The Case Study on Breakout Shear Failure in Concrete related to Anchor Edge Distance In Safety-Related Equipment Seismic Fragility Analysis

Hyoungkeun Yoo[1], Sangho Jeon[2] and Jeongguk Song[3]

[1] *KEPCO-ENC, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660, yhkeun99@kepco-enc.com*
[2] *KEPCO-ENC, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660, shjeon@kepco-enc.com*
[3] *KEPCO-ENC, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660, jeongguk@kepco-enc.com*

This study covers a concrete breakout shear failure phase of equipment foundation in analysis of seismic fragility related to an edge distance from anchor center to concrete foundation edge. The over 6 inch concrete pad on bottom slab is conservatively designed to prevent the internal flood-submerged of safety-related equipment in Nuclear Power Plant. In accordance with ACI349-13, Appendix D, RD6.2 (Ref. 1), it is assumed that the foundation will be broken as to anchor edge distance when 35° failure line meets an edge of it. But, there exist a margin because it is conservatively designed. To find a margin for HCLPF capacity improvement, simulation case study of concrete foundation anchorage failure phase is performed. Therefore, to estimate minimum edge distance for the foundation not to be broken, CCD (Concrete Capacity Design) method was adapted with KEPIC MDF A193 Gr. B7(Ref. 3) material anchor to simulate concrete breakout shear failure. Determined edge distance can optimize concrete pad height not to induce concrete failure. All dimension used in analysis were assumed similar to Nuclear Power Plant for the case study. This case study result can determine the critical minimum edge distance to prevent concrete breakout shear failure of equipment foundation, which also can optimize concrete pad height realistically helpful to HCLPF improvement.

I. BACKGROUNDS

The nuclear power plant has thousands of equipment and instrument, equipment of which has concrete pad with over 6 inch height to prevent internal flood effect. Failure modes of seismic fragility analysis of equipment consist of structural integrity including anchorage failure and functionality preservation during and after SSE (Safety Shutdown Earthquake). Anchorage failure has steel failure of an anchor and concrete failure of foundation in tension and shear. According to experience of real failure mode, concrete failure is much dominant rather than steel failure. Per ACI 349-13, appendix D (Ref. 1), concrete failure is classified to concrete breakout failure in tension, concrete breakout failure in shear, pullout failure of anchor in tension, concrete side-face blowout failure in tension and concrete pryout failure in shear.

Among concrete failures in shear, the concrete breakout failure is dominated by load combination, embedment depth and edge distance from anchor center to concrete edge, etc. To prevent concrete breakout failure, it can be determined critical edge distance with other factors to influence concrete bearing strength fixed when failure starts. Also, concrete pad height can be optimized not to induce concrete breakout shear failure by determined critical edge distance.

II. OBJECTIVES

This study is to determine critical edge distance not to fail in concrete breakout in shear in non-shear reinforced concrete foundation. Among many failure modes of anchorage (Ref. 1), only concrete breakout in shear was focused on irrespective of other failure modes. Through simulated calculation, critical edge distance can be found to depend on acting loads respectively. As critical edge distance determined, failure height of concrete pad is decided according to ACI 349 – 13, Appendix D (Ref. 1) (1.5 times edge distance in direction of shear force). To get soundness of concrete pad, the height of it should be designed below the failure height. Finally, the relationship can be investigated between edge distance and concrete pad height when real loads are acting.

Consequently, the aim to improve HCLPF (High Confidence of Low Probability of Failure) capacity of seismic fragility analysis with a margin between the critical edge distance and the designed according to ACI 349 – 13, Appendix D is significant.

Existing equipment concrete foundation have sufficient margin for design, all for study are finding the margin between the designed and the evaluated in this study to improve HCLPF capacity afterwards.

III. METHODOLOGIES

To simulate ideal foundation anchorage, all dimensions are assumed realistic to Nuclear Power Plant. The case study of this analysis was performed to apply for the specific anchorage designation to improve HCLPF capacity. (Ref. 2)

This case study covers only shear phase of non-reinforced concrete foundation and need to analyze one side direction to determine critical edge distance for illustration. The analysis cases have different concrete pad height, 9 inch (case 1) and 6 inch (case 2) each. One of them is optimized for design to preserve concrete anchorage soundness.

III.A. Adapted Code and Standards

For anchor bolt material, KEPIC 2011 Addendum, MDF was used. (Ref. 3)
For calculation of concrete failure phase, ACI 349-13, Appendix D was used. (Ref. 1)

III.B. Materials

(1) Case 1
- Concrete Compressive Strength (f_c) : 5,000 psi
- Anchor Bolt Material : MDF A193 Gr. B7 (Ref. 3)
- Anchor Bolt Size (d_o) & No. of Thread per inch (n_{thread}) : 0.75 inch, n_{thread}=10
- Assumed Concrete Pad Height (H_{pad}) : 9 inch
- Assumed Anchor Bolt Embedded Length (h_{ef}) : 12 inch

(2) Case 2
- Concrete Compressive Strength (f_c) : 5,000 psi
- Anchor Bolt Material : MDF A193 Gr. B7 (Ref. 3)
- Anchor Bolt Size (d_o) & No. of Thread per inch (n_{thread}): 0.75 inch, n_{thread}=10
- Assumed Concrete Pad Height (H_{pad}) : 6 inch
- Assumed Anchor Bolt Embedded Length (h_{ef}) : 12 inch

III.C. Schematic Configuration of Foundation

4'-6" Length x 2'-6" width x 9"(6") height foundation is shown Figure 1.
Coordinates of anchor bolts are like below.

X direction: West to East,
Y direction: Vertical (down to up)
Z direction: North to South

Gravity center of foundation is like below.

X_g = 1.97 inch Y_g = 12 inch Z_g = 1 inch

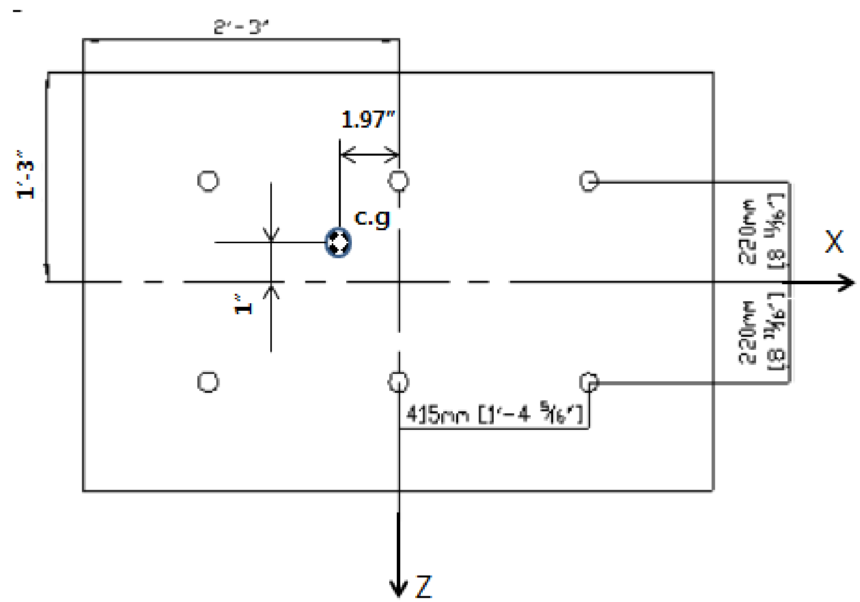

Fig. 1. Schematic Configuration of Foundation (Plan View)

III.D. Applied Loads acting on Anchor Bolts

In seismic fragility analysis, the total load is NOL (Normal Operating Load) + EQ load (Seismic Load) to find seismic margin. Assumed applied loads are like below.

F_{x_NOL} = 3.9 kips F_{y_NOL} = 2.9 kips F_{z_NOL} = 3.9 kips
F_{x_EQ} = 3.3 kips F_{y_EQ} = 3.8 kips F_{z_EQ} = 3.3 kips

M_{x_NOL} = 8.3 kips•ft M_{y_NOL} = 10.5 kips•ft M_{z_NOL} = 16 kips•ft
M_{x_EQ} = 6.9 kips•ft M_{y_EQ} = 7.3 kips•ft M_{z_EQ} = 11.7 kips•ft

III.E. Applied Equations to Determine the Critical Edge Distance

In this study, we only focus on shear resistance of concrete and failure, so shear force acting on anchor bolts is calculated. Also, x direction of shear force and resistance is analyzed.

III.E.1. Equation of Anchor Bolt Reaction

1) NOL condition

$$\text{Vx\_NOL} = \left(\frac{F_{x\_NOL}}{n} + \frac{M_{y\_NOL} \times z}{J}\right) \qquad (1)$$

Here, $J = I_x + I_y$; Torsional Constant

F_{x_NOL} : NOL Shear Force to X direction

n : Number of Anchor acted on Shear Force

M_{y_NOL} : NOL Torsional Moment

z : Length to z direction from x axis

2) EQ condition

$$Vx\_EQ = \left(\frac{F_{x\_EQ}}{n} + \frac{M_{y\_EQ} \times z}{J}\right) \qquad (2)$$

Here, $J = I_x + I_y$; Torsional Constant

F_{x_EQ} : EQ Shear Force to X direction

n : Number of Anchor acted on Shear Force

M_{y_EQ} : EQ Torsional Moment

z : Length to z direction from x axis

III.E.2. Equation of Concrete Shear Strength Evaluation (Ref. 1)

1) Conrete Breakout Strength in Shear

$$V_{cbg} = \frac{A_V}{A_{VO}} \times \varphi_{ec,V} \times \varphi_{ed,V} \times \varphi_{c,V} \times \varphi_{h,V} \times V_b \qquad (3)$$

Here, A_V : Projected Area of the failure surface on the side anchor or a group of anchors

A_{VO} : Projected area for a single anchor in a deep member with a distance from edges equal or greater than 1.5C in the direction perpendicular to the shear force

$\varphi_{ec,V}$: Factor used to modify shear strength of anchors based on eccentricity of applied loads

$\varphi_{ed,V}$: Factor used to modify shear strength of anchors based on proximity to edges of concrete member

$\varphi_{c,V}$: Concrete cracking factor

$\varphi_{h,V}$: Factor used to modify shear strength of anchors located in concrete members where Ha < 1.5C
(Ha : Thickness of Concrete Pad where the anchor is located)

2) Basic Concrete Breakout strength in Shear

$$V_b = 7 \times \left(\frac{L}{D_O}\right)^{0.2} \times \sqrt{D_O} \times \sqrt{f_c} \times C^{1.5} \qquad (4)$$

Here, L : Load bearing length of the anchor for shear

D_o : Outside diameter of anchor

f_c : Concrete compressive strength

C : Edge distance from anchor center to concrete edge in direction of shear force action

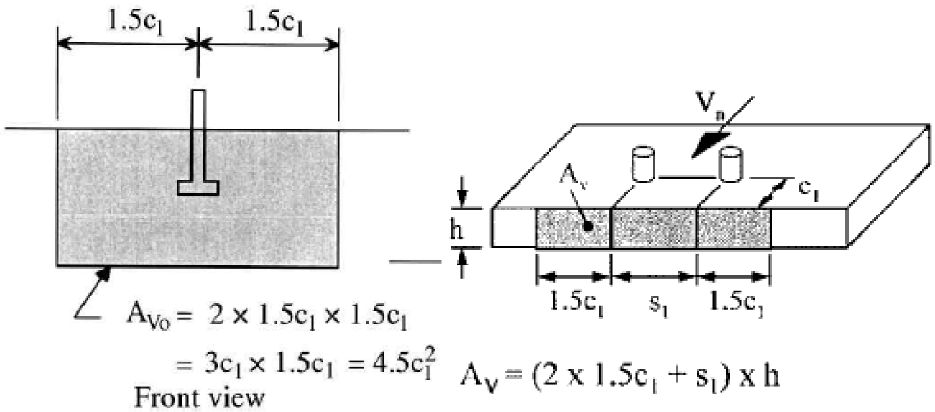

Fig. 2. Conceptional Diagram of A_{Vo} and A_V (Ref. 1)

III.E.3. Equation of Determination on Critical Edge Distance (Ref. 1)

1) Reduction factor for Non-ductile anchor

$$\rho = 0.6$$

2) Strength reduction factor for shear

$$\rho_S = 0.75$$

3) Equation to find constant critical to fail at concrete breakout

$$\frac{V_N + V_E}{X \times (\rho \cdot \rho_S \cdot V_{cbg})} = 1 \qquad (5)$$

To find X

X : Constant critical to fail at concrete breakout

V_N : Acting Shear Load of NOL (=Vx_NOL)

V_E : Acting Shear Load of EQ (=Vx_EQ)

4) Equation for determination of critical edge distance not to occur concrete break out in edge

$$\rho \cdot \rho_S \cdot V_{cbg} = X \cdot (V_N + V_E) \qquad (6)$$

5) Regression to equation (4) with found X value (Constant critical to fail at concrete breakout) to get critical edge distance (C)

Through calculation with equation (1) ~ (6), value X is found. This is critical factor for demand to be same with capacity, by which we can get C value by regression to equation (4).

The determined C value is critical edge distance when crack of a concrete breakout shear failure initiate.

III.F. Determination of Concrete Pad height based on the critical edge distance

Optimized concrete pad height with obtained critical edge distance is determined. One of case 1 and case 2 can be better option to design safe and sound. With this 35 degree failure line according to ACI 349 – 13, Appendix D (Ref. 1), better case of concrete pad height can be decided.

IV. RESULTS AND CONCLUSIONS

For case 1, the critical edge distance is calculated as 4 inch following above equations. According to ACI 349 Appendix D (Ref. 1), 1.5 times critical edge distance is failure height, which should be higher than designed concrete pad height (= 9 inch) not to induce concrete failure. In that point of view, case 1 did not satisfy the condition.

For case 2, the critical edge distance is 5.6 inch, 1.5 times of which is 8.4 inch, higher than concrete pad height (= 6 inch). This case satisfy the condition above mentioned. Summarized result is shown in table I and figure 3. As a result, critical edge distance to prevent concrete breakout shear failure can be determined by simulated case of equipment foundation, which can also optimize concrete pad height not to break in shear. But, being influenced by load combination, anchor size, embedment depth, concrete pad height and concrete compressive strength, the critical edge distance is changeable case by case of equipment. So, every single equipment has to go through analysis and evalutaion by specific calculation.

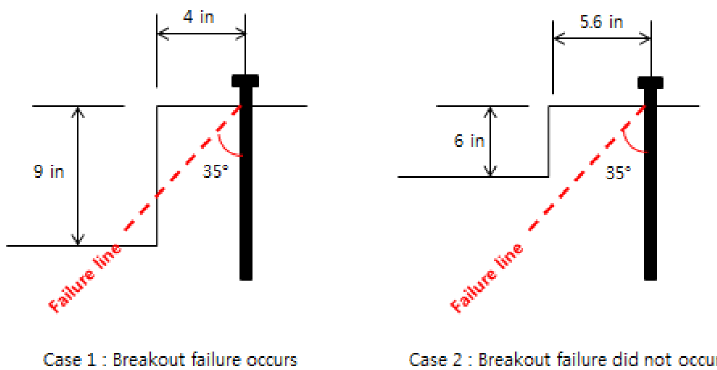

Fig. 3. Conceptional Elevation View of Case 1 and Case 2

TABLE I. Analyzed Results of Case 1 and 2

Case No.	Designed Concrete Pad height(H)	Critical Edge distance(C)	Failure height(1.5C)	Judgment
Case 1	9 inch	4 inch	6 inch	H>1.5C, N.G
Case 2	6 inch	5.6 inch	8.4 inch	H<1.5C, O.K

This case study shows there is margin between designed edge distance and realistic one. The margin dependent on edge distance become to improve HCLPF capacity of seismic fragility analysis. But, it is changeable by many variables above mentioned. The concept of seismic fragility analsysis is to simulate real state of SSCs (Structure, System and Components), also which can demonstrate HCLPF capacity improvement in case the calculation for critical edge distance is performed in advance. In this study, the margin of edge distance between design and realistic is 1.9 times, which affect 190% HCLPF capacity improvement. Furthermore, this study result might give design insight of non-shear reinforced concrete foundation anchorage. To prevent concrete breakout failure of edge of pad, case 2 result can be used and also case 1 can be adaped if pad height is designed under 6 inch conservatively. Besides case 1 and 2, there may be another failure mode which has over 35 degree of failure line from anchor center to point at which concrete pad meet the bottom slab. It would be practical forecast for engineering judegment, afterwards, this will have to be discussed and experimented.

ACKNOWLEDGMENTS

This study is supported by KEPCO – ENC Cooperation Company.

REFERENCES

1. ACI Committee 349, "Code Requirements for Nuclear Safety – Related Concrete Structures (ACI 349 – 13) and Commentary, (2013).
2. Electric Power Research Institute, "Methodology for Developing Seismic Fragilities", *TR-103959 Research Project* final Report, Palo Alto, California (1994).
3. Korea Electric Power Industry Code 2011 addendum, MDF (2011).