3rd International Conference on Transportation Geotechnics
4 September 2016 | Guimarães | Portugal

Ground Improvement and Soil Stabilisation

Dynamic Rollers in Earthworks: Compaction and Continuous Compaction Control

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1 Introduction

The quality of earth structures highly depends on the compaction state of fill layers, which can be made up of a wide range of various materials. Compaction is usually accomplished by vibratory rollers; the vibration of the drum is generated by rotating eccentric masses. Moreover, dynamic rollers with different types of excitation have been developed in the last decades, including rollers with directed vibration, feedback controlled rollers and oscillatory rollers.

A high-levelled quality management requires continuous control all over the compacted area, which can be achieved only by work-integrated methods. Roller integrated measurement and continuous compaction control (CCC) result in time and cost savings. CCC provides relative values representing the evolution of the material stiffness all over the compacted area. These values have to be calibrated to relate them to customary values such as deformation modulus of static and dynamic load plate tests defined in contractual provisions and standards.

2 Dynamic Roller Compaction

The concept of vibratory excitation for drums was implemented for the first time in the late 1950s and has become the commonly used type of excitation for dynamic drums. The major benefit of vibratory rollers compared to static rollers is their significantly higher vertical loading due to dynamic excitation, which results in a better compaction at depth.

The eccentric masses of a vibratory drum are shafted concentrically to the drum axis and rotate around this axis with a constant frequency. The rotation of the eccentric masses causes a cyclic translational vibration and a mainly vertical loading of the soil. This implies the main characteristics of vibrating drums, the larger compaction depth and higher ambient vibrations compared to oscillating rollers.

A further development of vibratory rollers was made by company Bomag in 1998 by producing the first roller with directed vibration, which was called Vario® roller. The drum of a roller with directed vibration comprises two counter-rotating eccentric masses of the same mass and eccentricity shafted concentrically to the drum axis. Thus, the eccentric masses generate a directed vibration. The direction can be adjusted manually by rotating the whole excitation unit from horizontal to vertical in defined steps.

The drum of a feedback controlled roller is in accordance with the drum of a roller with directed vibration. However, the inclination of the excitation unit is not adjusted manually but automatically controlled by defined control criteria.

The principle of oscillatory roller compaction was developed in the early 1980s. The dominant direction of compaction of oscillatory rollers results in a lower compaction depth compared to vibratory rollers of the same size and weight. However, an advantage of oscillatory rollers, which makes their application in earthworks a considerable option to vibratory rollers, is given by the significantly reduced ambient vibrations caused by oscillatory rollers. Therefore, oscillatory rollers can also be used in sensitive areas, such as inner city construction sites or on and near bridges.

The drum of an oscillatory roller has two eccentric masses; their shafts are mounted eccentrically but point symmetrically to the drum axis. Two identical eccentric masses with the same eccentricity rotate in the same direction, resulting in a sinusoidal moment around the drum axis that causes a torsional motion in terms of a fast forward-backward-rotation. The described rotation is superposed with the travelling speed of the roller.

3 Continuous Compaction Control (CCC)

In contrast to spot like testing methods continuous compaction control (CCC) is a roller and work integrated method for the identification of soil stiffness. The roller is not only used as compaction equipment but also serves as a measuring device at the same time.

The basic principle of a CCC system is to detect the soil stiffness by evaluating the motion behaviour of the drum. The initial research development of roller integrated measurement dates to 1974 when Heinz Thurner performed field studies for the Swedish Highway Administration with a 5-ton tractor-drawn Dynapac vibratory roller instrumented with an accelerometer. The tests indicated that the ratio between the amplitude of the first harmonic and the amplitude of the excitation frequency could be correlated to the compaction effect and the stiffness of the soil as measured by the static plate load test. In 1975 Thurner founded the company Geodynamik with his partner Åke Sandström to continue the development of the roller-mounted compaction meter. In cooperation with Lars Forssblad (of Dynapac) Geodynamik developed and introduced the compaction meter and the compaction meter value (CMV) in 1978 (Thurner & Sandström).

In the late 1980s Bomag developed the OMEGA value and the corresponding Terrameter® system. The OMEGA value provided a continuous measure of compaction energy and at that time it served as the only CCC alternative to CMV. In the late 1990s Bomag then developed the measurement value Evib, which provided a measure of dynamic soil modulus (Kröber, 2001). Ammann followed suit with the development of a soil stiffness parameter kB (Anderegg & Kaufmann, 2004). These latter Evib and kB parameters signalled an important evolution towards the measurement of more mechanistic soil properties, e.g. soil stiffness and deformation modulus.

Rollers using directed vibration and feedback controlled rollers can be used with CCC systems. When the roller is used as a measurement device the inclination and settings of the excitation unit have to remain constant since the vertical amplitude of the excitation has a large influence on the level of CCC values.

While various CCC systems for vibratory rollers are available no working CCC system existed for oscillating rollers until a short time ago. Therefore, a comprehensive research project on the compaction with oscillating rollers was launched by the German roller manufacturer HAMM AG in 2011 in cooperation with the Institute of Geotechnics at Vienna University of Technology. The aim of the project, which will be continued until September 2016, is a better understanding of the motion behaviour of an oscillating drum and its impact on the compacted soil as well as the development of a CCC system for oscillating rollers and, moreover, the indication of wear of the drum during operation. Within this project large-scale in situ tests were performed with a tandem roller possessing an oscillating drum and a vibrating drum in a gravel pit near Vienna Airport.

The experimental field tests showed a significant influence of the soil stiffness on the motion behaviour of the oscillatory drum and a formation of a secondary vibration with a double frequency compared to the excitation was observed in the vertical soil accelerations throughout all of the performed experimental tests. Because of the upward movement of the drum onto the bow wave during the forward motion and the upward movement onto the rear wave during the backward motion, two periods in vertical direction occur during the same time of one period in horizontal direction. Hence, the vertical acceleration shows a double frequency compared to the frequency of the horizontal acceleration. A novel CCC value for oscillating rollers has been defined based on the characteristic accelerations of the oscillating drum (Pistrol, 2016).

The CCC value for oscillating rollers was evaluated in the scope of the experimental field tests at which the presented CCC value for oscillating rollers properly reflected the increase in soil stiffness with increasing number of roller passes.

References

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