INFRASTRUCTURAL INTEGRITY

The Laboratory of Solid Structures at the University of Luxembourg details its methods of assessing structural integrity

From above, everything seems to be all right: nice bridge constructions in steel and concrete leading the traffic over roads, valleys, railway lines or rivers. The age of many of these bridges, and their daily traffic loads, is increasing, whereas their integrity is constantly decreasing so that many are continuously surveyed. Visual inspections and loading tests are used for condition assessment and, although some bridge constructions have already been repaired, inspectors have questioned the safety of many.

If a bridge is evaluated as 'insufficient', there is acute need for action as traffic safety or even the static integrity of the bridge can be jeopardised. In these cases, the authorities often reduce the speed limit or impose a weight limit, trucks have to look for alternative routes, and in extreme cases, the bridge is completely closed, often leading to traffic jams.

The current worldwide reconstruction needs of bridges constitute a high economic impact even if only priority investigations are taken into account. As such high amounts can no longer be deducted from the normal budgets for the 'preservation of civil engineering' alone, authorities start to launch special bridge modernisation programmes. Therefore tools/procedures that improve and streamline condition assessment activities are needed to provide information that assists authorities in checking that highway structures are safe for use and fit for purpose.

State-of-the-art

In research, as well as dynamic-based techniques, static-based condition assessment techniques are developed for gaining information on the condition of a structure. Especially, the identification and localisation of damage by analysing the response of a structure due to dynamic excitation remains difficult as it leads to a response of the whole structure, resulting in global eigenfrequencies and modes shapes. Research on the subject has shown that the drops in eigenfrequencies (due to a local stiffness reduction of large structures such as bridges) remain small and at the same order of magnitude as the changes observed due to an exposition of these structures to changing environmental conditions.

New promising research activities at the University of Luxembourg

In recent years the research group for Solid Structures LSS at the University of Luxembourg focused its research on the condition assessment of bridges and the development of tools and procedures for simplifying damage detection and the prediction of a bridge's lifespan. The intense co-operation with internationally reputed scientists and companies guarantees high-ranked scientific research results, as well as practical and relevant tools for bridge authorities. With this research the group LSS aims at providing answers to scientific, political and environmental challenges.

Several bridges have been made available by the Luxembourg bridge authorities before deconstruction. The specificity of these bridges was that their condition was initially undamaged and that they have been deconstructed only due to spatial and urban reorganisation. Before deconstruction these bridges had been gradually damaged by the research group, and the response of the structures due to static loading or dynamic excitation has been monitored. Furthermore, a new bridge has been equipped by a monitoring system delivering continuous data over many years. Especially, this bridge permitted the group to observe the tremendous dependence of the structure's response to environmental conditions. A specificity of this structure is an unusually thick asphalt layer, which was used to determine the impact of temperature variation on the structure's response due to static and dynamic excitation.

The ambient air temperature and solar radiation are affecting the soil, as well as the asphalt's and structure's stiffness, leading to expansion and retraction depending on the boundary conditions and hence affecting the deformation behaviour and eigenfrequencies. Furthermore, the structure's material stiffness is temperature-dependent and influences by itself the structure's deformation behaviour. As for damage assessment, the same parameters, deformation and eigenfrequencies are used, the difficulty amongst others consists in separating damage from environmental effects.

This was one of the aspects that have been further investigated by the research group LSS in the laboratory of the University of Luxembourg. Especially, the impact of stiffness variation of asphalt due to changing temperature on a pre-stressed structure has been studied within laboratory tests. When bridge structures are designed, asphalt is only taken into account as mass action. The additive stiffness is neglected, leading to a dimensioning on the safe side. As the condition assessment of bridges is done by *in situ* tests, the impact of the asphalt stiffness is included in all kinds of structures' responses to excitation and loading. Whether or not the

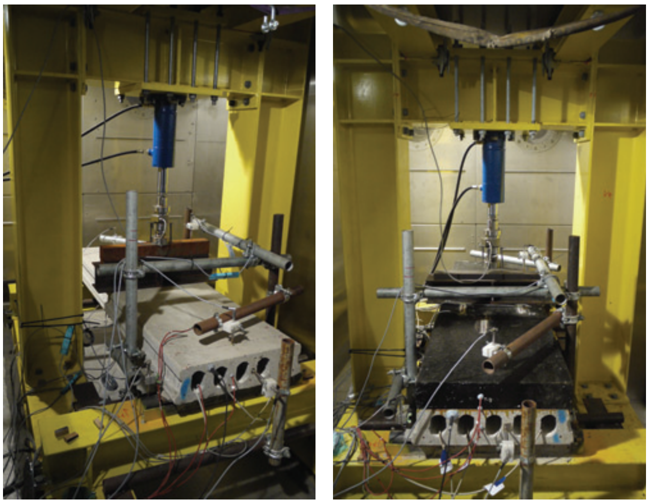

Fig. 1 Experimental set-up of the static tests without asphalt layer (left) and with asphalt layer (right)[1]

temperature-dependent stiffness of the asphalt layer can affect the deformation behaviour of a bridge deck has been studied by experimental tests on small pre-stressed slab components.

These hollow pre-stressed floor elements simulate the load bearing behaviour of a pre-stressed bridge structure on a reduced scale. The application method and the composition of the asphalt layer have been chosen according to usual bridge sections. Within a climatic chamber, the deformation behaviour of the different slabs has been investigated before and after application of the asphalt layer. The loading was gradually increased within the serviceability limit state so that the structure remained undamaged. This loading procedure has been repeated for different climatic conditions from -10°C to 40°C to investigate the temperature-dependence of the stiffness of the specimens, whereas the first measurement at 20°C served as a reference measurement.

While only small differences of the deformation behaviour could be identified for the components without an asphalt layer, the load-deformation behaviour of the slab with an asphalt layer showed considerable variations in function of higher or lower temperatures.

A comparison of the deformation behaviour of the component with asphalt layer at 20°C and -10°C showed a difference of about 53%. As it is known that asphalt becomes more viscous at high temperatures than at low temperatures, this could have been predicted. The impact, however, is higher than expected. By comparing the deformation of the structure without asphalt to the structure with asphalt, it becomes apparent that asphalt increases the stiffness of the whole system and cannot simply be considered as additional mass in *in situ* tests. This is particularly true for low temperatures, whereas at high temperatures the influence of the asphalt layer on the whole system significantly diminishes.

Within these tests the height of the asphalt layer compared to the height of the load bearing structure of a bridge was explicitly chosen to be too important to produce measureable deformation at serviceability limit states on small elements within the climatic chamber. Therefore, the results have been transferred to a realistic situation of a bridge structure respecting real height relations between load bearing structures and asphalt layers with the result that the impact of a changing stiffness of the asphalt layer due to variation of the environmental temperature remained impressive.

So the research group could prove that the *in situ* condition assessment of bridges must take these effects into account. However, their impact varies from bridge structure to bridge structure. If tests are realised at different moments within a year, and thus at different temperature conditions, the stiffness effect of the asphalt layer at different temperatures, especially at low temperatures, must be considered.

These results showed clearly that a condition assessment based on a global response of the structure as generated by dynamic excitation will remain difficult.

Therefore the LSS group based its further research activities on the analysis of the static response of bridge structures due to loading, and developed an algorithm based on deformation measurements able to detect and localise damage. The so-called 'DAD method' is based on the processing of local discontinuities of the deformation line and thus remains nearly insensitive to global influences such as temperature changes. However, continuous and precise deformation measurements are necessary to deliver the needed information. Within laboratory tests it could be proven that by using the deformation measurements from photogrammetry, the required precision could be reached. Furthermore, first tests combining the use of drones and photogrammetry showed very promising results.

So, with this kind of research the LSS group will further contribute to important societal research topics.

Reference

1 Scherbaum, F. Zustandsbewertung von Brücken unter Berücksichtigung der temperaturabhängigen Steifigkeit des Fahrbahnbelages. Dissertation, University of Luxemburg, 2014

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