MATEC Web of Conferences 24, 09002 (2015)
DOI: 10.1051/matecconf/20152409002

Investigation of temperature-dependent stiffness variation of a layer of asphalt and their possible effect on the deformation behaviour of concrete structures

D. Erdenebat[1], F. Scherbaum[1], D. Waldmann[1], St. Maas[1], A. Zürbes[2]

[1]*University of Luxembourg, Laboratory of Solid Structures, Luxembourg, Luxembourg.*
[2]*Fachhochschule Bingen, Germany.*

Abstract. In the time of increasing maintenance costs, the continuous inspection and the earliest possible damage detection become more and more important. In order to minimize future maintenance costs, the exact evaluation of the condition of the structure and the exact assessment of potential damages are of essential importance. Therefore the University of Luxembourg carries out projects to investigate an efficient application of different assessment methods taking into account praxis relevant test conditions. As a part of this project especially the changing temperatures which influence the stiffness of the materials are analysed. As a consequence, for the condition assessment of structures, the asphalt layer cannot only be taken into consideration as a mass applied as load on the structure. Due to bond effects of the asphalt layer to the load carrying element its changing stiffness induced by changing temperatures influences the stiffness of the whole structure.
Within this paper this effect will be illustrated. First the load carrying behaviour and the stiffness of pre-stressed concrete slabs realized with and without an additional asphalt layer will be investigated in a climate chamber and the results will be compared for different temperatures.

1 Introduction

The condition assessment of structures becomes more and more important as early detection of damage reduces considerably maintenance costs. To be successful in analysing existing structures all different aspects influencing the condition of bridges must be considered. This is particularly important when deformation measurements has to be interpreted: a temperature variation of the structure affects the deformation behaviour of the structure due to a changing temperature gradient and depending on the boundary conditions. Also, the electronic sensors itself may be affected by changing temperatures depending on the properties of the respective sensor and lead thus to different results. However these are not the only factors that affect the deformation assessment of structures. Depending on the different construction materials, their material stiffness is temperature-dependent and thus, influences evidently the deformation behaviour of the structure. Furthermore, the interaction of different layers building up one structure may also be temperature-dependent. Within this article the deformation behaviour of a pre-stressed concrete slab with and without an asphalt layer will be described in function of changing temperature conditions.

2 Temperature-depending material behaviour

2.1. Temperature-depending material behaviour of concrete

The temperature-depending material behaviour and especially the effect of changing temperature on the E-modulus is discussed in literature; e.g. in [1] and [2] the increase of compressive strength of concrete for very low temperatures such as-200 ° C is reported. However, these effects are linked to the influence of the moisture of the element. In [3] it is shown that very high temperatures of + 150 ° C resulted in a reduction of the E-modulus compared to the one at 20 ° C, while examinations at -10 ° C, however, did not significantly influence the E-modulus. So, it has been demonstrated that at least at extreme temperatures the elastic modulus is affected. However, some authors act on the assumption that the E-Modulus remains unchanged at +100 ° C even + 200 ° C as reported in the literature review in [3].

2.2 Temperature-depending material behaviour of asphalt

The material properties of asphalt is dominated by the temperature-depending material properties of bitumen. This effect is surely know, but for concrete bridges it is not taken into consideration as during the design of these structures the asphalt layer is only considered as an acting mass which has no influence on the deformation behaviour of the whole structure. The investigations described in [5] on an orthotropic deck slab and on laboratory samples of the bituminous layer under dynamic loading point out that interactions are however existing.

3. Investigations of the concrete slab and the concrete-asphalt composite system

As assumed in section 2, the temperature-dependent stiffness of the asphalt layer can affect the deformation behaviour of an deck slab which will be verified by experimental tests on small pre-stressed slab elements presented in the following: it will be investigated whether an asphalt layer can affect the deformation behaviour of such a pre-stressed concrete structure exposed to varying temperature conditions. As shown in section 2, temperature could affect the E-modulus of the pure concrete; this will first be investigated by analysing the pre-stressed structure without any asphalt layer.

3.1 Description of the concrete slab with and without asphalt layer

The tests have been realized on a hollow pre-stressed floor element which simulate the load-bearing behaviour of a bridge structure on a reduced size. One element has a length of 1.80 m and a maximum width of 59.7 cm; figure 1, shows its cross section. The slabs are pre-tensioned in the tension zone by four tendons (diameter 7 mm) with a tension force of 38.5 kN each and in the upper part of the section by an additional tendon (diameter 5 mm) with a tension force of 21 kN to secure the element during transport. The concrete is a C45/55 with an elastic modulus E = 35700 N/mm².

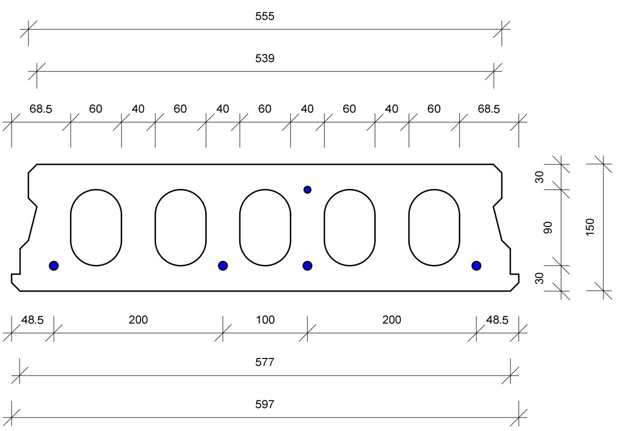


Figure 1. Cross section of the hollow pre-stressed floor element (including tendons) [6]

For the experimental tests with asphalt layer, the composition of the applied structure has been chosen according to usual bridge sections: on the concrete structure first two layers of epoxy resin have been applied whereby on the first layer sand has been strewed on. On top of this layer first a bituminous membrane has been flamed on before applying then a 10 cm-high mastic asphalt layer. Figure 2 illustrates the cross section of the different layers of the test specimen with asphalt

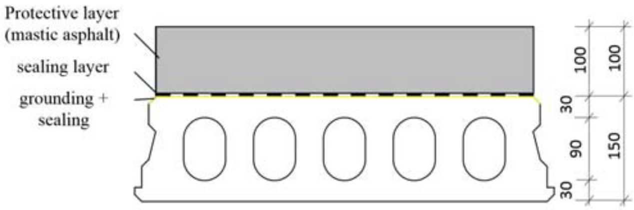


Figure 2. Cross section of test specimen with asphalt [6]

3.2 Description of test procedure

To describe the influence of temperature variation on the stiffness of the pre-stressed slabs with or without asphalt layer, both slabs have been investigated in a three point bending test by applying forces up to 34 kN. Under this maximum load the structure remained uncracked. Figure 3 shows on the left the experimental set-up of the slab without asphalt layer and on the right the test set-up with asphalt layer. In Figure 4, the scheme of the experimental set-up is described in a side view.

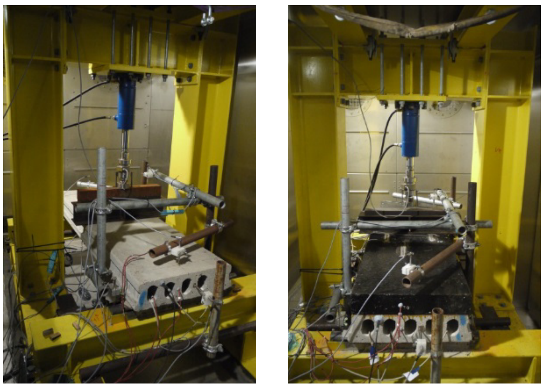


Figure 3. Experimental set-up of the static tests without asphalt layer (left) and with asphalt layer (right) [6]

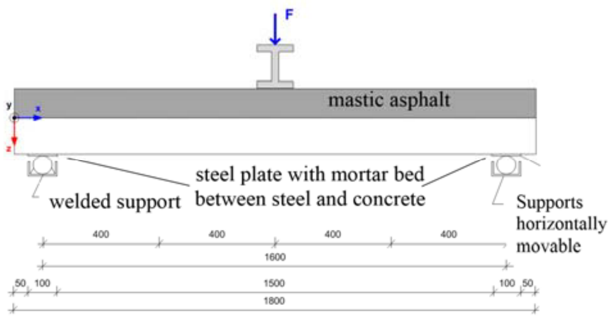


Figure 4. Side view of the experimental test set-up of the static tests [6]

Load is applied gradually by load steps including a hold time of 10 minutes per load step. In the last load step (#6), the load has been held for 70 minutes before discharging the element. Inductive displacement transducers record the deformation during the test. The position of the individual sensors is explained in the figures 5-7: deflections have been measured in the middle of the span (W-2) and at the quarter points (W-8 and W-9). To consider a possible support settlement the deformations of the supports (W-1 and W-4) have also been recorded.

Table 1. Load steps of static loading [6]

Load step	#0	#1	#2	#3	#4	#5	#6
Load [kN]	0	10	15	20	25	30	34

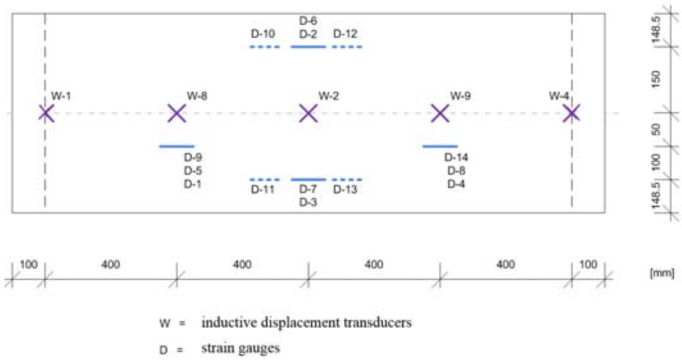


Figure 7. Position of the sensors and strain gauges (top view of the slab) [6]

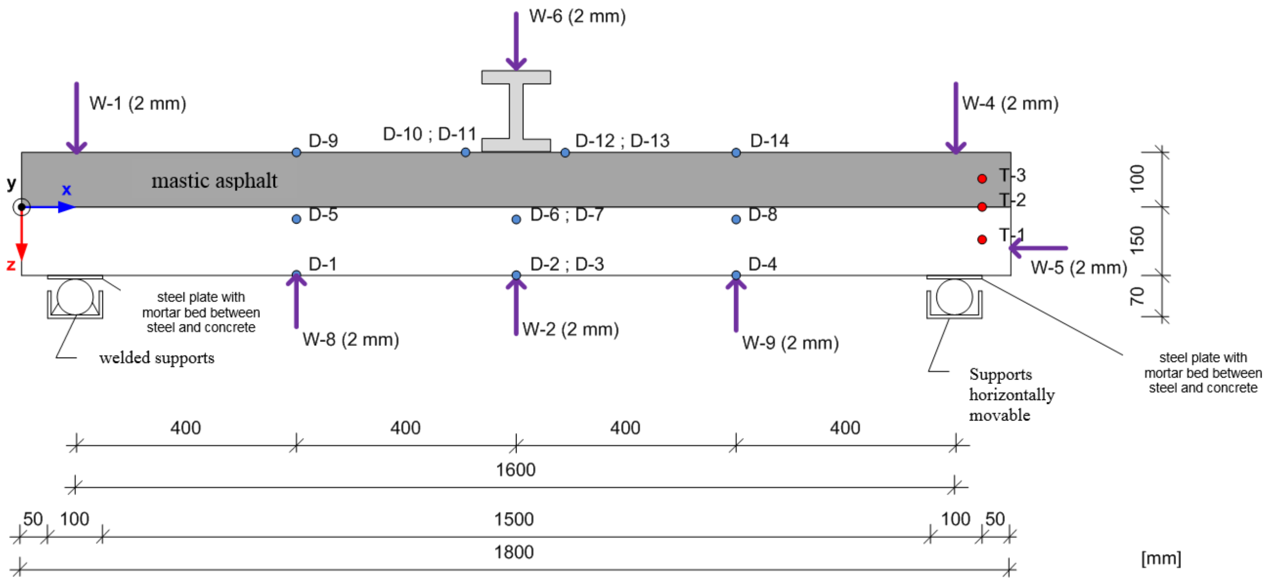


Figure 5. Position of sensors in the longitudinal section [6]

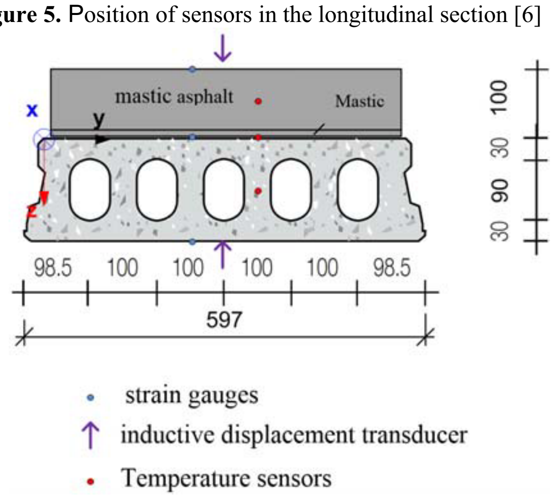
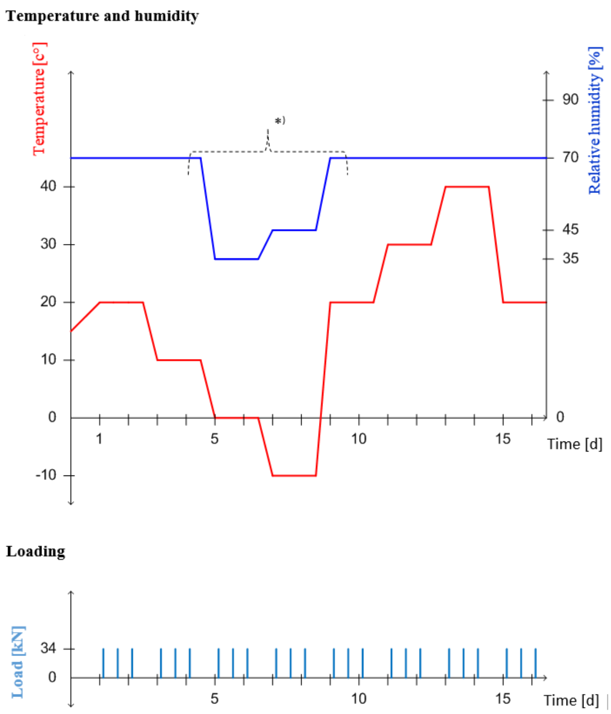


Figure 6. Position of the sensors in the cross section [6]

To investigate the temperature-dependence of the stiffness of the specimens the described test procedure has been realized for different climatic conditions. First an initial reference measurement has been carried out at 20°C. Then the specimens have been analysed at the following temperatures: 10°C, 0°C, -10°C, 20°C, 30°C, 40°C and again at 20°C. Figure 8 illustrates the temperature profile in the climatic chamber for a complete test series of one slab, as well as the corresponding relative humidity. Table 2 specifies the assignment of an abbreviation for a specific climate step following the temperature profile. Per climate step, 3 consecutive load tests have been carried out to ensure reproducibility.



*) Area in which the regulation of relative humidity in the climatic chamber was technically not possible (at T = 0 ° C → rel. humidity. = 35% and T =-10 ° C → rel. humidity = 45%)

Figure 8. Temperature profile and loading of the slabs with and without asphalt [6]

Table 2. Assignment of the different temperatures to the different climatic steps [6]

Climatic Step	K-1	K-2	K-3	K-4	K-5	K-6	K-6a	K-7	K-8
Temperature [C°]	20	10	0	-10	20	30	20	40	20

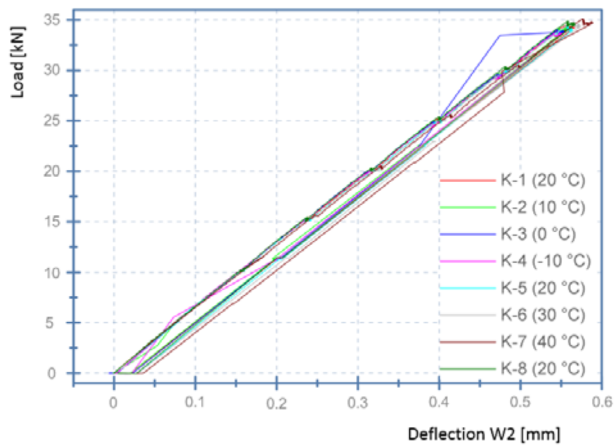


Figure 9. Slab without asphalt –Force-deformation diagram for the different climatic steps [6]

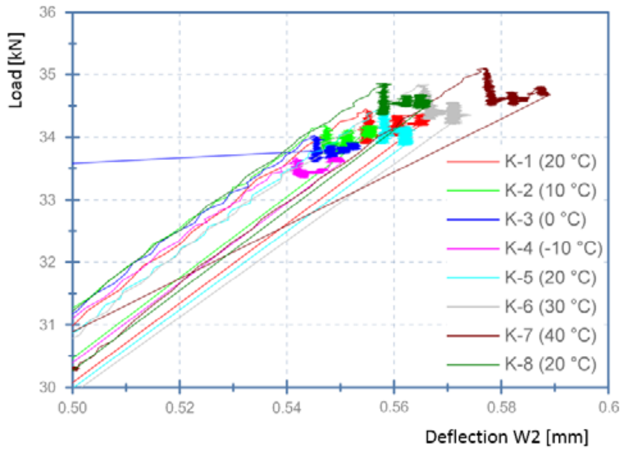


Figure 10. Slab without asphalt – Detail of the Force-deformation diagram (load step #6) for different climatic steps [6]

3.3 Measured temperature dependence of the slab without asphalt

According to the presented test sequence, the load deformation behaviour of the specimen is recorded for each climatic step. Figure 9 shows the load-deformation behaviour of the slab without asphalt layer for the deformations measured in the middle of the span (sensor W-2). The results identify only small differences between the different climatic steps. A detailed analysis of the load-deformation behaviour for load step #6 is shown in Figure 10. This detail demonstrates how close the results for the different climate steps are: between climate step K-1 (20°C - reference measurement) and K-7 (40°C) only a difference of 1.7 % can be retained while the deviation of K-4 (-10°C) to K-1 (20°C) is only 0.2%. So it can be stated that the stiffness of the pre-stressed elements is hardly depending on temperature.

3.4 Measured temperature dependence of the slab with asphalt

After performing the tests without any asphalt layer, an asphalt layer has been applied on the same slab (see description in 3.1) and the same test procedure has been applied. The only difference that has been generated was that after K-6 (30°C) another climate step K-6a (20°C) has been added permitting to exclude a degradation of the asphalt layer due to the temperature solicitation. Figure 11 shows the load deformation behaviour for the concrete slab with asphalt layer. It becomes evident that the load-deformation behaviour at the different climatic steps differ much stronger from the load deformation behaviour at K-1 (20°C – reference measurement) compared to the behaviour of the slab without asphalt layer. As asphalt behaves more viscous at high temperatures as at low temperatures, the load deformation behaviour at K-7 (40°C) differs about 13% from K-1 (20°C – reference measurement), while at lower temperatures the difference between K-4 (-10°C) and K-1 (20°C) is about 53%. Thus, it can be stated that the stiffness of the pre-stressed elements is depending on temperature.

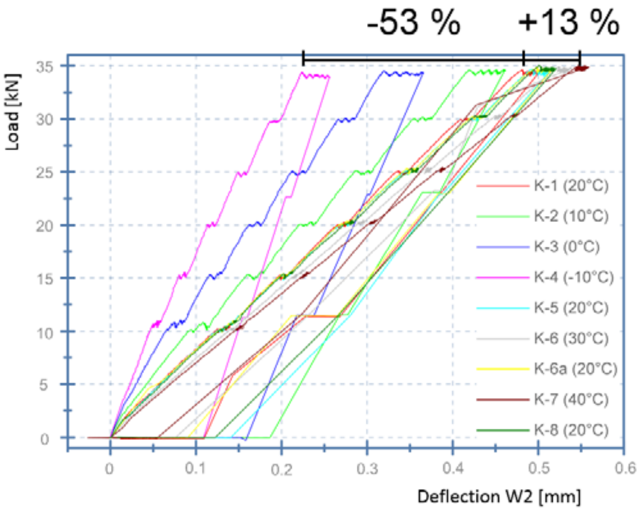


Figure 11. Slab with asphalt layer – Force-deformation diagram for the different climatic steps [6]

3.5 Comparison of the result with and without asphalt

To depict the influence of asphalt layer on the load deformation behaviour, as well as to identify its influence on the stiffness of the whole structure the load deformation behaviour of the pure concrete slab will be compared to one of the slab with asphalt layer. This is done for the climatic step K-1 (20°C – reference measurement), K-4 (-10°C) and K-7 (40°C). First, the load-deformation behaviour for climate level K-1 (20°C) is shown in Figure 12. As already mentioned all the represented measurements have been realized on one same slab. The situation with asphalt layer (blue line) shows a significantly reduced deformation for the same solicitation as the situation without asphalt layer (red line). This proves that applying an asphalt layer increases the stiffness of the whole system. Thus, the asphalt layer cannot only be understood as pure additional mass. In fact, the asphalt layer should be considered as stiffness affecting layer. Figure 13 shows the same for the climate stage K-4 (-10 ° C). At this climatic step the influence of the asphalt layer is much more pronounced as at the climatic step K-1 (20°C). This can be explained by an increasing stiffness of the asphalt layer at low temperatures. The load deformation characteristics of the slab with and without asphalt for the climate level K-7 (40°C) is shown in Figure 14. Here only a limited impact can be identified, which can be explained by an increasing viscosity and decreasing stiffness of the asphalt layer at high temperatures.

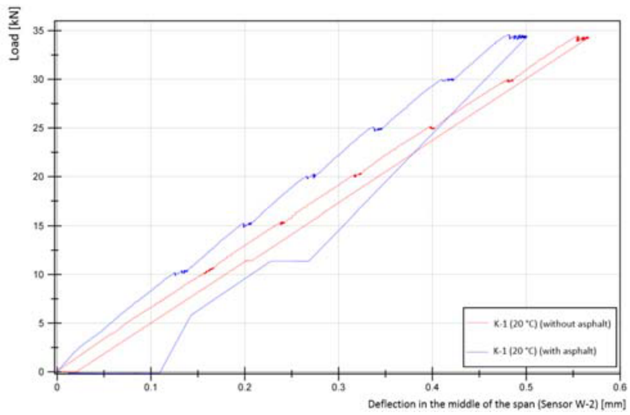


Figure 12. Comparison of the deflection in the middle of the span (sensor W-2) for the situation with (blue line) and without asphalt (red line) for the climatic step K-1 (20 °C) http://www.microsofttranslator.com/bv.aspx?from=de&to=en&a=http%3A%2F%2F131.253.14.125%2Fbvsandbox.aspx%3F%26dl%3Dde%26from%3Dde%26to%3Den%23_ftn1[6]

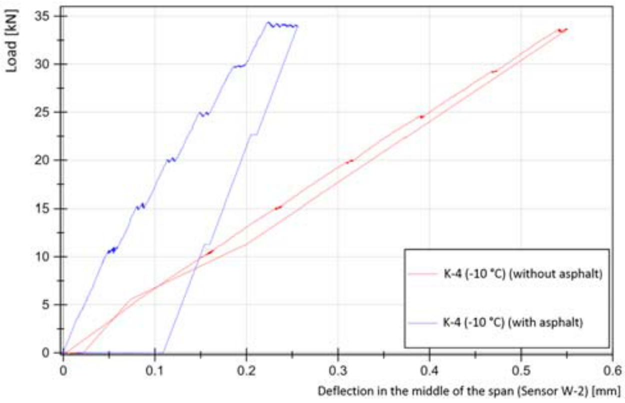


Figure 13. Comparison of deflection in the middle of the span (sensor W-2) for the situation with (blue line) and the situation without asphalt for the climatic step K-4 (-10 °C) [6]

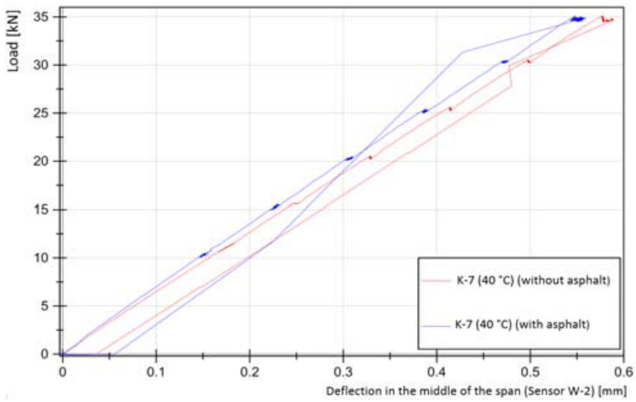


Figure 14. Comparison of deflection in the middle of the span (sensor W-2) for the situation with (blue line) and the situation without asphalt (red line) for the climatic step K-7 (40 ° C) [6]

4. Summary

In the described tests, it has been examined whether changing temperatures affect the stiffness of pre-stressed concrete elements with and without an asphalt layer. As demonstrated first on a pure concrete element, the stiffness of such a structure is hardly affected by changing temperatures. This is different for the elements with an additional asphalt layer. Here the structure behaves stiffer due to an increased stiffness of the whole structure which in return shows an increased temperature-dependent behaviour. Due to the material properties of the asphalt layer, the stiffness of the whole system is strongly affected at low temperatures, whereas at high temperatures the influence of the asphalt layer on the whole system significantly diminishes. Therefore, it cannot be assumed in particular that at low temperatures the asphalt layer acts only as pure addition mass, but its impact on the stiffness should be taken into account, where appropriate.

Although the height of the asphalt layer in the experimental setup was, compared to the one of a pre-stressed real sized bridge structure, much too important, a transfer of the presented results respecting the real relation between the thickness of the asphalt layer and the one of a bridge structure showed that the influence at low temperatures remains very impressive.

If loading tests with the aim to evaluate the condition of bridges are realized at different moments in the year and thus at different temperature conditions, the temperature-dependent properties of the asphalt layer on the stiffness of the whole structure must be considered. This is particular true if the loading tests are carried out at high and low temperatures.

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