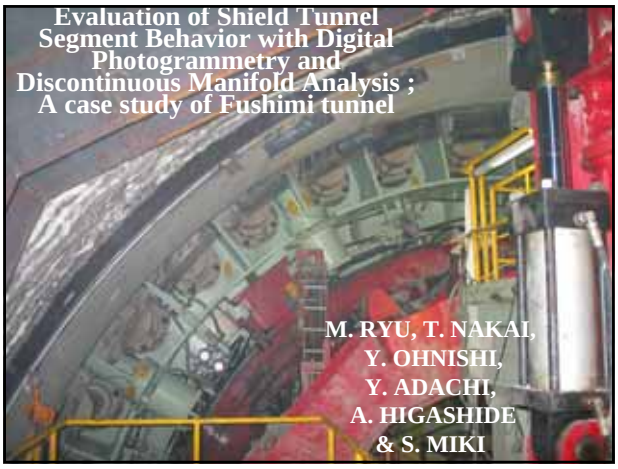
Evaluation of Shield Tunnel Segment Behavior with Digital Photogrammetry and Discontinuous Manifold Analysis ; A case study of Fushimi tunnel



M. RYU, T. NAKAI,
Y. OHNISHI,
Y. ADACHI,
A. HIGASHIDE
& S. MIKI

Contents

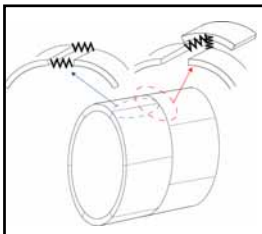
1. Target of this work

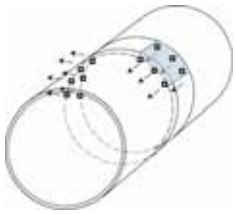
1.The Shield Tunnel is adopted in many cases in order to cope with soft ground at urban areas using segments.

2.Since the cost of segment takes from 20 to 40% of the whole cost of construction, efforts of cost reduction are required.

3.We propose application of the Manifold Method(MM) as the rational design method.

4.We also show a plan of examination for actual deformation of tunnel segment by using precise photogrammetry method at the Fushimi Tunnel now under construction.





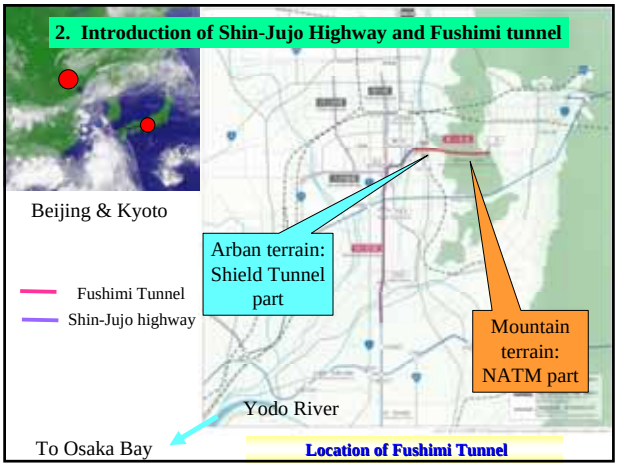
1.Segment ring consist of several hard and strong segments banded relatively weak connection.

2.The present design remains over specification in consideration of segment ring strength.

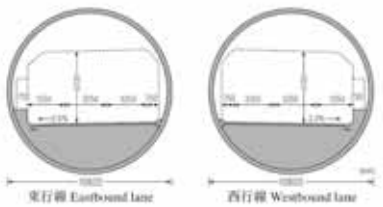
3.The MM may be able to treat the rigid body action in the weak foundation appropriately by analyzing segments as blocks.

4.Using precise photogrammetry method at the Segment ring, we expect to feed back the actual verification for applying MM analysis.

2. Introduction of Shin-Jujo Highway and Fushimi tunnel



The section of Fushimi tunnel



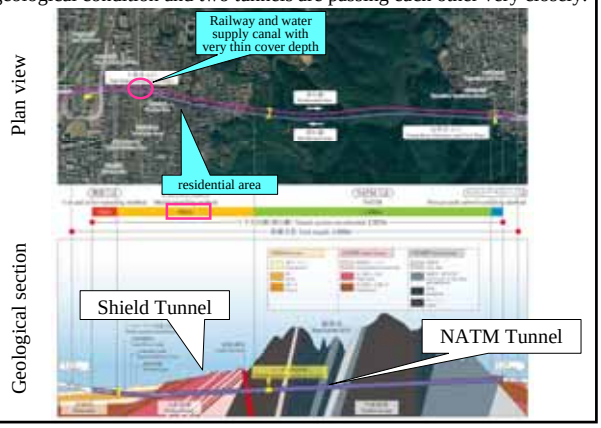
1.The length of the tunnel is 855m. (Shield part)

2.Geology consist of soil and rock.

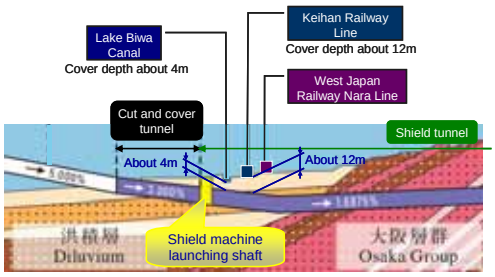
3.Tunnels cross railways and water supply canal with very thin cover depth, and excavated under high density residential area.

4.The slurry shield starts to excavate from west shaft in east direction, turns around at the huge under ground yard in rock site which was already constructed by NATM, and comes back to the arriving shaft where the machine started.

The Fushimi Tunnel is now under construction in the very complex geological condition and two tunnels are passing each other very closely.

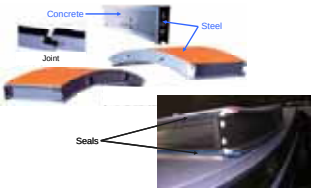


This figure shows critcal part of shield tunnel



1.The cover depth is only 4.3m at the water supply canal.
2.The cover depth is about 12m at the two railways.
3.The tunnel is planned under high density residential area required to care environment conditions.

Shield Machine & Segment

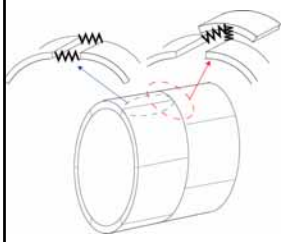


The geological condition varies from soil to hard rock including shear zone. Therefore, the machine should be designed to excavate in soil like as a slurry shield machine and to excavate in rock like as a TBM.

The Fushimi Tunnel uses composite segments which have combined advantages of compact, lightweight steel and rigid concrete. No bolts are needed, allowing efficient construction of the large-diameter of l0.82 m tunnel.

3. Analysis of Shield tunnel segment using MM

3-1 Outline of segment model



1.The rigidity of the joint portion of a segment decreases compared with material itself. Moreover, depending on the way of assembling which shifted the joint position called the Chidorigumi, rings are constructed so that a strong mutual portion may assist the weak portion of a joint where the rigid decrease.

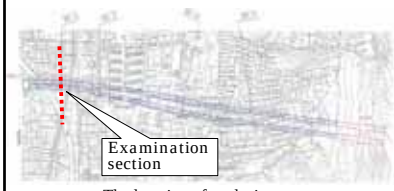
2.It becomes most important when designing a segment how the rigid decrease of a joint part.

3-2 The current status of segment ring models.

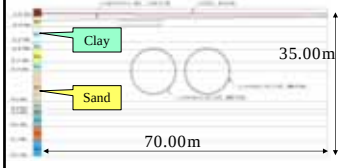
(1) Conventional method
a) Proposed around 1960 and has been used widely till the present. Structure as to be a flexural rigidity uniform ring without a segment joint.
b) Correction conventional method also proposed. In order to evaluate the rigid decrease of a joint part, the effectiveness rate η of flexural rigidity and the concept of the premium rate ζ of a moment were introduced.

(2) A segment joint is considered to be a multi-hinge system ring.
The model is calculated by making a segment joint portion into hinge structure. In this model, the moment to generate will become quite small (This model is economical but risky).

3-3 The analysis using Manifold Method (MM)



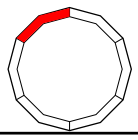
The location of analysis



Tunnel arrangement and foundation composition

Modeling of the tunnel

The segment ring was approximated by right 12 square shapes (the outer diameter of 10.6m, the inside of 10.1m).
The shield segment was taken as equal 6 division.
The modeled segment was regarded as a block divided by the discontinuities.



Material properties

Color	Material	E (kN/m²)	ν	γ (kN/m³)	C (kN/m²)	Φ (°)
	B	2.000E+04	0.45	20.0	0.00	30
	Dg1	4.000E+04	0.35	20.0	0.00	40
	Dc1	2.000E+04	0.40	20.0	100.00	0
	Dsc	2.000E+04	0.40	20.0	150.00	0
	Dsg	4.500E+04	0.35	20.0	0.00	40
	Dc2	2.000E+04	0.40	20.0	100.00	0
	Os1	8.000E+04	0.30	20.0	0.00	40
	Oc1	3.000E+04	0.40	20.0	280.00	0
	Oc2	3.000E+04	0.40	20.0	280.00	0
	Os2	8.000E+04	0.30	20.0	0.00	40
	Oc3	3.000E+04	0.40	20.0	280.00	0
	Segment	3.330E+07	0.30	27.0	0.50	

- Physical properties value

The material properties of each soil layer supposes that it is the same as prior subsidence FEM analysis also as it is shown in a table.

Young's Modulus：3.33×10^5 (0.01 times of FEM analysis) kN/m2

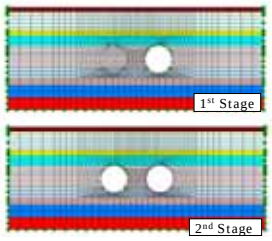
Poisson's ratio：0.3

Unit weight：27kN/m3

About the physical-properties value of joint, all cohesion set to 0.0 N/m2, and the internal friction angle was performed as follows.

Between the soil and shield segment : The internal friction angle of each soil

Between shield segments : 50 degrees



Digging of Westbound tunnel is carried out first and Eastbound tunnel after that.

3-3 Stage of analysis

The analysis flow to iteration 1500 times was performed as follows.

1～500 steps：gravity analysis

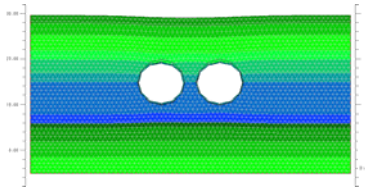
500 steps：Excavation of Westbound tunnel

600 steps：Introduce of Segment (The stress of the element of shield segment relevance part is set to 0.0, and material properties is changed into the value of segment)

1000 steps：Excavation of Eastbound tunnel

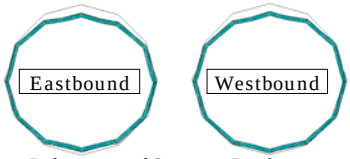
1100 steps：Introduce of Segment(The stress of the element of shield segment relevance part is set to 0.0, and material properties is changed into the value of segment)

1500 steps：End of Analysis

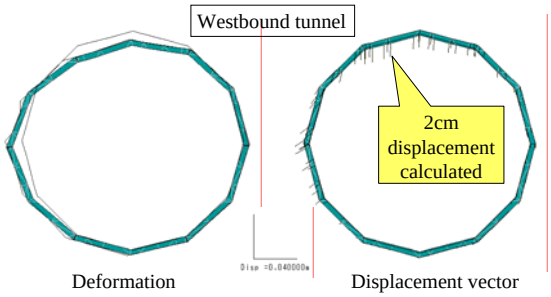


Displacement at the time of the 1500 steps on the basis of 500 steps

•In examination, we recognized the necessity to examine the stiffness value between segments.



Deformation of Segment Displacement at the time of the 1500 steps on the basis of 500 steps Displacement arrow is expanded by 10 times.



Deformation Displacement vector

Displacement vector of Westbound tunnel Displacement at the time of the 1500 steps on the basis of 1000 steps Displacement arrow is expanded by 50 times.

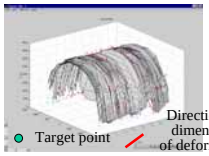
We could probe the deformation of segment as construction progresses by the MM method. Then, we decided to propose digital photogrammetry as the technique of the measurement to observe 3-D modification of segment ring.

4. Measurement of segment deformation using Digital camera Photogrammetry

Target image on CCD plane

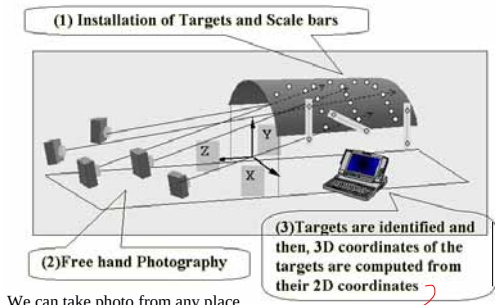
The reflective targets for precise photogrammetry was stuck on segment wall, by taking a photograph, the 3-dimensional coordinates of a target were acquired and deformation of tunnel wall was visualized.

In comparison with these actual deformation data as shown in Figure, we can verify the effectiveness of the result of MM analysis.



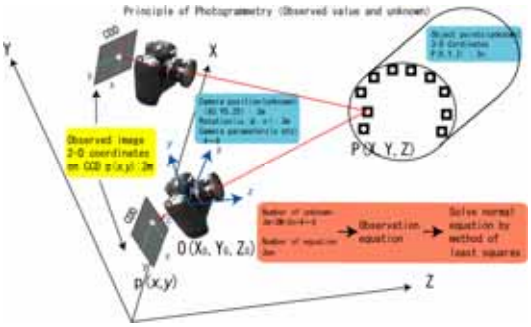
Result on 3-D coordinates of object space

The procedure for digital photogrammetry method



We can take photo from any place, any position freely.

on CCD images.



The fundamental mathematical model is a optical triangulation

It is perspective transformation from 2-D image coordinates to 3-D object space coordinates

This flow present the process by self-calibrating bundle adjustment

Object space coordinate of target

Object space coordinate of camera

General collinearity equations

$$x+\Delta x=-c\frac{a_{11}(X-X_0)+a_{12}(Y-Y_0)+a_{13}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)}$$

$$y+\Delta y=-c\frac{a_{21}(X-X_0)+a_{22}(Y-Y_0)+a_{23}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)}$$

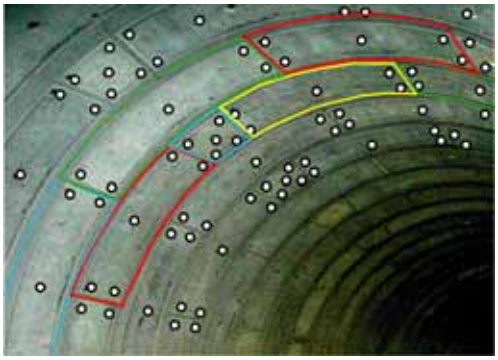
a_{ij}:Rotation Matrix of Camera

Observation equation：$L+v=Ax$

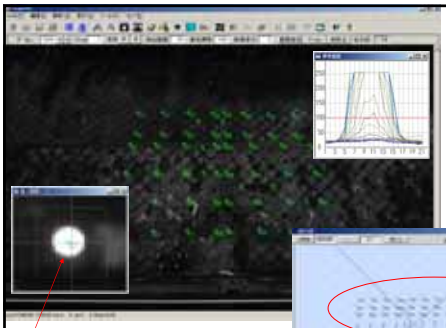
(Image coordinates+residuals=Coefficient matrix×unknowns)
(m×n) (n×1)

Use of Least Square Estimation: $v^2 \rightarrow$ *minimum*

→ Normal equation：$(A^TA)x=A^TL$



This is image chart of setting the targets on each segment.

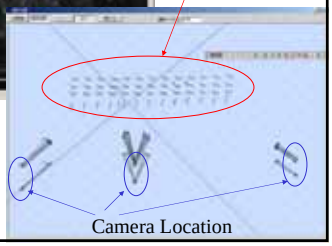


Digital image of a target

This screen is example of mesurement systm program.

Location of targets

An actual analysis computer screen



Camera Location

5. Conclusion

- We carried out a basic examination to propose the shield tunnel segment design method using MM. As a result, we recognized that the MM can treat segments as rigid blocks in soil ground appropriately.
- In examination, we also recognized the necessity to examine the stiffness value between segments.
- In order to verify the applicability of the MM, we planed the in-site observation by a photogrammetry method at Fushimi Tunnel, which is now under construction. By comparing the result of MM with actual data of displacement at Fushimi Tunnel, we expect that the result will be fed back to the determination of MM parameters such as Penalty Stiffness.

Thank you for your attention.