Comparison of Temperature Loadings of Bridge Girders

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This paper compares the effect of temperature changes on the superstructure of bridges, above all the effect of non-uniform temperature. Loadings according to standards ČSN 73 6203, ENV 1991-1-5 and DIN 1072 are compared here. The paper shows a short summary of temperature loading according to each standard and shows the comparison of bending moments arisen from these temperature loadings on superstructure made from continuous girder from a steel-concrete box girder with a composite concrete slab. With respect to a variety of design processes, the comparison is made without any coefficient of loading, combination or material.

Keywords: temperature loading, temperature gradients,bridge constructions, temperature difference components, deformation, temperature distribution, maximum moments from temperature loading.

Fig. 1: Border bridge on the D8 motorway in summer and in winter

1 Introduction

This paper will compare the effects of temperature changes in bridge girders, above all the effect of non-uniform temperature distributions. The loadings recommended by standards ČSN 73 6203, ENV 1991-2-5 and DIN 1072 will be compared here. Due to the variety of design processes, the comparison will be made without any coefficient of loading, combination or material.

2 Summary of loading, according to three standards

2.1 Loading according to ČSN 73 6203

When designing bridge structures, this standard considers two basic effects:

a) standard temperature changes of the structure as a whole (equal change in temperature)
b) unequal temperature changes or temperature changes of parts of a structure

2.1.1 Standard temperature changes of the structure as a whole (uniform temperature component)

The standard prescribes equal temperature changes for each type of structure. If this value cannot be set in any other way, the upper and lower boundary temperature is used other way. The values of these temperatures are shown in Table 1. The value $t_f = 10$ °C can be used as the initial temperature for most structures.

2.1.2 Unequal temperature changes (Temperature difference component)

Unequal temperature changes are given as a difference of temperatures, the temperature gradient between two points on surfaces of the structural member. If this is not known, the models presented in the standard will be used. These models approximate temperature changes depending on the structure type. Bridges with a span less than 50m can be designed according to simplified loading with a linear temperature gradient.

Table 1: Boundary temperatures for bridge structures

Boundary temperatures (°C)	bridge superstructure							
							without sunshine at all times	
	Steel	Concrete	Steel	Concrete	Compo site		steel fully hidden	concrete with covering layer higher than 0.5 m
			with rail bed		steel-concrete	concrete-concrete		
t_{max}	50	35	45	30	40	as concrete	35	30
t_{min}	–35	–20	–35	–20	–25		–35	–15

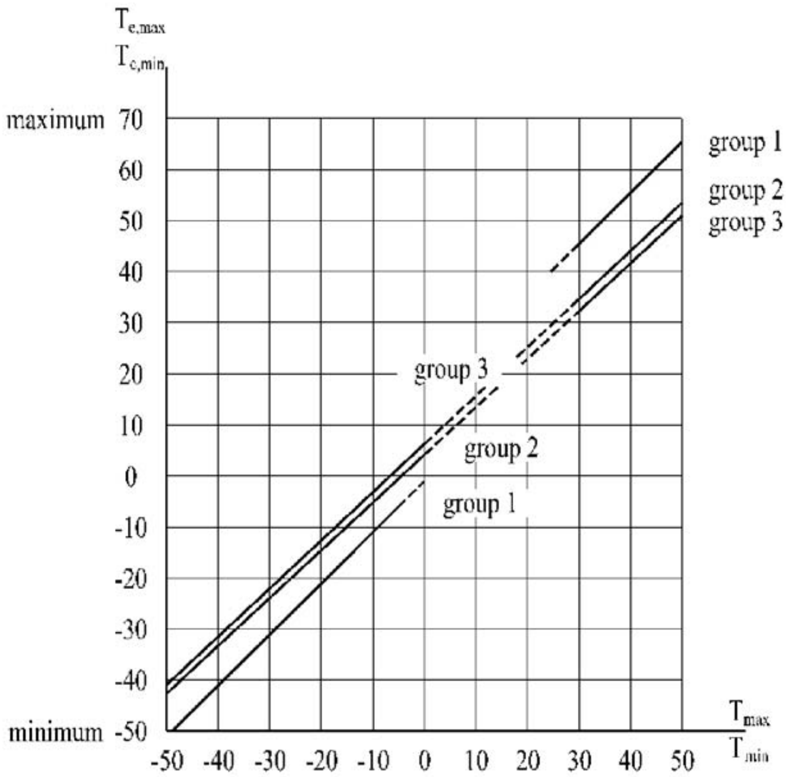

Fig. 2: Correlation between shade air temperature and structure temperature

2.2 Loading according to ENV 1991-2-5

This standard groups structures for temperature loading into three types:

- Type 1 – steel deck on steel girders.
- Type 2 – concrete deck on steel girders.
- Type 3 – concrete slab structure or concrete deck on concrete girders.

The temperature loading is divided into:

a) a uniform temperature component,
b) temperature difference components, or the vertical component and the horizontal component of the temperature variations,
c) differences in temperature between different structural elements.

2.2.1 Uniform temperature component

The uniform temperature component depends on the extreme temperatures. The minimum and maximum temperature that a bridge will achieve can be determined by applying the chart shown in Fig. 2. The shade temperature (T_{min}, T_{max}) for the site is derived from national isotherm maps.

According to NAD, the temperatures for the Czech Republic are T_{min} = –24 °C and T_{max} = +37 °C.

2.2.2 Temperature difference component

The temperature difference component means that the upper surface of the bridge deck will be exposed to maximum heating (top surface warmer) or to maximum cooling (bottom surface warmer) temperature variation. As in the case of

Table 2: Value of liner temperature differences

Deck type	Top warmer than bottom	Bottom warmer than top
	$\Delta T_{M,heat}$(°C)	$\Delta T_{M,cool}$(°C)
Type 1: steel deck	18	13
Type 2: composite deck	15	18
Type 3: concrete deck		
– concrete box	10	5
– concrete beam	15	8
– concrete slab	15	8

ČSN 736203, ENV applies a linear temperature gradient for some structures and nonlinear gradient for others. The linear temperature difference values are shown in table 2. The values given in the table are based on a surfacing depth of 50mm for roads and railways. Figures with temperature gradients and values are given in the standard.

2.2.3 Differences in temperature between different structural elements

These effects should be taken into account for structures where the difference in the uniform temperature component between the different element types may lead to adverse load effects. Recommended temperature values are:

- 15 °C between main structural elements,
- 10 °C and 20 °C for light and dark color, respectively, between suspension/stay cables and deck.

2.3 Loading according to DIN 1072

This standard divides the temperature loading into three groups, as does ENV 1991-2-5:

a) an uniform temperature component
b) temperature difference components
c) differences in temperature (temperature jump)

2.3.1 Uniform temperature component

To obtain the uniform temperature, we apply the basic temperature $T = +10$ °C. For each type of supporting structure the values are given as follows:

- steel bridges ±35 °C
- composite bridges ±35 °C
- concrete bridges +20 °C /–30 °C

For bridges with a construction depth more than 0.7 m and for backfilled structures the temperature values can be reduced by 5 °C.

2.3.2 Temperature difference components

The temperature difference components are given as a linear gradient in the vertical direction of the bridge girder. The temperature difference values between surfaces are shown in Table 3.

2.3.3 Differences in temperature

Differences in temperature refer to the fact that different parts of a structure (e.g., arch and deck) can have different temperatures. The temperature difference value for a concrete-concrete composite member is ± 5 °C, while for other kinds of composite members it is ± 15 °C.

3 Comparison of loadings

All standards that are compared here divide the loading by temperature of the bridge structure into at least in to two basic effects – the uniform the temperature component and temperature difference components. The ENV 1991-2-5 standard takes into account loading by a temperature gradient in the vertical direction, and also loading by a temperature gradient in the horizontal direction. This is used for complicated structural arrangements, where these loadings produce considerable effects.

For uniform temperature, each of the standards has its own technique for obtaining the temperature differences, but the final temperature values do not differ greatly.

For temperature differences, the standards generally take a nonlinear temperature gradient in the vertical direction. For simple structures, according to the ČSN and ENV standards, a simplified linear gradient can be used. The DIN standard uses this simplified linear gradient for all bridge structures.

4 Analysis on a real bridge structure

For a comparative analysis, a bridge on the D8 motorway, segment 0807, SO 217 – Border Bridge has been chosen. The bridge crosses the border with Germany, which is formed by a deep valley and the Border Brook.

4.1 Description of the border bridge

The structural system of the bridge is a continuous girder. It is supported by nine supports, two abutments and seven piers. At this point, the motorway has a constant curvature with radius $R = 1750$ m; there is a constant slope of 0.5 % in the vertical direction of the bridge.

Table 3: Temperature differences values

	Upper surface warmer		Bottom surface warmer	
	structural conditions	service conditions	structural conditions	service conditions
Steel bridges	15	10	5	5
Composite bridges	8	10	7	7
Concrete bridges	10	7	3.5	3.5

Fig. 3: View of bridge before completion

The bridge structure is made as a steel-concrete box girder with a composite concrete slab. Each direction of the motorway has one bridge girder with its own piers (Figs. 3 and 5). The abutments are the same for both girders. The width of one structure is 14.5 m and the bridge depth is 3.65 m. The length of the bridge is approx. 430 m. The continuous girder

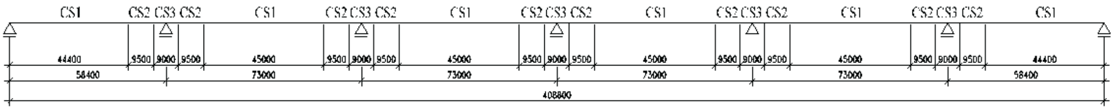

Fig. 4: Longitudinal section with cross section locations

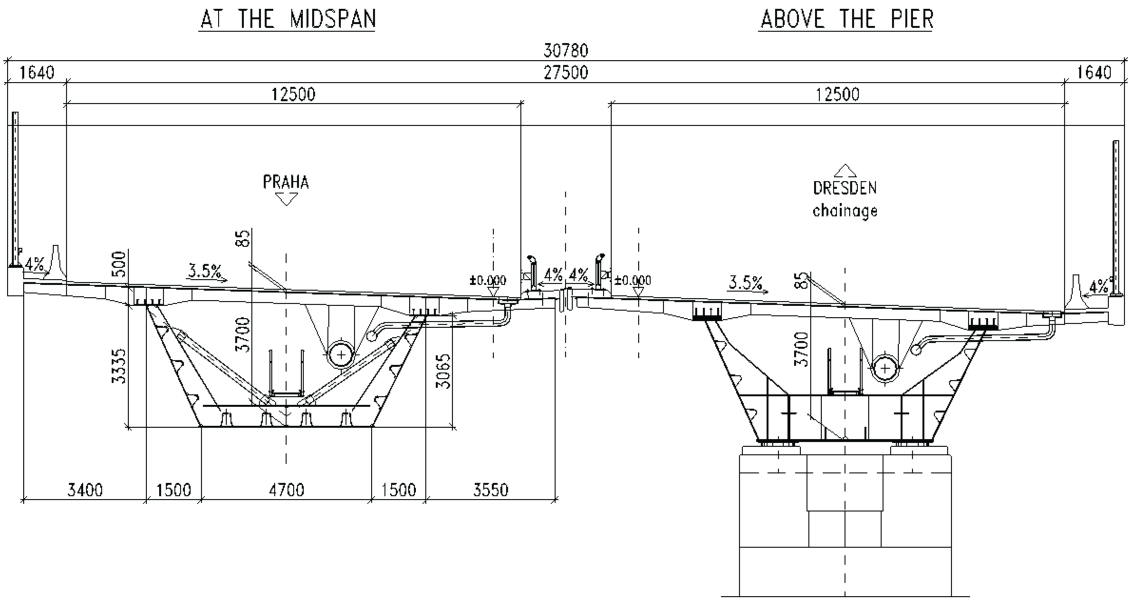

Fig. 5: Sample cross section

has spans (58.40 + 73 + 73 + 73 + 73 + 58.40) m, and it was launched into the final position from the Czech abutment. Only the steel box with the launching nose (length approximately 30 m) was launched. The deflection in the nose end during launching was about 1 m.

For casting, deck removable formwork was used. The casting step took 11 days. Six form travelers, each 25 m in length, were used. In order to eliminate cracks above the supports of the main girder, these parts were the last to be cast.

4.2 Analysis

As the bridge structure has the form of a continuous beam supported by fixed bearings on the two middle piers, the uniform temperature component causes axial displacements and produces a normal force accompanied by negligible bending moments only. Therefore this bending effect is not taken into consideration here; the uniform temperature values are only listed in the following sections.

An analysis of non-uniform temperature changes is performed on the beam model shown in Fig. 4. These figures show the positions of characteristic cross-sections on the beam axis.

4.2.1 Solution according to ČSN 73 6203

Uniform temperature component:

For composite bridges, the values for the boundary temperatures according to Table 1 are $t_{max} = +40$ °C and $t_{min} = -25$ °C. Using reference temperature $t_f = 10$ °C (temperature when the bridge girder was placed on the bearings), the uniform temperature components are as follows:

$$\Delta t_{max} = t_{max} - t_0 = +40 - 10 = +30\ °C$$

$$\Delta t_{min} = t_{min} - t_0 = -25 - 10 = -35\ °C$$

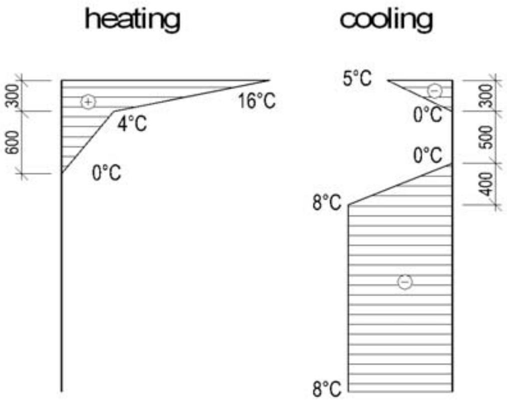

Fig. 6: Temperature gradient in the vertical direction, according to ČSN 73 6203

Temperature difference component:

Because the bridge span exceeds 50 m, it is not possible to use the simplified linear temperature gradient. The non-linear temperature gradient which is shown in Fig. 6 must be used.

4.2.2 Solution according to ENV 1991-2-5

Uniform temperature component:

According to ENV 1991-2-5 this bridge belongs to structure type 2. For maximum and minimum air temperatures in the Czech Republic $T_{max} = +37$ °C and $T_{min} = -24$ °C, the following temperature values for bridges are taken from Fig. 1:

$$T_{max} = +37\ °C \quad \rightarrow \quad T_{e,\,max} = +45\ °C$$

$$T_{min} = -24\ °C \quad \rightarrow \quad T_{e,\,min} = -24\ °C$$

Using reference temperature $T_0 = 10$ °C (the temperature when the bridge girder was placed on the bearings) the uniform temperature components are as follows:

$$T_{N,\,pos} = T_{e,\,max} - T_0 = +45 - 10 = +35\ °C$$

$$T_{N,\,neg} = T_{e,\,min} - T_0 = -20 - 10 = -30\ °C$$

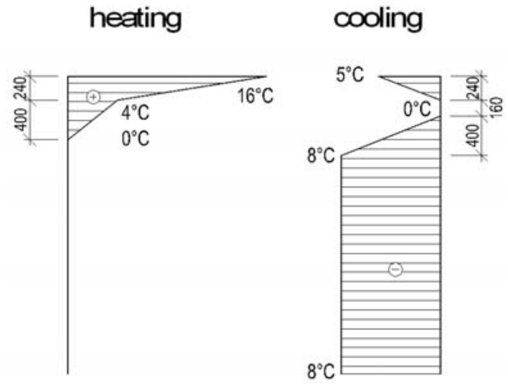

Fig. 7: Temperature gradient in the vertical direction, according to ENV 1991-2-5

Components with temperature differences:

Because a composite bridge girder is not a simple structure with acceptable details, it is necessary to apply a non-linear temperature gradient. The temperature gradient in the vertical direction of the superstructure is shown in Fig. 7.

4.2.3 Solution according to DIN 1072

Uniform temperature component:

For composite bridges, the uniform temperature is calculated from the referential temperature $T = +10$ °C with a change ±35 °C.

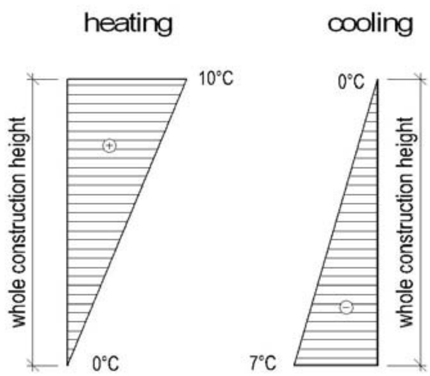

Fig. 8: Temperature gradient in the vertical direction, according to DIN 1072

Temperature difference components:

For loading with a temperature gradient according to the DIN standard, only linear temperature gradient is used. This is shown in Fig. 8.

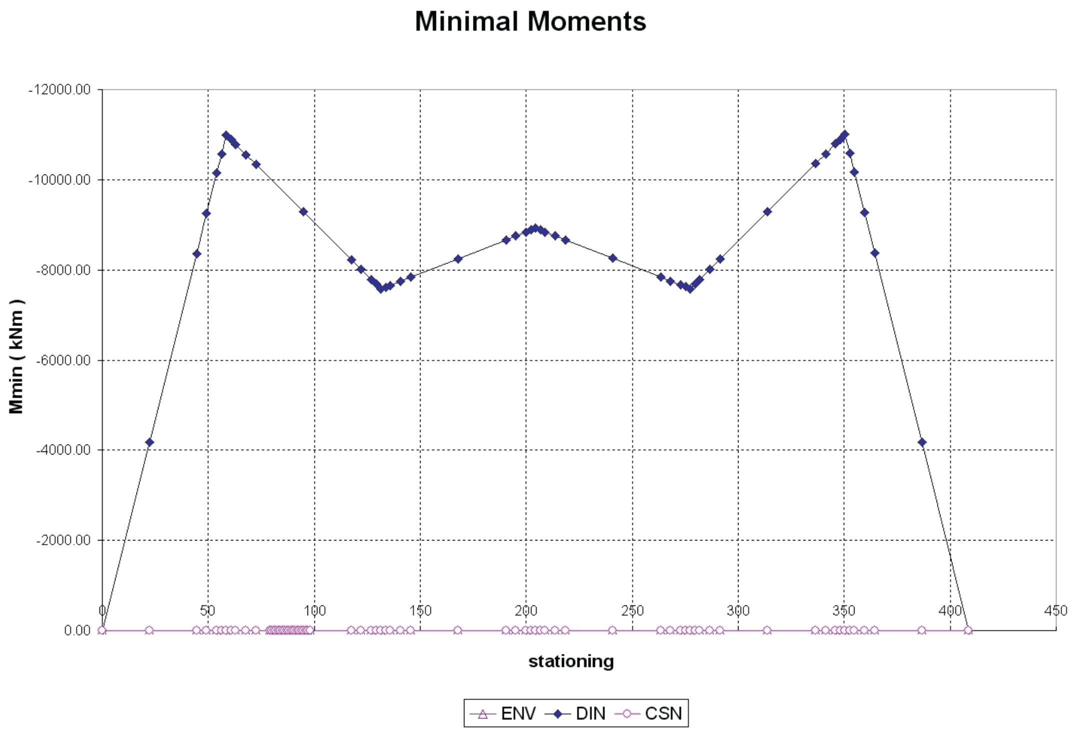

Fig. 9: Minimum moments from temperature loading

4.3 Comparison of results

The temperature gradient figure shows that, according to the ČSN and ENV standarts, which have almost the same temperature distribution, there will be only a one-side effect, and consequently only a positive or negative moment. The calculation confirmed this hypothesis, and the temperature difference component caused only positive moments. By contrast, the DIN standard, as shown by the temperature gradient, will cause both positive and negative moments. The calculated moments are shown in Figs. 9 and 10.

According to the DIN standard, loading with cooling will cause only negative moments, whereas the other two standards produce positive moments (Fig. 9). The DIN standard will produce a minimal moment −11MNm in contrast to a zero moment due to loading according to the ČSN and ENV standards.

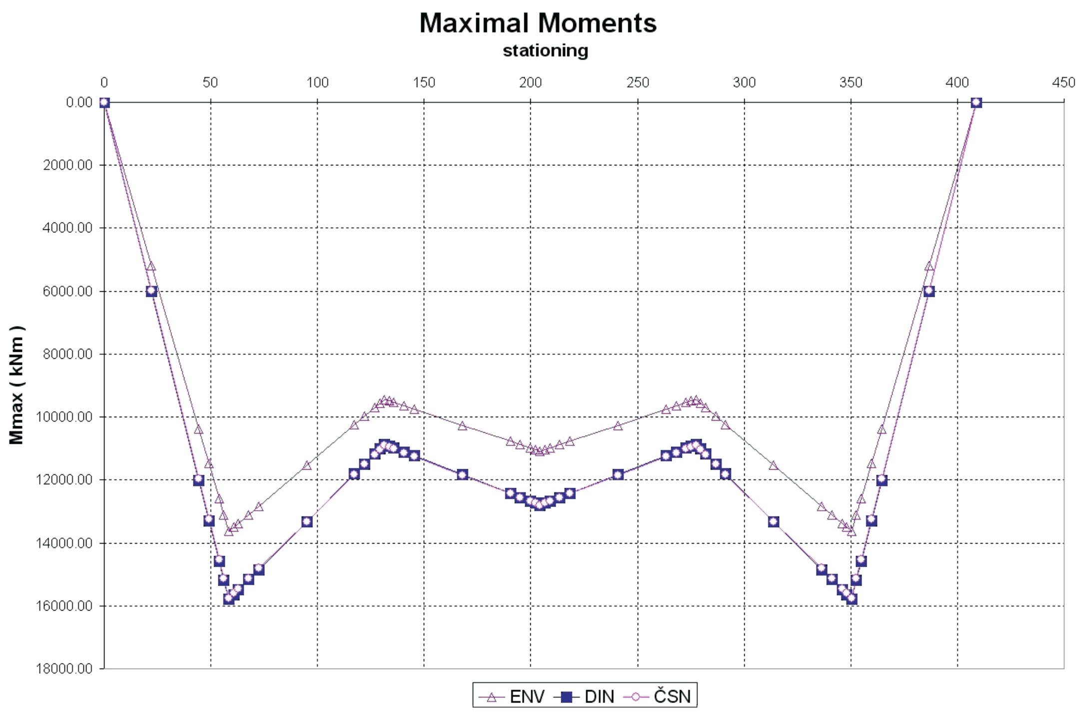

Fig. 10: Maximum moments from temperature loading

If we compare the maximal moments caused by the heating difference component (Fig. 10), no great differences in values appear. Although the temperature gradients given by the ČSN and ENV standards are significantly different, loading according to them causes almost the same moments. The difference between the moments equals approx. 1 %. The loading according to ENV produces about 15 % lower values, but design according to ENV uses many more coefficients than the compared standards. The resulting effect of loading according to this standard could be the same or worse.

5 Conclusion

The comparison of the standards took into account only basic values, without applying any coefficients (factors for actions or combination). The final effects from loading with maximum heating in the temperature gradient according to the ENV standard can, in some combinations, be higher than according to the other standards, though the effect is lower without the coefficients.

Without investigating other types of structures we cannot say whether this difference is generally observable, or whether it is only valid for this type of structure. In addition, it would be necessary to make universal measurements of temperature gradients on real structures in order to ascertain which standard determines true values, or which is closer to the truth.

It is necessary to investigate this problem on other structural types. First of all, the theoretical considerations and calculations according to the standards must be subjected to on-site experimental measurements of the temperature fields on bridge structures. Temperature fields and temperature gradients should be measured during diurnal cycles (24 hours) and year annual cycles. By evaluating these cycles it would be possible to learn whether the extreme measured effects do not to greatly exceed the values given by the standards, or it would be possible to determine how often they are exceeded.

It would be possible to assess how precisely and how reliably the individual standards prescribe the temperature gradients for the bridge design.

Acknowledgment

This project is being conducted with participation of Ph.D. student Ing. Jana Zaoralová, Ing. Simona Rohrböcková and undergraduate student Jakub Římal.

This research has been supported by the Grant Agency of the Czech Republic with grant No. 103/06/0815 and Research Project MSM 6840770005.

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