Numerical analysis of the effect of transverse reinforcement on mechanical behaviour of concrete column – abstract

The dissertation presents a numerical model of concrete confined phenomenon for estimating the axial force limit, transverse stresses and axial stiffness of a concrete column section with steel transverse reinforcement of any shape. The dissertation uses a two-dimensional model based on generalized plane strain state assumptions, nonlinear physical models of materials, and the solution was sought using a displacement formulation of the finite element method.

The dissertation is divided into 6 chapters and the appendix A, which is an integral part of the dissertation. In the introduction, the general assumptions of the dissertation are presented, the concept of concrete confining and the areas in which the phenomenon is vividly used are introduced. In addition, there is a description of the objectives of the dissertation, which can be summarized by the following statement – "to present a simple, efficient and reliable model of the investigated phenomenon", and the research thesis is presented, assuming that the adopted solutions allow for full implementation of these objectives. The next chapter presents the phenomenon of concrete column confining in Polish and world scientific literature. The review of literature is divided into three parts, which present, respectively, experimental research in this field, attempts to create computational procedures based on experimental and theoretical material, and various approaches to numerical modeling of confined concrete and concrete plasticity in complex stress state. This chapter also presents in a unified form a summary of 34 proposals for determining the resistance of confined sections in axial compression. The next chapter is devoted to the presentation of the problem formulation. The assumptions made are presented, such as rejection of the lagging in the analysis, adoption of a two-dimensional model in plane strain state and directly related to this the adoption of the principle of plane section and the principle of blurring of transverse reinforcement along the column height. In addition, it should be mentioned that the dissertation is limited to solving the task of columns made of normal strength concretes, since they give the best results for winding. It was pointed out that columns made of high strength concretes may be accompanied by additional phenomena, which are not included in the presented model. In the next part the equations comprising the formulated problem are presented. In the section devoted to the criteria of concrete ductility, apart from a list of criteria used in the further part of the dissertation (Mohr-Coulomb, Drucker-Prager, Willam-Warnke), a brief review of classical ductility conditions is presented. Finally, a weak variational formulation is included, which was solved by the finite element method. A description of the solution is then presented. It begins by explaining the time and space discretizations used. Time, or rather pseudo-time is introduced in order to apply the incremental method, due to the nonlinear nature of the system of equations. At each instant of time, an equilibrium state is sought after adding another increment of load (longitudinal shortening of the column). The solution is obtained by implicit (*backward*) method and iterative method was used for this purpose. The axial force in the column core is determined as the integral of the axial stress across the section. Its limiting value was read as the extreme value in the monotonic part of the axial force-shortening relationship of the column. Then the characteristics of the used finite elements - bar finite elements to model the transverse reinforcement and triangular surface finite elements to model the concrete cross-sectional area are included. The dissertation also describes methods of determining material constants used in the application of selected physical models. The presentation of the solution methods is supplemented by the characteristics of the computer software used to prepare the computational examples presented later in the dissertation. The chapter devoted to the presentation of the application of the model discussed in this dissertation begins with the comparison of the results obtained by simulation with its use and the results of experimental research presented in the articles: S. Y. L. Yin, J. C. Wang, and P. H. Wang. *Development of multi-spiral connections in rectangular columns for construction automation*. Journal of the Chinese Institute of Engineers, Transactions of the Chinese Institute of Engineers, Series A, 2012. s. Y.-l. Yin, T.-l. Wu, T. C. Liu, S. A. Sheikh, and R. Wang. *Interlocking Spiral Connement for Rectangular Columns*. Concrete International, 33(Specimen C):3845, 2011.The comparison results show a good representation of the mechanical behavior of columns made of normal strength concretes. Next, the results of simulations for concrete cross-sections of typical shapes (round, square, rectangular) with different degree of reinforcement are presented - and here, too, the results obtained thanks to simulations did not differ from the dependencies known from the literature. The next section shows what effects of confining can be obtained in rectangular cross-sections with different ratio of side lengths. The next one presents the effectiveness of using reinforcement of different shape in square cross-sections. It was found that the most effective among the presented proposals is the use of circular inserts covering the largest possible area of the cross-section. In this case the load capacity increase is up to about 20 % higher compared to the simplest method. Another presented example shows the solution in cross-sections less frequently considered in the context of using windings to improve their load capacity: concave cross-section, L-shaped, and ring cross-section, with free inner edge. The conclusions from these calculations indicate that the concave section is comparably effective as the rectangular one with a similar ratio of sides, while the hole inside the section contributes to a noticeable decrease in average transverse stresses and, as a result, lower load capacity increments than in the case of solid sections. In the conclusion of the chapter a comparison is made between the presented model (in three variants of selection of concrete ductility function) and various methods of estimating the load capacity of winding columns. It can be concluded that in the presented typical task the solution described in the dissertation does not differ from other verified methods. Additionally, in the summary of the chapter, the observations made are listed. Among the most important ones, it is worth mentioning the influence of winding on the axial stiffness, which is not decisive but, irrespective of the cross-section shape, approaches the value $\Delta E_c \approx 0{,}4\ \rho_T E_c$, and the fact that the model using the Mohr-Coulomb condition does not perform well enough in the tasks with non-uniform distribution of transverse stresses (all with inserts of long, straight sections and in cross-sections with holes). Appendix A, which follows, contains elements that do not fit directly into the content of the dissertation, but complement it in several places. The definitions of tensors and their invariants used earlier, the explicit method of integration of physical relations – as an alternative approach to the method used in the dissertation - are presented here. Similarly, the Prandtl-Reuss equations, which may be used to describe the behaviour of steel of transverse reinforcement, are presented further on. The last section of Appendix A shows the effect of material constants on the effects of confining – it is intended to be an additional verification of the correctness of the prepared model.