EN 1991-1-5 Thermal Actions

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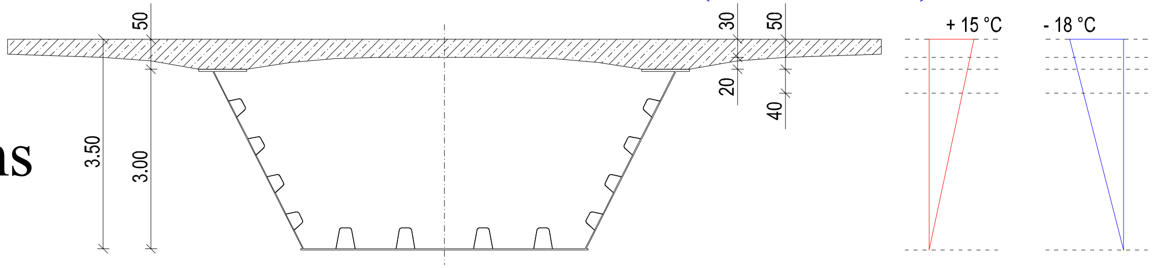
DAV 2003-11, Conversion of ENV 1991-2-5 (23 NDP)



- General
- Classification of actions
- Design situations
- Representation of actions
- Temperature changes in buildings
- Temperature changes in bridges
- Temperature changes in industrial chimneys, pipelines, etc.
- Annexes
- A – Isotherm of national temperatures (normative)
- B – Temperature differences in bridges decks (normative)
- C – Coefficients of linear expansions (informative)
- D – Temperature effects in buildings (informative)

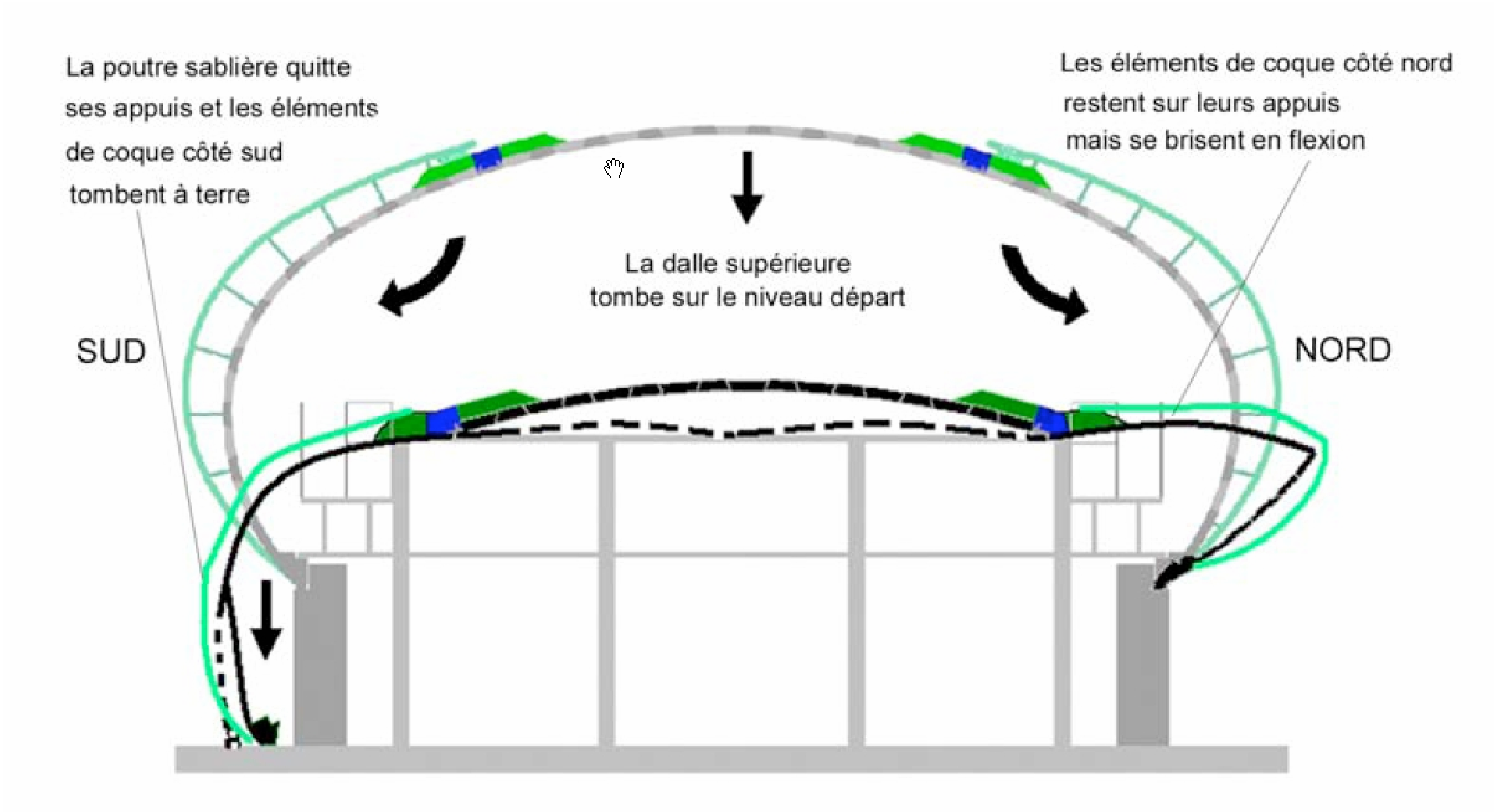
PPT file include 24 basic slides and additional (informative) slides.

Background documents

- *Background Document of New European Code for Thermal Actions*, Report No. 6, Pisa, Italy, 1999.
- Luca Sanpaolesi, Stefano Colombini, *Thermal Actions on Buildings*, Department of Structural Engineering, University of Pisa, Italy, Chapter 4 of Handbook 3, Leonardo da Vinci project CZ/02/B/F/PP-134007, 2004.
- EN ISO 6946, *Building components and building elements – Thermal resistance and thermal transmittance – Calculation methods,* 1996.
- EN ISO 13370, *Thermal performance of buildings – Heat transfer via the ground – Calculation methods*, 1998.
- ISO Technical Report 9492, *Bases for Design of Structures – Temperature Climatic Actions*, 1987.
- Emerson, M., TRRL Report 696, *Bridge temperatures estimated from shade temperatures*, UK, 1976.
- JCSS, *Probabilistic Model Code*, http://www.jcss.ethz.ch/, Zurich.

Collapse of the terminal E2 in Paris

Scheme of the collapse



Progressive weakening partly due to cracking during cycles of differential thermal movements between concrete shell and curved steel member.

Bridge in transient design situation

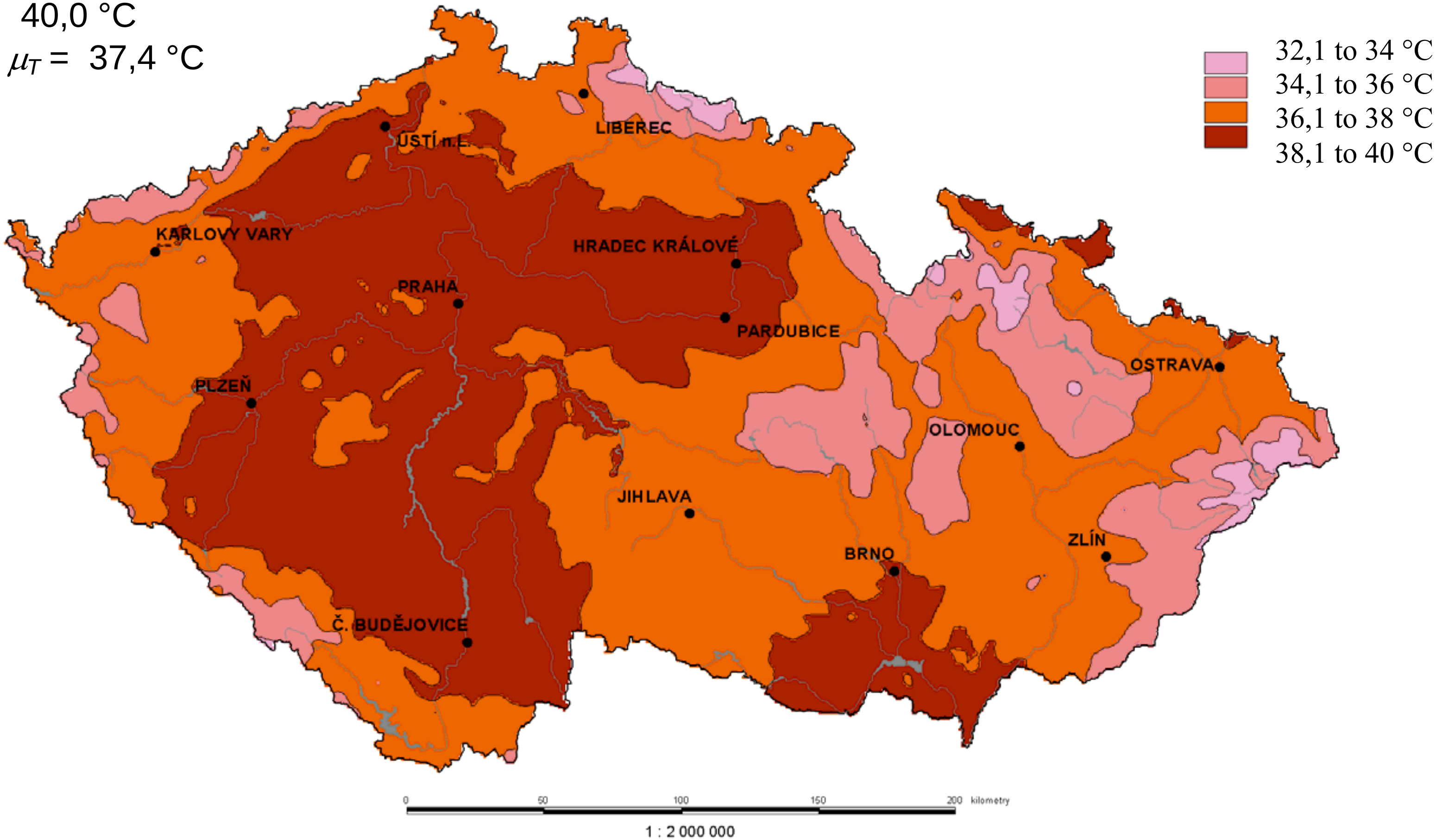
Basic principles and rules

- temperature changes are considered as variable and indirect actions
- characteristic values have probability of being exceeded 0,02 by annual extremes (return period of 50 years)
- the maximum and minimum shade air temperature measured by thermometers in a “Stevenson Screen” by the National Meteorological Service of each Member State
- thermal actions shall be considered for both persistent and transient design situations
- in special cases temperature changes in accidental design situations should be also verified

An example: map of maximum temperatures in CR

Maximum shade air temperatures of being exceeded by annual extremes with the probability of 0,02.

T_{min} = 32,1 °C
T_{max} = 40,0 °C
mean μ_T = 37,4 °C



Temperature changes in buildings

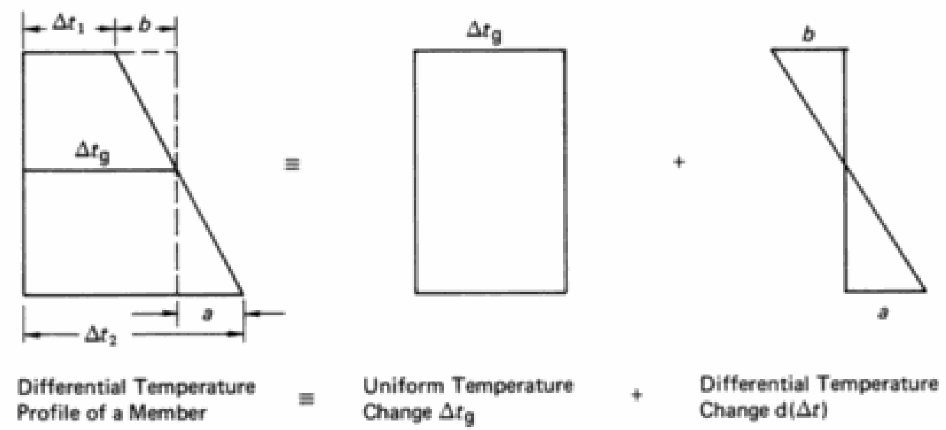
Thermal actions on buildings shall be considered when ultimate or serviceability limit state s may be affected.

Effect of thermal actions may be influenced by nearby buildings, the use of different materials, structural shape and detailing. Three basic components are usually considered:

- a uniform component ΔT_u

$$\Delta T_u = T - T_0$$

- temperature difference ΔT_M
- temperature differences of different structural parts ΔT_p

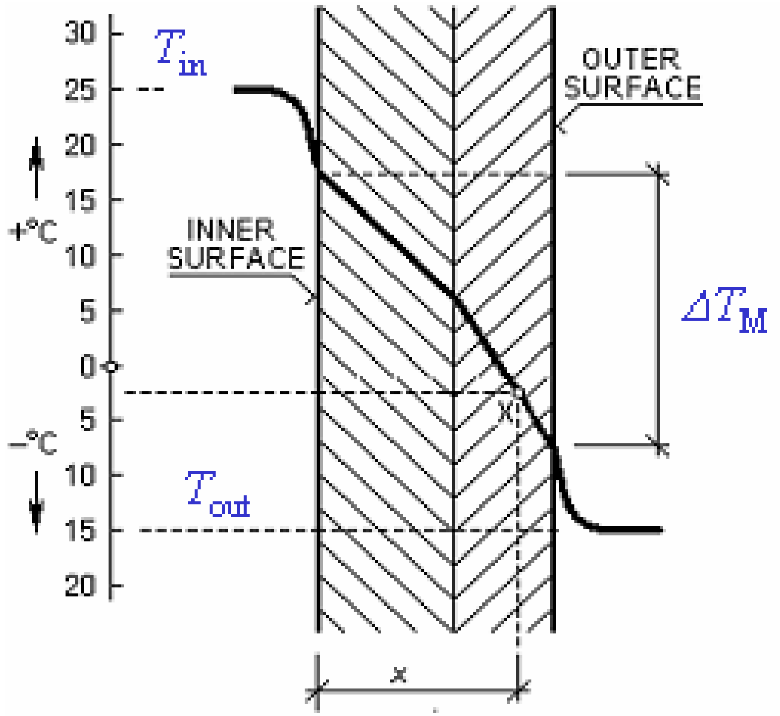


Inner temperatures in buildings

Season	Temperature T_{in} in ^{0}C
summer	T_1 (20 °C)
winter	T_2 (25 °C)

Recommended inner temperatures in the Czech National Annex

- summer 25 °C
- winter 20 °C



Outer temperatures T_{out}

Season	Relative absorptivity	Temperature T_{out} in ^0C
summer	0,5 bright light surface	$T_{max} + T_3$
	0,7 light coloured surface	$T_{max} + T_4$
	0,9 dark surface	$T_{max} + T_5$
winter		T_{min}

Recommended values:

	N, E, N-E	S, W, S-W and H
T_3	0 °C	18 °C
T_4	2 °C	30 °C
T_5	4 °C	42 °C

Uniform design temperatures in a building

An thermally unprotected steel structure

- ČSN 73 1401: $\Delta T_N = 60\ °C$ | $T_{e,\min} = -30\ °C$ | $T_{e,\max} = 30\ °C$

$$\Delta T_{Nd} = 60 \times 1{,}2 = 72\ °C$$

- ČSN P ENV 1991-2-5: $\Delta T_N = 61\ °C$ | $T_{e,\min} = -24\ °C$ | $T_{e,\max} = 37\ °C$

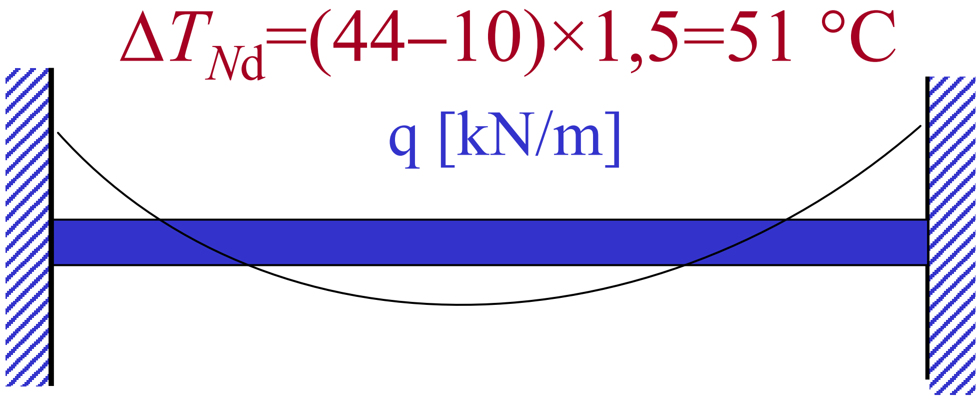
$$\Delta T_{Nd} = 61 \times 1{,}4 = 85\ °C$$

- ČSN EN 1991-1-5: in Prague for dark surface and North-East

$\Delta\ T_N = 76\ °C$ | $T_{e,\min} = -32\ °C$ | $T_{e,\max} = 40 + T_5 = 44\ °C$

$$\Delta T_{Nd} = 76 \times 1{,}5 = 114\ °C$$

An example of a fixed member



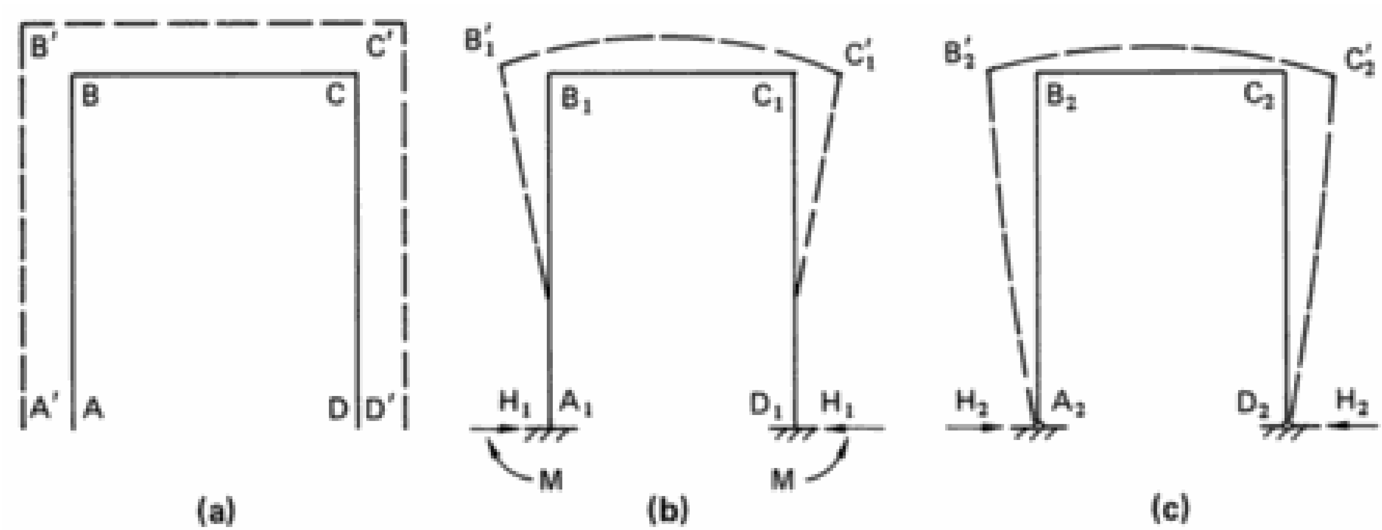
Material	Linear expansion $\alpha_{\mathrm{T}}\times10^{-6}\times°\mathrm{C}^{-1}$	Strain $\varepsilon_T\times10^{-3}$	Young modulus E MPa	Stress σ_T MPa
Concrete	10	0,51	30 000	15
Steel	12	0,61	200 000	122

A uniform temperature component

- National maps of isotherms T_{max}, T_{min}
- Effective temperatures in bridges – graphical tools

Maximum and minimum effective temperatures T

$$\Delta T_{N,\mathrm{con}} = T_0 - T_{\mathrm{e,min}}$$
$$\Delta T_{N,\mathrm{exp}} = T_{\mathrm{e,max}} - T_0$$
The total range $\Delta T_N = T_{\mathrm{e,max}} - T_{\mathrm{e,min}}$

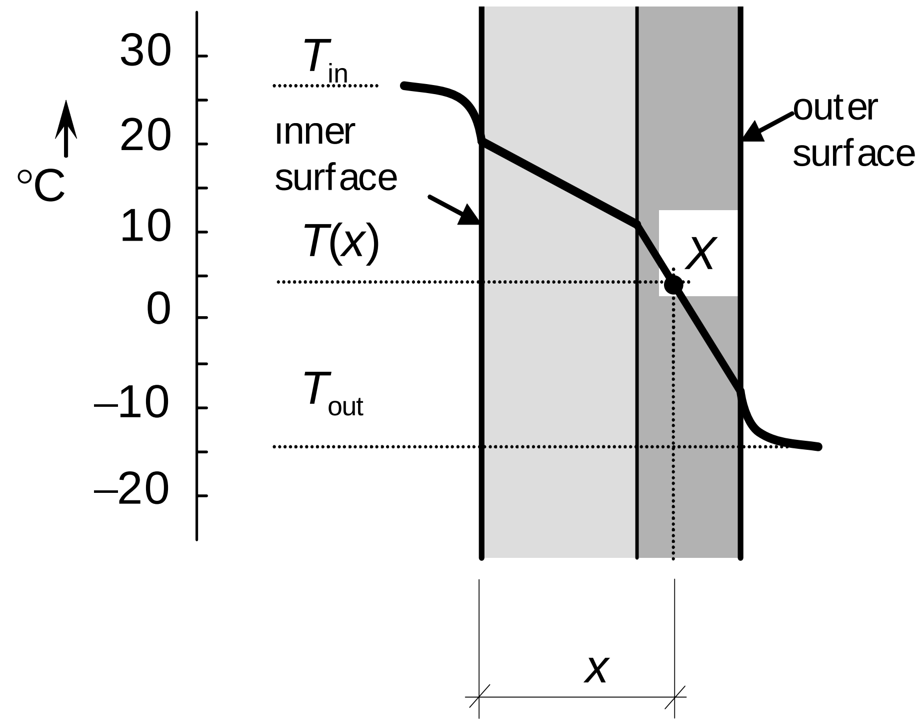


A frame under a uniform component and different support conditions

Annex D: temperatures in buildings

Temperatures

$$T(x) = T_{in} - \frac{R(x)}{R_{tot}}(T_{in} - T_{out})$$



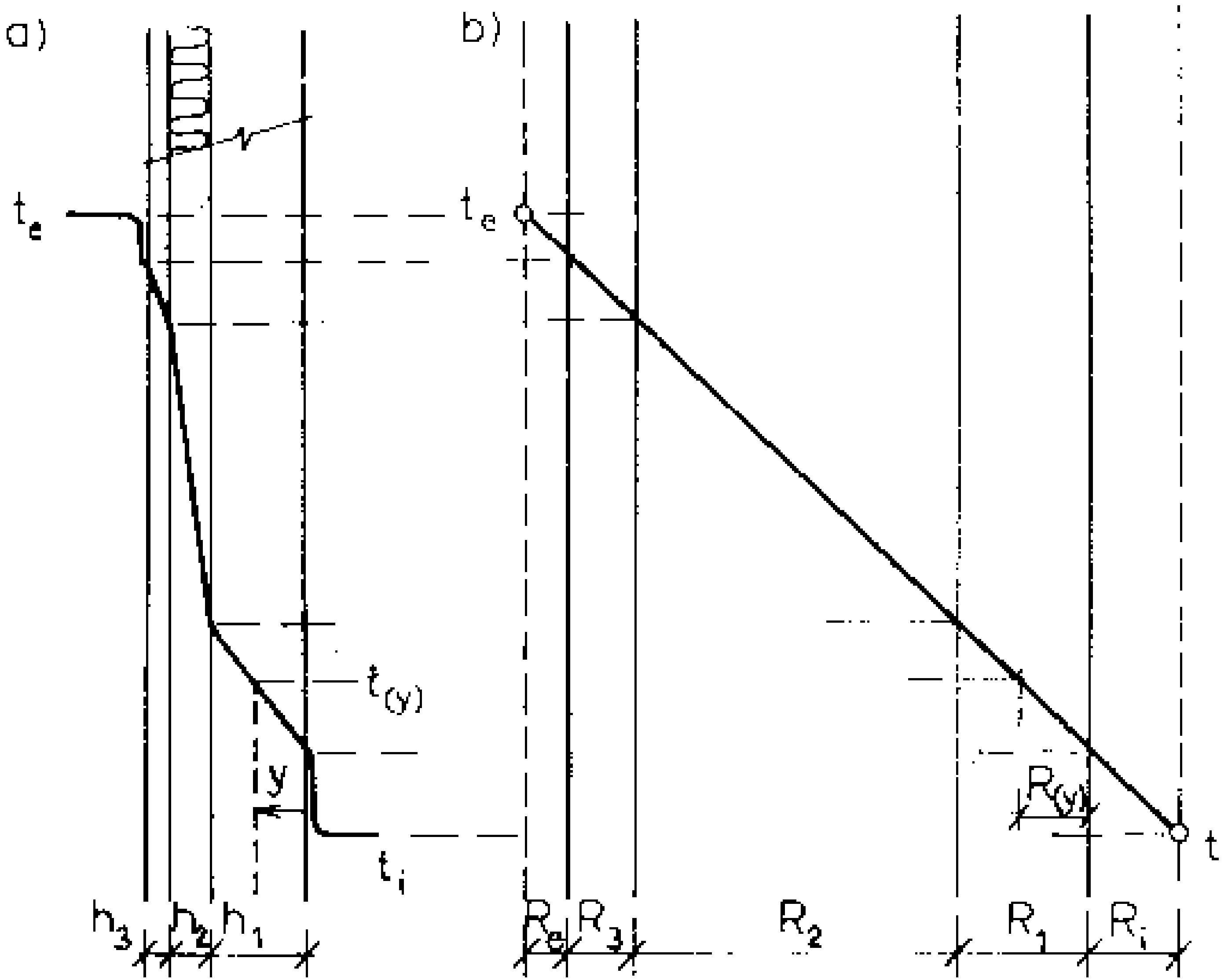
Thermal resistance [m^{2}K/W]

$$R_{tot} = R_{in} + \sum_i \frac{h_i}{\lambda_i} + R_{out}$$

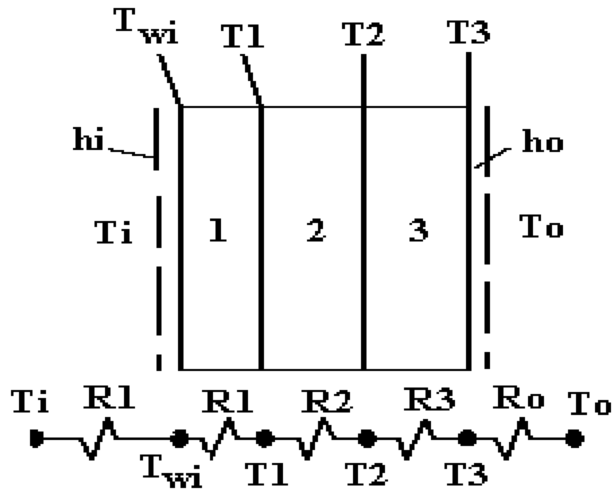
$$R(x) = R_{in} + \sum_i \frac{h_i}{\lambda_i}$$

where λ [W/(mK)] is thermal conductivity

Three layers wall - graphical method



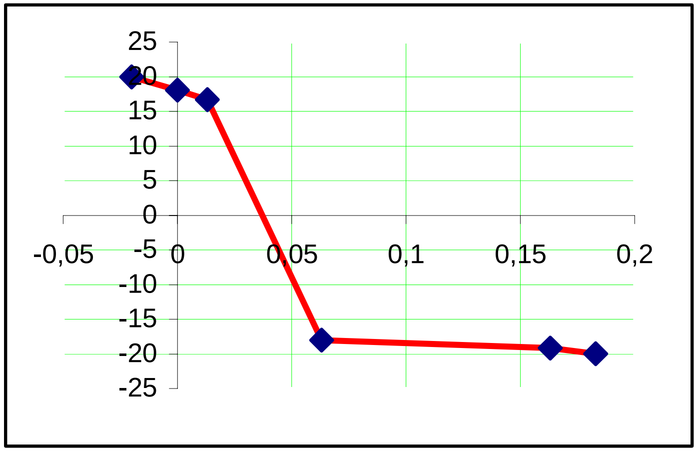
Three layers wall – EXCEL sheet



Wall with three layers and interior and exterior films

Input temperatures		Ti=	20	To=	-20	Heat flow Q=	17,323
		Transfer coef.	Thermal conduct.	Thickness	Resistance	Temperatures	
Layer	Material	W/m^2/°C	W/m/°C	m		°C	
	Inside					20	
0	Surface	9			0,111	18,075	
1	Gypsum		0,16	0,013	0,081	16,668	
2	Insulation		0,025	0,05	2,000	-17,979	
3	Brick		1,5	0,1	0,067	-19,134	
4	Outside	20			0,050	-20,000	
		The total resistance of wall Rtot =			2,309		

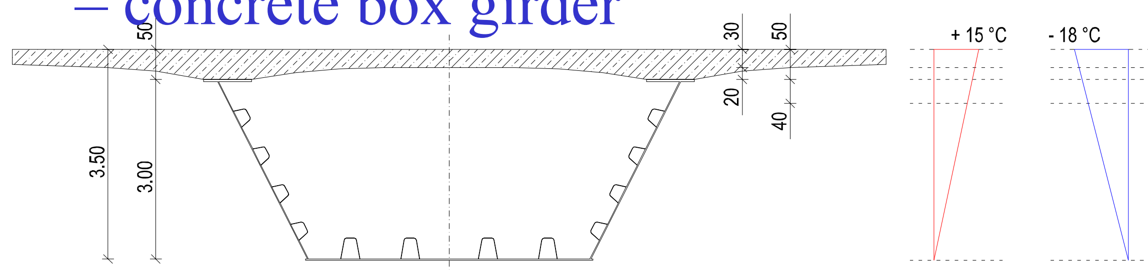
Graph	x	temp
	-0,02	20,000
	0	18,075
	0,013	16,668
	0,063	-17,979
	0,163	-19,134
	0,183	-20,000



Temperature changes in bridges

Three types of bridge superstructures are considered

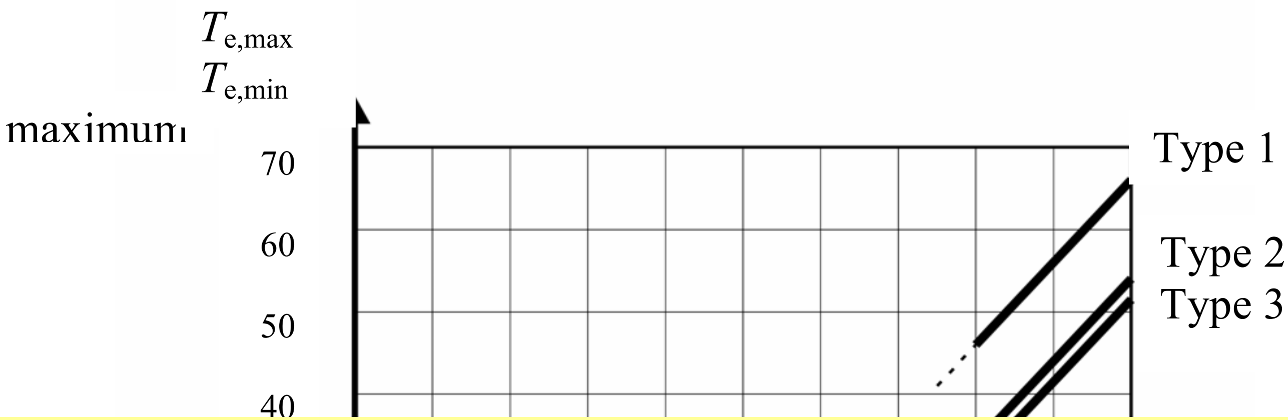
1. Steel deck – steel box girder
   – steel truss or plate girder
2. Composite deck
3. Concrete deck – concrete slab
   – concrete beam
   – concrete box girder



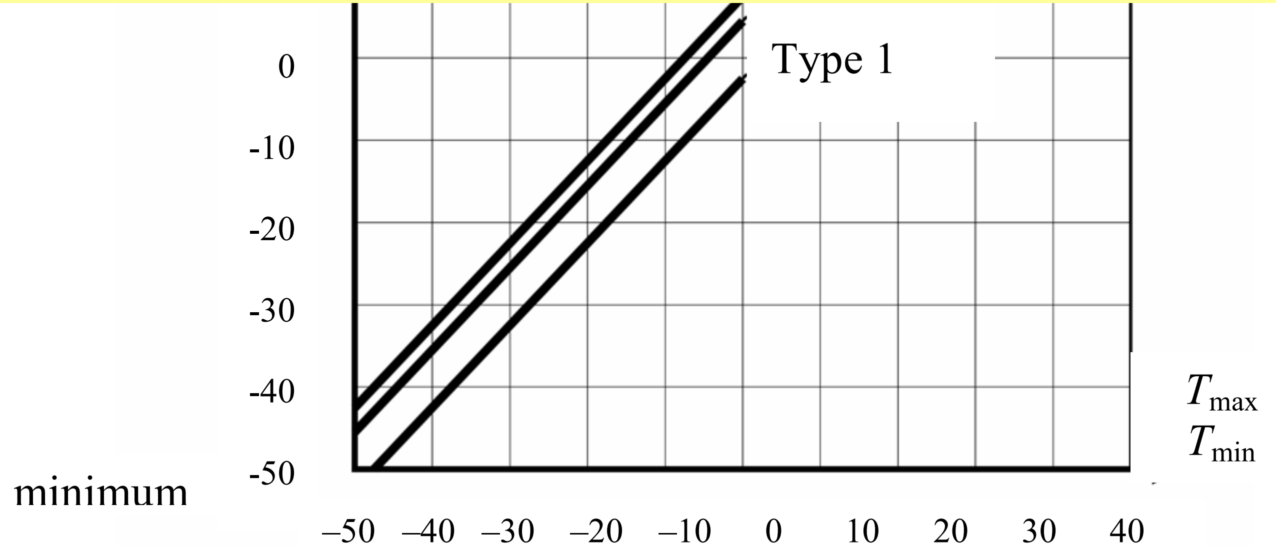
Basic temperature components

- ❖ a uniform component
- ❖ vertical temperature differences → approach 1 - linear; approach 2 - non-linear
- ❖ horizontal temperature differences

Uniform effective temperatures



$$\left.\begin{aligned} &\text{Type 1 } T_{e,max} = T_{max} + 16\,°C \\ &\text{Type 2 } T_{e,max} = T_{max} + 4{,}5\,°C \\ &\text{Type 3 } T_{e,max} = T_{max} + 1{,}5\,°C \end{aligned}\right\} \text{for } 30\,°C \le T_{max} \le 50\,°C \qquad \left.\begin{aligned} &T_{e,min} = T_{min} - 3\,°C \\ &T_{e,min} = T_{min} + 4{,}5\,°C \\ &T_{e,min} = T_{min} + 8\,°C \end{aligned}\right\} \text{for} -50\,°C \le T_{min} \le 0\,°C$$



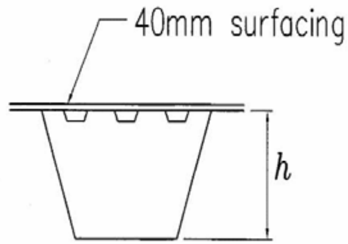
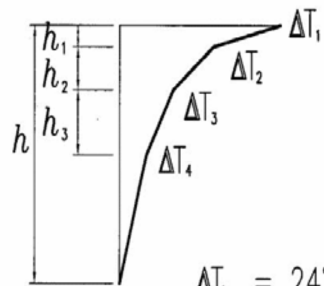
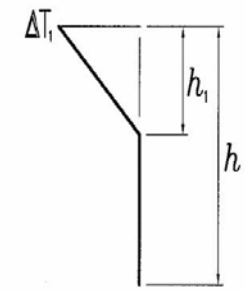
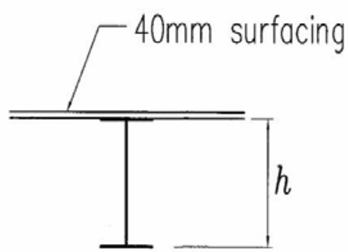
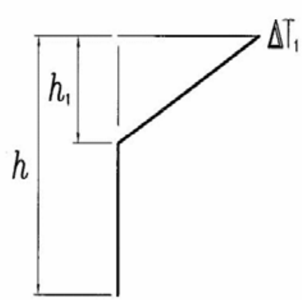
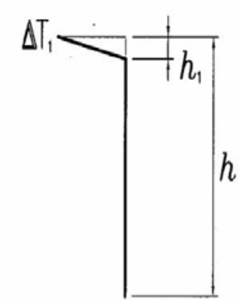
Approach 1: linear vertical differences

	$\Delta T_{M,heat}$ (°C)	$\Delta T_{M,cool}$ (°C)
Type 1, steel	18	13
Type 2, composite	15	18
Type 3, concrete		
box girder	10	5
beam	15	8
slab	15	8

Thickness of surfacing considered by reduction coefficient $k_{sur.}$

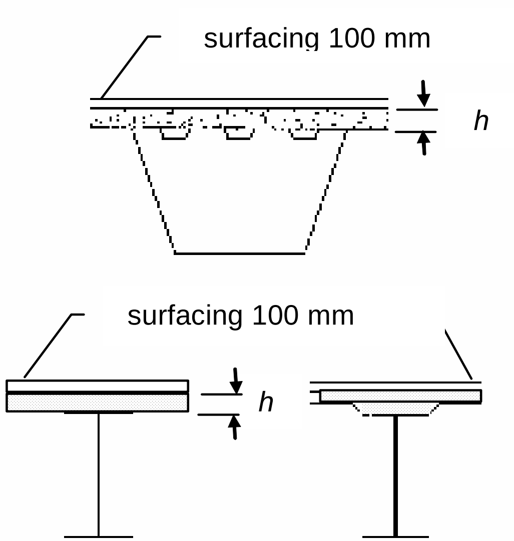
Approach 2: non-linear vertical difference

Type 1 (steel)

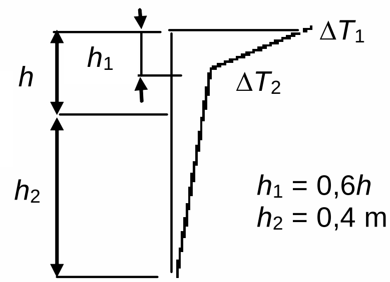
Type of Construction	Temperature Difference (ΔT)	
	(a) Heating	(b) Cooling
 1a. Steel deck on steel box girders	 $h_1 = 0.1m$ $\Delta T_1 = 24°C$ $h_2 = 0.2m$ $\Delta T_2 = 14°C$ $h_3 = 0.3m$ $\Delta T_3 = 8°C$ $\Delta T_4 = 4°C$	 $\Delta T_1 = -6°C$ $h_1 = 0.5m$
 1b. Steel deck on steel truss or plate girders	 $h_1 = 0.5m$ $\Delta T_1 = 21°C$	 $\Delta T_1 = -5°C$ $h_1 = 0.1m$

Approach 2: non-linear vertical differences

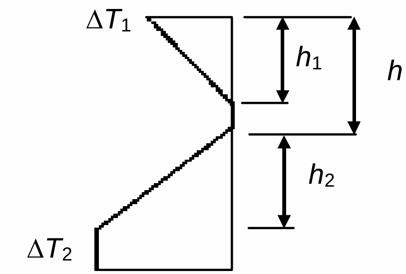
Type 2 (composite)	Temperature differences	
	(a) heating	(b) cooling



Normal procedure

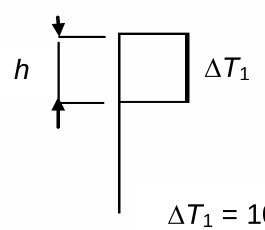


h	ΔT_1	ΔT_2
m	°C	°C
0,2	13	4
0,3	16	4

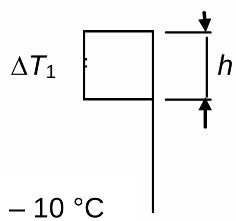


h	ΔT_1	ΔT_2
m	°C	°C
0,2	–3,5	–8
0,3	–5,0	–8

Simplified procedure



$\Delta T_1 = 10$ °C



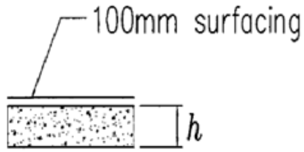
$\Delta T_1 = -10$ °C

Type 2 Concrete deck on steel box, truss or plate girders

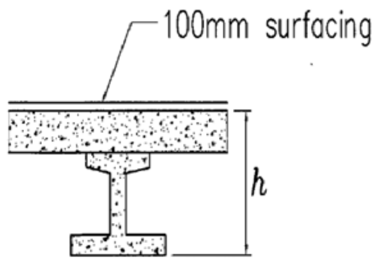
Approach 2: non-linear vertical differences

Type 3 (concrete)

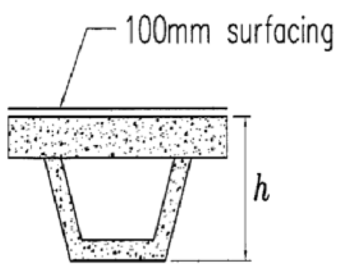
Type of Construction



3a. Concrete slab



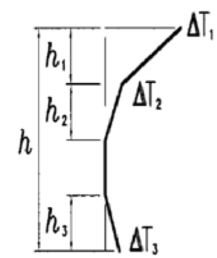
3b. Concrete beams



3c. Concrete box girder

Temperature Difference (ΔT)

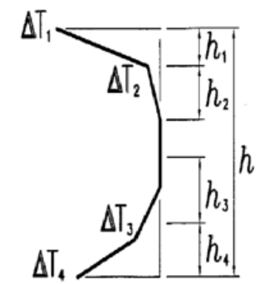
(a) Heating



$h_1 = 0.3h$ but ≤ 0.15m
$h_2 = 0.3h$ but ≥ 0.10m
but ≤ 0.25m
$h_3 = 0.3h$ but $\leq (0.10$m + surfacing depth in metres)
(for thin slabs, h_3 is limited by $h - h_1 - h_2$)

h	ΔT_1	ΔT_2	ΔT_3
m		°C	
≤0.2	8.5	3.5	0.5
0.4	12.0	3.0	1.5
0.6	13.0	3.0	2.0
≥0.8	13.0	3.0	2.5

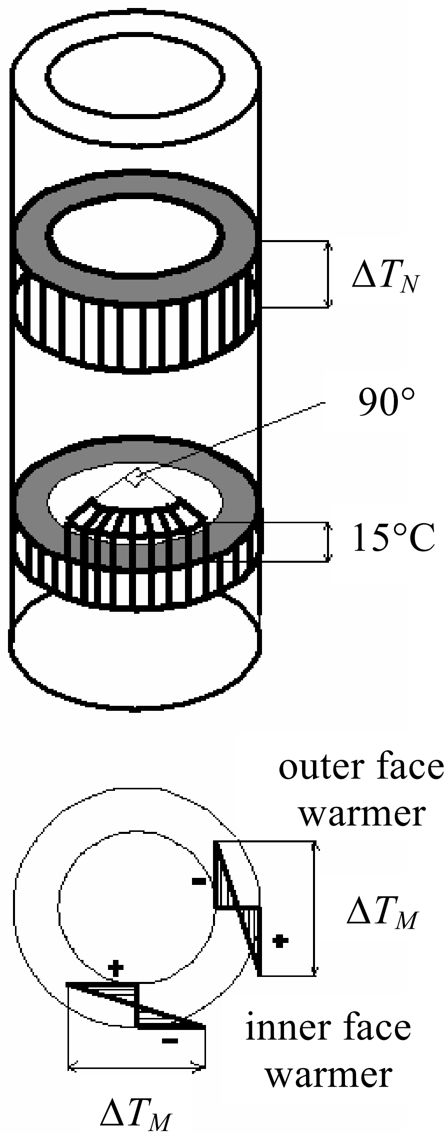
(b) Cooling



$h_1 = h_4 = 0.20h$ but ≤ 0.25m
$h_2 = h_3 = 0.25h$ but ≤ 0.20m

h	ΔT_1	ΔT_2	ΔT_3	ΔT_4
m		°C		
≤0.2	−2.0	−0.5	−0.5	−1.5
0.4	−4.5	−1.4	−1.0	−3.5
0.6	−6.5	−1.8	−1.5	−5.0
0.8	−7.6	−1.7	−1.5	−6.0
1.0	−8.0	−1.5	−1.5	−6.3
≥1.5	−8.4	−0.5	−1.0	−6.5

Temperature changes in industrial structures



(a) Uniform component

(b) Stepped component

(c) Linear component

Concluding remarks

Temperature effects may be in some cases significant and shall be considered in structural design.

The outer temperatures of a structure depend on absorptivity and orientation of the surface.

A uniform temperature component may be derived using national maps of isotherms.

For bridges the relationship is given for specification of uniform (effective) temperature component.

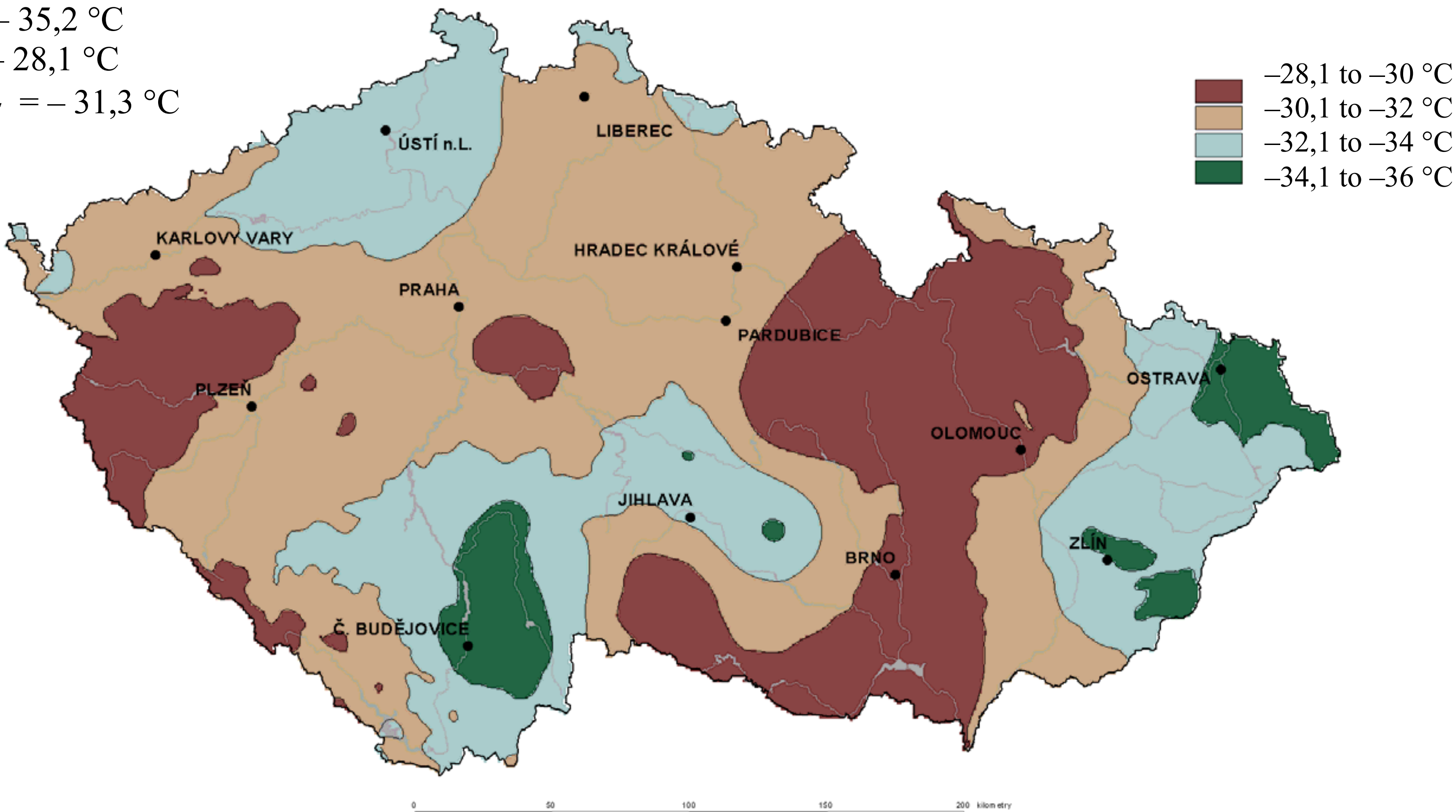
Two approaches for vertical temperature profile in bridges are given: either linear or non-linear profile should be used.

For industrial structures uniform, linear and stepped components are considered; technological temperatures in accordance of design specifications.

An example: map of minimum temperatures in CR

Minimum shade air temperatures of being exceeded by annual extremes with the probability of 0,02.

T_{min} = – 35,2 °C
T_{max} = – 28,1 °C
mean μ_T = – 31,3 °C



Linear expansion coefficients

Material	α_T ($\times 10^{-6} \times °C^{-1}$)
Aluminium, aluminium alloys	24
Stainless Steel	16
Structural steel	12
Concrete (except as specified below)	10
Concrete with light aggregates	7
Masonry	6-10
Timber, along grain	5
Timber, across grain	30-70

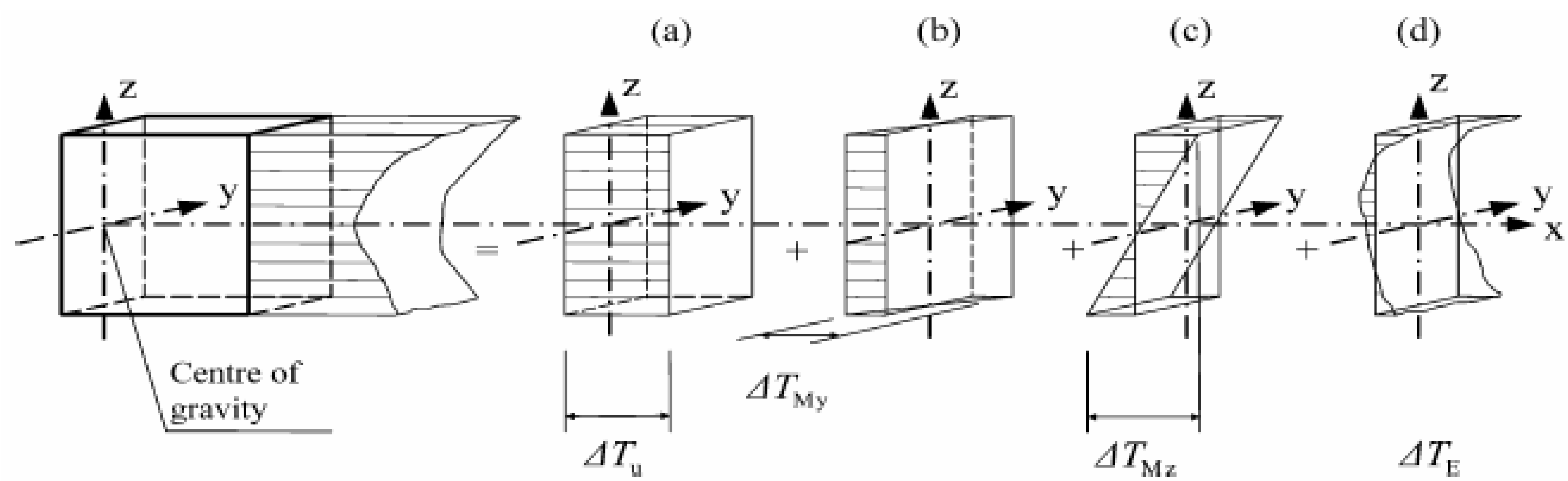
Constituent components of a temperature profile

a) a uniform component ΔT_u

b) a linear component about z-z, ΔT_{My} (in the direction of axis y)

c) a linear component about y-y-, ΔT_{Mz} (in the direction of axis z)

d) a non-linear component ΔT_E



Transient design situations

Return periods R for the characteristic values Q_k

Nominal period t	$t \leq 3$ days	Return period R	2 years	$p = 0{,}5$
	3 days $< t \leq 3$ months		5 years	$p = 0{,}2$
	3 months $< t \leq 1$ year		10 years	$p = 0{,}1$
	$t > 1$ year		50 years	$p = 0{,}02$

$$T_{\max,p} = T_{\max} \{k_1 - k_2 \ln [- \ln (1 - p)]\}$$

$$T_{\min,p} = T_{\min} \{k_3 + k_4 \ln [- \ln (1 - p)]\}$$

The coefficients k_1 to k_4 are given in EN 1991-1-5.

Reduction coefficients k for different return periods R

The characteristic value Q_k for return period R

$$Q_{k,R} = k\, Q_{k,50}$$

Return period R	p	Reduction coefficient k for			
		$T_{max,R}$	$T_{min,R}$	$s_{n,R}$ snow	$v_{b,R}$ wind
2 years	0,5	0,8	0,45	0,64	0,77
5 years	0,2	0,86	0,63	0,75	0,85
10 years	0,1	0,91	0,74	0,83	0,90
50 years	0,02	1	1	1	1

A uniform temperature component

ENV 1991-2-5: -24°C, 37 °C; in EN 1991-1-5, Prague -32 °C, 40°C

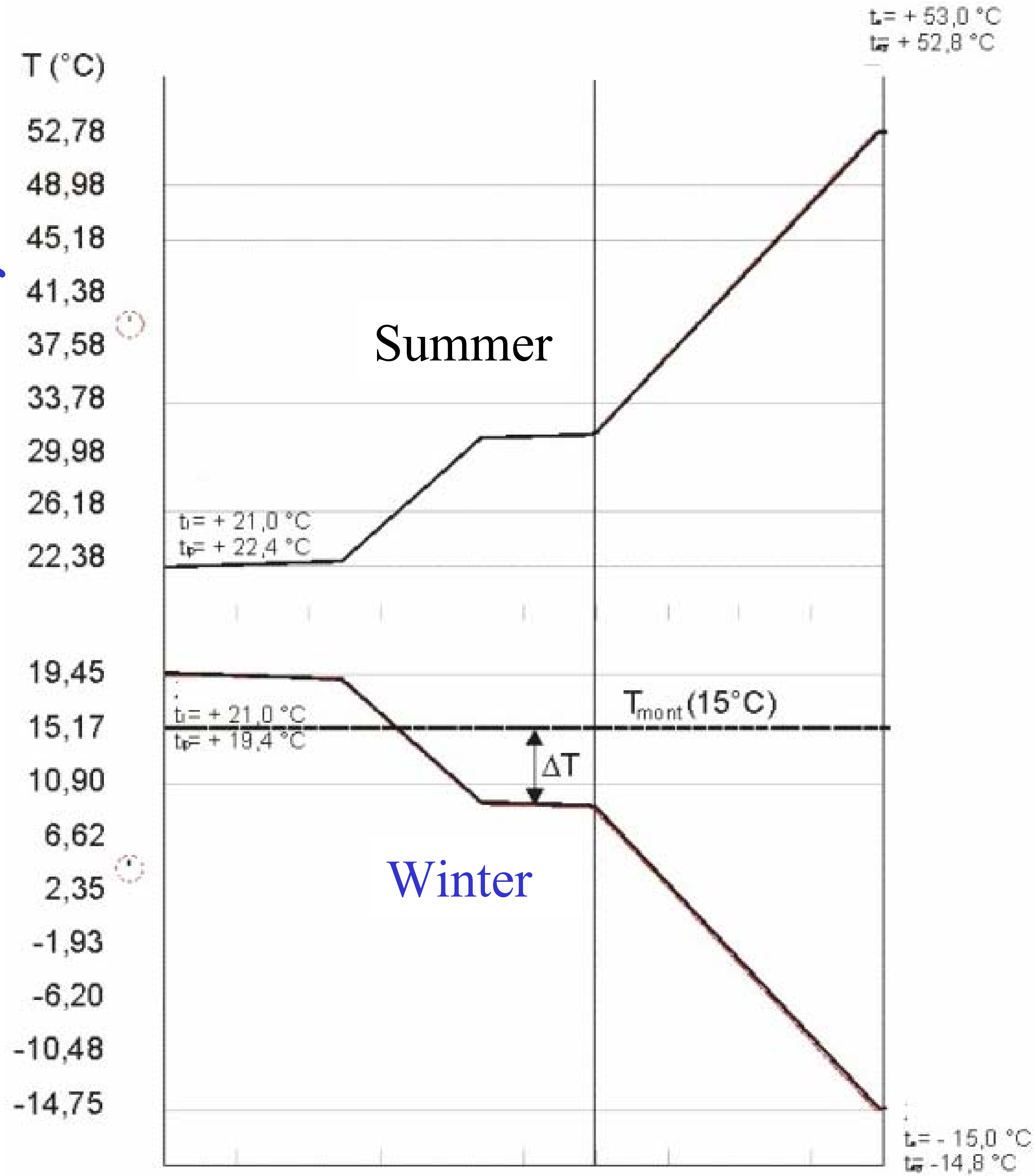
Prestressed concrete bridge

ČSN 73 6203: ΔT_N = 55 °C	$T_{e,\min}$ = -20 °C	$T_{e,\max}$ = 35 °C
ČSN P ENV 1991-2-5: ΔT_N = 55 °C	$T_{e,\min}$ = -16 °C	$T_{e,\max}$ = 39 °C
ČSN EN 1991-1-5: ΔT_N = **66 °C**	$T_{e,\min}$ = -24 °C	$T_{e,\max}$ = 42 °C

Composite bridge

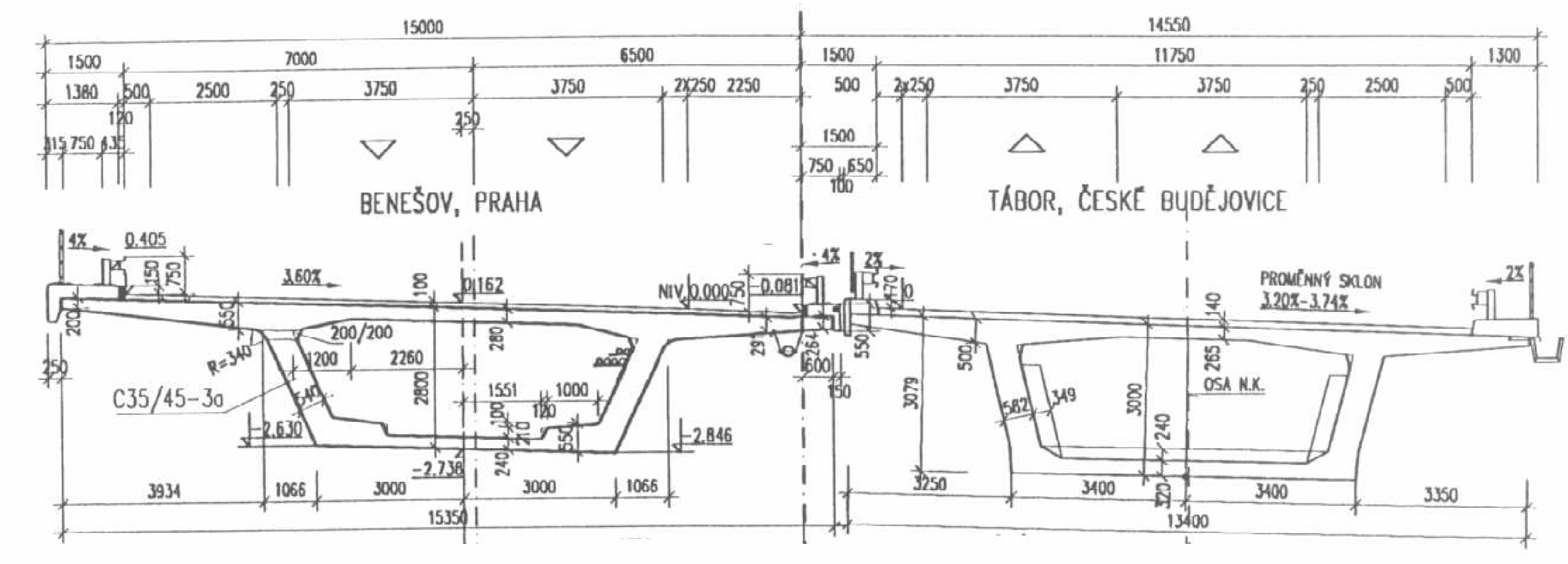
ČSN 73 6203: ΔT_N = 65 °C	$T_{e,\min}$ = -25 °C	$T_{e,\max}$ = 40 °C
ČSN P ENV 1991-2-5: ΔT_N = 62 °C	$T_{e,\min}$ = -20 °C	$T_{e,\max}$ = 42 °C
ČSN EN 1991-1-5: ΔT_N = **73 °C**	$T_{e,\min}$ = -28 °C	$T_{e,\max}$ = 45 °C

An example of temperature profile



An example of temperature effects-

Čekanice, Czech Republic



Typical section

Load combinations in accordance EN

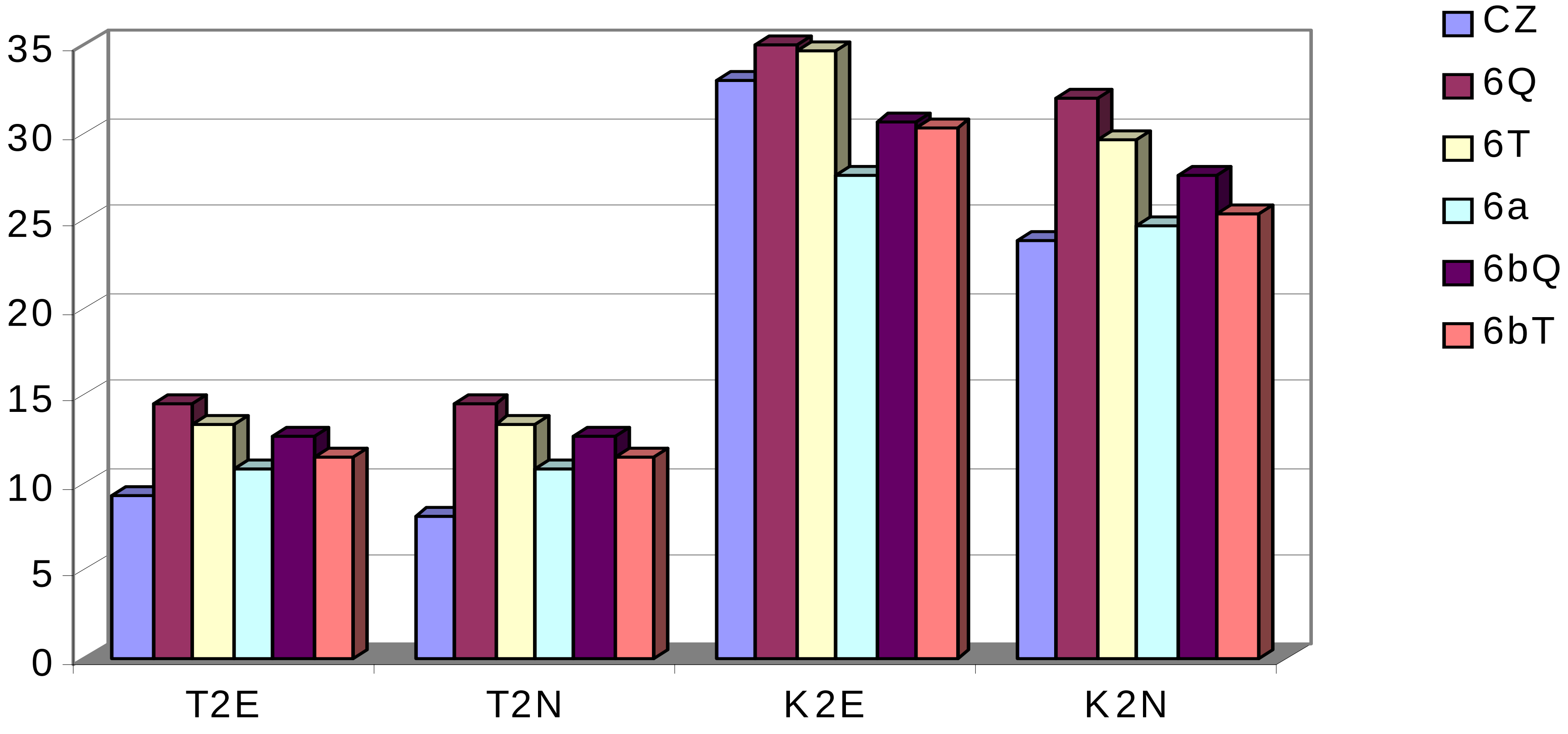
EN

Expr.	Main	Support section			Midspan section		
		M [MNm]	σ_{hor} [MPa]	σ_{dol} [MPa]	*M* [MNm]	σ_{hor} [MPa]	σ_{dol} [MPa]
6.10	*Q*	**-36,26**	1,23	-8,89	**34,97**	-6,21	3,54
6.10	*T*	-32,67	0,85	-8,27	34,65	-6,18	3,48
6.10a	-	-27,88	0,34	-7,44	27,61	-5,44	2,27
6.10b	*Q*	**-28,92**	0,45	-7,62	**30,6**	-5,75	2,78
6.10b	*T*	-25,32	0,069	-6,99	30,28	-5,72	2,73

ČSN

Support section			Mid-span section		
M [MNm]	σ_{hor} [MPa]	σ_{dol} [MPa]	*M* [MNm]	σ_{hor} [MPa]	σ_{dol} [MPa]
-32,85	0,32	-8,48	**32,93**	-5,83	2,99

Alternative load combinations in accordance with EN



Bending moments at mid-span sections T2 and K2 for linear (E) and non-linear (N) temperatures.

Simultaneous temperature components

$$\Delta T_{M,\,heat}\ (\text{or } \Delta T_{M,\,cool}) + \omega_N \Delta T_{N,\exp}\ (\text{or } \Delta T_{M,\,con})$$

$$\omega_M \Delta T_{M,\,heat}\ (\text{or } \Delta T_{M,\,cool})\ + \Delta T_{N,\,exp}\ (\text{or } \Delta T_{N,\,con})$$

Coefficients:

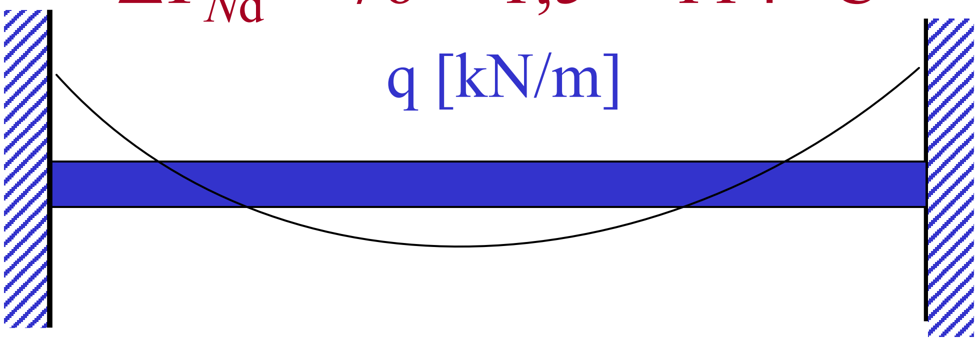
$$\omega_M = 0{,}75 \qquad \omega_N = 0{,}35$$

- Difference in uniform components of different members

- Differences of temperatures of bridge piers

An example of a fixed member

$\Delta T_{Nd} = 76 \times 1{,}5 = 114$ °C



Concrete: $\alpha_T = 10 \times 10^{-6} \times$ °C^{-1}

Linear expansion for $\alpha_T = 10 \times 10^{-6} \times$ °C^{-1}

Temperature strain $\varepsilon_T = 10 \times 10^{-6} \times 114 = 1{,}14 \times 10^{-3}$

Young modulus for concrete member, $E \approx 30\,000$ MPa

Stress $\sigma_T = E\,\varepsilon_T = 1{,}14 \times 10^{-3} \times 30\,000 = 34$ MPa

Structural steel: $\alpha_T = 12 \times 10^{-6} \times$ °C^{-1}, $E \approx 200\,000$ MPa

$\varepsilon_T = 12 \times 10^{-6} \times 114 = 1{,}37 \times 10^{-3}$

$\sigma_T = E\,\varepsilon_T = 1{,}40 \times 10^{-3} \times 200\,000 = 274$ MPa