REPORT

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Calculation under fire conditions of the capacity of roofing system, Areco TP200-350

(1 appendix)

Executive Summary and Conclusions

This report details the results and the calculation method used to determine the capacity of the ARECO TP200-350 roof product under fire conditions. The approach taken was analytical, and comprised the following stages:

- determining the temperature of the steel using a finite difference approximation accounting for both radiation and convection and based on a standard fire
- calculating the tensile capacity of the deck based on the temperature dependent yield strength of steel
- calculating the maximum load which the deck is capable of supporting in a catenary

The approach taken is in line with EN 1991:2009 Actions on Structures - Part 1-2 Actions on Structures Exposed to Fire and on EN 1993:2005 Design of Steel Structures - Part 1-2 General Rules, Structural Fire Design. The calculation method used is described in Appendix 1. The scope of the study was limited to the spans and thicknesses reported in the Areco TP200-350 information sheet. The deck is shown schematically in Figure 1.

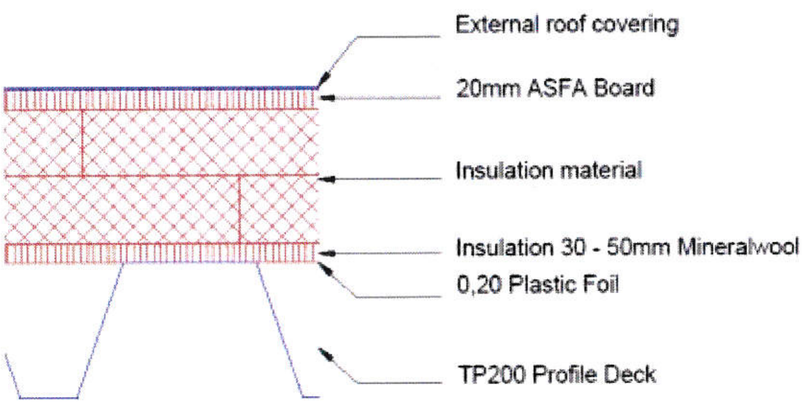

Figure 1 – Principle of insulation of TP200-350 roofing system

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The membrane effect used in the calculation is based upon the tensile resistance of the deck which is mobilized by large displacements which occur under fire – leading to the 'hanging cable effect', Figure 2. For the tensile forces to be available the connection at the vertical support needs to be protected so that it provides horizontal restraint. It is assumed in this study that adequate protection is provided to the connections.

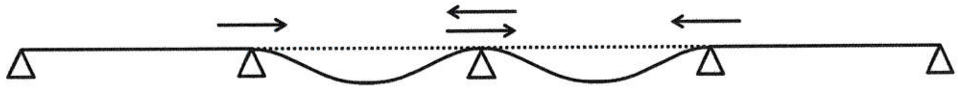

Figure 2 – Principle of the membrane action which supports the load on the roof

It is assumed in the calculation that the upper surface of the steel is adiabatic. This is a conservative assumption that has been made since the insulation material is not provided as part of the roof deck and therefore no information is available on the thermal properties of the materials. The limiting factor for insulation materials is therefore the self-weight rather than the thermal properties.

In order to make use of the bearing capacity in fire, the connections and roofing members should be protected internally and the underside of the deck should be protected a minimum of 500mm on either side of the connection detail, Figure 3. The end bays should be protected in their entirety since there are no adjacent bays to provide horizontal support to the membrane mechanism. The thickness and density of fire protection provided should be consistent with the fire resistance which the roof is being designed for. The supplier of the protection material should provide details of the thickness required and this will vary with the material used.

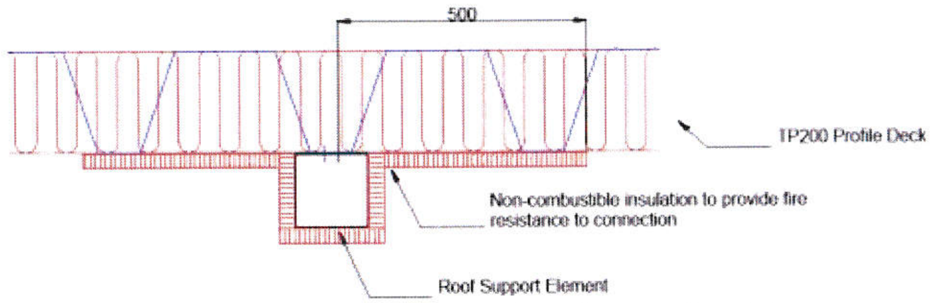

Figure 3 – Principal for protection of connection detail

The results of the study are presented in Tables 1 to 3.

Table 1 shows the capacity for various spans and thicknesses at different fire exposure times of the TP200-350 roof deck. Table 2 shows the maximum deflection of the TP200-350 as a lower bound based on the thermal loading only and is therefore presented for various spans at different fire exposure times – since mechanical loading is not included in this deflection the thickness of the deck is not a factor in this calculation. Table 3 shows the horizontal loading of the TP200-350 at the supports for different thicknesses as a result of the membrane mechanism.

Thickness	Fire resistance	Capacity kN/m²											
		Span											
		4.2	4.5	4.8	5.1	5.4	5.7	6	6.3	6.6	6.9	7.2	7.5
0.7	R15	10.94	10.21	9.57	9.01	8.51	8.06	7.65	7.29	6.96	6.66	6.38	6.12
0.7	R30	5.52	5.15	4.83	4.54	4.29	4.06	3.86	3.68	3.51	3.36	3.22	3.09
0.7	R60	3.30	3.08	2.89	2.72	2.57	2.43	2.31	2.20	2.10	2.01	1.93	1.85
0.8	R15	12.56	11.72	10.99	10.34	9.77	9.25	8.79	8.37	7.99	7.64	7.33	7.03
0.8	R30	6.31	5.89	5.52	5.20	4.91	4.65	4.42	4.21	4.02	3.84	3.68	3.54
0.8	R60	3.78	3.52	3.30	3.11	2.94	2.78	2.64	2.52	2.40	2.30	2.20	2.11
0.9	R15	14.39	13.43	12.59	11.85	11.19	10.60	10.07	9.59	9.16	8.76	8.39	8.06
0.9	R30	7.21	6.72	6.30	5.93	5.60	5.31	5.04	4.80	4.59	4.39	4.20	4.03
0.9	R60	4.30	4.02	3.77	3.54	3.35	3.17	3.01	2.87	2.74	2.62	2.51	2.41
1	R15	15.95	14.88	13.95	13.13	12.40	11.75	11.16	10.63	10.15	9.71	9.30	8.93
1	R30	7.96	7.43	6.96	6.55	6.19	5.86	5.57	5.30	5.06	4.84	4.64	4.46
1	R60	4.75	4.43	4.15	3.91	3.69	3.50	3.32	3.17	3.02	2.89	2.77	2.66
1.2	R15	19.30	18.02	16.89	15.90	15.01	14.22	13.51	12.87	12.28	11.75	11.26	10.81
1.2	R30	9.56	8.92	8.36	7.87	7.44	7.04	6.69	6.37	6.08	5.82	5.58	5.35
1.2	R60	5.69	5.31	4.98	4.69	4.43	4.19	3.98	3.79	3.62	3.46	3.32	3.19
1.5	R15	24.37	22.75	21.33	20.07	18.96	17.96	17.06	16.25	15.51	14.84	14.22	13.65
1.5	R30	11.92	11.12	10.43	9.81	9.27	8.78	8.34	7.94	7.58	7.25	6.95	6.67
1.5	R60	7.07	6.60	6.19	5.82	5.50	5.21	4.95	4.72	4.50	4.31	4.13	3.96

Table 1 – ARECO TP200-350 Capacity under fire conditions

Fire resistance	Deflection m											
	Span											
	4,2	4,5	4,8	5,1	5,4	5,7	6	6,3	6,6	6,9	7,2	7,5
R15	0,241	0,258	0,276	0,293	0,310	0,327	0,345	0,362	0,379	0,396	0,414	0,431
R30	0,258	0,277	0,295	0,313	0,332	0,350	0,369	0,387	0,406	0,424	0,443	0,461
R60	0,274	0,293	0,313	0,332	0,352	0,372	0,391	0,411	0,430	0,450	0,469	0,489

Table 2 – ARECO TP200-350 deflection under fire conditions (lower bound based on thermal loading only)

Thickness	Fire resistance	Horizontal Reaction kN
0.7	R15	99.99
0.7	R30	47.12
0.7	R60	26.60
0.8	R15	114.91
0.8	R30	53.94
0.8	R60	30.41
0.9	R15	131.75
0.9	R30	61.57
0.9	R60	34.67
1	R15	146.07
1	R30	68.00
1	R60	38.25
1.2	R15	177.07
1.2	R30	81.73
1.2	R60	45.86
1.5	R15	224.08
1.5	R30	101.94
1.5	R60	56.99

Table 3 – ARECO TP200-350 horizontal reaction for different thickness of roof deck at different exposure times

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Appendix (3 pages)

Appendix 1 - Calculation Method

A.1 Thermal response

The thermal response is calculated based on EN1991-1-2:2009. The temperature time curve used is that for a standard fire, EN 1363-1. Because of the insulation on the steel deck, heat losses to ambient are ignored. The total heat flux to the surface is given by:

$$\dot{q}_{net} = \dot{q}_c + \dot{q}_{rad}$$

The convective heat flux is given by:

$$\dot{q}_c = h_c(\theta_f - \theta_s)$$

Where h_c is the convective heat transfer coefficient, $25W/m^2K$ according to Eurocode 1, θ_s is the steel temperature and θ_f is the fire temperature.

The radiative heat flux is given by:

$$\dot{q}_r = h_{rad}(\theta_f - \theta_s)$$

Where h_{rad} is the radiative heat transfer coefficient, $h_{rad} = \varepsilon\sigma(\theta_f^{\ 2} + \theta_s^{\ 2})(\theta_f + \theta_s)$, ε is the emissivity of the steel (in this case assumed to be 0.8) and σ is the Stefan Boltzman constant.

The temperature in the steel, θ_s, may then be obtained from the forward difference approach:

$$\theta_s(t + \Delta t) = \frac{\dot{q}_{net}\Delta t}{\rho_s c_{ps} d_s} + \theta_s(t) \quad [1]$$

ρ_s, c_{ps} and d_s are the density, the specific heat and the thickness of steel respectively.

A.2 Tensile Capacity

The membrane capacity is based upon the tensile resistance of the roof deck. This means that all bending, or flexural capacity, is ignored in the calculation and the determination of the capacity is based upon the ability of the roof to 'hang' in tension. This means that there are large horizontal 'pull-in' forces generated at the supports. These forces are restrained by adjacent roof deck panels which generate equivalent forces in adjacent bays.

From Eurocode 3, the resistance of a tension member in fire conditions is given by:

$$T(\theta) = k_{y,\theta}T_{amb} \quad [2]$$

where T_{amb} is the tensile resistance of the member at ambient, and $k_{y,\theta}$ is the reduction factor of the yield stress at temperature θ.

A.3 Mechanical Response

The roof deck deflected shape and boundary conditions is shown in Figure A1. The deflection is labelled δ and varies with position (x) along the span. The maximum deflection, δ_{max}, occurs at the mid span. Based on the temperature alone, the total length, L_T, is given by:

$$L_T = L(1 + \alpha\Delta\theta_s)$$

Where L is the original length or the length between the supports, α is the coefficient of thermal expansion and Δ θ_s is the change in temperature from ambient. Approximating the deflected shape as a quadratic, the maximum deflection is therefore given by:

Appendix A

$$\delta = L\sqrt{\frac{3}{8}\alpha\Delta\theta_s} \qquad [3]$$

At the supports, there is a horizontal reaction component as a result of the tension in the deck at midspan, there is also a vertical shear reaction as well as the resultant tension in the roof deck. The load applied, q, is constant across the deck.

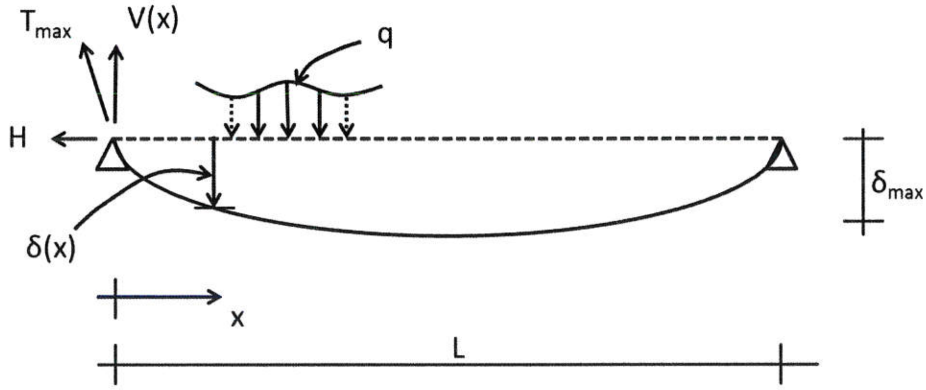

Figure A1 – The boundary conditions and deflected shape of the deck

Taking account of symmetry, and taking moments about one of the supports, the horizontal reaction in the deck can be determined to be:

$$H = \frac{qL^2}{8\delta} \qquad [4]$$

Considering the variation in shear and tension across the span, the tension in the roof system is equal to the resultant of these two forces, Figure A2. From equilibrium, the horizontal force is constant across the span of the deck. The shear force at any point, x, is given by:

$$V(x) = \frac{q(L-x)}{2}$$

The membrane force at x is given by:

$$T(x) = \sqrt{V(x)^2 + H(x)^2}$$

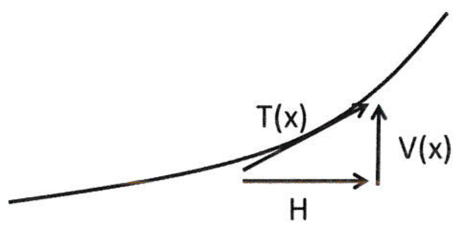

Figure A2 – Components of the force in the deck

Appendix A

At the supports of the floor, the shear force is at its highest, and therefore the membrane reaction in the roof deck is also highest, and is given by:

$$T_{max} = \sqrt{\left(\frac{qL}{2}\right)^2 + H^2} \quad [5]$$

By combining equations 4 and 5, the following expression is obtained for the maximum tension in the roof deck:

$$T_{max} = \sqrt{\frac{q^2L^2}{4} + \frac{q^2L^4}{64\delta^2}}$$

Rearranging this, the following expression for q is obtained:

$$q = \sqrt{\frac{{T_{max}}^2}{\left(\frac{L^2}{4} + \frac{L^4}{64\delta^2}\right)}} \quad [6]$$

Inserting into Equation 6 the maximum deflection and the maximum resistance of the deck calculated as a tension member, as shown above, we obtain the ultimate capacity of the deck, q_{ult}.

A.4 References

1. Areco TP200 Information Data Sheet
2. EN 1991:2009 Actions on Structures - Part 1-2 Actions on Structures Exposed to Fire
3. EN 1993:2005 Design of Steel Structures - Part 1-2 General Rules, Structural Fire Design
4. EN 1363-1:1999 Fire resistance tests – Part 1: General requirements