PARAMETRIC STUDY OF THERMAL CONDUCTIVITY OF REINFORCED CONCRETE SLAB

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Abstract - This paper presents a detailed parametric finite element study predicting the through-thickness thermal conductivity of reinforced concrete slab. The influence of three main structural parameters are investigated, which are: the concrete slab thickness, the steel bar diameter, and the spacing between two adjacent bars aligned in the same direction. The steel bar diameter found to be the dominant factors that influences the thermal conductivity of the slab

Keywords - Thermal conductivity, reinforced concrete slab, finite-element modelling.

I. INTRODUCTION

Concrete considered to be the most common building material all over the world[1]. The annual production of concrete exceeded ten billons tons[2]. This number is expected to jump to eighteen billons by 2050[3]. Reducing the thermal conductivity of concrete results in reducing conduction heat transfer through the building envelope[4]. Accurate prediction of thermal conductivity of walls and roofs of building gives accuratecalculations on thermal loads and therefore energy consumption. In literature, numerous amounts of research studies predict the effective thermal conductivity of concrete[4, 5]. All these studies focused on the effect of microstructure parameters of the concrete such as: moisture content, air voids, type of cement material, type and size of aggregate[1, 6]. The aim of this paper is to develop a numerical model that predicts the effective thermal conductivity of reinforced concrete. Also, to investigate the influence of three main structural parameters on thermal conductivity of the reinforced concrete, which are: the concrete slab thickness, the steel bar diameter, and the spacing between two adjacent bars aligned in the same direction.

II. FINITE ELEMENT MODELLING

2.1 Finite element unit cell

A finite-element model of the reinforced concrete slab is generated through observations and measurements of the reinforced concrete slab. The common reinforced concrete slab used in building consists of two layers of reinforcing steel bar mesh as shown in Figure (1). Modelling of the reinforced concrete slab is simplified by modelling a unit cell which is the smallest structure that produces the entire structure of the reinforced concrete slab by repeating itself through translation in the three orthogonal directions, X, Y, and Z. Figure (2) shows a top view of the reinforced concrete slab with transparent concrete showing the structure of unit cell. Figure (3) shows the unit cell with transparent concrete. ABAQUS software package was used to generate the finite element models and its mesh. The mesh of all model comprises of linear tetrahedral elements of type DC2D4 defined in ABAQUS element library.

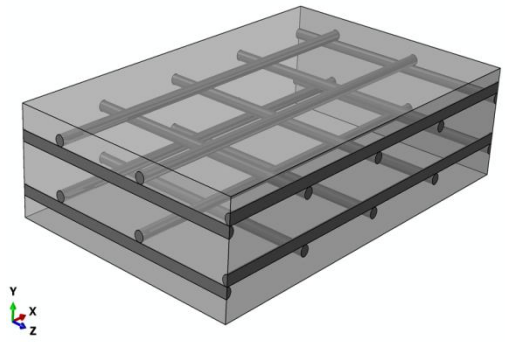


Figure 1: Rein forced concrete slab with transparent concrete showing location and distribution of steel bars.

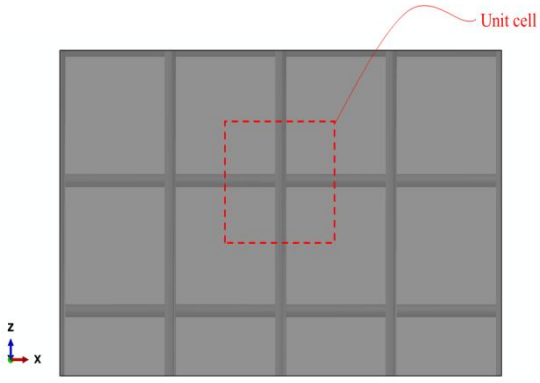


Figure 2: Top view of the reinforced concrete slab with transparent concrete showing the unit cell.

The dimensions of the unit cell are varying according the studied parameter. Three parameters are investigated which are: the concrete slab thickness, the steel bar diameter, and the spacing between two adjacent bars aligned in the same direction. Figure (4) shows these factors on a front view schematic of the reinforced concrete slab.

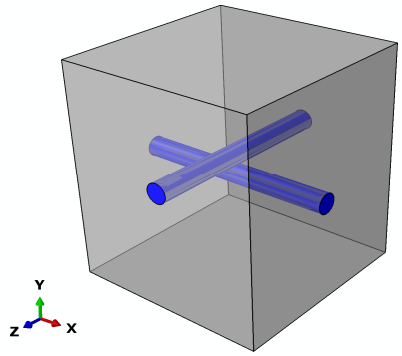


Figure 3: The unit cell with transparent concrete showing the reinforcement steel bars.

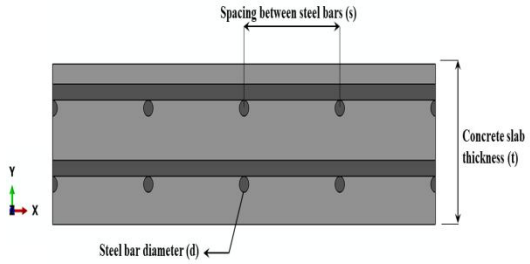


Figure 4: Front view of the reinforced concrete slab showing the different parameters.

2.2 Constituent materials

The constituent materials of unit cell are concrete and steel. Their input thermal properties are listed in table (1).

Table 1: Material properties of the constituent materials of the reinforced concrete slab.

Phase	Thermal conductivity (W/m-K)	Source
Steel	74.85	[7]
Concrete	2	[8]

2.3 Boundary conditions

A steady-state thermal analysis was carried out on the unit cell in through-thickness directions. The boundary conditions involve applying two different temperatures on two opposite surfaces, which are the top and bottom surfaces of the unit cell shown in Figure (3). This temperature gradients generates a constant heat flow towards the surface with the low temperature. Thermal conductivity is then calculated using the following equation:

$$k = -\frac{Q}{A}.\frac{L}{T_{hot} - T_{cold}}$$

where k is the through-thickness thermal conductivity of the reinforced concrete slab, Q is the total heat going towards the cooler surface, A is the surface area of the reinforced concrete slab unit cell in the direction perpendicular to the heat flow, L is the distance between the top and bottom surfaces, and T_{hot}andT_{cold} are the temperatures of the hotter and cooler surfaces, respectively.

III. RESULTS AND DISCUSSION

3.1 Effect of the concrete slab thickness

Several unit cells with varying thicknesses were constructed to investigate the effect of the slab thickness on the overall through-thickness thermal conductivity of the reinforced slab. Figure (5) shows the variation of through-thickness thermal conductivity as a function of slab thickness. It can be seen clearly that the higher the thickness the lower the thermal conductivity of the slab. This is a result of increasing the concrete phase which has lower thermal conductivity than steel. However, the reduction in thermal conductivity of the slab is not constant with the increase in the slab thickness. Specifically, thermal conductivity reduced by more than 5% when the slab thickness was 50 cm. However, more than 2% of this reduction was caused by the first 5 cm of the concrete thickness, and thickness larger than 0.3 m thus yield only a marginal decrease in thermal conductivity.

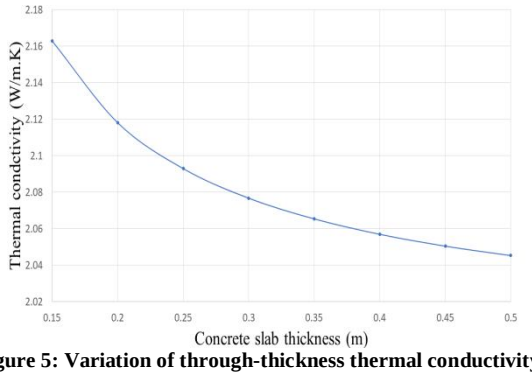


Figure 5: Variation of through-thickness thermal conductivity as a function of slab thickness.

3.2 Effect of steel bar diameter

The effect of the steel bar diameter was studied by constructing several unit cell with different steel bar diameters.

Figure (6) shows the variation of through-thickness thermal conductivity of the slab as a function of reinforcing steel bar diameter. The thermal conductivity of the slab is increasing with the increase of the steel bar diameter.

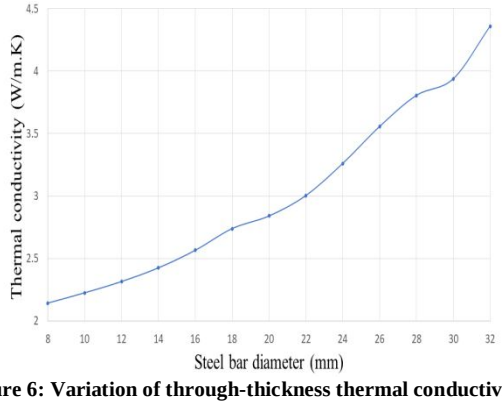


Figure 6: Variation of through-thickness thermal conductivity as a function of reinforcing steel bar diameter.

3.3 Effect of spacing between steel bars

The effect of the spacing between the steel bars was determined by constructing several unitcell with different width and depth. Figure (7) shows the variation of through-thickness thermal conductivity of the slab as a function of the spacing between the steel bars. The thermal conductivity of the slab is increasing with the reduction in the spacing between the steel bars.

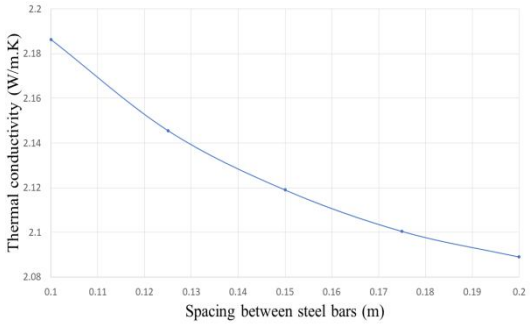


Figure 7:Variation of through-thickness thermal conductivity of the slab as a function of the spacing between the steel bars.

CONCLUSIONS

A parametric finite element modelling analysis was presented for a reinforced concrete slab. The through-thickness thermal conductivityof the slabwas predicted at different structural configurations. The investigated parameters were:the concrete slab thickness, the steel bar diameter, and the spacing between two adjacent bars aligned in the same direction. The results show that the thermal conductivity of the slab is increasing with increasing the steel bar diameter or by decreasing the spacing between the bars. Furthermore, changing the steel bar diameter has the dominant effect on the thermal conductivity of the slab. However, the results also show that the thermal conductivity of the slab can be decreasing by increasing the concrete slab thickness.

REFERENCES

[1] Asadi, I., et al., Thermal conductivity of concrete – A review. Journal of Building Engineering, 2018. 20: p. 81-93.
[2] Meyer, C., The greening of the concrete industry. Cement and Concrete Composites, 2009. 31(8): p. 601-605.
[3] Monteiro, P., Concrete: Microstructure, Properties, and Materials. 2006: McGraw-Hill Publishing.
[4] Faye, M., B. Lartigue, and S. Kane, Influence of structural and thermophysical parameters of insulating aggregates on the effective thermal conductivity of lightweight concrete. Journal of Building Engineering, 2019. 21: p. 74-81.
[5] She, W., et al., Numerical study on the effect of pore shapes on the thermal behaviors of cellular concrete. Construction and Building Materials, 2018. 163: p. 113-121.
[6] Batool, F., M.M. Rafi, and V. Bindiganavile, Microstructure and thermal conductivity of cement-based foam:A review. Journal of Building Engineering, 2018. 20: p. 696-704.
[7] Sheikh, M.A., et al., Measurement of thermal diffusivity of isotropic materials using a laser flash method and its validation by finite element analysis. Journal of Physics D: Applied Physics, 2000. 33(12): p. 1536.
[8] Nagy, B. and E. Paulik, Reinforcement-Dependent Thermal Properties of Reinforced Concrete Columns and Slabs Applied Mechanics and Materials, 2017. 12(861): p. 279-286.

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