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Calculation of magnetic field from steel rebar of building with machine producing high stray field

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ABSTRACT

Numerical verification is presented for modelling the magnetic effect of concrete structures reinforced with steel rebar. The model is based on the filling factor concept and takes into account magnetic anisotropy associated with the rebar pattern. Test problems are solved that prove applicability of the model in case of nonlinear properties of the reinforcement steel. A nonuniform field distribution is studied for a reinforced structure with an internal field source. Accuracy of simulated field maps with high gradients near ends of modelled structures has been assessed. The model has been verified in comparative computations with the use of other models. As an example, the proposed approach has been applied to a simplified magnetic model of the ITER tokamak complex. Then fields perturbations associated with the tokamak building structures have been evaluated for the gas breakdown at plasma initiation.

1. Introduction

An efficient computational method has been proposed [1] for assessment of field perturbations associated with concrete structures reinforced with steel rebar and, therefore, magnetized by machines with high stray magnetic field. The method utilizes a modified isotropic model that allows for the percentage of steel and rebar pattern thus imitating the anisotropic effects. Such model offers much more realistic predictions with better accuracy and reduced computational cost as compared to the isotropic model with a homogeneous reinforcement equivalent.

The reinforced concrete structure of a building is modelled via alternating planar isotropic layers of magnetic and nonmagnetic materials. In the extreme case, the model is limited to a single isotropic layer. Geometry and effective properties of every layer are predetermined in detailed 3D field simulations over a periodicity cell of the modelled lattice.

The calculation technique was described in [1]. The method was examined for the conditions of (i) constant permeability of steel bars, (ii) uniform external field, (iii) rectangular reinforced slab, (iv) single layer approximation. The layered model was verified in a comparison with the detailed model describing every bar of the lattice in a realistic way.

This paper is focused on applicability of the proposed computational method to generalized conditions. They are: (i) nonlinear magnetic properties of the reinforcement, (ii) non-uniform external field, (iii) complex geometry of reinforced slabs, (iv) multi-layered models. The conditions (i) and (iv) are investigated using the same test problem of a reinforced slab in the uniform external field as in [1]. The conditions (ii) and (iii) are tested regarding the shielding effect of a hollow reinforced cube with a field source in its center.

Similar to the study [1], a comparison is made for the results obtained with 3 models, shown in Fig. 1 (sketch of cross-sections) and Fig. 2 (3D finite element models):

1) a detailed 3D model with realistic description of the shape, position, and properties of every steel bar (Figs. 1a, 2a);
2) an isotropic model in which the steel lattice is replaced by an equivalent homogeneous isotropic material with the filling factor determined as described in [2] (Figs. 1b, 2b);
3) a modified (layered) isotropic model with alternating layers of homogeneous isotropic materials [1] (Figs. 1c–e, 2c).

Test field simulations have been carried out with the use of the code KOMPOT [3,4] using the T-Ω method [5] in terms of the scalar magnetic potential.

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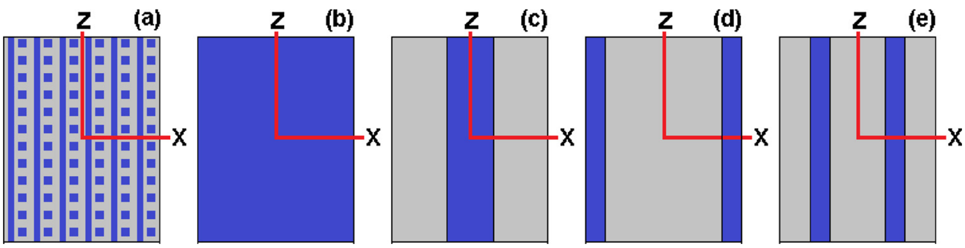
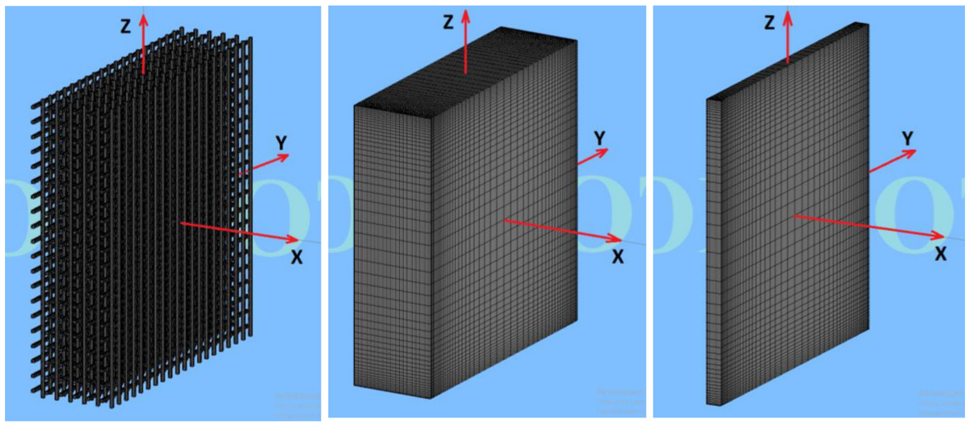


Fig. 1. Schematic view of computation models of reinforced slab: detailed 3D model with rebar (a), isotropic model (b), one-layered (c) and two-layered (d,e) models. Non-magnetic material is gray, magnetic material is more dark (blue) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).



(a) (b) (c)

Fig. 2. Structure 1: (a) detailed 3D model of reinforced slab, (b) isotropic model, (c) one-layered model.

In general, the field strength **H** at a point can be divided into two parts – $\mathbf{H}_0$ due to the source currents in free space and $\mathbf{H}_m$ due to iron magnetization. The T-Ω method [3] allows mathematical formulation of the magnetostatic problem in terms of the scalar potential Ω determined by the equation $\mathbf{H}_m = -\text{grad}\ \Omega$ at the known field $\mathbf{H}_0$ given by Biot-Savart's Law. In the case of a uniform external field, $\mathbf{H}_0$ is simply a constant 3-component vector at any point.

Practical results are presented for field perturbations occurred in the plasma region due to reinforced concrete structures of the ITER tokamak building. The results are validated in comparative simulations with the code KLONDIKE [4] using the layered and isotropic models for the simplified global model of the Tokamak Complex [2].

2. Magnetic effect of steel rebar with nonlinear properties

The test model described in [1] has been used to verify the generality of the modelling approach. A reinforced concrete slab with several criss-cross layers of steel bars in a uniform external field is modelled. Non-linear properties of the steel bars are implemented via the B–H curve [6,7] presented in Fig. 3. To assess the anisotropic effect of the reinforcement, Structure 1 studied in [1] is considered:

Structure 1 is a 0.6 × 4 × 4 m reinforced slab with the steel volumetric filling factor k = 8%. Structure 1 is described in a Carthesian coordinate system with its origin in the slab geometrical center and axes parallel to the slab ends. Every two layers of steel bars are placed in the YZ plane so that the bars in one layer are parallel to the axis Y while the bars in another layer are parallel to the axis Z. The spacing between bars in a layer is 0.1 m. The axis X is directed normally to the bars along the short side. A uniform external field is taken equal to 100 G. Two cases of the external field orientation are considered: parallel and normal to the bar layers.

Fig. 2 illustrates the detailed model for Structure 1. The field and relative permeability inside of two steel bars located along Z axis are shown in Fig. 4. The plots demonstrate that μ varies greatly (approximately from 300 to 2300) within a bar. Nevertheless, such variations lie within the typical range μ > 100, where characteristic parameters of the layered model depend on μ very weakly. These parameters are [1]: the effective filling factor k_1 for a magnetic layer with steel, defined as the ratio of the effective susceptibility of the magnetic layer to the actual steel susceptibility, and the geometrical filling factor k_2 for a structure with magnetic layers, such that the product of k_2 and the total width of the structure gives the total width of the magnetic layers. In this case, they can be used as pre-determined parameters for the entire layered model.

Two cases of the applied external field and comparative field simulations outside the reinforced slab with the detailed, isotropic, and layered models are presented in Figs. 5–7.

In the external field parallel to the bars (along the axis Z), all three models give near identical field distributions outside the slab at a distance of few bar spacings. With the external field directed normally to

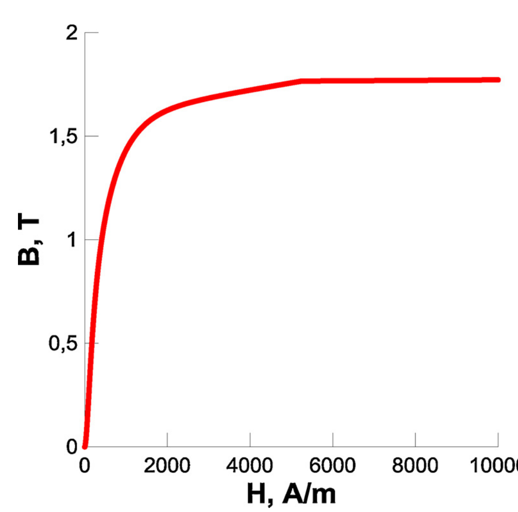


Fig. 3. *B*(*H*) curve for cold rolled steel in ITER tokamak building structures [5,6].