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A Procedural Framework for the First Filling of the Water Conductor System at the Tehri Pumped Storage Plant (4x250 MW)

Rajeev Prasad, Vinod Jhinkwan
Hindustan Construction Company, Mumbai, India

Abstract- The first filling of a Water Conductor System (WCS) is the most critical non-operational test for any large-scale underground hydropower or pumped storage project. This process validates the structural integrity, water tightness, and geo-mechanical interaction of the system with the surrounding rock mass under hydrostatic pressure for the first time. This paper presents the philosophy and step-by-step methodology adopted during the first filling of the water conductor system at the 1000 MW Tehri Pumped Storage Plant. It also provides valuable insights and reference information for conducting first filling operations in similar large-scale hydroelectric projects. As a critical pre-commissioning activity, the first filling is designed to test the integrity and performance of all hydraulic components under controlled conditions for the first time. The methodology adheres to Indian Standard codes (IS 12633:1989) and project-specific requirements, implementing a phased, step-wise approach to pressurize the system gradually. The process is segmented into four distinct stages: Stage 1 involves filling the Tail Race Tunnel (TRT) up to the downstream surge shaft; Stage 2 covers the Head Race Tunnel (HRT) from the intake to the Butterfly Valve Chamber (BVC); Stage 3 entails filling the pressure shafts from the BVC to the Main Inlet Valve (MIV); and Stage 4 completes the balance filling of the upstream surge shaft. This paper provides detailed volumetric computations, filling discharge rates, prescribed waiting periods for strata stabilization, and a complete timeline for each stage. The total cumulative filling time, inclusive of all mandatory stabilization gaps, is calculated for two potential upper reservoir level scenarios (EL. 775 m and EL. 780 m), ensuring a controlled and safe commissioning process for the Tehri PSP.

Keywords: Tehri, pumped storage, first filling, water conductor system, hydropower, commissioning, tunnels, surge shaft, penstock.

I. INTRODUCTION

1000 MW Tehri PSP hydropower is a modified use of conventional hydropower technology tostore and manage energy or electricity. As shown on Figure 1. The Tehri PSP store electricity by moving water between an upper and lower reservoir. Electric energy is converted to potential energy and stored in the form of water at the upper reservoir. Pumping the water uphill for temporary storage “recharges the battery” and, during periods of high electricity demand, the stored water is released back through the turbines and converted back to electricity like a conventional hydropower station. The use of variable-speed technology allows Tehri PSP to provide fast ramping, both up and down, and frequency regulation services in both the generation and pump modes. This is important because many of the renewable energy resources being developed (e.g., wind and solar) are generated at times of low demand and off-peak energy demand periods are still being met with fossil fuel resources, often at inefficient performance levels that increase the release of greenhouse gas emissions.

Water Conductor System of the Tehri PSP is an extensive network of underground structures, including head race and tail race tunnels, surge shafts, pressure shafts, and associated chambers. Before operational commissioning, this entire system must be filled with water for the first time—a high-stakes activity known as "first filling."

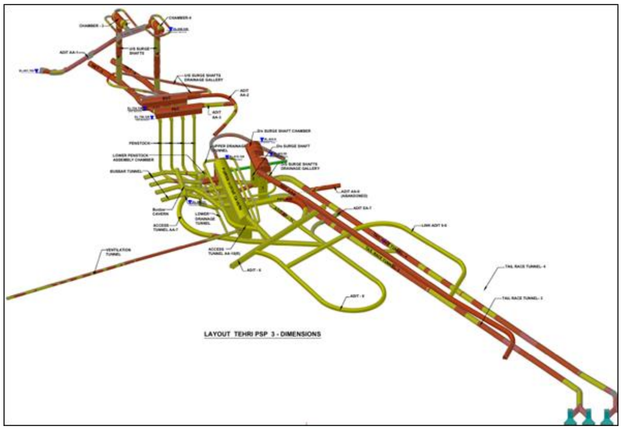


Figure 1 :-1000 MW Tehri PSP Layout

II.OBJECTIVE

The primary objective of this first filling is to subject all components to their design hydraulic loads in a controlled, incremental manner. This allows for the detection and rectification of any leaks, verification of gate and valve operations, and stabilization of the surrounding rock strata. The Water Conductor System(WCS) includes the Tail Race Tunnel(TRT) upto Downstream Surge Shaft (DSSS), Head Race Tunnel (HRT) from intake gate upto Butterfly Valve Chamber (BVC), Vertical Pressure Shaft from BVC to Main Inlet Valve(MIV) and balance filling of upstream surge shaft (USSS).

The initial filling serves as the first test to evaluate the performance of the components in fulfilling their intended functions. Considering the need to execute the filling operation in a controlled manner and in accordance with the proposed filling pattern, a stepwise approach has been adopted. All components of the Water Conductor System (WCS) have been thoroughly analyzed with respect to their geometry and operational characteristics.

III. PROJECT SALIENT FEATURES

The key components and their specifications relevant to the first filling are as follows:

Component	Specification
Upper Reservoir	FRL = 830 m, MDDL = 740 m
Head Race Tunnel (HRT)	Diameter = 8.5 m
Penstock / Pressure Shaft	Diameter = 6 m
Tail Race Tunnel (TRT)	Diameter = 9.1 m (bifurcating to 7 m)
Lower Reservoir	FRL = 612.50 m, MDDL = 606.00 m
Upstream Surge Shaft	Diameter = 20.92 m
Downstream Surge Shaft	Diameter = 18.44 m

IV. PRE-FILL CHECKS & MONITORING

Before the commencement of the filling operation, it shall be ensured that all construction materials, labor, and departmental personnel are completely cleared from the entire water conductor system. Prior to initiating the actual filling process, the following checks shall be carried out in accordance with the relevant BIS code provisions.

INTAKE STRUCTURE

The trash rack and air vent shall be thoroughly cleaned, and their respective cleaning devices shall be checked for proper operation. In case the Trash Rack Cleaning Machine (TRCM) has not been installed, the trash racks shall be inspected and cleaned manually. The service and emergency gates shall be examined to ensure proper sealing, correct alignment of tracks and guides, and smooth operation. The filler valve shall also be inspected for functionality and leak-tightness.

All hoisting arrangements shall be checked for their proper working condition. The automatic systems related to gate operation and alarm mechanisms shall be tested to confirm their reliability.

A telephone or wireless communication set shall be provided at the gate location, and trained personnel shall be stationed for gate operation during the filling process.

HEAD RACE TUNNEL (HRT)

- The entire length of the Head Race Tunnel (HRT) shall be thoroughly inspected prior to the commencement of filling operations. All construction materials, tools, and equipment shall be removed to ensure that the tunnel is completely clear of any extraneous matter. Necessary repairs shall be carried out wherever required.
- All cold joints and seepage locations shall be properly treated, and any uneven surface profiles shall be rectified. Contact grouting shall be verified throughout all prescribed reaches as per design requirements, while consolidation grouting shall be confirmed in accordance with the approved design specifications.
- All openings, such as gate points and construction adits, shall be properly sealed or plugged as per design provisions. All instruments required for observation before, during, and after filling shall be installed at the designated locations and tested to ensure proper functionality.
- Drainage holes and dewatering pipes, wherever provided, shall be checked to confirm proper operation and absence of any particle flow. Arrangements for gradual filling and dewatering shall be verified for operational readiness.
- Air vent pipes, as well as their inlet and outlet surroundings, shall be inspected to ensure that no obstruction exists. Gates provided at adit plugs shall be checked for smooth operation, and all seals shall be securely bolted and locked in position.

SURGE SHAFT

- Gates provided in the surge shaft shall be inspected to ensure proper sealing, correct guide alignment, and smooth operation by raising and lowering them within their respective slots. The filler valve shall be tested to confirm balanced and reliable gate operation. Hoisting arrangements shall be examined for proper functioning and mechanical soundness.
- Water level indicators, automatic operating systems, and alarm mechanisms shall be tested to verify their responsiveness and accuracy. Construction adits shall be properly plugged in accordance with the approved design specifications. Air vents shall be inspected to ensure that they are free from any obstruction and capable of effective ventilation.
- All instruments required for monitoring before, during, and after filling shall be installed at designated locations and checked to confirm proper functioning and calibration.

PENSTOCK / PRESSURE SHAFT

- The entire length of the penstocks and pressure shafts shall be thoroughly cleaned, painted, and completed in all respects prior to the commencement of water filling. All valves shall be inspected to ensure smooth and proper operation.
- All manhole bolts shall be checked and securely tightened. The bolts and seals of expansion joints shall be carefully inspected, and a maintenance team equipped with the necessary tools shall remain on standby during filling operations to address any leakage by tightening, if required.
- All instruments provided on the pressure shafts and anchor blocks shall be monitored to verify accurate functioning. Grouting holes shall be properly plugged and repainted after completion. Air vents shall be inspected to confirm they are free from obstruction, and all air valves shall be checked for proper operation.
- The entire filling and dewatering system shall be tested and verified for proper functioning and operational readiness.

TAIL RACE TUNNEL (TRT)

- Any temporary barriers or cofferdams provided at the downstream end shall be completely removed prior to filling operations. Dewatering pumps for the tail race shall be kept in a state of readiness for immediate use in case of emergency or excess water accumulation.
- The area surrounding the tail race shall be thoroughly cleared of any obstructions to ensure

unobstructed movement of equipment, vehicles, and personnel during inspection and operation

POWER HOUSE

- All pre-commissioning tests in the dry stage shall be completed and duly certified by the manufacturer and the erection agency before the commencement of filling operations. The operational staff required for the power plant shall be deployed and assigned specific duties to ensure smooth coordination during the filling and commissioning stages.
- Adequate spare dewatering pumps shall be positioned at various floors of the power house for emergency use. All temporary drainage and dewatering stops used during construction shall be removed and tested against the full tail race level. All drainage and dewatering pumps shall be serviced, conditioned, and kept in operational readiness.
- Turbine seals and inlet valve seals shall be tested and confirmed for perfect sealing. An alternate power source for operating auxiliaries shall be ensured with 24-hour availability. Electrical Overhead Travelling Cranes (EOTCs) shall be tested and confirmed to be in good operating condition. All vacuum valves, air release valves, and drainage valves shall be tested for proper operation.
- Adequate security arrangements shall be established to restrict unauthorized entry into the power house area. The complete complement of operation and maintenance staff shall be deployed in shifts before the commencement of the initial filling operation to ensure round-the-clock monitoring and response capability.

V. OBSERVATION POINTS

- Before filling the water conductor system, observation points shall be judiciously located at convenient locations along the system and monitored during and after the filling operation.
- These observation points may be established at or near the following locations:
- Tunnel plugs
- Intermediate adits in the Head Race Tunnel (HRT) or Tail Race Tunnel (TRT)
- In the vicinity of the surge shaft
- Along the penstock slopes
- Existing springs, if any
- Water levels in nearby wells, if any
- Retaining walls, if any
- Low-cover reaches
- If any leakage is observed at an observation point, or if an appreciable change in the surge tank water level is noticed, the matter shall be reported and attended to immediately.

As minor leakages through plug concrete may occur, grouting equipment — such as grout pumps, pipes, nozzles, drilling machines, cement, sand, and water — shall be kept readily available to address any urgent requirements.

VI. CHECKS BEFORE START OF FILLING

- Prior to commencement of the filling operation, final clearance shall be obtained from the Engineer-in-Charge (EIC) to ensure that no personnel, materials, or equipment remain inside the tunnel or any associated works. Filling shall only commence after the EIC issues formal clearance and authorizes the closure of all access gates.

THE FOLLOWING CHECKS SHALL BE CARRIED OUT AND VERIFIED:

- Confirm that the adit gate (if provided) is properly closed and securely locked.
- Ensure that all penstock inlet valves are in the closed position.
- Verify that the surge shaft gates are completely closed.
- Check the reservoir water level. Filling operations shall commence only when the reservoir level is at the design level specified in the initial filling computations.

VII.FILLING OF WATER CONDUCTOR SYSTEM

As per BIS Code IS 12633:1989, for projects involving long headrace tunnels, the water conductor system shall initially be filled up to the surge shaft, if gates are provided. Otherwise, the system shall be filled up to the valves located downstream of the surge shaft. Accordingly, the initial filling of the Water Conductor System (WCS) of the Tehri Pumped Storage Project (PSP) is planned in the FOLLOWING STAGES:

THE FOLLOWING PROCEDURE SHALL BE ADOPTED FOR INITIAL FILLING OF THE WATER CONDUCTOR SYSTEM:

- Reservoir Level Management: The intake gates shall be lowered, and the reservoir level shall be maintained at the desired elevation using the spillway radial gates and/or other discharge outlets.
- Valve and Gate Positioning: The penstock inlet valves of all units and the surge shaft gates shall be kept in the closed position during the initial filling phase.

- **Controlled Filling by Crack Opening:**
- The intake gate shall be raised to a height calculated based on the discharge requirement to achieve the scheduled filling rate within the planned timeframe.
- The velocity of water through the gate shall be restricted to about 6 m/s.
- The crack opening is generally maintained between 20 mm and 40 mm.
- To limit the velocity through the intake gate, the water level in the reservoir shall not
- exceed 500 mm above the sill level of the intake gate.

However, in the case of Tehri Pumped Storage Project, the above provision is not applicable, as valves provided in the intake gates will be used for the initial filling operation. The corresponding reservoir levels shall be maintained as follows:

- Upper Reservoir: EL. 775 m / EL. 780 m
- Lower Reservoir: EL. 603 m

As per the codal provisions (IS 12633:1989), the tunnel shall be filled in appropriately pre-determined steps of water head to ensure that excessive tensile stresses are not induced in the tunnel lining. These steps should be determined based on the known properties of the surrounding rock mass and the structural characteristics of the lining.

However, the following water head steps were adopted for the Tehri Pumped Storage Project during initial filling operations:

Stage	Waiting Period	
	Between first and second step (hrs)	Each subsequent step (hrs)
Stage 1 (Filling of the TRT upto downstream surge shaft)	24	12
Stage 2 (Filling the HRT Upto BVC)	24	12
Stage 3 (Filling of Pressure Shaft from BVC Upto MIV)	3	3
Stage 4 (Balance filling of upstream surge shaft)	12	continuous filling upto upper reservoir level

STAGE 1: FILLING OF THE TAIL RACE TUNNEL (TRT) UP TO THE DOWNSTREAM SURGE SHAFT GATE

In this stage, the TRT upto downstream surge shaft needs to be filled upto EL.603.00 m. For this case, the downstream reservoir level has been considered as EL. 603 m.

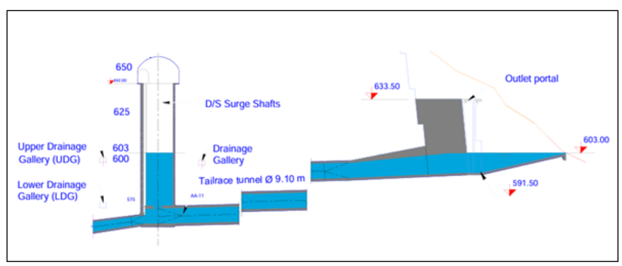


Figure 2: -Typical sketch showing stage 1 filling.

Each outlet gate consists of 2 gate valves i.e., for filling of each TRT, a total of 4 gate valves are present. However, only 2 gate valves (one per gate) have been considered operational for filling of each TRT. The summary of Table I is given below:

Lower reservoir level (m)	Valve elevation (m)	Number of valves operational for each TRT (Nos)	Filling discharge for each TRT (Cumecs)
EL 603.00	EL.597.75	2	1.09

During the filling process of the Tail Race Tunnel (TRT), proper monitoring and observation shall be maintained at all key locations to detect any signs of distress or abnormal behavior in the structure. Depending on the observed response, suitable modifications in the rate of filling or time intervals between steps may be implemented to ensure safety.

The water level in the downstream surge shaft will rise concurrently with the filling of the TRT. Continuous observation of the surge shaft levels shall be undertaken during each filling step, as any irregular fluctuation or delay in level rise may indicate possible seepage or leakage within the system.

As per the planned filling schedule, the time interval after the first step shall be 24 hours, followed by 12-hour intervals between each subsequent step. The invert level at the downstream surge shaft gate location is EL. 562.50 m.
The detailed step sequence for the TRT filling operation is outlined below:

Step No.	Water Level (EL. m)	Incremental Rise (m)	Time Gap (hrs)	Remarks
1	574.50	12.00	24	Initial filling step
2	580.50	6.00	12	
3	586.50	6.00	12	
4	592.50	6.00	12	
5	598.00	5.50	12	Reaches overt level near outlet gate
6	603.00	5.00	12	Final filling up to designed lower reservoir level

The above filling sequence ensures a controlled and gradual rise in hydraulic head, minimizing stress on the tunnel lining and associated components. The total time taken for filling of TRT upto downstream surge shaft is Calculated below:

TRT: GATE VALVE OPERATION		
Valve Elevation	m	597.75
Water Height U/S of valve	m	5.25
D/S reservoir Level	m	603
Number of Valves	Nos	2
Area of Valve one Valve	m2	0.0671
Discharge coefficient of Valve, C	-	0.8
Discharge through one Valve, Qv	m3/sec	0.54
Total Discharge, Q	m3/sec	1.09

TRT 3 and TRT 4 bifurcates into two tunnels of 7.0 m diameter each. Consequently, the outlet structure comprises two gates for filling each TRT. As each gate consists of two valves, it is assumed that only 2 valves are opened for filling of each TRT i.e., one valve of each gate. This approach is considered for the slow filling process.

Considering the rate of filling 1.09/m3/sec. the total time taken for filling of TRT 3 & 4 will be below.

TRT	Lower reservoir level (m)	Filling upto elevation (m)	Total time taken for filling.(Days and hrs)
TRT 3	EL. 603.00	EL. 603.00	3 days and 20.53 hrs
TRT 4			3 days and 22.32 hrs

STAGE 2: FILLING OF THE HEADRACE TUNNEL (HRT) UP TO THE BUTTERFLY VALVE CHAMBER (BVC) VALVE.

In this stage, the water conductor system from HRT intake gate up to BVC needs to be filled up to an elevation of EL. 728.50 m.

The total time taken for filling of HRT from intake gate upto BVC is calculated below

HRT: GATE VALVE OPERATION			
Description	Unit	Upstream reservoir water level at EL. 775 m	Upstream reservoir water level at EL. 780 m
Valve Elevation	M	730	730
Water Height U/S of valve	M	45	50
Upstream Reservoir Level	M	775	780
Number of Valves	Nos	2	2
Area of one Valve	m2	0.0502	0.0502
Discharge coefficient of Valve, C	-	0.8	0.8
Discharge through one Valve, Qv	m3/sec	1.19	1.26
Total Discharge, Q	m3/sec	2.39	2.52

Considering the filling rate of 2.39 m3/sec & 2.52 m3/sec in both the cases. The total time taken for the initial filling of the Head Race Tunnel (HRT), from the intake gate up to the Butterfly Valve Chamber (BVC), has been estimated as below.

Case	HRT	Upstream reservoir level (m)	Filling upto elevation (m)	Total time taken for filling. (Days and hrs)
Case 1	HRT 3	EL. 775.00	EL. 728.50	2 days and 5.98 hrs
	HRT 4			2 days and 6.46 hrs
Case 2	HRT 3	EL. 780.00	EL. 728.50	2 days and 5.67 hrs
	HRT 4			2 days and 6.12 hrs

During the filling process of the Head Race Tunnel (HRT) up to the Butterfly Valve Chamber (BVC), proper monitoring and observation shall be maintained at all key locations throughout the tunnel reach to identify any signs of distress, seepage, or abnormal behaviour. Based on field observations, necessary adjustments in the rate of filling or time intervals may be made to ensure structural safety and hydraulic stability.

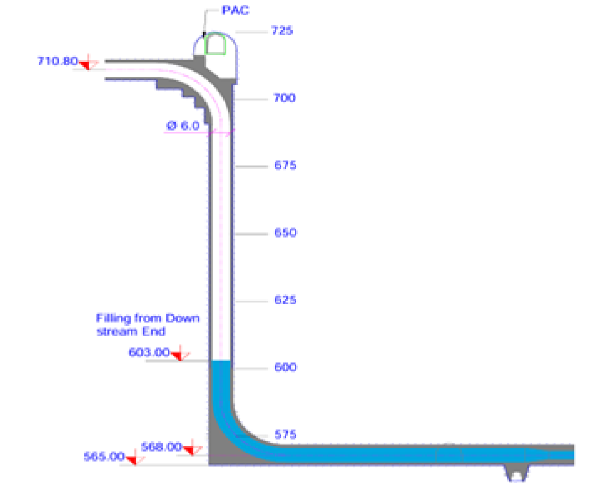
The time interval after the first step of filling shall be 24 hours, followed by 12-hour intervals between each subsequent step, allowing sufficient time for stabilization and inspection.

The invert level at the pressure shaft near BVC is EL. 706.55 m. The HRT is proposed to be filled up to EL. 724.55 m in steps of 6 m water head. Thereafter, a final increment of 3.95 m is planned to raise the water level up to the overt level (EL. 728.50 m) near the gate shaft.

This schedule ensures a controlled hydraulic rise, consistent with the codal provisions of BIS 14815:2000 for hydraulic structure filling operations, thereby minimizing the risk of undue stress on tunnel lining and adjoining structures.

STAGE 3: FILLING OF THE PRESSURE SHAFT FROM THE BVC UP TO THE MAIN INLET VALVE (MIV).

In this stage, the pressure shaft from BVC upto MIV needs to be filled upto EL.713.80 m. The filling of upper horizontal pressure shaft, vertical pressure shaft and lower horizontal pressure shaft is done upto EL. 713.80 m (overt level of pressure shaft at BVC).



Typical sketch showing philosophy of stage 3 filling.

The total time taken for filling of each pressure shaft from BVC upto MIV is evaluated below

Upstream reservoir level (m)	Valve Elevation (m)	Filling discharge for each pressure shafts.(Cum)	Total time taken for filling*(days and hrs)
EL. 775.00/ EL. 780.00	EL.713.80	1.29	0 days and 21.86 hrs

During the filling of the pressure shaft, continuous monitoring and observation must be conducted to detect any signs of distress at key points along the entire reach. Appropriate adjustments in the filling rate or time intervals may be required based on these observations. For this operation, a time gap of 3 hours is considered between each filling step. The bottom-most invert level of the pressure shaft near the MIV is at EL 565.00 m. The pressure shaft is filled up to the balancing head of the lower reservoir at EL 603.00 m, and further, from EL 603.00 m to EL 713.80 m. Water is added in increments corresponding to a height of 15 m at each step.

STAGE 4: BALANCE FILLING OF THE UPSTREAM SURGE SHAFT.

The balance filling of the upstream surge shaft and upstream gate shaft will be carried out from EL 728.50 m up to the upper reservoir level at EL 775 m / EL 780 m. The filling rates will follow the same procedure as described in Stage 2. The water level in the surge shaft will be closely monitored during each increment, which will help indicate any potential seepage. It is proposed that the filling be conducted in two steps, each with a water increment of 15 m and a time gap of 12 hours. After these steps, the shafts will be continuously filled up to the upper reservoir level.

The total time taken for filling is evaluated below:

Case	Upstream reservoir level (m)	Filling upto elevation (m)	Total time taken for filling* (Days and hrs)
Case 1	EL. 775.00	EL. 775.00	1 days and 2.37 hrs
Case 2	EL. 780.00	EL. 780.00	1 days and 2.49 hrs

VIII. MONITORING AND OBSERVATION DURING FILLING

During the filling operation, the following activities shall be carried out to ensure safe and controlled progress of the process:

WATER LEVEL MONITORING:

The water levels in the surge tank shall be recorded continuously throughout the filling operation.

STEPWISE OBSERVATION:

At the end of each filling step, the intake gate valves shall be closed, and the water level in the surge shaft shall be observed at hourly intervals.

Any loss of water from the tunnel or leakage through the penstock inlet valves shall be accurately recorded.

INSTRUMENTATION SURVEILLANCE:

All installed instruments in the head race tunnel, pressure shaft, tail race tunnel (TRT), and surge shaft shall be closely monitored before, during, and after the filling operation to assess behaviour under changing hydraulic conditions.

LEAKAGE INVESTIGATION:
If a significant drop in water level is observed at any stage, the cause of leakage shall be thoroughly investigated, and necessary remedial measures shall be implemented.
Further stages of filling shall only proceed after ensuring that the preceding step shows no abnormal water level variation.
INSPECTION OF STRUCTURES:
All gates, stop logs, observation points, and valves shall be monitored for leakage both during and after the filling process to confirm the integrity and tightness of the system.

Water levels in the surge tank shall be recorded continuously during filling. At the end of each step, intake gate valves shall be closed, and surge shaft water levels monitored hourly. Any loss of water or leakage through penstock inlet valves shall be recorded. All instruments installed in the HRT, pressure shaft, TRT, and surge shaft shall be monitored before, during, and after filling. In case of abnormal water level drop at any stage, the cause shall be investigated and rectified before proceeding to the next step. All gates, stop logs, observation points, and valves shall be thoroughly inspected for leakage during the filling operation.

IX. CONCLUSION

The first filling of the Water Conductor System is a milestone event, representing the culmination of the construction phase and the first true validation of the project's hydraulic integrity. For the 1000 MW Tehri Pumped Storage Plant, this process is meticulously engineered to be a controlled, incremental, and highly monitored activity, adhering to the guidelines of IS 12633:1989 and project-specific requirements.

The proposed four-stage methodology—sequentially filling the Tail Race Tunnel, Head Race Tunnel, Pressure Shafts, and finally, the Upstream Surge Shaft—ensures that hydraulic loads are applied gradually to all underground structures. This step-wise pressurization, with prescribed waiting periods at critical head increments, is crucial for allowing the surrounding rock mass to stabilize, for the linings to accommodate the stresses, and for any potential leaks or distress to be detected and addressed proactively.

The successful execution of this first filling plan will verify the structural soundness and water-tightness of the entire system, from the intake to the powerhouse. It will provide critical baseline data on the geo-mechanical behaviour of the tunnels and shafts under operational loads, ensuring the long-term safety and reliability of the plant. The insights and procedural framework established for the Tehri PSP not only serve to de-risk its own commissioning but also set a valuable precedent for the execution of first filling operations in other large-scale underground hydropower and pumped storage projects. Ultimately, a successful first filling paves the way for the safe and efficient commissioning of one of India's most significant energy storage infrastructures.

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