SIMULATION OF FIRE EXPOSED STRUCTURES. VALIDATION OF THE PROGRAMS BISTRA & VOLTRA ACCORDING TO SP REPORT 1999:36

Contents

Introduction

This document discusses the BISTRA and VOLTRA simulation results for 8 the reference cases described in *A Scheme for Verification of Computer Codes for Calculating Temperature in Fire Exposed Structures*[1].

Reference case 1

BISTRA data B_rc1.bst
VOLTRA data V_rc1_004.vtr, V_rc1_016.vtr, V_rc1_064.vtr, V_rc1_256.vtr, V_rc1_256_dt4s.vtr

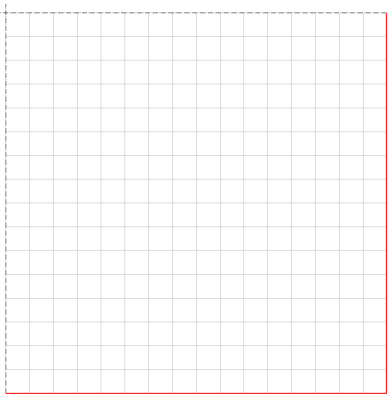

Figure 1. Geometry of case 1

Reference case 1 concerns a comparison against analytical results using constant material properties.
The geometry considered is a quadrant of a square with width 2L (Figure 1).
Material properties: constant values of λ (thermal conductivity), c (specific heat) and ρ (density).

[1] "A Scheme for Verification of Computer Codes for Calculating Temperature in Fire Exposed Structures"., Ulf Wickström, Johan Pålsson, SP REPORT 1999:36, published by the SP Swedish National Testing and Research Institute, Fire Technology, ISBN 91-7848—739-5.

Boundary conditions:
- Convective heat transfer at 2 sides of the quadrant: $q_c = h\ (T_\infty - T_s)$.

Initial temperature T_∞ = 1000 °C. T_∞ = 0 °C for t > 0 s.
- Adiabatic conditions at the opposite sides.

Required thermal diffusivity $a = \lambda/c\rho = 1$.
Required Biot number $Bi = hL/\lambda = 1$.
The following values fulfil these requirements:
λ = 210 W/mK ρ = 6 kg/m^3 c = 35 J/kgK h = 3.5 W/m^{2}K L = 60 m
The Fourier number Fo = 1 for t = 3600 s.
The centre temperature has to be calculated for an increasing number of elements: n = 4, 16, 64, 256. Figure 1 shows the grid for the case with 256 elements.
All cases were simulated using VOLTRA, using a calculation time step of 20 s (Fo/180) for the 4 grid cases considered. For the grid n = 256 a supplementary simulation is done with a time step of 4 s (Fo/900).
With BISTRA one case was simulated, using a fine grid (16718 nodes) and a time step of 2 s (Fo/1800).

T [°C] in centre	dimensionless time Fo					
	0,1	0,2	0,4	0,6	0,8	1
analytical	986,4	903,8	690,2	514,7	382,7	284,5
TASEF n=4	978	903	703	528	393	293
TASEF n=16	984	904	694	518	386	287
TASEF n=64	986	904	691	516	384	285
TASEF n=256	986	904	691	515	384	285
VOLTRA n=4, Δt=Fo/180	979,3	904	701,7	525,5	391	290,7
VOLTRA n=16,Δt=Fo/180	984,9	906,2	695,5	519,2	386,3	287,2
VOLTRA n=64,Δt=Fo/180	986,8	906,5	693,8	517,7	385,1	286,4
VOLTRA n=256,Δt=Fo/180	987,4	906,6	693,4	517,3	384,9	286,2
VOLTRA n=256,Δt=Fo/900	986,3	904,3	691,2	515,6	383,6	285,3
difference (analytical - VOLTRA)	**0,1**	**-0,5**	**-1**	**-0,9**	**-0,9**	**-0,8**
BISTRA n = 16718, Δt=Fo/1800	986,4	904	690,8	515,3	383,4	285,1
difference (analytical - BISTRA)	**0,0**	**-0,2**	**-0,6**	**-0,6**	**-0,7**	**-0,6**

Table 1. Results for case 1

Table 1 contains the analytical solution, the TASEF results, the VOLTRA results and the BISTRA results. The results show the convergence to the analytical solution with increasing number of elements.

Reference case 2

BISTRA data B_rc2_a.bst, B_rc2_b.bst, B_rc2_c.bst
VOLTRA data V_rc2_a.vtr, V_rc2_b.vtr, V_rc2_c.vtr

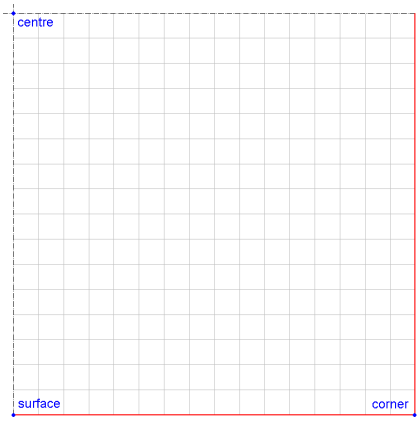

Figure 2. Geometry of case 2

Reference case 2 concerns non-linear boundary conditions and constant material properties.
The geometry considered is a quadrant of concrete column with a half width L = 0.1 m (Figure 2).

Constant material properties:
thermal conductivity $\lambda = 1$ W/mK specific heat c = 1000 J/kgK density $\rho = 2400$ kg/m^3.
Boundary conditions:

- Radiative and convective heat transfer at 2 sides of the quadrant:
  $q = \varepsilon\sigma(T_f^4 - T_s^4) + h_c (T_f - T_s)$ emissivity $\varepsilon = 0.8$
  0 Stefan Bolzmann constant $\sigma = 5.67.10^{-8}$ W/m^{2}K^4
  convective heat transfer coefficient $h_c = 10$ W/m^{2}K
  initial temperature $T_f = 0$ °C
  alternative A constant fire temperature $T_f = 1000$ °C
  alternative B ISO 834 fire curve $T_f = 345 \log (8t + 1)$
- Adiabatic conditions at the opposite sides.

The centre temperature is calculated for 256 elements (Figure 2). As BISTRA uses a triangular grid the number of elements is slightly different.
The calculation time step used is 60 s.
An alternative C was considered: ISO 834 fire curve, doubled grid and time step 30 s.
Table 2, Table 3 and Table 4 show the TASEF, BISTRA and VOLTRA results respectively for the alternatives A, B and C. The agreement is very good. Refining the grid and the time step (alternative C) improves the already small differences.

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	942	965	976	984	989	992
corner	994	997	998	999	999	999
centre	27	216	429	594	714	799
TASEF surface	944	965	977	984	989	992
corner	997	999	999	999	1000	1000
centre	32	224	435	599	716	800
Δ surface	**2**	**0**	**1**	**0**	**0**	**0**
corner	**3**	**2**	**1**	**0**	**1**	**1**
centre	**5**	**8**	**6**	**5**	**2**	**1**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	942	965	976	984	988	992
corner	994	997	998	999	999	999
centre	26	215	428	594	714	798
TASEF surface	944	965	977	984	989	992
corner	997	999	999	999	1000	1000
centre	32	224	435	599	716	800
Δ surface	**2**	**0**	**1**	**0**	**1**	**0**
corner	**3**	**2**	**1**	**0**	**1**	**1**
centre	**6**	**9**	**7**	**5**	**2**	**2**

Table 2. Results for case 2, alternative A

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	718	872	952	1005	1045	1077
corner	803	919	982	1027	1061	1088
centre	9	125	313	491	638	756
TASEF surface	723	873	952	1006	1046	1077
corner	811	922	984	1028	1062	1089
centre	10	128	315	492	639	756
Δ surface	**5**	**1**	**0**	**1**	**1**	**0**
corner	**8**	**3**	**2**	**1**	**1**	**1**
centre	**1**	**3**	**2**	**1**	**1**	**0**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	718	872	952	1005	1045	1077
corner	805	919	983	1027	1061	1089
centre	8	124	312	490	638	756
TASEF surface	723	873	952	1006	1046	1077
corner	811	922	984	1028	1062	1089
centre	10	128	315	492	639	756
Δ surface	**5**	**1**	**0**	**1**	**1**	**0**
corner	**6**	**3**	**1**	**1**	**1**	**0**
centre	**2**	**4**	**3**	**2**	**1**	**0**

Table 3. Results for case 2, alternative B

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	720	872	952	1005	1045	1077
corner	807	920	983	1027	1061	1089
centre	9	126	314	491	639	757
TASEF surface	723	873	952	1006	1046	1077
corner	811	922	984	1028	1062	1089
centre	10	128	315	492	639	756
Δ surface	**3**	**1**	**0**	**1**	**1**	**0**
corner	**4**	**2**	**1**	**1**	**1**	**0**
centre	**1**	**2**	**1**	**1**	**0**	**-1**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	720	872	952	1005	1045	1077
corner	808	920	983	1027	1061	1089
centre	9	126	313	491	639	756
TASEF surface	723	873	952	1006	1046	1077
corner	811	922	984	1028	1062	1089
centre	10	128	315	492	639	756
Δ surface	**3**	**1**	**0**	**1**	**1**	**0**
corner	**3**	**2**	**1**	**1**	**1**	**0**
centre	**1**	**2**	**2**	**1**	**0**	**0**

Table 4. Results for case 2, alternative C

Reference case 3

BISTRA data B_rc3_a.bst, B_rc3_b.bst
VOLTRA data V_rc3_a.vtr, V_rc3_b.vtr

Reference case 3 is identical to case 2, but the thermal conductivity is varying bi-linearly with temperature:

$\lambda_{(T=0)}$ = 1.5 W/mK, λ_{200} = 0.7 W/mK, λ_{1000} = 0.5 W/mK.

2 alternatives are considered:

alternative A with a constant fire temperature
alternative B with the ISO 834 fire curve.

Table 5 and Table 6 show the TASEF, BISTRA and VOLTRA results respectively for the alternatives A and B. The agreement is very good.

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	955	971	979	984	987	990
corner	996	998	999	999	999	999
centre	34	135	243	364	470	560
TASEF surface	957	971	979	984	987	990
corner	999	999	1000	1000	1000	1000
centre	35	134	243	362	468	558
Δ surface	**2**	**0**	**0**	**0**	**0**	**0**
corner	**3**	**1**	**1**	**1**	**1**	**1**
centre	**1**	**-1**	**0**	**-2**	**-2**	**-2**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	955	971	979	984	987	990
corner	996	998	999	999	999	999
centre	34	135	243	363	470	560
TASEF surface	957	971	979	984	987	990
corner	999	999	1000	1000	1000	1000
centre	35	134	243	362	468	558
Δ surface	**2**	**0**	**0**	**0**	**0**	**0**
corner	**3**	**1**	**1**	**1**	**1**	**1**
centre	**1**	**-1**	**0**	**-1**	**-2**	**-2**

Table 5. Results for case 3, alternative A

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	742	884	958	1008	1046	1077
corner	808	920	983	1027	1061	1089
centre	18	101	191	301	412	512
TASEF surface	744	884	958	1009	1047	1077
corner	815	923	985	1028	1062	1089
centre	18	99	189	299	409	510
Δ surface	**2**	**0**	**0**	**1**	**1**	**0**
corner	**7**	**3**	**2**	**1**	**1**	**0**
centre	**0**	**-2**	**-2**	**-2**	**-3**	**-2**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	741	884	958	1008	1046	1077
corner	810	921	983	1027	1061	1089
centre	18	101	191	301	412	512
TASEF surface	744	884	958	1009	1047	1077
corner	815	923	985	1028	1062	1089
centre	18	99	189	299	409	510
Δ surface	**3**	**0**	**0**	**1**	**1**	**0**
corner	**5**	**2**	**2**	**1**	**1**	**0**
centre	**0**	**-2**	**-2**	**-2**	**-3**	**-2**

Table 6. Results for case 3, alternative B

Reference case 4

BISTRA data B_rc4_a.bst, B_rc4_b.bst
VOLTRA data V_rc4_a.vtr, V_rc4_b.vtr

This case is identical to case 3, but latent heat due to 5 % by weight water in the range of 100 °C to 120 °C is considered. This is simulated by using a specific heat of 5650 J/kgK in the range of 100 °C to 120 °C and of 1208 J/kgK outside this range.
Again 2 alternatives are considered: alternative A with a constant fire temperature and alternative B with the ISO 834 fire curve.

Table 7 and Table 8 show the TASEF, BISTRA and VOLTRA results respectively for the for the alternatives A and B. The agreement is very good.

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	947	964	973	978	982	985
corner	994	997	998	999	999	999
centre	17	75	101	177	301	404
TASEF surface	948	965	973	978	982	985
corner	998	999	999	1000	1000	1000
centre	17	74	101	186	303	403
Δ surface	**1**	**1**	**0**	**0**	**0**	**0**
corner	**4**	**2**	**1**	**1**	**1**	**1**
centre	**0**	**-1**	**0**	**9**	**2**	**-1**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	947	964	973	978	982	985
corner	995	997	998	999	999	999
centre	17	74	101	175	300	403
TASEF surface	948	965	973	978	982	985
corner	998	999	999	1000	1000	1000
centre	17	74	101	186	303	403
Δ surface	**1**	**1**	**0**	**0**	**0**	**0**
corner	**3**	**2**	**1**	**1**	**1**	**1**
centre	**0**	**0**	**0**	**11**	**3**	**0**

Table 7. Results for case 4, alternative A

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	725	874	951	1003	1042	1073
corner	805	919	982	1027	1061	1088
centre	9	57	98	107	236	350
TASEF surface	728	875	951	1003	1042	1073
corner	813	923	985	1028	1062	1089
centre	8	56	98	110	241	350
Δ surface	**3**	**1**	**0**	**0**	**0**	**0**
corner	**8**	**4**	**3**	**1**	**1**	**1**
centre	**-1**	**-1**	**0**	**3**	**5**	**0**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	722	874	951	1002	1041	1073
corner	806	920	983	1027	1061	1088
centre	8	56	97	106	232	346
TASEF surface	728	875	951	1003	1042	1073
corner	813	923	985	1028	1062	1089
centre	8	56	98	110	241	350
Δ surface	**6**	**1**	**0**	**1**	**1**	**0**
corner	**7**	**3**	**2**	**1**	**1**	**1**
centre	**0**	**0**	**1**	**4**	**9**	**4**

Table 8. Results for case 4, alternative B

Reference case 5

BISTRA data B_rc5_a.bst, B_rc5_a_dt10.bst, B_rc5_b.bst, B_rc5_b_dt10.bst
VOLTRA data V_rc5_a.vtr, V_rc5_a_dt10.vtr, V_rc5_b.vtr, V_rc5_b_dt10.vtr

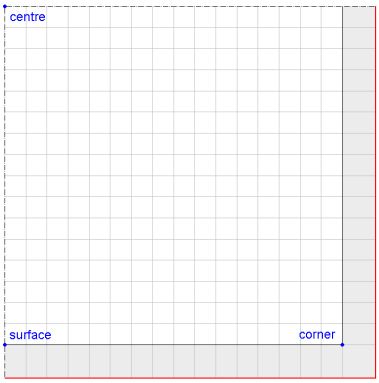

Figure 3. Geometry of case 5

In reference case 5 a detail with steel and concrete is considered.
The geometry considered is a quadrant of concrete column with a half width L = 0.1 m inside a 10 mm thick steel tube (Figure 3).
Material properties of concrete: as in reference case 4 (including latent heat).
Material properties of steel:
- Bi-linear thermal conductivity $\lambda_{(T=20)}$ = 54 W/mK, λ_{800} = 27.3 W/mK, λ_{1200} = 27.3 W/mK.
- Constant specific heat c = 600 J/kgK, constant density ρ = 7850 kg/m^3.

Boundary conditions are as specified in reference case 2 (2 alternatives).
The centre, surface and corner temperature is calculated for 256 (concrete) elements (Figure 3).
The calculation time step used is 60 s. 2 supplementary simulations use a time step of 10 s.

Table 9 and Table 10 show the TASEF, BISTRA and VOLTRA results respectively for the alternatives A and B.
Table 11 and Table 12 show the result for a time step of 10 s instead of 60 s.

The agreement is good. There is a little better agreement by taking a smaller time step.

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	935	961	971	977	982	985
corner	970	985	990	992	994	995
centre	13	69	100	155	286	391
TASEF surface	944	966	975	980	984	987
corner	975	987	991	994	995	996
centre	14	69	101	174	295	397
Δ surface	**9**	**5**	**4**	**3**	**2**	**2**
corner	**5**	**2**	**1**	**2**	**1**	**1**
centre	**1**	**0**	**1**	**19**	**9**	**6**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	941	965	975	980	984	987
corner	975	988	992	994	995	996
centre	12	68	100	150	283	389
TASEF surface	944	966	975	980	984	987
corner	975	987	991	994	995	996
centre	14	69	101	174	295	397
Δ surface	**3**	**1**	**0**	**0**	**0**	**0**
corner	**0**	**-1**	**-1**	**0**	**0**	**0**
centre	**2**	**1**	**1**	**24**	**12**	**8**

Table 9. Results for case 5, alternative A, time step 60 s

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	936	961	971	977	982	985
corner	971	985	990	992	994	995
centre	13	68	100	168	292	396
TASEF surface	944	966	975	980	984	987
corner	975	987	991	994	995	996
centre	14	69	101	174	295	397
Δ surface	**8**	**5**	**4**	**3**	**2**	**2**
corner	**4**	**2**	**1**	**2**	**1**	**1**
centre	**1**	**1**	**1**	**6**	**3**	**1**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	943	966	975	980	984	987
corner	977	988	992	994	995	996
centre	13	68	100	167	291	395
TASEF surface	944	966	975	980	984	987
corner	975	987	991	994	995	996
centre	14	69	101	174	295	397
Δ surface	**1**	**0**	**0**	**0**	**0**	**0**
corner	**-2**	**-1**	**-1**	**0**	**0**	**0**
centre	**1**	**1**	**1**	**7**	**4**	**2**

Table 10. Results for case 5, alternative B, time step 60 s

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	643	860	944	998	1038	1070
corner	690	891	967	1016	1053	1082
centre	6	48	92	103	210	328
TASEF surface	645	860	948	1001	1041	1072
corner	688	890	969	1018	1054	1083
centre	6	48	93	106	224	336
Δ surface	**2**	**0**	**4**	**3**	**3**	**2**
corner	**-2**	**-1**	**2**	**2**	**1**	**1**
centre	**0**	**0**	**1**	**3**	**14**	**8**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	650	865	948	1002	1041	1072
corner	703	897	970	1019	1055	1084
centre	5	47	92	103	208	326
TASEF surface	645	860	948	1001	1041	1072
corner	688	890	969	1018	1054	1083
centre	6	48	93	106	224	336
Δ surface	**-5**	**-5**	**0**	**-1**	**0**	**0**
corner	**-15**	**-7**	**-1**	**-1**	**-1**	**-1**
centre	**1**	**1**	**1**	**3**	**16**	**10**

Table 11. Results for case 5, alternative A, time step 10 s

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	650	860	944	998	1038	1070
corner	698	891	967	1016	1053	1082
centre	5	47	92	104	219	334
TASEF surface	645	860	948	1001	1041	1072
corner	688	890	969	1018	1054	1083
centre	6	48	93	106	224	336
Δ surface	**-5**	**0**	**4**	**3**	**3**	**2**
corner	**-10**	**-1**	**2**	**2**	**1**	**1**
centre	**1**	**1**	**1**	**2**	**5**	**2**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	659	866	949	1002	1041	1073
corner	711	897	971	1019	1055	1084
centre	5	47	92	103	218	333
TASEF surface	645	860	948	1001	1041	1072
corner	688	890	969	1018	1054	1083
centre	6	48	93	106	224	336
Δ surface	**-14**	**-6**	**-1**	**-1**	**0**	**-1**
corner	**-23**	**-7**	**-2**	**-1**	**-1**	**-1**
centre	**1**	**1**	**1**	**3**	**6**	**3**

Table 12. Results for case 5, alternative B, time step 10 s

Reference case 6

BISTRA data B_rc6_a.bst, B_rc6_b.bst
VOLTRA data V_rc6_a.vtr, V_rc6_b.vtr

This case is identical to case 5, but the concrete is replaced by mineral wool and the steel thickness is reduced to 0.1 mm.
Constant properties of mineral wool:
thermal conductivity λ = 0.05 W/mK, specific heat c = 1000 J/kgK, density ρ = 50 kg/m^3.
Because of the lower inertia, a time step of 10 s is taken.
Boundary conditions are as specified in reference case 2 (2 alternatives).

Table 13 and Table 6 show the TASEF, BISTRA and VOLTRA results respectively for the alternatives A and B. The agreement is good.

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	999	999	1000	1000	1000	1000
corner	1000	1000	1000	1000	1000	1000
centre	327	716	883	952	980	992
TASEF surface	999	999	999	1000	1000	1000
corner	1000	1000	1000	1000	1000	1000
centre	343	722	885	952	980	992
Δ surface	**0**	**0**	**-1**	**0**	**0**	**0**
corner	**0**	**0**	**0**	**0**	**0**	**0**
centre	**16**	**6**	**2**	**0**	**0**	**0**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	999	999	1000	1000	1000	1000
corner	1000	1000	1000	1000	1000	1000
centre	334	720	884	952	980	992
TASEF surface	999	999	999	1000	1000	1000
corner	1000	1000	1000	1000	1000	1000
centre	343	722	885	952	980	992
Δ surface	**0**	**0**	**-1**	**0**	**0**	**0**
corner	**0**	**0**	**0**	**0**	**0**	**0**
centre	**9**	**2**	**1**	**0**	**0**	**0**

Table 13. Results for case 6, alternative A

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
VOLTRA surface	819	924	985	1029	1062	1090
corner	821	925	986	1029	1062	1090
centre	203	560	775	900	977	1028
TASEF surface	818	924	985	1029	1062	1090
corner	820	925	986	1029	1062	1090
centre	199	556	773	899	976	1027
Δ surface	**-1**	**0**	**0**	**0**	**0**	**0**
corner	**-1**	**0**	**0**	**0**	**0**	**0**
centre	**-4**	**-4**	**-2**	**-1**	**-1**	**-1**

T [°C] in 3 points	time (min)					
	30	60	90	120	150	180
BISTRA surface	819	924	985	1029	1062	1090
corner	821	925	986	1029	1062	1090
centre	198	558	774	900	976	1028
TASEF surface	818	924	985	1029	1062	1090
corner	820	925	986	1029	1062	1090
centre	199	556	773	899	976	1027
Δ surface	**-1**	**0**	**0**	**0**	**0**	**0**
corner	**-1**	**0**	**0**	**0**	**0**	**0**
centre	**1**	**-2**	**-1**	**-1**	**0**	**-1**

Table 14. Results for case 6, alternative B

Reference case 7

BISTRA data B_rc7a.bst, B_rc7b.bst
VOLTRA data V_rc7a_08.vtr, V_rc7a_08_gridx2.vtr, V_rc7a_08_gridx4.vtr, V_rc7a_08_widthx10.vtr
V_rc7b_02.vtr, V_rc7b_04.vtr, V_rc7b_08.vtr,V_rc7b_08_gridx2.vtr, V_rc7b_08_gridx4.vtr
V_rc7b_08_gridx8.vtr, V_rc7b_08_gridx16.vtr, V_rc7b_08_gridx32.vtr, V_rc7b_08_gridx64.vtr

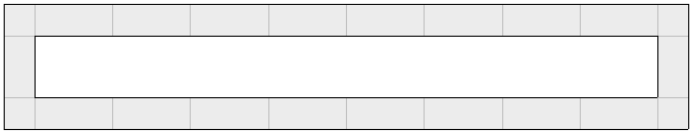

Figure 4. Geometry of case 7

In reference case 7 heat transfer in voids is considered.
A rectangular void, 100 mm x 10 mm, is surrounded by a 5 mm thick wall.
The material has a thermal conductivity λ = 1 W/mK.
The emissivity is 0.8 for all surfaces.

Steady state boundary conditions:
- Case A (± one-dimensional case):
  Short external sides with adiabatic conditions.
  Long external sides with known surface temperature: 0 °C and 1000 °C.
- Case B (two-dimensional case):
  Long external sides with adiabatic conditions.
  Short external sides with known surface temperature: 0 °C and 1000 °C.

For case A, 4 VOLTRA simulations were done:
- grid n = 8 (as shown in Figure 4)
- doubled grid
- quadrupled grid
- grid n = 8, but the void width is 1000 mm instead of 100 mm.

For case A, 1 BISTRA simulation was done using a fine grid (1774 nodes).

For case B, 9 VOLTRA simulations were done:
grid n = 2 / grid n = 4 / grid n = 8 (as shown in Figure 4) / grid n = 8, x 2 / grid n = 8, x 4 / grid n = 8, x 8 / grid n = 8, x 16 / grid n = 8, x 32 / grid n = 8, x 64.
For case B, 1 BISTRA simulation was done using a fine grid (1773 nodes).

Table 15 shows the analytical result and the TASEF, VOLTRA (4 simulations) and BISTRA results for case A. The VOLTRA solutions converge with an increasing number of elements. It does not converge exactly to the analytic solution, because the thermal bridge effect of the wall sides of the void affect the temperatures in the centre of the void. When increasing the width of the void, the agreement with the one-dimensional analytical solution becomes perfect.
The BISTRA results correspond to the VOLTRA results using a fine grid (n=8x4).

T [°C] in 2 points	1	2
analytical	779,4	220,6
TASEF n=8	779	220
VOLTRA n=8	779,0	216,9
VOLTRA n=8 x2	779,3	218,9
VOLTRA n=8 x4	779,3	219,2
VOLTRA n=8 / width = 1000 mm	779,3	220,6
BISTRA n=1774	779,4	219,1

Table 15. Results for case 7A

Table 16 shows the TASEF, the SAFIR and VOLTRA results for case B.
It can be seen that the VOLTRA solution converges with an increasing number of elements. The agreement with the TASEF and SAFIR results is reasonable, but from the VOLTRA results it is clear that the solutions based on a grid n=8 can be improved by refining the grid. This is due to the strong non-linear character of the radiation in the void. This can be seen clearly in Figure 6. Figure 5 shows the temperature at position 0 for the 3 TASEF simulations and for the 9 VOLTRA simulations. Although some more TASEF simulations would be of interest, the TASEF and VOLTRA seem to converge to the same value.
The BISTRA (Figure 6) results are almost identical to the VOLTRA results using the fine grid.

T [°C] in position [mm]	0	12,5	25	37,5	50	62,5	75
TASEF n=2	881				629		
TASEF n=4	898		748		675		499
TASEF n=8	906	820	779	723	662	587	485
SAFIR n=8	917	820	777	724	662	586	484
VOLTRA n=2	687				561		
VOLTRA n=4	806		725		633		505
VOLTRA n=8	874	822	775	724	667	597	508
VOLTRA n=8 x2	897	834	783	729	667	592	493
VOLTRA n=8 x4	906	835	782	727	663	586	484
VOLTRA n=8 x8	911	835	781	726	662	584	481
VOLTRA n=8 x16	913	835	782	726	662	583	479
VOLTRA n=8 x32	915	837	784	727	662	582	477
VOLTRA n=8 x64	917	841	789	731	663	579	472

Table 16. Results for case 7B

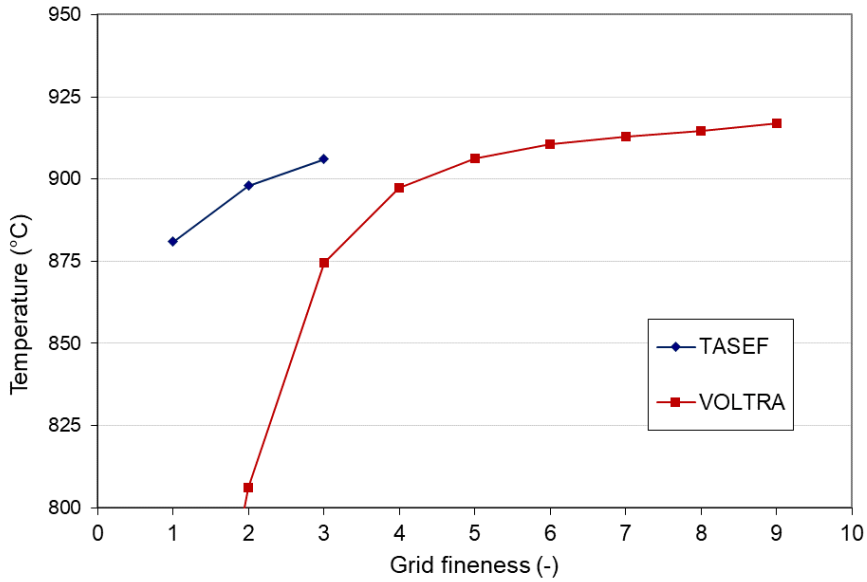

Figure 5. Temperature at position 0 mm as a function of the grid fineness.

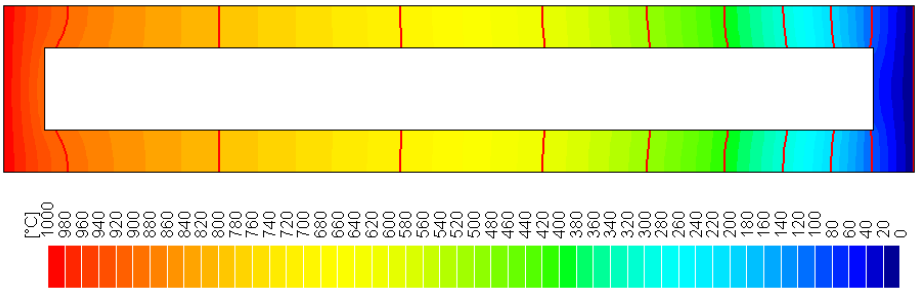

Figure 6. Temperature distribution for case 7B obtained using BISTRA.

BISTRA data B_rc8.bst
VOLTRA data V_rc8_a.vtr, V_rc8_b.vtr

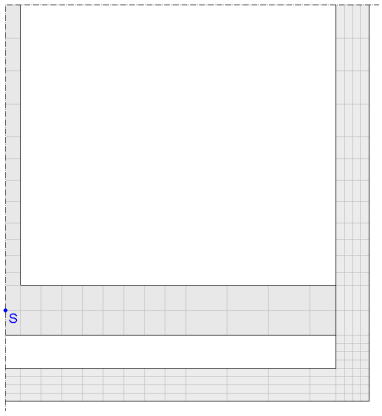

Figure 7. Geometry of case 8

In reference case 8 heat transfer an insulated steel section with 2 voids is considered.
A steel section with boards of which a quarter is shown in Figure 7 is exposed to the ISO 834 fire from all sides. The steel beam (HE200B) half height and half width are both 100 mm. The beam heart has a half thickness of 9 mm. The beam sides have a thickness of 15 mm.
Material properties of steel as in reference case 5.
Material properties of insulation board:
- Bi-linear thermal conductivity $\lambda_{(T=0)}$ = 0.174 W/mK, λ_{250} = 0.188 W/mK, λ_{1100} = 0.188 W/mK.
- Constant specific heat c = 1130 J/kgK.
- Constant density ρ = 870 kg/m^3.

The emissivity is 0.8 for all surfaces.
At the outer boundary the conditions are as in reference case 2, with initial temperature 20 °C.
For the convective heat transfer in the voids: $q_c = h_c (T_{air} - T_s)$
with uniform air temperature T_{air} in the voids
with a convective heat transfer coefficient h_c = 2 W/m^{2}K in the large void
with a convective heat transfer coefficient h_c = 1.5 W/m^{2}K in the small void.

2 VOLTRA simulations were done: a first with the grid as shown in Figure 7 and another with a doubled grid. 1 BISTRA simulation was done using a finer grid with 6584 nodes. The calculation time step used is 10 s.

Table 17 shows the temperature in the point S (Figure 7) obtained by TASEF and VOLTRA.
The agreement between the results is good but weaker compared to the previous reference cases. The agreement does not improve by doubling the grid in VOLTRA. The grid used in TASEF is quite coarse, and it would be interesting to compare the programs using finer grids.

T [°C]	time (min)			
	30	60	90	120
TASEF n=357	246	536	746	885
VOLTRA n=357	229	520	737	880
Δ n=357	17	16	9	5
VOLTRA n=357 gridx2	228	518	735	879
Δ n=357 gridx2	18	18	11	6
BISTRA n=5644	223	509	726	871
Δ BISTRA	23	27	20	14

Table 17. Results for case 8

Conclusions

- The validation of BISTRA and VOLTRA according to SP REPORT 1999:36 was performed. The data in the report suffice to do the thermal simulations.
- TASEF uses forward difference method in the time domain, while BISTRA and VOLTRA use the Crank-Nicolson finite difference method. For the time factors used with TASEF and the time steps used with BISTRA and VOLTRA, the difference in method seems not affecting the results.
- Generally spoken the agreement of the BISTRA and VOLTRA results and the TASEF results is excellent. It would be interesting to have a further study on case 8 by using a finer grid.