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Serviceability Limit State and Crack Width Analysis of Concrete Structures in Nuclear Power Plants

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INTRODUCTION

It is typical for the reinforced concrete structures of nuclear power plants that they are thick and massive compared to structures in ordinary buildings. The tightness or long-term stiffness needed for several critical structural components made of reinforced concrete are the reasons that the serviceability is perhaps more stringent requirement than the ultimate capacity in the designing of reinforced concrete structures. However, their design is largely based on codes developed for non-nuclear applications, and the challenge is the application of beam theory based code formulas to complicated multidimensional structures of nuclear facilities, where the temperature changes may produce a substantial part of loading. A special feature of reinforced concrete is that the effect of temperature changes depends on the stiffness of the structure, which on the other hand depends on cracking. Thus, it is important to have a design tool by which it is possible to update the stiffness of the structure due to cracking and to consider the effect of stiffness changes on the redistribution of stresses.

The paper presents the in-house design tool comprising of several independent programs that are chained to analyse and dimension three dimensional reinforced concrete structures iteratively. The main parts of the design tool are a commercially available program based on general finite element method and the in-house programmes that define the cracking, update stiffness and calculate reinforcement bars in different directions. The results of the tool are the actual amounts of reinforcement required by each element in the finite element mesh. The reinforcement received can finally be transferred to drawing programs. The design tool can be used either for dimensioning of reinforcement of a new structure or for analysis of crack widths of an existing structure. The influence of the order in which the loads affect the structure can also be studied by the tool.

DESIGN METHOD

In general the shell structures, where the surface reinforcements have been placed on two layers in two orthogonal directions, the design forces and moments are defined by the method of minimum resistance according to Gupta (1977 and 1981). If the shell structure is reinforced by a combination of orthogonal and inclined bars, the design forces and moments are defined from the equilibrium and compatibility conditions by Duchon (1972). Each reinforcement component is dimensioned with a separate cross-sectional study. The neutral axis and the stresses and strains of the cross-section are defined by the Gurfinkel's (1971) method. The mechanical and thermal stresses are studied separately, which enables the reduction of the thermal stresses due to concrete cracking.

The basic principle of the design method is shown in Fig. 1. At first, elastic stress distribution is calculated and then the structure is dimensioned against these elastic stresses. After the first design loop, the stiffness of the structure is updated to consider the effect of cracking. The updated structural stiffness defined by the cross-sectional studies will be used in the next FEM-analysis and so the non-linear effects are taken into account. The second design loop will be made using a new stress distribution. The final result is achieved when the change of the reinforcement between the consecutive loops is small enough. The design method has been presented in detail by Turunen (2007).

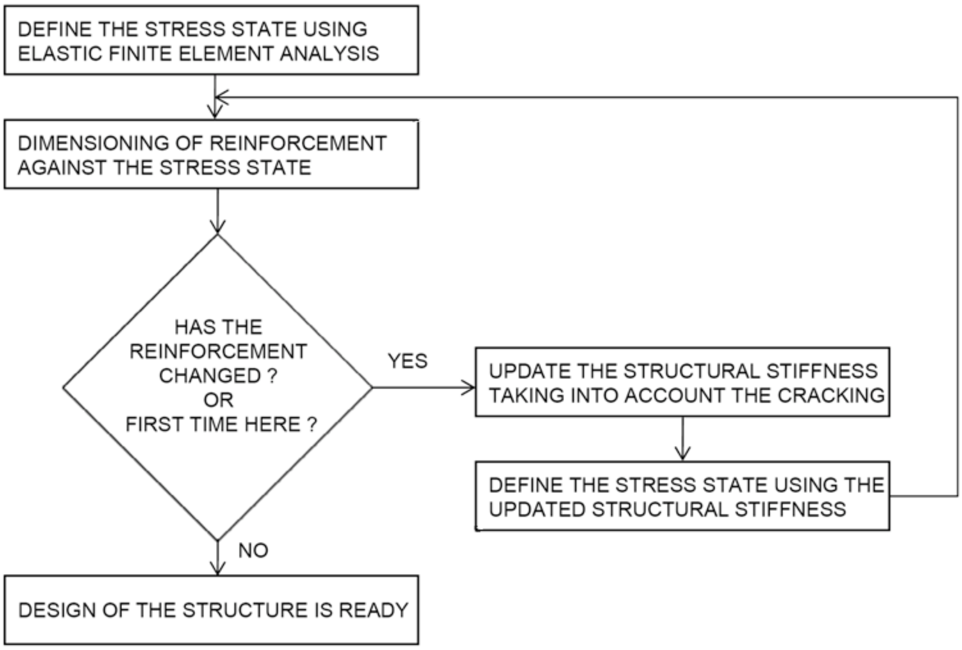

Figure 1. Basic principle of the design method

CONCLUSION

The presented in-house design tool is able to analyse and dimension three dimensional reinforced concrete structures iteratively according to the National Building Code of Finland “B4: Concrete structures” and the European Standard “Eurocode 2: Design of concrete structures”.

The calculation formulas of the design codes B4 and Eurocode 2 have been compared and their differences have been demonstrated by two examples. The results reveal that these codes lead different reinforcement even if they both are official codes in Finland presently. For example with the same crack width requirement, the amount of required reinforcement according to Eurocode 2 is about 5% less in bending and in a pure tension about 30% more than required by B4. If the comparison is made using the same exposure class, the amount of required reinforcement given by Eurocode 2 is less than according to B4 both for bending (33%) and for pure tension (7%), as the requirement for the crack width in B4 is often stricter than the requirement in Eurocode 2. As the crack width is often a dimensioning factor for concrete structures, the reinforcement required seems to be clearly dependent on the design code applied.

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