AN ANALYTICAL STUDY ON THE ULTIMATE TENSILE STRENGTH OF ANCHOR BOLTS IN CONCRETE UNDER THE PULL-OUT LOADING

ハリヤディ

https://doi.org/10.15017/1543948

出版情報：九州大学, 2015, 博士（工学）, 課程博士
バージョン：

（別紙様式２）

論　文　要　旨

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論文題名　AN ANALYTICAL STUDY ON THE TENSILE ULTIMATE STRENGTH OF ANCHOR BOLTS IN CONCRETE UNDER THE PULL-OUT LOADING

（引抜き荷重を受けるコンクリート中のアンカーボルトの終局引張強度に関する解析的研究）

論　文　内　容　の　要　旨

Generally, the strength of an anchor bolt in the concrete is evaluated by several simple assumptions such as the load is applied statically, a single crack generates and the stress distribution is uniform. Many efforts have been done to analyze the strength and failure mode of anchor bolt by numerical analysis and experimental program. However, a numerical analysis that can predict exact failure mode and real strength still need to explore. Hence, the experimental approach and numerical analysis conducted in this study. In general, Finite Element Method (FEM) is not suitable for discontinuous failure phenomena such as reinforced concrete. On the other hand, Smoothed Particle Hydrodynamics (SPH) method can be more reliable on a large deformation problem. In this analysis, two-parameter pressure dependent model, Drucker-Prager (DP) was applied to concrete materials, whereas the pressure independent (von Mises -VM) criterion was employed to steel anchor bolt.

Anchor bolt is a case of hybrid/composite structures, so when the different properties materials combined, the problem of bond character assumption between them arises. For further analysis, the developed bond character was applied to model specifically on the contact surface between concrete and steel anchor bolt. The simulated results using SPH conform to the design standard in term of the maximum loading capacity.

In Chapter I, the main objective and scope of the study were declared. A literature review of the design formulas to predict the ultimate pull-out capacity of anchors was provided. After that, the assumed problems in the design and analysis of anchor bolt structures in the design standards were presented.

In Chapter II, the numerical calculation setting and a solution of the particle deficiency problem of SPH method was presented. A basic formulation and calculation procedure of SPH were expressed. Constitutive model consists of von Mises and Drucker-Prager were also described in this chapter. Dummy particles apply to solve the boundary problem in the anchor bolt and the result showed that the distribution of the dummy particles around the boundary area was very useful to solve problems under the free surface condition.

The experimental part of this study was described in Chapter III. The shallow depth of anchors and the normal strength of mortar concrete was conducted to investigate the failure mechanisms of the anchors. The failure mode, loading capacity, and concrete cone stress of the anchor bolt structure were presented and discussed. Finally, a comparison between the experimental results and design standard has been presented.

In Chapter IV, the numerical calculation setting and several examples of the analysis on the strength of anchor bolt under pull-out load were precisely explained. The effect of anchor bolt depths was investigated by the proposed numerical method. By adopting the VM model for anchor bolt and DP model for concrete and applying cut-off procedure, the ultimate pull-out strength and failure mechanism can be evaluated. The change of load-displacement behavior, failure mode and maximum pull-out strength due to various embedment depths can be expressed by using the proposed SPH analysis and it adequately described the large deformation and the failures of the anchor bolt structures. However, bonding failure between bolt and concrete was not considered in this analysis. By ignoring the effect of bond character, the numerical analysis may give a higher pull-out strength and it was preferable to consider the possibility of bond failure in the next step.

The bond character of numerical model was proposed in Chapter V, since a combination failure between bond failure and cone failure is generally found in anchor structures. In order to solve the phenomenon, a modified constitutive model was constructed and applied to simulate the effects of the bonding zone on developing cracks around the contact surface between anchor bolt and concrete. All models analyzed in Chapter IV were re-investigated by applying the bond character. Then, the numerical analysis results between without and with considering bond character were compared and reviewed. The result showed that by applying the bond character model, the loading capacity of all anchor bolt structure models reduced.

In Chapter VI, a comparison between the numerical results, standard design, and experimental results were presented. The size and material properties of model were fully adopted from the experimental tests in Chapter III. The numerical model, in this chapter, was divided by the model with and without considering the bond character. In addition, the perfect elastic-plastic for bonding characteristic was applied with the calculation of the limit ultimate strain of shear by considering the fracture energy which is equal to the fracture energy of tensile softening. The numerical analysis results were compared to the experimental results and the design standard equation to verify the accuracy of results. Comparison of the numerical analysis results between with and without considering bond character shown that by applying the bond character the pull-out loading capacity reduced 2%. On the other hand, the numerical analysis result with bond character showed higher around a half (61%) of loading capacity than the experimental result. In general, it can be concluded that the certain correction factor should be used when the numerical analysis will be applied to the design and analysis of anchor bolt structures. Finally, the proposed numerical method may reliable to use for design and analysis the anchor bolt structures, and the correction factor should be used to get the safe structures.