The effect of embedment depth on the steel-to-concrete post-installed joint under cyclic loading

Yue Zhang¹, Qun Xie*¹ and Ming-Qiang Lin¹
¹ School of Civil Engineering and Architecture, University of Jinan, Jinan, Shandong, 250022, China

*Corresponding author’s e-mail: cea_xieq@ujn.edu.cn

Abstract. In this paper, ABAQUS software is used to simulate the performance of steel-to-concrete post-installed joint under cyclic loading. The failure modes for post-installed joint with different embedment depth 15 d, 20 d, and 25 d have been analyzed and compared. Hysteresis curves, stiffness degradation curves, and skeleton lines are used to evaluate the earthquake performance based on the simulation results. The conclusion can be drawn that longer embedment depth can enhance the bearing capacity, increase the ability of energy dissipation, and strengthen seismic performance of the post-installed joint.

1. Introduction
In recent years, there have been a lot of researches on the post-installed joint in the world. The anchor spacing, edge distance, shear span ratio, concrete strength and embedment depth can all affect the performance of post-installed joint. Zhang X S has conducted a cyclic loading test on three groups of full-scale models consisting of inorganic anchorage frame joints and a group of integral casting frame joints to study their seismic performance[1]. Deng Z C has studied the influence of embedment depth on the seismic performance of post-installed joint[2]. Wu L Z has conducted a seismic test for intumescent anchors, expanded anchors, and chemical anchors in crack-free concrete[3]. Zhao T S has researched on group anchors and summarized the influence of factors such as concrete thickness, reinforcement ratio and stiffness on the pull-out bearing capacity[4]. Liu S R and Zhang Q L have explored the constitutive relation of single anchor bolts through finite element software[5]. Zhang S G and Li J J have simulated the influence of margins on the basement concrete and anchor bolts by using finite element software[6]. Li Y J has analyzed the damage of anchor bolt under the action of tension by means of numerical simulation, studied its mechanical elements, and proposed the group anchor effect[7]. Delhomme F has investigated the effects of loading type (static or cyclic load), edge distance, and concrete cracking state of the concrete on the anchorage performance[8]. Burzt J L has put forward the effect of anchor spacing on the mechanical properties of anchor bolts, and the critical spacing of anchors is obtained[9]. The famous expert Kunz C J in the field of anchor bolts has concluded that spacing affects the diameter and depth of damage to concrete cones[10]. Ozbolt J has used 3D finite element method to analyze the mechanical properties of anchor bolt under fire[11].The research on the effect of embedment depth on the post-installed joint for steel-concrete is few in the world.

2. Model information

2.1. Model
As shown in figure 1 below, the model includes concrete base, steel plate, I-shaped steel beam, stiffener, bonded-in reinforcement and fire protection.

![Model Diagram](image)

Figure 1. Model

2.2. Meshing
Solid element C3D8R has been used in the model in order to facilitate analysis of specific performance, reduce the level of freedom, and accelerate the calculation and analysis. Steel in the concrete is established as a linear element T3D2 which is adopted to simulate the steel reinforcement.

3. Analysis of simulation results

3.1. Analysis of bearing capacity
As shown in table 1, the embedded rebar has reached the peak state, and the specimens with the different embedment depths all showed high bearing capacity, and the peak load of joints enhance with the embedment depths increasing.

| Embedment depth (mm) | Peak load (kN) | Maximum displacement (mm) |
|----------------------|----------------|--------------------------|
| 25 d                 | 80.4           | 5.9                      |
| 20 d                 | 76.3           | 4.5                      |
| 15 d                 | 70.4           | 3.0                      |

It can be seen from the figure 2 that the embedded rebar with different embedment depths has different degrees of necking. Through comparison, it is found that the necking of 15 d specimens is most obvious. Larger displacement occurs at the embedded rebar, but the displacement of inner concrete is smaller due to the presence of adhesive force.

![Displacement Diagram](image)

(a) 25 d
3.2. Hysteretic performance analysis
As shown in figure 3, the area of hysteresis loops in the three specimens is large, which shows good seismic performance. After several cyclic loading loops, the phenomenon of slippage of 15 d specimens is obvious. The ultimate bearing capacity of 25 d, 20 d, and 15 d decreased gradually, and after 15 d reached the ultimate bearing capacity, there is a significant drop. The residual strength of 25 d and 20 d specimens still keep a high value even after the peak load.

3.3. Skeleton curve analysis
As shown in figure 4, the curve of 25 d specimen is divided into elastic stage and smooth stage. The 20 d specimen and 15 d specimen are divided into elastic stage and descending stage. The decline of 15 d specimen drops more. In the elastic stage, the curve slopes in rising segment for 20 d and 25 d specimens are relatively large, which show better stiffness. In comparison, the slope of 15 d specimen is smaller. In the elastic stage, the specimens with different embedment depths reach different peak loads, and the peak load of 25 d specimens is larger, which is obviously greater than the peak load of specimens of 20 d and 15 d.

Through comparison, it is found that increasing embedment depth can enhance the ultimate bearing capacity of post-installed joint, thereby improving the seismic performance.
3.4. Analysis of stiffness degradation

It can be seen from the figure 5 that the initial stiffness of 25 d specimen is greater than that of 20 d and 15 d specimens. By comparison, it can be seen that although the initial stiffness of 25 d specimen is larger than 20 d, the stiffness degradation path is roughly the same. And the peak of 25 d is obviously higher than 20 d and 15 d.

3.5. Energy dissipation and ductility analysis

It can be seen from table 2 that the area of hysteresis loop decreases with 25 d specimens, 20 d specimens, and 15 d specimens respectively. The seismic performance decrease gradually, and the peak load of three specimens also decrease gradually. It is found that the equivalent viscosity coefficients of 25 d and 20 d specimens are not much different, both of them have good energy dissipation capabilities, and both of them have better seismic performance.

| Specimen | Peak load(kN) | Limit displacement(mm) | Ductility coefficient | Hysteresis loop area (kN·mm) | Equivalent viscosity coefficient |
|----------|---------------|------------------------|-----------------------|------------------------------|--------------------------------|
| 25 d     | 80.4          | 5.9                    | 4.2                   | 1773.6                       | 0.460                          |
| 20 d     | 76.3          | 4.5                    | 3.2                   | 1708.0                       | 0.443                          |
| 15 d     | 70.4          | 3.0                    | 2.1                   | 1128.0                       | 0.401                          |

4. Conclusion

(1) Comparing with the ultimate bearing capacity of each test piece, the 25 d test specimens are higher than the 20 d test specimens and 15 d test specimens. The ultimate bearing capacity of 20 d specimens
is reduced by 4.8% compared with that of 25 d specimens. The ultimate bearing capacity of 15 d specimens is reduced by 11.7% than 25 d. It illustrates that increasing embedment depth can enhance the bearing capacity of joints.

(2) From the hysteresis curves of three specimens, the hysteresis curves of 25 d specimens possess the largest Area of hysteresis curve and show the best seismic performance. From the perspective of skeleton curves of the specimens, in the elastic stage, the slopes of 25 d specimen and 20 d specimen are relatively large, and stiffness of the two specimens is relatively large, which is significantly greater than the stiffness of 15 d specimen. After the specimen reaches the ultimate bearing capacity, the 25 d specimen can still maintain a high bearing capacity. There is no downward trend, and the displacement continues to increase. There is still a higher bearing capacity, and a better ductility.

(3) From the equivalent viscous damping coefficient, it increases with the embedment depths, which indicates that increasing embedment depth can advance the ability of energy dissipation, and enhance seismic performance of the post-installed joint.

Acknowledgement
This work was supported by the Shandong Provincial Key Research and Development Program of China (Grant no.2017GSF22106) and the Natural Science Foundation in Shandong Province of China (Grant no. ZR2014EL037).

Reference
[1] Zhang, X.S. (2013) Study on Seismic Performance of Frame Joints Reinforced by Planting Reinforcement [D]. Hebei: Hebei University of Engineering.
[2] Deng, Z.C., Zhong, L.H., Zhang, Y.F., Zeng, H.C., Fan, S.P. (2011) Seismic Behavior Research of RC Structure with Post-installed Chemically Rebar. Journal of Beijing University of Technology, 37:707-712.
[3] Wu, L.Z., Li, D.B., Xu, F.Q. (2013) Experimental Study on Seismic Behavior under Dynamic Tension Loads of the Anchors. Earthquake resistance and reinforcement, 35:101-107.
[4] Zhou, M. (2012) Study on Tensile Properties of Anchors in Chemical Anchor Bolts of Concrete Structures [D]. Wuhan: Huazhong University of Science and Technology.
[5] Liu, S.R., Zhang, Q.L., Ni, J.G., Gu, M.J. (2008) Test and finite element analysis on tension bearing capacity for single anchor bolt. building structure, 38:102-105.
[6] Zhang, S.G., Li, J.J. (2010) The finite element analysis of tension performance of embedded steel-bars by fasteners in concrete. Journal of Changchun Institute of Technology (Natural Science Edition), 11:24-28.
[7] Li, Y.J., Bellingshausen, R. (2002) Numerical analysis of quadruple fastenings with bonded anchors. ACI Structural Journal, 99:149-156.
[8] Delhomme, F., Roure, T., Arrieta, B., Limam, A. (2015) Static and cyclic pullout behavior of cast-in-place headed and bonded anchors with large embedment depths in cracked concrete. Nuclear Engineering and Design, 287:139-150.
[9] Burtz, J.L. (2008) Behavior and design of grouted anchors loaded in tension including edge and group effects and qualification of engineered group products. Journal of Chromatography A, 331:83-90.
[10] Ronald, A., Kunz, C.J. (1998) Behavior and design of single adhesive anchors under tensile load in uncracked concrete. ACI Structural Journal, 92:9-25.
[11] Ozbolt, J., Kozar, I., Periskie, G. (2007) Three dimensional FE analysis of headed stud anchors exposed to fire. Extreme man-made and natural hazards in dynamics of structures, 2:177-198.