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A NEW MODEL FOR SIMULATING THE BEHAVIOR OF SEGMENTS IN SHIELD TUNNEL

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1. INTRODUCTION

It is significant of the design and construction of shield tunnel to understand sufficiently the characteristics of the segment, especially the linking part or joint between the two adjacent segments. Model test and prototype test are one important research way, and also numerical analysis is another way. Now, beam-spring element based on linearly elastic theory has employed to model the function of the segments and joints by most of all the researchers in Japan. This paper presents a new model, beam-joint element, to explain the mechanism of the segments and their linking parts. The new model is suitable to non-linear relation between the internal forces and deformations associated with the joint. The new model have been compared with several other models by the calculated results for designing the segments in shield tunnel.

2. DESCRIPTION OF THE MODEL

There are several different models which were used to evaluate the internal forces of lining structure in tunnel. During earlier period, beam element and node element were used to model the performances of the structure in mining and railway tunnel, and recently beam-spring element has been introduced to analyze the combination of the segment and its linking part in shield tunnel. The model, as shown in Fig.1, is composed of beam element for segment and spring element for linking part in series and is obtained from Castigliano's second theorem under the assumption of linearly elastic structure. That is to say, the responses of both the segments and their linking parts behave linearly elastic properties as loading and unloading. In fact, many experiments have shown that the internal force-deformation relationship of the linking part of the ring is non-linear , and the displacements at the two sides of adjacent segments are discontinuous, especially under the application of larger moment M shown in Fig.2.

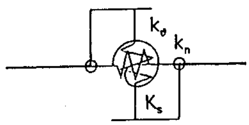


Fig.1 Beam-Spring model

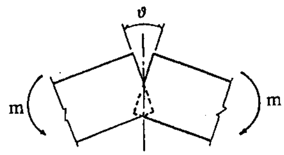


Fig.2 Discontinuous deformation

Taking account of the discontinuity of the displacements in the segments near the linking part from Fig.2, therefore, a beam-joint element will be presented. Here, we will divide the segment into straight or curved beam elements with three free variables of forces at each end, and the linking part into one-dimensional joint element which is similar to Goodman joint element in two or three dimensional problem with rotation effect.

To define the force-deformation law of joint, first, we need to take the direction of equally-divided angle between the two beams and its perpendicular one as a local coordinate system, illustrated in Fig.3 . So we have

$$\{\sigma\}=[K']\bullet\{\varepsilon\} \qquad (1)$$

in which

$$\{\sigma\}=\{\sigma_n, \tau_s, m\}^T,\ \{\varepsilon\}=\{u_1'-u_2', v_1'-v_2', \vartheta_1'-\vartheta_2'\}^T$$

$$[K']=\begin{bmatrix} k_n & & \\ & k_s & \\ & & k_\theta \end{bmatrix}$$

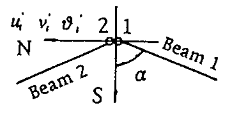


Fig.3 Beam-Joint model

where σ_n, τ_s are the forces along N and S direction in Fig.3, respectively, and m is the moment; u_i', v_i' are the displacements of nodal point 1,2, ϑ_i' is the rotation displacement.

Translating u_i', v_i', ϑ_i' into the components of displacement $\{\delta\}$ along the local coordinate directions for the adjacent beams, $\{\varepsilon\}$ becomes

$$\{\varepsilon\}=[B]\bullet\{\delta\} \qquad (2)$$

where $[B]=[T,-T^T]$,[T] is a translation matrix related to the half angle α between the two beams. Thus, we can obtain easily

$$[K_i]=[B]^T[K'][B] \qquad (3)$$

according to the variational principle. By the way, we known that this model is applicable to elastic bodies that follows a non-linear force-displacement relationship because linearity has not been invoked.

3. CASE STUDY

To demonstrate the differences between the new model and other models, we give an example about a shield tunnel buried in clay soil. The parameters of segment are: $E=1.7\times10^6Kg/cm^2$,$I=3.48\times10^4cm^4$, $A=282.8cm^2$, $R_C=530cm$, the stiffnesses of linking part are[1]: $K_n=3.0\times10^6Kg/cm$, $K_s=1.0\times10^5Kg/cm$, $K_\vartheta=2.5\times10^8Kg\bullet cm/rad$, and the coefficient of reaction force of ground is $0.3Kg/cm^3$. The loading condition and calculating sketch are illustrated by Fig.4.

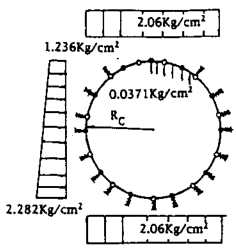


Fig.4 Loading condition and calculating sketch

The rotation displacement curve around segment is expressed in Fig.5. We have found that the value of the rotation displacement ϑ from the beam-joint element model is located between the beam element and the beam-spring element model, and a jumping variation takes place at every linking part. The same phenomenon for the displacements in the direction of coordinate axes also occurs, but the degree of the jumping is not so serious. The internal forces of the segment are given in Fig.6 for some different element models. They have no so great change in size between the beam-spring element and the beam-joint element.

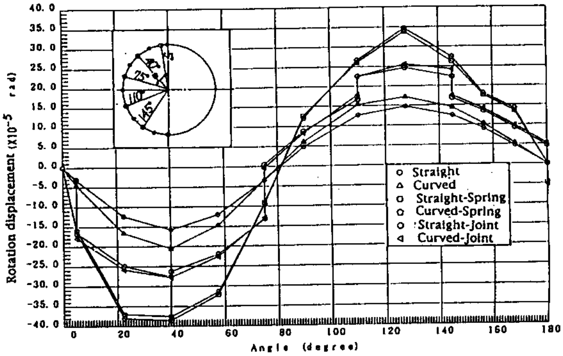
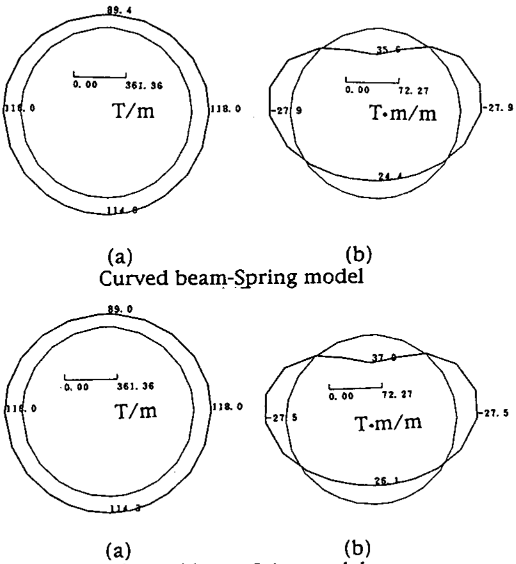


Fig.5 Rotation displacement vs angle φ



(a) (b)
Curved beam-Spring model

(a) (b)
Curved beam-Joint model
Fig.6 Internal forces for some different models
(a) Axial force (b) Moment

4. CONCLUSION

Through the comparison by the above analysis, we have known that the new model, beam-joint element, has reflected the actual characteristics of the segment, i.e., the discontinuity of the deformation at the linking part. Furthermore, we can apply this new model to the non-linear force-displacement relation of linking part.

REFERCNCE

[1] T. Hanya, Y. Koyama, H. Kawada, Advancement of the new designing method of segment, Tunnel and Underground(in Japanese), Vol. 18, No. 6, (1987) ,PP17-26.