The Development of Numerical Analysis Model for Cast-In-Place Anchor Considering Interaction between Concrete and Anchor Bolt

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1. Introduction

The Cast-In-Place (CIP) anchor is widely used as fastening system to fix the mechanical and electrical equipment and piping system, etc. to concrete structure at Korean Nuclear Power Plant (NPP) and ACI 349 Code is being applied as design code for the design of the CIP anchor in Korea. But, ACI 349 Code which was revised in 2001, is only available for the anchor with diameter not exceeding 2 in. and tensile embedment not exceeding 25 in. in depth. So, ACI 349 Code can’t be applied to the design of the large sized anchors which fasten the SG, RV, RCP, and PZR, etc. in NPP.

Therefore, to investigate the application of ACI 349 Code for the design of the large sized anchor using the numerical analysis, numerical analysis model is developed on a basis of the various test data of CIP anchor in this study. Especially, interaction between concrete and anchor bolts is considered to develop the numerical analysis model.

2. Numerical analysis

2.1 Analysis model

ABAQUS 6.4-3 program is used to develop the numerical analysis model. The principal features of the numerical analysis model are that Drucker-Prager model is employed as constitutive model for concrete and the Riks method is employed as numerical solution process for nonlinear plastic problem. The elastic analysis is carried out for the anchor bolt and the square plate because their stresses exist in the elastic range under the failure load.

2.2 Verification of numerical analysis model

In order to verify the reliability of numerical analysis model which is developed in this study, the numerical analysis results are compared with various test results which were carried out previously to CIP anchor. In that case, the numerical analysis considered identically the test conditions like the dimension of CIP anchor system, material characteristics, load and boundary condition. Table 1 shows the test conditions which are considered in numerical analysis

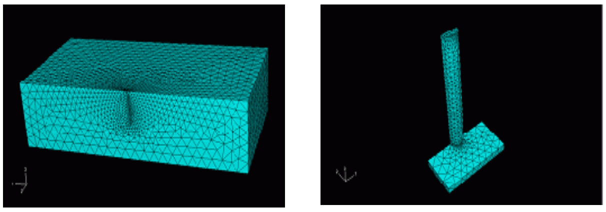
Table 1. Test conditions

Case	Load	Embedment Depth (cm)	Anchor type	Edge distance (cm)
1	Tensile load	20	Single	Center
2		20	Group	
3		30	Single	15

Table 2. Other analytical conditions

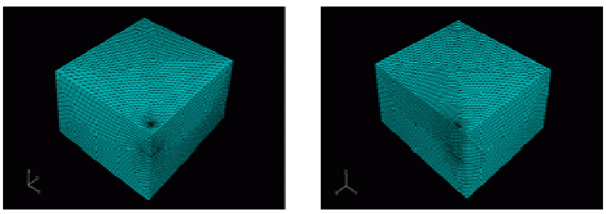
Classification		Property
Concrete	Compressive stress	280 kgf /cm^2
	Young`s modulus	274,880 kgf /cm^2
Concrete size	Case1	1.6×1.6×0.4（m）
	Case2	1.6×1.6×0.4（m）
	Case3	1.4×2.8×0.7（m）
Steel	Young`s modulus	2,142,000 kgf /cm^2

Interaction effect between concrete and anchor bolts is considered using “the contact option” of ABAQUS program. The finite separation and sliding which can occur at the interface between concrete and anchor bolts under the applied load, can be embodied by using the contact option. The semi or quarter-sectional analysis is carried out for the effective analysis. Fig. 1 and 2 show the numerical analysis model of Table 1.



(a)The whole model (b)The anchor bolt and the square plate

Figure 1. Numerical analysis model (case1)



(a)case2 (b)case3

Figure 2. Numerical analysis model (case2 and 3)

Actually, the concrete which is located in the lower part of the square plate doesn't affect the tensile capacity of CIP anchor because that concrete is separated from the square plate under the tensile load. However, it is very difficult to embody that interaction to numerical model using the existed option of ABAQUS program.

In order to exclude the interaction between concrete and square plate, "the void area" is employed in the numerical analysis model. The void area means that minor space is formed among the concrete and the lower and side part of the square plate. Fig. 3 and 4 show the numerical analysis model which the contact option and the void area are considered.

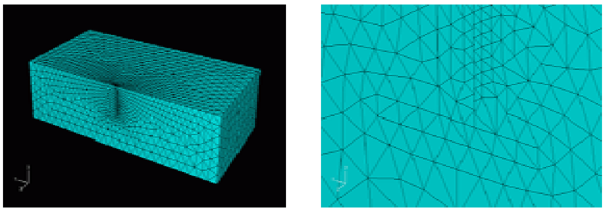


Figure 3. Numerical analysis model using contact option

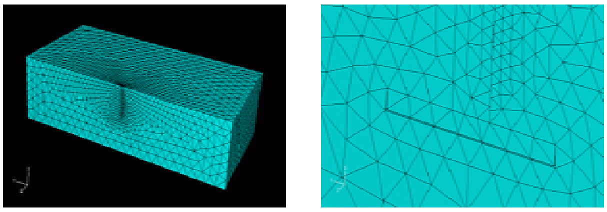
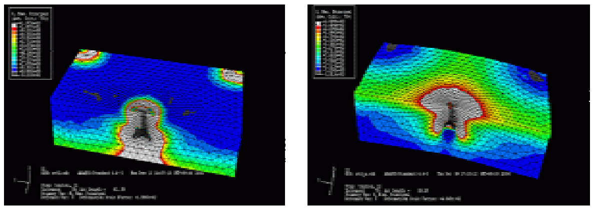


Figure 4. Numerical analysis model using the void area

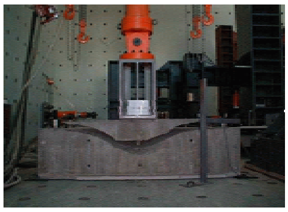
As a result, the numerical analysis model with void area expects accurately the concrete breakout strength by test and the failure shape of CIP anchor under the tensile load as shown in Table 3 and Fig. 5. On the other hand, the numerical analysis model with contact option shows the large difference with test results. Therefore, the numerical analysis model with void area can be available for evaluating the appropriateness of design code for CIP anchor.

Table 3. Comparison of concrete breakout strength

Case	Test results (tonf)	Contact		Void area	
		Results (tonf)	Difference (%)	Results (tonf)	Difference (%)
1	33.8	24.6	-27.2	34.0	0.6
2	58.4	32.3	-44.7	52.0	-11.0
3	33.4	17.9	-46.4	36.4	9.0



(a)the contact option model (b)the void area model



(c) Test result

Figure 5. Comparison of the failure shape

3. Conclusion

In order to investigate the application of ACI 349 Code for the design of the large sized anchor using the numerical analysis, the numerical analysis model is developed on a basis of the various test data of cast-in-place anchor in this study. Especially, in order to exclude the interaction between concrete and square plate, the void area is employed in the numerical analysis model.

The numerical analysis model with void area expects accurately the concrete breakout strength by test and the failure shape of CIP anchor under the tensile load and the numerical analysis model with void area can be available for evaluating the appropriateness of design code for CIP anchor.

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