大唐（老挝）萨拉康水电有限公司
Datang(Lao)Sanakham Hydropower Co.,Ltd

SANAKHAM HYDROPOWER PROJECT

Hydraulic Physical Model Investigation of Filling and Emptying System

中国电建
POWERCHINA
西北勘测设计研究院有限公司
NORTHWEST ENGINEERING CORPORATION LIMITED

October 2018

Contents

LIST OF TABLES

LIST OF FIGURES

1 Introduction

Sanakham Hydropower Station is the 5th stage hydropower station on the Mekong River in Lao People’s Democratic Republic, which is a multi-purpose hydroelectric complex mainly for power generation and also for navigation and fish pass. The main structures include powerhouse, discharging sluice, navigation lock and fish way.

Navigation lock is one of the main structures of the Sanakham Hydropower. It is at left bank and designed as a single-lift. The designed vessels are 500t barge and 2×500t barge tows which makes that this is a Class Ⅳ lock according to the National Standards of the People's Republic of China *Navigation standard of inland waterway*. The recommended effective dimension of the lock chamber is 120m×12m×4m (usable length × clear width × sill depth), the maximum designed lift is 20.59m, and the designed operation time is no more than 10min.

According to the detailed layout study and hydraulic calculation analysis of two optional filling and emptying systems, which are two lock wall culverts bottom centered lateral-manifolds system and in-chamber bottom longitudinal culvert system, the latter is selected for the Sanakham lock. This report introduces the hydraulic model investigation results about the selected filling and emptying system, which gives the verification and optimization of the hydraulic characteristics of the system and also gives the recommended detailed layout of the system.

The hydraulic model tests are carried out under two conditions, which are designed maximum lift condition and lowest upstream water level condition (see section 2.1). For determining the operations of filling and emptying valves, four opening times(5min、6min、7min、8min) for valves and two operation patterns(Normal two-valve synchronously and single valve) have been chosen for the tests. According to the test results, the recommended valve opening time has been determined as 6min. This report only gives the investigation results under the 6min-valve-opening condition.

2 Basic Data

2.1 Characteristic water levels and their combinations

Water levels for lock hydraulic model test are as follows:

Highest upstream navigable water level 220.00m

Highest downstream navigable water level 213.36m

Lowest upstream navigable water level 219.00m

Lowest downstream navigable water level 199.41m

Downstream navigable water level when 10 turbines full load working(discharge 4560m^3/s) 204.16m

The main water level combinations are as follows:

(1) Highest upstream navigable water level ~ Lowest downstream navigable water level, the lift under this combination is the maximum designed lift 20.59m;

(2) Lowest upstream navigable water level ~ Downstream navigable water level when 10 turbines full load working, and the lift under this combination is 14.84m.

2.2 Designed vessel and fleet

The designed vessel and fleet type and their dimensions are as follows:

2×500t push tows: 111m×10.8m×1.6m（overall length × width × designed draft）;

500 t barge: 67.5m×10.8m×1.6m（length × width × designed draft）

2.3 Layout of the filling and emptying system

Based on the hydraulic calculation and comprehensive comparison, the in-chamber bottom longitudinal culvert filling and emptying system has been selected for the Sanakham lock, which is also used for model test. The overall layout of the filling and emptying system is shown in Fig.2.1, detailed layout are shown in Fig.2.2 ~ Fig.2.7. The typical dimensions of the system are shown in Tab.2.1.

Table 2.1 Characteristic dimensions of the in-chamber bottom longitudinal culvert

No.	Position	Description	Area（m^2）	Area ratio to valve section
1	Valve section culvert	Bottom elevation: 190.50m, top ceiling elevation: 193.00m, submerged depth under maximum lift condition: 7.01m	2-2.0×2.5=10.0	1.00
2	Intake	3 vertical side ports on guide wall, throat section height of each port is same, throat section width of each port reduces along the flow direction.	2-3×2.5×3.0=45.0	4.50
3	Filling culvert	Filling culvert top ceiling enlarges gradually after the filling valve section, the culvert height increases from 2.5m to 3.0m. Then the filling culvert connects the in-chamber bottom longitudinal culvert via a Y-type culvert. The bottom elevation and top ceiling elevation increased from 190.50m and 193.50m to 192.00m and 195.00m respectively at the same time.	2-2.0×3.0=12.0	1.20
4	Bottom longitudinal culvert with manifolds	Connected to the filling culvert and emptying culvert via two Y-type culverts. Total length of this culvert is 70m, equal to 58.3% of the lock usable length.	2-2.0×3.0=12.0	1.20
5	Side ports	There are 14 side ports on each side of the bottom culvert. Dimension of the port are: 0.4m×1.0m(width × height)、port spacing is 5.0m, length of the port is 1.2m, inlet and outlet of the port should be round out, the trimming circle radius is 0.3m.	2-14×0.4×1.0=11.2	1.12
6	Open ditch for energy dissipation in lock chamber	Open ditches should be set up out of the side port, the width and depth of the ditch are 2.5m and 4.0m respectively. Wall baffles should also be set up 2m higher than the ditch bottom on the lock wall.	/	/

No.	Position	Description	Area（m^2）	Area ratio to valve section
7	Emptying culvert	The emptying culvert connects the in-chamber bottom longitudinal culvert via a Y-type culvert. The bottom elevation and top ceiling elevation decreased from 195.00m and 192.00m to 193.50m and 190.50m respectively at the same time. Then culvert top ceiling contracts gradually before the emptying valve section, the culvert height decreases from 3.0m to 2.5m. After the emptying valve section culvert top ceiling enlarges gradually, the culvert height increases from 2.5m to 3.0m again.	2-2.0×3.0=12.0	1.20
8	Outlet	Double of the culvert area, inside guide walls should be set up.	2-2×2.0×3.0＝24.0	2.40
9	Energy dissipation chamber out of outlet	Top ports and side ports are set up on the chamber walls, asymmetry baffles are set up in the chamber.	24×0.5×2.0+12×0.5×3.0＝42.0	4.20

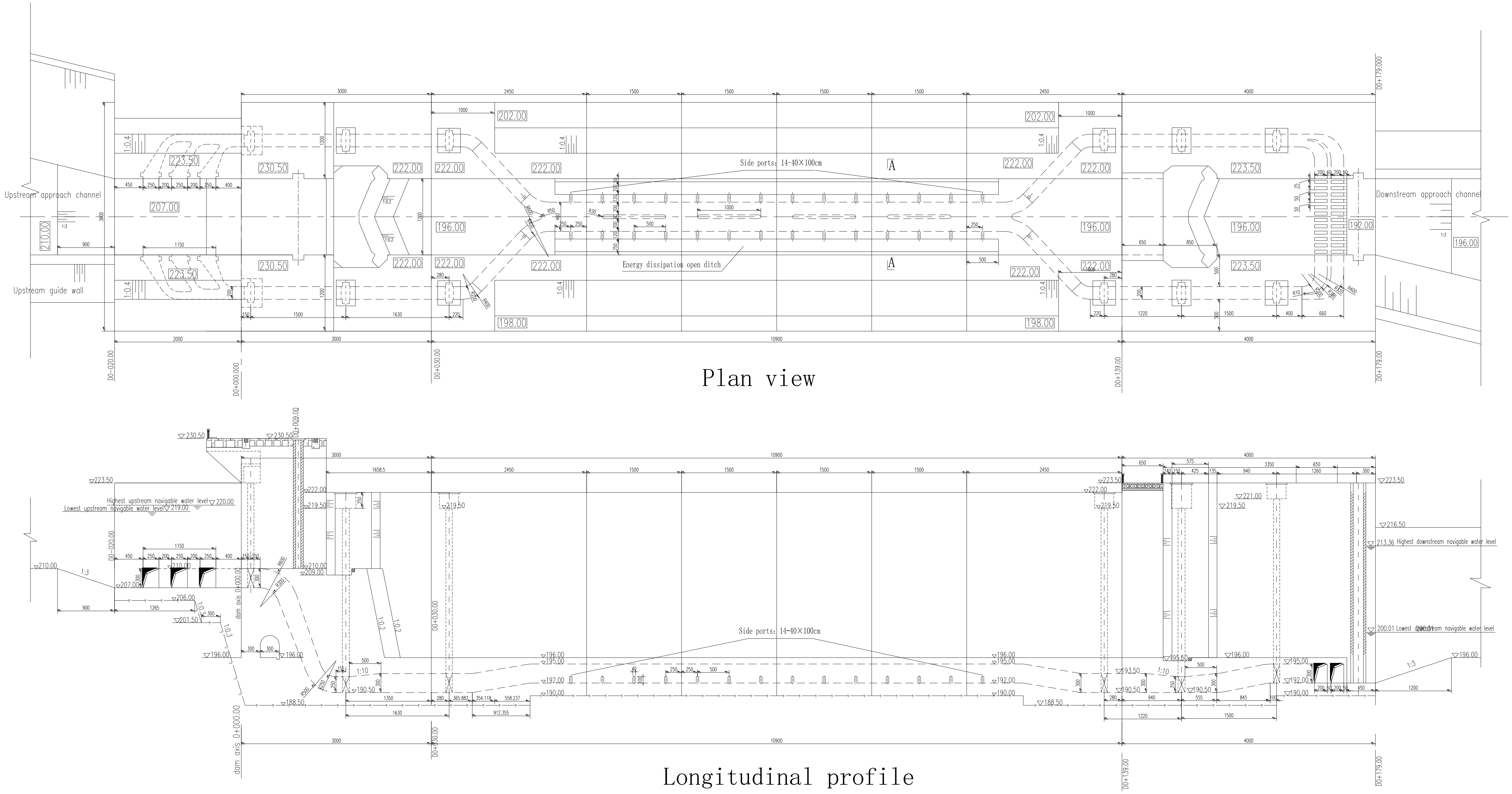


Figure 2.1 Initial layout of the in-chamber bottom longitudinal culvert filling and emptying system of the Sanakham lock（Unit：Elevation m，Length cm）

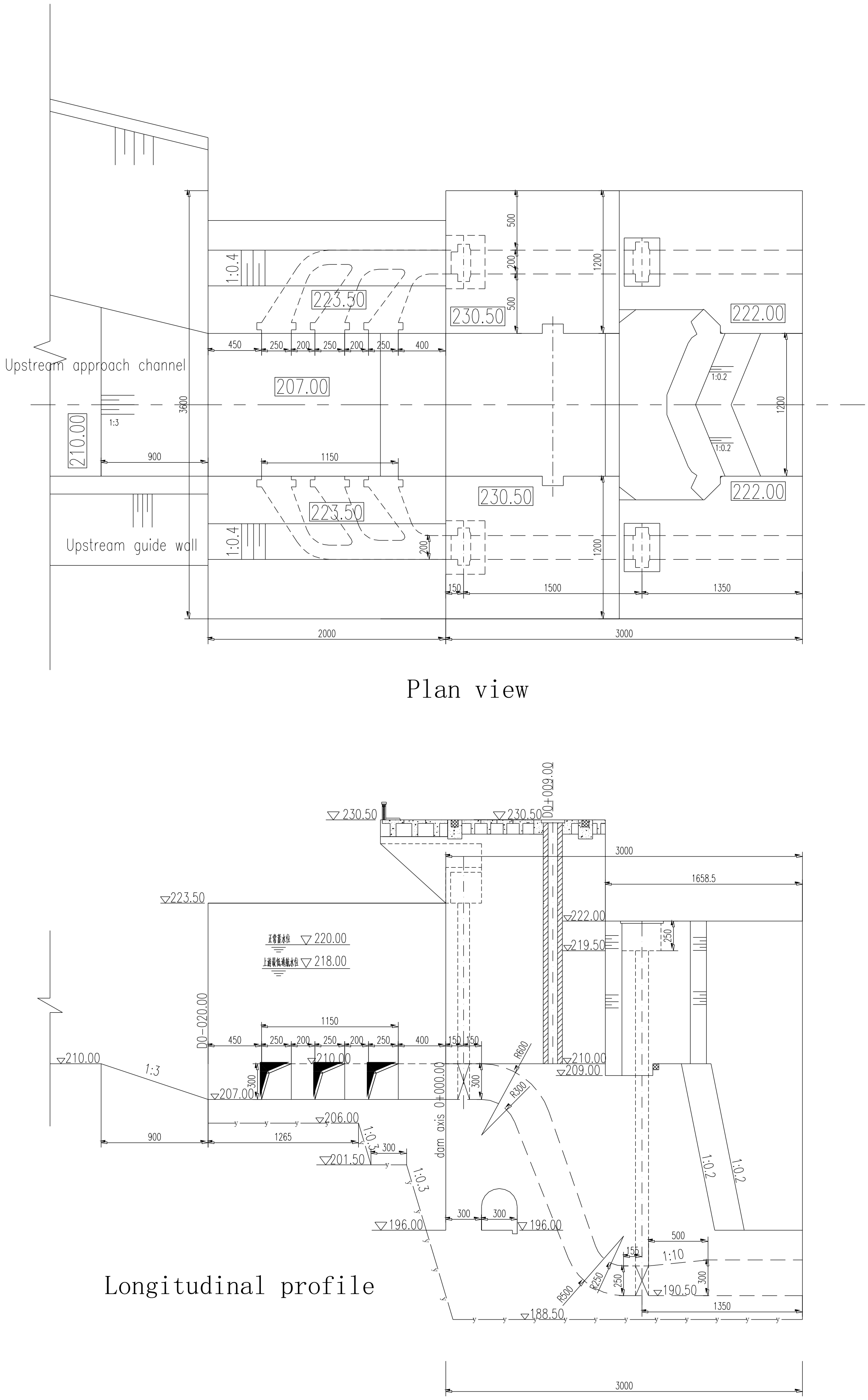
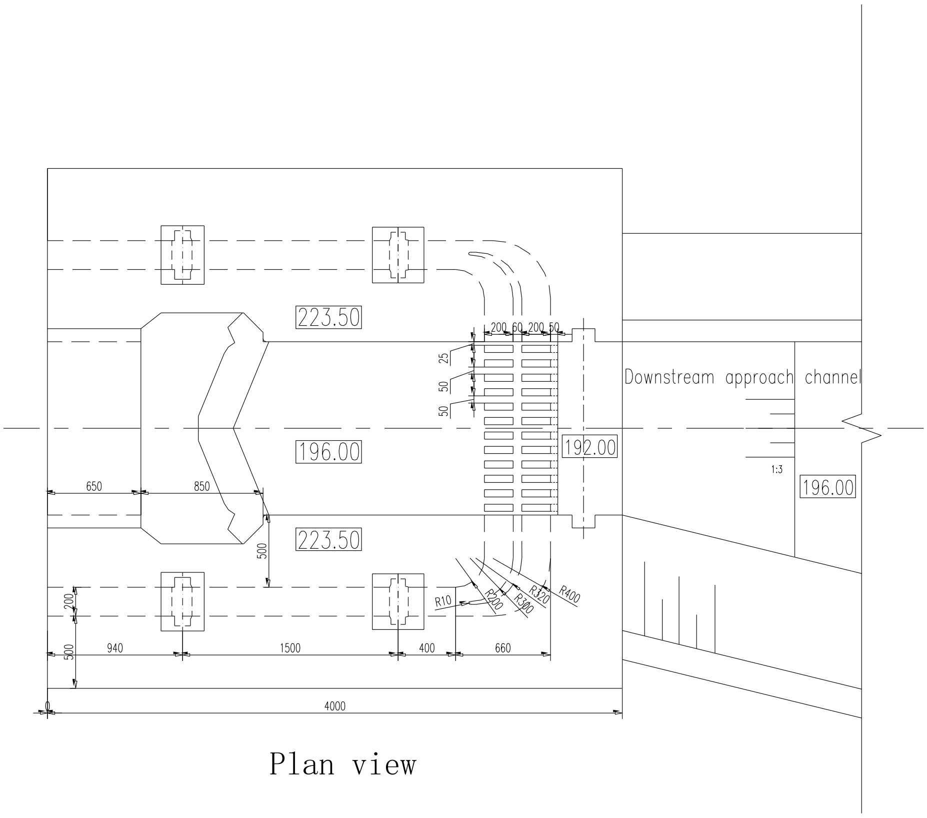
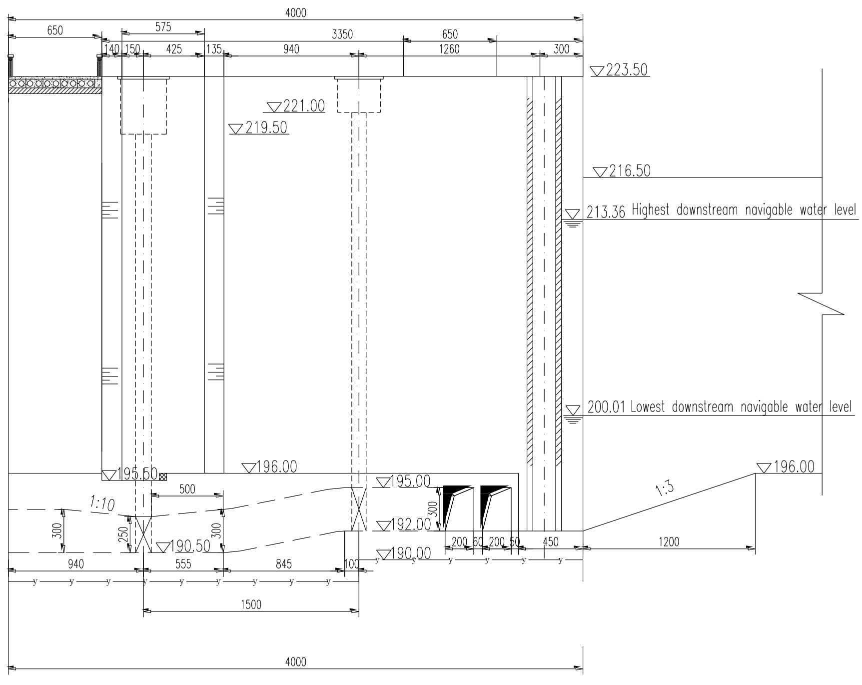


Figure 2.2 Layout of the upper lock head（Unit：Elevation m，Length cm）

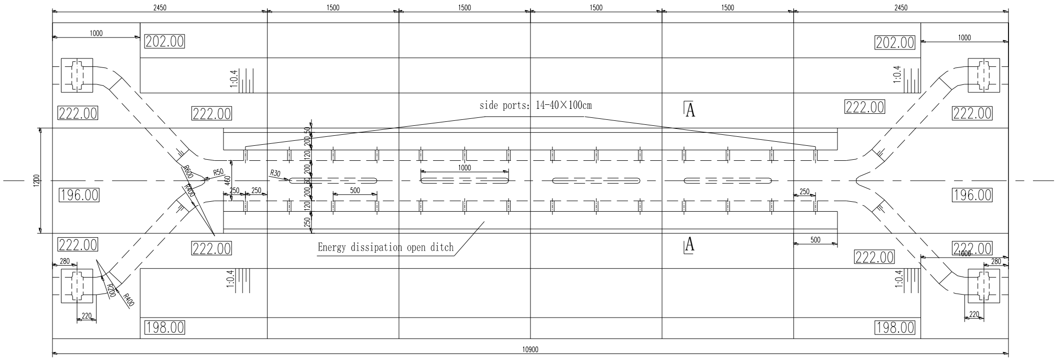


Plan view

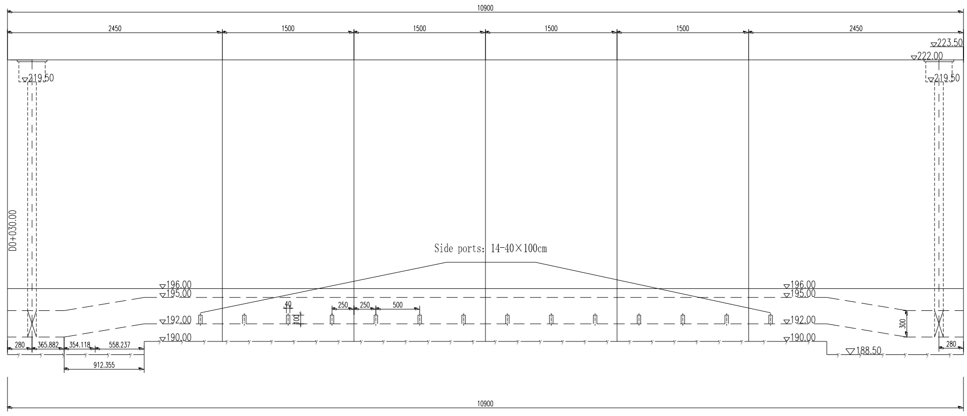


Longitudinal profile

Figure 2.3 Layout of the lower lock head（Unit：Elevation m，Length cm）



Plan view



Longitudinal profile

Figure 2.4　Layout of in-chamber bottom longitudinal culvert with manifolds（Unit：Elevation　m，Length　cm）

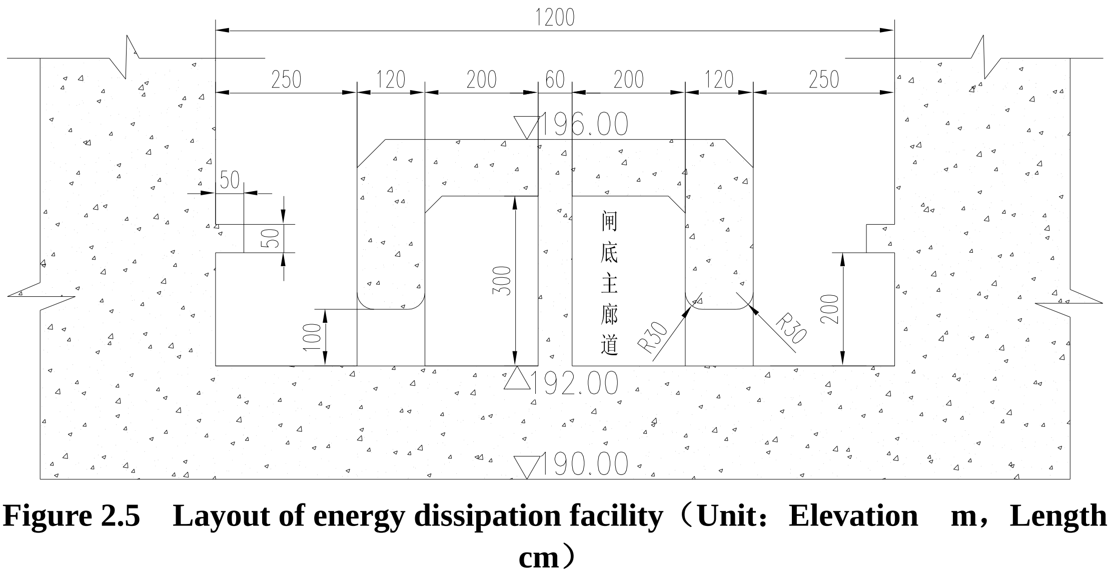
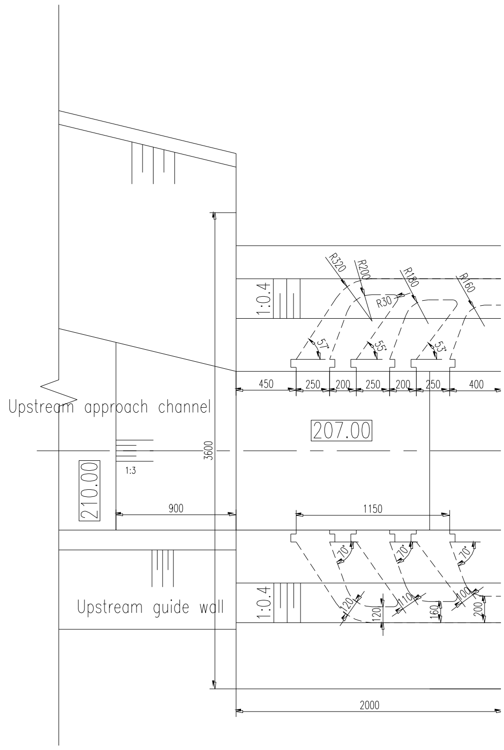
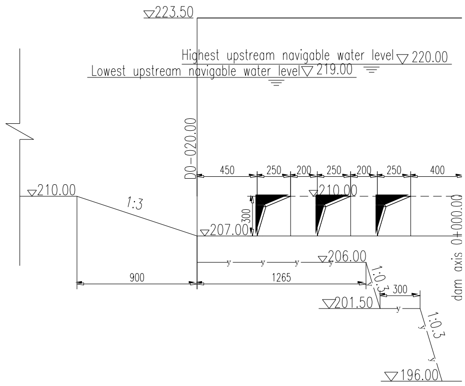


Figure 2.5　Layout of energy dissipation facility（Unit：Elevation　m，Length　cm）



Plan view



Longitudinal profile

Figure 2.6　Layout of upstream intake（Unit：Elevation　m，Length　cm）

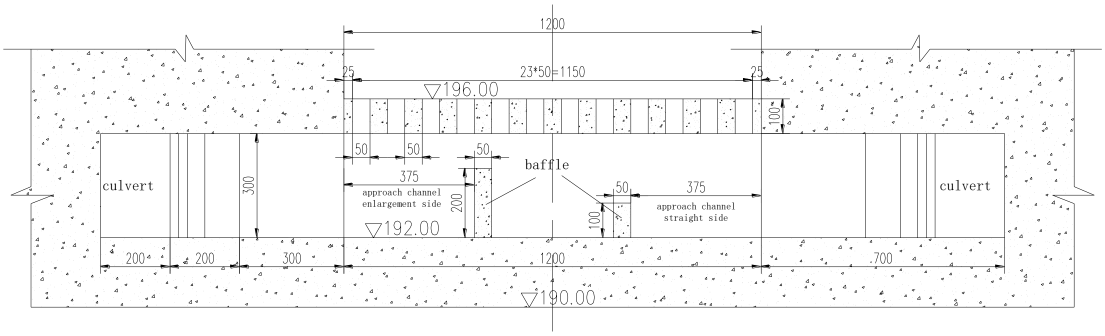


Figure 2.7　Cross section of the outlet and energy dissipation chamber（Unit：Elevation　m，Length　cm）

3 Model investigation contents and methods

3.1 Investigation contents

The main investigation contents are as follows:

1) Surveying and plotting the relationships between filling and emptying hydraulic characteristics and time, see Section 5.

2) Surveying the filling and emptying time and also the rate-of-rise and rate-of-fall of the water level in lock chamber, see Section 5.

3) Surveying the overfill or overempty in lock chamber, see Section 5.

4) Observing the local hydraulic phenomenon around the intake and outlet, in lock chamber and approach channels, see section 8.

5) Observing the vessel’s berthing condition in lock chamber, see section 6.

6) Surveying the vessel’s hawser forces in lock chamber, see section 6.

7) Surveying the velocity distribution in downstream approach channel, see section 8.

8) Surveying the pressure distribution of the culverts, surveying local average piezometric pressures and local transient or fluctuating pressures, see section 7.

3.2 Investigation methods

A 1:25-scale model is established for studying the hydraulic characteristics of the filling and emptying system. Via the model test, we can determine the layout of the filling and emptying system and also the opening patterns of the filling and emptying valves, we can survey the vessel’s berthing conditions in lock chamber and each hydraulic characteristic of the filling and emptying system. Based on analysis of the model test results, we can give the modification suggestions to the layout of the filling and emptying system, which can give the technical supports for the design.

4 Introduction to the model

4.1 Model design

The accepted equations of hydraulic similitude, based on the Froudian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transference of the model data to prototype equivalents, or vice versa, are presented in the following tabulation:

Dimension	Ratio	Scale relations
Length	$L_r = L$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3125
Time	$T_r = L_r^{1/2}$	1:5
Force	$F_r = L_r^3$	1:15625

The model reproduced part of the upstream approach channel, the entire filling and emptying system including intakes, valves, culverts, and the outlet, the lock chamber, and part of the downstream approach channel.

The lock chamber was constructed of steel sheet, the culverts were constructed of polyethylene(PE) plastic, the valve section culvert and one side of the lock wall were constructed of methyl methacrylate(PMMA) for the convenience of observing hydraulic phenomenon, the upstream and downstream approach channels were constructed of concrete precast slab with cement sand plaster. The model ships were constructed of glass fiber reinforced plastics.

The real model is shown in Fig.4.1 and Fig.4.2.

Figure 4.1 Model of Sanakham Lock

a Culvert of filling valve section

b Culvert of emptying valve section

Figure 4.2 Model of culverts of valve section

4.2 Instruments and equipment

The upstream and downstream water level are controlled by overflow tank, the valve are driven by stepper motor which can achieve stepless speed regulation. The water level in lock chamber and the local transient or fluctuating pressures in culvert are measured by resistance-type pressure sensor, the local average piezometric pressures are measured by piezometric tube. The vessel's hawser forces are measured by full-circular resistance-type dynamometer invented by Nanjing Hydraulic Research Institute. The velocities in approach channels are measured by Acoustic Doppler Velocimeter(ADV). The discharge is measured by rectangle measuring weir with the width 60cm. All the data are collected by WaveBook 516E high-speed data acquisition system. The model control and data acquisition system are shown in Fig.4.3.

Figure 4.3 Model control and data acquisition system

5 Investigation results of lock filling and emptying hydraulic characteristics

Model tests have been carried out under the two water level combinations mentioned in section 2.1. The water level and discharge hydrograph, filing and emptying time, and other hydraulic characteristics have been measured and calculated under different valve opening patterns.

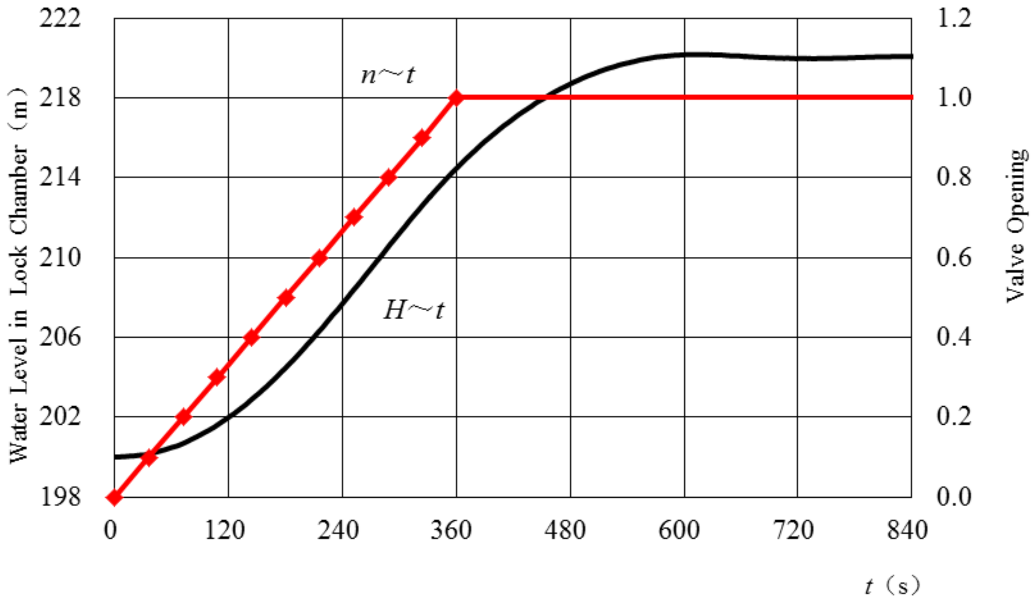
5.1 Maximum designed lift condition

The main hydraulic characteristics under maximum designed lift condition (water level combination: 220.00m～199.41m, lift: 20.59m) are shown in Tab5.1 and Fig5.1 ~ Fig5.2.

Table 5.1 hydraulic characteristics under maximum designed lift condition (water level combination: 220.00m～199.41m, lift: 20.59m)

Operation pattern		t_v (min)	H (m)	T (min)	Q_{max} (m^3/s)	U_{max} (m/min)	Ua (m/min)	d (m)
Filling	Double valves	6	20.59	9.62	96	3.66	2.08	+0.34
Emptying		6	20.59	9.98	88	3.36	2.00	-0.23

Note：t_v is the valve opening time, H is the lock lift, T is the filling or emptying time, Q_{max} is the maximum filling or emptying discharge, d is the overfill or overempty, U_{max} is the maximum rate-of-rise or rate-of-fall of the water level in lock chamber, U_a is the average rate-of-rise or rate-of-fall of the water level in lock chamber.



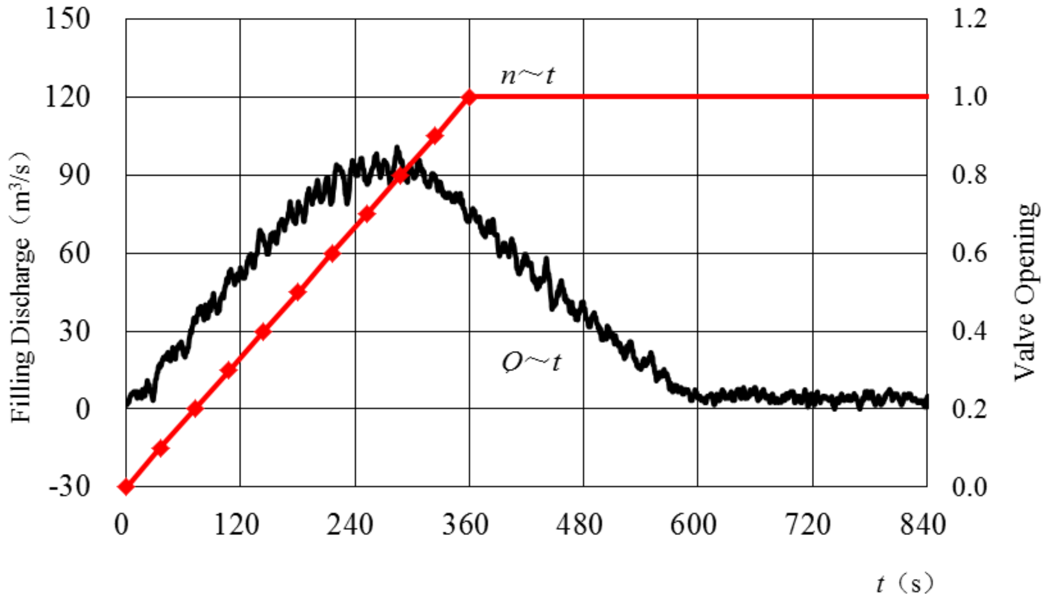
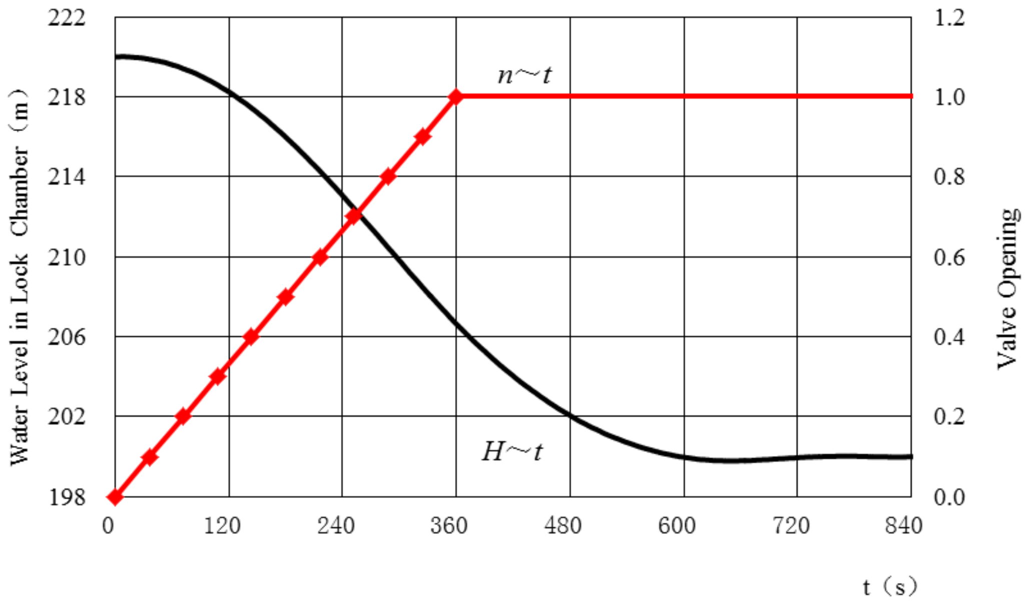


Figure 5.1 Filling hydraulic characteristics, double valves, tv＝6min （220.00 m~199.41m，H is water level in lock chamber, Q is discharge, n is valve opening， t is time）



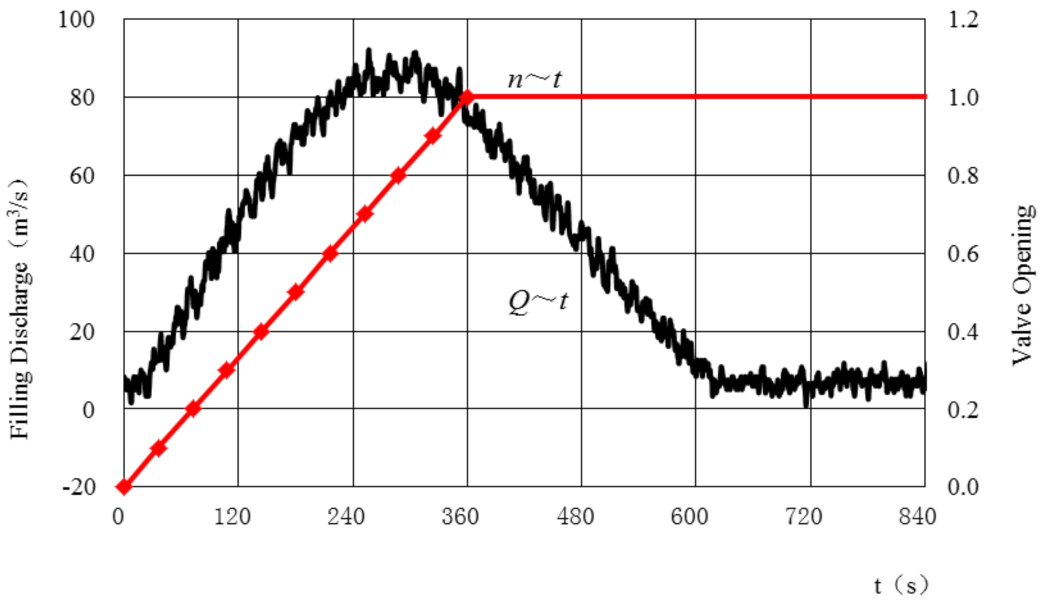


Figure 5.2 Emptying hydraulic characteristics, double valves, tv＝6min（220.00 m~199.41m，H is water level in lock chamber, Q is discharge, n is valve opening， t is time）

The test results indicate that, when double filling valves open in 6min uniformly and synchronously, the filling time is 9.62min, the maximum filling discharge is 96m^3/s. The maximum average velocity of main culvert's cross section is 8.00m/s, the maximum average velocity of culvert's cross section at valve section is 9.60m/s, the maximum average velocity of intake is 2.13m/s. All above hydraulic characteristics can satisfy the Chinese standards and operation safety.

When double emptying valves open in 6min uniformly and synchronously, the emptying time is 9.98min, the maximum filling discharge is 88m^3/s. The maximum average velocity of main culvert's cross section is 7.33m/s, the maximum average velocity of culvert's cross section at valve section is 8.80m/s. All above hydraulic characteristics can satisfy the Chinese standards and operation safety.

If the filling and emptying valves both open in 6min uniformly and synchronously, the average operation time is 9.8min. Considering the scale effect in lock hydraulic model test, the prototype discharge coefficient will increase compared with model, the prototype operation time will decrease. So, if the opening time of filling and emptying valve is less than 7min, the prototype operation time will less than 10min, which indicate that the main dimensions of the filling and emptying system is appropriate.

The overempty is 0.23m and it satisfies the Chinese standard, however, the overfill is 0.34m and it is higher than the allowable valve(0.25m) according to the Chinese standard. In prototype, we can use the countermeasure to reduce the overfill that opening the miter gate when the water level become equal on both sides of the gate, and this countermeasure has been successfully used in the Three Gorges Navigation Lock.

The relationship between operation time and valve opening time under maximum lift condition is shown in Fig.5.3.

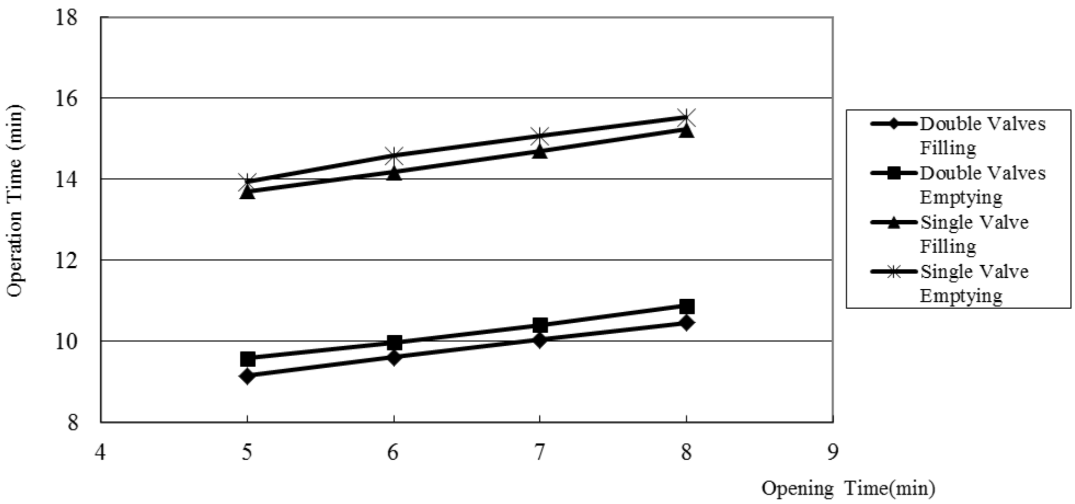


Figure 5.3 Relationship between operation time and valve opening time under maximum designed lift condition

5.2 Lowest upstream navigable water level condition

The main hydraulic characteristics under lowest upstream navigable water level condition (water level combination: 219.00m～204.16m, lift: 14.84m) are shown in Tab5.2, the relationship between operation time and valve opening time is shown in Fig.5.4.

Table 5.2 Hydraulic characteristics under Lowest upstream navigable water level condition (water level combination: 219.00m～204.16m, lift: 14.84m)

Operation pattern		t_v (min)	H (m)	T (min)	Q_{max} (m^3/s)	U_{max} (m/min)	Ua (m/min)	d (m)
Filling	Double valves	6	14.84	8.32	74	2.82	1.78	+0.34
Emptying		6	14.84	8.83	70	2.67	1.68	-0.23

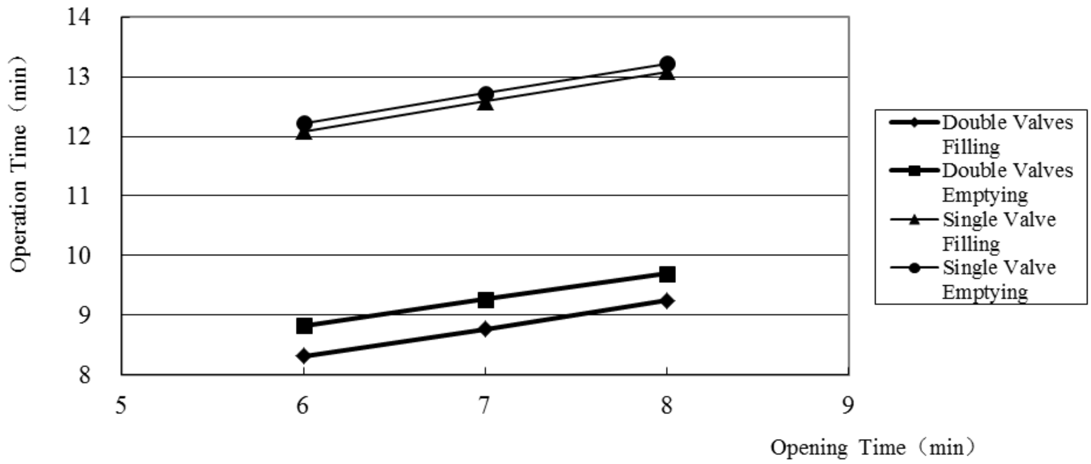


Figure 5.4 Relationship between operation time and valve opening time under Lowest upstream navigable water level condition

Under this condition, the lift of the lock reduces to 14.84m, 5.15m lower than the maximum designed lift condition. All of the hydraulic characteristics reduce, such as velocity in culvert, maximum average velocity in intake, and the operation time will also less than 10min. Above all can satisfy the rules of the Chinese standard and design needs. The same countermeasure to reduce the overfill under the maximum designed lift condition can also be used here.

6 Vessel's berthing condition in lock chamber

The vessel's berthing condition is mainly controlled by the filling procedure. When designing the layout of the filling and emptying system, we have already considered the longitudinal and transvers flow distribution in lock chamber to improve the berthing condition.

The hawser forces of the designed vessel and fleet are measured under the maximum designed lift condition. The test results indicate that the water surface is quite smooth during the filling procedure, there is no obvious longitudinal and transverse flow in lock chamber. The measured maximum hawser forces are shown in Tab.6.1, and the typical hawser force curves are shown in Fig.6.1 ~ Fig.6.4.

Table 6.1 Maximum hawser forces of the designed vessels in lock chamber

<table>
<tr><th>Vessel type</th><th>Valve operation pattern</th><th>t_v (min)</th><th>Berthing position</th><th>Longitudinal hawser force (kN)</th><th>Bow transverse hawser force (kN)</th><th>Stem transverse hawser force (kN)</th></tr>
<tr><td>2×500t fleet</td><td rowspan="4">Double valve open</td><td>6</td><td>Middle chamber</td><td>16</td><td>4</td><td>2</td></tr>
<tr><td rowspan="3">500t barge</td><td rowspan="3">6</td><td>Upper chamber</td><td>11</td><td>2</td><td>1</td></tr>
<tr><td>Middle chamber</td><td>10</td><td>3</td><td>1</td></tr>
<tr><td>Lower chamber</td><td>10</td><td>2</td><td>1</td></tr>
</table>

Note: According to the Chinese Standard, the allowable longitudinal hawser force for 500t vessel is 25kN, the allowable transverse hawser force for 500t vessel is 13kN.

The results indicate that, when double filling valves open in 6min uniformly and synchronously, the maximum longitudinal hawser force of the designed 2×500t fleet is 16kN, the maximum transverse hawser force is 4kN; the maximum longitudinal hawser force of the designed 500t barge is 11kN, the maximum transverse hawser force is 3kN. All of the hawser forces satisfy the Chinese Standard and have more than needed, which indicate the appropriateness of the design of the filling and emptying system.

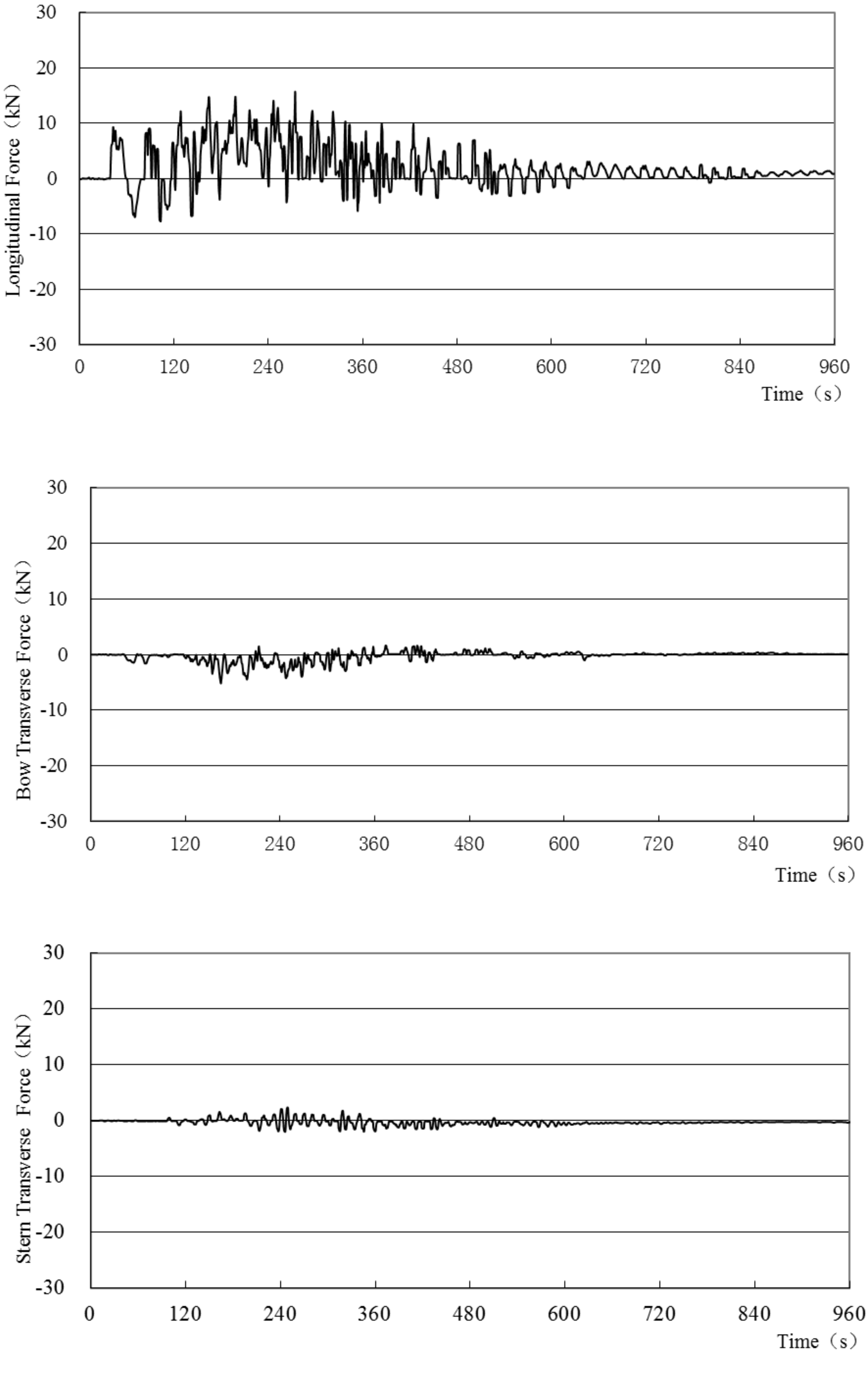


Figure 6.1 Hawser forces of 2×500t fleet berthing in middle chamber （H=20.59m，Double valve open，tv=6min）

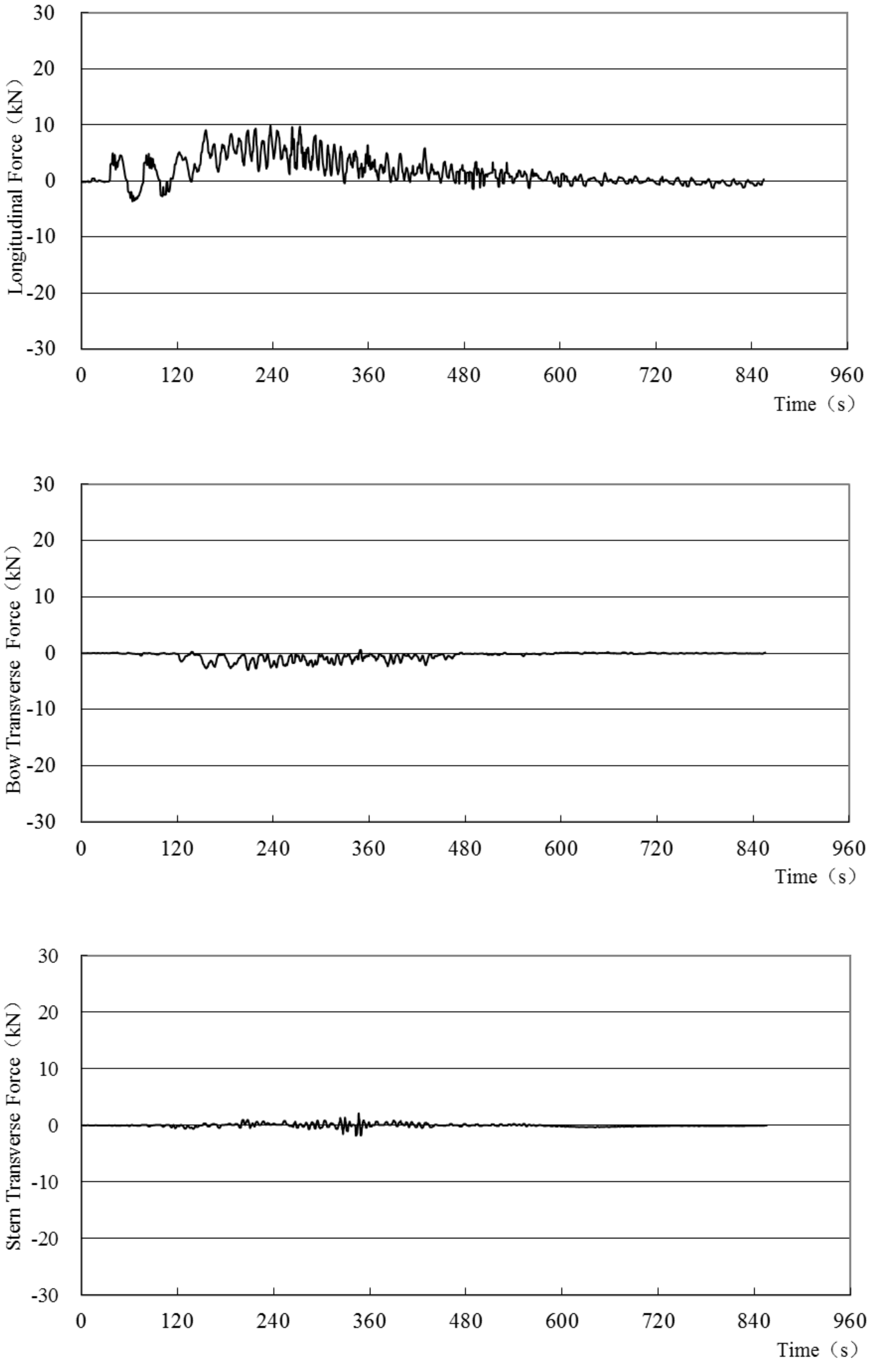


Figure 6.2 Hawser forces of 500t barge berthing in upper chamber（H=20.59m，Double valve open，tv=6min）

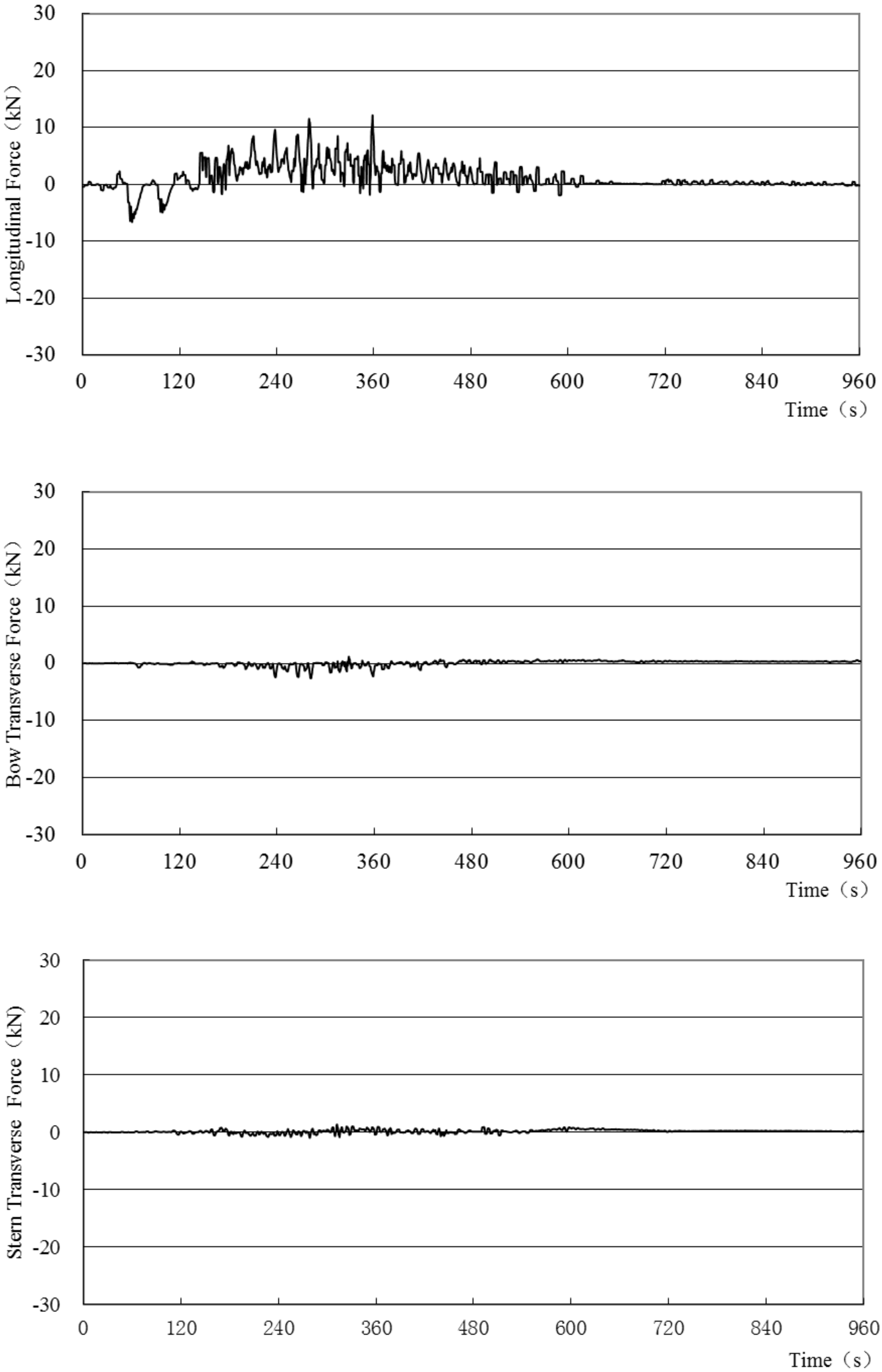


Figure 6.3 Hawser forces of 500t barge berthing in lower chamber（H=20.59m，Double valve open，tv=6min）

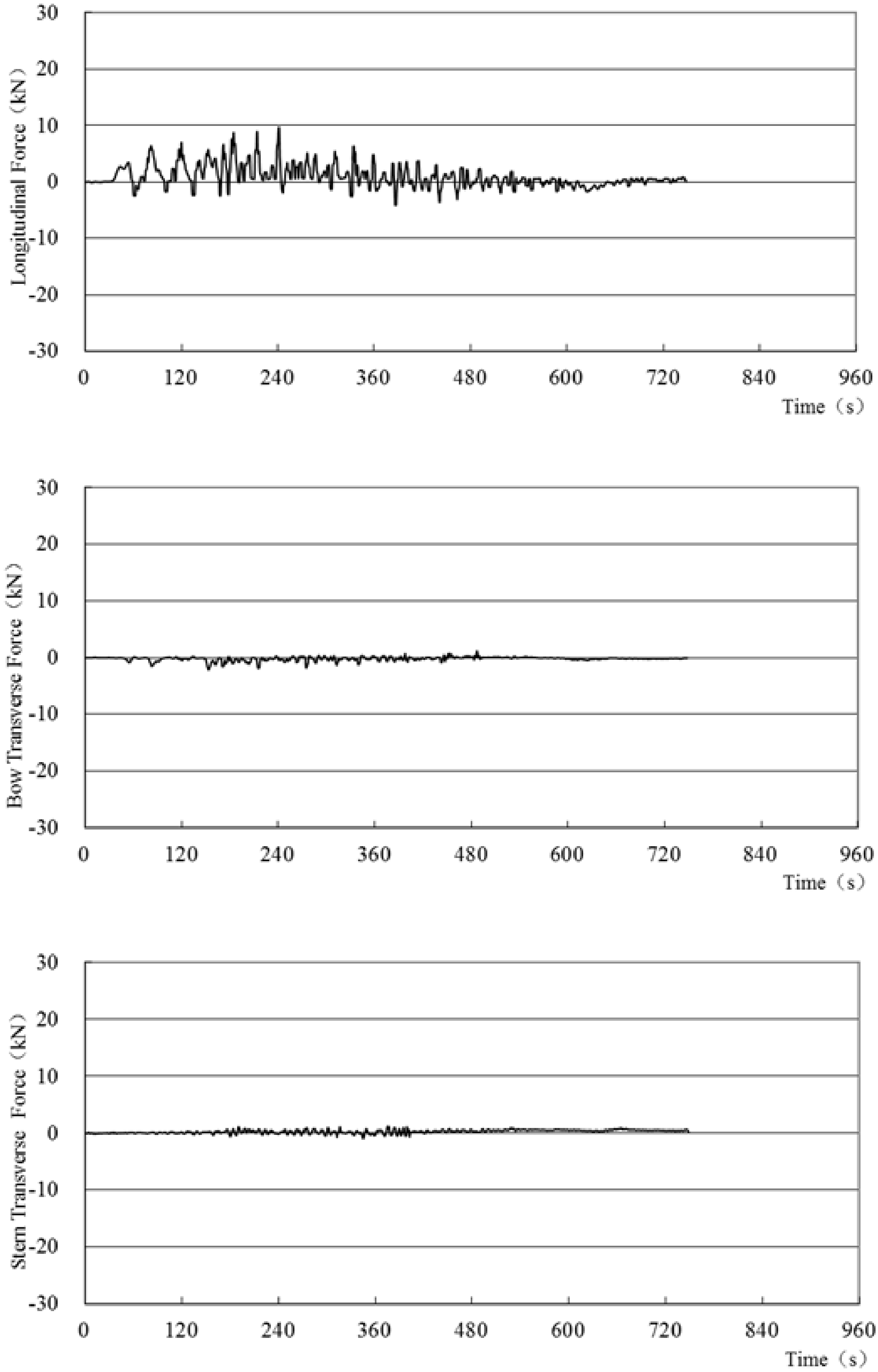


Figure 6.4 Hawser forces of 500t barge berthing in lower chamber（H=20.59m，Double valve open，tv=6min）

7 Discharge coefficient and pressure characteristics

7.1 Resistance coefficient and discharge coefficient

The sectional resistance coefficient, overall resistance coefficient and discharge coefficient of the filling and emptying system can be calculated by the measured valves of pressures at typical section and the water levels in lock chamber and approach channels. The calculation results are shown in Tab.7.1 ~ Tab.7.4

Table 7.1 Resistance coefficient and discharge coefficient of filling culverts

Section	Intake	Goose neck & Valve section	Y-type culvert	Manifolds	Total Resistance coefficient $\sum\xi$	Discharge coefficient μ
	Upstream water surface to measure point No.1	Measure point No.1 to measure point No.10	Measure point No.10 to measure point No.11	Measure point No.11 to lock chamber water surface		
Double valve open	0.360	0.349	0.213	1.063	1.985	0.710

Table 7.2 Resistance coefficient and discharge coefficient of emptying culverts

Section	Manifolds	Y-type culvert	Valve section	Outlet	Total Resistance coefficient $\sum\xi$	Discharge coefficient μ
	Lock chamber water surface to measure point No.17	Measure point No.17 to measure point No.18	Measure point No.18 to measure point No.25	Measure point No.25 to downstream water surface		
Double valve open	1.379	0.234	0.291	0.485	2.389	0.647

Table 7.3 Resistance coefficient and discharge coefficient of filling culverts under different valve opening

Operation pattern	Valve opening *n*	0.2	0.4	0.5	0.6	0.8	1.0
Double valve open	Total Resistance coefficient $\sum\xi$	43.858	9.239	5.723	3.906	2.441	1.985
	Discharge coefficient μ	0.151	0.329	0.418	0.506	0.64	0.710

Table 7.4 Resistance coefficient and discharge coefficient of emptying culverts under different valve opening

Operation pattern	Valve opening *n*	0.2	0.4	0.5	0.6	0.8	1.0
Double valve open	Total Resistance coefficient $\sum\xi$	39.555	9.889	6.782	4.546	2.873	2.389
	Discharge coefficient μ	0.159	0.318	0.384	0.469	0.590	0.647

We can know that the filling and emptying discharge coefficients are 0.710 and 0.647

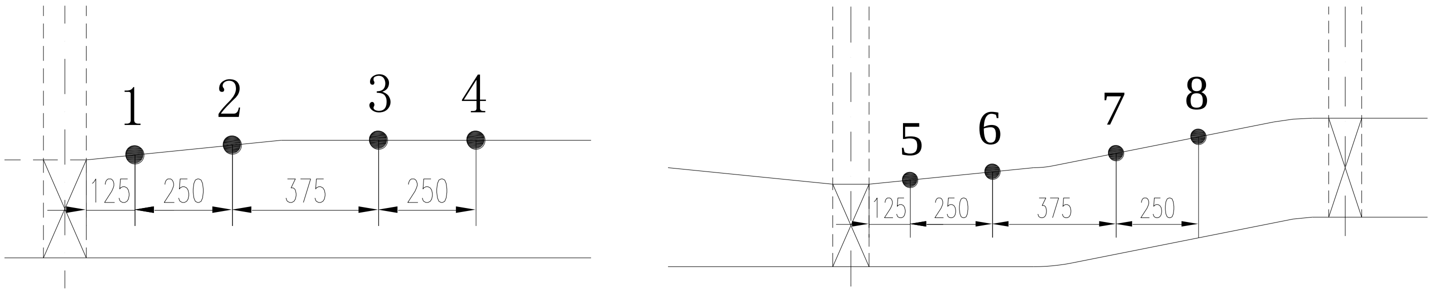
respectively.

Besides, we did not set up the trash racks at the intake in the model, so it will have little influence on the results of resistance coefficient. But the resistance coefficient of the trash rack is quite small (here the valve is about 0.05 ~ 0.1) and it will not have great influence on the overall resistance coefficient.

The resistance coefficient of the prototype is mainly influenced by the construction quality, but it will be always smaller than model, the actual value should be measured and calculated in field.

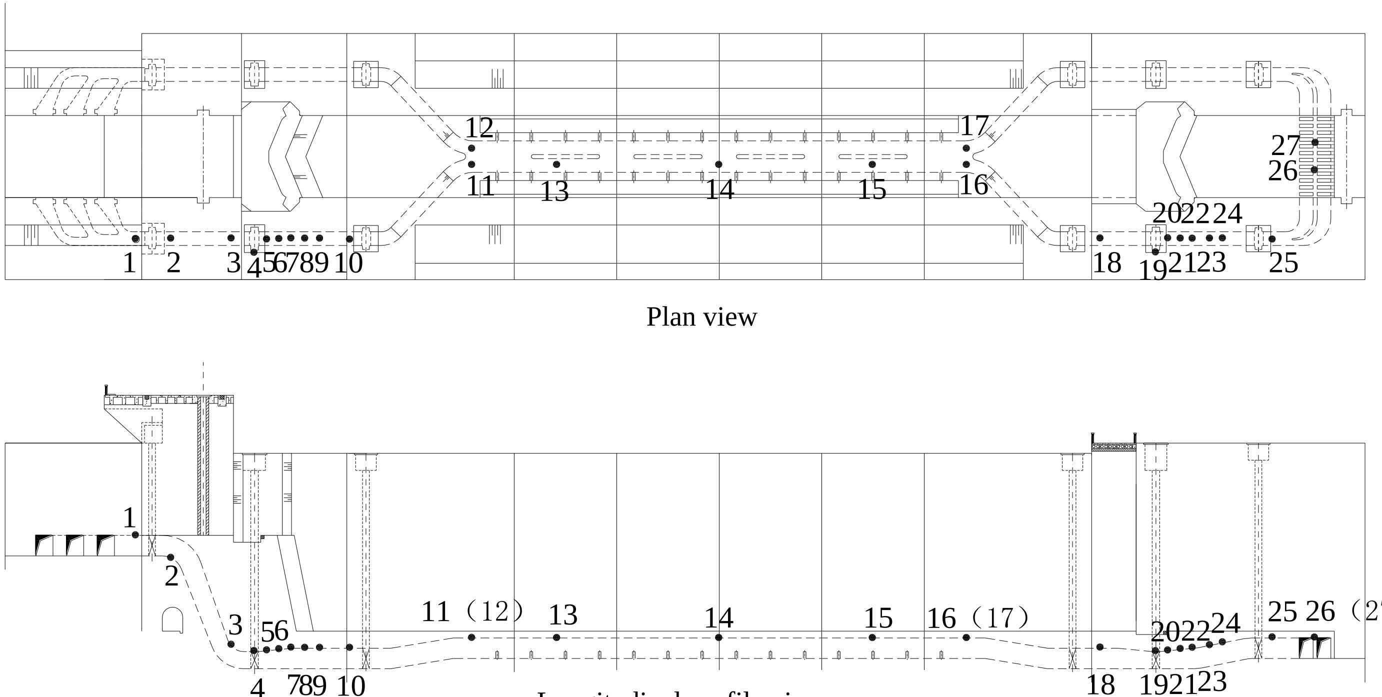
7.2 Pressure characteristics

8 pressure sensors were set up(see Fig7.1) on the top ceiling of the culvert after the filling and emptying valves to measure the local transient or fluctuating pressures. At the same time, 27 average piezometric pressure tubes were set up(see Fig7.2) to measure the average piezometric pressures and analyze the pressure distribution. The local transient pressure elevations under typical condition are shown in Fig.7.3 ~ Fig.7.4, results of steady flow test are shown in Tab.7.5 ~ Tab.7.6.



（a）Filling valve section （b）Emptying valve section

Figure 7.1 Position of pressure sensors at valve section（Unit：cm）



Plan view

Longitudinal profile view

Figure 7.2 Position of average piezometric pressure tubes

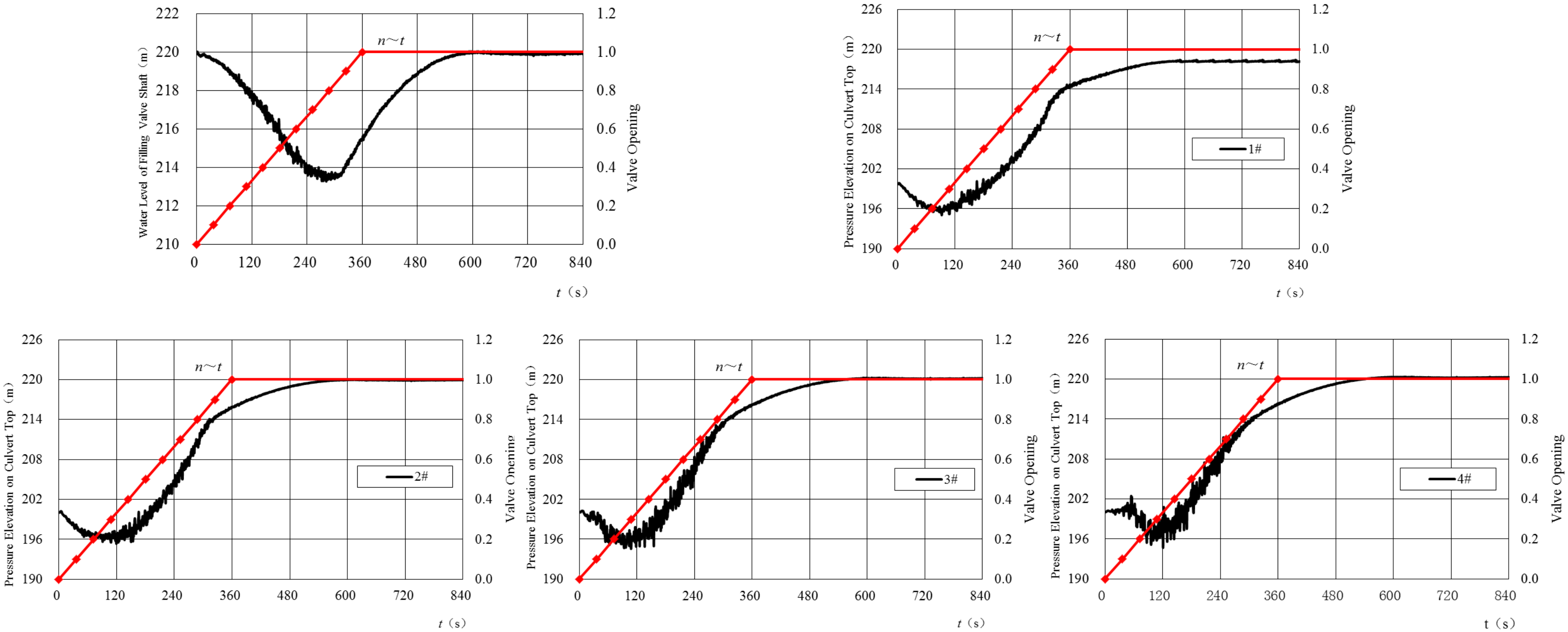


Figure 7.3　Culvert local transient pressure elevations after filling valve

（Water level combination：220.00m～199.41m，double valve open, tv＝6min）

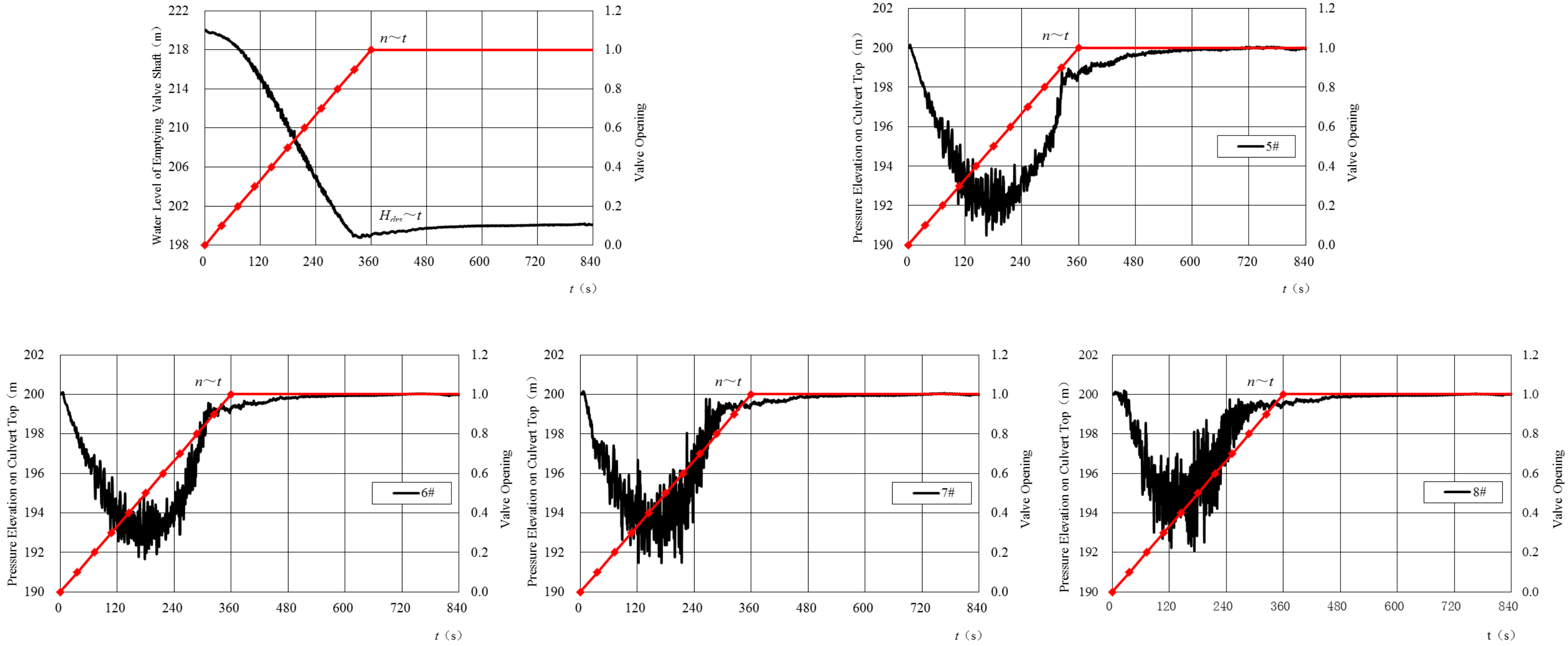


Figure 7.4　Layout of the upper lock head（Unit：Elevation　m，Length　cm）
（Water level combination：220.00m～199.41m，double valve open, tv＝6min）

Table 7.5 Average piezometric pressure elevations of filling culverts under steady flow condition（m）

（Water level combination：220.00m～199.41m，double valve open，tv=6min）

Measure Point	Valve opening					
	0.2	0.4	0.5	0.6	0.8	1.0
1	9.62	7.87	7.02	7.52	5.19	6.42
2	12.90	10.40	9.02	9.90	9.15	8.27
3	25.45	21.67	19.52	20.97	15.87	18.37
4 Water level in valve shaft	219.32	217.20	215.77	216.72	213.40	214.85
5	2.97	2.40	4.15	6.82	13.75	21.27
6	2.90	2.35	4.02	6.77	13.95	21.52
7	2.44	2.22	3.85	6.57	14.72	21.65
8	1.67	2.10	4.77	6.97	17.20	21.80
9	2.19	3.57	6.65	8.35	17.70	21.75
10	7.27	5.52	9.02	10.77	17.90	21.72
11	5.65	7.97	9.90	11.57	16.47	20.07
12	5.60	8.07	9.97	11.52	16.65	20.07
13	5.77	8.27	10.27	11.87	16.82	20.32
14	5.72	8.65	10.82	12.50	17.77	21.02
15	5.77	8.82	11.02	12.72	18.22	21.35
16	5.70	8.85	11.15	12.78	18.28	21.43
17	5.70	8.85	11.15	12.78	18.28	21.43
Water level in lock chamber	200.35	202.05	203.50	205.12	209.15	213.22

Table 7.6 Average piezometric pressure elevations of emptying culverts under steady flow condition（m）
（Water level combination：220.00m～199.41m，double valve open，tv=6min）

Measure Point	Valve opening					
	0.2	0.4	0.5	0.6	0.8	1.0
11	24.32	22.27	20.52	18.57	14.57	11.02
12	24.32	22.27	20.52	18.57	14.57	11.02
13	24.27	22.27	20.52	18.52	14.65	11.02
14	24.15	21.77	19.80	17.62	13.50	10.12
15	23.67	20.00	17.30	14.40	9.52	6.77
16	23.65	20.05	17.20	14.33	9.35	6.72
17	23.65	20.05	17.28	14.33	9.45	6.72
18	24.90	20.75	17.65	14.45	9.15	6.88
19 Water level in valve shaft	218.40	214.43	211.28	208.03	202.15	199.20
20	2.53	0.57	-0.10	-0.13	1.65	5.82
21	2.53	-0.22	-0.28	-0.35	1.60	5.90
22	2.32	-0.47	-0.72	-0.38	2.28	6.07
23	1.46	-0.54	-0.41	0.21	4.66	5.66
24	1.82	0.02	0.70	1.62	4.87	5.25
25	5.20	4.45	4.22	4.22	4.20	4.40
26	5.25	5.65	5.53	5.90	6.07	5.68
27	5.25	5.35	5.53	5.60	5.75	5.45
Water level in lock chamber	219.80	218.35	217.10	215.60	212.00	208.10

The test results indicate that:

Under unsteady flow condition, when double filling valves open in 6min uniformly and synchronously, the lowest average transient pressure and the lowest transient pressure are 2.84kPa and 2.12kPa (measure point No.1) respectively, the pressure fluctuation is about 1.47kPa; When double emptying valves open in 6min uniformly and synchronously, the lowest average transient pressure and the lowest transient pressure are -0.75kPa and -2.29kPa (measure point No.5) respectively, the pressure fluctuation is about 3.92kPa.

Under steady flow condition, when double filling valves open in 6min uniformly and synchronously, the average piezometric pressure is about 1.64kPa (n=0.2, measure point No.8); When double emptying valves open in 6min uniformly and synchronously, the average piezometric pressure is about -0.71kPa (n=0.5, measure point No.22).

According to the above results, we can know that the culvert pressure can satisfy the Chinese Standard (no less than -2.94kPa).

However, there are some suggestions to confirm the valve's safety:

1) Because of the high lift of the Sanakham Lock, the valve's working condition will be quite worse if plane valve is adopted. The safeguard rate, the adjust and adaptive capacity of the plane valve is lower than reverse tainter valve, that because if the flow condition or valve working condition is worse in prototype, we can optimize the operation pattern of the reverse tainter valve such as partial open or interval open and we can do nothing to the plane valve. So we suggest the valve should be reverse tainter valve, which can not only improve the valve's working condition and the lock's safeguard rate, but also simplify the valve section culvert's layout.

2) Set up aeration pipes at top sealing sill of the valve and also on the top ceiling of culvert after valve, which can increase the pressure of the valve section culvert and improve the valve's working condition.

3) Carry out special research on valve hydrodynamics to further study the working condition, opening and closing characteristics, cavitation characteristics, and to determine the layout of the aeration pipes.

The maximum residual pressure (pressure elevation of the measure point minus water level in lock chamber at the same time) under double valves uniformly and synchronously open condition (t_v=6min), when filling, this pressure is about 4.05kPa (measure point No.16 and No.17); when emptying , this pressure is about -7.50kPa (measure point No.16 and No.17);

8 Flow conditions around intake/outlet and in approach channels

8.1 Flow conditions around intake and outlet

The intake of the Sanakham Lock is on the upper guide walls and has 3 side ports each side, the initial top elevation of the intake port is 210.00m, which means there is 10m submerged depth above the intake under the maximum designed lift condition, and 9m submerged depth above the intake under the lowest upstream navigable water level condition.

When double filling valves open in 6min uniformly and synchronously, the maximum average velocity of intake is 2.13m/s. In the test, a harmful vortex above the intake has been found under the initial layout which can bring negative influence to the flow condition in lock chamber, so we have adjusted the top elevation of the intake. Finally, the top elevation of the intake reduced 2m to 208.00m (see Fig.8.1), and the flow condition around intake became well improved, there is no vortex and only few low-strength rotating currents on the water surface above the intake which would not influence the flow condition in lock chamber.

The flow condition around the intake at the maximum discharge point when double filling valves open in 6min uniformly and synchronously under maximum designed lift condition is shown in Fig.8.2.

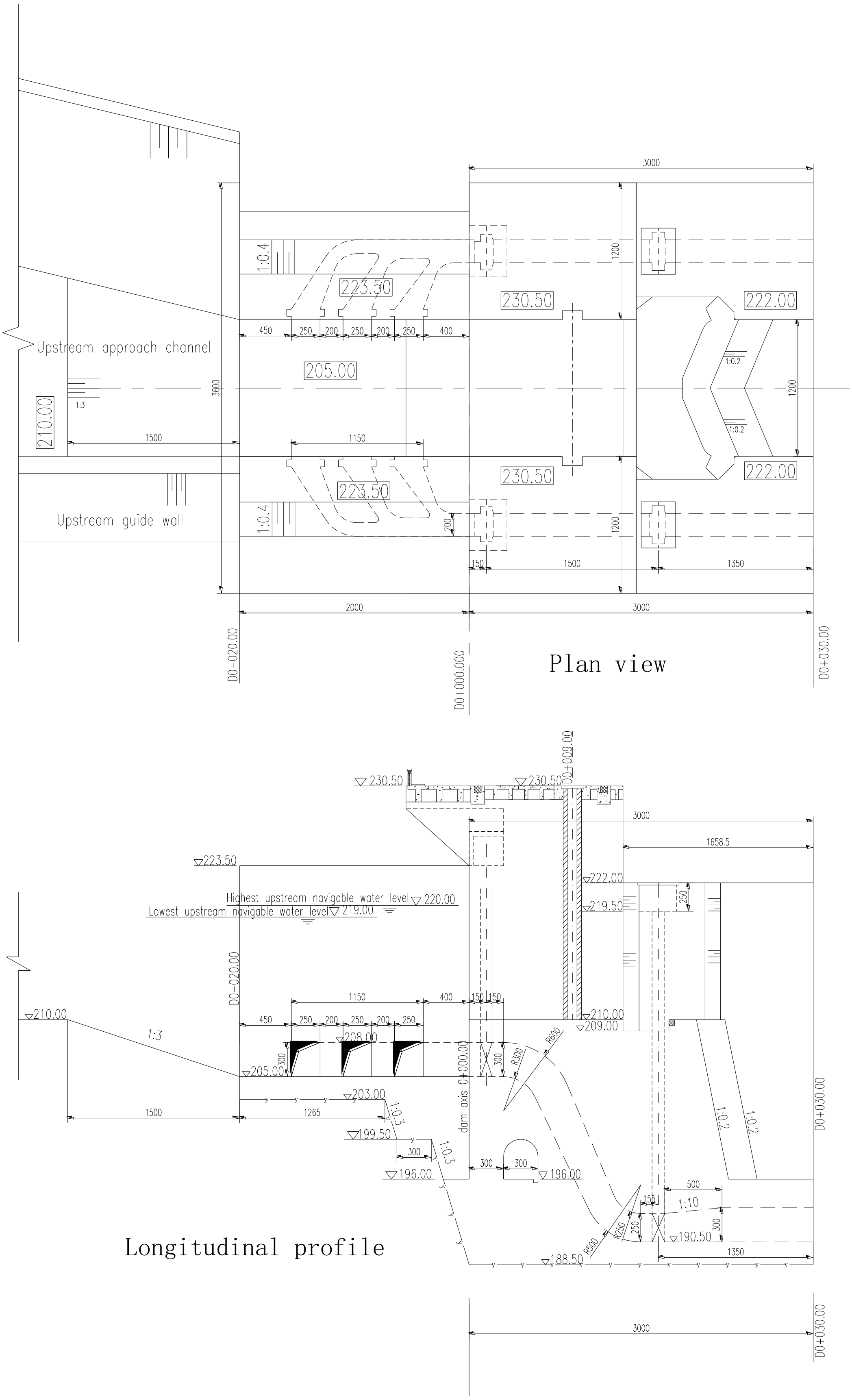


Figure 8.1　Adjusted layout of intake and upper lock head（Unit：Elevation　m，Length　mm）

Figure 8.2　Flow condition around intake（double valve open filling ，tv=6min）

The outlet of the Sanakham Lock adopts the energy dissipation chamber with top ports and side ports, the flow condition observation shows that the surge height and turbulence strength are both small.

8.2 Flow conditions in approach channels

The maximum average velocities in upstream and downstream approach channels when double filling or emptying valves open in 6min uniformly and synchronously under different conditions are shown in Tab.8.1.

Table 8.1　Maximum average velocity in approach channel (m/s)

Valve open pattern		Maximum designed lift condition（220.00m～199.41m）		Lowest upstream navigable water level condition（219.00m～204.16m）	
		Upstream approach channel	Downstream approach channel	Upstream approach channel	Downstream approach channel
Double valve open	6min	0.24	0.55	0.21	0.44
	7min	0.23	0.52	0.19	0.41

The results indicate that the controlled condition for upstream and downstream approach channel flow condition is the maximum designed lift condition. Under this condition, the water depth of upstream approach is 10m, the discharge section area is 400m^2, the maximum discharge is only 90m^3/s, so the maximum average velocity is less than 0.25m/s, further less than the allowable value 0.5～0.8m/s according to the Chinese Standard. Under the same condition, the water depth of downstream approach is 4m, the discharge section area is 160m^2, the maximum discharge is also about 90m^3/s, so the maximum average velocity is about 0.55m/s, also less than the allowable value 0.8～1.0m/s.

Besides, in the initial layout of the outlet, there are two asymmetry baffles set up in the energy dissipation chamber which used to adjust the velocity distribution in the downstream approach channel. Under this layout, the velocity distribution is uniform, but the velocity at side is little higher than in the middle, so we optimized the baffles. Finally, two symmetric baffles with the height of 0.5m were adopted (see Fig.8.3). Under this layout, the velocity distribution in the downstream approach channel is quite uniform.

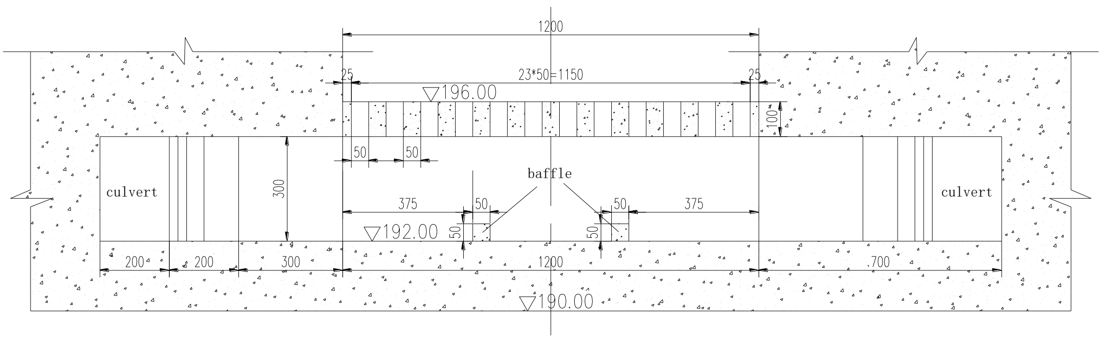


Figure 8.3 Adjusted baffle layout at the outlet

The flow condition in the downstream approach channel when double emptying valves open in 6min uniformly and synchronously under maximum designed lift condition is shown in Fig.8.4.

Figure 8.4 Flow condition in the downstream approach channel（double valve open emptying, tv=6min）

The final recommended layout of the filling and emptying system after model test is shown in Tab.8.2 and Fig.8.5.

Table 8.2 Characteristic dimensions of the recommended in-chamber bottom longitudinal culvert filling and emptying system of the Sanakham lock

No.	Position	Description	Area（m^2）	Area ratio to valve section
1	Valve section culvert	Bottom elevation: 190.50m, top ceiling elevation: 193.00m, submerged depth under maximum lift condition: 7.01m	2-2.0×2.5 =10.0	1.00
2	Intake	3 vertical side ports on guide wall, throat section height of each port is same, throat section width of each port reduces along the flow direction. The top elevation is 208.00m	2-3×2.5×3.0 =45.0	4.50
3	Filling culvert	Filling culvert top ceiling enlarges gradually after the filling valve section, the culvert height increases from 2.5m to 3.0m. Then the filling culvert connects the in-chamber bottom longitudinal culvert via a Y-type culvert. The bottom elevation and top ceiling elevation increased from 190.50m and 193.50m to 192.00m and 195.00m respectively at the same time.	2-2.0×3.0 =12.0	1.20
4	Bottom longitudinal culvert with manifolds	Connected to the filling culvert and emptying culvert via two Y-type culverts. Total length of this culvert is 70m, equal to 58.3% of the lock usable length.	2-2.0×3.0 =12.0	1.20
5	Side ports	There are 14 side ports on each side of the bottom culvert. Dimension of the port are: 0.4m×1.0m(width × height)、port spacing is 5.0m, length of the port is 1.2m, inlet and outlet of the port should be round out, the trimming circle radius is 0.3m.	2-14×0.4×1.0 =11.2	1.12
6	Open ditch for energy dissipation in lock chamber	Open ditches should be set up out of the side port, the width and depth of the ditch are 2.5m and 4.0m respectively. Wall baffles should also be set up 2m higher than the ditch bottom on the lock wall.	/	/
7	Emptying culvert	The emptying culvert connects the in-chamber bottom longitudinal culvert via a Y-type culvert. The bottom elevation and top ceiling elevation decreased from 195.00m and 192.00m to 193.50m and 190.50m respectively at the same time. Then culvert top ceiling contracts gradually before the emptying valve section, the culvert height decreases from 3.0m to 2.5m. After the emptying valve section culvert top ceiling enlarges gradually, the culvert height increases from 2.5m to 3.0m again.	2-2.0×3.0 =12.0	1.20
8	Outlet	Double of the culvert area, inside guide walls should be set up.	2-2×2.0×3.0 ＝24.0	2.40
9	Energy dissipation chamber out of outlet	Top ports and side ports are set up on the chamber walls, two symmetric baffles with the height of 0.5m are set up in the chamber.	24×0.5×2.0 +12×0.5×3.0 ＝42.0	4.20

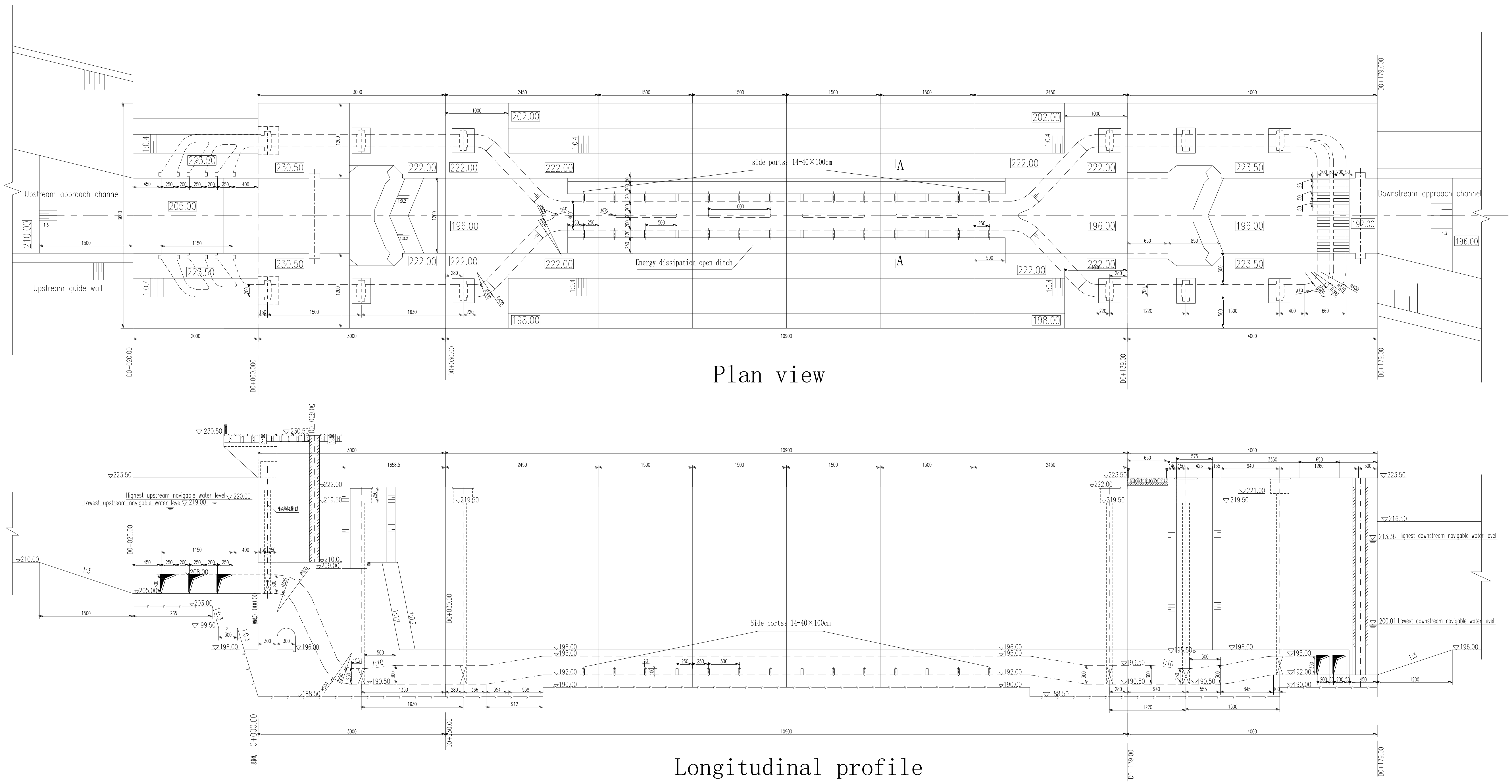


Figure 8.5 Final recommended layout of the in-chamber bottom longitudinal culvert filling and emptying system of the Sanakham lock

（Unit：Elevation m，Length cm）

9 Summary

Lantsang River – Mekong River is a quite important international river running through China, Laos, Myanmar, Thailand, Cambodia and Vietnam. The Sanakham lock is a quite important navigation structure on Mekong river with the maximum lift of 20.59m. Because of the high lift, short operation time, high hydraulic index and the importance to navigation of Mekong river and also to the social and economic development of local area, it is necessary and important to carry out the hydraulic investigations to keep the safety of the lock and the vessels passing through the lock.

The in-chamber longitudinal filling and emptying system is recommended finally based on actual conditions. The investigation results based on the 1:25 scale model test are as follows:

1) The layout of the recommended in-chamber longitudinal filling and emptying system for the Sanakham lock is appropriate.

2) The recommended valve opening time is 6min both for filling and emptying valves. The filling and emptying time under above valve opening patterns are 9.62min and 9.98min respectively, which both satisfy the design requirements.

3) The water surface is quite smooth when lock filling, there is no obvious longitudinal and transverse flow in lock chamber. Under the recommended valve opening pattern, the hawser forces of designed vessel and fleet all satisfy the Chinese Standard and have more than needed.

4) The culvert pressures all satisfy the Chinese Standard, but the pressure fluctuation is quite high.

According to the construction and operation experiences of Chinese high lift lock, we suggest the recommended valve type is reverse tainter valve, the concrete strength of the culvert in the valve section should be increased, aeration pipes at top sealing sill of valve and on the top ceiling of the culvert after valve should be set, and a special investigation on valve hydrodynamics should be carried out.

5) The flow conditions around intake/outlet, and in the approach channels under recommended layout and valve opening pattern are quite well, there is no harmful flow phenomena in above areas. The velocities in approach channels are small and have a uniform distribution.

6) Because the Sanakham lock is a high lift lock, and there exists scale effect in lock hydraulic model test, the hydraulic index will increase in prototype. So there are some suggestions: a) The opening time of valve can be adjusted (from 5min to 7min), so that we can optimize the valve operation pattern according to the prototype flow condition; b) Prototype observation and debug should be carried out before the lock opening, so that we can give the necessary technical data for lock operation and management.

10 References

[1] Chinese Industry Standard, *Code for master design of shiplocks* (JTJ305-2001), 2001.

[2] Chinese Industry Standard, *Design code for filling and emptying system of shiplocks* (JTJ306-2001), 2001.

[3] Chinese Industry Standard, *Code for design of lock gates and valves of shiplocks* (JTJ308-2001), 2001.

[4] Chinese Industry Standard, *Technical regulation of modelling for hydraulics of navigation structure* (JTJ/T 235-2003), 2003.

[5] *Hydraulic Design of Navigation Locks* (EM 1110-2-1604), US Army Corps of Engineers,2006.

[6] *Filling and emptying system for high-lift navigation lock*, Glenn A.Pickering,P.E., Hydraulic Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi, USA.

[7] PIANC. Final report of the international commission for the study of locks, 1986.

[8] PIANC. Innovations in navigation lock design, 2009.