitable to design the dam with a central impervious core. In order to improve the shear properties and compressibility etc, the core material has been prepared by blending clay with pebbles. Width of the core at the crest has been kept 10 m which has been further flared to 15 m near abutments for providing better abutment contact.

Material placed in shell zones is a well-graded gravelly material picked directly from the river terraces (max. particle size 600mm), having fines (<4.75 mm) limited upto 35% to maintain free drainability of these zones. However, in the lower portions of the d/s shell, coarser shell material having lesser fines (2C / 2D zones with average fines upto 16 % & 14 % respectively), obtained by processing have been placed. The shell material has been compacted to dry density of 2.36 T/cum.

A two layered transition zone (filters) has been provided on both the u/s and d/s of core. In the design of these filters, the criteria of impenetrability of core material into filter material and that of the filter material into shell material have also been taken into account besides following the Terzaghi and USBR criteria, for piping and permeability. First layer of transition zone (fine filter) comprises of a graded sand and gravel with silt content upto 3 percent and maximum size of particle upto 20 mm. Second layer of transition zone (coarse filter) comprises of well graded mixture of coarse sand and gravel with max. size of particle upto 80 mm

A well-graded riprap (upto 1.2 m size) of hard blasted quartzitic rock has been provided for the protection of dam slopes, increasing stability of slopes during seismic activity, and for providing rapid dissipation of pore pressures generated due to seismic loads in the upstream portions of dam. The thickness of riprap is 10 m (normal to slope), on both u/s and d/s faces of the dam. The percentage of fines in the riprap has been limited for increasing free drainability of riprap on u/s slope.

SEEPAGE CONTROL MEASURES

Uncontrolled seepage through an embankment dam and its foundation can lead to piping failures. It can also result in excessive pore pressures in embankment or foundation, which can cause weakening of the soil mass resulting in sand boils, abutment failures, and u/s or d/s slope failures.

In view of above, adequate seepage control measures have been adopted at Tehri dam and its foundation, which are as follows:

For Embankment Dam

Moderately sloping impervious core. Material for the core was produced by blending clay with pebbles. Compacted dry density of the core was 1.9 T/cum in central portion and 1.85 T/cum near abutments. Permeability of the core material was of the order of $1x10^{-6}$ cm / sec.

- Two layers of filter (fine & coarse filter) on the d/s of dam core.
- A horizontal drain at the lower levels (upto El. 635 m) of the d/s part of the dam connected to vertical coarse filter. Material for horizontal drain was produced by processing shell materials by segregation cone method. Permeability of material placed in horizontal drain was very high (0.1 to 0.9 cm / sec).
- A RCC Collector pipe, with regular intermittent gaps, surrounded by filter material placed in the dam toe at El. 617 m + /- having discharging end at El. 614 m +/- towards the tail water side.

For dam foundation

- Surface treatment of foundation has been done which involved removal of overburden and weathered rock as per specified criteria. Subsequently, stripped core surface has been provided with a 50mm thick layer of guniting after the treatment of weak zones and shears.
- In order to fill the voids, fractures and cracks around the core foundation contact and improve its impermeability, 10 m deep consolidation grouting (3m x 3m grid pattern) has been done in the dam core seat foundation
- For providing a barrier to impede the flow of water under and around the dam, a two rows grout curtain (hole spacing 4m / 2m) has been provided at the centre line of core with maximum depth as 60m.
- Provision of drainage galleries at various levels in the d/s abutments of the dam for collecting seepage crossing the grout curtain.

MEASUREMENT OF SEEPAGE DISCHARGE

Through Dam Body

Measurement of variation of seepage passing through the dam body is being done by measuring the seepage discharge at the outlet end of a collector pipe placed in the dam toe at El. 617 m + /- .

The discharge measured through collector pipe includes: seepage through dam core; some part of seepage through d/s abutments; ground water and surface runoff which are not connected to the reservoir; and precipitation on the d/s slope of the dam etc. Therefore, the above discharge is a very useful index of the total seepage / leakage on the d/s of the dam.

Through Foundation / Abutments

A network of drainage galleries has been provided in the d/s part of the abutments on both the banks for relieving their saturation after reservoir impoundment **(**Fig. 4**)**. Measurement of seepage is being taken at the outlet portals of drainage galleries, except in a drainage gallery going deep into the dam foundation (El. 570.5 m +/-) on right bank, where it is being measured in a sump well provided at the deepest point of the gallery.

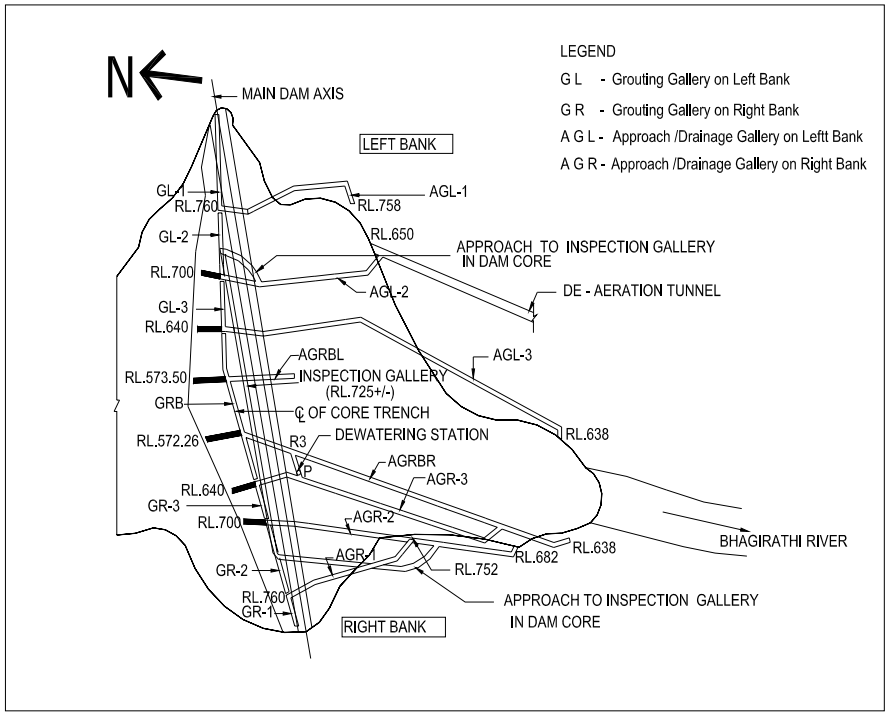


Fig. 4. General Arrangement of Grouting & Drainage Galleries in Dam Foundation

INITIAL FILLING OF RESERVOIR

Initial filling of Tehri reservoir commenced on 29th Oct'05 with the closure of last diversion tunnel T-2. In India, monsoon period falls during June to September. This is the period during which maximum filling of reservoir is done. During the first year of filling the reservoir had attained a maximum level of 785.25m by mid October i.e. by 15th Oct'06. During non-monsoon period, water stored in the reservoir was utilized for power generation, irrigation requirements and drinking water supply etc. as a result of which the reservoir depleted to its dead storage level.

Second filling of reservoir above the dead storage level was started from the last week of June '07. By 10th Oct'07, reservoir had touched a maximum level of 816 m which was slightly above the maximum reservoir level of 815m planned for this year (equal to crest level of chute spillway, i.e. 815 m).

Reservoir is planned to be filled upto full reservoir level (El. 830 m) by the end of monsoon of next year i.e. 2008. Between El. 815m and El. 830m a controlled filling of reservoir is envisaged @ 60 cms per day holding the reservoir rise at intermediate levels.

A curve showing the initial filling of reservoir for the complete period between 29th Oct'05 and 30th Sept'07 is shown in Fig. 5.

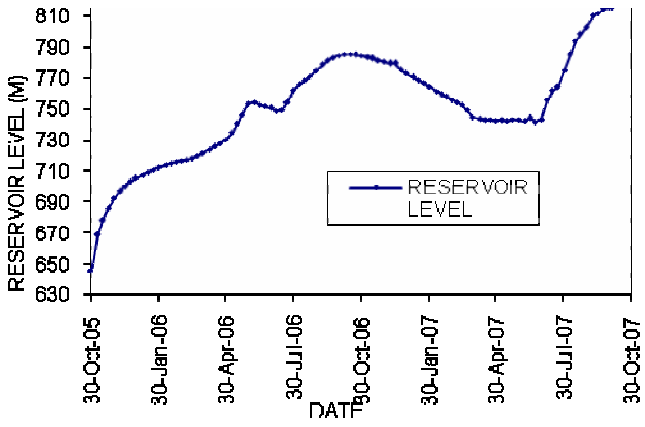


Fig.5. Initial Filling of Reservoir

OBSERVATION OF SEEPAGE & ANALYSIS OF DATA

Since the commencement of initial filling of Tehri reservoir on 29th Oct'05, regular observation of quantum of seepage through the foundation / abutments and body of dam vis-à-vis the reservoir level, besides keeping a watch on the clarity of seeping water, is being taken so that any serious development inside the foundation and dam are revealed in advance and remedial measures are taken up timely. Analysis of observed seepage through abutments and dam body for the period between 29th Oct'05 and 30th Sept'07 is presented below.

Seepage Discharge through Foundation / Abutments

On left abutment, there are three drainage galleries, AGL-3 (El.640m +/-), AGL-2 (El. 650 – 700 m +/-) and AGL-1 (El. 760 m +/-). Whereas, on the right abutment there are four drainage galleries, AGRBR (El. 570 – 638 m +/-), AGR-3 (El.640 m +/-), AGR-2 (El. 700 m +/-) and AGR-1 (El. 760 m +/-).

The Plots of observation of seepage discharges from various drainage galleries on the left and right abutment for the complete period from Oct'05 to Sept'07 are shown in Fig. 6 & 7.

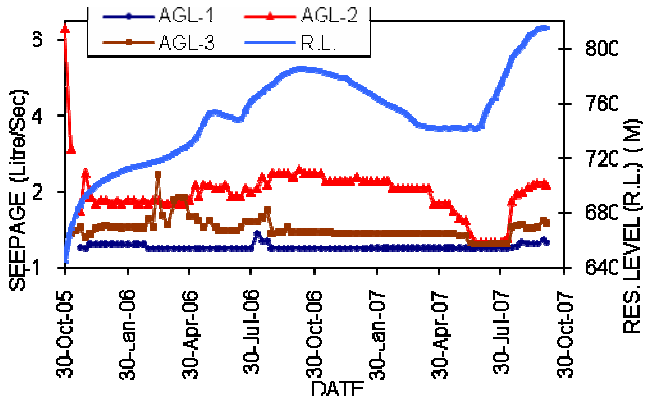


Fig.6. Seepage Through Left Abutment Galleries

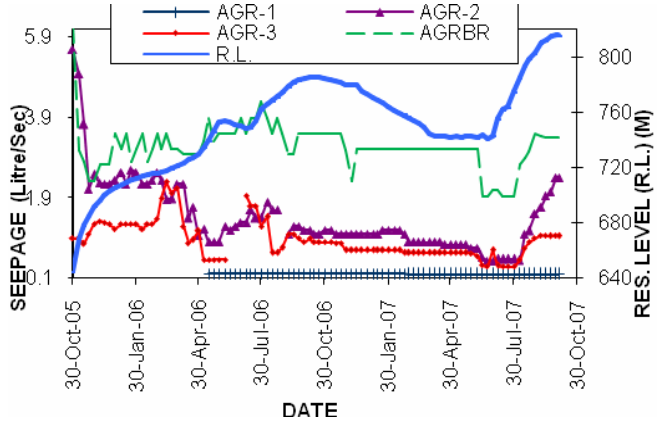


Fig.7. Seepage Through Right Abutment Galleries

In addition to above, quantum of seepage observed through abutments on some specific dates / reservoir level for two successive years of initial filling of reservoir are given in Table. 1.

Left Bank

(i) AGL-3

Drainage gallery at the lowest levels on the left bank is AGL-3 (El. 640m +/-). Initially during first year of filling, the seepage in this gallery had shown a slight rise with rise in reservoir, but thereafter, it gradually came down (even with the rising reservoir). In the major period of observation between Oct'06 & May' 07, when the reservoir was falling down, seepage discharge in this gallery has been around 0.4 – 0.5 lit / sec, except some intermittent rises. After May'07, upto 16th June'07, although the reservoir level remained between 741.5 m and 743.8 m, but seepage came down from 0.41 lit / sec to 0.13 lit / sec. During second year of filling, upto 10th Aug' 07, seepage remained around 0.1 lit / sec, although by that time reservoir has risen upto a level of 787.25m. But, thereafter, within next five days i.e. by 15th Aug'07 (Reservoir level – 793.85m), it reached upto 0.6 lit / sec. However, after this, there has not been any abrupt rise in seepage. It appears that after second year of filling reservoir has started saturating the rockmass around this gallery. But, the quantum of seepage is quite normal.

(ii) AGL-2

Drainage gallery at the next higher level on the left bank is AGL-2 (El. 700 – 650 m +/-). In this gallery during first year of filling and drawdown, seepage discharge had shown a little correspondence with the rise / fall in reservoir level. The process of reduction in seepage with the fall in reservoir level continued even upto about mid of June'07. During second year of filling seepage remained almost constant at 0.2 lit / sec upto 3rd Aug'07 (reservoir level - 778.2m). By 13th Aug'07 (reservoir level - 791.1m), seepage was only 0.36 lit / sec, i.e. there was a marginal increase only. But, thereafter within next three days i.e. by 16th Aug'07 (Reservoir level – 794.75m), it reached upto 1.6 lit / sec. Thus, during this period there was a significant rise in seepage with the rise in reservoir level. In the subsequent days after 16th Aug'07, there has not been further abrupt rise in discharge. It appears that filling reservoir has definitely some effect on the saturation of the rockmass around this gallery. But, the quantum of seepage is quite normal.

(iii) AGL-1

Drainage gallery at the highest level on left bank is AGL-1 (El. 760 m +/-). Seepage discharge in this gallery has been very low in the complete period of observation. Only during the later part of second year of filling, when reservoir crossed a level of about El. 801 m, seepage varied between 0.1 to 0.4 litre / sec. It appears that there is still no effect of reservoir filling on the saturation of rockmass around this gallery. This shall be studied further during the next year of filling.

Table 1. Seepage through Abutments during Initial Filling of Reservoir

S.N.	Date	Reservoir Level (M)	Seepage Discharge (Litre / Sec.)						
			Left Abutment			Right Abutment			
			AGL-3	**AGL-2**	**AGL-1**	**AGRBR**	**AGR-3**	**AGR-2**	**AGR-1**
1.	30.10.05	645.25	-	5.82	-	6.22	0.9	5.58	-
2.	30.12.05	705.35	0.635	1.3	0.1	3.5	1.13	2.35	-
3.	15.05.06	739.8	0.756	1.4	0.03	3.88	0.36	0.8	0.01
4.	15.10.06	785.25*	0.45	2.0	0.02	3.5	0.8	1.0	0.02
5.	22.06.07	741.15	0.13	0.2	0.0	1.94	0.2	0.33	0.0
6.	08.08.07	784.8	0.1	0.3	0.03	2.72	0.35	0.35	0.0
7.	30.09.07	815.7**	0.75	1.75	0.25	3.4	0.98	2.4	0.0

(*) Maximum reservoir level achieved during first year (2005-06) of filling.
(**) Maximum reservoir level achieved during second year (2006-07) of filling

Right Bank

(i) AGRBR

Drainage gallery at the lowest levels on the right bank is AGRBR (El. 570 – 638 m +/-). In this gallery, during first one month of first year of filling there was sharp reduction in seepage. But thereafter upto 15th Oct'06 (reservoir level – 785.25m), it was observed that with the rise in reservoir level, discharge increased only slightly but the peak value of discharge was attained during the heaviest portion of rainy season and did not correspond to the time of maximum level of reservoir. Subsequently, with the lowering of the reservoir upto 741m +/- by 22.06.07, seepage came down, and thereafter increased slightly with the rise in reservoir level during second year of filling. The quantum of seepage at the maximum reservoir level of 815.7 m was 3.4 lit / sec only, which is normal and indicates a good degree of tightness of grout curtain at lower levels of the foundation. It is worthwhile to mention here that for tackling emergency situations arising due to abnormally high seepage in this gallery, a pumping station with discharge capacity of 60 lit / sec. has been provided.

(ii) AGR-3

Drainage gallery at the next higher level on the right bank is AGR-3 (El. 640 m +/-). During first year of filling, it was observed that there was intermittent rise in discharge but it had no connection with the rise in reservoir level. However, during the subsequent drawdown of the reservoir, discharge indicated falling trend. During second year of filling, with the rise in reservoir level from about El. 743.85m to El. 776.85 m by 2nd Aug'07, discharge remained almost constant at about 0.2 litre / sec. But, after 13th Aug'07 (reservoir level – 791.1 m), within next 4 days i.e. by 17th Aug'07 (reservoir level – 795.3 m), seepage increased from 0.3 lit / sec to 0.8 lit/ sec. But thereafter no significant rise in seepage was observed and seepage on 30th Sept'07 (reservoir level – 815.7 m) was 0.98 lit / sec. It appears that after second year of filling reservoir has started saturating the rockmass around this gallery. But, the quantum of seepage is quite normal.

(iii) AGR-2

Drainage gallery at the next higher level on the right bank is AGR-2 (El. 700 m to El. 682 m +/-). During the first year of filling, in general there was a reduction in discharge with the rise in reservoir level. During the subsequent drawdown of the reservoir, discharge had further gone down. During second year of filling, on 10th Aug'07 discharge was about 0.4 litre / sec. only. But, thereafter, within next five days i.e. by 15th Aug'07 (Reservoir level – 793.85m), it reached upto 1.0 lit / sec. Thereafter, between 27th Aug'07 and 29th Aug'07, seepage further went up from 1.1 lit/ sec to 1.66 lit / sec. The rising trend of discharge continued further. It seems that now there is some effect of the reservoir level on the quantum of seepage. But, this needs to be studied further.

(iv) AGR-1

AGR-1 is drainage gallery at the highest level on right bank (El. 760 m to El. 752 m +/-). It has been observed that there is still no effect of reservoir impoundment on the saturation of d/s abutment rockmass around this gallery as the measured seepage is almost nil.

Seepage Discharge in Collector Pipe placed at Dam toe & Total Seepage on D/S

The plot of observation of seepage discharge from collector pipe placed in dam toe from Oct' 05 to Sept' 07 is shown in

Fig. 8. As presently the seepage discharge from few drainage galleries is being directly disposed off on the d/s slope of the dam, therefore, seepage measured at collector pipe includes this portion of seepage also. Therefore, in order to have an idea of the total amount of seepage discharge on the d/s side of the dam from various sources, discharge of remaining drainage galleries have also been added into the discharge being observed through the collector pipe. The plot of total seepage on D/s of dam is also shown in Fig. 8.

In addition to above, quantum of seepage observed through dam body on some specific dates / reservoir level for two successive years of initial filling of reservoir are given in the Table-2.

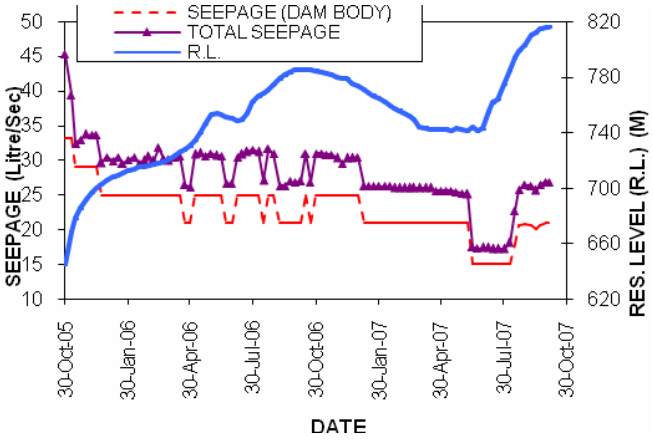


Fig.8. Seepage Through Dam Body & Total Seepage on D/S of Dam

Table 2. Seepage through Dam body & Total Seepage during initial filling of reservoir

S. N.	Date	Reservoir Level (M)	Seepage on Collector Pipe (Lit./Sec.)	Total Seepage on D/s of Dam (Lit. /Sec.)
1.	30.10.05	645.25	33.2	45.24
2.	30.12.05	705.35	25.0	30.435
3.	15.05.06	739.8	25.0	31.036
4.	15.10.06	785.25*	25.0	30.95
5.	22.06.07	741.15	15.0	17.474
6.	08.08.07	784.8	15.0	18.12
7.	30.09.07	815.7**	20.9	26.8

(*) Maximum reservoir level achieved during 2005-06.
(**)Maximum reservoir level achieved during 2006-07.

It has been observed that during the first year of filling, initially the seepage discharge measured at collector pipe had reduced. Thereafter, any increase with the rise in reservoir level was not seen. However, subsequently with the drawdown of the reservoir, a reduction in the discharge was observed. During second year of filling, some increase has been seen in the discharge with the rise in reservoir level, but the peak value of discharge was smaller than the peak discharge during first year of filling. Thus, practically there is no increase in seepage through dam body.

Similarly, from the plot of total amount of seepage discharge on the d/s of the dam, it is observed that the total seepage discharge had also reduced during the first year of filling. Subsequently with the drawdown of the reservoir, a reduction in the total discharge was observed. During second year of filling, very little increase in the total discharge with the rise in reservoir level was found. Thus, it can be conclusively stated that there is practically no increase in total seepage on the d/s of dam with the rise in reservoir level.

CONCLUSION

Analysis of seepage discharge data of abutments and dam body of first two years of initial filling period has led to the following important conclusions:

1. There is very insignificant variation in the quantum of seepage passing through the dam body vis-à-vis the reservoir level, which indicates a very good degree of compaction and impermeability of core material placed in the dam body. It also indicates that the flow regime inside the core is yet to be stabilized at higher levels.
2. There is very little increase in the quantum of seepage through the drainage gallery connected to the riverbed foundation gallery vis-à-vis the rise in reservoir level. This indicates a good degree of effectiveness of grout curtain at lower levels of the foundation.
3. At middle levels of the abutments (between El. 640m and 730m) on both the banks, variation in quantum of seepage vis-à-vis the reservoir level appears to get corroborated. In mid of Aug'07, it was observed that a sudden increase in seepage in various drainage galleries at middle levels had occurred, which had stabilized at a later stage. This phenomenon is being closely monitored.
4. At higher levels of the d/s abutments (in about top 80 to 90 m), effect on the quantum of seepage with the rise in reservoir level is yet to take place.

REFERENCES

Appraisal Note on Dam Instrumentation, 35th TAC meeting, Tehri dam Project, Sept'07.

Bulletin: Series B, Number 62, "Tehri dam Project A Geotechnical Appraisal", GSI, 2006.