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FINITE ELEMENT ANALYSIS OF ANCHORAGE PERFORMANCE OF PIPE EMBEDDED IN THE CAISSON TYPE FOUNDATION SUBJECTED TO UPLIFT LOAD

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Abstract

A caisson type foundation is generally used for power transmission towers in mountainous areas. The leg of the tower, which is a steel pipe with ribs, is embedded in the cylindrical concrete structure as an anchor. Some experiments have been conducted by pulling the anchor for investigating the failure mode and ultimate capacity. It was found that the failure mode is the splitting one with cracks propagating from the pipe rib.

This paper describes the simulation of the behavior of the concrete cylinder with pullout anchors. It is impossible to simulate the propagation of splitting cracks by a pure axial symmetric analysis. Therefore, a quasi 3-dimensional alalysis using an axial symmetric geometry with the smeared crack element and the non-linear constitutive model in the circumferential direction based on fracture mechanics was carried out. The results of the simulations showed the same failure mode and load-displacement relationship compared with experimental ones. Some real size foundations, having a diameter of three to five meters, were also computed by the same numerical method, and, it was found that the bearing capacity has a clear size effect which is proportional to diameter the minus one over four power.

Key words: Finite element analysis, Splitting crack, Pull out

1 Introduction

Many reports on the method to anchor into a concrete block foundations have been published in recent years (ex. Tepfers, 1979).

The anchor method of the caisson type foundation for transmission towers uses pipes with ribs embedded into the foundation body. The main reinforcements of the caisson type foundations are arranged in the axial direction, and a few shear reinforcements are arranged around the main reinforcements in the circumferential direction, so the resistance carried by shear reinforcements can be neglected. According to previous studies, a splitting failure caused by circumferential tensile stress can be observed when an uplift load is subjected (Okuyama et al., 1986, Hironaka et al., 1995).

We proposed a new constitutive equation based on fracture mechanics that may be useful for simulation of failure mode since the footing body can be modified as mass concrete (Saito et al., 1996).

The numerical model of the anchorage based on the fracture mechanism is proposed. The bearing capacity of the anchor subjected to uplift load is simulated by a constitutive equation in terms of the crack width and tensile stress of concrete and the simulations are in good agreement with the results of existing experiments. Furthermore, the scale effect is estimated by simulating real size RC structures.

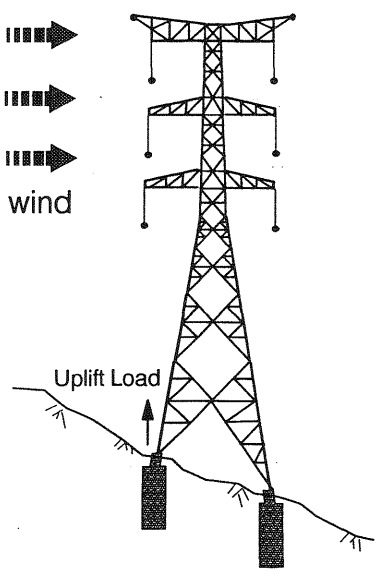


Fig. 1. Transmission tower

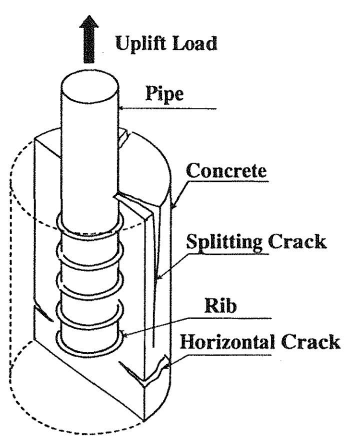
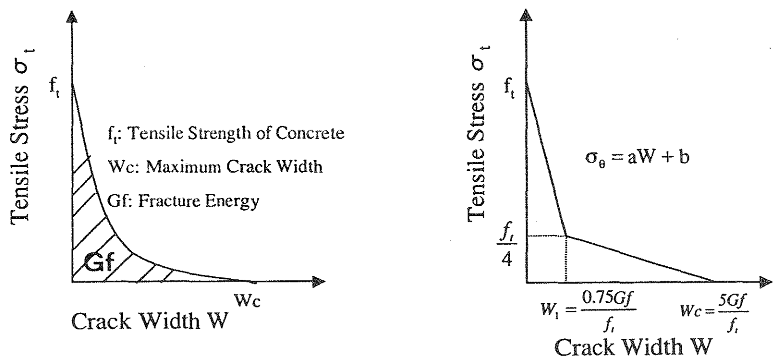


Fig. 2. Failure mode

2 Numerical method

2.1 Numerical method

It is well known that concrete does not immediately release stress after cracking but gradually releases the stress corresponding to crack width as shown in Fig. 3(a). The behavior of concrete after cracking is described by assuming that the relationship between crack width and tensile stress may be modified as the bi-linear model with tension softening curve shown in Fig. 3(b). Several splitting cracks were observed in the experiments. The number of cracks in the simulation is assumed to be four as four cracks were seen in most experiments as shown in Fig.4.



(a) General model (b) Model used in analysis

Fig. 3. Tension softening characteristics

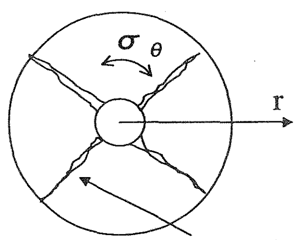


Fig. 4. Splitting cracks observed in experiments

2.2 Constitutive equation of splitting crack

The mean stress-strain relationship in the circumferential direction can be obtained by assuming that the stress of a concrete cylinder in the circumferential direction is uniform. Displacement in the circumferential direction δ_θ can be described given by Eq.(1) by the summation of the displacement by four splitting cracks' widths and the elastic displacement of concrete without cracking generated by the circumferential stress σ_θ at radius r as shown in Fig. 4.

$$\delta_\theta = nw + \frac{\sigma_\theta}{E} 2\pi r \quad (1)$$

where, n: number of cracks, E: Young's modulus of concrete, w: crack width. Therefore, the mean strain is given by:

$$\bar{\varepsilon}_\theta = \frac{\delta_\theta}{2\pi r} = \frac{nw + \frac{\sigma_\theta}{E} 2\pi r}{2\pi r} \quad (2)$$

The tension softening curve is assumed as the model which consists of two linear segments. Therefore, each segment is described as:

$$\sigma_\theta = aw + b \quad (3)$$

The mean stress-strain relationship in the circumferential direction is obtained by using Eq.(2)and Eq.(3). The mean stress σ_θ can be obtained from Eq.(4) as:

$$\bar{\sigma}_\theta = \frac{1}{\frac{n}{2\pi a r} + \frac{1}{E}} \left(\bar{\varepsilon}_\theta + \frac{nb}{2\pi a r} \right) \quad (4)$$

The mean stress-strain relationship in the circumferential direction corresponding to Fig. 3(b) is obtained as the tri-linear curve shown in Fig. 5 using above Eq.(4).

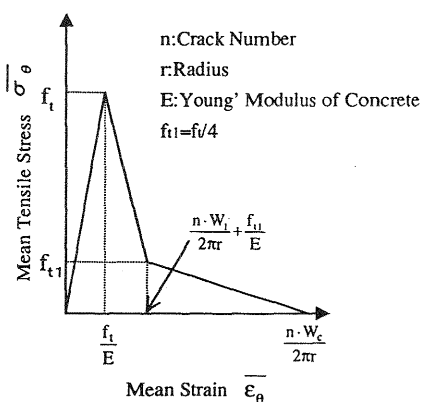


Fig. 5. Mean stress-strain model

2.3 Model

The pipe, ribs and concrete cylinder in the analysis are modeled as shown in Fig. 6 and 7. The finite element mesh is shown in Fig.8. The three-dimensional behavior of the concrete cylinder subjected to uplift load can be approximately treated with an axially symmetric model using

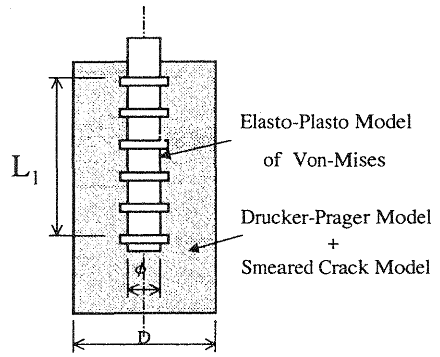


Fig. 6. Outline of foundation body

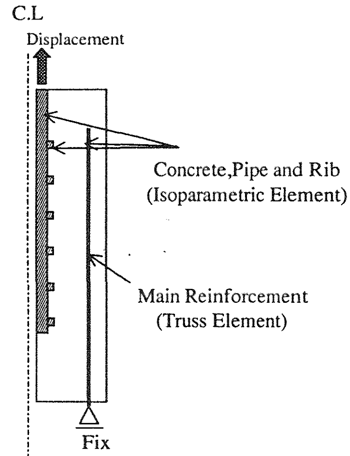


Fig. 7 Element and boundary condition used in analysis

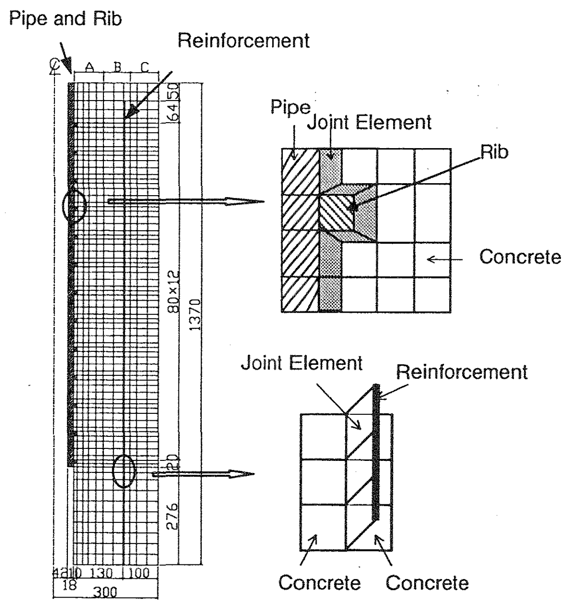


Fig.8. Finite element mesh

Table 1. Material properties of concrete

Compressive strength f 'c (kgf/cm^2)	Tensile strength f t (kgf/cm^2)	Young's modulus E (kgf/cm^2)	Fracture energy G_F(kgf/cm)
300	26.0	278,000	0.1

the mean stress-strain relationship involving splitting cracks to the circumferential direction. Shear reinforcements in the concrete cylinder is neglected because few reinforcements are used. An analytical model can be derived by using isoparametric elements with four nodes for pipe, ribs and concrete cylinder and truss elements for main reinforcement. The interface between pipe or rib and concrete cylinder can be modeled by joint elements considering slip at the interface. The bottom of the reinforcement is restricted and forced displacement is loaded at the top of the pipe. In order to consider the elasto-plastic deformation of pipe and ribs, elasto-plastic model based on the Von-Mises yield criterion is used. The concrete is assumed to be elastic until cracking occurs. The Drucker-Prager yield criterion is used in concrete subjected to compressive stress. Cracking is described by a smeared cracking model in this paper. Normal stiffness to splitting crack is assumed to be governed by the mean stress-strain relationship as shown in Fig. 5. Shear stiffness is assumed to decrease to one tenth of the initial stiffness after shear crack occurs. Table 1 shows the parameters of material properties of concrete.

3 Results of analysis

The ultimate bearing capacity in the analysis and experiment is shown in Table 2. The ratio of the ultimate bearing capacity in the experiment to that in the analysis ranges from 0.94 to 0.96 as shown in the table. The relationship between uplift load and displacement of Case 1 with base anchor length and Case 2 with long anchor length are shown in Fig.9. Displacement is obtained by measuring the slip of the pipe from the top of concrete cylinder. Both computed values coincided with the experimental values before horizontal tension cracking occurres. Although the computed value of Case 1 almost coincided with the experiment values after the ultimate load, the computed displacement in Case 2 is rather bigger than the experimental values after splitting cracking occures. It is seemed that both computed values may coincide with the experimental results in view of the uncertainty of the laboratory test. Fig. 10 indicates the propagation of in-plane cracking of Case1 in

Table 2. Comparison with experiments and analyses

Case No.	Pipe diameter ϕ (cm)	Cylinder Diameter D(cm)	Anchor length L_1(cm)	Ultimate bearing capacity		Pue/Pua
				Experiment Pue(tf)	Analysis Pua(tf)	
Case 1	12	60	96	160	171	0.94
Case 2	12	60	192	308	320	0.96

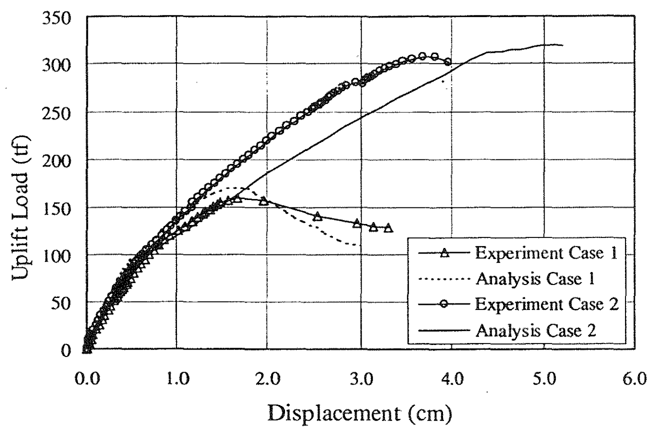
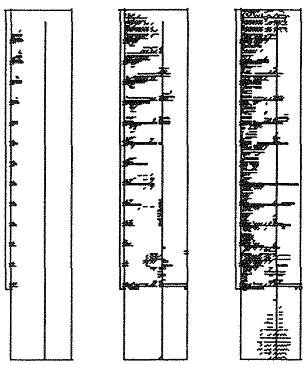


Fig. 9. Load-displacement relationship

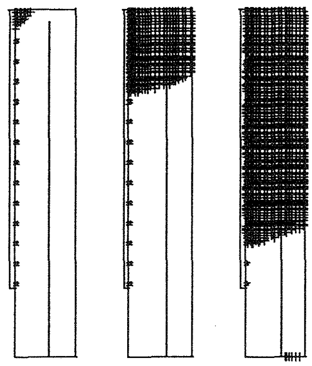
analysis. Fig. 11 indicates the propagation of splitting cracks of Case 1. Hatching in these figures indicate the occurrence of splitting cracks. The splitting cracks occure in the top of concrete cylinder not in the experiments but in the analyses as shown in Fig.11 at load 50tf. The load 170 tf is the ultimate load. The load 100 tf is intermediate between these two. The splitting crack gradually propagates downward from the top as the uplift load increases as shown in the figure. Fig. 12 shows the computed and experimental results of splitting crack propagation around the surface at each load step. From the figure, the results of crack propagation in both seem to coincide. Fig. 13 indicates the strain distribution of the pipe. The distributions of both cases seem to coincide with the experiments. Since strain gages on the pipe in the experiment are arranged between ribs, the shared load of each rib can be obtained by using the slope of the strain distribution on the pipe. The strain distribution of both the experimental and computed results in Case 2 indicates a flat shape at the upper part of the concrete cylinder. This is because that the resistance at the upper part may have disappeared.

Therefore, the simulation using the proposed method can explain the tendency of the strain distribution.



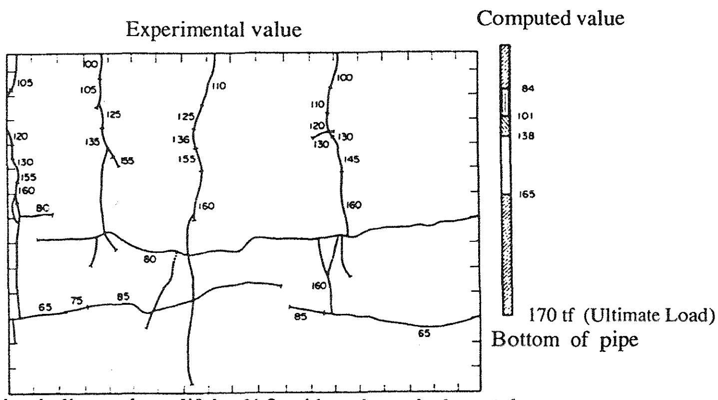
50tf 100tf 170tf

Fig .10. In-plane cracking



50tf 100tf 170tf

Fig .11. Splitting crack

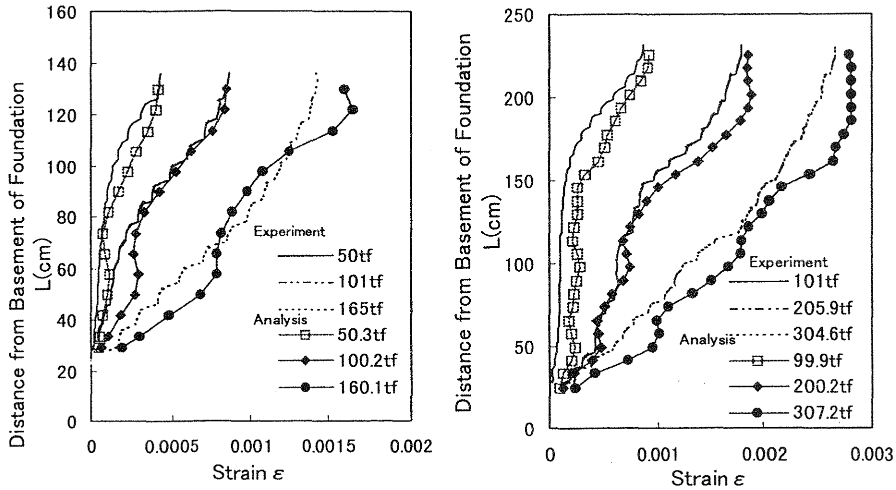


The number indicates the uplift load(tf) with each crack observed

Fig. 12. Splitting crack propagation

4 Size effect

Real size structures used in the foundation of transmission tower are simulated by the proposed numerical method and the results of analysis are compared with those of experiments. Table 3 indicates the computation results. As shown in the table, nominal anchor strength $\eta = Pua/D \cdot L_l \cdot f_t$ is assumed in order to verify the influence of size effect of the concrete cylinder. Fig.14 indicates the relationship between the size of specimen and η. η decreases as the size of concrete cylinder increases. The size effect may be thus obtained by using tension softening characteristics in the analysis and it is propotional to diameter the minus one over four power.



(a) Case 1 (b) Case 2

Fig. 13. Distribution of strain on the pipe

Table 3. Computed values

Case No.	D (cm)	L_1 (cm)	ϕ (cm)	D/ϕ	L_1/ϕ	Concrete strength (kgf/cm^2)		Pua (tf)	η
						f'c	ft		
1	60	96	12	5	8	300	26	171	1.14
2	60	192	12	5	16	300	26	320	-
3	110	72	12	9	6	300	26	206	1.00
4	300	480	60	5	8	300	26	2852	0.76

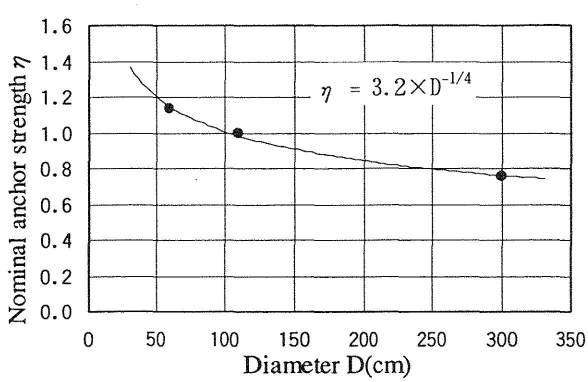


Fig. 14. Relationship between size D and nominal anchor strength η

5 Conclusion

The numerical model of the concrete based on fracture mechanics was proposed in this paper. The findings in this paper were as follows.
(1) The load-displacement relationship of existing specimens can be simulated using the proposed numerical model. Especially, the flat shape of the strain distribution on the pipe caused by the disappearance of the resistance in the upper part of the concrete cylinder can be simulated.
(2) The splitting crack gradually propagating as the uplift load increases can be simulated.
(3) The size effect of the concrete cylinder can be described by using tension softening characteristics.

6 Acknowlegments

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7 References

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