



EVALUATION OF ASEISMIC PERFORMANCES OF STIC AGAINST THE L2 SEISMIC MOTION AND LIQUEFACTION

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SUMMARY

STIC method (*Shield Tunnel Interfaces with Conduits*) is an equipment method to diverge some cables through the shaft conduit connecting the telecommunication tunnel and manhole and to make the telecommunication tunnels high performance and effective. The seismic performances of STIC against the L2 seismic motion and liquefaction are evaluated using some ground models.

As a result, in any case main body and the joint of shaft conduit of STIC is clarified safe against the L2 seismic motion. For examining the influence of liquefaction, two types of phenomena, ground displacement and ground subsidence, are modeled respectively. In case the ground only subsides, the calculated strain of the conduit is confirmed far smaller than the criterion. However, measures such as reinforcement in the upper part of telecommunication tunnel and improvement of expansion-contraction function of manhole joint part are necessary according to the ground condition. On the other hand, in the case of ground displacement occurring, the calculated strain of the main body reaches the limit.

In the past Nippon Telegraph and Telephone Corporation standard operation principle, STIC has been assumed to be no construction to the ground where the risk of liquefaction is high. Based on this analytical result, construction is enabled in the ground where only the liquefaction subsidence is assumed even when liquefaction is assumed. However, the construction of STIC in the ground where the occurrence of the ground displacement is assumed has been made outside similar application up to now.

INTRODUCTION

Up to now, to enable the offer of the stable service at the disaster, Nippon Telegraph and Telephone Corporation has advanced making of the telecommunication cable underground. Telecommunication tunnel is equipment to accommodate about 100 from tens of, and to defend the telecommunication cable. The function was not ruined though there was damage of some water leaks etc. at the 1995 Hyogoken-Nanbu Earthquake. STIC method is an equipment method to diverge some cables through the shaft conduit connecting the telecommunication tunnel and manhole and to make the telecommunication tunnels high performance and effective.

Nippon Telegraph and Telephone Corporation have not constructed the STIC method in the liquefaction ground in the principle in consideration of safety now. However, to clarify a more reasonable application

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ground, authors executed performance evaluation to the L2 earthquake movement, the liquefaction subsidence and the lateral flow.

1. EXAMINATION OF L2 EARTHQUAKE MOVEMENT

When the analytic model was made, we assumed the middle part of the STIC method to be a beam which had the nonlinear characteristic, the manhole joint part to be coupling which had expansion-contraction and rotational characteristic and the telecommunication tunnel joint part to be coupling which had only rotational characteristic. It was assumed that both of the characteristic of coupling were linear. Moreover, it was assumed the ground spring which had a nonlinear characteristic in each node.

(1) Analysis to L2 earthquake movement

A primary mode and a secondary mode by which the upper part of telecommunication tunnel was made a basic side for the external force setting of the L2 earthquake movement were assumed. The displacement magnitude in the ground level was set referring to the Water Service Indicator¹⁾ and the 1995 Hyogoken-Nanbu earthquake severe earthquake record. The analytical model is shown in Figure 1.1 and an analytical case is shown in Table 1.1. Only a typical case is shown here for easiness though a lot of analyses were executed.

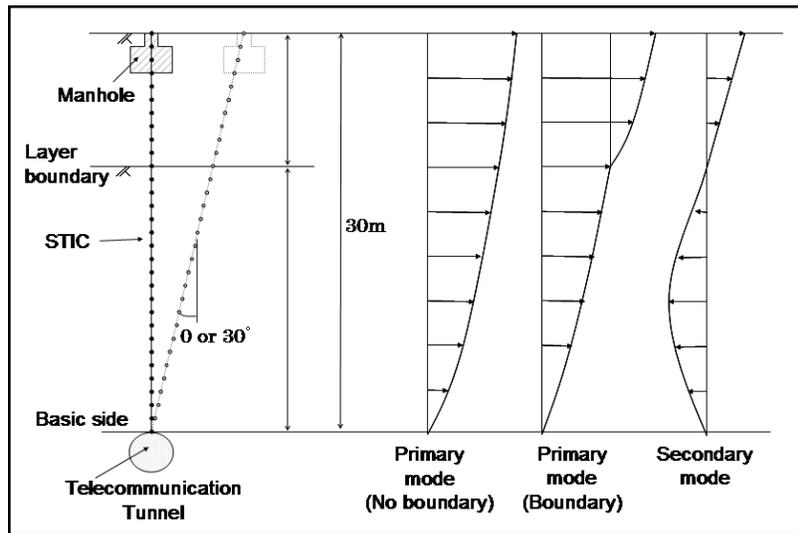


Fig 1.1 Analytical model (L2 earthquake)

Table 1.1 Analytical cases (L2 earthquake)

Case No.	Inclination of STIC	Ground condition	Earthquake movement	Displacement magnitude of ground level
1-1	0	Soft subsoil	Waterworks indicator	14.2
1-2		Upper layer : Soft subsoil Lower layer : General ground		14.2 3.0
1-3		Soft subsoil	Earthquake record	15.9
1-4	30 degrees	Soft subsoil	Waterworks indicator	14.2
1-5		Upper layer : Soft subsoil Lower layer : General ground		14.2 3.0
1-6		Soft subsoil	Earthquake record	15.9

Table 1.2 shows the result of the analysis. As for the main body of STIC, each case is following a permissible stress degree and a permissible strain. And each case with the joint has fallen below criterion. The safety of the STIC method to the L2 earthquake movement was shown from the above-mentioned result.

Table 1.2 Analytical results (L2 earthquake)

Case No.	STIC main body				Joint		
	Maximum bending stress (KN/cm ²)	Maximum shear stress (KN/cm ²)	Maximum axial stress (KN/cm ²)	Maximum strain (μ)	Manhole side expansion (cm)	Manhole side rotating angle (degree)	Tunnel side rotating angle (degree)
1-1	2.2	0.08	0	107	0.0	0.09	0
1-2	14.0	0.70	0	845	0.0	0.43	0
1-3	2.5	0.09	0	120	0.0	0.10	0
1-4	2.0	0.06	3.1	950	0.8	0.07	0
1-5	1.3	0.63	6.2	602	1.7	0.38	0
1-6	2.2	0.07	3.5	106	0.9	0.08	0

2. EXAMINATION OF LIQUEFACTION SUBSIDENCE

The analysis used and executed the expression shown in the following which had been obtained from the balancing type of power.

Displacement of main body of STIC

1) Lower layer of liquefaction layer

$$u_1(z) = -\frac{FH_1}{EA\lambda} \frac{\sinh(\lambda z)}{\cosh(\lambda H_1)}$$

2) Liquefaction layer

$$u_2(z) = \frac{F}{EA} \left\{ \frac{1}{2} z^2 - (H_1 + H_2)z + H_2 \left(H_1 + \frac{H_2}{2} \right) - \frac{H_1}{\lambda} \tanh(\lambda H_1) \right\}$$

Axial force of main body of STIC

$$0 \leq z \leq H_1 \quad N_1(z) = -\frac{FH_1}{\cosh(\lambda H_1)} \frac{\cosh(\lambda z)}{\cosh(\lambda H_1)}$$

$$H_1 \leq z \leq H_1 + H_2 \quad N_2(z) = F(z - H_1 - H_2)$$

Axial force in the upper part of telecommunication tunnel

$$N = -\frac{FH_1}{\cosh(\lambda H_1)}$$

z : Distance from telecommunication tunnel (m)
 H_1 : Thickness of liquefaction layer (m)
 H_2 : Distance from telephone-tunnel under liquefaction layer (m)
 F : Frictional force according to subsidence (N/m)
 K : Spring axially (N/m²)
 EA : Axle rigidity of main body of STIC (N)
 $\lambda = \sqrt{\frac{K}{EA}}$

To set the analytic model, we investigated telecommunication tunnel of the in existence in Tokyo and Osaka region where the liquefaction risk was high. The ground condition which seemed to be appropriate based on the investigation result was set. Because a manhole joint part was connected socket structure to have the expansion-contraction function, manhole self-respect was disregarded, and the analytic model was made (Fig 2.1). Because the calculation method of the frictional force to the shell generated by liquefaction was not established, we applied the negative friction which the Japan Railway Standard²⁾ provided. Moreover, we set the ground axially reactive force coefficient of the third layer referring to the Japan Railway Standard.

Table 2.1 shows the list of the criterion. Moreover, the list of an analytical case and an analytical result is shown in Table 2.2.

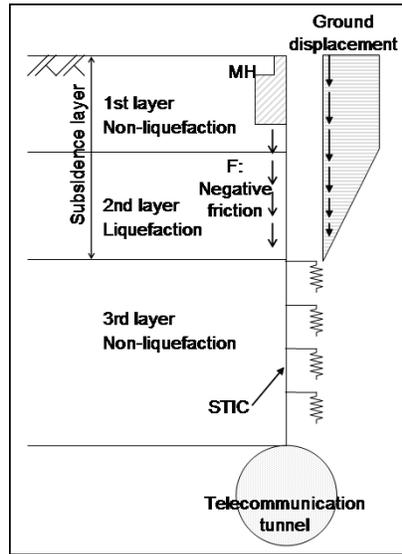


Fig 2.1 Analytical model (Liquefaction subsidence)

Table 2.1 criterion of liquefaction subsidence analysis

Permissible strain of main body of STIC (%)	Permissible relative displacement of manhole joint (pull) (cm)	Permissible relative displacement of manhole joint (push) (cm)
0.55	13.2	54.25

Table 2.2 Analytical cases and results (liquefaction subsidence)

Case No.	Surface thickness (m)	1st layer				2nd layer				3rd layer				Evaluation to the criterion			
		clay N=5 (m)		sand N=3 (m)		clay N=5 (m)		sand N=20 (m)		clay N=5 (m)		sand N=20 (m)		Strain of main body of STIC (%) *1)	Maximum Displacement of STIC (cm) *2)	Ground subsidence (cm) *3)	Tunnel side axial force (cm) *4)
2-1	25	5		3		17		-		-		O.K.	O.K.	O.K.	O.K.		
2-2				5		15		-		-		O.K.	O.K.	O.K.	O.K.		
2-3				10		10		-		-		O.K.	O.K.	O.K.	O.K.		
2-4				15		5		-		-		O.K.	O.K.	NG	NG		
2-5	15	5		3		7		-		-		O.K.	O.K.	O.K.	O.K.		
2-6				5		5		-		-		O.K.	O.K.	O.K.	O.K.		
2-7				10		0		-		-		O.K.	O.K.	O.K.	NG		
2-8	25	5		3		-		17		-		O.K.	O.K.	O.K.	O.K.		
2-9				5		-		15		-		O.K.	O.K.	O.K.	O.K.		
2-10				10		-		10		-		O.K.	O.K.	O.K.	O.K.		
2-11				15		-		5		-		O.K.	O.K.	NG	NG		
2-12	15	5		3		-		7		-		O.K.	O.K.	O.K.	O.K.		
2-13				5		-		5		-		O.K.	O.K.	O.K.	O.K.		
2-14				10		-		0		-		O.K.	O.K.	O.K.	NG		

- *1): Evaluation to the criterion (permissible strain)
- *2): Evaluation to the criterion (Permissible relative displacement (pull))
- *3): Evaluation to the criterion (Permissible relative displacement (push))
- *4): Evaluation in basic design to tolerance of telecommunication tunnel

Consideration with the each criterion is shown in the following. It was able to be confirmed that the application of STIC in the liquefaction ground was possible by considering the following appropriate measures though there was a case to exceed the criterion according to the item.

1) Main body of STIC

The safety was confirmed from falling below greatly than the criterion for the strain generated in the main body of STIC.

2) Manhole joint part

When the manhole subsides with the ground, the relative displacement of the manhole and STIC becomes about 75cm in the maximum, and exceeds tolerance (compression). For this case, it is necessary to improve the expansion and contraction function of the manhole joint part.

When the manhole surfaces by liquefaction, the amount of permissible relative displacement is very a small 13.2cm. So the surfacing prevention measures are necessary.

3) Telecommunication tunnel joint part

It is necessary to consider measures such as the ring reinforcement in the shield when assumed that this numerical value is exceeded to do a basic design to the self-respect of the main body of STIC.

3. EXAMINATION OF LATERAL FLOW

The ground condition which seemed to be more appropriate than the investigation result of Nippon Telegraph and Telephone Corporation telecommunication tunnel as well as the time of the liquefaction subsidence was set. Moreover, the lateral flow external force was set referring to the designing method of a piling basic structure that the STIC structure looked like the form (Japan Railway Standard and Road Standard³⁾). The analytic model is shown in Figure 3.1 and the list of an analytical case and the result is shown in Table 3.1. As a result of the analysis, the amount of the lateral flow of about 100cm can be endured according to the ground condition. However, the joint part with the flexural strain of the shell or the manhole arrives at the criterion for a small lateral flow within 30cm, and damage occurs in a lot of cases. The difficulty the application of STIC as well as the situation to date was reconfirmed in a ground dangerous might exert the influence on the offer of the stable service where the lateral flow occurred which was.

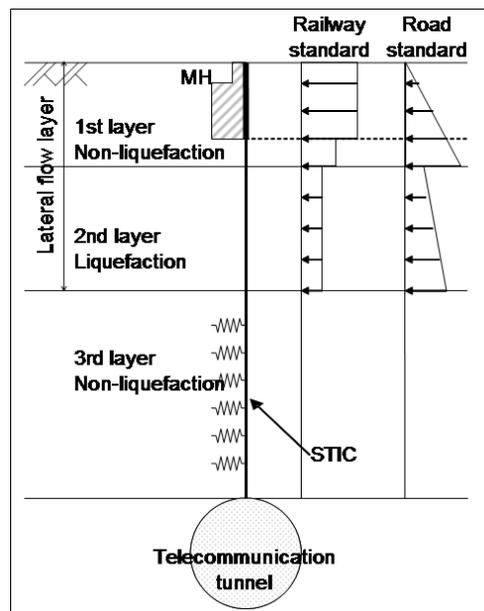


Fig 3.1 Analytical model (Liquefaction lateral flow)

Table 3.1 Analytical cases and results (liquefaction lateral flow)

Case No.	Surface thickness (m)	1st layer	2nd layer	3rd layer		Railway standard		Road standard	
		clay N=5 (m)	sand N=3 (m)	clay N=5 (m)	sand N=20 (m)	Displacement at limit (cm) *1)	Limit part *2)	Displacement at limit (cm) *1)	Limit part *2)
3-1	25	2	3	20	-	20	MH	13	MH
3-2			5	18	-	16	STIC	16	MH
3-3			10	13	-	32	STIC	34	MH
3-4		5	3	17	-	13	STIC	8	MH
3-5			5	15	-	17	STIC	13	MH
3-6			10	10	-	27	STIC	31	STIC
3-7	15	2	3	10	-	19	MH	13	MH
3-8			5	8	-	16	STIC	18	MH
3-9			10	3	-	68	MH	124	MH
3-10		5	3	7	-	14	STIC	8	MH
3-11			5	5	-	19	STIC	14	MH
3-12			10	0	-	31	STIC	98	STIC
3-13	25	5	3	-	17	7	STIC	6	MH
3-14			5	-	15	11	STIC	10	MH
3-15			10	-	10	22	STIC	25	STIC

*1): Amount of lateral flow at the criterion

*2): Part which reaches the criterion

MH: Rotating angle in manhole joint part

STIC: Permissible strain of main body of STIC

4. EXAMINATION CONCERNING EXPANSION OF APPLIED REGION

4.1 Application of STIC structure in liquefaction ground

The result of examining the application of the STIC structure to the ground subsidence and the lateral flow in the liquefaction ground is brought together.

(1) To the liquefaction subsidence

When the liquefaction subsidence is generated, the STIC structure undertakes the following influence.

- 1) The compressive force is generated in the main body of STIC.
- 2) The main body of STIC subsides for the generated compressive force.
- 3) Telecommunication tunnel undertakes the influence of the main body of STIC axial force.
- 4) The manhole subsides along with the ground subsidence.

Because the main body of STIC is not damaged by compressive strain generated in the main body of STIC, it is unquestionable. Moreover, because the settlement can be absorbed by the expansion and contraction function of a main body of STIC and manhole connected socket even if the main body of STIC subsides in the compressive force, it is unquestionable.

Measures are needed for the liquefaction subsidence according to the ground condition. In each design indicator, the necessity of the examination of the ground subsidence is described, and the amount of the ground subsidence of the thickness of the liquefaction layer is assumed to be 5%. STIC and manhole joint socket structure can absorb a manhole settlement according to the ground subsidence up to 54.25cm. Because the manhole subsides exceeding this amount of expansion and contraction when the thickness of the liquefaction layer exceeds 11m, measures are needed. The reinforcement of telecommunication tunnel is needed according to the ground condition. When a liquid lower thickness is 10m or larger than the thickness of non-liquefaction layer which exists in the lower side, reinforcement is needed from this analytical result. It is necessary to examine the expansion and contraction function reinforcement in the manhole joint part and the reinforcement of telephone-tunnel in the ground where a liquid lower thickness exceeds 10m above.

(2) To the lateral flow

The STIC structure is damaged to the lateral flow, when the ground displacement magnitude of a manhole ground level becomes the order of several ten the cm. Therefore, the STIC structure cannot be constructed in the ground where the lateral flow occurs as well as the situation to date.

It is an inclination ground and a shore protection back ground that the lateral flow occurs. The lateral flow even is confirmed in a loose inclination ground of about several percent. Moreover, it is thought that there is a possibility that the lateral flow occurs from the shore protection in the liquefaction ground within 100m for the shore protection back ground.

It is judged that the STIC structure cannot be constructed in the following region where liquefaction is forecast above.

- 1) Inclination ground
- 2) The distance from the shore protection is a ground within 100m.

In addition, it is necessary to examine even the remote situation from the shore protection by 100m or more because there is a ground where the lateral flow of several-meter order occurs, too.

4.2 Expansion of scope of STIC method

The ground where the risk of liquefaction is high is assumed outside application as a ground where the STIC structure is constructed by the Nippon Telegraph and Telephone Corporation standard execution method. The content which has been being examined at this time is brought together, and new examination flow when the STIC structure in the liquefaction ground is constructed is shown in Figure 4.1. The STIC structure cannot be constructed in the ground where the lateral flow occurs in the liquefaction ground as well as the situation to date. However, the STIC structure can be constructed in the liquefaction ground where the lateral flow does not occur by taking necessary measures for the liquefaction subsidence.

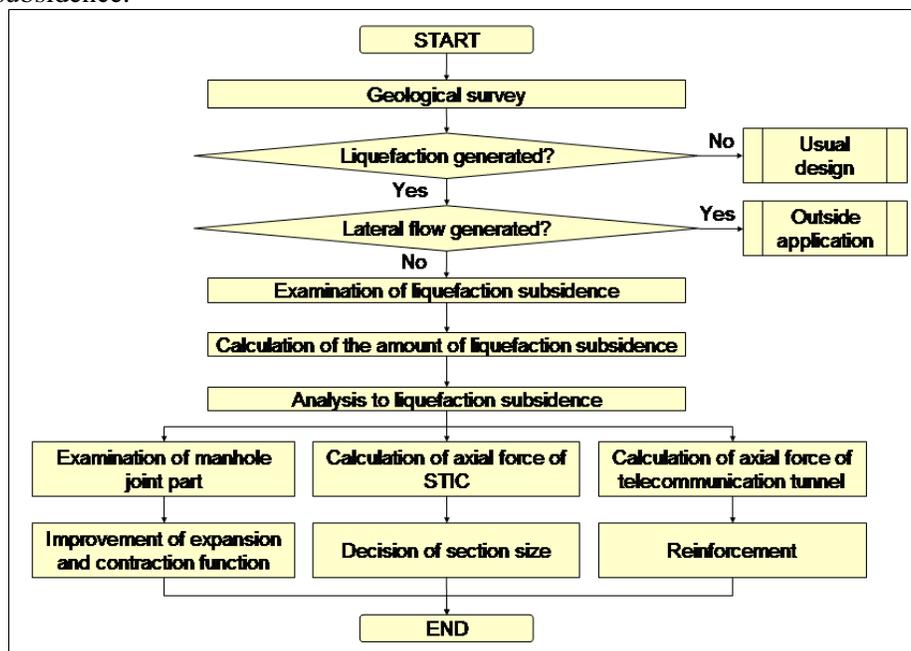


Fig 3.1 Examination flow of STIC structure in liquefaction ground

REFERENCES

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