Temperature Effects on Tall Steel Framed Buildings

Part 1—Response of Steel Columns to Temperature Exposure

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IN TALL BUILDINGS the steel frame is usually inside the curtain wall line, so that the columns are protected from the temperature fluctuations of the weather (Fig. 1a). In this constant temperature position the length of the column remains constant and stresses due to temperature change are avoided. Many new designs place the columns on the wall line, where they are subjected to temperature variations which are a portion of the variations in the weather air temperature.

The American Iron and Steel Institute sponsored research to determine the response of columns to changes in air temperature and what effects these responses might have on dimensions and stresses.

A standard 14-in. wide flange section weighing 228 lbs per ft was selected for two columns to be exposed simultaneously.

Three column locations were used to simulate the face-exposed, semiexposed, and fully exposed locations of the column in the wall. In the first instance (Fig. 1b), only the outside flange extended beyond the wall line. In the second case (Fig. 1c), the wall line intersected the neutral axis of the column. In the fully exposed position (Fig. 1d), the entire web of the column was beyond the wall line.

The bare or uncovered columns were observed, as well as columns with covers and various arrangements of insulation and fireproofing. Temperatures were observed at numerous locations on the column (Fig. 2), after equilibrium had been attained with a warm-side air temperature of approximately 75°F and cold-side air temperatures of 20°, 0° and −20°F.

BARE COLUMNS

The bare columns are subject to the greater temperature differences between flanges. The thick steel flanges conduct the heat quite rapidly to or from the web and each flange is nearly uniform in temperature (Fig. 3). There is, however, quite a temperature drop along the web as it attempts to conduct the heat from the warm to the cold flange (Fig. 4).

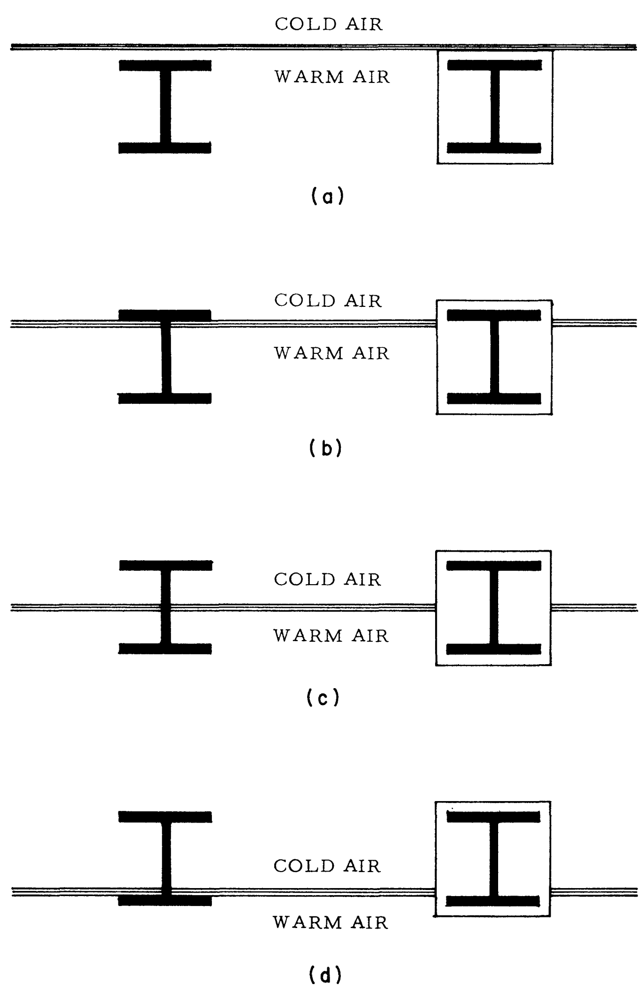

Fig. 1. Position of columns in curtain wall

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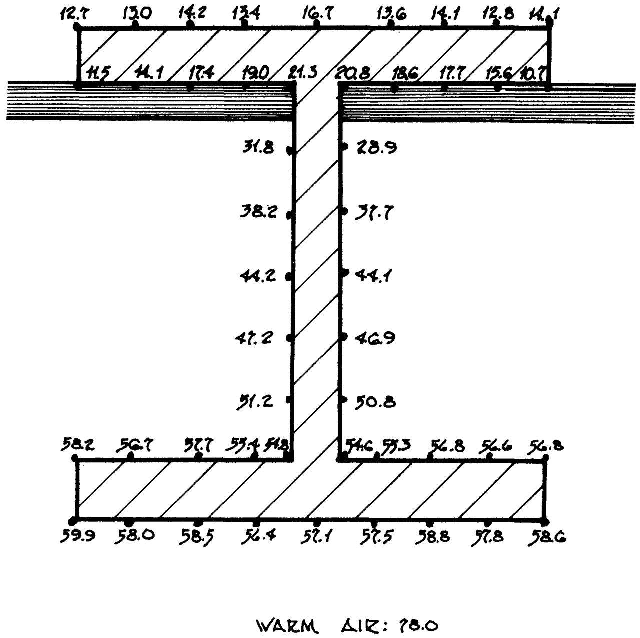

Fig. 2. Thermocouple locations and typical observed temperatures

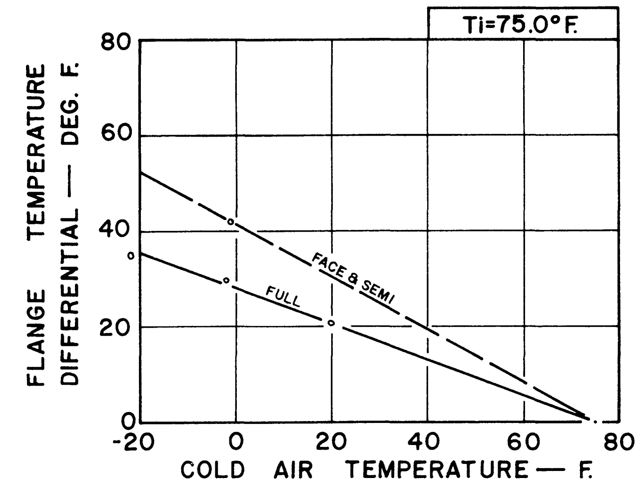

Fig. 4. Temperature differentials between flanges of bare columns

General equations have been prepared to express the various temperatures in terms of the warm-air to cold-air temperature differential and an exposure factor that recognizes the portion of the web exposed to the cold air. This exposure factor, E, is 0.00 for the face-exposed condition, 0.50 for the semiexposed condition, and 1.00 for the fully exposed condition.

The temperature difference between flanges, ΔT, is represented by the equation:

$$\Delta T = [0.55 - 0.30\,(\mathrm{E} - 0.25)^2]\,(T_i - T_0) \qquad (1)$$

The mean temperature for the flange is represented by the equation:

$$T_m = T_0 + (0.47 - 0.22\,E)\,(T_i - T_0) \qquad (2)$$

Another temperature of interest may be the temperature at the midpoint on the web, T_{wc}.

$$T_{wc} = T_0 + (0.57 - 0.42\,E)\,(T_i - T_0) \qquad (3)$$

T_{wc} and T_m are identical for the semiexposed condition, for which $E = 0.50$.

The temperature of the web at the wall line (Fig. 5) can be expressed as:

$$T_{ww} = T_0 + [0.362 - 0.24\,(E - 0.42)^2]\,(T_i - T_0) \qquad (4)$$

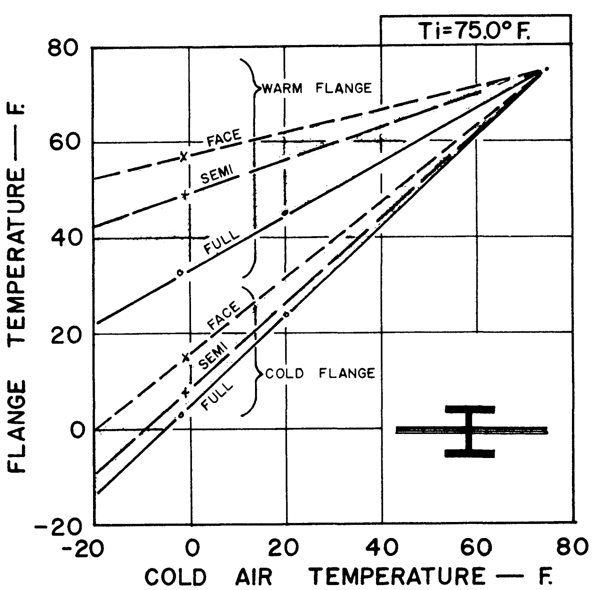

Fig. 3. Flange temperatures of bare columns.

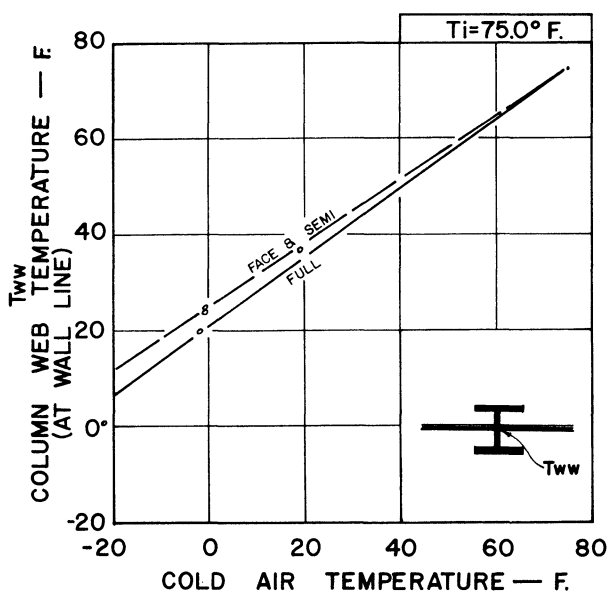

Fig. 5. Web temperatures at wall line of bare columns

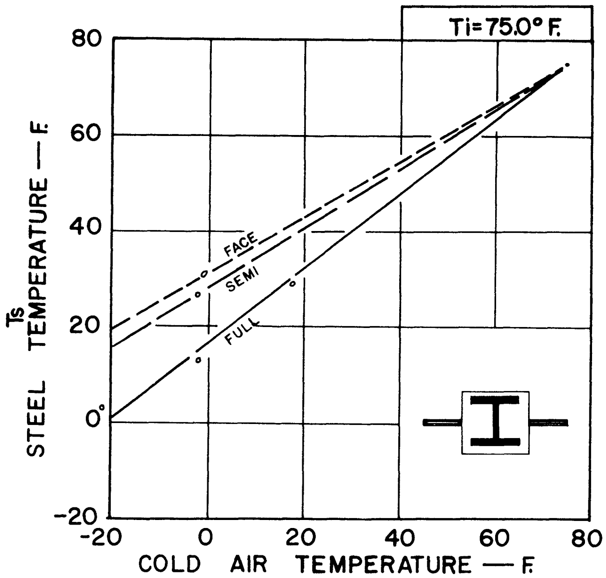

Fig. 6. Temperatures of columns with covers only

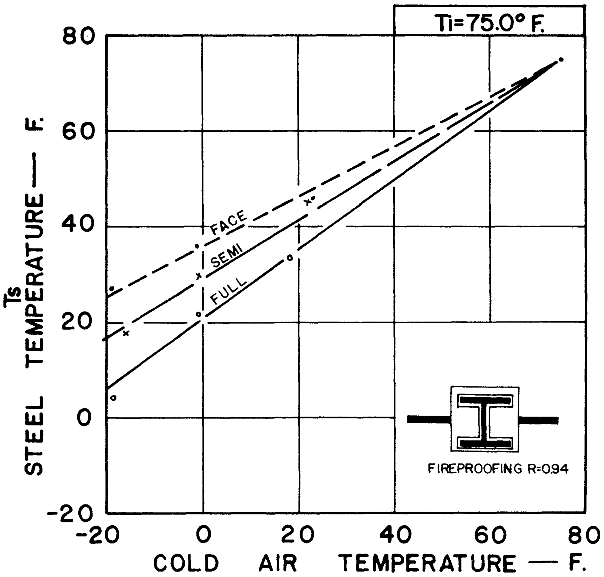

Fig. 7. Temperatures of columns with fireproofing and covers

COLUMNS WITH COVERS ONLY

Columns enclosed in sheet metal covers tend to attain a relatively uniform temperature in response to the average temperature of the air surrounding the column. The air is free to flow by convection and the average temperature is the result of the net effect of the resistance to heat flow into the cover and the resistance to heat flow out of the cover. At equilibrium the heat flow in is equal to the heat flow out. The temperature of the column (Fig. 6) is a guide to the relative magnitudes of the resistances to heat flow.

$$T_s = T_0 + [0.41 - 0.24\,(E - 0.08)^2]\,(T_i - T_0) \quad (5)$$

COLUMNS WITH FIREPROOFING

A column covered with fireproofing and a sheet metal enclosure attains a near uniform temperature throughout the steel section. Figure 7 shows the steel temperatures for a column with fireproofing having a thermal resistance of 0.94°F, sq ft, hr/Btu. The equation for this series of curves is:

$$T_s = T_0 + [0.41 - 0.30\,(E - 0.25)^2]\,(T_i - T_0) \quad (6)$$

The resistance of the fireproofing has a small effect on the temperature attained by the column (Fig. 8). The observations with the cover only represent a thermal resistance of zero in this series. The temperatures observed at zero were nearly identical to those observed with fireproofing having a resistance of 1.5°F, sq ft, hr/Btu. With fireproofing having a resistance between these two values the observed temperatures were slightly higher. A general equation for the column covered with fireproofing is:

$$T_s = T_0 + [1.14 - 0.58E^2] \times [0.434 - 0.114\,(R_f - 0.75)^2]\,(T_i - T_0) \quad (7)$$

where R_f is the thermal resistance of the fireproofing in deg F, sq ft, hr/Btu

INSULATION ON THE COLD COVER

Adding insulation to the cold cover will increase the steel temperature further (Fig. 9). Adding a layer of fibrous glass having a thermal resistance of 4.2°F, sq ft, hr/Btu (R_f = 0.94 for fireproofing) produced a combination for which the equation is:

$$T_s = T_0 + [0.522 - 0.14\,(E + 0.107)^2] \times [1.10 - 0.222\,(R_f - 0.675)^2]\,(T_i - T_0) \quad (8)$$

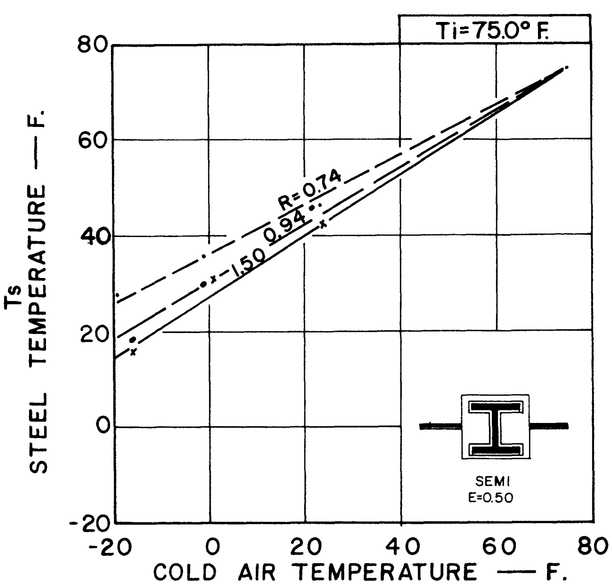

Fig. 8. Temperatures of columns with fireproofing having several different thermal resistances

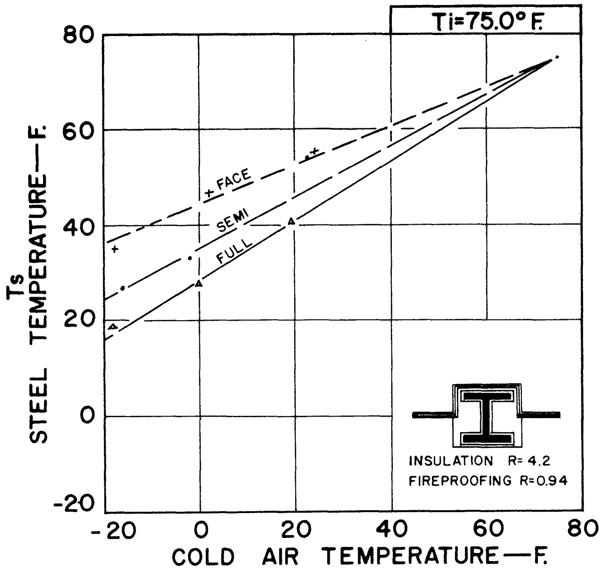

Fig. 9. Temperatures of columns with fireproofing (R = 0.94) and insulation (R = 4.2) on the cold cover, three exposures.

Insulating the cold cover when there is no fireproofing on the column produces similar steel temperatures. Observations for the face-exposed and the semiexposed exposures indicate a simplified equation:

$$T_s = T_0 + [0.522 - 0.14\,(E + 0.107)^2]\,(T_i - T_0) \qquad (9)$$

Observations were not made on a full exposure.

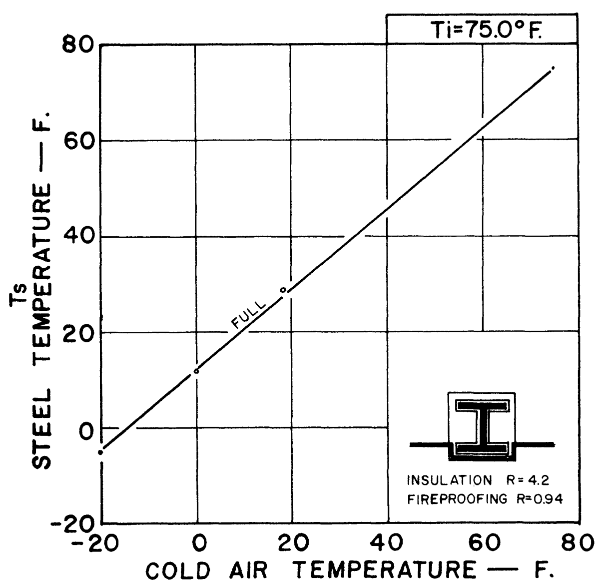

Fig. 10. Temperatures of columns with insulation on the warm cover

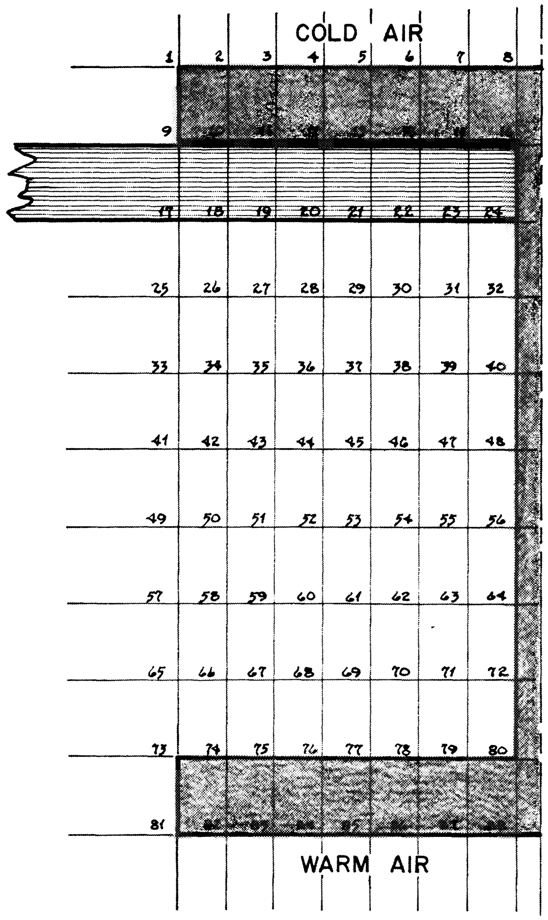

Fig. 11. Grid used in computer analysis

INSULATION ON THE WARM COVER

Adding insulation to the warm cover depresses the steel temperature (Fig. 10). Observations on a fully exposed column with fireproofing, R_f = 0.94, and insulation, R = 4.2, on the warm cover indicate the equation:

$$T_s = T_0 + 0.17\,(T_i - T_0) \qquad (10)$$

In this case the steel experiences a temperature change equal to 83 percent of the change in the cold air temperature.

COMPUTATION PROGRAM

An attempt was made to calculate the steel temperatures by a method of finite differences, using a grid (Fig. 11) and expressing the heat flow as an equation at each of 88 points. The 88 equations were solved simultaneously. The temperatures at points along the flanges and the web are shown in Fig. 12. The calculated temperatures are solid dots. For comparison, the observed temperatures are plotted as open circles. To attain the degree of agreement shown, several adjustments were required and the surface conductances finally used ap-

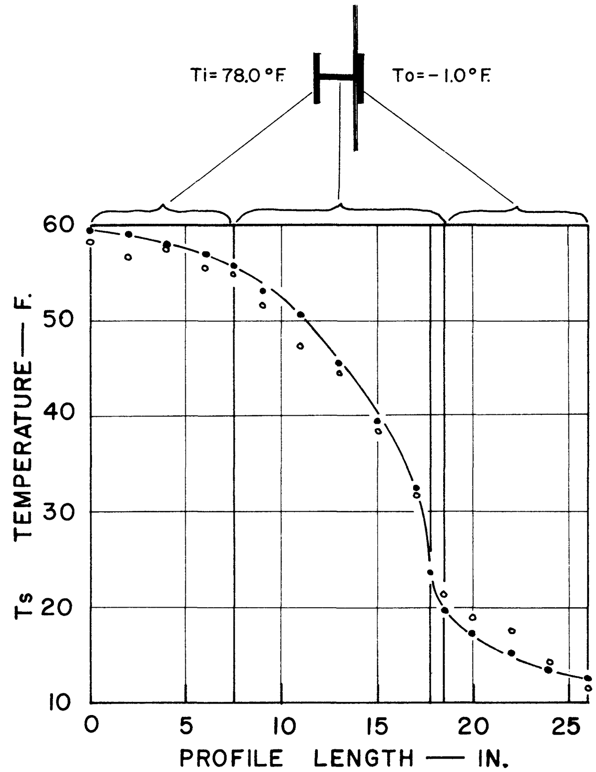

Fig. 12. Comparison of steel temperatures, calculated and observed.

pear to be low on the warm surface and high on the cold surface. More detailed information is required to refine this approach.

CONCLUSION

The temperature attained by a steel column in response to changes in the weather air temperature is influenced primarily by the thermal resistance of the materials surrounding the column. Any material added between the warm air and the column depresses the column temperature in cold weather, and it is difficult to counterbalance this effect with material between the column and the cold air. This is particularly true where the major portion of the column web extends beyond the wall line. The information developed is a guide to the order of magnitude of the temperature changes to be expected.

Curves have been presented for various exposures based on an inside air temperature of 75°F. Where observations were made with air at slightly warmer temperatures, adjustments to 75°F were made during the development of the coefficients for the equations. The general equations permit the calculation of column temperatures under the influence of any combination of indoor and outdoor temperatures.