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Behavior of Concrete Expansion Anchors subjected to Installation Torque and Vertical Loading

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1. Introduction

Post-installed mechanical anchors in concrete are frequently used to fix systems and components such as pipelines, electric motors, tanks, chillers, power supplies and others that are important for safety in nuclear power plants.

Therefore, the structural integrity and adequate behavior of anchors are important for the proper function of systems and components fixed by them subjected to seismic loading, pipe rupture loading and other design basis or beyond design basis loadings.

Torque-controlled expansion anchor is most frequently used type of post-installed anchors, which is set by the expansion of one or more sleeves or other elements against the sides of the drilled hole through the application of torque.

A structural analysis was carried out focusing on the behavior of torque-controlled expansion anchor under installation torque and vertical tensile loading according to slip conditions between components of the anchor and loading conditions.

2. Properties and conditions for the analysis

2.1 Overview of heavy-duty sleeve anchor's behavior

A heavy-duty sleeve anchor type was chosen of torque-controlled expansion anchors for the analysis.

It is installed by drilling a hole, removing drilling dust and debris, inserting the anchor into the hole and securing it by applying a specified torque.

Once it achieves bearing against the base material, the further application of torque draws the cone at the embedded end of the anchor up into the expansion sleeve, thereby expanding the expansion elements against the side of the drilled hole.

It transfers external tensile forces to the base material via friction and, to a limited extent, via mechanical interlock in the region of the deformed concrete. As the torque is induced, it generates a pre-stressing force in the bolt which at the same time clamps the item to be fastened against the surface of the base material. After setting, tensile loading can cause additional expansion (follow-up expansion).

2.2 Load transfer mechanism due to installation torque

As applying of the installation torque, the resultant forces (torque, friction, normal and transverse forces) are induced.

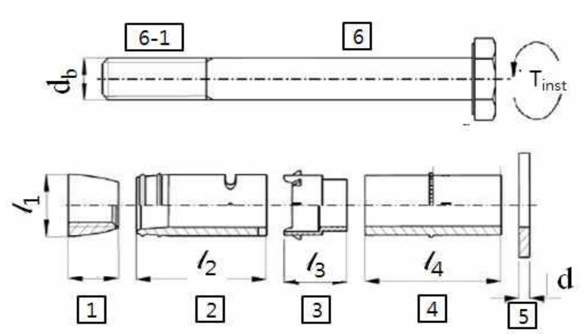

Fig. 1 Components of the anchor considered in this research

Table 1 Mechanical properties and dimensions of components

Part	Designation	f_{yk} (N/mm2)	f_{uk} (N/mm2)	L (mm)
1	Cone	-	550	31.6
2	Expansion sleeve	440	550	65.0
3	Collapsible element	-	-	39.0
4	Distance sleeve	-	690	77.0
5	Washer	-	690	4.0
6	Hexagonal bolt	640	800	-
6-1	Thread in rod	-	800	60

Components of the anchor in this research and mechanical properties and dimensions of them are described and summarized in Fig. 1 and in Table 2, respectively.

Forces are transferred from bolt to cone, cone to expansion sleeve and expansion sleeve to concrete mainly by friction on contact surfaces as described in Fig. 2. The resultant forces at the contact surfaces induced from initial torque of 400N-m of the bolt are calculated as given in Table 2

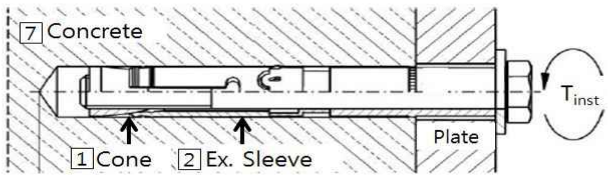

Fig. 2 Schematic diagram of the anchor-concrete contact

Table 2 Resultant forces induced due to initial torque [400N-m] [1]

Part	Contact Surface [μ_s]	T_r (N-m)	F_{nom} (kN)	F_{tran} (kN)	A_{con} (mm)
6&1	Bolt-Cone [0.16]	400	100	-	353
1&2	Cone-Ex. sleeve [0.16]	66	100	14	1232
2&7	Ex. sleeve-Conc. [0.6]	66	100	14	var.

μ_s : static friction coefficient, T_r : resultant torque,
F_{nom} : axial force, F_{tran} : radial force, A_{con} : contact area

In addition, the case is also considered that follow-up expansion is not possible when the friction resistance between the cone and the expansion sleeve is more than the friction between the cone and the expansion sleeve is less than the friction forced generated between the sleeve and the sides of the drilled hole.

Table 3 Resultant forces with the same condition in table2 except **μ**

Part	Contact Surface [μ_s]	Tr (N-m)	F_{nom} (kN)	F_{tran} (kN)	A_{con} (mm)
1&2	Cone-Ex. sleeve [0.7]	236	100	14	1232
2&7	Ex. sleeve-Conc. [0.6]	236	100	14	var.

3. Analysis and Results

3.1 Modeling of the anchor and concrete [axi-symmetry]

The components of the anchor and concrete are axi-symmetrically modeled as shown in Fig. 3.

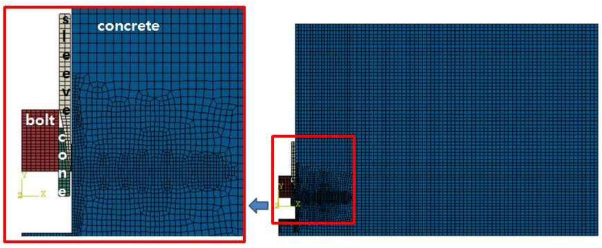

Fig. 3 FEM modeling of the anchor and concrete

The von Mises failure criterion was used for the material properties and geometries of components of the anchor were modeled based on table 1.

A damaged plasticity model was defined to simulate the material non-linearity of concrete with strain hardening and tension stiffening.

3.2 Performed analysis

The initial torque of 250kN and 400kN, with friction coefficient(**μ**) at cone to expansion sleeve contact surface of 0.16 and 0.7, were applied respectively as given in Table 4.

And then axial tension of the bolt up to 160kN were applied for each cases

Table 4 Analysis condition for each case

Case	Friction Coefficient at Cone-Ex. sleeve [μs]	Installation Torque Tr (N-m)
1	0.16	250
2	0.16	400
3	0.7	250
4	0.7	400

The mean anchor stiffness β shall be determined by Eq. (1)

$$\beta = \frac{N_{30\%} - N_{10\%}}{\Delta_{30\%} - \Delta_{10\%}} \left[\frac{kN}{mm}\right] \quad (1)$$

3.3 Results of the analysis

In order to check coupling degree between anchor and concrete, the mean anchor stiffness(β)es were checked for each cases. From the analysis result, the mean anchor stiffness were increased with higher initial torque and friction coefficient as given in Table 5.

Table 5 Analysis results for each case

Case	β (kN/mm)	Failure Mode	N_u(kN/kN) normalized
1	150	Concrete cone failure	1.00
2	1600	Concrete cone failure	0.95
3	8100	Pull-out	0.45
4	9200	Pull-out	0.75

For the cases of 1 and 2, the failure modes were 'concrete cone failure', but for the cases of 3 and 4, they were 'pull-out failure' because of the lack of follow-up expansion.

The ultimate tensile forces, normalized with the value of case1 are given in Table 5. The ultimate tensile forces of case 3 and 4 were less than those of case 1 and 2, even though the mean anchor stiffness are higher in case 3 and 4 than in case 1 and 2 due to the lack of follow-up expansion.

In the comparison of the results in case 3 and case 4, the ultimate resistance increases with higher installation torque in the pull-out failure.

4. Conclusions

Based on the analysis results, it is confirmed that follow-up expansion is only possible when the friction resistance between the cone and the expansion sleeve is less than the friction force generated between the sleeve and the sides of the drilled hole.

For the cases that the follow-up expansion does not occure, the pull-out resistance of the anchor increases with higher installation torque.

REFERENCES

[1] ACI 355.2, 2007, Evaluating the Performance of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-07) and Commentary (ACI 355.2R-07)

[2] ICC-ES : AC 193, 2012, Acceptance Criteria for Mechanical Anchors in Concrete Elements