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1. Petru CÂRDEI, 2. Dragoș MANEA

CONVERGENCE STUDY FOR A HEAT TRANSFER PROBLEM

1-2.National Institute of Research – Development for Machines and Installations designed to Agriculture and Food Industry – INMA Bucharest, ROMANIA

Abstract: This paper presents a convergence study for a structural analysis problem that models a heat exchange phenomenon. Although the main subject is the exposure of the convergence study method, the model itself is also interesting. From a physical point of view, the heat exchange between the fluid flowing through a pipe and the ground where it is buried is modelled. The soil through which the duct passes is a portion of the soil of a solar. It is considered a thermal regime of heat, in which the soil in the root area of the plants must be cooled, to favour plant health. Returning to the main purpose, the exposure aims to demonstrate to users the need for a convergence study for the structural models of thermal phenomena, under the particular conditions to be considered for them. On the other hand, the results of the article prove the usefulness of the proposed structural model, in the design of the thermal system, by the possibility of estimating the temperature in the radicular area according to the thermal parameters of the environment.
Keywords: model, structural, convergence, heat, change, solar

1. INTRODUCTION

Among the problems of mathematical physics, an important place deals with those problems, which refer to the transfer of energy and substance in different environments. Structural analysis programs have included by long time this domain of the mathematical physics in their solution packages. Specialty literature is very rich in the domain of the heat and mass transfer [1]. On the line of published articles on some problems of structural models, [2–5], the authors continue to study the convergence of these models in various fields of mathematical physics. We do not repeat in this article the reasons for the need for convergence studies and their traps, we made only refer to the papers [2–5]. The subject of this model was chosen from the author's specific concern. The simulation of thermal phenomena, which takes place in greenhouses and solariums, is an open subject and continues to provide utilities for their design and automation. This article exposes a fragment of an elementary model, the authors investigating complex 2 and 3 dimensional models, whose results will return as they are finalized.

2. MATERIAL AND METHOD

The subject (material)

The radiant energy transmitted by the Sun is absorbed and converted to caloric energy by the Earth's surface, causing the surface of the soil to dry, i.e. the soils, the water surfaces and the air in the lower layer of the atmosphere – the troposphere [10]. Partially, the accumulated heat is propagate to the deeper layers of soil and water, but also in the tropospheric air, and the other is consumed in different physical, chemical and biological processes that occur at the Earth's surface, [9]. So the Earth's crust has the property of transforming radiation energy into caloric energy and distributing caloric energy.

The warming of the terrestrial surface is achieved by the absorption and transformation of radiant energy reaching the surface of the soil in the form of caloric energy. From the surface of the soil the heat is transmitted in three main directions, soil, water and air, according to the laws of heat propagation, according to the particularities of the respective mediums [6].

Method

It is considered a volume of soil in a solar, where the air temperature increases very much, as happens during in the very hot days. The volume of soil will be considered as a parallelepiped having the length L = 3 m, width, l = 0.2 m and thickness (corresponding to the depth of the soils considered), h = 0.1 m.

The structural model of the physical process described above is based on the geometric model of Figure 1. The OABCDEFG volume represents a volume of soil considered to be a uniform and homogeneous continuous body with a density of 1100 kgm^{-3}, thermal conductivity of 0.5 W / m^{-1}K^{-1} and specific heat, 1380 Jkg^{-1}[7]. The reference system and its orientation are shown in Figure 1. The reference system and orientation are of great importance for determining the coordinates of the points in which the solution is read and validated, in terms of convergence[1]. The UV right line, which overlaps the axis of longitudinal symmetry of the soil volume, represents the idealization of a duct through which the coolant passes. To simplify the model, it was assumed that cooling water moved through the metal pipe quickly enough to make the water temperature losses negligible. Thus, the unidimensional entity can be considered as a single body, used to cool the volume of soil. We considered for this cooling body the mass density and thermal characteristics of the steel pipe: density 7850 kgm^{-3}, thermal conductivity 40 Wm^{-1}K^{-1}, specific heat 490 Jkg^{-1}.

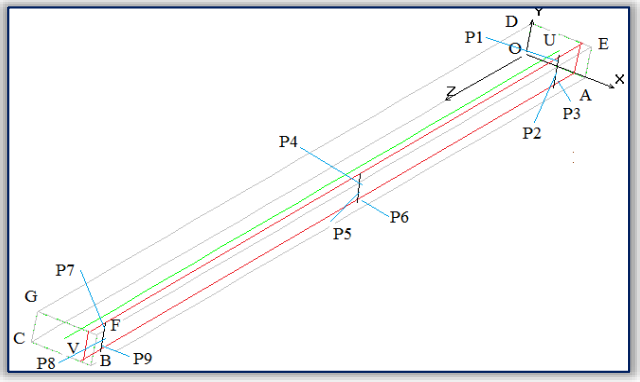

Figure 1. The geometric model of the soil cooling process in the roots zone, made by using the pipe through which the water flows

The cold water pipeline was meshed with BEAM3D one–dimensional elements. The volume of soil was meshed with SOLID three–dimensional elements. Both types of finite elements were taken from the library of elements of the COSMOS / M 2.8, [8], program, with which modelling and calculation were performed. Both types of elements can be used in thermal analysis.

The border conditions are as follows: surface temperature in contact with solar air, 60^{o}C, temperature on the surface opposite to the one in contact with solar air, 35^{o}C, temperature on the side faces, 50^{o}C. The temperature of the cooling water pipeline, which crosses the volume of soil along its length along the longitudinal symmetry axis, is assumed to be constant (it is assumed that the flow velocity of the water in the pipe is great enough so that its temperature modification, over the length of 3 m to be negligible), 10^{o}C.

Table 1. The coordinates of the locations of the convergence estimators

Label	X, m	Y, m	Z, m
P1	0.15	0.075	0.1
P2	0.15	0.050	0.1
P3	0.15	0.025	0.1
P4	0.15	0.075	1.5
P5	0.15	0.050	1.5
P6	0.15	0.025	1.5
P7	0.15	0.075	2.9
P8	0.15	0.050	2.9
P9	0.15	0.025	2.9

3. RESULTS

The convergence estimators are the values of the thermal field in the coordinate points given in Table 1. Table 2 gives the thermal field values in each of the points P1,..., P9, for the six meshing performed until satisfactory convergence is achieved.

Table 2. The values of the convergence estimators for six meshing density.

Number of elements/ location	510 (480+30)/^{0}C	990 (960+30) /^{0}C	1950 (1920+30) /^{0}C	3870 (3840+30) /^{0}C	7740 (7680+60)/^{o}C	11580 (11520+60)/^{o}C
P1	44.40	48.39	50.83	51.47	51.35	51.47
P2	39.73	46.14	43.88	44.95	44.42	44.59
P3	38.00	38.28	39.23	40.11	39.39	39.53
P4	53.75	43.21	50.85	51.23	51.15	51.28
P5	41.87	45.91	43.70	44.29	44.22	44.40
P6	38.35	38.62	38.11	39.36	39.33	39.47
P7	47.50	48.39	52.16	51.47	51.35	51.47
P8	39.73	46.14	44.11	44.95	44.42	44.60
P9	38.00	38.28	38.06	40.11	39.39	39.53

[1]We underline once again that, according to what I have stated in other articles on the convergence of structural models, the validation of convergence (by the date method in all articles as in the present) and the model (which is done by experiment) are only practical actions. A true verification should contain a set of points (of convergence check, respectively of experimental verification), having at least the power of the points that make up the structure, that is, the continuum power (the cardinality of the continuum). As in reality we cannot obtain such control, we agree to trust the proposed method. This method is also involved in the validation of the structural model, since it is preferable that the points in which is made the convergence check is included in the set of points where the experimental validation (ie the measurement points) is made.

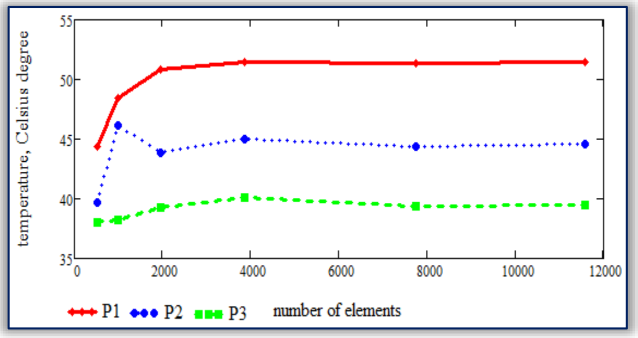

Figure 2. The dependence of the calculated temperature, in the points P1, P2 and P3, depending on the number of finite elements of the structural model mesh.

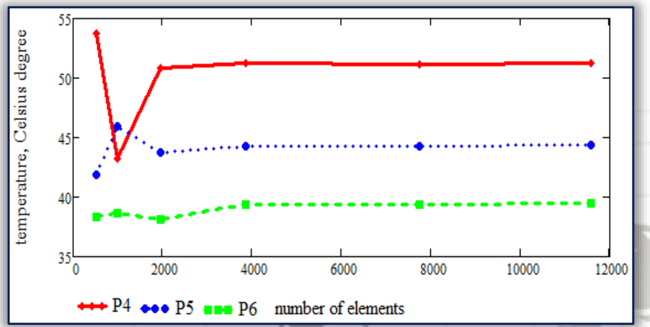

Figure 3. The dependence of the calculated temperature, in the points P4, P5 and P6, depending on the number of finite elements of the structural model mesh.

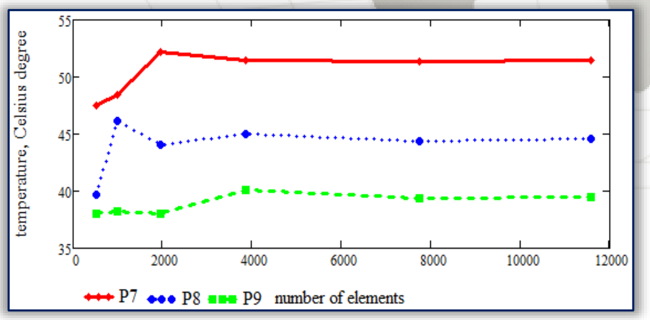

Figure 4. The dependence of the calculated temperature, in the points P7, P8 and P9, depending on the number of finite elements of the structural model mesh

4. CONCLUSIONS

The results presented in the previous chapter allow extracting some conclusions regarding both the main subject (model convergence) and the practical application of this model in the design of thermal control systems.

- The values in Table 2 and the graphical representations of Figure 2, 3 and 4 show that the structural model presented is convergent (in the sense of convergence defined in [2–5]). Convergence can be considered as achieved for meshing the structure with more than 4000 finite elements. The achievement of convergence is also manifested in the plane of the cross section, perpendicular to the longitudinal axis of the model, as shown by the representation of the thermal field

The head of Table 2 informs about the total number of elements for the whole structure, but also specifies how many elements belong to the volume of soil and how many elements belong to the straight line that shapes the pipe. Using the data from the Table 2, the graphical representations of Figures 2, 3 and 4 were realized. In the Figures 2, 3 and 4, we can observe the dependence of the thermal field values in the reference points for verification, P1, ..., P9, by the number of elements used for meshing the structure.

Figure 5 gives the last result obtained, the one that has the greatest utility for the designer of such a soil temperature control system. Figure 5 gives the temperature distribution in the median transverse section perpendicular to the longitudinal axis of the model for the initial and final meshing. From the point of view of convergence, one can see the greater fineness of the isothermal curves for the final meshing, which has the highest density of elements. The designer of this cooling system can read, under the given conditions, the values of the thermal field in the roots area.

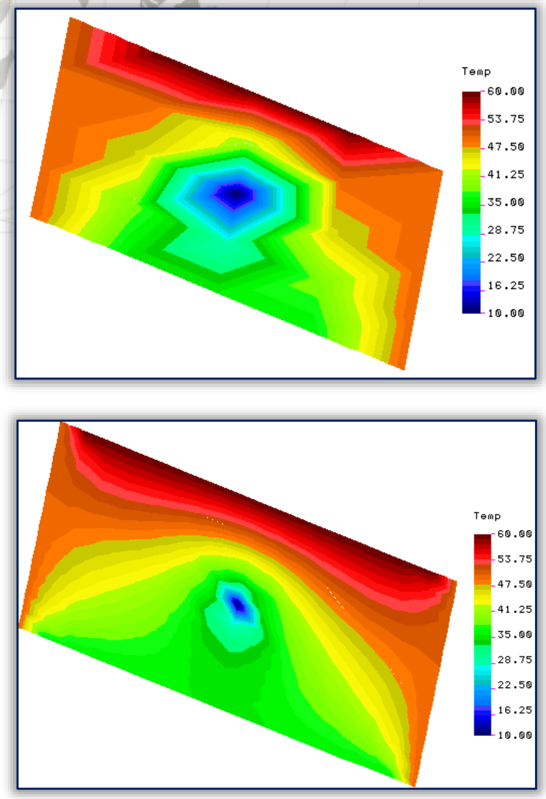

Figure 5. The distribution of temperature inside the soil volume in the normal centre section on the axis of longitudinal symmetry, which coincides with the axis of the pipeline through which the cooling water passes; the distribution corresponds to the coarsest (left) and the finest (right) respectively.

distribution in Figure 5. For better precision in reading radiative field values, it is necessary to increase the meshing density in the plane of the cross section perpendicular to the longitudinal axis.

- The exposed structural model applies into the design of temperature control systems of this type. The designers can read, on sections like the one in figure 5, the values of the thermal field. The values read are compared to those admissible from the point of view of plant health. Then, depending on the need, a coolant temperature value can be selected to ensure that the values of the heat field in the root zone are within the range that does not affect the health of the plant.
- The model can be improved to increase the precision (on computation and read) of the thermal field values and for use in the design of the cooling system. The model can be enhanced by increasing meshing density, or by making a superior, three–dimensional model or at least hybrid 2 and 3 dimensional model. This improvement will make a decisive contribution to increasing the degree of applicability in the design and operation of such systems.
- The structural model used to obtain the results presented in this article can also be used in an attempt to optimize the soil cooling process. The objective functions of the optimization process may be related to the condition that the cooling water leaves the system when its temperature has become equal to the soil at the depth of movement, or provided the temperature is as uniform as possible in the root zone.

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