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Monitoring Analysis of Hushan Reservoir during Initial Filling Stage

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Abstract

Completion of Hushan reservoir was in July, 2014 and started initial filling in 2016. By November, 2018 the storage water level has reached EL. 205.47m, 6.03m lower than the high water level EL. 211.5m, and can be estimated reaching high water level in 2019 as initial filling of reservoir.

Monitoring systems are installed within the dams and surrounding mountain ridges, measurements recording pre-filling and filling stages to achieve full monitoring of reservoir's safety. According to the analysis results of monitoring instruments, the dams and ridges are currently in stable states. Pore water pressure variations recorded by the dam foundation base piezometers show seepage flow detouring along the cut-off walls. The results of core zone piezometers show corresponding increase of pore water pressure during the 3rd stage of water raise. Both dam body and foundation base seepage flows gradually increase along with filling of reservoir and are within alert range. As predicted, primary consolidation is currently occurring within dam body and the settlements are also within alert range.

Keywords: Reservoir, Pore water pressure, Piezometer, Storage water level.

1 Layout

Hushan Reservoir is an off-stream reservoir with advantage of decreasing siltation that can extend its service lifespan. Reservoir is located 10km southeast of Touliu city, Yunlin County upon Merlin River System with catchment area of approximately 6.5 km^2, see Fig 1-1. Main facilities include the dams, spillway and outlet works etc; The dams consists of Hushan Main Dam, Hushan Auxiliary Dam, and Hunan Dam and the heights are 75m, 63m and 75m,respectively. External inlet works consists of Tontou Weir upon Qingshui River, open channels, closed conduits and tunnels. Top view of reservoir is shown in Fig1-2.

2 Monitoring System and Frequency

2.1 Monitoring System

In order to secure safety of Reservoir, monitoring systems are installed within Hushan Main Dam, Hushan Auxiliary Dam, and Hunan Dam. The locations of monitoring system are illustrated in Fig.2.1-1 and Fig.2.1-2.

Fig. 1-1: Top View of Reservoir Locations and Surroundings

Fig. 1-2: Top View of Reservoir Main Facility Locations

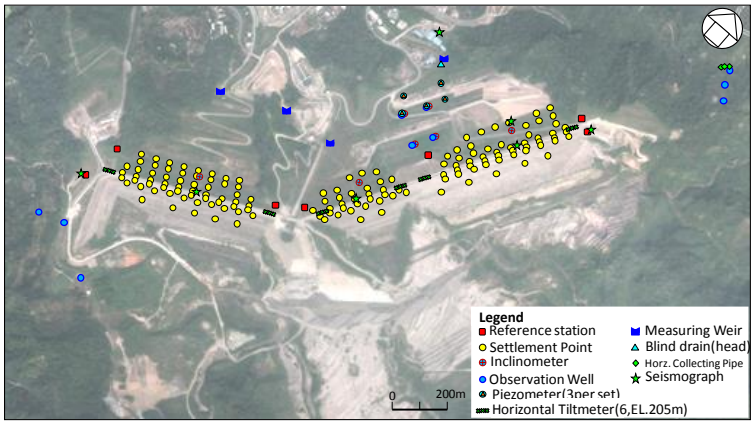


Fig. 2.1-1: Top View of Dams and Monitoring Systems Locations

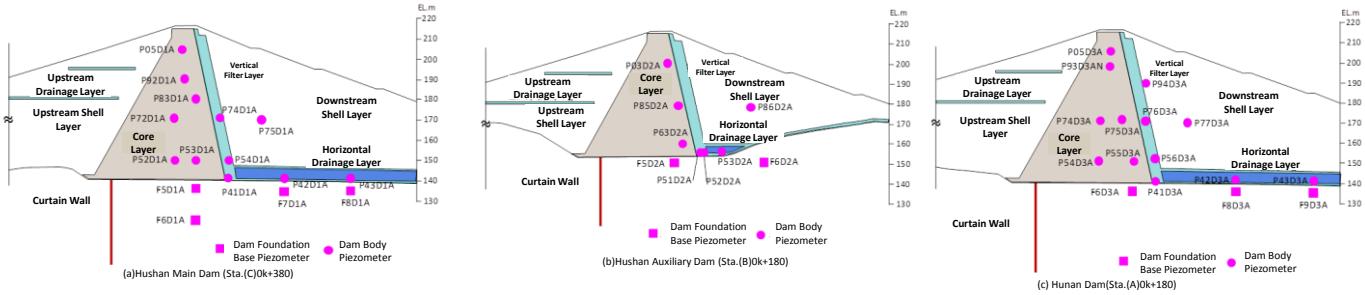


Fig. 2.1-2: Profile of Dams and Piezometers Locations

2.2 Monitoring Frequency

The monitoring frequencies for the mentioned monitoring systems are listed in Tab. 2.2-1. Besides regular monitoring and standard additional monitoring when encountering heavy rainfall or earthquake, measuring frequencies are increased during initial filling stage.

Tab. 2.2-1: Frequencies for Main Monitoring Device

<table>
<tr><td rowspan="2">Device</td><td colspan="3">Monitoring Frequency</td></tr>
<tr><td>Regular</td><td>During Filling</td><td>Heavy Rainfall or Earthquake</td></tr>
<tr><td>Piezometer</td><td rowspan="9">Twice per month</td><td rowspan="2">Once per day</td><td rowspan="9">One additional measurement after each event</td></tr>
<tr><td>Horizontal Collecting Pipe</td></tr>
<tr><td>Settlement Point</td><td rowspan="3">Twice per week</td></tr>
<tr><td>Inclinometer</td></tr>
<tr><td>Slope Inclinometer</td></tr>
<tr><td>Horizontal Tiltmeter</td></tr>
<tr><td>Observation Well</td><td rowspan="3">Once per week</td></tr>
<tr><td>Open Head Piezometer</td></tr>
<tr><td>Measuring Weir</td></tr>
<tr><td>Seismograph</td><td colspan="3">Download data per month and one additional action after each earthquake.</td></tr>
</table>

3 Initial Filling Plan and General Situation during Implementation

3.1 Initial Filling Plan

Three stages are scheduled for the initial reservoir filling. The starting & finishing water level and raising rate for each stage are listed in Tab. 3.1-1.

3.2 General Situation during Implementation

Hushan Reservoir has completed its 1st and 2nd stages during durations of 2016/4/2~2016/9/9 and 2017/4/17~2017/8/11, respectively. The 3rd stage has started since 2018/8/1. On 2018/11/6, when reaching water level of EL.205.14m, reservoir water level gradually starts to decrease due to shortage of water source and has dropped to EL.199.76m on 2018/12/31. The finishing period of the 3rd stage is estimated to occur in mid 2019. Duration curve up to 2018/12/31 of reservoir water level variations is shown in Fig3.2-1.

Tab. 3.1-1: Initial Reservoir Filling Plan

Filling Stage	Starting/Finishing Water Level Per Stage	Raising rate if Reservoir Water Level
1st	EL.160m/EL.170m	◆Max rate:0.6 m /day; ◆Sustain water level for at least 15 continuous days when reaching EL. 170m.
2nd	EL.170m/EL.185m	◆ Max rate:0.5 m /day; ◆ Sustain water level and increase monitoring frequently for 7 continuous days when reaching elevations EL.175m and EL.180m, respectively; ◆ Sustain water level and increase monitoring frequently for at least 15 continuous days when reaching EL. 185m.
3rd	EL.185m/EL.211.5m	◆ Max rate:0.5 m /day; ◆Sustain water level and increase monitoring frequently for 7 continuous days when reaching elevations EL.190m, EL.195m, EL.200m, and EL.205m, respectively; ◆ Sustain water level at approximately EL.209.5m to EL.211.5m and increase monitoring frequently for at least 30 continuous days when reaching full water level of EL. 211.5m.

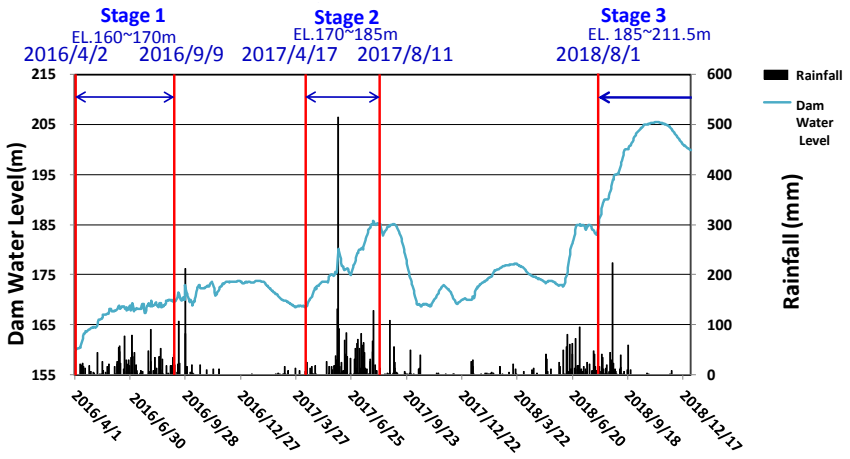


Fig. 3.2-1: Duration curve up to 2018/12/31 of dam water level variations

4 Monitoring Results

Up to 2018/12/31, within duration of the initial filling stage, pore water pressure, seepage flow and settlement of dam are analyzed and discussed in the following contents.

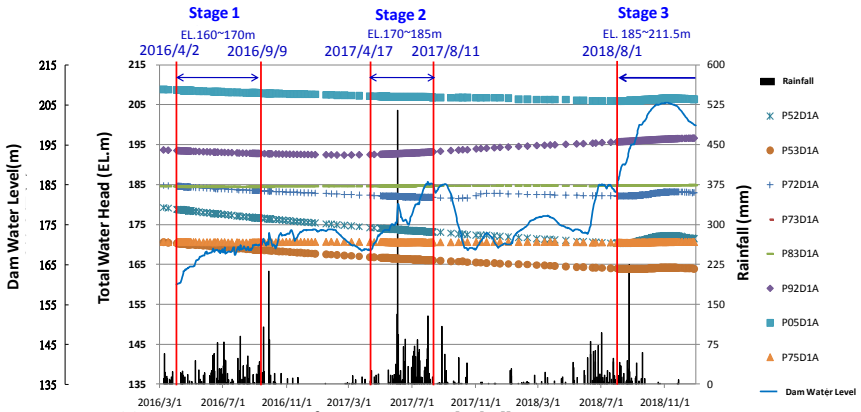
4.1 Pore Water Pressure in Hushan Main Dam

Fig.4.1-1(a)~(c) show relations between total water head of dam body and foundation base and time; Pore water pressure measured from piezometers within core zone has apparently increased during 3rd stage of filling, as shown in Fig.4.1-1(a), while no visible change occurred within the filter drainage layer, as shown in Fig.4.1-1(b). Foundation piezometers have recorded water pressure variation during the 2nd and 3rd stages of filling, and apparent change occurred in piezometers F5D1A and F6D1A during the 3rd stage, as shown in Fig.4.1-1(c). By plotting dam profile onto total water heads measured on 2018/11/6 considering dam water level EL.205.47m, the measured total heads generally accord with theoretical seepage behavior, see Fig.4.1-2.

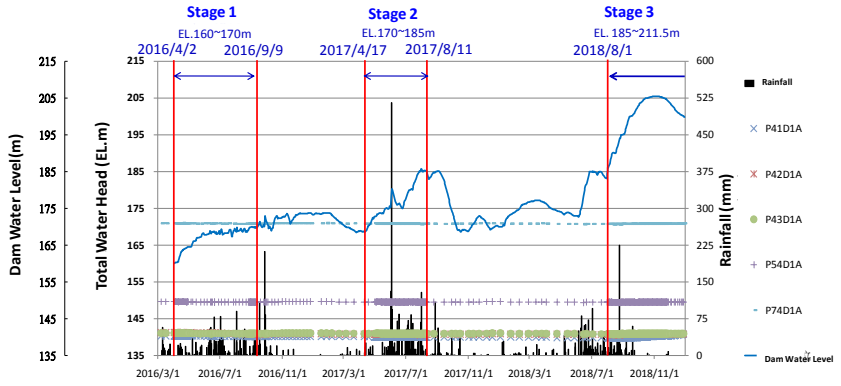
Foundation Piezometers F5D1A and F6D1A

- Water head increment, measured from foundation piezometers F5D1A, F6D1A, F7D1A and F8D1A during 3rd stage of filling, and increase of dam water level ratios are listeded in Tab.4.1-1. Ratio order from most to least is F6D1A(24.39%), F5D1A(17.52%), F8D1A(3.27%), and F7D1A(2.18%).
- Relations between total head of F5D1A and F6D1A and dam water level are illustrated in Fig.4.1-3. Both curves show similar tendency, while average gradient of F6D1A curve is larger. The result indicates that stratum where F6D1A is located bears relatively higher permeability which corresponds with

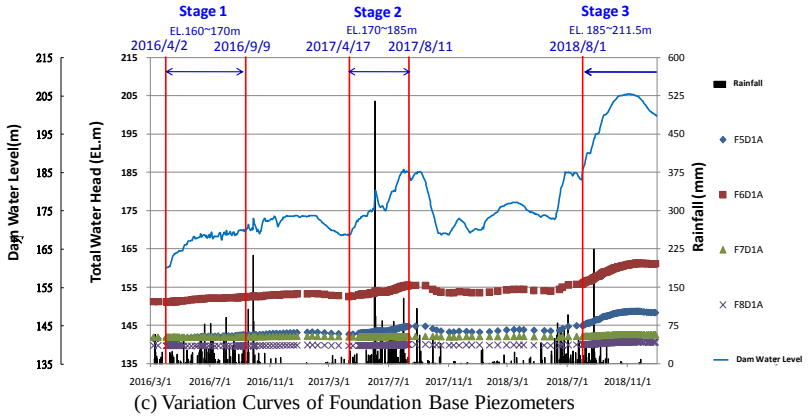
actual strata information. Moreover, hysteresis has been discovered in both curves during the 3rd stage declining of water level which corresponds with the loop phenomenon observed during 2nd stage of peak water raise to decrease in Fig. 4.1-3. This shows seepage flow within Hushan Main Dam accords with theoratical behavior.



(a) Variation Curves of Core Layer and Shell Layer Piezometers



(b) Variation Curves of Filter and Drainage Layer Piezometers



(c) Variation Curves of Foundation Base Piezometers

Fig. 4.1-1: Total Water Head Variations Measured from Dam Body and Foundation Base Piezometers of Hushan Main Dam

Tab. 4.1-1: Water Head Variation Chart Measured from Foundation Piezometers of Hushan Main Dam during Water Filling (2018/8/1~2018/11/6)

Piezometer		2018/8/1 Water Head(a)	2018/11/6 Water Head (b)	Water Head Increment (b-a)	Water Head Increment And Water Level Raise Ratio
No.	Installed EL.m	EL.m	EL.m	m	(%)
F5D1A	135.05	144.90	148.61	3.71	17.52
F6D1A	120.05	155.78	160.95	5.17	24.39
F7D1A	135.43	142.18	142.64	0.46	2.18
F8D1A	135.14	139.95	140.64	0.69	3.27

Noted: Water level raised from EL.184.29 to EL.205.47 during 2018/8/1 to 2018/11/6.The total increment is 21.18m

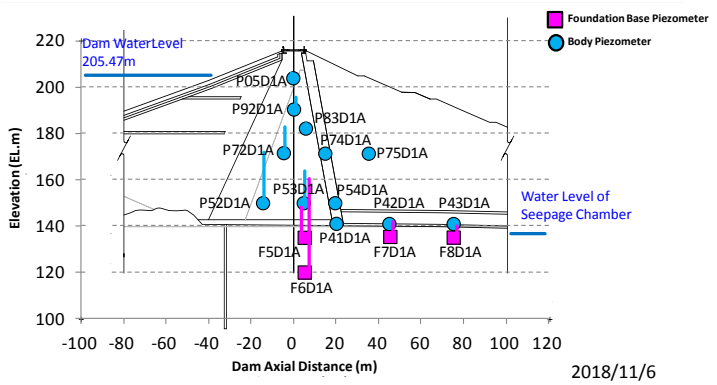


Fig. 4.1-2: Profile of Hushan Main Dam Considering Total Water Head Measured from Piezometers and Water Levels of Upstream and Downstream

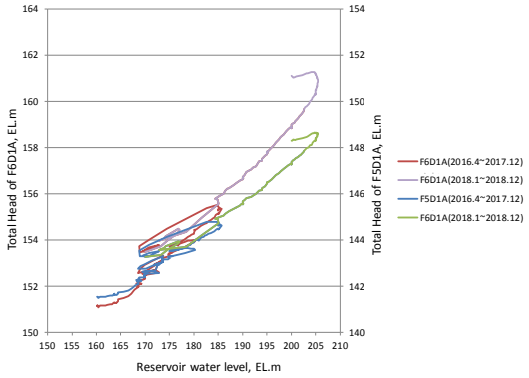


Fig. 4.1-3: Foundation Base Piezometers F5D1A and F6D1A Total Water Head and Dam Water Level Relation Curve

Core zone Piezometers P52D1A, P53D1A and P72D1A

- During 3rd stage of water level raise, piezometers P52D1A, P53D1A, and P72D1A are starting to be influenced by the filling process and show diffrent degree of increase in pore water pressure, see Tab.4.1-2. The order of pressure head increment and water level raise ratio from most to least is P52D1A(9.74%), P72D1A(7.87%), and P53D1A(3.65%). The increment variations correspond with the piezometers locations and show normal seepage behavior.
- During 3rd stage of water level decline, pore water pressures measured from piezometers P52D1A, P53D1A, and P72D1A do not immediately decrease, generally sustained average level, while instead start to gradualy decline 11~21days later. The hysteresis behavior also accords with the seepage theory.

Tab. 4.1-2: Water Head Variation Chart Measured from Core Layer Piezometers of Hushan Main Dam during Water Filling (2018/8/1~2018/11/6)

Piezometer		Data When Core Layer Piezometer Starts to Record Pore Water Pressure Increase			Data of 2018/11/6		Water Head Increment, m	Water Head Increment And Water Level Raise Ratio (%)
No.	Elev., EL.m	Date	Water Level, EL.m	Total Head of Piezometer, EL.m	Water Level, EL.m	Total Head of Piezometer, EL.m		
P52D1A	150	107/8/2	186.10	170.30	205.47	172.19	1.89	9.74
P53D1A	150	107/9/9	197.81	163.86	205.47	164.14	0.28	3.65
P72D1A	171.64	107/8/24	193.33	182.17	205.47	183.13	0.96	7.87

4.2 Seepage of Dams

Seepage flows of the dams are measured and their relations with time are shown in Fig.4.2-1. The results indicate that reservoir water level raise may cause increase of seepage flow, but influenced by rainfall factor. Thus Tab. 4.2-1 is established to observe seepage flow during dry season. Considering Hushan Reservoir is still within initial filling stage, seepage flow shall increase until dam body saturation line and saturation degree reach steady states.

Tab. 4.2-1: Increase of Seepage Flow Caused by Water Level Raise during Initial Filling Stages

Dam Name	Seepage Flow meter No.	Background Seepage Flow During Empty，CMD	Deviation Compared with Background Value, CMD		
			Dry Season after 1st Stage Filling	Dry Season after 2nd Stage Filling	Dry Season after 3rd Stage Filling
Hushan Main Dam	SP2D1	36~49	6.98~8.64	8.64~13.64	31.64~34.56
Hushan Auxiliary Dam	SP2D2	10.4~14.3	2.12~5.16	5.572~6.016	21.12~23.3
Hunan Dam	SP2D3	25.9~33.7	3.74~7.56	12.26~18.14	39.74~41.78

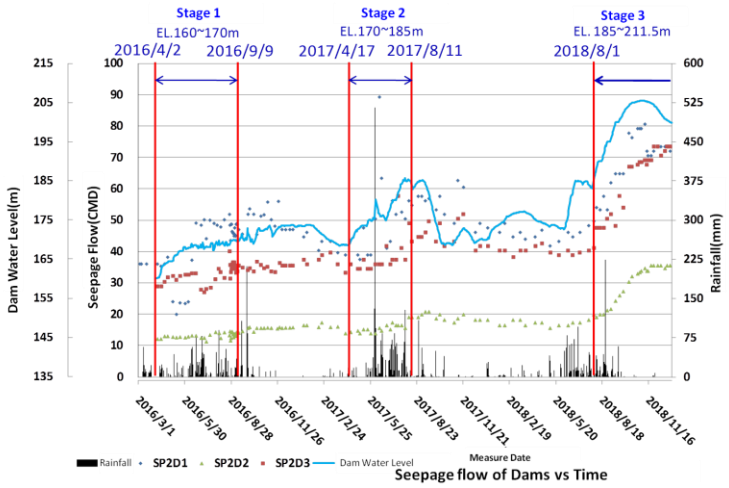


Fig. 4.2-1: Seepage flow and time relations of Hushan Main Dam, Hushan Auxiliary Dam, and Hunan Dam

4.3 Settlement of Dams

The surface monitoring for dam consolidation of Hushan Main Dam, Hushan Auxiliary Dam, and Hunan Dam has started since completion. The results, see Tab.4.3-1, the maximum consolidation of dams only account for 0.143~0.281%, of their height which are still below design value of 1%. Fig. 4.3-1 illustrates the consolidation distribution contour of Hushan Main Dam and shows minor changing rate.

Tab. 4.3-1: Maximum Settlement Chart of Hushan Main Dam, Hushan Auxiliary Dam, and Hunan Dam

Dam Name	Position	Maximum Settlement, (mm)	Dam Height (m)	Percentage of Consolidation, (%)
Hushan Main Dam	Upstream,EL.215m	166.3	75	0.222
	Downstream,EL.215m	147.1		0.196
Hushan Auxiliary Dam	Upstream,EL.215m	130.9	63	0.208
	Downstream,EL.215m	90.1		0.143
Hunan Dam	Upstream,EL.215m	201.2	75	0.268
	Downstream,EL.215m	210.9		0.281

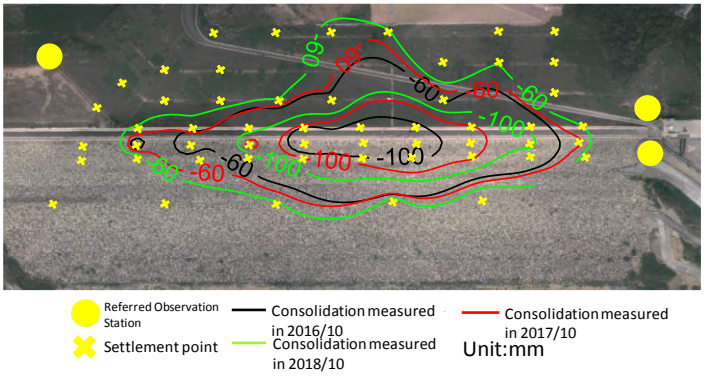


Fig. 4.3-1:Consolidation Distribution Contour of Hushan Reservoir Main Dam

5 Conclusions

After integrating monitoring results of initial filling stage up to now, Hushan Reservoir is currently in stable states and conclusions are as follows:

- In accordance with pore water pressure monitoring results, the curtain walls have served their purpose, as predicted, causing seepage flow detouring along wall body downstream. The results of dam core piezometers show corresponding gradual increase of pore water pressure during water raise. Increment behavior meets with seepage theory: decreases from upstream to downstream and from low to high positions.
- Both dam body and foundation base seepage flow increase along with filling of reservoir and the water quality is clear. It is predicted that seepage flow shall

increase till steady states corresponding with increase of dam body saturation range.

- Current consolidation of dam body is still within design range, general variations are minor and no excessive differential settlement occurred.

References

Central Region Water Resources Office, WRA, MOEA (2019). *2019 Monitoring Analysis of Hushan Reservoir Final Report (「107 年度湖山水庫監測及安全檢查－水庫安全監測分析」安全監測總報告).*

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