TYPE 703: SLAB ON GRADE (INTERFACES WITH TYPE 56)

General Description

This routine models the energy transfer from a horizontal surface (commonly a concrete slab) to the soil beneath the surface. The energy transfer is assumed to be conductive only and moisture effects are not accounted for in the model. The model relies on a 3-dimensional finite difference model of the soil and solves the resulting inter-dependent differential equations using a simple iterative method. The user enters the temperature of the zone side surface of the slab, the slab U value, the soil properties and grid geometry, and the conditions outside of the slab (near-field). The initial soil conditions may be calculated from the Kasuda correlation [1] or read from a user-supplied data file. The surface conditions for the near-field and far-field soil may be calculated in one of three ways; 1) from the Kasuda correlation, 2) from an energy balance on the surface plane, 3) provided as an input to the model. The near-field soil temperatures are affected by the heat transfer from the slab. The far-field soil temperatures are only affected by the surface conditions (time of year) and depth.

This slab model is intended to be used in conjunction with Type56. If you wish to use this slab model in conjunction with a simplified building model, you should use Type704 instead.

Nomenclature

m	[kg]	Mass
C_p	[kJ/kg]	Specific heat
$\dot{Q}_{in}$	[kJ/hr]	The rate at which energy enters a fluid, soil or slab node.
$\dot{Q}_{out}$	[kJ/hr]	The rate at which energy exits a fluid, soil or slab node.
$T_{x,y,z}$	[ºC]	The temperature of a given soil node.
x	[m]	The distance along the length direction.
y	[m]	The distance along the width direction.
z	[m]	The depth dimension (node 1 is at the surface, increasing downwards).
k	[kJ/hr.m]	Thermal conductivity.
dx	[m]	The x direction dimension of a soil or slab node.
dy	[m]	The y direction dimension of a soil or slab node.
dz	[m]	The z direction dimension of a soil or slab node.
$T_{surface}$	[ºC]	The surface temperature of a node exposed to ambient conditions.
$T_{boundary}$	[ºC]	The temperature of a node on the near field / slab boundary
L_{slab}	[m]	The total length of the slab
W_{slab}	[m]	The total width of the slab
$\dot{Q}_{Type56}$	[kJ/hr]	The energy transferred through the slab into the ground (calculated by Type56)

Detailed Description

1. Appropriate Building Models

Simplified building models such as the lumped capacitance or degree-day models (Types 660, 80, and 12 in TRNSYS for example) lack two concepts on which this version of the slab on grade model depend. First, they do not contain the concept of a boundary wall and second, they do not perform the radiation exchange calculations that determine the appropriate interior surface temperatures of all walls, floors and ceilings. Users wishing to utilize a slab-on-grade model for these simplified building models should consider using the TESS Type704 model instead. This model (Type703) is intended to interface with detailed building models that calculate the inside surface temperature of the wall and take as an INPUT the outside surface temperature of the wall. The standard multi-zone building model in TRNSYS, Type56, is such a model.

By defining a wall as a boundary wall in Type56, one assumes that there is either a known temperature on the other (non-zone) side of the wall, or that the temperature on the non-zone side is identical to the temperature in the zone. Normally the boundary temperature specified is the temperature of a node connected to the back surface of the wall through a pure resistance (such as an air temperature coupled to the back side of the wall through a convective resistance). However by specifying the convective resistance of the back side of the boundary wall to zero, the Type56 zone model assumes that the boundary temperature specified is the back-side surface temperature of the boundary wall – which is exactly what one needs for the interface between the soil storage model and the Type56 zone model to work correctly. Figure 1 depicts the front and back side temperatures used by the combination of Type56 and this slab model.

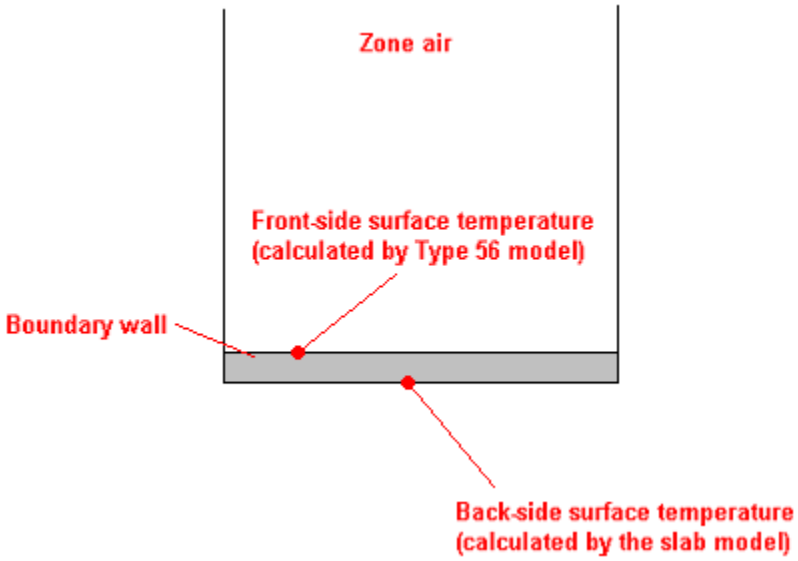


Figure 1: Boundary Wall Definition

To use Type703, one defines the slab floor in Prebid as a boundary wall with a "user defined" temperature as an input (as opposed to as a schedule or a constant value), and with a back-side heat transfer coefficient of zero. The boundary wall should contain all the layers comprising the wall (carpeting, pad, concrete etc.). The user will also have to specify that one of the outputs from Type56 is the temperature of the slab surface. The user then connects the slab surface temperature from Type56 to the slab model's input and connects the first output of the slab model back to the boundary wall temperature required by Type56. Note that the slab's thermal properties are not specified in Type703; these are accounted for within Type56 and by the definition of the slab as a boundary wall. In essence Type703 does not calculate any of the thermal behavior of the slab, it takes the temperature at the

slab/zone air boundary from Type56 and computes the slab/soil boundary temperature required by Type56.

2. Slab and Surroundings

Type703 divides the slab and its surroundings into three parts. First is the slab itself, for which the user specifies the length and width as shown in Figure 2.

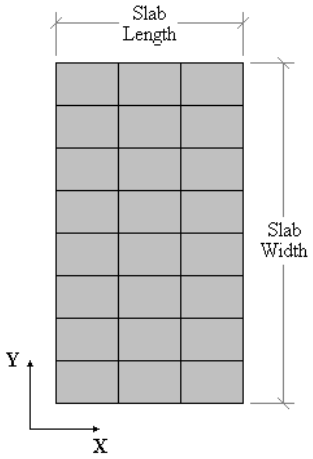


Figure 2: Slab Dimensions and Coordinate System

Note that while the user does specify the number of nodes in the x and y directions, these are used ONLY for sizing the soil nodes beneath the slab. This model does not perform any thermal computations on the slab itself, leaving those to the building model to which it is attached during a given simulation.

The slab is assumed to be sitting on top of soil, for which the user must specify the thermal properties. It is assumed that the edge of the slab is adiabatic, and that consequently, no heat transfer occurs between the edges of the slab and the surroundings. The soil volume surrounding the slab in the x, y and z directions as shown in Figure 3 is referred to as the near-field. Nodes contained in the near-field can vary in size in all three dimensions (user-specified), usually becoming larger as they get farther from the slab, and are included in the slab energy balance. The near field is in turn surrounded by the far field, which is assumed to be an infinite energy sink/source (energy transfer with the far-field does not result in a temperature change of the far-field). Users have a number of options as to how they wish to treat the soil in both the near and far fields as discussed in Section 3.

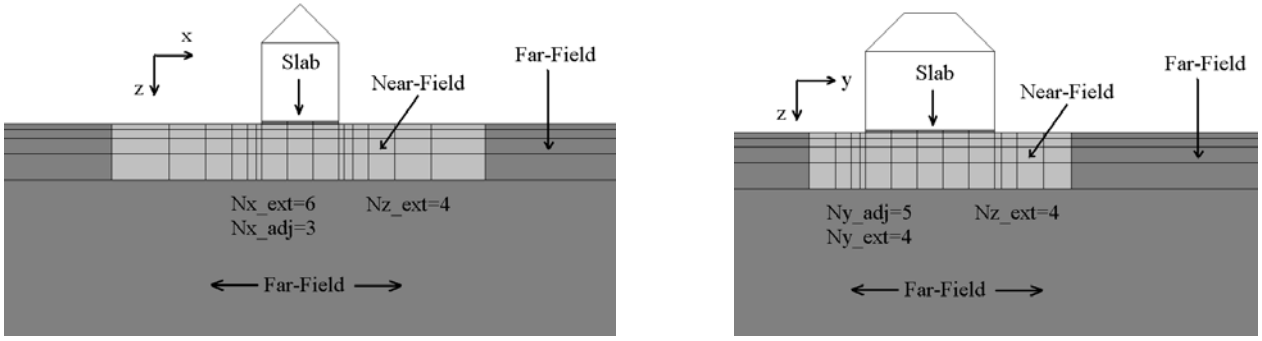


Figure 3: Slab, Near and Far Field Dimensions

The sizes of the soil nodes directly beneath the slab in the x and y-directions are automatically determined by the length and width of the slab, and by the user-specified number of nodes along the length and width of the slab. For near-field soil nodes, the user not only specifies how many nodes are to be considered in the x, y, and z-directions beyond the slab, but the length, width and depth of the nodes starting at the slab-to-soil boundary and moving outwards and downwards.

3. Ground Temperature Options

Users are asked to specify one of three near and far-field ground temperature options using Parameter 24. The same assumption is made for both the near and the far-field.

The first option is to employ an energy balance on the soil surface to calculate the surface temperature. In this option, the user provides the ambient temperature, sky temperature, and the amount of incident solar radiation on the soil surface to the model as Inputs. An energy balance is applied to the surface to determine the surface temperature, and conduction to the soil nodes provides the heat transfer to the ground from the surface. The Kasuda ground temperature profile [1] (which calculates a depth-dependent soil temperature based on the average annual surface temperature, the amplitude of the annual surface temperature, and the day of the year at which the minimum annual surface temperature occurs) sets the initial ground temperature profile for both the near-field and for the far-field.

The second option is to use the Kasuda correlation to set the surface temperature as a function of the time of the year. In the near field, the Kasuda correlation is used to set the initial temperature profile in the soil and to obtain a time dependent surface temperature. The temperature of near field soil nodes depends upon conduction effects from neighboring nodes and from conduction heat transfer from the imposed Kasuda calculated surface temperature. In the far field, the Kasuda correlation is used to set the temperature of all nodes. The temperature of these nodes will change, but only as a function of depth and time of year.

The third option is for the user to supply the surface temperature as an INPUT to the model. In both the near and far-fields, the Kasuda correlation is used to set the initial temperature profile in the soil. The near and far-field nodes then change temperature due to conduction effect from other nodes (vertical direction only in the far-field) influenced by the surface temperature provided by the user.

4. Energy Balances

The basic energy balance on a node contained in the slab or the soil is shown in Equation 1:

$$mC_p \frac{dT}{dt} = \dot{Q}_{in} - \dot{Q}_{out} \qquad \text{(Eq. 703.1)}$$

The equations describing Q_{in} and Q_{out} change depending upon the type of node and its location. Three types of nodes exist: internal nodes, boundary nodes (between the slab and the near field or between the near field and the far field for example), and surface nodes.

4.1 Internal Slab/Soil Nodes

If a node is contained entirely within the near field and does not border either the far field or the slab itself, its energy balance is made up of purely conductive terms. The equations for Q_{in} and Q_{out} are:

$$\dot{Q}_{in} = \frac{k_{soil}\, dy\, dz}{x_i - x_{i-1}}\left(\overline{T}_{x-1,y,z} - T_{x,y,z}\right) + \frac{k_{soil}\, dx\, dz}{y_i - y_{i-1}}\left(\overline{T}_{x,y-1,z} - T_{x,y,z}\right) + \frac{k_{soil}\, dx\, dy}{z_i - z_{i-1}}\left(\overline{T}_{x,y,z-1} - T_{x,y,z}\right) \quad \text{(Eq. 703.2)}$$

$$\dot{Q}_{out} = \frac{k_{soil}\, dy\, dz}{x_{i+1} - x_i}\left(T_{x,y,z} - \overline{T}_{x+1,y,z}\right) + \frac{k_{soil}\, dx\, dz}{y_{i+1} - y_i}\left(T_{x,y,z} - \overline{T}_{x,y+1,z}\right) + \frac{k_{soil}\, dx\, dy}{z_{i+1} - z_i}\left(\overline{T}_{x,y,z} - T_{x,y,z+1}\right) \quad \text{(Eq. 703.3)}$$

It should be noted that some internal soil nodes may have an additional resistance term added because Type703 allows insulation on the perimeter of the slab to extend down below the slab as far as desired.

4.2 Boundary Nodes

Two types of boundary nodes exist: nodes on the boundary between the near and far-fields, and nodes on the boundary between the slab and the near-field.

Nodes in the near field on the boundary with the far field are governed purely by conduction. The far-field temperature to which the node conducts is not affected by energy passing from the node to the far-field, only by time of year and depth as given by the Kasuda correlation (for mode 2) or by conduction in the vertical direction (modes 1 and 3). Nodes at the bottom corners of the near field can conduct to two different far field temperatures while nodes only along the depth of the near field conduct to a single far field temperature (along the horizontal plane). The conduction length between the node and the far-field is one-half of the corresponding nodal distance. For example, the conduction length between a node along the bottom of the near-field and the far-field is dz/2.

Conduction between the near and far fields may be neglected, if desired, by setting parameters 18 and 19 to the appropriate values.

4.3 Surface Nodes

As stated in Section 1, Type703 does not require that the user specify the thermal properties of the slab itself as these are taken into account by the building model. Type703 takes the Type56 generated slab/air node interface temperature in order to calculate the temperature of the slab/soil interface (which is an Input back to the Type 56 model)

It is important to note that the surface temperature ($T_{surface}$ in Figure 4) is the same in all these calculations but that the soil node temperature ($T_{soil\ node}$ in Figure 4) change. The boundary temperatures for the top of each soil node are computed assuming that the conductivity of the slab material and the conductivity of the soil are the same.

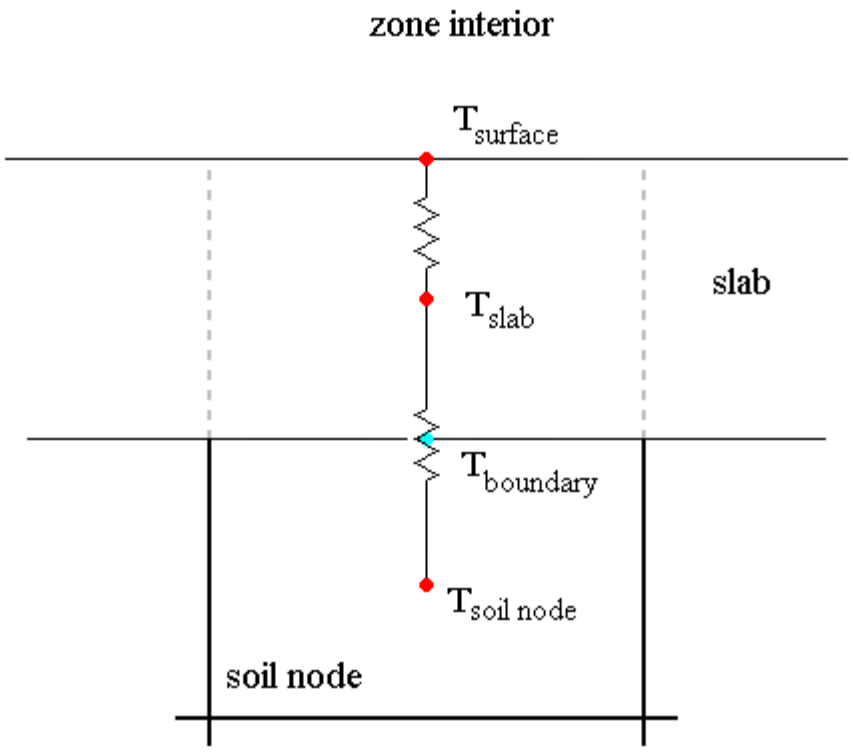


Figure 4: Energy Balance on Surface Nodes

Once the boundary temperatures are known, an area weighted average temperature is calculated and provided as output 1 of this model, which is normally connected back to the building model as an input.

5. Model Execution Speed

Because the near-field volume of soil modeled by this component is broken up into a large number of nodes, model execution speed is often significantly reduced. Execution speed can be increased by reducing the number of nodes in the near field but this in turn sacrifices accuracy. As an alternative, the convergence tolerance on the soil temperatures contained within the near-field is provided as a PARAMETER to this model. Users may plot the energy imbalance output of the model and loosen the tolerances to increase speed while making sure that the energy imbalance does not increase inordinately.

References

[1] Kasuda, T., and Archenbach, P.R. "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States", ASHRAE Transactions, Vol. 71, Part 1, 1965