# Estimation of Concrete Breakout Strength of Anchor for Essential Service Water Pump Using Design Code and Experiment

Gyeonghee An [a*], Junhee Park [a]
[a]*Structural and Seismic Safety Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Korea*
[*]*Corresponding author: akh425@kaeri.re.kr*

## 1. Introduction

The evaluation of seismic fragility of equipment is essential for risk assessment of nuclear power plants (NPPs). For evaluation of seismic fragility, it is necessary to identify the failure mode of the equipment and determine its median capacity and variability. The essential service water (ESW) pump is a critical component of NPPs, and its failure mode is typically concrete breakout failure of anchor. Evaluating the median capacity and variability of anchor is challenging due to the inherent uncertainty of concrete material and various conditions adapted to anchors. In this study, the concrete breakout strength in tension for ESW pump is estimated using both experimental results and the ACI 349-06 design code. The design code is used to consider conditions that were not considered in experiment. The estimated concrete breakout strength will be used for further research to analyze the seismic fragility of ESW pump.

## 2. Description of the ESW pump and Experimental Conditions

ESW pump consists of a motor(Westinghouse), a pump(Ingersoll-Dresser), and supporting anchors as shown in Fig. 1 [1]. The total weight (operating weight including motor and sea water) is approximately 21.3 ton (46.86 kip) and its natural frequency is approximately 7Hz.

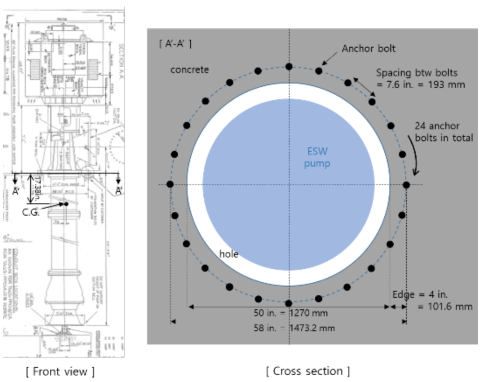


Fig. 1. Front view and cross section of ESW pump

To conduct experiments, anchor bolt and concrete with properties similar to those specified in the reference document [1] are prepared. Specifically, we used cast-in-place(CIP) anchors and concrete with a compressive strength of 27 MPa (4000 psi). However, due to the limitations of the experimental facility, it is unable to replicate the exact conditions of the actual ESW pump anchor. Table 1 summarizes the differences between the actual anchor and experimental conditions. These differences should be taken into account when interpreting the experimental results.

Table 1 Comparison of actual and experimental conditions

| Condition | ESW pump | Exp. |
|---|---|---|
| Number of anchors | 24 (Group) | 1 (Single) |
| Diameter of anchor bolt (mm) | 38 | 30 |
| Effective embedment depth (mm) | 425 | 250 |
| Distance from anchor to the edge of concrete (mm) | 101.6 | - |

## 3. Estimation of Tensile Strength of Anchor

### *3.1 Experimental Result*

The experimental result of a single anchor subjected to cyclic tension loading is shown in Fig. 2. The orange line in Fig. 2 represents the hysteretic model in OpenSees program [2]. The measured tensile strength of the anchor was 522.5 kN.

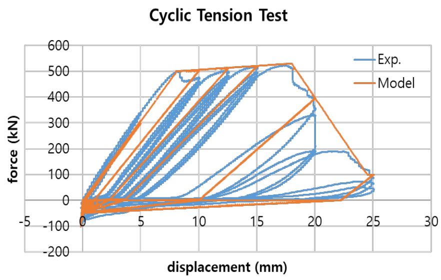


Fig. 2. Experimental result of a single anchor behavior

### *3.2 Estimation of Concrete Breakout Strength of Anchor for ESW pump*

In accordance with ACI 349-06 [3], the nominal concrete breakout strength in tension for a group of anchors shall not exceed Eq. (1).

$$N_{cbg} = \frac{A_{Nc}}{A_{Nco}} \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b \tag{1}$$

where $A_{Nc}$ is projected concrete failure area of a group of anchors, $A_{Nco}$ is projected concrete failure area of a single anchor if not limited by edge distance or spacing, $\psi_{ec,N}, \psi_{ec,N}, \psi_{ed,N}, \psi_{c,N}, \psi_{cp,N}$ are factors used to modify tensile strength of anchors, and $N_b$ is basic concrete breakout strength in tension of a single anchor in cracked concrete.

The area can be calculated as $A_{Nco} = 9h_{ef}^2$. The factor $\psi_{cp,N}$ used for post-installed anchors can be neglected herein.

The basic concrete breakout strength in tension of a single anchor in cracked concrete $N_b$ shall not exceed Eq. (2).

$$N_b = 10\sqrt{f_c{}'}h_{ef}^{1.5} \quad (2)$$

where $f_c{}'$ is specified compressive strength of concrete and $h_{ef}$ is effective embedment depth of anchor.

For $280\text{mm} \le h_{ef} \le 635\text{mm}$, $N_b$ shall not exceed Eq. (3).

$$N_b = 3.9\sqrt{f_c{}'}h_{ef}^{5/3} \quad (3)$$

The modification factor for edge effects, $\psi_{ed,N}$, can be calculated as Eq. (4) if the minimum distance from the anchor to the edge of concrete, $c_{a,min} \le 1.5h_{ef}$.

$$\psi_{ed,N} = 0.7 + 0.3\frac{c_{a,min}}{1.5h_{ef}} \quad (4)$$

Table 2 presents the strength calculated using Eq. (1) based on the conditions of the ESW pump and experimental setup. It is assumed that there is no eccentricity of the applied load and no crack in concrete.

Table 2 Calculation of concrete breakout strength in tension

| | ESW pump | Experiment |
|---|---|---|
| $N_b$ (kN) | 486.8 (by Eq. (3)) | 205.4 (by Eq. (2)) |
| $h_{ef}$ (mm) | 425 | 250 |
| $A_{Nco}$ (mm$^2$) | 1625625 | 562500 |
| $A_{Nc}$ (mm$^2$) | 3775600 | 562500 |
| $\psi_{ec,N}$ | 1 | 1 |
| $\psi_{ed,N}$ | 0.75 | 1 |
| $\psi_{c,N}$ | 1.25 | 1.25 |
| $N_{cbg}$ (kN) | 1057.0 (44.0 / EA) | 256.7 |

If the effects of embedment depth, projected failure area, and edge are considered the same as in the design code, the experimental result from section 3.1 can be adjusted based on the strength ratio of anchors in Table 2. The concrete breakout strength of each anchor in the ESW pump can be estimated as 89.6 kN.

### *3.3 Coefficient of variance*

Variability of anchor breakout strength depends on various factors, such as the type of anchor, crack condition, edge, embedment depth, etc. NUREG/CR-5563 [4] suggests coefficient of variance (COV) for anchors in six categories, as shown in Table 3. The mean values in Table 3 represent the ratios of observed to predicted concrete tensile breakout strength using concrete capacity method (CC method), which is the basis of ACI 349 code.

Table 3 Mean and COV of breakout strength in tension (uncracked concrete, static load)

| Category | mean | COV |
|---|---|---|
| Single, No edge, shallow embedment(<=188mm) | 0.981 | 0.197 |
| Single, edge, shallow embedment(<=188mm) | 1.033 | 0.271 |
| Group, No edge, shallow embedment(<=188mm) | 1.081 | 0.192 |
| Single, No edge, deep embedment(>188mm) | 1.11 | 0.189 |
| Single, edge, deep embedment(>188mm) | 1.203 | 0.173 |
| Group, no edge, deep embedment(>188mm) | 1.336 | 0.254 |

## 4. Conclusions

In conclusion, this study estimated the median capacity of the anchor for ESW pump based on both the experimental result and the design code(ACI 349). This study has some limitations due to the assumptions made in the calculations. Additionally, more research is needed to determine the variability for group anchors with an edge effect. Nevertheless, the result of this research will be useful for fragility analysis of ESW pump and risk assessment of NPPs in future studies.

## ACKNOWLEDGEMENTS

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