Monitoring and Assessment of 100 year Old Alzbrücke Seebruck

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Abstract Alzbrücke Seebruck has been erected in 1933. It is a RC bridge using gerber hinges. These gerber hinges had been deteriorated over time in a significant way and the bridge was foreseen for replacement by a new structure. During preparation of the new structure the bridge should be kept open to the traffic for some 3 years. A monitoring concept has been established that allowed to check and assess the structural capacity in real time including check of traffic loads, alarm functions and all that based on static analysis. This paper shows the structure, the static details of the hinges, the monitoring concept and its results over time and lessons learned.

1 Introduction

The 115m-long Alzbrücke in Seebruck was constructed in 1933 and is located at the northern shore of Lake Chiemsee spanning over its only outlet, the River Alz, around 80 km south-east of Munich. The nine-span superstructure had been designed as a Gerber girder – or cantilever girder – system to allow the number of piers in the muddy ground to be reduced. Each of the main girders overlaps two supporting piers and shorter girders are placed between the cantilevers. The connections between girders are formed by half-joints in a statically determinate system that avoids temperature-induced stresses but provides hardly any redundancy in the structure.

Following a structural evaluation of the load bearing capacity of the Alzbrücke there had been a weight limit of 12 t imposed in 2018, and plans were under way for a replacement structure by the bridge owner (the local road authority Staatliches Bauamt Traunstein). However, a further assessment in July 2018 revealed extensive damage in the superstructure, with hinges between girders showing strong concrete spalling as well as corrosion in the exposed reinforcement bars and numerous cracks in highly stressed regions of the hinges, s. Figure 3.
Consequently, a structural health monitoring was proposed to assess the degradation of the hinges, detect further degradation and to check loading by traffic, Figure 2. This would allow the bridge to remain open for traffic until the construction of the new bridge could begin in early 2022.

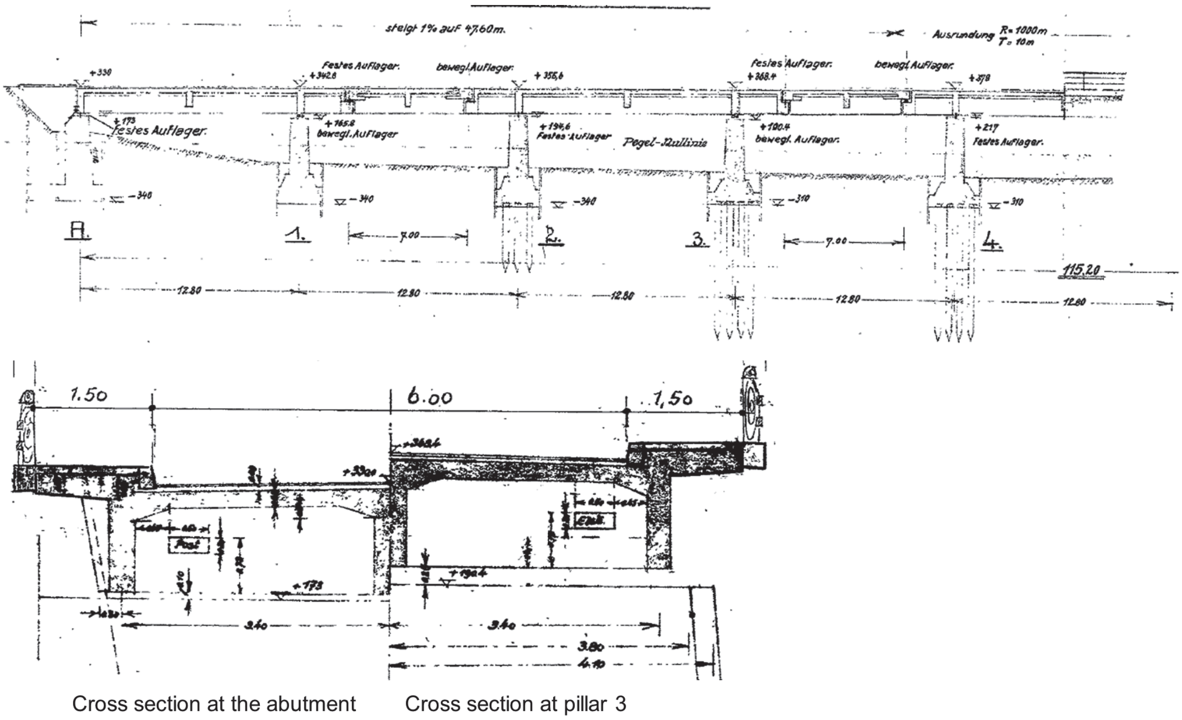

Figure 1: Longitudinal and cross sections of the struktur

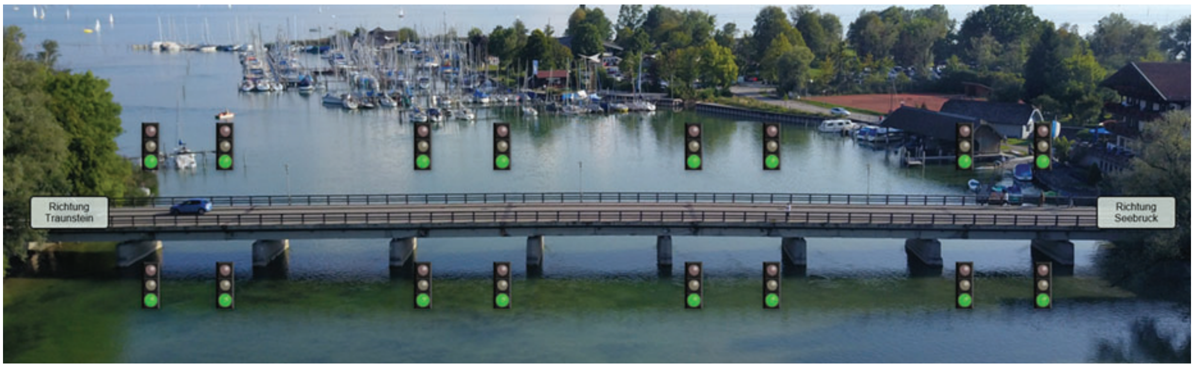

Figure 2: Alzbrücke in Seebruck: Visualization of the actual state of the bridge during the monitoring campaign

2 Static examination of Gerber joints regarding notification of failure

Prior to setting up the monitoring system, all local areas at the hinges had to be structurally assessed in detail in order to demonstrate through reliable calculations that the hinges would not fail suddenly, causing a major bridge collapse, and also for reassurance that monitoring could help in detecting damage.

For this purpose, in a first step the state of all joints was systematically recorded. In order to quantifying the load bearing capacity the load transfer mechanism at the joints was analysed based on a truss model. Figure 4 shows exemplarily the chosen truss model of the outer console of the cantilever beam taking into account the observed cracks and corrosion of the reinforcement. In order

Figure 3: Strongly corroded reinforcement at the girders (left); Detail: corroded bearing between two girders (right)

to evaluate the resistance, the horizontal and vertical tensile capacity (Zh, Zd) of the reinforcement as well as the compressive capacity of the concrete (D1) was determined and compared to the actual loading by traffic (SLW 12) and gravity forces. In order to obtain a realistic estimate of the actual loading, the safety factor of the gravity forces was reduced and the dynamic amplification factor of the traffic loads neglected. In a second step the resistance was evaluated regarding notification of failure taking into account the degradation and further unconsidered load bearing reserves.
Table 1 summarizes the static utilization (quantitatively), load-bearing reserves and the state of degradation of the 4 console types and evaluates the overall situation by overlaying the three factors and gives a recommendation for the monitoring task.
All in all, a sufficient load-bearing capacity of the damaged structure could be demonstrated. Furthermore, it could be shown that a structural failure caused by further degradation or fatigue will occur with sufficient ductility.

Figure 4: Load transfer mechanism of the cantilever beam of the external console

3 Monitoring concept

3.1 Choice of sensors and installation

The static analysis showed that the main reasons for a structural failure due to further degradation are caused by

a) fatigue and or a further reduction of the cross section of the reinforcement by corrosion

Table 1: Assessment of the load bearing resistance

		Loading* [kN]	Resistance [kN]	capacity factor [%]			Further load bearing reserves	Degradation	Assessment				
				ZD	ZH	D1			ZD	ZH	D1	Critical?	Monitoring
Cantilever girder	outer console	310	419	74%	53%	42%	Activation of 2nd diagonal supplementary reinforcement	width of compression zone, anchorage of ZH, surface reinforcement d12	9	6	6	ZD	local
Cantilever girder	inner console	490	557	88%	84%	75%	Increase of the inclination of the compression strut; activation of surface reinforcement d12	anchorage of ZH due to small concrete cover and clorid exposure	7	6	6	-	-
Suspended girder	outer console	201	224	90%	42%	42%	use of an alternative truss model for the gravity forces	width of compression zone, anchorage of ZH, surface reinforcement d12	8	6	5	ZD	local
Suspended girder	inner console	368	362	101%	89%	64%	small load bearing reserves using an alternativ truss model	anchorage of ZH due to small concrete cover and clorid exposure	7	8	5	ZH	global

*) G with γ_G=1.20, Q=SLW12 with γ_Q=1.50 without amplification factor

Legend	load bearing capicity	Load bearing reserves	Degradation	Assessment
(orange)	small	small	high	critical (8-10)
(yellow)	sufficient	sufficient	tolerable	sufficient (6-7)
(green)	high	high	small	good (0-5)

b) a failure of the anchorage zone of the reinforcement and/or

c) a failure due to compression / splitting tension at the bearings.

A failure of the anchorage b) leads to a small slip of the reinforcement until a re-anchoring of the hooked bars occurs. Both the mechanism a) and b) cause an increase of the stresses in the reinforcement leading to a further strain in the reinforcement at the cracks. A further strain in the reinforcement due to further degradation will lead to an increasing crack width and thus can be detected by measurements. Instead of using the absolute value of the crack width which might be affected by drift errors, e.g. due to thermal expansion of connecting cables, the relative crack deformation Δw caused by the dynamic opening and closing of the crack by the weight of the passing truck is monitored using crack sensors.

A failure of the compression zone c) can only be measured indirectly. It can be assumed that splitting tensions will lead to cracks perpendicular to the compression strut. As the exact position of the crack is unknown, changes in the strain can be detected globally by means of strain measurements over a larger length, s. Figure 6 (left).

In total 33 crack bridging strain gauges were mounted on 16 hinges at both sides of the based on the results of the static analysis and the crack situation. These strain gauges recorded relative and absolute crack deformation at a rate of 50 Hz until January 2022, s. Figure 5

Figure 6 shows exemplarily the instrumentation of a damaged hinge using crack sensors to detect overstressing of the reinforcement (blue) and a global sensor (red) to detect overstressing of the compression zone at an early stage.

3.2 Data collection, -reduction und -transmission

A long-term monitoring system was installed on the bridge in August 2019 that would survey all the critically damaged locations at the bridge in real time.

Strain data of the entire monitoring network was collected locally by a computer. Trucks passing over the bridge generated data peaks of the deformation that were automatically detected.

Many data points were reduced to relative crack opening (peak height) and absolute deformation before and after the recorded peak (base value) with the corresponding time stamp. Only the reduced peak data was sent onwards wirelessly to the online server. The server provided data to

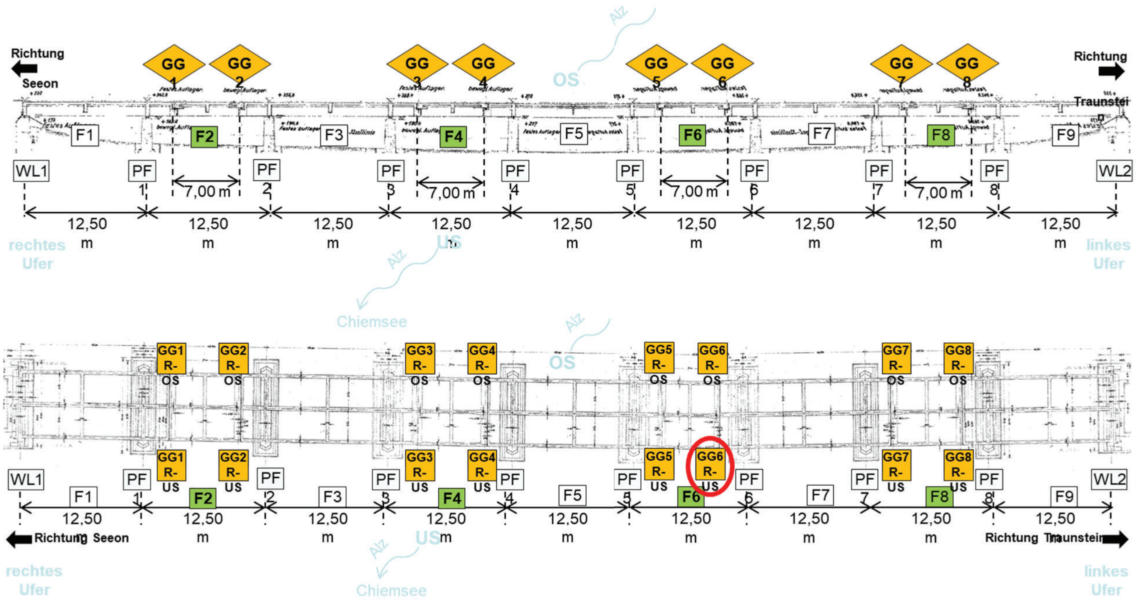

Figure 5: Location of the sensors at the Alzbrücke

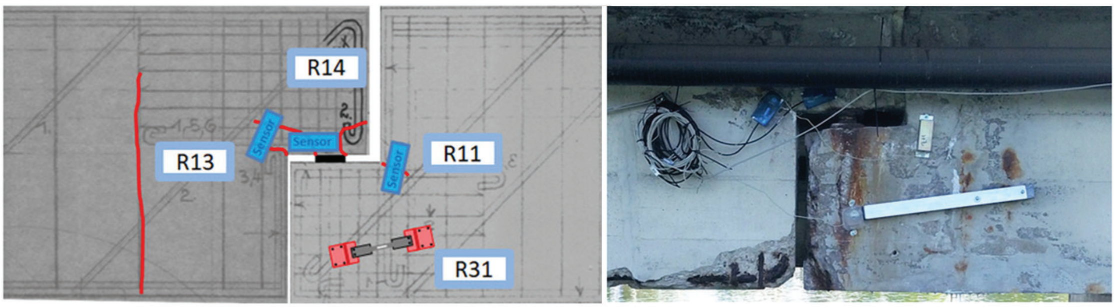

Figure 6: Local crack sensors (blue) and global sensor (red) to detect an overstressing of the reinforcement and/or the compression zone at the hinge GG6 R-US

a website where peaks could be examined by all persons involved in the project, s. Figure 7. The server also compared the received peaks with predefined warning thresholds and, if these were exceeded, it would also send out warnings. Thresholds were derived individually for each sensor from the peak levels recorded during the first two months of the monitoring campaign.

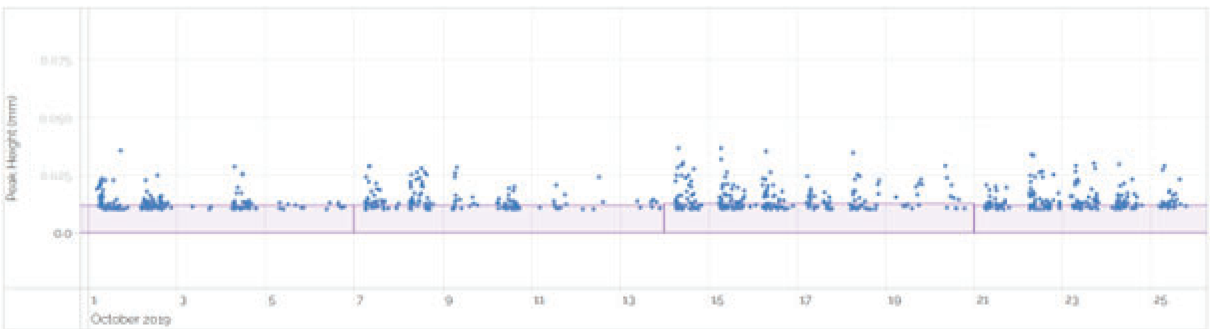

Figure 7: Recorded peak heights as displayed on a website in real-time

Yellow and red warning levels were established, with yellow alerts defined as low-level warnings at peak heights that were rarely reached, but which nonetheless occurred at several occasions during the campaign. Along with all additionally available information and raw data, these peaks were analysed by supervising engineers. If no further warning signs were detected, no consequences would be imposed. The red alert level was planned to automatically activate a protocol for immediate closure of the bridge by the local fire department. However, the red alert emergency protocol was never activated.

3.3 Calibration and monitoring of traffic loads

To validate the monitoring network and set a reference for the measured peaks, two trucks with known axle load and spacing were driven over the bridge, one with a total weight of 12 t and the other 25 t. As the bridge was temporarily closed to other traffic, the heavier truck could be allowed even though it exceeded the weight limit.
The peak heights generated by passing trucks did not only depend on the total weight but also on the number and spacing of axles, which means that the exact identification of the weights of these vehicles was not possible. However, up to 100 vehicles per week exceeded the response measured from the 25 t reference truck, which indicated that the imposed weight limit was regularly being exceeded. Consequently, the local road authority enhanced signage for the official diversion route and instructed the police to conduct weight controls in order to emphasise the urgency of the imposed weight limit. The mobility restrictions imposed by the onset of the Covid pandemic in early 2020 was the most successful factor in limiting the number of instances of traffic exceeding load limitations.

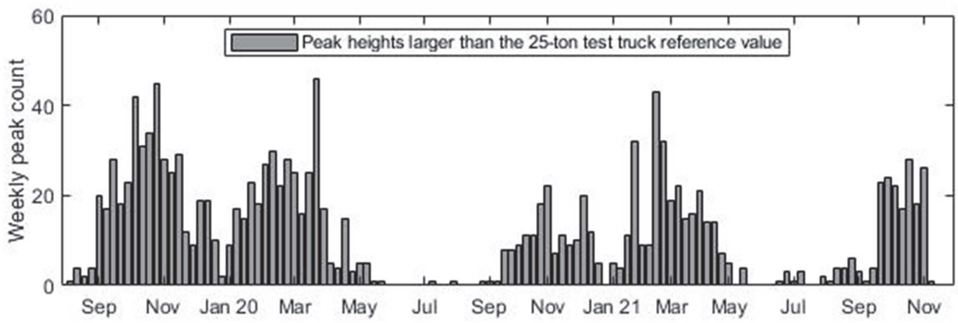

Figure 8: Example of long term evaluation of one sensor by weekly peak count

3.4 Monitoring of degradation

Along with the analysis of individual events, one of the objectives of the monitoring campaign was to identify a possible gradual deterioration of the load bearing capacity of the hinges.
Recorded peaks were categorised by their severity with regard to the 12 t and 25 t test trucks' reference values. The number of their occurrences were evaluated on a weekly basis and investigated for possible long-term trends. Recording an increasing number of low peaks, as well as recording increasingly high peak values would have strongly indicated a deterioration of the condition of the

hinges, which was not observed. The installation of sensors at all the hinges enabled responses from the same vehicle to be compared, so that increasing peaks at one sensor against stable peaks for the others would indicate degradation, for example a smooth bar slipping or losing bond, or a reduction of rebar section due to fatigue.

To establish a regular reference between actual truck weight and the response recorded by the sensors, public transportation movements were used. A night bus scheduled to pass the bridge on weekends at 1am was regularly detected by the sensors and could be clearly identified, in contrast with daytime buses that crossed with regular traffic. The bus company provided the model and specification of the bus as well confirmed that that the number of passengers was quite low as would be expected in a rural area at night. The peak heights generated by the night bus did not increase over time and thus did not indicate gradual deterioration of the condition of the hinges.

While peak heights represented relative crack deformations caused by passing trucks, base values represented the absolute crack deformation before and after a peak was recorded. Continuous growth of the absolute crack opening deformations without external loading was investigated. Ambient temperature was found to have a major influence on the recorded base values. Cold temperatures caused the absolute crack opening deformations to increase in winter. During summer, warm temperatures led absolute crack opening sizes to return to previous levels. These seasonal wave-like effects were also observed on a smaller scale for day and night temperature differences. Continuously increasing crack growth was not detected throughout the monitoring campaign, which would have enforced bridge closure.

Extremely cold temperatures were found to produce a remarkable jump in crack opening deformation at several locations. In January and February 2021 temperatures dropped below -5°C in three periods of three to five continuous days. Within 12 hours, base values locally grew to levels previously only seen at the passage of extraordinarily heavy trucks. Blocked bearings that due to extensive corrosion could not absorb large temperature-induced deformations were assumed to be the reason for these unusual events. With ambient temperatures again rising above -5°C, crack openings returned to their previous levels. Curiously, -5°C was found to be the temperature threshold for this jump to occur, which in the other winter seasons 2019/2020 and 2021/2022 had never been reached.

4 Summary and Lessons learned

The long term monitoring campaign that took place at Alzbrücke between 2019 and 2022 ensured the operation of the bridge for two and a half years even though extensive damage was present at the hinges.

A network of a total of 33 strain gauges processed and recorded crack opening deformations in real time, enabling the detection of any critical excessive deformations or long term deterioration of the condition of the hinges.

During the campaign the defined limits of the warning system were exceeded several times. In most cases the warnings were the result of crossings of extremely heavy trucks with a total weight significantly exceeding the permissible weight. After interpreting the measured values and checking on site, it could be shown that they did not result in any measurable increase in damage (plastic

deformation) and hence a closure of the bridge could be avoided during the time.
Initially it was planned to start a defined alarm chain when a certain limit is exceeded. In practice this was not possible due to several reasons. Firstly, based on the measurements only the change in the behavior of the structure can be recognized, consequently it is only possible to draw conclusions about its condition to a limited extent. Secondly, although it is technically possible to trigger a defined alarm chain, neither the local road authority nor the emergency services (fire department) are sufficiently staffed e.g. to set up a closure of the bridge at short notice at any time. Third, an automated evaluation of the deformation behavior requires a certain sharpness to ensure the static load capacity and thus carries the risk of repeated “false alarms” leading to a loss of trust in the system within the population on a long run.
All in all, the Alzbrücke showed no significant progression of damage within its last 2.5 years of operation. The construction of a new slender steel composite superstructure on the existing piers and abutments started in early 2022 and was completed - as planned - at the end of the same year.

Figure 9: The new Alzbrücke