5.2 Water Quality Investigation

5.2.1 5.2.1 Investigation Background and Purpose

The climate in Syria is Mediterranean and therefore, rainy season usually takes place between October and May where the water capacity of Figeh spring increases. Rainfall quantity reaches its peak in January and February and there is almost a dry period starting June to the end of September. At the beginning of spring in mid to late March, snow accumulated on the mountains and hills around Figeh spring start to melt and water quantity inside the tunnels increases to its maximum value during April and May in order to allow the maximum possible storage for to be utilized during the dry season. According to DAWSSA, during the rainy season, underground water level around the tunnels rises, leak inside the tunnels and may affect, badly, the quality of the water running through them.

In order to investigate the effect of seasonal change on the quality of water running through the tunnels, DAWSSA monthly water quality analysis reports between 2000 and 2003 and the results of the quality of water of samples taken at the Figeh entrance and Wali exit of both tunnels during the investigation were analyzed.

5.2.2 Syrian Water Quality Standard

Table2.1 shows the Syrian water quality standard compared to other international standards. The values given by the Syrian standard for different items are almost coinciding with the international values. DAWSA has also a special standard for Barada, such as conductivity and degree of alkalinity as shown in the table.

Table2.1 Water Quality Standards in Syria and Internationally

No.	Item	Unit	Syria	Japan	WHO	EU	USEPA	Remarks
1	Standard Plate Count Bacteria	Colony/*ml*	≦20	≦100	------	≦100	≦500	Bacteriological Aspects
2	E.Coli & Fecal Coliform	Colony/*ml*	0	0	0	0	≦5%	
3	Arsenic	*mg/l*	≦0.01	≦0.01	≦0.01	≦0.01	≦0.05	Chemical Aspects (Health Related Inorganic Constituents)
4	Cadmium	*mg/l*	≦0.005	≦0.01	≦0.003	≦0.003	≦0.003	
5	Total Chromium	*mg/l*	≦0.05	≦0.05	≦0.05	≦0.05	≦0.10	
6	Cyanide	*mg/l*	≦0.05	≦0.01	≦0.07	≦0.05	≦0.20	
7	Lead	*mg/l*	≦0.01	≦0.01	≦0.01	≦0.01	≦0.015	
8	Mercury	*mg/l*	≦0.001	≦0.0005	≦0.001	≦0.001	≦0.002	
9	Selenium	*mg/l*	≦0.01	≦0.01	≦0.01	≦0.01	≦0.05	
10	Nickel	*mg/l*	≦0.2	≦0.01	≦0.02	≦0.02	------	
11	Flouride	*mg/l*	≦1.5, ≦0.7*	≦0.8	≦1.5	≦1.5	≦4.0, ≦2.0*	
12	Boron	*mg/l*	≦0.3	≦1.0	≦0.5	≦0.5	------	
13	Nitrate	*mg/l*	≦10	≦10	≦50	<50	≦10	
14	Nitrite	*mg/l*	≦0.01	≦0.05	≦0.20	≦0.50	≦1.00	
15	Antimony	*mg/l*	≦0.005	≦0.015	≦0.018	≦0.005	≦0.006	
16	Dichloromethane	*mg/l*	≦0.01	≦0.02	≦0.02	≦0.02	------	Chemical Aspects (Health Related Organic Constituents)
17	Carbontetrachloride	*mg/l*	≦0.002	≦0.002	≦0.004	------	≦0.005	
18	1,1- Dichloroethene	*mg/l*	≦0.03	≦0.02	≦0.03	------	≦0.007	
19	1,2-Dichloroethene	*mg/l*	≦0.05	≦0.04	≦0.05	------	≦0.07	
20	Trichloroethene	*mg/l*	≦0.03	≦0.03	≦0.07	≦0.01	≦0.005	
21	Tetrachloroethene	*mg/l*	≦0.01	≦0.01	≦0.04	≦0.01	≦0.005	
22	Benzene	*mg/l*	≦0.01	≦0.01	≦0.01	≦0.001	≦0.005	
23	pH	------	6.5-8.5	5.8-8.6	------	6.5-9.5	6.5-8.5	Aesthetic Aspects for Drinking Water
24	Colour	*mg/l*	≦15	≦5	≦15	------	≦15	
25	Taste	------	Acceptable				------	
26	Odor	------	Acceptable				≦3TON	
27	Turbidity	NTU	1.0-5.0	≦2	1.0-5.0	------	1.0	
28	Total Disloved Solids	*mg/l*	≦1000	≦500	≦1000	≦500	≦1000	
29	Hardness	*mg/l*	≦500	≦300	------	------	------	
30	Chloride	*mg/l*	≦250	≦200	≦250	≦250	≦250	
31	Sodium	*mg/l*	≦200	≦200	≦200	≦200	------	
32	Manganese	*mg/l*	≦0.1	≦0.01	≦0.4	≦0.05	≦0.05	
33	Iron	*mg/l*	≦0.3	≦0.3	≦0.3	≦0.2	≦0.3	
34	Copper	*mg/l*	≦1.0	≦1.0	≦2.0	≦2.0	≦1.3	
35	Aluminum	*mg/l*	≦0.2	≦0.2	≦0.2	≦0.2	≦0.2	
36	Zinc	*mg/l*	≦3.0	≦1.0	≦3.0	------	≦5.0	
37	Phenols	*mg/l*	≦0.500	≦0.005	≦0.200	------	------	
38	Residual Chlorine	*mg/l*	------	≦1.0	0.6-1.0	------	MRDL=4.0	
39	Conductivity	*μS/cm*	≦1500	------	------	------	------	Water Qaulity Standards for Barada River
40	Calcium	*mg/l*	≦50	------	------	------	------	
41	Alkalinity	*mg/l*	≦20	------	------	------	------	
42	Bicarbonate	*mg/l*	≦200	------	------	------	------	
43	Sulfate	*mg/l*	≦250	------	------	------	------	
44	Ammonia	*mg/l*	≦0.05	------	------	------	------	
45	Temprature	C°	5.0-25.0	------	------	------	------	

** Upper limits: from 8 to 12 ^{0}C; and lower limits: from 15 to 30 ^{0}C.*

*** Source: DAWSSA, Data Book 9, Water Quality and Environment, 9-a & 9-d*

5.2.3 Water Quality Investigation Results

Water samples were taken at Figeh and Wali of both old and new tunnels for laboratory chemical analysis. The samples were tested at DAWSSA Central Laboratory and were taken as shown in Table2.2 here below.

The investigations showed that water is flooding freely inside the old tunnel a rate of about 1.0 *l/s* from an old 10 cm steel pipe in the upper right side of the tunnel wall at TD 977.50 as shown in Figure2.1.

Table2.2　Locations and Date of Water Quality Samplings

Sampling Location		Sampling Date
New Tunnel	Figeh	2004/12/8
	Wali	
Old Tunnel	Figeh	2004/12/9
	U/S Siphon (Gate No.32)	
	D/S Siphon (Gate No.33)	
	Wali	
	TD977.5	2004/12/11, 2004/12/18

Figure2.1　Water Flooding into Old Tunnel at TD977.5

The results of water quality analysis are shown in Table2.3.　Table2.3 shows that the results at Figeh and Wali are almost coinciding in spite of water leaking in or out the tunnels, which means that leakage has not affected the water quality of the flowing water in the tunnels.

Table2.3. shows that there is no remarkable difference in the values of pH, hardness, total dissolved solids, conductivity, bicarbonate and calcium at both Figeh entrance and Wali exit and water flooding inside the tunnel at TD977.5.　Water leaking inside the old tunnel is in low rate and of high quality, and in spite that the flow in the tunnel is small; it has no negative effect on the water quality running through the tunnel. However, from safety management point of view, allowing water into the tunnel without purification is an important issue which requires the immediate shut down of the water pipe at TD977.5.

Table2.3 Water Quality Test Results

No.	Item	Unit	Syria Standard	New Tunnel		Old Tunnel					
				Figeh	Wali	Figeh	U/S Siphon	D/S Siphon	Wali	[(1)] TD 977.50 m	
				08/12/04		09/12/04				11/12/04	18/12/04
1	Turbidity	NTU	1.0-5.0	0.5	0.5	0.9	0.7	0.9	1.0	0.9	0.9
2	pH	------	6.5-8.5	7.3	7.4	7.3	7.7	7.6	7.7	7.4	7.3
3	Hardness	*mg/l*	≦500	17.0	17.0	17.2	17.0	17.0	17.2	15.0	15.0
4	Chloride	*mg/l*	≦250	5.5	5.5	5.9	5.9	5.9	6.4	5.5	7.0
5	Nitrate	*mg/l*	≦10	8.5	8.5	8.5	8.5	8.5	8.5	6.0	6.0
6	Nitrite	*mg/l*	≦0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	Total Disloved Solids	*mg/l*	≦1000	191.0	195.0	193.1	194.0	195.4	193.1	178.0	179.0
8	Residual Chlorine	*mg/l*	≦0.5	0.5	0.4	0.4	0.35	0.35	0.37	0.00	0.00
9	Conductivity	mc/cm^2	≦1500	335.0	341.0	338.0	340.0	342.0	338.0	311.0	314.0
10	Calcium	*mg/l*	≦50	48.0	48.0	48.0	48.0	48.0	48.8	48.0	50.0
11	Alkalinity	*mg/l*	≦20	14.8	14.8	15.4	15.4	15.4	15.4	13.0	12.8
12	Bicarbonate	*mg/l*	≦200	180.7	180.7	188.0	188.0	188.0	188.0	159.0	156.0
13	Sulfate	*mg/l*	≦250	11.0	12.0	11.0	11.0	11.0	12.0	9.0	9.0
14	Ammonia	*mg/l*	≦0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	Temprature	C^o	5.0-25.0	13.0	14.0	13.0	14.0	14.0	14.0	13.0	-----

(1) Water entering the tunnel at TD 997.5m from outside through an old 10 cm steel pipe

** Water quality tests were conducted at DAWSSA centeral laboratory

5.2.4 Seasonal Water Quality Change Analysis

In order to investigate the effect of seasonal change on the quality of water running through the tunnels, DAWSSA monthly water quality analysis reports between 2000 and 2003 were analyzed, the results of the quality of water between tunnels entrance at Figeh spring and exit at Wali reservoir were compared and the effect of underground water leaking into tunnels on water quality was examined.

5.2.4.1 Prosperities of Water Quality inside Tunnels

Rainy season usually takes place between October and May where the water capacity of Figeh spring increases. Annual rainfall rate on Barada catchment area ranges between 300mm and 1000mm and reaches its peak in January and February. Water quantity at Figeh increases to its maximum value during March and April. During the same period, underground water level around the tunnels rises as expected. Figure2.2 shows the relation between the monthly rain fall rate on Barada catchment area and average monthly discharge of flow at Figeh.

In order to investigate the effect of seasonal change on the quality of water transmitted through the tunnels, DAWSSA monthly water quality analysis reports between 2000 and were analyzed and the results of the quality of water between tunnels entrance at Figeh spring and exit at Wali reservoir are summarized in Table2.4 here below.

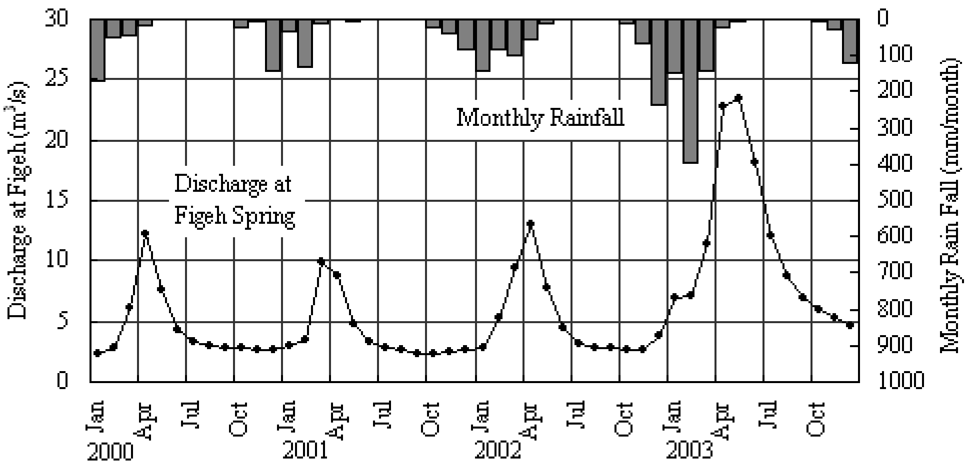
Table2.4 shows that there is no remarkable difference in the values of pH, hardness, total dissolved solids, conductivity and calcium at both Figeh entrance and Wali exit. However, the following could be pointed out of the results of turbidity, chloride, sulfate, calcium and hardness:

* Turbidity: Although there is no significant difference, the value of turbidity at Figeh entrance is higher than that at Wali exit. This means that turbidity value of water source is high during discharging.

* Chloride: The value of chloride at Wali exit in 08 August, 2001, as given in DAWSSA annual report, is unusual and it is thought to be erred. It can be said that there is no difference in chloride values between Figeh entrance and Wali exit if this unusual value is neglected.

* Sulfate: The test results show that the value of sulfate at Wali exit is higher than that at Figeh entrance. The increase of the sulfate content in the water inside the tunnel is thought to be resulted from the ground water penetrating inside the tunnel. According to DAWSSA annual reports, the test values of sulfate during April to June period were small while increased during July to September period. This means that sulfate value is not related to rain fall activities.

* Calcium: More than half the values of calcium were slightly over the Syrian standard of 50*mg/l*.



* Hardness: In general, hardness all over the year is high[1].

Figure2.2 Monthly Rain Fall Rate on Barada Catchment Area and Average Monthly Tunnels' Discharges

Table2.4 Seasonal Water Quality Analysis (2000-2003)

Item		Turbidity	pH	Hardness	Chloride	Total Disolved Solids	Conductivity	Calcium	Sulfate	Remarks
Unit		NTU	-	*mg/l*	*mg/l*	*mg/l*	*mc/cm2*	*mg/l*	*mg/l*	
Syria Standard		1.0-5.0	6.5-8.5	≦500	≦250	≦1,000	≦1,500	≦50	≦250	
Average	Entrance	1.7	7.7	16.8	5.3	174.8	302.5	46.8	8.3	Rate of change in water quality between tunnels entrance at Figeh and exit at Wali is calculated as follows: Rate = (Value at entrance-Value at exit)/Value at entrance
	Exit	1.5	7.8	17.1	5.6	183.5	313.1	48.5	10.1	
	(Ratio)	10%	1%	1%	6%	5%	4%	4%	21%	
Maximum	Entrance	5.0	7.9	18.0	6.0	190.0	340.0	52.0	11.0	
	Exit	5.0	7.9	19.0	8.0	205.0	350.0	56.0	13.0	
	(Ratio)	0%	0%	6%	33%	8%	3%	8%	18%	
Minimum	Entrance	0.5	7.7	13.0	4.0	140.0	220.0	36.0	5.0	
	Exit	0.5	7.7	13.0	4.0	140.0	220.0	36.0	5.0	
	(Ratio)	0%	0%	0%	0%	0%	0%	0%	0%	
Average Maximum	Entrance	3.3	0.2	1.2	0.7	15.2	37.5	5.2	2.7	Rates are giving the change of the maximum and minimum values of the average water quality values at both Figeh entrance and Wali exit
	(Ratio)	199%	2%	7%	14%	9%	12%	11%	32%	
	Exit	3.5	0.1	1.9	2.4	21.5	36.9	7.5	2.9	
	(Ratio)	233%	1%	11%	42%	12%	12%	16%	29%	
Average Minimum	Entrance	1.2	0.0	3.8	1.3	34.8	82.5	10.8	3.3	
	(Ratio)	70%	1%	23%	24%	20%	27%	23%	40%	
	Exit	1.0	0.1	4.1	1.6	43.5	93.1	12.5	5.1	
	(Ratio)	67%	1%	24%	29%	24%	30%	26%	50%	

Source: DAWSSA Annual Report of Water Quality Test

[1] The average value of hardness is 170*mg/l*, which is about 1/3 the Syrian standard of 500*mg/l*. Yet, according to WHO, hard water is defined at value between 120 to 180 *mg/l* while it is very hard water for values over 180 *mg/l*.

As shown in Table2.1, in addition to the tests shown in Table2.4, DAWSSA conducts Health Related Inorganic Constituents analysis tests at Figeh twice a year as shown in Table2.5. The five years results given in Table2.5 show that all values are under the Syrian standard values and hence there is no problem with water quality. On the other hand, DAWSSA carries out daily Health Related Organic Constituents tests. The analysis of the tests' results during the same five years period did not enable the study team to come to conclusions as most of records are not practically available.

Table2.5 DAWSSA Test Record on Health Related Inorganic Constituents at Figeh

Constituents		Copper	Manganese	Iron	Cadmium	Chromium	Lead	Zinc	Aluminium	Mercury	Selenium	Arsenic
Symbol		Cu	Mn	Fe	Cd	Cr	Pb	Zn	Al	Hg	Se	As
Unit		(μg/L)	(μg/L)	(μg/L)	(μg/L)	(μg/L)	(μg/L)	(μg/L)	(μg/L)	(μg/L)	(μg/L)	(μg/L)
Syrian Standard		≤1,000	≤100	≤300	≤5	≤50	≤10	≤3,000	≤200	≤1	≤10	≤10
Test Date	Mar. 2000	N.A.	0.6	12	0.4	3	4	9	6	N.A.	N.A.	N.A.
	Nov. 2000	N.A.	1.0	13	0.5	3	5	11	6	N.A.	N.A.	N.A.
	Mar. 2001	N.A.	0.9	17	0.3	3	6	10	4	N.A.	N.A.	N.A.
	Nov. 2001	N.A.	0.9	11	0.7	3	5	10	8	N.A.	N.A.	N.A.
	Oct. 2002	N.A.	0.9	12	0.3	2	6	10	7	N.A.	N.A.	N.A.
	Mar. 2003	N.A.	0.9	18	0.5	4	5	10	8	N.A.	N.A.	N.A.
	Nov. 2003	N.A.	1.0	17	0.5	4	5	11	6	N.A.	N.A.	N.A.
	Mar. 2004	N.A.	1.0	17	0.7	4	6	12	5	N.A.	N.A.	N.A.
	Nov. 2004	N.A.	1.0	15	0.6	3	6	11	6	N.A.	N.A.	N.A.

* N.A.: No Data Available

5.2.4.2 Analysis of the Effect of Underground Water Leaking inside Tunnels and Seasonal Water Quality Change

According to DAWSSA, during the rainy season, water quantity inside the tunnels increases to its maximum value and underground water level around the tunnels rises, leak inside the tunnels and may affect, badly, the quality of the water running through them. In order to investigate the seasonal tunnel water quality change, the relation between water quality and tunnels discharges was analyzed and the water quality at the tunnels entrance and exit was compared.

The coefficient of correlation between discharge at Figeh and different water quality items was determined as shown in Table2.6. Most of water quality items were correlated to discharges. As shown in the table, all significant correlation coefficients, which are regarded over 0.7, are negative. Yet, contrary to DAWSSA apprehension, water quality decreases with the increase of Figeh discharge, the amount of supplied substances, as a water quality index, does not change with discharge and therefore, water quality is predicted to decrease with the increase of discharge. However, though the coefficient of correlation is low, turbidity is increasing with the increase of discharge in the tunnel, which may reflect the impression given by DAWSSA.

A review of the water quality change rate between tunnels entrance at Figeh and exit at Wali is given in Table2.7. The average change rate in the value of sulfate is 20% and increase with the flow downstream. It is also shown that there is no remarkable difference in the values of other items between Figeh entrance and Wali exit.

Table2.6 Coefficient of Correlation between Discharge at Figeh and Water Quality

Item	Water Quality Correlated to Figeh Discharge	Correlation Status*
Turbidity	0.62	Not Correlated
Conductivity	-0.87	Correlated
pH	0.07	Not Correlated
Total Hardness	-0.90	Correlated
Calcium	-0.85	Correlated
Magnesium	-0.33	Not Correlated
Sodium	-0.80	Correlated
Kalium	-	-
Alkalinity	-0.88	Correlated
Bicarbnate	-0.88	Correlated
Sulfate	-0.68	Not Correlated
Chloride	-0.63	Not Correlated
Nitrate	-0.66	Not Correlated
Total Disolved Solids	-0.86	Correlated

*Correlated: if correlation coefficient is≧0.7

Table2.7 Water Quality Change Ratio between Figeh and Wali

Item	Change Ratio*			
	Maximum	Median	Minimum	Average
Turbidity	100.0%	0.0%	-50.0%	-4.4%
Conductivity	26.9%	0.0%	-3.2%	1.9%
pH	2.6%	0.0%	-2.5%	1.0%
Total Hardness	11.8%	0.0%	0.0%	1.0%
Calcium	16.7%	0.0%	0.0%	1.4%
Magnesium	0.0%	0.0%	0.0%	0.0%
Sodium	50.0%	0.0%	0.0%	2.6%
Kalium	0.0%	0.0%	0.0%	0.0%
Alkalinity	13.3%	0.0%	0.0%	1.1%
Bicarbnate	13.1%	0.0%	0.0%	1.1%
Sulfate	120.0%	9.1%	0.0%	20.8%
Chloride	100.0%	0.0%	0.0%	7.9%
Nitrate	28.6%	0.0%	0.0%	1.5%
Total Disolved Solids	17.1%	2.6%	0.0%	3.0%

*Change Ratio(%) = $[(P_{Wali} - P_{Figeh}) / P_{figeh}]$ X 100

where, $P_{wali\ and}$ P_{Figeh} are the values of measured water quality at Wali and Figeh, respectively.

5.2.5 Conclusions

The correlation between water quality and discharge at Figeh is generally high and are of negative values. Yet, water quality does not depend on discharge, the supply of the substances related to water quality index is almost uniform and water quality is diluted with the increase of discharge. The review of water quality change rate between tunnels entrance at Figeh and exit at Wali clarifies that sulfate is increasing with the flow downstream the tunnels. Other water quality items have given almost no change in values.

5.3 Basic Design of Tunnel Rehabilitation Works

5.3.1 Notice in Construction

To make the basic plan of rehabilitation works, access route, working condition and environment along tunnels were considered.

There are nine accessible gates along the old tunnel, Gate Nos. 4, 5, 7, 11, 20, 24, 32, 33 and 38 except Figeh inlet. Accessibility into the tunnel for the rehabilitation works of the old tunnel is within 1km through these, though the works will carried out either tunnel is in or out of service, repeatedly. Flammable remedial works such as welding are possibly avoided because sectional space of the tunnel is very small.

The rehabilitation works along the entire reach of the new tunnel will be more readily implemented because battery cars, which are on stand by at the inlet and outlet of the tunnel and both Bassime and Al Ayoun accesses, allow accessibility to the works.

Environmental impact during construction works shall be considered such as noise, vibration and water pollution. The old tunnel is mainly covered with less earth above it. However, most of sites to be improved are not close to residential area and also, it is not planed to use heavy equipment. In addition, water pollution would not be seriously when the materials with quick hardening propertied are chosen. However, it is necessary to observe water quality periodically.

5.3.2 Remedial Works and Materials

5.3.2.1 Tunnel Remedial Works to Prevent Water Leakage

1) Comparison of Alternatives

According to the results of leakage investigation, distinct leakage from the old tunnel was observed between Figeh(TD260) and Gate No.7(TD3,094) and its ration was 22.3%. In addition, water leakage was found at midstream where is between Gate No.7 and upstream of the Siphon. Water leakage from the new tunnel, meanwhile, was little.

Therefore, the basic design aimed to prevent water leakage at upstream of the old tunnel are listed below.

(a) Panel Method Remedy

i) FRP lining
ii) Steel Plate lining

(b) Bypass Tunnel Remedy

i) Route 1
ii) Route 2
iii) Route 3

(c) Open Air Method Remedy

All alternatives are compared with construction, environmental impact, construction period and costs. Table3.1 shows summarized results.

2) Selected Alternative

According to the results of comparison, FRP lining was selected due to high comprehensive assessment. FRP plate with 10mm thickness was selected as remedial material considering easier construction and higher endurance for corrosion and scouring. In addition, material processing is also easy.

3) Type of Lining

Following five types of lining were selected based on purpose of each remedial work.

i) Arch crowned shape with 3 face lining
Apply to section with leakage or cracks at invert and both sides to prevent leakage.

ii) Rectangular shape with 3 face lining
Apply to section with leakage or cracks at invert and both sides to prevent leakage.

iii) Rectangular shape with 3 face lining to reinforcement
Apply to section with damaged lining concrete reinforced in 60's to prevent leakage. Improvement of hydraulic condition with FRP (roughness coefficient: n=0.010) can be expected.

iv) Rectangular shape with 4 face lining
Apply to section with deteriorated or damaged top besides invert and both sides, where covered rather less earth above tunnel, to prevent leakage and improve section.

v) Rectangular shape with top lining
Apply to section with damaged top and eroded reinforcement bar to improve lining concrete.

5.3.2.2 Remedial Works to Prevent Leakage at Cracks

Most leakage is occurred in the old tunnel. Ground water level around the old tunnel is lower than that of inside of the tunnel. Sections where covered with less earth were constructed by open cut work and backfilled with cobble and stone, so that permeability is rather high. Consequently, water is easy to leak out through cracks.

Cracks of wider than 0.2mm width were selected as the target of remedial works. Small cracks, meanwhile, narrower than 0.2mm width shall be inspected by DAWSSA continuously. Injection method is adequate for these crack.

High adhesive and tensile strength is needed for the grouting material to be united with concrete. In addition, rapid hardening property is required considering limited workable time a day. Therefore, epoxy resin was selected as injection material.

5.3.2.3 Remedial Works to Prevent Deterioration

Some deterioration and damage with concrete flaking and peeling or exposed reinforcement bars were observed in upstream rectangular sections of the old tunnel and defective section of the new tunnel.

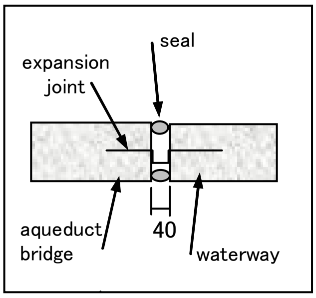
Peeling of rust-proof paint on steel pipes installed in 1960's were also found from TD9,968 to TD13,938 in the old tunnel. Surface of steel pipes were rusted but there were no damage inside.

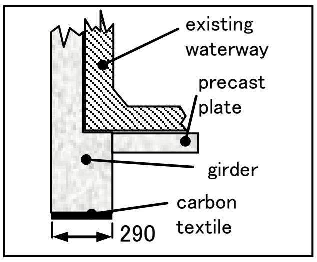
To remedy such deterioration and damage, high adhesive material is needed. Considering easier construction, one material only should by used for the works. The polymer cement mortar was selected to improve damaged concrete where surface was flaked and peeled off or exposed rusted reinforcement bars.

5.3.2.4 Remedial Works to Prevent Leakage at Aqueduct No.3

There are four aqueducts in the old tunnel. At the joint of aqueduct No.1, 2 and 3, waterstops were damaged and deteriorated. Some leakage also was observed at ground surface around the aqueduct No.3. These waterstops shall be replaced.

These aqueducts (No.1 to No.3) were improved in 1960's. At the aqueduct No.3, however, concrete girder was again damaged where surface is flaked and peeled and exposed reinforcement bars.





Replace of Waterstop at Joint **Carbon Textile at Aqueduct No.3**

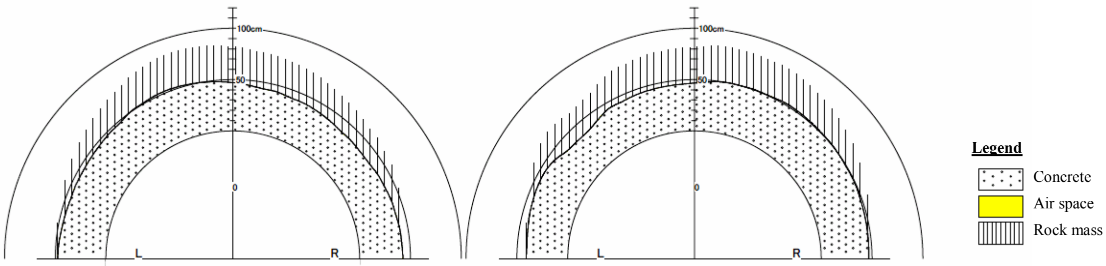
Since it is dangerous to cut concrete and replace reinforcement bars, carbon textile (0.29m width $\times$48.9m$\times$2lines=28.13m^2) is placed on the bottom surface of the girder. There are two purposes to use carbon textile. One is to prevent deterioration caused of water and oxygen, and another is to improve strength instead of corroded reinforcement bars. Therefore, two direction fibrous carbon textile (200 g/m^2) is selected.

5.3.2.5 Remedial Works to Prevent Deterioration of New Tunnel at TD3,170

Flaked and peeled surface of concrete in the new tunnel were mainly caused of expansion of mud stone which mixed in construction period. Same material of the old tunnel will be used for remedial works of the new tunnel after existing ingredients were removed.

From TD3,166 to TD3,172 (6m length), on the other hand, surface of concrete was deteriorated and changed into soft and breakable. This chemical corrosion probably caused of acid contents from the surrounding ground.

Chemical corrosion of concrete was observed on all surfaces except invert, and its depth was 15cm approximately. This section will be improved after concrete are chipped off with 15cm thickness and cleaned. Thickness of existing lining to be improved section is shown below.



TD3,166 **TD3,172**

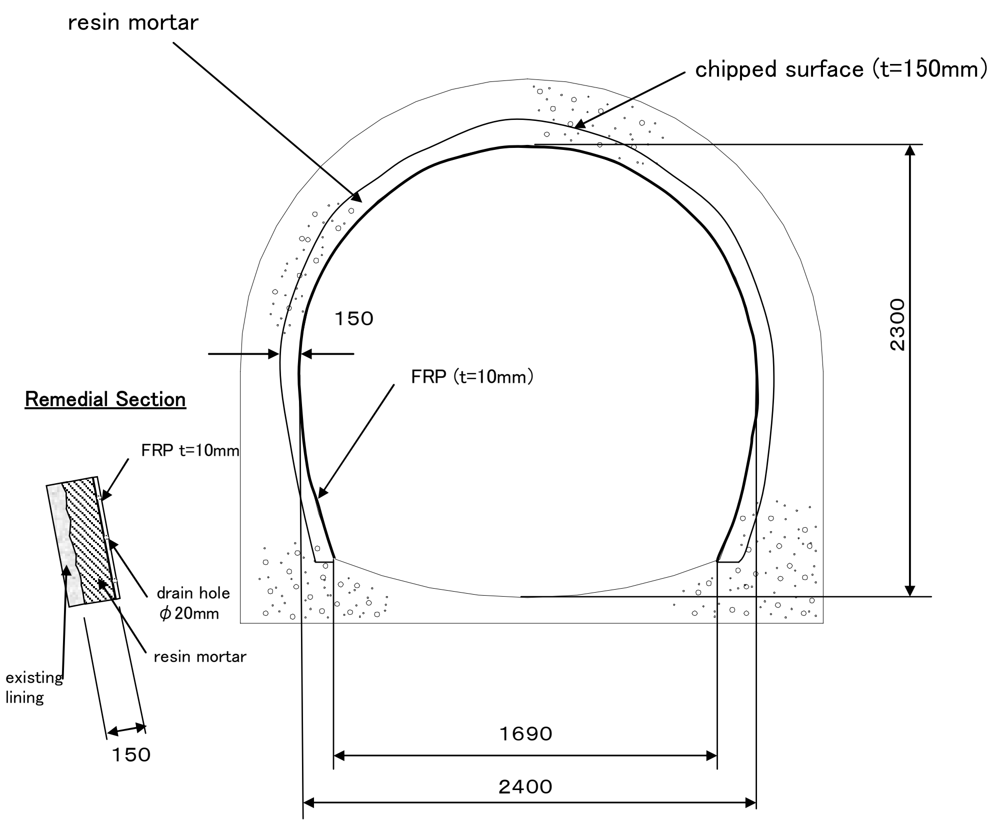
Existing Lining Thickness of Existing Lining to be Improved Section

Both sections have 40cm thickness of concrete, therefore, 25cm thickness can be kept as design concrete thickness after deteriorated surfaces were chipped off.

Remedial materials with corrosion-proof and rapid construction period are recommended considering limited workable time in accordance with suspension of water service.

FRP (Fiber Reinforced Plastic) panel will be installed at inner surface, and polymer cement mortar will be injected behind of FRP. In addition, staggered drain holes with 20cm diameter will be provided on FRP to prevent further chemical corrosion at inside. Surface of FRP panel shall be kept cleaned by DAWSSA's periodical inspection.

Summary of remedial works are shown in table below.

Method	**Chip Off Corrosion and Install FRP**
Drawing	
Outline	・Chip off the corroded surface, install FRP and inject resin mortar（excluding invert）
Advantage	・Improvement of durability ・Existing concrete surface is isolated from leakage ・Leakaged water can not affect structure due to drain holes
Dis-Advantage	・Demolishing method should be considered during suspension of water supply ・Road expansion is partly necessary ・Surplus soil should be carried out to the stockpile yard
Construction	・Easy to carry matterials in the tunnel from Bassime and Al Ayoun adit ・Easy to construct of grouting mortar when plant is provided in the tunnel ・Tunnel can be in survice though less suspension of water service because of FRP panel
Environment Impact	・Less noise for residential quarter ・Less adhesion on the surface
Const. Period	・Suspension of water supply shall be considered　Period : 5m/month
Costs	・Demolision, install FRP and mortar grouting　Costs : 500,000 Yen/m
Comprehensive Assess	○

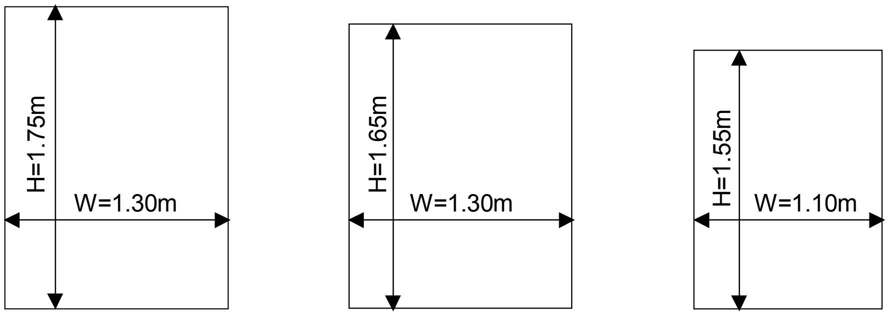
5.3.2.6 Hydraulic Check for FRP Section in Old Tunnel

Design discharge of the old tunnel is $2.5m^3/s$, though its capacity was planed as $3.5m^3/s$ considering future water demand.

Flow capacity at the rectangular section, from TD1,380 to TD3,000 where surface will be improved with FRP panel, was confirmed below.

(1) Cross Section

In 1968, several sections were improved between TD1,380 and TD3,000, so that three kinds of cross sections were selected for a hydraulic calculation as shown below. It was considered that improved section with FRP should be 6cm increased for both height and width.



(a)Initial **(b)Improved 1** **(c)Improved 2**

(2) Hydraulic Calculation and Design Parameter

Manning's formula was applied for a hydraulic calculation as mentioned below.

$$Q = A \quad V, V = \frac{1}{n} \quad R^{2/3} \quad I^{1/2}$$

$Q: Discharge(m^3/s)$

$A: Flow\ section(m^2)$

$V: Velocity(m/s)$

$n: Manning's\ coefficient$

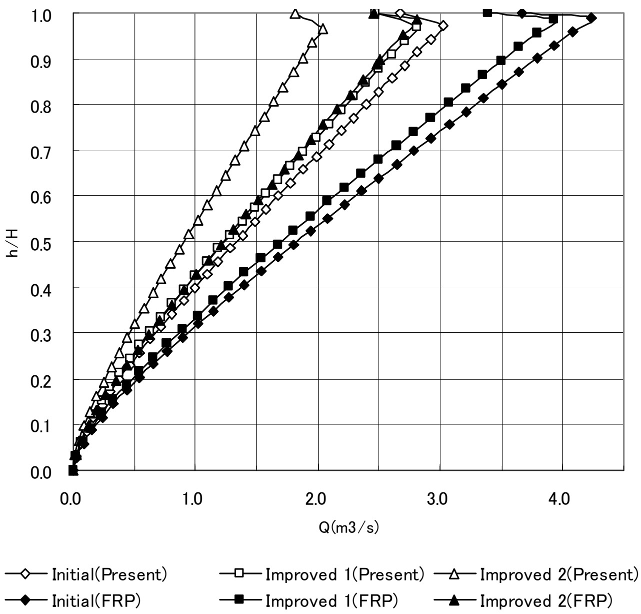
$R: Hydraulic\ radius(m)$

$I: Bed\ slope$

〈Parameter〉

- Manning's coefficient : n Present : 0.015, FRP : 0.010
- Bed slope : I 1/867(=0.00115)

(3) Results



The graph shows flow capacity of both present and improved (with FRP) condition.

The old tunnel has to satisfy design discharge with 90% of water height (0.9h/H) because it is non-pressure tunnel.

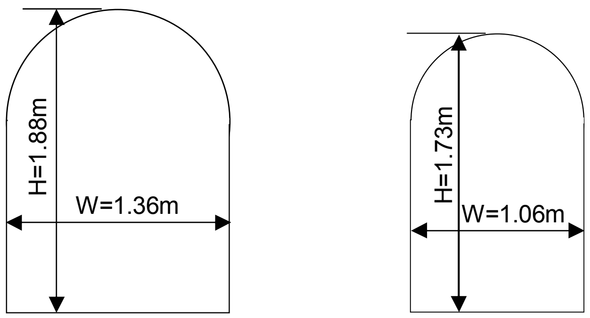
It was confirmed that all sections can pass design discharge of 2.5m3/s due to smaller Manning's coefficient even cross sections were decreased by FRP.

5.3.2.7 Hydraulic Check for Steel Support Section in Old Tunnel

Both steel support and rock bolt were considered for remedial work in the old tunnel from TD300 to TD345. Remedial work with steel support occurs to reduction of flow area, therefore, flow capacity of its section was confirmed.

1) Cross Section

Following cross sections, present condition and improved condition with steel support, were applied for a hydraulic calculation. It was considered that improved section with steel support should be 15cm increased for both height and width.



(a) Initial(Present) **(b) Improved(Steel Support)**

2) Hydraulic Calculation and Design Parameter

Manning's formula was applied for a hydraulic calculation. FRP panel will be installed as both side and invert to prevent leakage.

〈Parameter〉

- Manning's coefficient : n
  Present : 0.015, Steel plate (arch crown) : 0.015
  FRP plate (sides and invert) : 0.010
- Bed slope : I 1/867(=0.00115)

3) Results

The graph shows flow capacity of both present and improved condition.

It was confirmed that improved section can pass design discharge of 2.5m^3/s. However, flow capacity of improved section is decreased of 14% compared with present condition. Considering further degradation of roughness coefficient, flow capacity is not enough. Therefore, remedial works with steel support is not suitable method for a hydraulic condition.

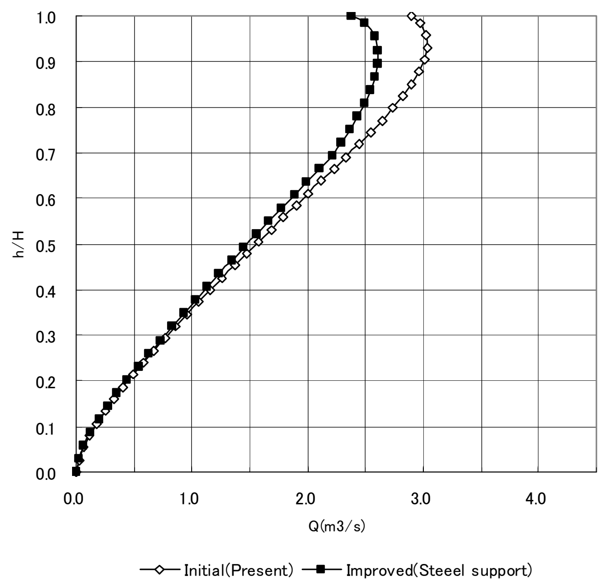


Table3.1 Alternative Measures for Water Leakage Prevention of Old Tunnel Upstream

Method	1. Panel Lining Method				3. Open Air Method	
	FRP Lining		Steel Plate Lining			
Outline	FRP panels will be fixed to the tunnel inner faces with anchors after cleaning the tunnel faces. To grout the space between the panels and faces.		Steel plate panels will be installed to the tunnel inner faces with anchors and will be welded after cleaning the tunnel faces. To grout the space between the panels and faces.		Heavy equipment excavates the covering earth material above the tunnel. The tunnel will be rehabilitated in open air.	
Advantage	· Roughness coefficient of FRP is so small that tunnel can retain the design capacity · The panel can stop water leakage and intrusion of tree roots. · Easy handling the light material.		· Roughness coefficient is so small that tunnel can retain the design capacity. · Steel plate can resist external force more than FRP. · The panel can stop water leakage and intrusion of tree roots.		· Structure durability improves because the deteriorated slab can be replaced. · External reinforcement can be undertaken.	
Dis-Advantage	· The material will be affected by ultraviolet rays. · Replacement is needed when thin plate is broken during grouting.		· Panel size is small due to entrance and welding length becomes long. · Steel plate does not have flexibility due to high rigidity. · Field process is needed.		· Applicable tunnel length is short. Resident houses are closed to the tunnel. · Road widening is needed. · Excavated material shall be hauled to spoil bank.	
Construction	· Easy to bring in the material. · Electric power is needed for tools.		· Not easy to transport the heavy steel in tunnel. · Electric power is needed for welding and tools. · Plate size becomes small for transportation.		· Temporary works of road widening and spoil bank are needed. · Rock fall prevention fences are needed on slope. · Though construction cost becomes low, applicable tunnel length is short.	
Environment Impact	· No liquidation to water. · Material hardly adheres to the surface.		· Ventilation is needed due to welding work. · Periodical painting is needed.		· Measures for construction noise are needed. · Measures for land slide on slope are needed.	
Const. Period	10 m/day		7 m/day		1 m/day for direct work	
Costs	100,000 Yen/m, **15 million Yen**		150,000 Yen/m, 22 **million Yen**		50,000 Yen/m (Excavation, breaking, concreting, filling)	
Comprehensive Assess	Most effective against water leakage.	**A**	Ventilation is needed during construction. Periodical Painting is needed.	**C**	Applicable tunnel length is very short. Rehabilitation work in the tunnel is superior in this Project.	**C**

Method	2. Bypass Tunnel Method					
	Route-1		Route-2		Route-3	
Outline	Tunnel connecting points: TD 150 - 3,160		Tunnel connecting points: TD 150 - 1,700 (L=1,790 m) Tunnel connecting points: TD 2,300 - 3,160 (L=1,480 m)		Tunnel connecting points: TD 150 - 1,700 (L=1,790 m) Tunnel connecting points: TD 2,400 - 2,660 (L=260 m)	
Advantage	· Long durability and no water leakage. · Bypass tunnel is located far from housing area. Tunnel is not affected by then · Tunnel flow will be interrupted only when tunnel connection.		· Long durability and no water leakage. · Bypass tunnel is located far from housing area. Tunnel is not affected by the · Re-use of the old tunnel in good condition.		· Long durability and no water leakage. · Countermeasures are limited to prevention of water leakage and tree root intrusio · Re-use of the old tunnel in good condition.	
Dis-Advantage	· The non-use old tunnel shall be plugged. · Large scaled temporary works and facilities are needed.		· The non-use old tunnel shall be plugged. · Large scaled temporary works and facilities are needed.		· The non-use old tunnel shall be plugged. · Large scaled temporary works and facilities are needed.	
Construction	· Working space at the tunnel inlet is sufficient at Figeh Office. · Working space at the tunnel outlet is not sufficient at Gate 7.		· Working space at the tunnel inlet is sufficient at Figeh Office. · Working space at the other tunnel inlet/outlet is not sufficient.		· Working space at the tunnel inlet is sufficient at Figeh Office. · Rehabilitation in the tunnel from gate No.7.	
Environment Impact	· Attention shall be paid to Figeh district. · The non-use old tunnel shall be plugged not to invite collapse in future.		· Attention shall be paid to Figeh district. · The non-use old tunnel shall be plugged not to invite collapse in future.		· Attention shall be paid to Figeh district. · The non-use old tunnel shall be plugged not to invite collapse in future.	
Const. Period	30 months		30 months		25 months	
Costs	**1,500 million Yen**		**1,340 million Yen**		**780 million Yen**	
Comprehensive Assess	The alternative provides superior advantages, but costs are very high.	**C**	The alternative provides superior advantages and the old tunnel is re-used, but costs are still high.	**C**	The alternative provides superior advantages and the old tunnel is re-used, but costs are high.	**B**

Table3.2 Comparison of Panel Material for Old TunnelUpstream

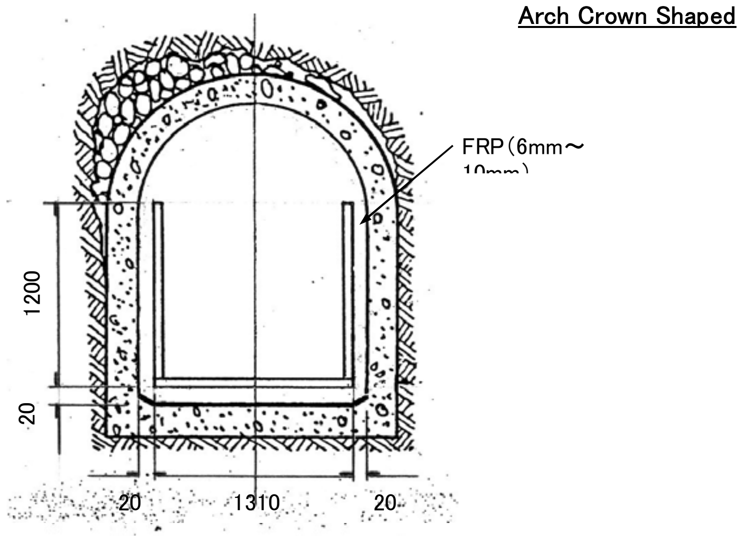
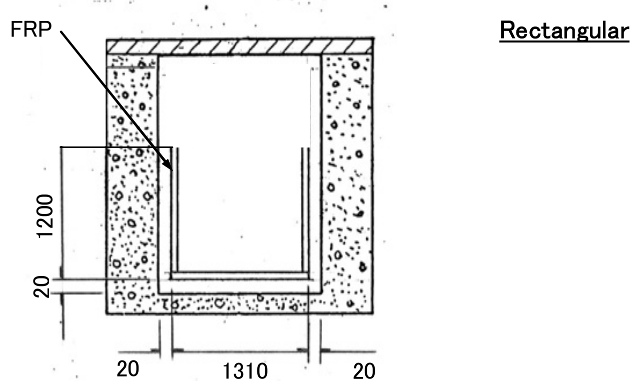
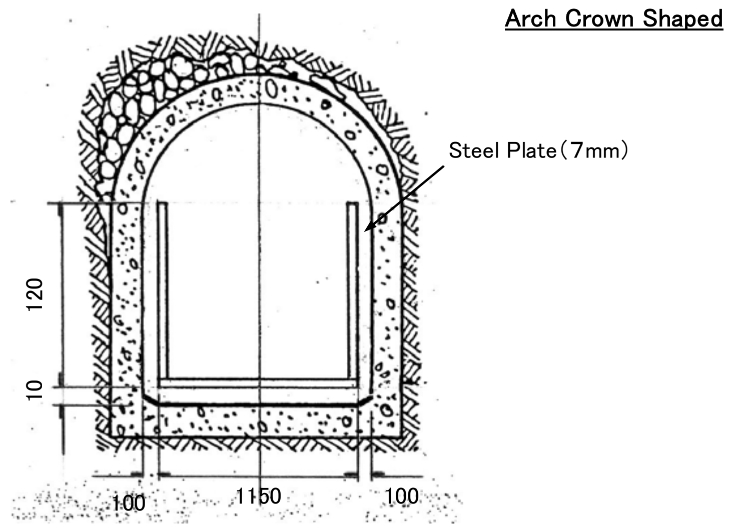
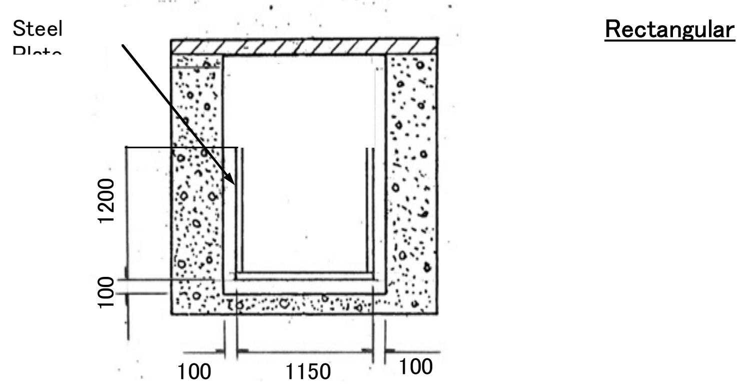
Method	FRP lining	Steel Plate lining
Drawing	 	 
Outline	・FRP panels will be fixed to the tunnel inner faces with anchors after cleaning the tunnel faces. To grout the space between the panels and faces.	・Steel plate panels will be installed to the tunnel inner faces with anchors and will be welded after cleaning the tunnel faces. To grout the space between the panels and faces
Advantage	・Roughness coefficient of FRP is so small that tunnel can retain the design capacity ・The panel can stop water leakage and intrusion of tree roots ・Easy handling the light material ・Applicable material for corners	・Roughness coefficient is so small that tunnel can retain the design capacity ・Steel plate can resist external force more than FRP ・The panel can stop water leakage and intrusion of tree roots
Dis-Advantage	・The material will be affected by ultraviolet rays ・Replacement is needed when thin plate is broken during grouting	・Panel size is small due to entrance and welding length becomes long ・Steel plate does not have flexibility due to high rigidity ・Field process is needed
Construction	・Easy to bring in the material ・Electric power is needed for tools	・Not easy to transport the heavy steel in tunnel ・Electric power is needed for welding and tools ・Plate size becomes small for transportation
Environment Impact	・Long endurance ・Less adhesion on the surface	・Ventilation is needed due to welding work ・Periodical painting is needed （every 10 years）
Const. Period	・Suspension of water supply shall be considered Period : 10 m/day	・Suspension of water supply shall be considered Period : 7 m/day
Costs	・100,000 Yen/m	・150,000 Yen/m
Comprehensive Assess	A	C

Table3.3　Comparison of Bypass Tunnel Alternatives for Old Tunnel Upstream

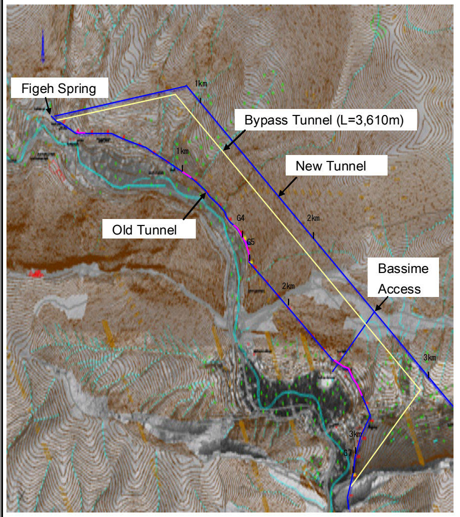
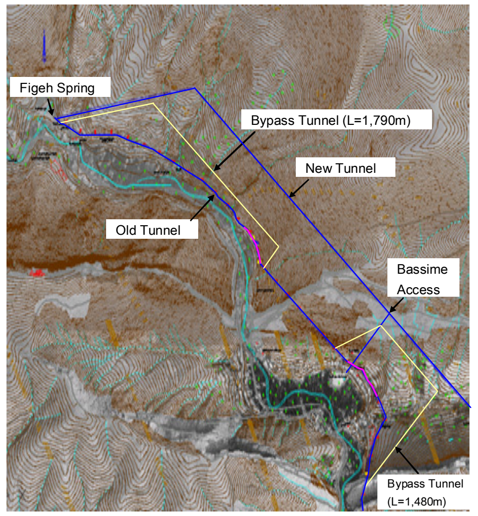
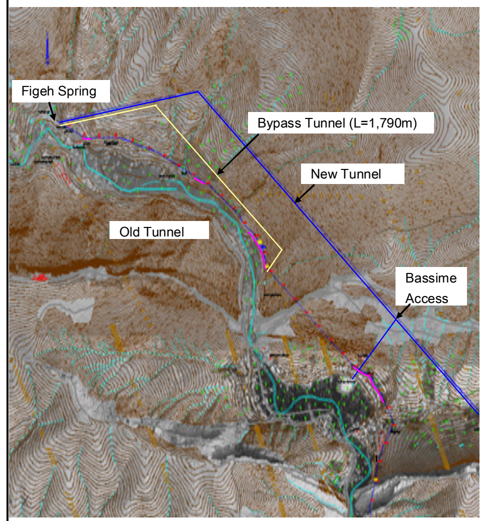
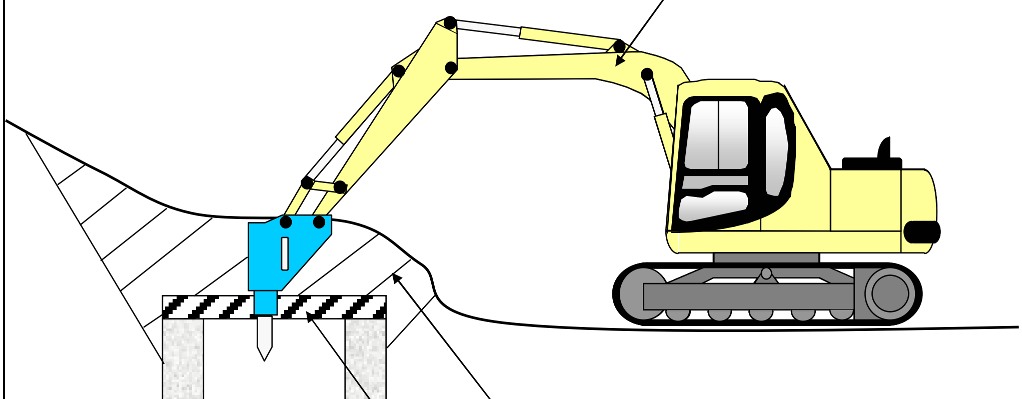
Method	Route 1	Route 2	Route 3
Drawing	 Route 1 (Total Length : L = 3,610 m) Connection Section : TD.150~3,160	 Route 2 (Total Length : L = 3,270 m) Connecting Section 1 : TD.150~1,700 (Length : L=1,790m) Connecting Section 2 : TD.2,300~3,160 (Length : L=1,480m)	 Route 3 (Total Legth : L = 1,790m) Connecting Section : TD.150~1,700 (Length : L=1,790m) Improved Section : TD.2,400~2,660 (Length : L=260m)
Outline	Tunnel connectiong point : TD.150-3,160 The bypass tunnel (inclined tunnel) starts Figeh Office toward TD.150	Tunnel connecting point 1 : TD.150-1,700 (Length : L=1,790m) The bypass (inclined tunnel) starts Figeh Office toward TD.150 Tunnel connecting point 2 : TD.2,300-3,160 (Length : L=1,480m) Bassime access (L=400m) can be used as working adit for tunnel excavation	Tunnel connecting point : TD.150-1,700 (Length : L=1,790m) The bypass tunnel (inclined tunnel) starts Figeh Office toward TD.150 Improved Section : TD.2,400-2,660 (Length : L=260m) Tunnel inner face is improved with panel lining to prevent water leakage and intrusion of tree roots
Advantage	・No remedial work is needed because of detour for upstream deterioration area ・Bypass tunnel is located far from housing area, therefore tunnel is not affected by them ・Tunnel flow will be interrupted only when tunnel connection	・No remedial work is needed because of detour for upstream deterioration area ・Bypass tunnel is located far from housing area, therefore tunnel is not affected by them ・Re-use of the old tunnel in good condition ・Tunnel flow will be interrupted only when tunnel connection	・No remedial work is needed because of detour for upstream deterioration area ・Countermeasures are limited to prevention of water leakage and tree root intrusion ・Re-use of the old tunnel in good condition
Dis-Advantage	・The non-use old tunnel shall be plugged ・Large scaled temporary works and facilities are needed	・The non-use old tunnel shall be plugged ・Large scaled temporary works and facilities are needed	・The non-use old tunnel shall be plugged ・Water service is suspended during remedial works ・Large scaled temporary works and facilities are needed
Construction	・Working space at the tunnel inlet is sufficient at Figeh Office ・Working space at the tunnel outlet is not sufficient at Gate 7	・Working space at the tunnel inlet is sufficient at Figeh Office ・Working space at the other tunnel inlet/outlet is not sufficient	・Working space at the tunnel inlet is sufficient at Figeh Office ・Working space at the tunnel outlet is not sufficient ・Gate No.7 is used for remedial works
Environment Impact	・Attention shall be paid to Figeh district ・The non-use old tunnel shall be plugged not to invite collapse in future	・Attention shall be paid to Figeh district ・The non-use old tunnel shall be plugged not to invite collapse in future	・Attention shall be paid to Figeh district ・The non-use old tunnel shall be plugged not to invite collapse in future
Const. Period	・Suspension of water supply shall be considered　Period : 30 month	・Suspension of water supply shall be considered　Period : 30 month	・Suspension of water supply shall be considered　Period : 25 month
Costs	・Tunnel : 350,000 Yen/m × 3,610 m =1,263.5 million Yen ・Existing tuunel plug : 3,100 m × 2.3 m2 × 35,000 Yen/m3 (air mortar) = 249.5 million Yen **・Total : 1,510 million Yen**	・Tunnel : 350,000 Yen/m × 3,270 m = 1,144.5 million Yen ・Existing tuunel plug : (1,550m + 860m) × 2.3 m2 × 35,000 Yen/m3 (air mortar) = 194 million Yen **・Total : 1,340 million Yen**	・Tunnel : 350,000 Yen/m × 1,790 m = 626.5 million Yen ・Remedial work : 260m × 100,000 Yen/m = 26 million Yen ・Existing tuunel plug : 1,550m × 2.3m2 × 35,000 Yen/m3 (air mortar) = 124.8 million Yen **・Total : 780 million Yen**
Comprehensive Assess	△	△	○

Table3.4　Open Cut Works

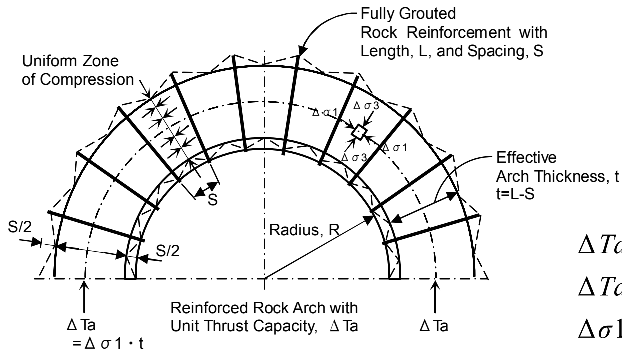
Method	**Open Cut Works**
Drawing	
Outline	・Heavy equipment excavates the covering earth material above the tunnel. The tunnel will be rehabilitated in open air.
Advantage	・Structure durability improves because the deteriorated slab can be replaced. ・External reinforcement can be undertaken.
Dis-Advantage	・ Resident houses are closed to the tunnel ・Road widening is needed ・Excavated material shall be hauled to spoil bank
Construction	・Temporary works of road widening and spoil bank are needed ・Rock fall prevention fences are needed on slope ・Construction cost may be expensive due to temporary works
Environment Impact	・Measures for construction noise are needed ・Measures for land slide on slope are needed
Const. Period	・1m/day
Costs	・Excavation, Demolision, Concrete, Backfill　50,000 Yen/m　(Approximately L=100m)
Comprehensive Assess	△

5.3.2.8 Remedy for Structural Cracks in Old Tunnel (TD300 - TD345)

Little obvious cracks could be seen in the old tunnel from TD300 to TD345. This section is located under the residential area and where has been taken excess non-uniformed earth pressure. Structural model at this section is similar to shearing model. Rock bolts or steel supports are effective to improve this section to fix tunnel lining with rock ground.

1) Rock Bolt

Rock bolts bind deteriorated rock ground each other. When rock bolts were applied, arched action can be expected as shown below. In addition, increase of stress in the rock ground can be expected by tightened rock bolts.



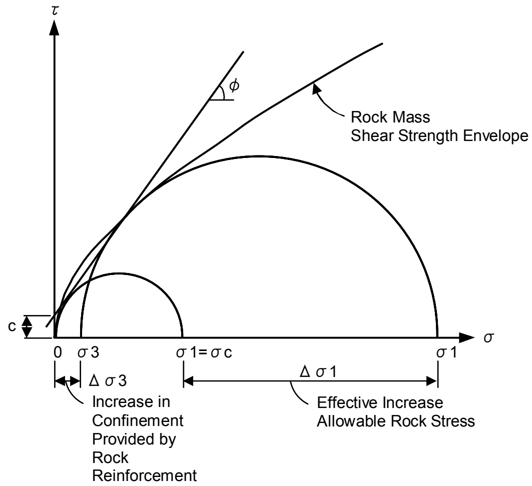
Model of Arched Action

$\Delta Ta = \Delta\sigma 1 \quad t$

ΔTaRock Strength

$\Delta\sigma 1$Effective increased stress along arch

t : Effective thickness



Increase of Rock Stress by Rock Bolt

$\Delta\sigma 1 = \tan^2(45^\circ + \varphi/2) \quad \Delta\sigma 3$

$\Delta\sigma 1$:Effective increased stress along arch

φ : Internal friction angle of rock

$\Delta\sigma 3$:Effective increased stress along radius (equivalent to tightness of rock bolt)

$\Delta\sigma 3 = \sigma b \quad Ab/S^2$

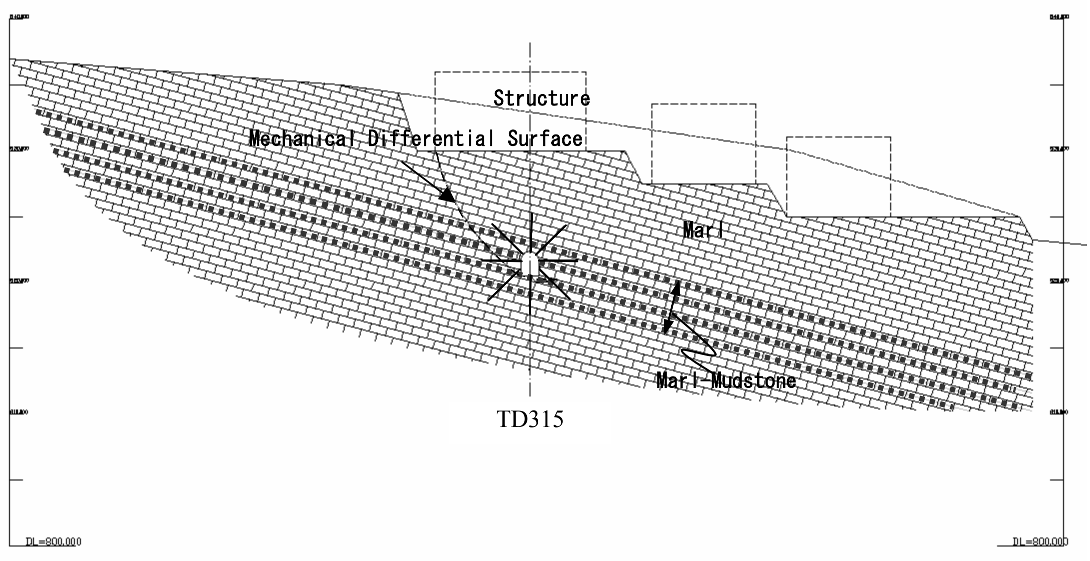
σb : Yield stress of steel bar

Ab : Sectional area of steel bar

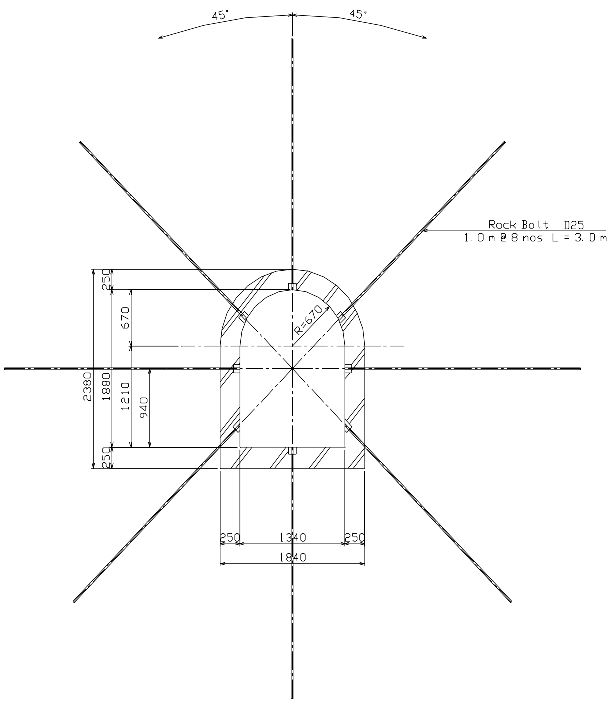
S : Spacing of rock bolts

$$\Delta Ta = \tan^2(45^\circ + \varphi/2) \quad \frac{\sigma b \quad Ab}{S^2}(L \quad S)$$

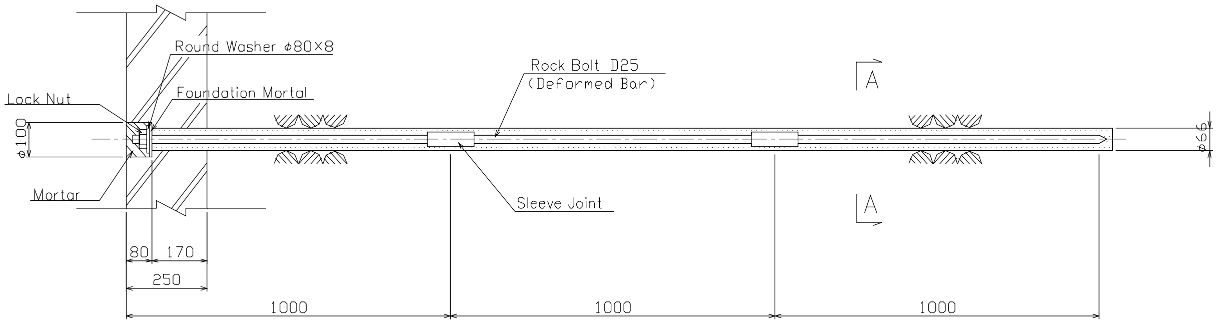
In this section, it was assumed that there was mechanical discontinuous face of rock ground as shown below. Rock bolts, therefore, shall be installed to cross mechanical discontinuous face. To satisfy this condition, 3m length of rock bolt is chosen. Spacing of rock bolts, meanwhile, is 1m based on experience which should be smaller than half of rock bolt length.



Effective Range



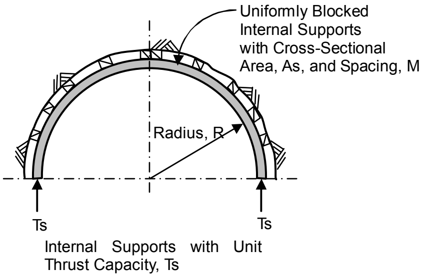
Arrangement of Rock Bplts



Details of Rock Bolt

2) Steel Support

Some blocks will be prepared between steel support and rock surface, as shown below, to keep high tightness with rock surface. Spacing of steel support was determined based on equivalent strength of rock bolt as shown table below.



Mechanical Model of Steel Support

$$Ts = \frac{\sigma s \quad As}{M}$$

Ts: Strength of steel support

σs: Yield stress of steel support

As: Sectional area of steel support

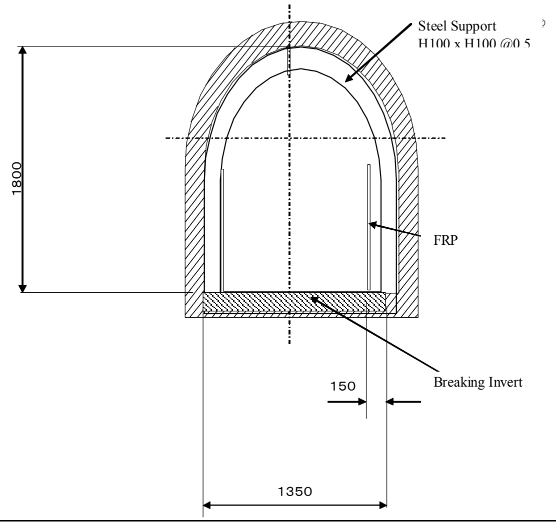
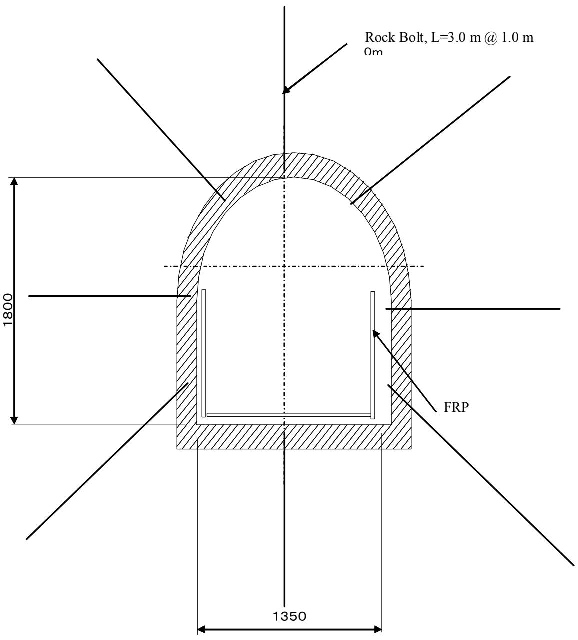
M: Spacing

Steel Support	Unit	Type	Value
Yield Stress	N/mm^2	SS400	245
Sectional Area	mm^2	H-100	2,190
Spacing (500mm pitch)	mm		597
Strength (ΔTa)	N		899
Rock Bolt			
Yield Stress	N/mm^2	SD345	345
Sectional Area	mm^2	screw	353
Length of Rock Bolt	mm		3,000
Spacing (Longitudinal)	mm		1,000
Spacing (Arch)	mm		1,000
Internal Friction Angle	degree		35
Strength (Ts)	N		899

3) Selected Method

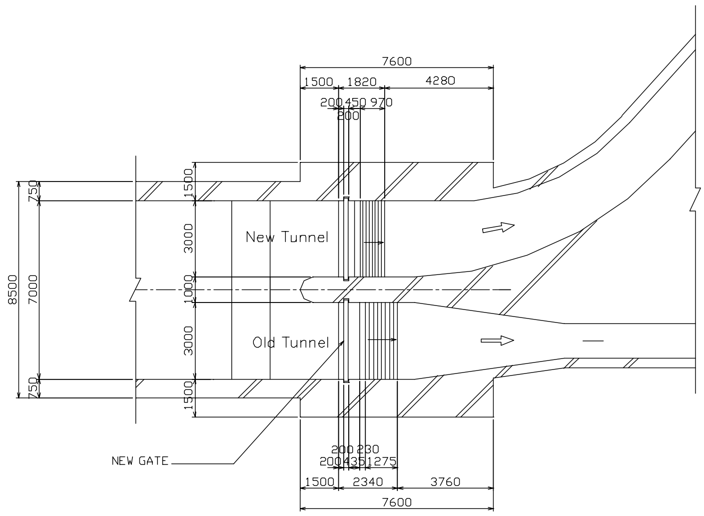
Rock bolt was selected based on comprehensive assessment of both methods as shown in Table3.5.

Table3.5 Alternative Measures for Structural Cracks TD300-345 of Old Tunnel

	Steel Support	Rock Bolt
Sketch		
Method	To install H-still in tunnel to resist external force. FRP is installed to stop water leakage.	To provide rock bolts into rock to resist external force. FRP is installed to stop water leakage.
Advantag	· This is common application as a temporary measure. · After tunnel lining loses resistance against external force, H-still resists it.	· This is common practice as a permanent measure. · External rock foundation resists deformation. It has strong resistance.
Disadvantage	· New crack in the lining concrete is the cause of water leakage. · Flow area is reduced. Design flow capacity can not be hold. · This method is inferior against long term external force.	· It takes time to drill holes due to limited space.
Construction	· To transport H-steel from upstream, and to install them from downstream.	· A few drilling machine will be mobilized to expedite drilling work.
Environment Impact	· Steel support will rust.	· No rust problem.
Periods	2.0 months	10 months (3 units of drill machine)
Costs	15 million Yen	18 million Yen

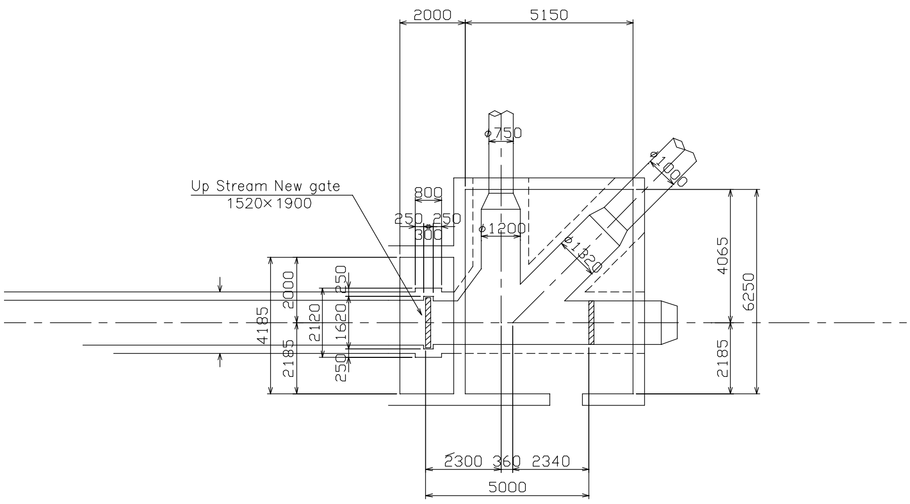
5.4 Design of Gate at Intake and Siphon

There was leakage at the intake gate (W=3m, H=1.5m) of Figeh, so that it is inconvenient to operate and maintain by DAWSSA. Therefore, it was understood that gate slots and leaf should be replaced.



Location of Intake Gate at Figeh

There is the Siphon (Φ=1,400mm) which is in daily use. There are also three Siphons beside it. Gates are installed at both up and downstream of each three Siphon. These gates, however, had become too old to operate, so that inside of each Siphon were filled with leaked water. According to the leakage investigation, there was little leakage from each Siphon. It means these three Siphons are good condition and useful for emergency if inner water was drawn and kept inside without water. Therefore, improvement of gate was recommended. Two gates (W=1.4m, H=1.9m) will be installed newly at both up and downstream of confluence of three Siphons.



Location of Gate at Siphon

5.4.1 Gate Type

The slide gate with chain block was selected as same as present condition.

5.4.2 Material of Gate

1) Applicable Material

Table4.1 shows applicable materials for the gate structure and characteristic.

Table4.1 Table 4.1 Material of Gate

Material (Standard)	Characteristic
Rolled Steel (SM400,SM490)	・ Most general material for structure ・ Easy for purchase and processing ・ Corrosion-proof is needed on gate leaf ・ Periodical maintenance (re-painting) is needed ・ Period of overall re-painting is around 10years
Stainless Steel (SUS304)	・ General material for structure ・ Hard to purchase in Syria ・ Corrosion-proof is not needed so that lower maintenance cost ・ Higher material cost (300 to 500% of rolled steel) ・ Rather complicated fabrication than others
Stainless Clad Steel (SM400+SUS304 etc.)	・ Stainless steel covers rolled steel ・ Various material can be applied ・ Higher material cost (130 to 150% of stainless steel)
Carbon Steel Casting (SC450)	・ Useful material if many gates will be installed ・ Higher cost because casting form is needed ・ Heavier weight than others

2) Comparison of Material

Material of gate was selected based on comparison of NPV (Net Present Value). Only painting cost was included as maintenance cost to select gate material. Because cost of other materials for maintenance were almost same and could be neglected even the gate material is different.

Table4.2 Cost Item for Gate Maintenance

Item	Description	Interval (year)
Oiling		1
Painting	Re-painting	10
Water Seal	Replace	20
Control Board	Replace	20
Hoisting	Replace	25

i) Method of Comparison

Material of Gate was determined based on NPV considering the initial cost (I) for fabrication and the maintenance cost (R) for re-painting of gate.

$$Pn = R \times 1 / (1 + i)^n$$

Where, Pn : Cost for re-painting after n years

i : discount rate = 0.045

n : Year

ii) Conditions

- Fifty years is applied as durable life of the gate facility
- Epoxy resin is applied for painting material considering water level at the gate
- Interval of re-painting of the gate leaf is 10 years
- Coffering is considered because temporary works will be necessary during re-painting

iii) Selected Material

Result of cost comparison is shown in Table4.3.

No particular maintenance is needed for stainless steel though higher initial cost than that of rolled steel. Considering site condition at Figeh and Siphon, stainless steel is most suitable as the gate material. In addition, stainless steel shows most economical NPV as shown in Table4.3.

Table4.3 Cost Comparison

Material	Rolled Steel (SM400)	Stainless Steel (SUS304)	Stainless Clad Steel (SM400+SUS304)	Carbon Steel Casting (SC450)
Weight of Gate Leaf	Intake Gate : 0.8ton Siphon Gate : 0.8ton Total : 1.6ton	Intake Gate : 0.8ton Siphon Gate : 0.8ton Total : 1.6ton	Intake Gate : 0.8ton(0.1)※ Siphon Gate : 0.8ton(0.1)※ Total : 1.6ton(0.2)※ ※( ): Clad (Skin plate only)	Intake Gate : 1.2ton Siphon Gate : 1.2ton Total : 2.4ton
Material Cost (①)	Unit Cost : 100,000 Yen/ton Sub-total : 160,000 Yen	Unit Cost : 350,000 Yen/ton Sub-total : 560,000 Yen	Unit Cost : 420,000 Yen/ton(Clad) 100,000 Yen/ton(SM) Sub-total : 224,000 Yen	Unit Cost : 500,000 Yen/ton Sub-total : 1,200,000 Yen
Labor Cost (②)	Unit Cost : 1,000,000 Yen/ton (Cutting, Welding, Processing) Sub-total : 1,600,000 Yen	Unit Cost : 1,300,000 Yen/ton (Cutting, Welding, Processing) Sub-total : 2,080,000 Yen	Unit Cost : 1,100,000 Yen/ton (Cutting, Welding, Processing) Sub-total : 1,760,000 Yen	Unit Cost : 500,000 Yen/ton (Processing) Sub-total : 1,200,000 Yen
Cost for Painting and Cleaning Acid (③)	Painting Area : 23m^2 Unit Cost : 5,000 Yen/m^2 (epoxy) Sub-total : 115,000 Yen	Painting Area : 23m^2 Unit Cost : 4,000 Yen/m^2(acid) Sub-total : 92,000 Yen	Painting Area : 19m^2/Acid : 4m^2 Unit Cost : 5,000 Yen/m^2 (epoxy) Unit Cost : 4,000 Yen/m^2(acid) Sub-total : 111,000 Yen	Painting Area : 23m^2 Unit Cost : 5,000 Yen/m^2(epoxy) Sub-total : 115,000 Yen
Direct Cost (④)	①+②+③ = 1,875,000 Yen	①+②+③ = 2,732,000 Yen	①+②+③ = 2,095,000 Yen	①+②+③ = 2,515,000 Yen
Indirect Cost (⑤)	②×75% = 1,200,000 Yen	②×75% = 1,560,000 Yen	②×75% = 1,320,000 Yen	②×75% = 900,000 Yen
Administration Cost (⑥)	(②+③+⑤)×30% = 875,000 Yen	(②+③+⑤)×30% = 1,120,000 Yen	(②+③+⑤)×30% = 957,000 Yen	(②+③+⑤)×30% = 665,000 Yen
Total (Initial Cost : I)	**3,950,000 Yen**	**5,412,000 Yen**	**4,372,000 Yen**	**4,080,000 Yen**
Periodical Painting Cost (Maintenance Cost : R)	Paint : 15,000 Yen/m^2(w/temp. work) Coffer : 1,000,000 Yen/time Sub-total : **1,345,000 Yen/time**	－(nil)	Paint : 15,000 Yen/m^2(w/temp. work) Coffer : 1,000,000 Yen/time Sub-total : **1,285,000 Yen/time**	Paint : 15,000 Yen/m^2(w/temp. work) Coffer : 3,000,000 Yen/time Sub-total : **1,345,000 Yen/time**
Net Present Value (50 years) ※※	I＋1.497×R **= 5,953,000 Yen**	I＋1.497×R **= 5,412,000 Yen**	I＋1.497×R **= 6,296,000 Yen**	I＋1.497×R **= 6,094,000 Yen**

※※ Cost for 4times periodical painting $= P_{10} + P_{20} + P_{30} + P_{40} = R \times \frac{1}{(1+0.045)^{10}} + \frac{1}{(1+0.045)^{20}} + \frac{1}{(1+0.045)^{30}} + \frac{1}{(1+0.045)^{40}} = R \times 1.497$

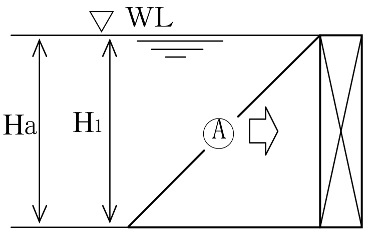
5.4.3 Design of Inlet Gate

1) Design Condition

Gate Type	Stainless Stoplog			
Number of Gate	1 nos.			
Width	3.000 m			
Height	1.500 m			
Design Water Depth				
	Front Surface		1.500	m
	Back Surface		0.000	m
Sealing Type	Upstream 3-side rubber sealing			
Corrosion Margin				
	Plate girder	(one side)	0.00	cm
	Skin plate	(one side)	0.00	cm
Deflection	Smaller than 1/ 600 of its span			
Design Criteria	Technical Standard of Hydraulic Gate and Penstock			

2) Water Pressure

I) Design Water Pressure



P : Design Water Pressure (kN)
A : Front Water Pressure (kN)
B : Back Water Pressure (kN)
H_1 : Front Design Water Depth = 1.500 m
H_2 : Back Design Water Depth = 0.000 m
L_0 : Loading Width = 3.000 m
Ha : Front Loading Height = 1.500 m
Hb : Back Loading Height = 0.000 m

w : Unit Weight of Water = 1.00 t/m^3

g : Acceleration of Gravity = 9.807 m/s^2

$$A = \frac{H_1^2 - (H_1 - Ha)^2}{2} \times L_0 \times w \times g$$

$$= \frac{1.500^2 - (1.500 - 1.500)^2}{2} \times 3.000 \times 1.00 \times 9.807$$

$$= 33.099 \text{ kN}$$

$$B = \frac{H_2^2 - (H_2 - Hb)^2}{2} \times L_0 \times w \times g$$

$$= \frac{0.000^2 - (0.000 - 0.000)^2}{2} \times 3.000 \times 1.00 \times 9.807$$

$$= 0.000 \text{ kN}$$

Design Water Pressure P = (A - B)= 33.099 kN

3) Arrangement of Plate Girder and Distributed Load

I) Distributed Load

Distributed Load on Upper Plate Girder $P = \{\frac{lu}{2}(pm+pu) + \frac{ld}{6}(2\times pm+pd)\}\times L_0$

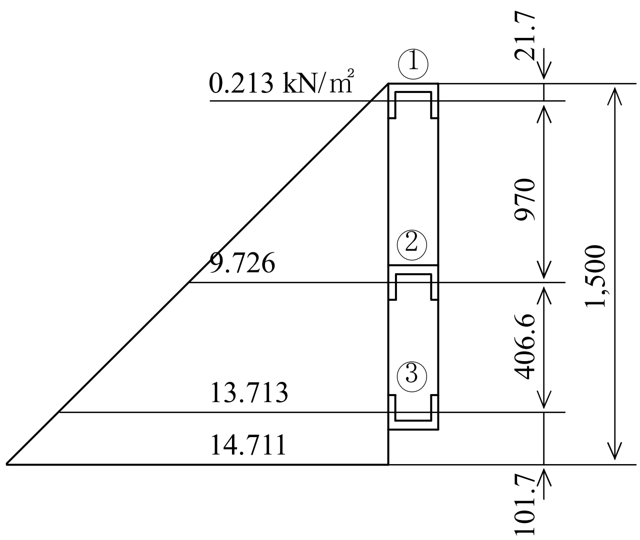
Distributed Load on Middle Plate Girder $P = \{\frac{lu}{6}(2\times pm+pu) + \frac{ld}{6}(2\times pm+pd)\}\times L_0$

Distributed Load on Lower Plate Girder $P = \{\frac{lu}{6}(2\times pm+pu) + \frac{ld}{2}(pm+pd)\}\times L_0$

P : Distributed Load
lu : Distance from center of gravity to upper plate girder
ld : Distance from center of gravity to lower plate girder
pm : Mean water pressure at center of gravity of girder
pu : Upper mean water pressure from center of gravity of girder
pd : Lower mean water pressure from center of gravity of girder

		<1>	<2>	<3>	
Mean Water Pressure p (kN/m²)	0.000	0.213	9.726	13.713	14.711
Distance l (m)		0.0217	0.9700	0.4066	0.1017
Distributed Load P (kN)		4.930	16.279	11.889	

Calculation is carried out for the plate girder <2>, which has the maximum load.



4) Sectional Character of Girder

I) Sectional Area

Type of steel

A × B × C × D

CH 150×75×9.0×9.0

Material

SUS304

Corrosion margin (F)

One side 0.00 cm

II) Moment of Inertia

I :Moment of inertia (cm^4)

B_2: B−(2×F) = 7.50 cm

H_2: A−(2×F) = 15.00 cm

B_1: B_2−(C−2×F) = 6.60 cm

H_1: H_2−2×(D−2×F) = 13.20 cm

$$I = \frac{1}{12} \times (B2 \times H2^3 - B1 \times H1^3)$$

$$= \frac{1}{12} \times (7.50 \times 15.00^3 - 6.60 \times 13.20^3)$$

$$= 844.4 \ cm^4$$

III) Modulus of Section

Z : Modulus of Section (cm^3)

$$Z = \frac{2 \times I}{H2}$$

$$= \frac{2 \times 844.4}{15.00}$$

$$= 112.6 \ cm^3$$

5) Strength of Girder

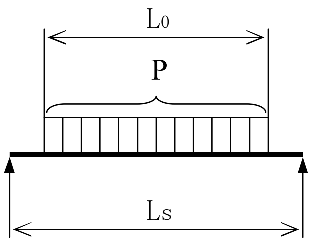
I) Bending Moment

M : Bending Moment (N-mm)
P : Maximum Load = 16,279 N
L_0 : Loading Width = 3,000 mm
L_s : Width of Gate = 3,160 mm

$$M = \frac{1}{8} \times P \times (2 \times L_s - L_0)$$

$$= \frac{1}{8} \times 16,279 \times (2 \times 3,160 - 3,000)$$

$$= 6,755,900 \quad \text{N-mm}$$



II) Bending Stress

σ : Bending Stress (N/mm^2)
Z : Modulus of Section = 112.6×10^3 mm^3

$$\sigma = \frac{M}{Z}$$

$$= \frac{6,755,900}{112.6 \times 10^3}$$

$$= 60.0 \ N/mm^2 < 100.0 \ N/mm^2$$ (許容応力)

III) Length of Deflection

δ : Length of deflection (mm)
E : Modulus of Elasticity = 1.93×10^5 N/mm^2
I : Moment of Inertia = 844.4×10^4 mm^4

$$\delta = \frac{P}{48 \times E \times I} \times \left(L_s^3 - \frac{L_s \times L_0^2}{2} + \frac{L_0^3}{8} \right)$$

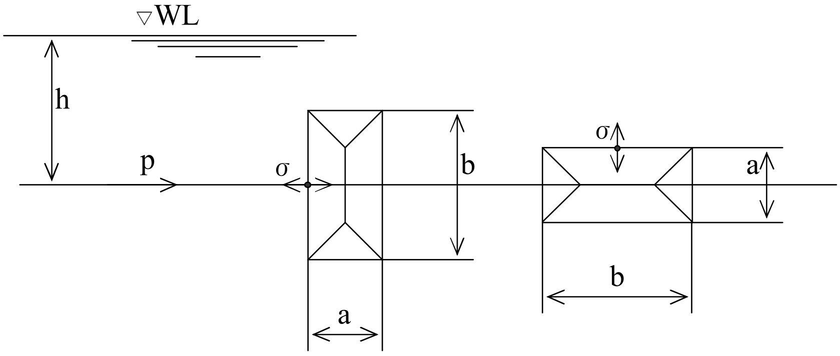
$$= \frac{16,279}{48 \times 1.93 \times 10^5 \times 844.4 \times 10^4} \times \left(3,160^3 - \frac{3,160 \times 3,000^2}{2} + \frac{3,000^3}{8} \right)$$

$$= 4.31 \quad mm$$

IV) Deflection

$$\frac{\delta}{L_s} = \frac{4.31}{3,160} = \frac{1}{733.2} < \frac{1}{600.0}$$ (Allowable deflection)

6) Strength of Skin Plate



Value of K

b／a	K
1.00	30.9
1.25	40.3
1.50	45.5
1.75	48.4
2.00	49.9
2.50	50.0
3.00	50.0
∞	50.0

σ : Stress (N/mm^2)

p : Mean Water Pressure (N/mm^2)

a : Shorter Length (mm)

b : Longer Length (mm)

K : Coefficient by b / a

T_0 : Thickness of Plate = 9.0 mm

F : Corrosion Margin = 0.0 mm (one side)

t : Effective Thickness = $T_0 - 2 \times F$ = 9.0 mm

Maximum stress at the center of longer length is

$$\sigma = \frac{1}{100} \times K \times a^2 \times \frac{p}{t^2}$$

No	a	b	b／a	K	p	σ	(Allowable Stress)
1	715.0	895.0	1.25	40.3	0.005124	13.0	100.0
2	300.0	715.0	2.38	50.0	0.011719	6.5	100.0

7) Summary of Material

Guide Frame

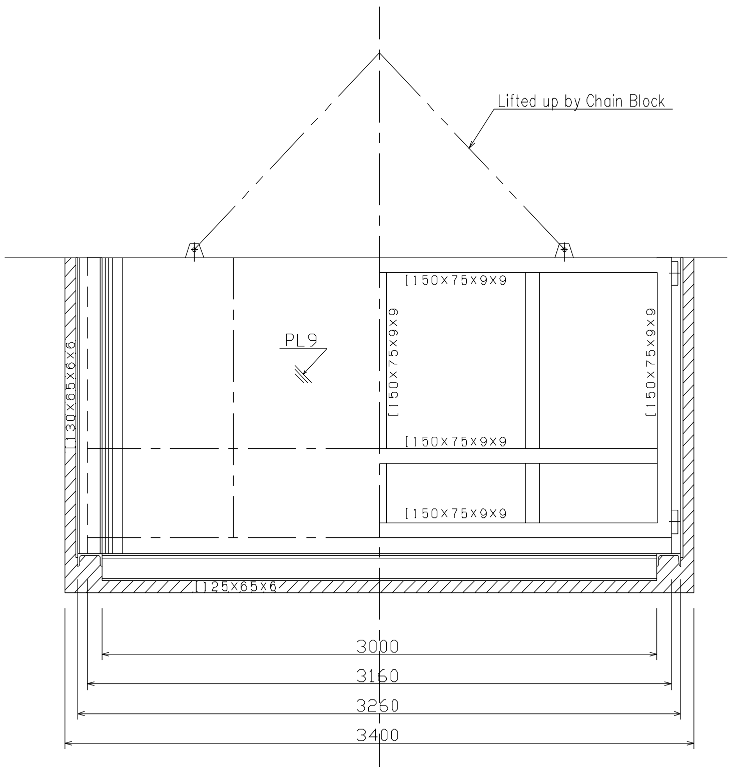
Part	Shape	Dimension	Width	Length	No.	Unit Weight	Weight	Material	Painted Area
Back side frame	CH	130 x 65 x 6 x 6		1.5000	2	11.99	35.97	SUS304	(1.560)
Front side frame	CH	130 x 65 x 6 x 6		1.5000	2	11.99	35.97	SUS304	(1.560)
Bottom	CH	125 x 65 x 6 x 8		3.0000	1	13.40	40.20	SS400	——
Bottom	CH	130 x 65 x 6 x 6		0.3200	2	11.99	7.67	SUS304	(0.333)
Bottom water sea	PL	6	0.0850	3.0000	1	47.58	12.13	SUS304	(0.510)
Bottom water sea	PL	6	0.1300	0.0685	2	47.58	0.85	SUS304	(0.036)
Side Plate	PL	6	0.2600	1.4200	2	47.58	35.13	SUS304	(1.477)
Bottom	PL	9	0.0540	0.1180	4	71.37	1.82	SUS304	(0.051)
Anchor Bar	FB	25 x 4		0.2150	12	0.79	2.04	SUS304	(0.129)
Bolt		M 16 x 45 x 38 BN2W			8	(0.17)	1.36	SS400	——
					Total Weight		173.14	kg	0.000 m^2
									(5.656) m^2

Gate Leaf

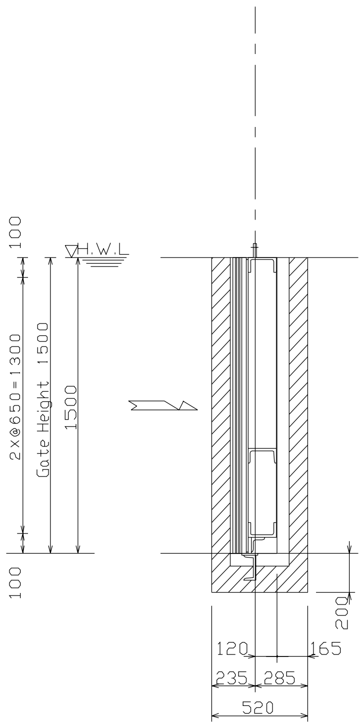
Part	Shape	Dimension	Width	Length	No.	Unit Weight	Weight	Material	Painted Area
Skin plate	PL	9	3.1400	1.4850	1	71.37	332.79	SUS304	(9.326)
Main girder	CH	150 x 75 x 9 x 9		3.1420	1	20.25	63.63	SUS304	(1.414)
Horizontal girder	CH	150 x 75 x 9 x 9		3.1420	2	20.25	127.25	SUS304	(2.828)
Side girder	CH	150 x 75 x 9 x 9		1.4200	2	20.25	57.51	SUS304	(1.278)
Vertical girder	CH	150 x 75 x 9 x 9		0.4320	3	20.25	26.24	SUS304	(0.583)
Vertical girder	CH	150 x 75 x 9 x 9		0.9610	3	20.25	58.38	SUS304	(1.297)
Bottom seal	L	75 x 75 x 9		2.9400	1	10.10	29.69	SUS304	(0.882)
Side seal	FB	50 x 6		1.4950	2	2.38	7.12	SUS304	(0.299)
Plate	PL	4	0.0400	1.4000	2	31.72	3.55	SUS304	——
Front shoe	PL	12	0.0400	0.1500	4	95.16	2.28	SUS304	(0.048)
Guide	PL	12	0.0400	0.1500	4	95.16	2.28	SUS304	(0.048)
Hanger	PL	16	0.0700	0.1000	2	126.88	1.78	SUS304	(0.028)
Bolt		M 12 x 40 x 30 BN2W			16	(0.09)	1.44	SUS304	——
Bolt		M 12 x 55 x 30 BNP2W			18	(0.10)	1.80	SUS304	——
Bolt		M 16 x 55 x 38 BNP2W			16	(0.18)	2.88	SUS304	——
Bolt		M 16 x 80 x 38 BNP2W			2	(0.22)	0.44	SUS304	——
Bolt		M 16 x 65 x 38 BNP2W			4	(0.20)	0.80	SUS304	——
Sealing rubber		L-18 rubber		1.5050	2	3.38	10.17	chloroprene	——
Sealing rubber		85 x 15		2.9400	1	1.66	4.88	chloroprene	——
Sealing rubber		75 x 9		0.0750	2	0.88	0.13	chloroprene	——
					Total Weight		735.04	kg	0.000 m^2
									(18.031) m^2

8) Details of Gate

Elevation View



Cross Sectional View



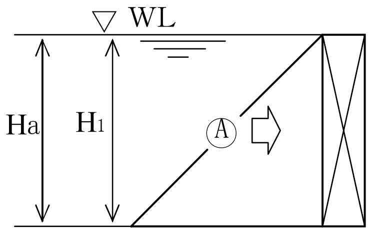
5.4.4 Design of Gate at Siphon

1) Design Condition

Gate Type	Stainless Stoplog		
Number of Gate	1 nos.		
Width	1.400 m		
Height	1.900 m		
Design Water Depth			
	Front Surface	1.900	m
	Back Surface	0.000	m
Sealing Type	Upstream 3-side rubber sealing		
Corrosion Margi			
	Plate girder （one side）	0.00	cm
	Skin plate （one side）	0.00	cm
Deflection	Smaller than 1/ 600 of its span		
Design Criteria	Technical Standard of Hydraulic Gate and Penstock		

2) Water Pressure

I) Design Water Pressure



P : Design Water Pressure (kN)
A : Front Water Pressure (kN)
B : Back Water Pressure (kN)
H_1 : Front Design Water Depth = 1.900 m
H_2 : Back Design Water Depth = 0.000 m
L_0 : Loading Width = 1.400 m
Ha : Front Loading Height = 1.900 m
Hb : Back Loading Height = 0.000 m

w : Unit Weight of Water = 1.00 t/m^3

g : Acceleration of Gravity = 9.807 m/s^2

$$A = \frac{H_1^2 - (H_1 - Ha)^2}{2} \times L_0 \times w \times g$$

$$= \frac{1.900^2 - (1.900 - 1.900)^2}{2} \times 1.400 \times 1.00 \times 9.807$$

$$= 24.782 \text{ kN}$$

$$B = \frac{H_2^2 - (H_2 - Hb)^2}{2} \times L_0 \times w \times g$$

$$= \frac{0.000^2 - (0.000 - 0.000)^2}{2} \times 1.400 \times 1.00 \times 9.807$$

$$= 0.000 \text{ kN}$$

Design Water Pressure P = (A − B) = 24.782 kN

3) Arrangement of Plate Girder and Distributed Load

I) Distributed Load

Distributed Load on Upper Plate Girder $P = \left\{ \frac{lu}{2}(pm+pu) + \frac{ld}{6}(2 \times pm+pd) \right\} \times L_0$

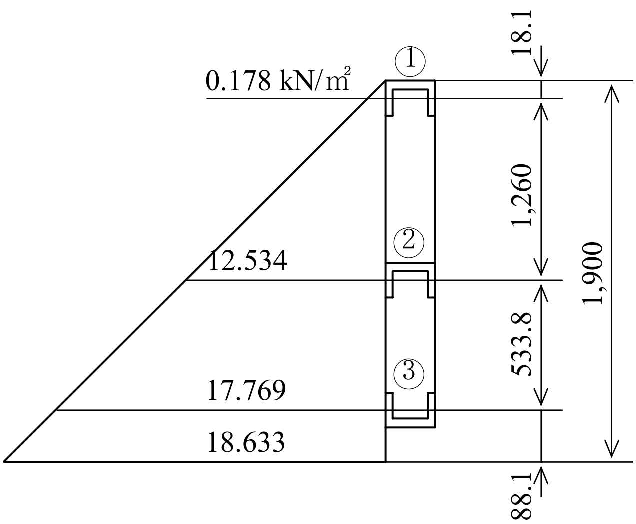
Distributed Load on Middle Plate Girder $P = \left\{ \frac{lu}{6}(2 \times pm+pu) + \frac{ld}{6}(2 \times pm+pd) \right\} \times L_0$

Distributed Load on Lower Plate Girder $P = \left\{ \frac{lu}{6}(2 \times pm+pu) + \frac{ld}{2}(pm+pd) \right\} \times L_0$

P : Distributed Load
lu : Distance from center of gravity to upper plate girder
ld : Distance from center of gravity to lower plate girder
pm : Mean water pressure at center of gravity of girder
pu : Upper mean water pressure from center of gravity of girder
pd : Lower mean water pressure from center of gravity of girder

		<1>	<2>	<3>	
Mean Water Pressure p (kN/m²)	0.000	0.178	12.534	17.769	18.633
Distance l (m)	0.0181	1.2600	0.5338	0.0881	
Distributed Load P (kN)		3.792	12.758	8.233	

Calculation is carried out for the plate girder <2>, which has the maximum load.



4) Sectional Character of Girder

I) Sectional Area

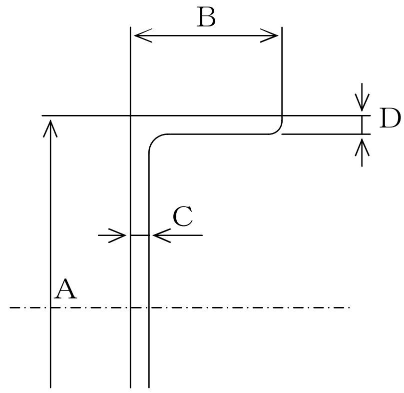
Type of steel
A × B × C × D

CH 130×65×6.0×6.0

Material
SUS304

Corrosion margin (F)

One side 0.00 cm



II) Moment of Inertia

I : Moment of inertia (cm^4)
B_2: B−(2×F) = 6.50 cm
H_2: A−(2×F) = 13.00 cm
B_1: B_2−(C−2×F) = 5.90 cm
H_1: H_2−2×(D−2×F) = 11.80 cm

$$I = \frac{1}{12} \times (B_2 \times H_2^3 - B_1 \times H_1^3)$$

$$= \frac{1}{12} \times (6.50 \times 13.00^3 - 5.90 \times 11.80^3)$$

$$= 382.2 \ cm^4$$

III) Modulus of Section

Z : Modulus of Section (cm^3)

$$Z = \frac{2 \times I}{H2}$$

$$= \frac{2 \times 382.2}{13.00}$$

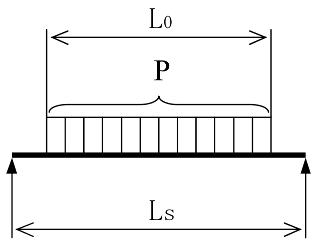
$$= 58.8 \ cm^3$$

5) Strength of Girder

I) Bending Moment

M : Bending Moment (N-mm)
P : Maximum Load = 12,758 N
L_0 : Loading Width = 1,400 mm
L_s : Width of Gate = 1,560 mm

$$M = \frac{1}{8} \times P \times (2 \times L_s - L_0)$$



$$= \frac{1}{8} \times 12{,}758 \times (2 \times 1{,}560 - 1{,}400)$$

$$= 2{,}743{,}000 \quad \text{N-mm}$$

II) Bending Stress

σ : Bending Stress (N/mm^2)

Z : Modulus of Section = 58.8×10^3 mm^3

$$\sigma = \frac{M}{Z}$$

$$= \frac{2{,}743{,}000}{58.8 \times 10^3}$$

$$= 46.6 \quad N/mm^2 \quad < \quad 100.0 \quad N/mm^2$$ (許容応力)

III) Length of Deflection

δ : Length of deflection (mm)

E : Modulus of Elasticity = 1.93×10^5 N/mm^2

I : Moment of Inertia = 382.2×10^4 mm^4

$$\delta = \frac{P}{48 \times E \times I} \times \left(L_s^3 - \frac{L_s \times L_0^2}{2} + \frac{L_0^3}{8} \right)$$

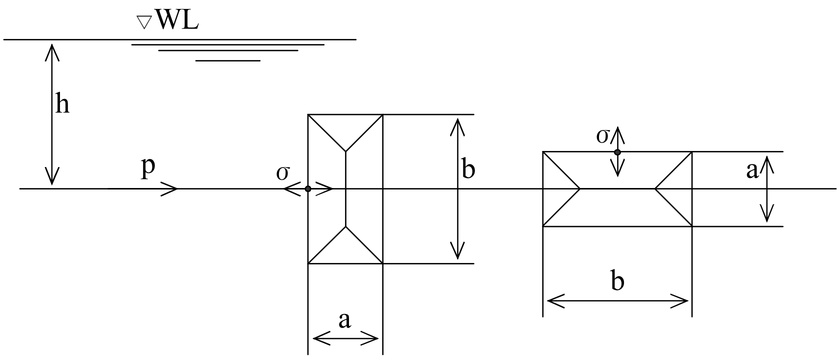
$$= \frac{12{,}758}{48 \times 1.93 \times 10^5 \times 382.2 \times 10^4} \times \left(1{,}560^3 - \frac{1{,}560 \times 1{,}400^2}{2} + \frac{1{,}400^3}{8}\right)$$

$$= 0.94 \quad mm$$

IV) Deflection

$$\frac{\delta}{L_s} = \frac{0.94}{1{,}560} = \frac{1}{1{,}658.5} < \frac{1}{600.0}$$ (Allowable deflection)

6) Strength of Skin Plate



Value of K

b／a	K
1.00	30.9
1.25	40.3
1.50	45.5
1.75	48.4
2.00	49.9
2.50	50.0
3.00	50.0
∞	50.0

σ : Stress (N/mm^2)

p : Mean Water Pressure (N/mm^2)

a : Shorter Length (mm)

b : Longer Length (mm)

K : Coefficient by b / a

T_0 : Thickness of Plate = 9.0 mm

F : Corrosion Margin = 0.0 mm (one side)

t : Effective Thickness = $T_0 - 2 \times F$ = 9.0 mm

Maximum stress at the center of longer length is

$$\sigma = \frac{1}{100} \times K \times a^2 \times \frac{p}{t^2}$$

No	a	b	b／a	K	p	σ	(Allowable Stress)
1	682.5	1195.0	1.75	48.4	0.006497	18.1	100.0
2	440.0	682.5	1.55	46.2	0.015152	16.7	100.0

7) Summary of Material

Guide Frame

Part	Shape	Dimension	Width	Length	No.	Unit Weight	Weight	Material	Painted Area
Bck side frame	CH	130 x 65 x 6 x 6		1.9000	2	11.99	45.56	SUS304	(1.976)
Front side frame	CH	130 x 65 x 6 x 6		1.9000	2	11.99	45.56	SUS304	(1.976)
Bottom	CH	125 x 65 x 6 x 8		1.4000	1	13.40	18.76	SS400	——
Bottom	CH	130 x 65 x 6 x 6		0.3000	2	11.99	7.19	SUS304	(0.312)
Bottom water sea	PL	6	0.0850	1.4000	1	47.58	5.66	SUS304	(0.238)
Bottom water sea	PL	6	0.1300	0.0660	2	47.58	0.82	SUS304	(0.034)
Side Plate	PL	6	0.2400	1.8200	2	47.58	41.57	SUS304	(1.747)
Bottom	PL	9	0.0540	0.1180	4	71.37	1.82	SUS304	(0.051)
Anchor Bar	FB	25 x 4		0.2150	16	0.79	2.72	SUS304	(0.172)
Bolt		M 16 x 45 x 38 BN2W			8	(0.17)	1.36	SS400	——
					Total Weight		171.02	kg	0.000 m^2
									(6.506) m^2

Gate Leaf

Part	Shape	Dimension	Width	Length	No.	Unit Weight	Weight	Material	Painted Area
Skin plate	PL	9	1.5400	1.8850	1	71.37	207.18	SUS304	(5.806)
Main girder	CH	130 x 65 x 6 x 6		1.5480	1	11.99	18.56	SUS304	(0.604)
Horizontal girder	CH	130 x 65 x 6 x 6		1.5480	2	11.99	37.12	SUS304	(1.207)
Side girder	CH	130 x 65 x 6 x 6		1.8300	2	11.99	43.88	SUS304	(1.427)
Vertical girder	CH	130 x 65 x 6 x 6		0.5580	1	11.99	6.69	SUS304	(0.218)
Vertical girder	CH	130 x 65 x 6 x 6		1.2540	1	11.99	15.04	SUS304	(0.489)
Bottom seal	L	65 x 65 x 6		1.3400	1	5.97	8.00	SUS304	(0.348)
Side seal	FB	40 x 6		1.8950	2	1.90	7.20	SUS304	(0.303)
Plate	PL	4	0.0400	1.8100	2	31.72	4.59	SUS304	——
Front shoe	PL	16	0.0400	0.1500	4	126.88	3.05	SUS304	(0.048)
Guide	PL	12	0.0400	0.1500	4	95.16	2.28	SUS304	(0.048)
Hanger	PL	16	0.0700	0.1000	2	126.88	1.78	SUS304	(0.028)
Bolt		M 12 x 35 x 30 BN2W			8	(0.08)	0.64	SUS304	——
Bolt		M 12 x 45 x 30 BNP2W			8	(0.09)	0.72	SUS304	——
Bolt		M 12 x 50 x 30 BNP2W			30	(0.10)	3.00	SUS304	——
Bolt		M 12 x 65 x 30 BNP2W			2	(0.11)	0.22	SUS304	——
Bolt		M 12 x 55 x 30 BNP2W			6	(0.10)	0.60	SUS304	——
Sealing rubber		L-13 rubber		1.9030	2	2.10	7.99	chloroprene	——
Sealing rubber		73 x 10		1.3400	1	0.95	1.27	chloroprene	——
Sealing rubber		63 x 9		0.0600	2	0.74	0.09	chloroprene	——
					Total Weight		369.90	kg	0.000 m^2
									(10.526) m^2

8) Details of Gate