TEMPERATURE MEASUREMENTS AT THE NESENBACH-VALLEY BRIDGE

TEMPERATUR - MESSUNGEN AN DER NESENBACHTALBRÜCKE

MESURE DES TEMPERATURES SUR LE PONT DE LA VALLEE DU NESENBACH

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SUMMARY

A composite structure – consisting of a reinforced concrete slab and a space truss out of steel pipes – was used for a multi span bridge without intermediate bearings and without expansion joints at the bridge ends where the slab is connected directly to the base plates of the tunnels on both ends of the bridge. Shrinkage of the concrete and temperature differences will produce restraint forces in particular in the concrete slab. Temperature-, strain- and deformation measurements were performed to get information about the magnitude and time function of the sources for these restraint forces.

ZUSAMMENFASSUNG

An einer mehrfeldrigen Verbundbrücke – bestehend aus Stahlbeton-Fahrbahnplatte und Raumfachwerk aus Stahlrohren – wurde auf Lager und Fahrbahnübergänge verzichtet und die Stahlbetonplatte direkt an die Sohlplatten der beiden anschließenden Tunnelstücke angeschlossen. Schwinden des Betons und Temperaturunterschiede erzeugen Zwangschnittgrößen, insbesondere in der Stahlbetonplatte. Durch Temperatur-, Dehnungs- und Verschiebungsmessungen sollte die Größe und der zeitliche Verlauf der maßgebenden Ursachen ermittelt werden, die den Zwang bestimmen.

RESUME

Un pont à structure composite (tablier en béton armé et treillis en tubes d'acier) avec six travées et a été construit sans paliers et sans joints de dilatation. Au culées, le tablier est joint de façon monolithique avec les dalles des bases des tunnels situés de part et d'autre du pont. Le retrait du béton et les différences de température produisent des contraintes, en particulier dans le tablier. Des mesures de température, de déformation et de déplacement ont été réalisées afin de déterminer l'amplitude et l'évolution de ces effets qui sont l’origine des forces de contrainte.

KEYWORDS: temperature, strain, deformation, measurements, shrinkage

1. INTRODUCTION

The bridge, crossing the Nesenbach-valley as a part of the eastern by-pass road of Stuttgart-Vaihingen, is built as a composite structure, where the concrete deck slab is connected to both following tunnels without joints. This construction method - avoiding bearings and transitions - has two main advantages:

- Improved noise protection by avoiding the noise of truck-crossing of transitions
- Economics, regarding the high inspection and repairing costs for bearings and transitions

As a consequence of the statical system the deformations of the superstructure due to shrinkage and temperature-changes create restraint forces, in particular within the concrete deck slab.

There is very less experience available with this construction method. Therefore the erection of this bridge was accompanied by different measurements to determine the origin of the restraint forces and to get quantitative information about amount and time function of these forces.

As a cooperation between the owner (Tiefbauamt of the city of Stuttgart), and the designing Engineering office (Schlaich, Bergermann und Partner) a measuring plan was developed, which was the basis for the below reported measurements. They were conducted between the casting date of the concrete deck slab (5.11.1998) and the end of 1999.

The presented report summarizes the different types of measurements and gives some background information for these measurements. Parts of the received data are developed according to different criteria. Some of these measurements are still under way in order to receive information for a longer period.

2. DETAILS OF THE BRIDGE-STRUCTURE

A principal side view of the bridge is given in fig. 1; fig. 2 shows the cross section of the most relevant concrete deck slab. The six-span-bridge has a length of about 150 m. The superstructure has a three dimensional steel truss as lower chord and a reinforced concrete slab as upper chord. The thickness of the slab is normally 0,25 m with a central girder and side girder of 0,60 m thickness. In the plan view half of the bridge length is straight, then starts a klothoide curve.

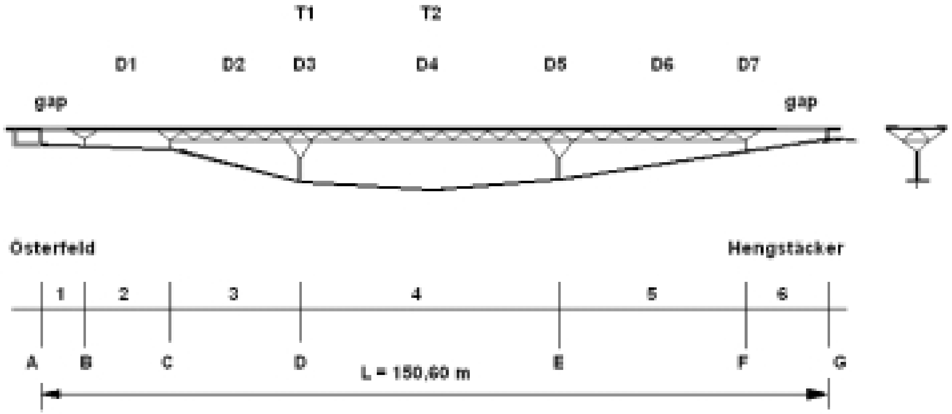

Fig. 1. Side view of the bridge deck slab

The concrete deck slab was planned to be cast in one procedure except gaps on both sides of the bridge. Some months later, these so called shrinkage-gaps should be closed to get a fixed connection to the bottom slabs of the two tunnels at both ends of the bridge. With these gaps most of the strains due to shrinkage should occur without producing restraint forces. Only the late residual shrinkage and following temperature changes could then produce restraint forces. The measuring plan had to follow this erecting sequence.

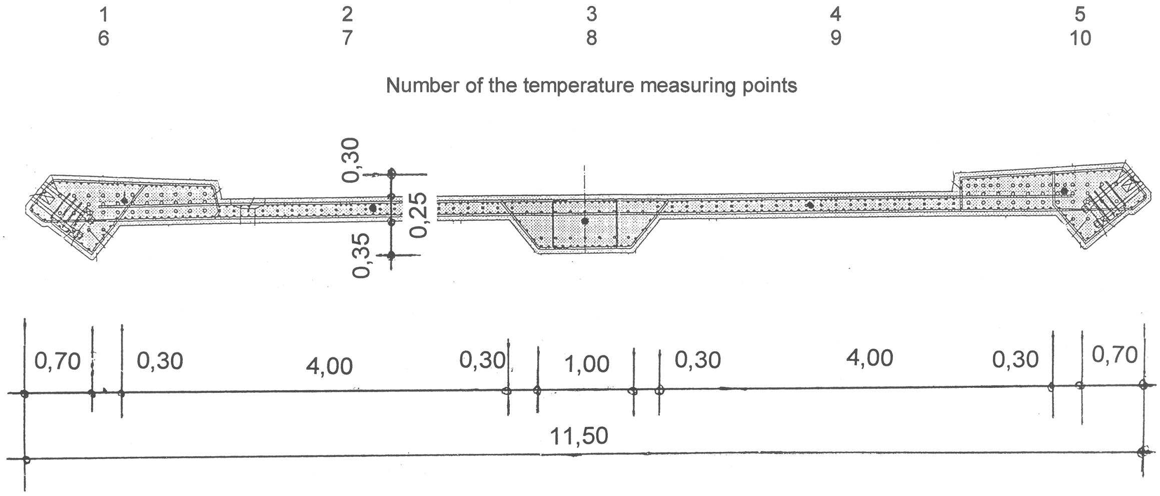

Fig. 2. Cross section of the bridge

3. TYPE AND SCOPE OF THE MEASUREMENTS

3.1 Temperature measurements

With 10 thermo-elements the temperature in the concrete deck slab was recorded – starting with the casting of the concrete – in time steps between 10 minutes and two hours. The position of the thermo-elements in the two cross-sections T1 and T2 is given in Fig. 1 and 2. Section T1 (with the numbers 1 to 5) is at the intermediate support D; Section T2 (with the numbers 6 to 10) lies in the middle of the largest span. The measurement points No. 1 and 5, (resp. 6 and 10) were in the center of the side girders; the points 3 (8) in the center of the middle girder. The points No. 2 and 4 (resp. 7 and 9) were in the middle of the deck slab.

3.2 Strain measurements at the concrete prisms

Together with the bridge slab, 7 concrete prisms (150/150/700 mm) were cast in order to determine the stress-independent deformations of the concrete:

- 3 prisms were brought to the laboratory where they remained under ordinary laboratory climate at about 20°C (laboratory prisms LP-1 to LP-3),
- 2 prisms remained on the bridge site near the Österfeld - tunnel (prisms Österfeld BPÖ-1 and 2),
- 2 prisms remained on the bridge site near the Hengstäcker - tunnel (prisms Hengstäcker BPH-1 and 2).

All prisms got measurement points on two opposite sides immediately after demoulding to measure the longitudinal strains with a mechanical strain indicator on a basis of 500 mm.

The concrete prisms on the site (BPÖ and BPH) were covered on the two other sides with 50 mm thick isolating foam plates to simulate the two-dimensional drying process of the bridge deck plate.

The strain measurements at the concrete prisms were performed in unregular time periods, starting immediately after hardening of the concrete and depending on the building process of the bridge.

3.3 Strain measurements at the bridge structure

7 cross-sections were selected to measure the longitudinal strains at the inclined face of the side girders, both on the hill- and valley-side, taking the same mechanical strain indicator, which also was used for the strain

measurement of the prisms. The location of the measurement points is listed in tab. 1.

Tab. 1. Position of the strain measurement points at the bridge deck slab

Section No.	Position
D1	In span (2) 16,5 m
D2	In span (3) 24,75 m
D3	At support (D)
D4	In span (4) 49,5 m
D5	At support (E)
D6	In span (5) 35,75 m
D7	At support (F)

To fix these strain measurements points, it was necessary to wait until the complete demoulding of the bridge slab.

3.4 Geodetic measurements

A number of geodetic measurement points were fixed on the bridge to determine the global deformations of the structure. These measurements were organized and performed by the department “Vermessung“ of the "Tiefbauamt" of the city of Stuttgart. Parts of these results were presented in this report. Part 1 of this program – starting from hardening of concrete until application of the bituminous layer – concerned measurement points on the concrete bridge deck slab, listed in tab. 2.

Tab. 2. Geodetic measurements part 1 - List of measurement points

Point-number	Name	Position
7555	A	Support Österfeld, hillside
7557	B	Support Österfeld, valley side
7558	C	End bridge slab Österfeld, valley side
7559	D	End bridge slab Österfeld, hillside
7566	E	End bridge slab Hengstäcker, hillside
7567	F	End bridge slab Hengstäcker, valley side
7565	G	Support Hengstäcker, hillside
7568	H	Support Hengstäcker, valley side

The coordinates of these points were measured at 14 different times.

This measuring program should particularly answer the following questions:

- Deformation of the shrinkage gaps
- Average strains of the bridge deck slab in longitudinal direction
- Deformation of the "Fix-points" at the tunnels

Due to the erecting process, some of these measurement points were not more available after a certain time. It was therefore necessary to add other measuring points whose positions are listed in tab. 3:

Tab. 3. Geodetic measurements part 2 - List of measurement points

Point number	Name	Position
7582	I	Support Österfeld, hillside
7583	K	Support Österfeld, valley side
7594	L	Intermediate support B, hillside
7595	M	Intermediate support C, hillside
7596	N	Intermediate support D, valleyside
7597	O	Intermediate support E, hillside
7598	P	Intermediate support F, valley side
7599	Q	Intermediate support G, hillside
7592	R	Support Hengstäcker, hillside
7593	S	Support Hengstäcker, valley side

3.5 Crack measurements

Originally it was scheduled to inspect in regular time periods the concrete deck slab optically to plot the crack pattern and to measure the crack width. The erection procedure made it impossible to perform a complete crack inspection of the top side of the concrete slab. The bottom surfaces were first visible not before the complete remove of the formwork; but it was afterwards very difficult to make these surfaces accessible without special inspection equipment. Only the surfaces of the center girder and of limited parts of the slab can be easily inspected from an special inspection passage. The crack inspection therefore was limited to this areas.

4. PRESENTATION AND DEVELOPMENT OF TEST DATA

4.1 Temperature measurements

4.1.1 General remark

The continuous registration of the concrete temperatures was performed by a battery-supplied data-logger, who registered the temperatures of the 10 thermo-elements according to free-programmable time-intervals. After a time-period of about 4 to 6 weeks the data were copied to a notebook and then converted to an EXCEL-File. Within the one year interval such a huge amount of data was produced, that a listing of this date is not more convenient. The results were therefore presented only in diagrams.

During the planning of these measurements it was questioned, if the recording of air-temperatures is necessary and the final decision was no! During the evaluating of the results it was sometimes disadvantageous, that no reliable air-temperatures were available.

4.1.2 Temperature change during hardening of concrete

The time-dependent concrete temperatures immediately after casting of the concrete are plotted in fig. 3 for a period of 5 days (= 120 h) . This diagram refers to section I; Similar values were recorded for section II. The registration of the temperature starts in the evening before casting at 18:00 h. This time refers to t = 0. About 7:30 in the following morning the concreting front reaches section II; at about 8:30 the concrete reaches section I.

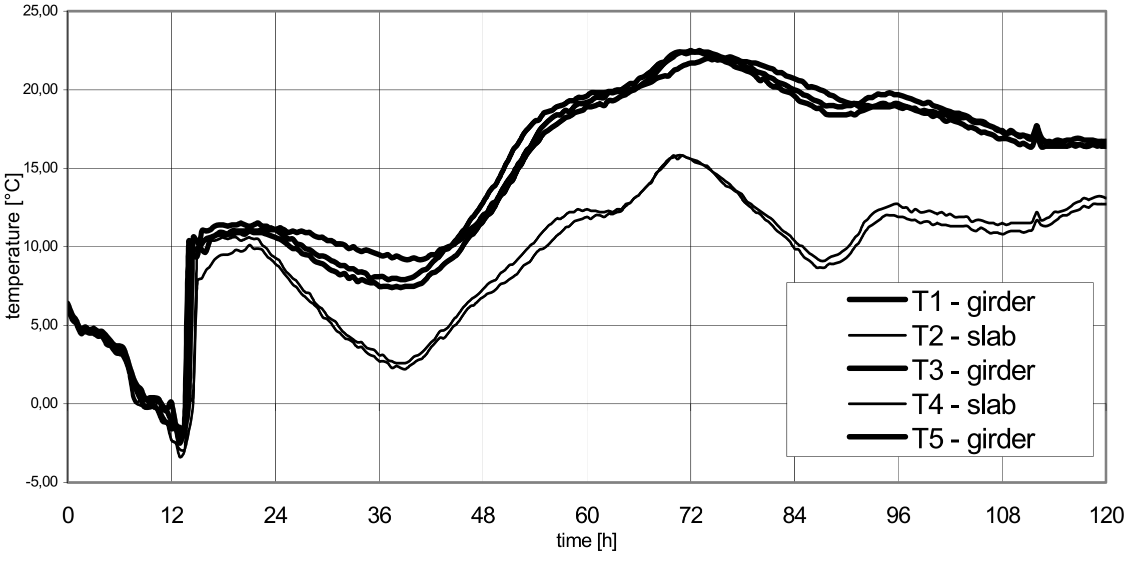

Fig. 3. Temperature increase during hardening of the concrete (section I)

At this time the concrete temperature sharply increases from the surrounding air-temperature of -2°C to the chosen temperature of the fresh concrete. About 60 h later the concrete reaches its maximum temperatures of about 23 °C for the three girders and about 16 °C for the thinner concrete slab.

4.1.3 Daily temperature change

The daily temperature change is plotted for a summer day in fig. 4 (section I); similar results were achieved for section II. The diagram starts on 2.6.99 at 0:00 in the morning (t = 0) and ends on 3.6.00 at 24:00 (t = 48 h). The extreme values always occur in the slab. The lowest values are 24 °C in the first and 18 °C in the second night: the maximum values in the late afternoon were 35 °C and 33 °C.

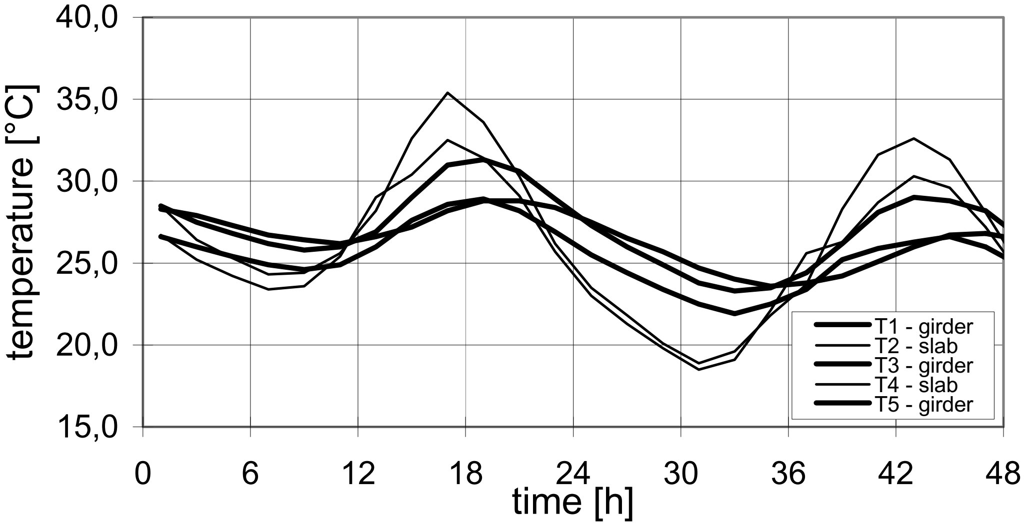

Fig. 4. Daily temperature change during a summer day

The temperature change during a winter day is plotted on fig. 5. On 12.02.1999 the temperatures start at 0:00 (t = 0) and end two days later at midnight (t = 48). The temperatures in the three girders show very small periodical changes within a general degreasing tendency within the chosen time period. The temperatures in the slab decrease to values of about - 10 °C . The maximum values are measures at about 16 h in the afternoon.

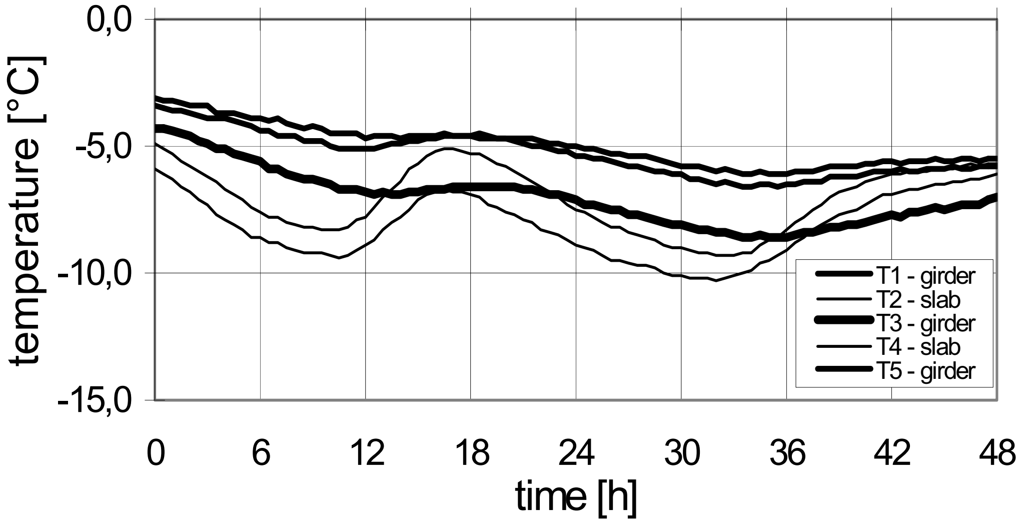

Fig. 5. Daily temperature change during a winter day

Both diagrams indicate, that the thin slab reaches much quicker the surrounding air temperature than the thicker girders.

The one and a half - year - time function of the temperature in the slab is plotted on fig. 6. Besides a peak value of 40 °C (see following figure) the temperature range lies about between 35 °C and –9 °C.

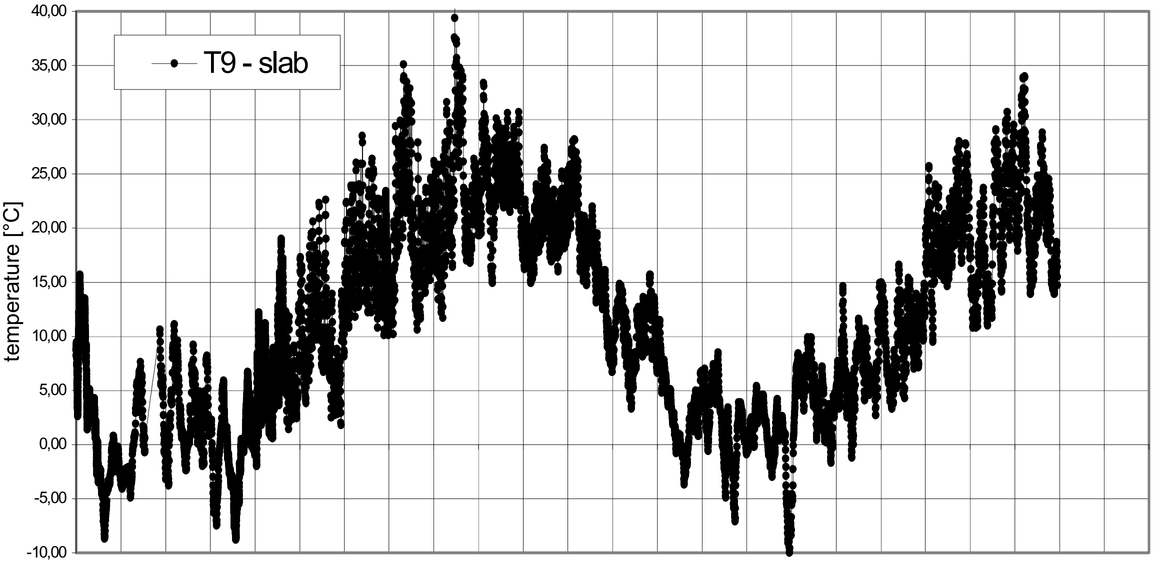

Fig. 6. Temperature variation during one year

A special stress situation was created during the application of the hot bituminous deck layer. The associated temperature curves are given in fig. 7. Starting from an almost equal distributed level of 20 - 21 °C the temperatures in the slab increased up to 43 °C, the inner girder showed slowly increasing temperatures as a consequence of the heat flow from the slab to this girder. There was almost no temperature increase in the side girders.

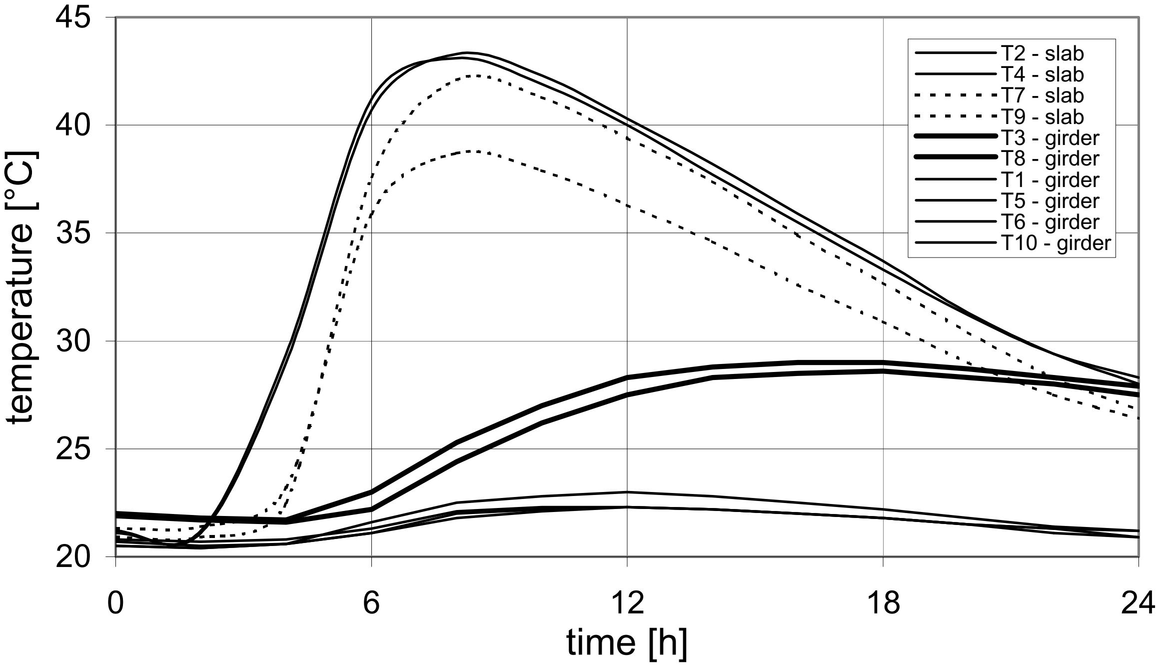

Fig. 7. Temperature increase during application of the bituminous layer

4.1.4 Temperature difference within the deck slab

As a consequence of the slow temperature increase of the girders compared to the thin slab the bridge deck shows temperature differences due to the daily temperature course. This effect is plotted on fig. 8 for section I during a summer day - using the average values of the two side girders an the two parts of the slab. These values refer to the same time period as in fig. 4. The highest negative differences (slab colder than girders) occur about 7 h in the morning; the highest positive differences (slab warmer than girders) were measured between 16 h and 18 h in the afternoon.

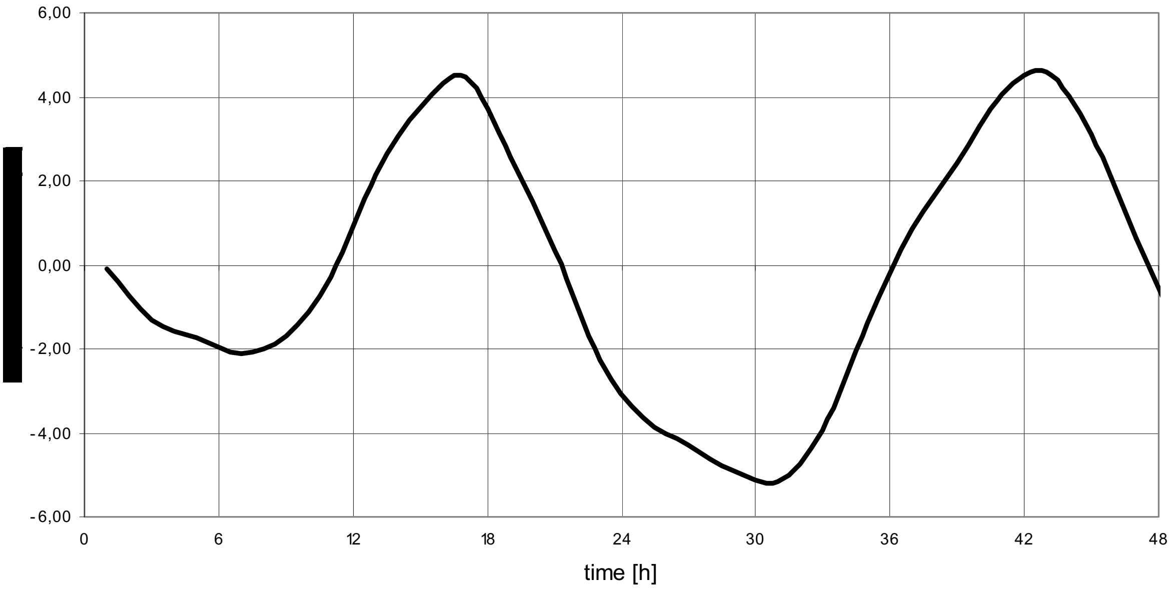

Fig. 8. Temperature difference within the deck slab

4.2 Strain measurements at the concrete prisms

4.2.1 Prisms stored in the laboratory

The strain measurement of the 12 measurement points at the 3 prisms in the laboratory were performed at selected times, which were chosen according to the construction progress of the bridge. The deviation of the measured strains were small so that an average value from all measurements was appropriate. The 3 values

ε_{tot}	Average measured strain value
ε_T	Strain due to temperature change in the laboratory
$\varepsilon_S = \varepsilon_{tot} - \varepsilon_T$	Strain due to shrinkage

are plotted on fig. 9 as a function of time. As expected there is a strong degreasing tendency of shrinkage with a strain value of about -0,55 ‰ after 100 days.

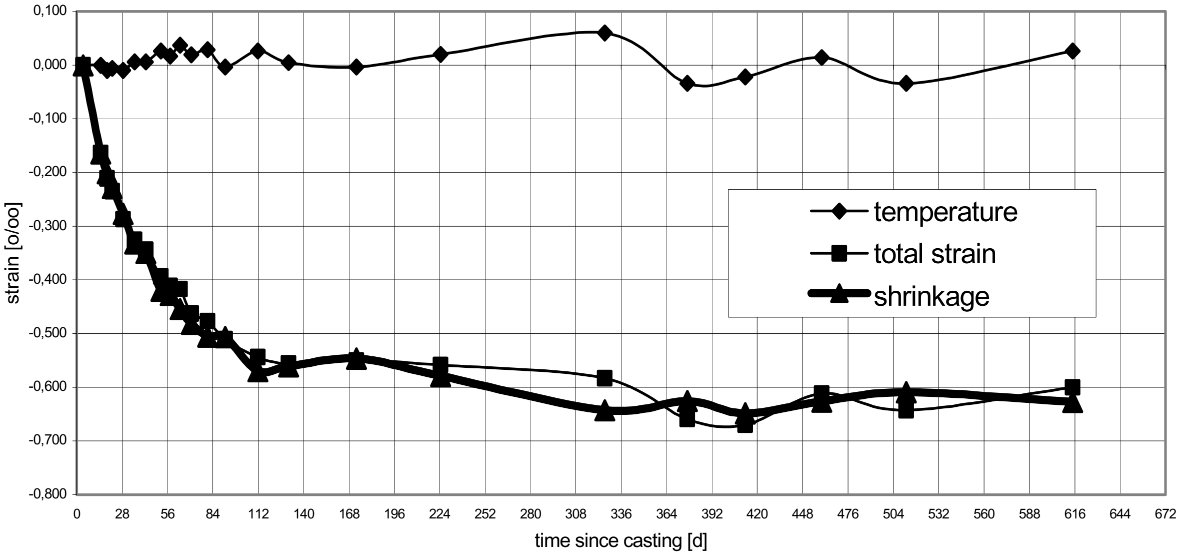

Fig. 9. Strains at the laboratory-prisms

4.2.2 Prisms stored on the bridge site

For each two prisms, stored at both ends of the bridge it was scheduled to perform the same measurement program as for the laboratory prisms. Unfortunately there were some practical problems which lead to some restricted test results:

Obviously this test specimen distracted the regular building process of the bridge: they were moved away and were used for depositing of building material. Both had the consequence that the measurement points – glued on the surfaces of these prisms – often were destroyed and had to be refixed without having continuous readings. Also the isolating panels, which were fixed to have similar drying process as in the bridge deck, were often misused or even disappeared. Finally the prisms at Hengstäcker tunnel completely disappeared, so that no further measurements could be taken.

The useful part of the measurements were evaluated similarly as the laboratory prisms. The measured total strains – taken from the prisms at Österfeld tunnel – were plotted on fig. 10; those from the prisms from Hengstäcker tunnel on fig. 11. The strains due to shrinkage were again calculated as difference between total strains and temperature strains.

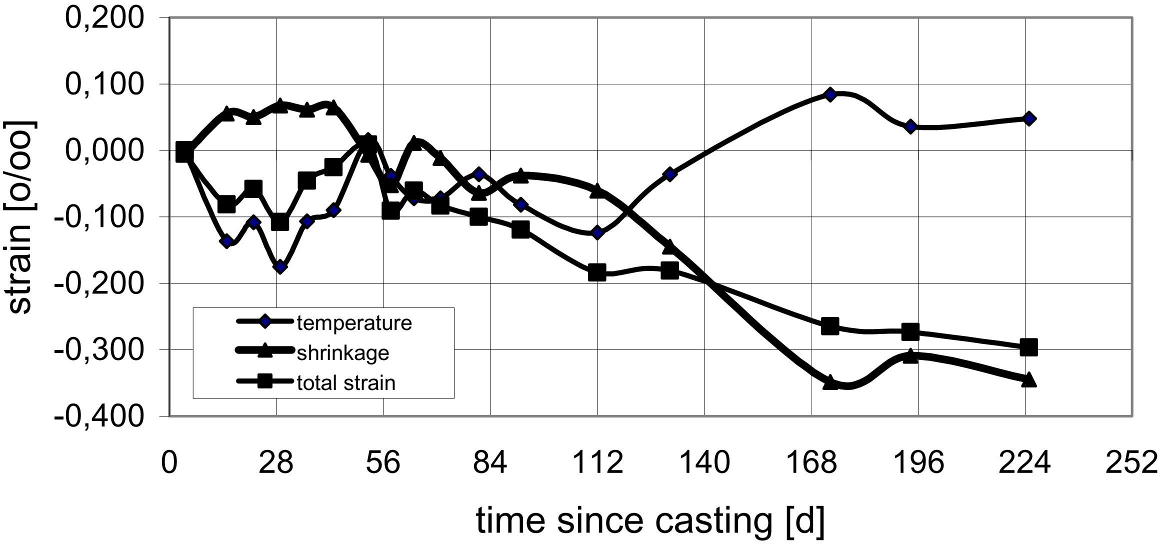

Fig. 10. Strains at the site-prisms – Österfeld

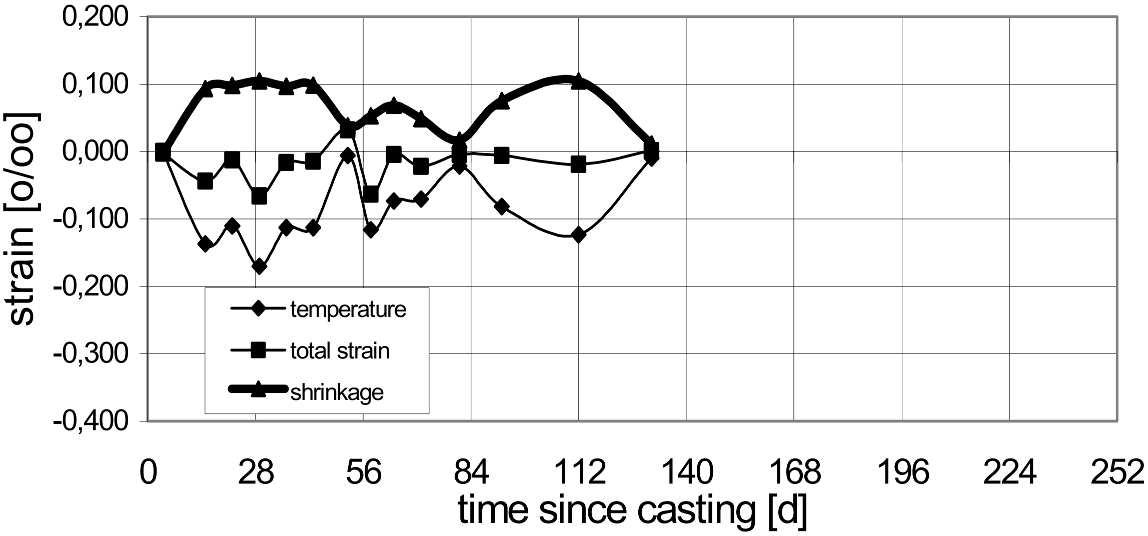

Fig. 11. Strains at the site-prisms – Hengstäcker

The test results from Hengstäcker side – which end at an age of 130 days – showed almost no shrinkage. The Österfeld prisms however displayed at this age a small shrinkage strain of about –0,15 ‰; the shrinkage strain at the laboratory prisms was measured to –0,55 ‰. The tests at the Österfeld prisms had to be terminated at an age of 225 days, having reached then a shrinkage strain of about –0,35 ‰, compared to –0,60 ‰ for the laboratory prisms at this age.

4.3 Geodetic measurements

4.3.1 Deformation of the shrinkage gaps

The change of the distances AD and BC (for the Österfeld shrinkage gap) and the distances EG and FH (for the Hengstäcker shrinkage gap) is plotted in fig.12 versus the time as the average value of both results. There is also indicated the time for closing the two gaps, which is t = 43 d for the Österfeld gap and t = 90 d for the Hengstäcker gap. Up to closing the first gap, both gaps behave similarly; afterwards the temperature induced deformations were concentrated at the still existing gap.

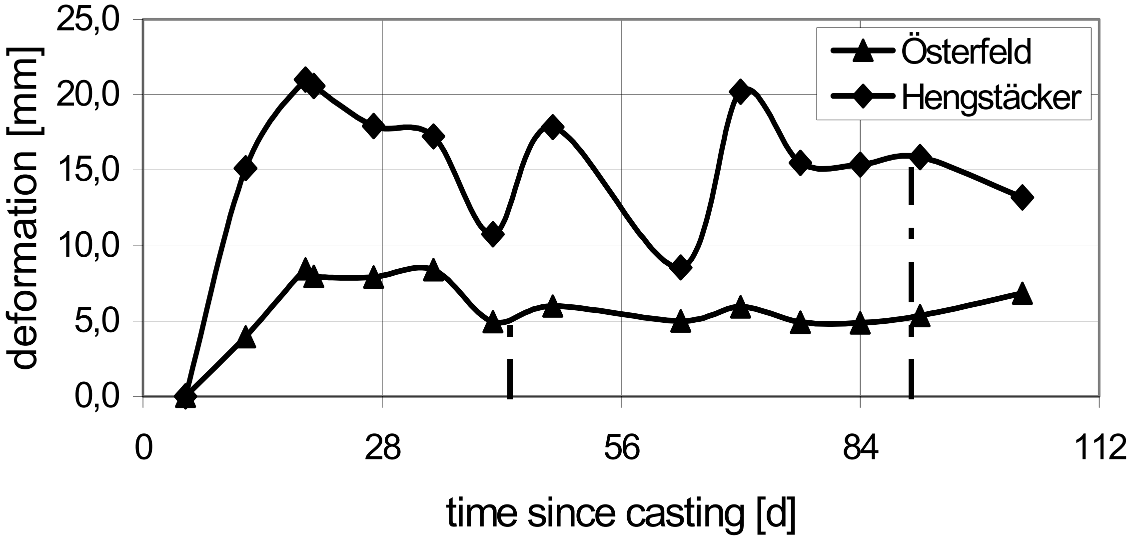

Fig. 12. Deformation of the shrinkage gaps

4.3.2 Strains in the concrete deck slab

The change of distance of the measurement points on the concrete slab CF and DE , converted into strains, were plotted in fig. 13 as time function. Here also the total strains were modified by the temperature strain to calculate the shrinkage strain. Similar to the behaviour of the on-site-prisms, which showed no shrinkage – even slight swelling - within the first 100 days, the strains at the bridge also indicate small swelling behaviour.

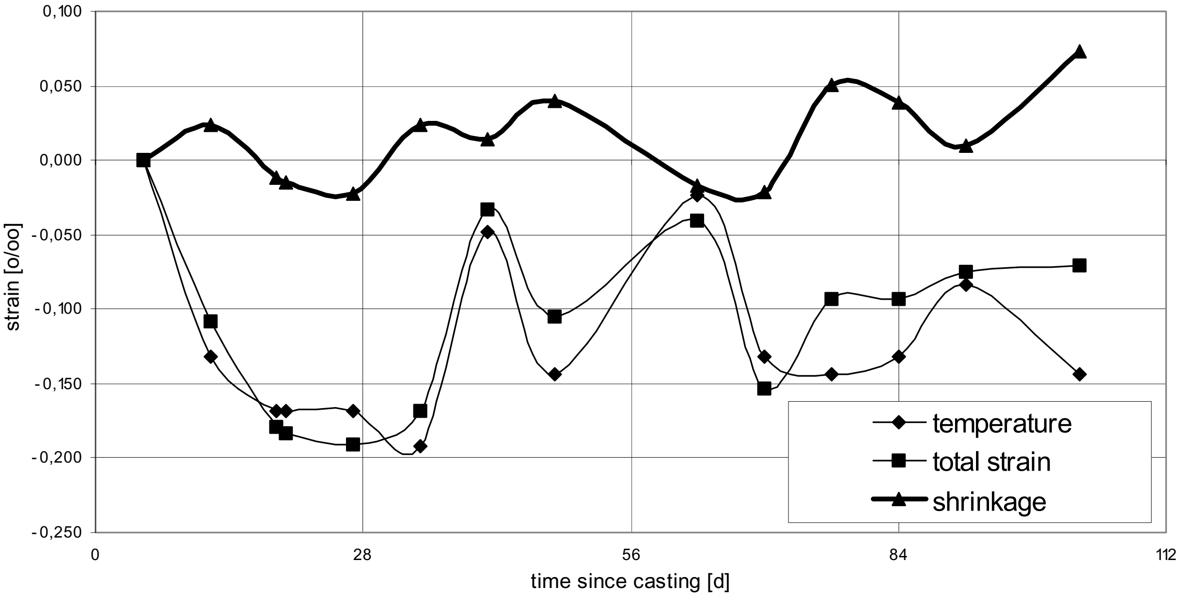

Fig. 13. Longitudinal strains in the slab – measuring period I

4.3.3 Geodetic measurements part II

Again the total strains were determined from two points at both ends of the bridge an plotted on fig. 14 versus the time and modified by the measured temperature strains. The diagram starts at t = 103 days; all following measurement refer to these values. This starting point may be compared with fig. 13, which ends with a shrinkage strain of about –0,075 ‰. From this time the bridge deck slab shows an continuous increase of shrinkage.

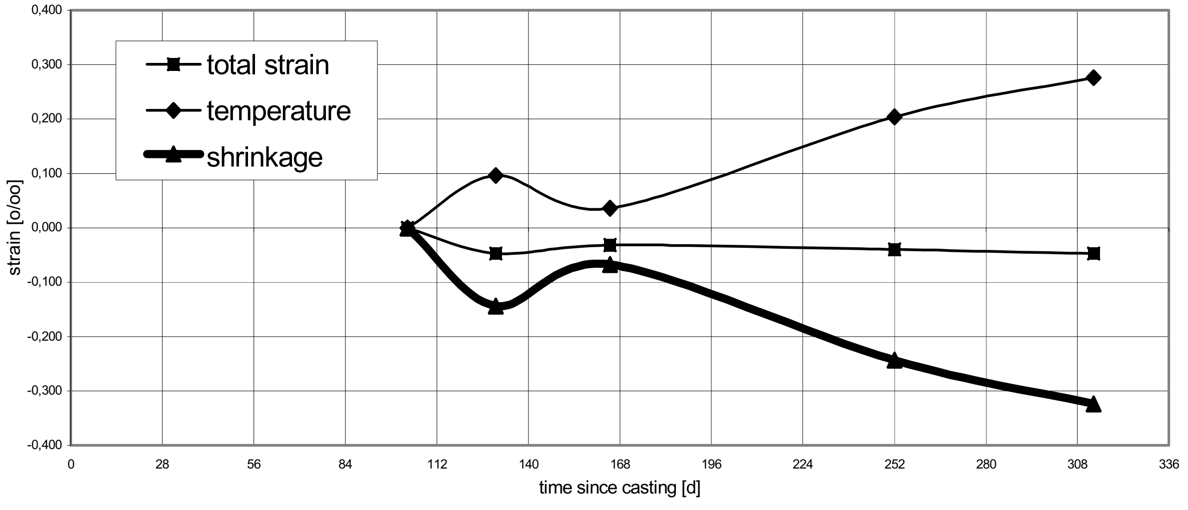

Fig. 14. Longitudinal strains in the slab – measuring period II

5. FINAL COMMENTS

After having fixed the thermo-elements to the reinforcement bars, the reading of the temperature values was very easy and created no problems. Only during the demoulding of the concrete deck slab the wires between the thermo-elements and the data-logger had to be handled carefully to avoid their rupture.

The strain measurements – both on the bridge slab and on the prisms – created more problems due to weather and construction conditions.

Despite these problems the achieved results are a very helpful information to understand the answer of such a bridge system to the climate conditions. One of the most remarkable results was the different time function for shrinkage: The prisms – subjected to laboratory climate – showed shrinkage strains immediately after the hardening of the concrete. The structure itself and the prisms on the site showed within the first about 100 days almost no shrinkage – even some swelling. This was during wintertime. The shrinkage effect started with increasing air temperatures.

These results are good tools for the designing and building of future bridges of this type.

The author thanks very much to the responsible persons of the bridge owner (Tiefbauamt der Stadt Stuttgart) for the financing of the measurements and the designing Engineering Office (Schlaich, Bergermann und Partner) for the cooperation during planning and executing of this measurement program.