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MSC NASTRAN application to prediction of heat leakage through fish hold wall section

SUMMARY

The paper presents results of the heat transfer analysis, performed with the use of MSC NASTRAN, of 14 m hold wall section of a fishing vessel. The results are compared with available experimental results as well as other computations.

Some differences revealed from the comparison and their possible sources are left to further considerations.

INTRODUCTION

The heat flow analysis presented in the paper is a pilot calculation for a further, much bigger, purpose project on thermal analysis of a large 650 000 cu fts reefer vessel. The project is supported by State Committee for Scientific Research. The main subject of the project is thermal stress determination with the effect of insulation accounted for. Temperature pattern in a refrigerated hold steel structure is the first step of solution.

Three factors significantly affect heat flow through the hold boundaries. The first is insulation thickness which varies significantly in practice. The second is penetration of steel frames which act as „thermal bridges" across the insulated section, dramatically increasing heat flow in some cases. The third factor relates to materials and fasteners for the inside liners. Sheet steel, plywood and fibreglass are common as inside liners of the hold.

Heat transfer through hold wall section was investigated in the paper [1] to improve prediction of heat leakage through fish hold boundaries of steel fishing vessels. A finite difference heat transfer model was developed and eight fish hold wall sections representative of a 14 m boat were tested by using the „guarded hot box" technique. A good agreement was obtained between the predicted and test results. Both are used as the base for verification of the research results reported in the paper.

The research was aimed at better understanding of the factors influencing thermal resistance of hold sections and better appreciation of the potential hazards of poor insulation practice. The specific task is to develop a finite element model capable of predicting the thermal resistance of hold wall sections.

METHOD OF SOLUTION

The prediction model is based upon the steady state, two dimensional heat conduction equation :

$$\frac{\partial}{\partial x}\left[k(x,y)\frac{\partial T}{\partial x}\right]+\frac{\partial}{\partial y}\left[k(x,y)\frac{\partial T}{\partial y}\right]=0 \qquad (1)$$

with convective boundary conditions on the cold and warm surfaces :

$$-k(x,y)\frac{\partial T}{\partial y}=h\left(T_s-T_a\right) \qquad (2)$$

and with adiabatic boundary conditions on the other two surfaces :

$$\frac{\partial T}{\partial x}=0 \qquad (3)$$

The problem was solved by using MSC NASTRAN Thermal Analysis Solver 153 for a finite element mesh described further, according to the User's Guide [2]. When the temperature distribution was calculated, heat flux, average cold and warm surface temperatures, thermal transmittance, panel conductance, and panel resistance were computed.

The calculations were performed for Structure 2 (Fig.1) used in the experimental verification described in [1]. The finite element mesh is shown in Fig. 2 for only one flat bar frame, assuming that no heat flow occurs between frames, acc. to (3). The mesh is equivalent to the finite difference method mesh acc. to [1], provided that each QUAD4 element is centered in an appropriate finite difference method node location.

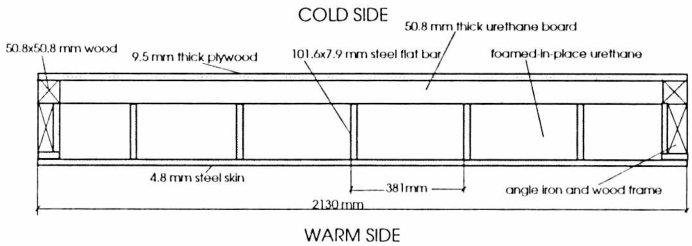

Fig.1. Structure 2 (1.78 m wide) with flat bar frames, according to [1]

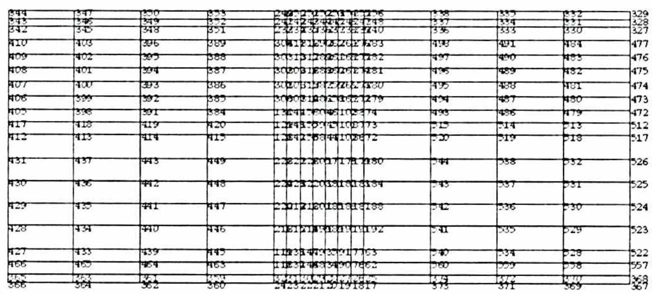

Fig.2. Finite element method mesh assumed for MSC NASTRAN analysis (direct graphic output)

All conductivity values, shown in Tab.1,were assumed identical to those given in [1].

Tab.1. Thermal conductivity values k [W/m·K]

Board Urethane	0.02
Foamed in Place Urethane	0.016
Plywood	0.1155
Steel	42.9

RESULTS OF CALCULATION

Some results of the calculations are shown in Fig.3 to 5 in the form of the so called XY-Plots.

A temperature distribution on warm and cold surfaces is shown in Fig.3 and 4, respectively. The „thermal bridge" effect which results from steel frame penetrating the insulation layer, can be observed on the diagrams. This effect, even much more pronounced, is visible in Fig.5 where the temperature distribution along steel flat bar frame is shown. Temperature is practically constant along the frame (due to very high conductivity of steel) but very large temperature gradient occurs in insulation layer above the frame depth. The thermal bridge effect due to steel frames dramatically affects thermal resistance of the side panel. For the considered panel it amounts only to 25% of the thermal resistance of the appropriate panel without frames, which was analyzed by using simple formulae from a textbook [3]. Thermal resistance of the panel can even drop by 70% if the insulation layer above frame is removed, i.e. only plywood liner exists above frame depth. As it follows from [1], the panel insulation effectiveness for the insulation having a thickness greater by 25 mm than the frame depth, was about two times greater than that for the insulation thickness equal to the frame depth.

Results of the heat transfer analysis are shown in Tab.2, together with the experimental and calculation results acc. to [1]. The thermal transmittance U (an overall value with surface convection effect included) is defined as follows :

$$U = \frac{q}{A\left(T_h - T_c\right)} \tag{4}$$

The panel conductance C which does not account for the surface convection, is defined as :

$$C = \frac{q}{A\left(T_1 - T_2\right)} \tag{5}$$

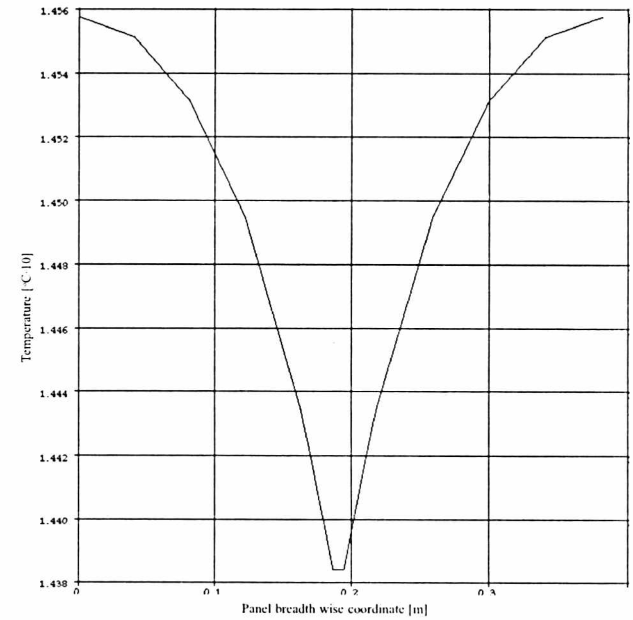

Fig.3. Temperature distribution along warm side

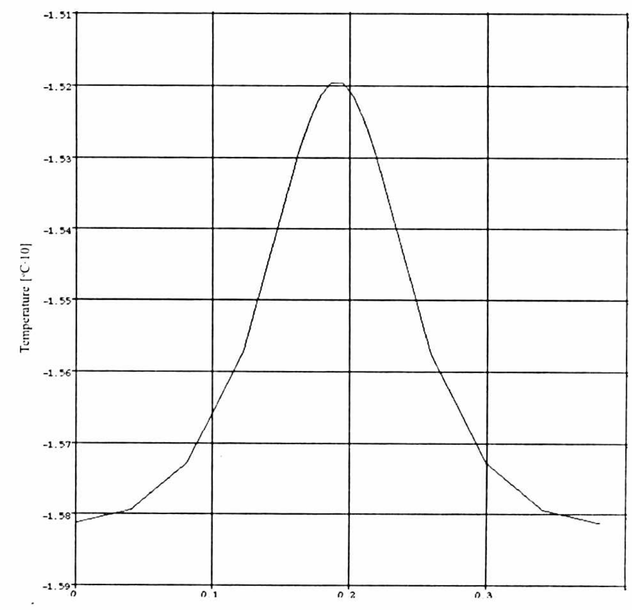

Fig.4. Temperature distribution along cold side

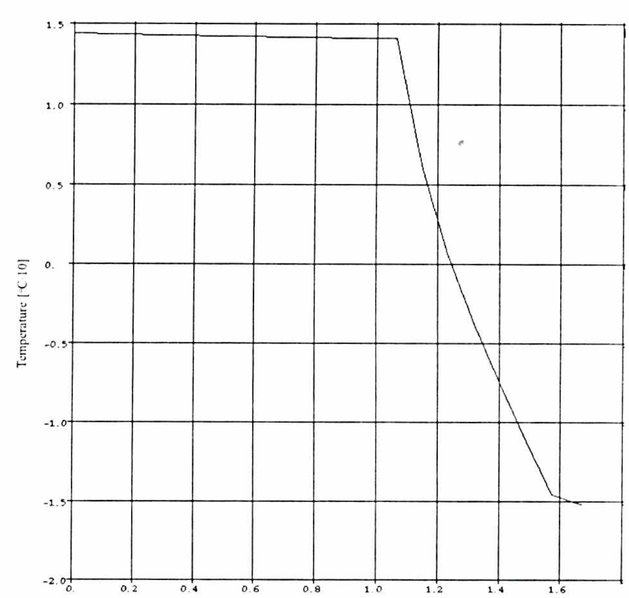

Fig.5. Temperature distribution along flat bar frame depth

Since convective resistance is different in each particular application, the thermal resistance of the panel alone, defined as :

$$R = A(T_1 - T_2)/q \qquad (6)$$

is used as the calculated value. In Tab.2 calculated values of the panel resistance are compared with panel test results.

The following test conditions are assumed for MSC NASTRAN analysis, as given in Tab.2:

- warm and cold air temperature
- warm and cold surface convection coefficient.

Moreover, in the first analysis the insulation thermal conductivity of 0.02 and 0.016 is assumed, Tab.1.

Tab.2. shows that the predicted panel resistance is almost 20% greater than the test value (NASTRAN analysis No.1) while the finite difference method result [1] is greater by 5.6% only . Unfortunately, neither actual conditions nor intermediate results concerning the analysis were published. According to [1] the resistance for heat leakage calculations should be increased by about 5% to allow for the effect of steel fasteners (which are disregarded in all numerical calculations), but it is still too little to explain the significant difference between the NASTRAN analysis and test result.

3D heat flow analysis of the same side panel, but with the third dimension, z = 890 mm (half of the panel breadth), was performed later [4]. The convective conditions (2) were also assumed at the panel boundary z = 890 mm, which was equivalent to removal of any insulation from there. Results of the analysis are shown in Tab.2 as „NASTRAN analysis No.2". This time, contrary to the 2D case, too high thermal transmittance (and too low panel resistance) is obtained, in comparison with the measurement results. This could be expected, as no heat flow was actually assumed along the boundary of z = 890 mm in the 2D analysis. During the experimental investigation, described in [1], some amount of heat flow probably took place because the average values from NASTRAN analysis No.1 and 2 well coincide with the measured values.

Tab.2. *Test conditions and results versus numerical results*

Item	Test conditions and results acc. to [1]	Numerical results acc. to [1]	NASTRAN analysis No.1 (2D case)	NASTRAN analysis No.2 (3D case*)
Heat flow rate, W/m²	5.95		5.046	6.84
Warm air temperature, °C	15.4		15.4	15.4
Cold air temperature, °C	-16.4		-16.4	-16.4
Thermal transmittance U, W/m²K	0.19		0.159	0.215
Area weighted average warm surface temp., °C	14.4		14.5	14.62
Area weighted average cold surface temp., °C	-15.5		-15.5	-15.82
Mean temperature of the panel, °C	-0.6		-0.5	-0.6
Warm surface convection coefficient, W/m²K	5.62		5.62	5.62
Cold surface convection coefficient, W/m²K	6.30		6.30	6.30
Panel conductance, C, W/m²K	0.20	0.188	0.169	0.225
Panel resistance, R, m²K/W	5.03	5.31	5.985	4.45

**) The convective condition (2) along the panel boundary z=890 mm*

CONCLUSIONS

- The thermal bridge effect due to steel frames penetrating the insulation layer dramatically affects thermal resistance of the side panel and must not be disregarded in calculations of heat leakage.

- Insulation thickness plays a very important role in the thermal performance of steel vessel wall sections.The insulation thickness equal to frame depth is critical. The best configuration is that of the insulation thickness greater by 50-60 mm than the frame depth.

- The subject of thermal conductivity of insulation needs further research because of the significant differences between the NASTRAN analysis results and both experimental and finite difference method analysis results published in [1].

NOMENCLATURE

A - area normal to heat flow, m²
C - thermal conductance, W/m²K
h - convection coefficient, W/m·K
k - thermal conductivity, W/m·K
q - heat flux, W/m²
R - thermal resistance of panel, m²K/W
R_c - contact resistance, K/W
T - temperature, °C
T_a - ambient temperature, °C
T_c - average air temperature in the point 75 mm or more apart from cold surface, °C
T_h - average air temperature, in the point 75 mm or more apart from hot surface, °C
T_s - surface temperature, °C
T_1 - area weighted average temperature of warm surface, °C
T_2 - area weighted average tempreature of cold surface, °C
U - thermal transmittance of panel, W/m²K
x,y - Cartesian coordinates

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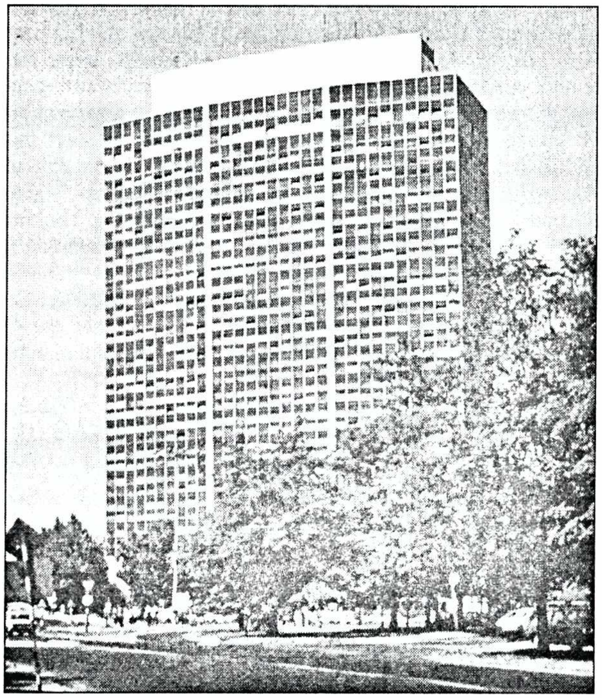
CTO



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