FEM for Heat Transfer Problems Part5

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FEM for Heat Transfer Problems (Finite Element Method) Part 5

Case Study: Temperature Distribution of Heated Road Surface

Figure 12.20 shows a cross-section of a road with heating cables to prevent the surface of the road from freezing. The cables are 4 cm apart and 2 cm below the surface of the road. The slab rests on a thick layer of insulation, and the heat loss from the bottom can be neglected. The conductivity coefficients are kx = ky = 0.018 W/cm°C and the surface convection coefficient is h = 0.0034 W/cm°C. The latter corresponds to about a 30–35 km/hr of wind velocity. The surface temperature of the road is to be determined when the cable produces 0.080 W/cm of heat, and the air temperature is —6°C.

Modelling

Since the road is very long in the horizontal direction, a representative section shown in Figure 12.20 can be used to model the whole problem domain. The FE mesh is shown in Figure 12.21, together with boundary conditions specified.

The mesh shown in Figure 12.21 demonstrates mesh transition from an area consisting of a sparse mesh to an area of denser mesh. The analyst has chosen to mesh it this way, since the temperature distribution at the bottom of the model is not that critical. Hence, computational time is reduced as a result. The transition is done with the use of triangular elements in between larger rectangular elements and smaller rectangular elements. Note that all the elements used are linear elements, and hence the mixture of elements here is still compatible.

ABAQUS Input File

Part of the ABAQUS input file is shown here:

```
*HEADING
Calculation of 2D heat transfer
**
*NODE
1, 0., 6.
2, 0.5, 6.
3, 1., 6.
4, 1.5, 6.
5, 2., 6.
⋮
46, 1., 1.
47, 2., 1.
48, 1., 0.
49, 2., 0.
**
```

Nodal cards
Node ID, *x*-coordinate, *y*-coordinate.

```
*ELEMENT, TYPE=DC2D4, ELSET=QUAD
1,45,48,46,44
2,48,49,47,46
⋮
31,14,15,10,9
32,9,10,5,4
**
```

Element (connectivity) cards
Element type here is DC2D4 which represents a 2D, four-node quadrilateral, heat transfer element. (Element ID, node 1, node 2, node 3, node 4)

```
*ELEMENT, TYPE=DC2D3, ELSET=TRI
33,41,37,36
34,41,42,37
⋮
37,39,43,40
38,42,43,39
**
```

Element (connectivity) cards
Element type here is DC2D3 which represents a 2D, three nodal triangular, heat transfer element. (Element ID, node 1, node 2, node 3)

```
**
*SOLID SECTION, ELSET=QUAD, MATERIAL=ROAD
1.,
**
*SOLID SECTION, ELSET=TRI, MATERIAL=ROAD
1.,
**
```

Property cards
Define properties to the elements of sets "QUAD" and "TRI". They will have the material properties defined under "ROAD".

```
**
*MATERIAL, NAME=ROAD
**
*CONDUCTIVITY, TYPE=ISO
0.018,
**
```

Material cards
Define material properties under the name "ROAD". Thermal conductivity coefficient is being defined. TYPE=ISO represents isotropic properties.

```
**
*STEP
**
*HEAT TRANSFER, STEADY STATE
0.1, 1.
**
```

Control cards
Indicate the steady state, heat transfer analysis.

```
*ELSET, ELSET=SURFACE
11, 18, 25, 32
*ELSET, ELSET=LEFT_QUAD, GENERATE
1, 2, 1
5, 11, 1
*ELSET, ELSET=RIGHT_QUAD, GENERATE
3, 4, 1
26, 32, 1
*ELSET, ELSET=BASE
1, 3
*ELSET, ELSET=LEFT_TRI
33
*ELSET, ELSET=RIGHT_TRI
37
*NSET, NSET=SOURCE
21
```

Element sets
Group elements into sets to be referenced when defining boundary conditions.

```
**
*FILM, OP=NEW
SURFACE, F3, -6., 0.0034
**
** insulated edges
**
*DFLUX, OP=NEW
LEFT_QUAD, S4, 0.
RIGHT_QUAD, S2, 0.
BASE, S1, 0.
LEFT_TRI, S3, 0.
RIGHT_TRI, S2, 0.
```

BC cards
The keyword *FILM is used to define the heat convection properties. In the data line, the first input refers to the element set SURFACE, the second refers to the surface or edge the convection is occurring, the fourth is the sink temperature, and lastly, the convection coefficient.

*DFLUX is for specifying distributed heat flux. In this case, the left, right and bottom edges are all insulated (= 0).

```
**
** heat source
**
*CFLUX, OP=NEW
SOURCE, 11, 0.08
```

Load cards
The load here is a concentrated heat flux or source defined by *CFLUX and applied on node 21 or node set SOURCE. Note that in this case the DOF for the temperature is defined by the number 11.

```
**
*NODE PRINT, FREQ=1
NT,
*NODE FILE, FREQ=1
NT,
**
*END STEP
```

Output control cards
Define the requested output. In this case, NT is the nodal temperature.

The information provided in the above input file is used by the software in similar ways as discussed in case studies in previous topics.

Result and Discussion

Running the above problem in ABAQUS, the nodal temperatures can be calculated. Figure 12.22 shows a fringe plot of the distribution of the temperatures in the model. It can be seen clearly how the temperature varies from a maximum at the heat source (the heating cables) to other parts of the road cross-section.

In the analysis, the temperatures at all the nodes are calculated. For this problem, we would be interested in only the temperature of the road surface. Table 12.1 shows the nodal temperature on the surface of the road. It can be seen here how the presence of the heating cables under the road is able to keep the road surface at a temperature above the freezing point of water (0°C), as shown in Table 12.1. This would prevent the build up of ice on the road surface during winter, which makes it safer for drivers on the road. The usefulness of the finite element method is demonstrated here, as there are actually many parameters involved when it comes to designing such a system. For example, how deep should the cables be buried underground; what should be the distance between cables; what amount of heat generated by the heating cables is sufficient for the purpose, and so on.

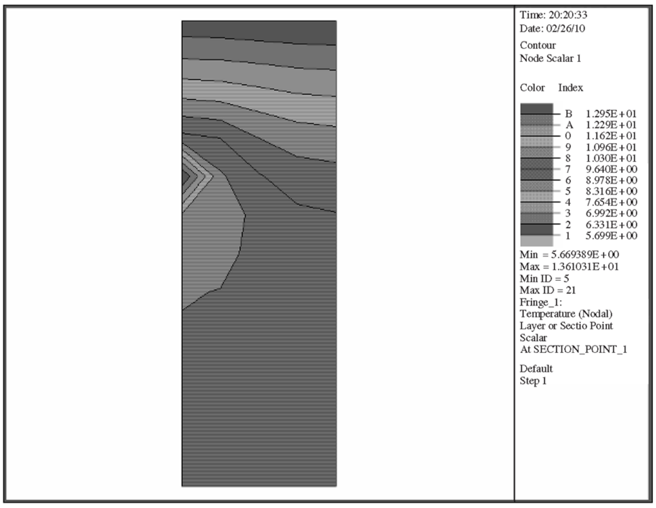

Figure 12.22. Temperature distribution of the cross-section of a road.

Table 12.1. Nodal temperatures of road surface

Node	**Temperature (^{0}C)**
1	5.861
2	5.832
3	5.764
4	5.697
5	5.669

The finite element method used here can effectively aid the engineer in deciding upon all these parameters.