A Study on Natural Disasters Added to the Non-Lining Tunnels of Tatsumi Waterworks*

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Abstract

The tunnels of the Tatsumi waterworks, constructed in the early Edo period, were excavated through masses of stratified solid rock without using supports.The surface of the rock inside the tunnel was covered over with a protective layer of plastic, metamorphosed rock. The top inner surface, however, had suffered from weathering in the course of years, while the flowing water had washed out the weaker part of the rock under the surface of the water. Beside, the tunnels were made so near to the surface of the earth that roots of the trees wedged into rockjoint, gradually and steadily cleaving them.

In addition, the great Kansei earthquake of 1799 had caused the waterworks a lot of damage. So, in Tempo period (1834), in order to secure more capious flow of water, tunnels were built to take the place of open channels that were more liable to damage by tumbling masses of earth and rocks down the bench-terraced slopes.

Since the tunnels have received further damage from natural disasters, it was pointed out that they were in urgent need of repair in many ways.

Four tunnelled routes leading to the Kiji intake were built about 360 years ago. No documents have yet been found to show why and when the outermost tunnel, still in use today, was reconstructed.

Presumably it has to do with repairing upon the damage done by the aforementioned earthquake. Trial calculation by terrestrial magnetism estimates the date of its construction at around the beginning of the nineteenth century, just after the earthquake.

The tunnels excavated some 360 years ago speak volumes for the then new techniques of tunnelling in the early Edo period.

1. Introduction

The Kaga clan constructed Tatsumi waterworks at clan expenses in the early Edo period. Its water was used for the fire prevention and the service water in the castle.

The waterway was composed of the new devised tunnel and the traditional open channel.

The waterway length was 7,418.6 m and the tunnel length was 3,400 m[1].

Many complicated faults and folds that grew at the geologic eras existed in the tunnel course. There are many strata in this area which are called by special name[2].

The climate in Kanazawa is subject to extreme changes. The average precipitation[3] was 2,565 mm since 1886 to 1970.This means that Kanazawa was in an area with much rain including over 80 cm snow depth. By these climate condition, Kiji intake must have suffered from great floods. The inner rock of the tunnel fell and the open channel was blockaded by tumbling masses of earth and rocks down to the bench-terraced slopes.

2. Dredging in waterway

The waterway was needed to keep the flow of water. Therefore dredging up mud on the waterway must have been done every year. The maintenance cost was paid by the feudal clan.

At early time, the inner rocks of tunnel did not fall, and the intake only or around waterway suffered from the flood. We presumed the

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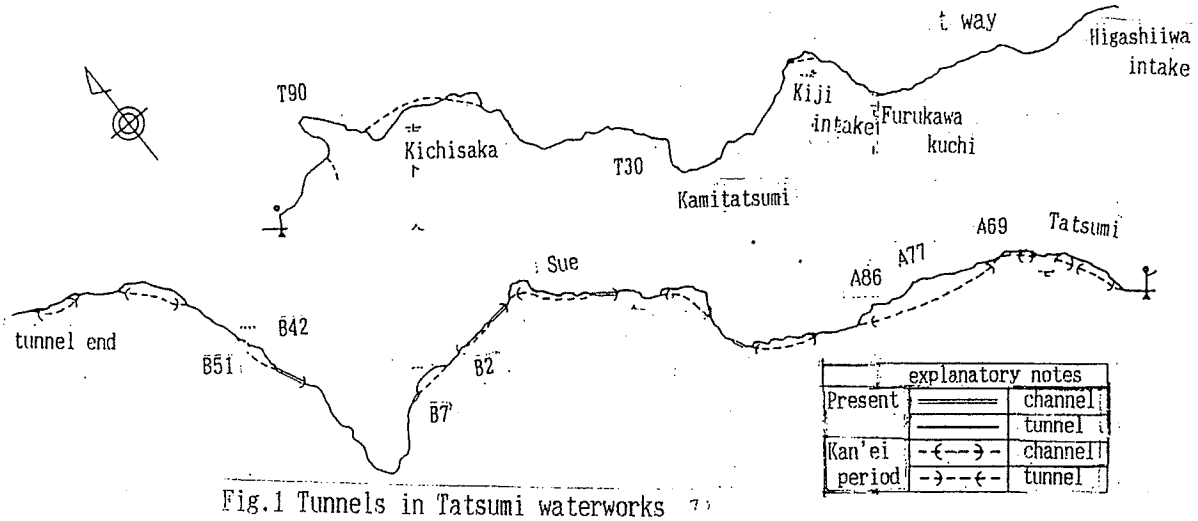

Fig.1 Tunnels in Tatsumi waterworks (1/11000)

needed overhaul workmen in the early days on the waterway.

The following letter are based on Kaisakusho Kyuki[4] (Record of the Maintenance and Control Office) which was recorded around 30 years after the completion.

I am sorry to say, dear sir;
The waterway of Tatsumi waterworks was buried by earth deposit at winter.
Following your orders,we dredge the waterway from Kiji intake to Ueno bridge every year. Especially, the waterway in the powder magazine was blockaded, so the water flowed into its warehouse site. Shall we excavate?
Please, make us dredge the waterway.

Tae Mura Gohei
Manji period 3(1660).1.25
Dear Mr. Sirobei Takebe and
Mr. Hikobei Tiaki

This is an application letter to a Magistrate sent by a farmer[5].
Next letter was sent next year(Kanbun period 1).

A receipt for wages
Total 403.75 monme with 'shufuu silver'.
It is wages for 475 heads,that is 0.85 monme per head per day.

The surface of the rock inside the tunnel was covered over with a protective layer of plastic, metamorphosed rock. However, the top inner surface had suffered from weathering in the course of years, while the flowing water had washed out the weaker part of the rock under the surface of the water.

So, in Tempo period(1834), the clan ordered to secure more capious flow of water, and tunnels were built to take the place of open channels that were more liable to damage by tumbling masses of earth and rocks down the bench-terraced slopes.

The waterway dredging cost were 69.7 yen in 1898 and 51.6 yen in 1908. Therefore the number of dredging workmen for tunnels has decreased to about 250 heads because of completion of tunnels. This value is compared with 475 heads in Kanbun priod.

3. The collapse of a waterway at the Kansei earthquake

The greatest earthquake at Kansei period (1799) occurred, and then Kiji intake, tunnels and open channels had been damaged a lot.

Jintoku Zatsuki which is one of historical materials giving an account of the roughly outline.

The most disastrous earthquake that has ever been experienced,occurred at fourteen o'clock on the 20th in May.

The Kanazawa castle and Tatsumi waterworks suffered from great damage.

The damaged parts of tunnels were three sections[5].These parts were ascertained on the inquiry in 1981. The 1st part was from A69 to A86 where the open channel on the tuffaceous

bed rock slipped down to the river bed. The 2nd part was from B2 to B7,and the3rd part was from B42 to B51.Both parts were the tunnels in the pumiceous tuff and the tuffaceous mudstone, and they were collapsed.

Those parts were reconstructed in the method of constructing a new waterway bypassing the old tunnels. Those total length was 328.6 m.

And yet, an adit on A77 was the most typical adit constructed for repairing.

4. Collapse in the plastic zone and erosion in the weaker parts

The preservative and repairing investigation for the Tatsumi waterworks were carried out in early Heisei period.

These waterways have been maintained in good condition. The rock in the tunnels is mainly composed of mudstone or tuff. Therefore mechanical weathering resistance of the rock is poor. The investigation reports said that since the rock was poor for the mechanical force or erosion by the flowing watr or some reasons, there were some transformations.

The flowing water had washed out and had scalped off the rock surface in the tunnel section.

We have evaluated that there were many places damaged by the flowing water, tear down from rockjoint, weathering and so on in the section of 1500 m out of total length. Especially in the section of about 127.3 m, the deformation was seen in all the section, or in half section from the sidewall to the top inner surface.

We took a tentative aid by collapse preventive works. The compound collapse sections is given in Table-1.

Those length increased a little more than those twenty five years ago.

Table-1 Compound collapse section

Transfiguration	Length(m)	Remarks
All section	53.8	
Left sidewall +ceiling	48.0	
Right sidewall +ceiling	25.5	
Total	127.3	

5. Compound callapse at Kiji intake[3]

We gave my opinions in the Kaga Tatsumi waterworks that the Kiji intake suffered from disasters,and the upper stream site of the waterway was transferred and rebuilt. I compared the values of the table of distances in various references with the actual mesuring results. I believe firmly that Kiji intake was transferred to Furukawakuchi by 1799.

1)According to the table of distances in the reference of Kansei period, picture scroll in the year of Bunka period 6, and picture scroll in the year of Tenpo 5, the distance from the intake to Kichizakasita is the same as the measuring data. Therefore We believe that Kiji intake was already transferred to Furukawakuchi by 1799.

2) According to Fig.3(ruins of the Kiji intake),waterways were transferred from routes A-D-E to B-F-E, and to C-F-E. Site A or B was the intake in possibility, however, site B might be an adit.

3) If site A was adit, waterways routes were transferred from B-D-E to B-F-E, and to C-F-E.

4) C waterway existed in roundabout route.

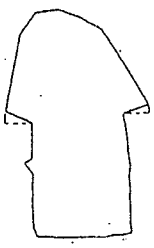

Fig.2 Quaguaversal tunnel section at T90(1/150)

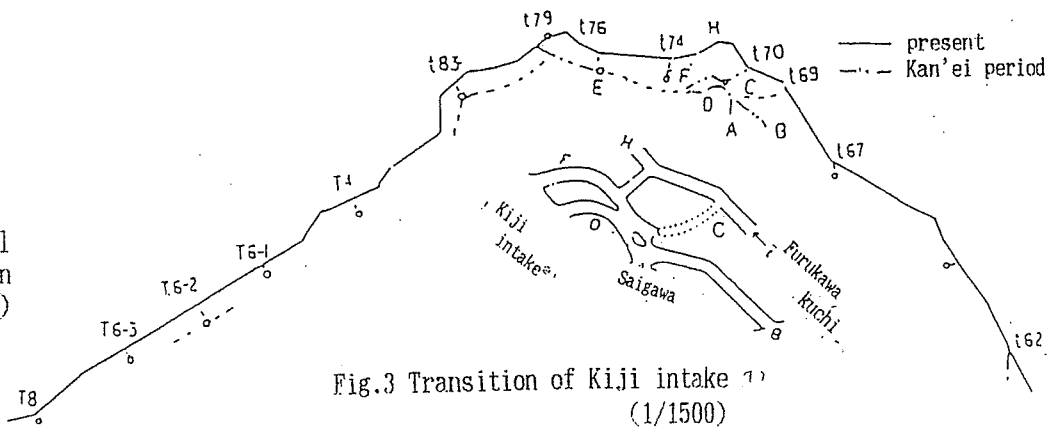

Fig.3 Transition of Kiji intake [1] (1/1500)

It is close to the present bypass tunnel where the tunnel bottom level is 0.3 m below C waterway. The tunnel bottom might be digged down in 1950.

5) Waterways D and F were not connected to E by any tunnel. This reason might be the earthquake or a cave-in due to plastic deformation just after the completion of the tunnel before the earthquake.

6. Transition of the intake from Kiji to Furukawakuchi[9]

The process which Kiji intake was transferred to Furukawakuchi is still unknown. It is probable that the intake was destroyed by the Kansei earthquake.

Today, a waterway exists as a roundabout route which make a detour of tunnel join to Kiji. That section between t69 and t79 is a detour tunnel.

On picture scroll in the year of Ansei period 2, the distance from the Higashiiwa intake was about 620 m(340ken). The value was longer than the distance to Furukawakuchi but almost the same as that to the Kiji-kami Renrakuko.

From this fact, I supposed that the tunnel had been excavated after the earthquake or in 1855(at the same time as Higashiiwa tunnel).

7. Verification based on the direction angle at adit[10]

On picture scroll in the year of Ansei period 2, the distance from the Higashiiwa intake to Kiji was inscribed. Therefore we thought the Furukawakuchi might be a temporary intake.

Trial calculation by terrestrial magnetism, the adits of the outermost tunnel around Kiji inlet and several adit in Higashiiwa tunnel, the date of its construction was estimated as the beginning of the nineteenth century, just after the earthquake.

By the same calculation method, we found that four adits in Higashiiwa tunnel were dug as a test at the same period.

Trial calculation of the terrestrial magnetism was carried out using the direction of adits in the tunnel constructed in Kan'ei priod. The computer program using BASIC language is as follows;

```
210 INPUT "number of divided direction N=
    ";N
230 AN=360/N
2010 II=5 TO 10 STEP 0.125
2030 NN=0
2040 GD=II
2100 FOR I=1 TO 22
2100 GOSUB 5500
2130 Y1=Y-GD
2140 GOSUB 5700
2150 NEXT I
2170 RESTORE 8040:REM do DATA all over
     again
2180 NEXT II
5500 REM
5530 READ S$,SN,S,S1:REM adit no.,
     line(K～K+1) azimuth angle, between line
     (K-1～K)to(K～K+1)direction angle,between
     (K- 1～K) to (adit)direction angle
5540 SN=CDEG(SN):S=CDEG(S):S1=CDEG(S1)
5550 S2=S-S1
5560 IF S2>SN THEN Y=360-(S2-SN):GOTO 5670
5570 IF (SN-S2)<180 THEN Y=180+(SN-S2):
     GOTO 5670
5580 IF (SN-S2)>=180 THEN Y=(SN-S2)-180
5670 RETURN
5700 REM
5710 IF Y1<0 THEN Y1=360+Y1
5712 IF Y1>=360 THEN Y1=Y1-360
5720 IF Y1=>357.75 THEN GOTO 7900
5730 IF Y1<=2.25 THEN GOTO 7900
5750 FOR J=1 TO N-1
5760 IF Y1>=AN*J-2.25 THEN GOTO 5770 :
     ELSE GOTO 7800
5770 IF Y1<=AN*J+2.25 THEN GOTO 7900
5780 NEXT J
7800 REM
7890 NN=NN+1
7900 RETURN
```

The allowable error in direction angle of adit center line is 1.25° at revival time and 1.0° at primary time.

The former error comes from the facts that the tunnels were excavated through masses of solid rock without using supports and had suffered from weathering while the latter graduations of a compass of those days. Therefore, an allowable total error for this program is 2.25° ～-2.25° .

8.Appllication of a trial calculation method of the terrestrial magnetism

We tried to apply this method for fifteen adits in Higashiiwa tunnels built in 1855.

Terrestrial magnetic declination was observed in Kanazawa at the same time[11]. Refering to the long term changing curve in southwestern part of Ishikawa prefecture, We estimated the declination value at 2.3° W.Applying the trial calculation method, adit No.t2,t14,t26,t44,and t51 might be excavated as a test-pit for a geological survey in the former period of Ansei.

Table-2 Numerical data within t-section

unit:dist.m;angle °

adit	added dist.	SN	S	S1
t2	37.576	289.0352	181.2628	88.5036
t4	67.304	285.3828	184.1507	91.4152
t8	95.361	277.1655	169.1524	86.0057
t11	124.185	284.4903	190.4622	93.4234
t14	151.355	284.4903	183.2140	93.2711
t17	151.355	303.1950	196.1808	84.4124
t21	214.653	336.4314	182.4926	93.0443
t26	266.985	300.0850	191.5548	94.4319
t30	297.407	295.2442	191.1541	96.3551
t34	317.561	292.5853	185.0800	100.1641
t37	347.237	306.0108	192.4606	88.3600
t42	387.635	306.0937	194.5839	97.2706
t44	410.936	298.3504	192.4307	91.4218
t47	434.291	317.3434	211.2923	100.3830
t51	463.110	310.3113	188.2222	98.0305
t63	583.0	354.5554	189.0701	89.5856
t67	619.4	352.4005	204.0205	39.5801
t74	670.5	306.0615	194.1103	88.3437
t76	685.9	317.1057	191.0439	75.1639

notes: SN,S,S1 is direction angle.

Table-3 Construction age presumed by terrestrial magnetism

unit: west deflect angle °

deflection angle(w)	number of value over allowable error
-1.125	2
-1	1
-0.875	1
-0.75	1
-0.625	1
-0.5	1
-0.375	1
-0.25	1
-0.125	0
0	0
0.125	0
0.25	0
0.375	0
0.5	0
0.625	0
0.75	0
0.875	0
1	0
1.125	0
1.25	1
1.375	1
1.5	2

9. Conclusion

The Tatsumi waterworks is one of the well-known waterwoks. Moreover, it is the most important one.

This waterway was excavated through masses of the rock without using supports. Therefore it required the perpetual and temporary repairs. This waterway has some frontier civil engineering techniques in early Edo period.

This is a cultural inheritance for the prosecution of historical and scientific studies.

However, a protective layer of plastic approached to the surface of earth, in T30 or Takizaka in Sue-machi.

Apart from an emergency repair, we hope to protect the waterway from such a critical condition and keep the waterway be at the initial condition.

References

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2)Reference 1) ; Kaga Tatsumi Waterworks,p.76

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