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AN EVALUATION OF ACI 349 CODE FOR DESIGN OF THE FASTENING SYSTEM AT NUCLEAR POWER PLANT

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ABSTRACT

ACI 349 Code, revised on 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 anchor with diameter exceeding 2 in. and tensile embedment exceeding 25 in. in depth which fastens the SG, RV, RCP, PZR, etc. at containment building. Therefore, an application of ACI 349 Code was investigated for the design of the small and large sized anchors under tensile load using the numerical analysis model which was developed on a basis of the various test data of cast-in-place anchor in this study. In conclusion, it is proved that ACI 349 Code is available for the design of the small and large sized cast-in-place anchor.

Keywords: ACI 349 Code, Concrete breakout strength, Cast-in-place anchor, Fastening system

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 Plants (NPPs) and ACI 349 Code is being applied as design code for the design of the cast-in-place anchor in Korea. But, CCD method of CEB-FIP Code, which is being applied in Europe, pointed out that the ACI 349 Code overestimated than the real tensile and shear capacity of the anchor (Fuchs, 1995; Klingner, 1999). So, in order to improve the overestimated effect, ACI 349 Code was revised on 2001 (ACI 349, 2001).

But, the revised ACI 349 Code is only available for the design of 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 anchor with diameter exceeding 2 in. and tensile embedment exceeding 25 in. in depth which fastens the SG, RV, RCP, PZR, etc. at containment building. The relevant regulations recommend that the design approaches consistent with the test data through case-by-case review, should be adopted for the design of the large sized anchor but the relevant test data don't be satisfied all large sized anchors at NPPs (US NRC, 1996).

Therefore, an application of ACI 349 Code was investigated for the design of the small and large sized anchors using the numerical analysis model which was developed on a basis of the various test data of CIP anchor in this study.

2. ACI 349 CODE

The nominal concrete breakout strength N_{cb} of a single anchor in tension shall not exceed :

$$N_{cb} = \frac{A_N}{A_{No}} \psi_1 \psi_2 \psi_3 N_b \quad \text{(unit : lb)} \qquad \text{(Eq. 1)}$$

A_N is the projected area of the failure surface for the anchor that shall be approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward $1.5h_{ef}$ from the centerlines of the anchor, or in the case of a group of anchors, from a line through a row of adjacent anchors. A_N shall not exceed nA_{No}, where n is the number of tensioned anchors in the group. A_{No} is the projected area of the failure surface of a single anchor remote from edges.

$$A_{No} = 9h_{ef}^2 \quad \text{(unit : } in^2 \text{)} \qquad \text{(Eq. 2)}$$

The basic concrete breakout strength N_b of a single anchor in tension in cracked concrete shall not exceed :

$$N_b = k\sqrt{f_c}\, h_{ef}^{1.5} \quad \text{(unit : lb)} \qquad \text{(Eq. 3)}$$

Where $k = 24$ for CIP anchor

f_c = Compressive strength of concrete (unit : lb/in^2)

h_{ef} = Effective anchor embedment depth (unit : in.)

ψ_1 is the modification factor for eccentrically loaded anchor groups and doesn't be considered in this study.

ψ_2 is the modification factor for edge effects and obtained from Eq. 4.

$$\psi_2 = 1 \quad \text{if} \quad c_{\min} \geq 1.5h_{ef} \qquad \text{(Eq. 4.1)}$$

$$\psi_2 = 0.7 + 0.3\frac{c_{\min}}{1.5h_{ef}} \quad \text{if} \quad c_{\min} < 1.5h_{ef} \qquad \text{(Eq. 4.2)}$$

Where $c_{\min}$ is the smallest edge distance.

When an anchor is located in a region of a concrete member where analysis indicates no cracking $(f_t < f_r)$ under the load combinations with load factors taken as unity, the following modification factor shall be permitted

$$\psi_3 = 1.25 \quad \text{for CIP anchors} \qquad \text{(Eq. 5)}$$

When analysis indicates cracking under the load combinations with load factors taken as unity, ψ_3 shall be taken as 1.0 for CIP anchors.

3. NUMERICAL ANALYSIS MODEL

3.1 Numerical Analysis Model

Program MASA 3 is used to carry out the numerical analysis for evaluating the tensile capacity of CIP anchor. Program MASA 3 is aimed to be used for nonlinear three-dimensional smeared fracture finite element analysis of structures made of quasi-brittle materials (Ozbolt, 2003).

The principal features of the numerical analysis model are that the microplane model is employed as constitutive model for concrete and damage phenomena are embodied in smeared crack model. Also, in order to prevent localization of damage into a zero volume and make the analysis independent of the size and arrangement of finite elements, the localization limiter is employed and second stiffness method is employed as numerical solution process for nonlinear problem. Fig. 1 and 2 shows the stress – strain relationship of microplane model.

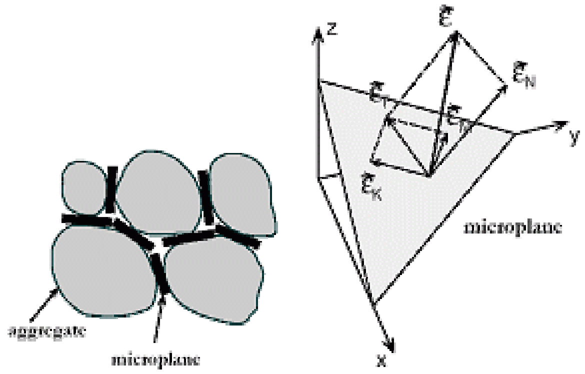
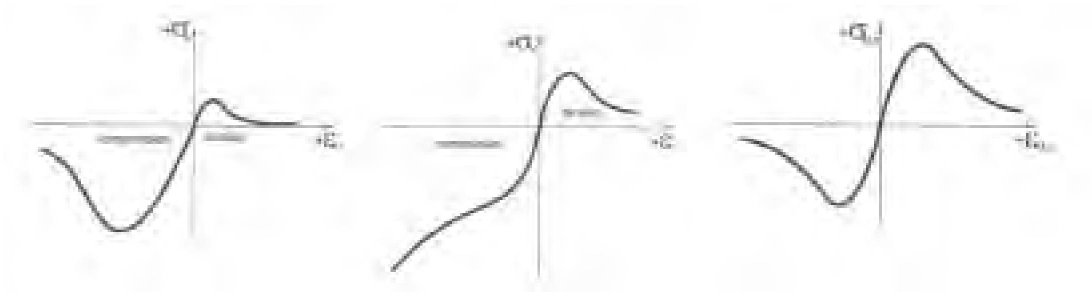


Fig. 1 Microplane Model



(a) Deviatoric part *(b) Volumetric part* *(c) Shear stress-strain*

Fig. 2 Stress – Strain Relationship of Microplane Model

3.2 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 and concrete breakout strengths by test and Fig. 3 shows the CIP anchor.

Table 1 Test Conditions

Test Condition	Load Condition	Embedment Depth (cm)	Anchor Type	Edge Distance (cm)	Concrete Breakout Strength (tonf)	Remark
1	Tension	20	Single	Center Point	33.8	
2	Tension	20	Group	Center Point	58.4	Anchor Distance:20 cm
3	Tension	30	Single	15	33.4	

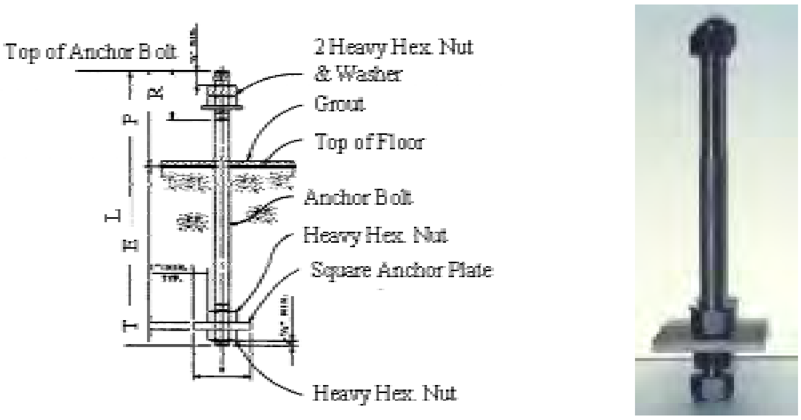
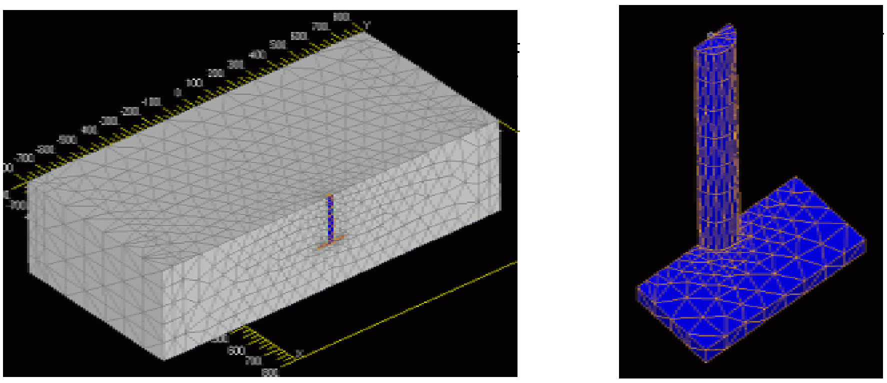


Fig. 3 Cast-In-Place Anchor

In order to model the CIP anchor for numerical analysis, 4-node solid element is used and semi-sectional analysis is carried out because every test condition is symmetric centering on the anchor bolt. Fig. 4 shows the numerical analysis model of test condition 1 in Table 1.



(a) The entire numerical analysis model (b) anchor bolt

Fig. 4 Numerical Analysis Model

As a result, numerical analysis expects accurately the concrete breakout strength by test and failure shape of CIP anchor under the tensile load as shown in Table 2 and Fig. 5. Therefore, the developed numerical analysis model can be available for evaluating the appropriateness of design code for CIP anchor.

Table 2 Comparison of Concrete Breakout Strength

Test Condition	Test Result (tonf)	Numerical Analysis Result (tonf)	Difference (%)
1	33.8	33.3	-1.5
2	58.4	55.5	-5.0
3	33.4	32.9	-1.5

4. THE EVALUATION OF DESIGN CODE

4.1 Analytical Condition

The appropriateness of ACI 349 Code is evaluated using the developed numerical analysis model for the design of CIP anchor. In order to evaluate the cases which exceed the applicable range of ACI 349 Code, the large sized anchors with diameter exceeding 2 in. and tensile embedment exceeding 25 in. in depth are considered.

Also, the analytical condition with edge effect is considered which gave a non-conservative design result before ACI 349 Code was revised on 2001. Table 3 shows all analytical conditions and Fig. 6 shows the typical numerical analysis model to carry out the numerical analysis of Table 3.

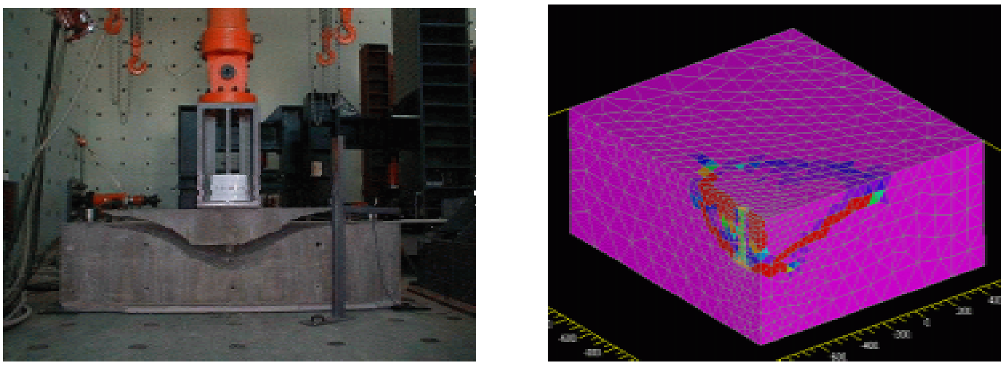
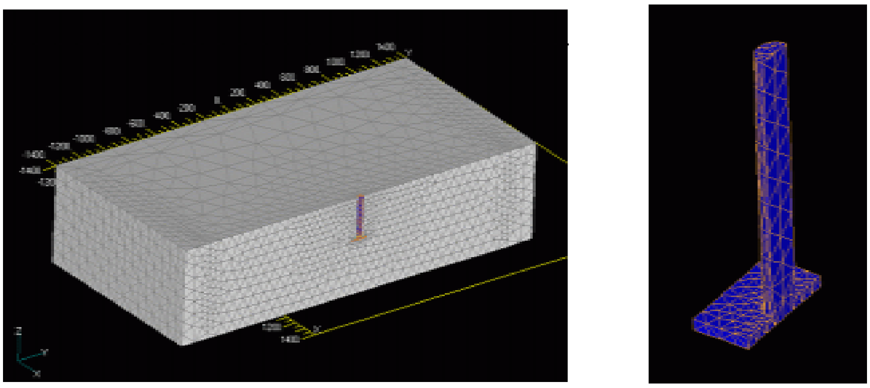


Fig. 5 Comparison of Failure Shape

Table 3 Analytical Condition

Analytical Condition	Embedment Depth (cm)	Diameter (cm)	Edge Distance (cm)	Remark
1	5	1.9	Center Point	Applicable Range of ACI 349 Code
2	10	1.9	Center Point	
3	20	2.9	Center Point	
4	30	4.1	Center Point	
5	64	7.0	Center Point	Non-applicable Range of ACI 349 Code
6	89	9.5	Center Point	
7	64	7.0	32	



(a) The entire numerical analysis model (b) anchor bolt

Fig. 6 Numerical Analysis Model

4.2 Analytical Result

Fig. 7 and 8 shows the typical failure shape of CIP anchor without and with edge effect and concrete breakout failure is occurred in all analytical conditions as expected. The numerical analysis results and design results of ACI 349 Code and CEB-FIP Code are compared at Fig. 9. As shown in Fig. 9, the design results of ACI 349 Code are in accordance with the design results of CEB-FIP Code and these design codes give the conservative results compared with the numerical analysis results. Especially, ACI 349 Code has a limitation with diameter not exceeding 2 in. and tensile embedment not exceeding 25 in. in depth but ACI 349 Code gives conservative results to analytical condition 5 ~ 7 with exceeding the applicable range. Therefore, ACI 349 Code can be applied to the design of the large sized anchors with diameter exceeding 2 in. and tensile embedment exceeding 25 in. in depth. However, the difference between result of each design code and numerical analysis result becomes large in proportion to embedment depth of anchor bolt and then the design codes have to be revised for the optimized design of nuclear power plant.

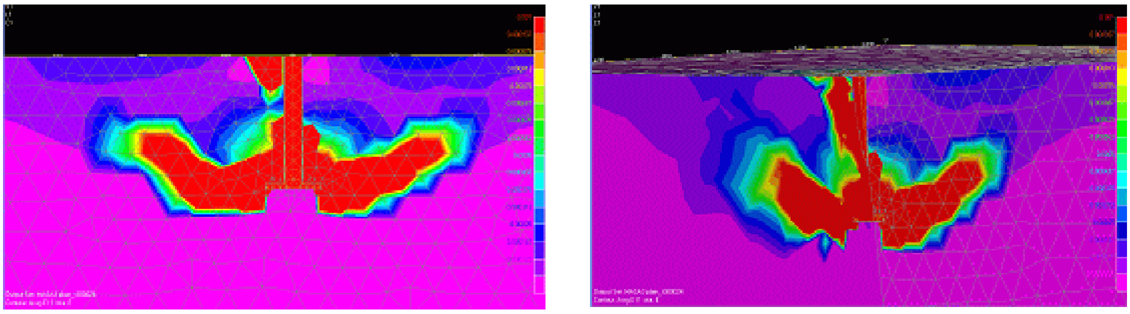


Fig. 7 The Failure Shape of CIP Anchor without Edge Effect

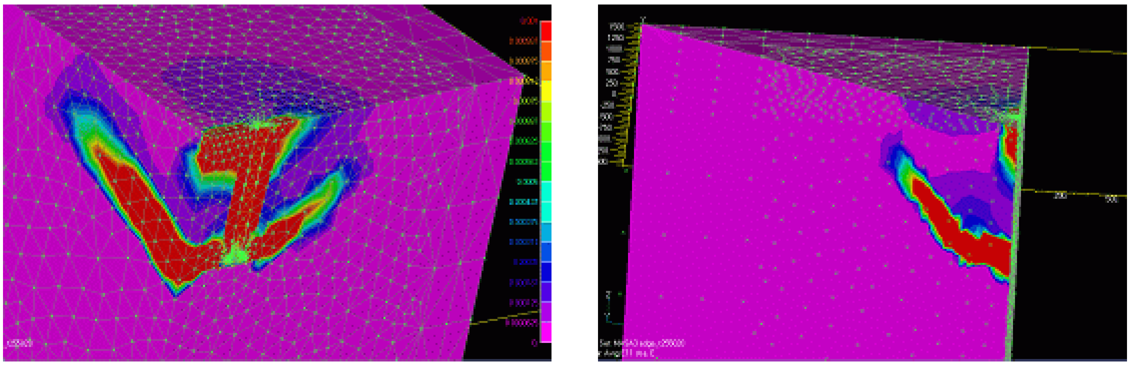
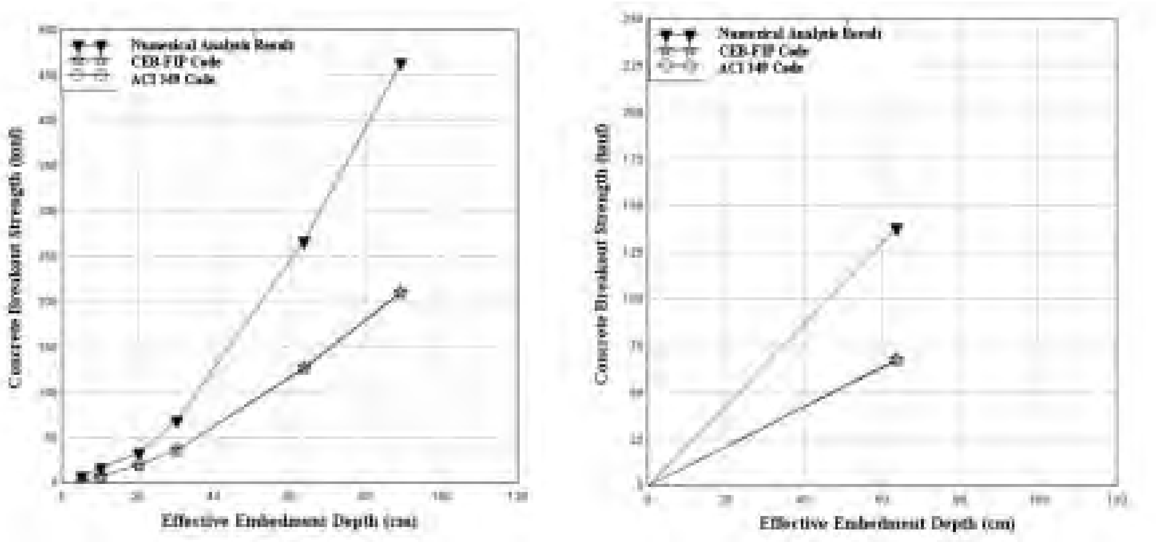


Fig. 8 The Failure Shape of CIP Anchor with Edge Effect



(a) Analytical Condition 1 – 6 (b) Analytical Condition 7

Fig. 9 Comparison of Results by Numerical Analysis and Design Codes

5. CONCLUSIONS

An application of ACI 349 Code was investigated for the design of the small and large sized anchors under tensile load using the numerical analysis model which was developed on a basis of the various test data of CIP anchor in this study. As a result, ACI 349 Code can be applied to the design of the large sized anchors with diameter exceeding 2 in. and tensile embedment exceeding 25 in. in depth. However, the difference between result of each design code and numerical analysis result becomes large in proportion to embedment depth of anchor bolt and then the design codes have to be revised for the optimized design of nuclear power plant.

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