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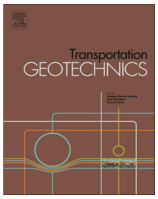

Resonant roller compaction of gravel in full-scale tests

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ABSTRACT

Results from a recent study indicated that compaction by vibratory roller can be made more time- and energy-efficient by operating at a vibration frequency close to resonance. In this paper, the results are verified and the reduction in operating time is quantified by conducting detailed full-scale tests under realistic conditions at two frequencies: the standard operating frequency of the roller and a lower frequency slightly above resonance. Compaction was done in two tests per frequency with 16 passes in each test. The obtained compaction was quantified using a combination of measurement techniques, including laser levelling, nuclear density gauge and static plate load tests. The results confirm that the lower frequency is more efficient for compaction and that utilizing resonance in the roller-soil system can reduce the number of passes. In addition, lowering the frequency reduces energy consumption, environmental impact and machine wear.

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Introduction

Soil compaction is obtained by relative motion of the soil particles and the most important parameter for densification is thus the strain amplitude [5,20] along with the number of loading cycles. A vibratory roller generates vibrations by means of a rotating eccentric mass in the drum, which gives rise to dynamic loads in the soil. This causes a cyclic shear strain with an amplitude depending on the vibration amplitude. It is thus essential to maintain a high amplitude in the soil during compaction. Recently, it has been shown that operating close to the coupled resonant frequency of the roller-soil system can increase the vibration amplitude and the compaction efficiency [18]. Since rollers operate above resonance, this implies lowering the frequency to a value that is closer to resonance. A lower frequency is also beneficial from the point of view of energy and fuel consumption, environmental impact and machine wear.

Utilization of resonance for increased compaction efficiency was discussed in early studies [6–9]. None of these studies included experimental results from variable-frequency roller compaction. In deep compaction using vibratory probes, however, the concept of resonant compaction has been applied in a number of projects with successful results [11,12]. Automatic frequency control of vibratory rollers has been discussed by [3,4,19] and the technology for automatic frequency adjustment is already available for asphalt compaction rollers [21].

To investigate whether resonance can be utilized to obtain a more efficient compaction process, the influence of frequency on vibratory surface compaction of granular material was studied experimentally in a recent paper [18]. The results suggested that compaction can be made more time- and energy-efficient by lowering the vibration frequency of the roller to a value closer to resonance. The tests were conducted for nine different frequencies in six passes on previously compacted material with measurements of settlement and density. The study was based on small-scale tests in the laboratory with a vibrating plate [17] and showed that the frequency-dependent compaction behaviour is similar for both a roller and a plate.

This paper verifies the results of the previous study statistically for the same roller and test material by conducting more extensive tests under realistic conditions with an extended amount of measurement techniques. Furthermore, it quantifies the possible reduction in operating time that results from a lower compaction frequency. Detailed tests were conducted at two selected frequencies where the number of passes was increased to 16, the material was previously un-compacted and static plate load tests (SPL) were added to the measurements.

Abbreviations: COV, Coefficient of variation; NDG, Nuclear density gauge; PDF, Probability density function; SPL, Static plate load test.

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Methods and materials

The tests were conducted with a Dynapac CA3500D single-drum soil compaction roller at Dynapac's indoor research facility in Sweden. The roller was operated at the high amplitude setting, with an eccentric moment of 7.38 kgm and a nominal amplitude of 1.9 mm. The actual displacement amplitude, however, depends on the dynamic response of the soil, as presented in [18]. The resulting amplitude is amplified around resonance and is increasing for each pass due to increasing soil stiffness. The roller and test bed are shown in Fig. 1. The test surface had a length of 20 m and a width equal to that of the roller's drum, 2.13 m. The test material was well-graded gravel (GW), consisting of crushed rock with coefficient of uniformity $C_u = 60$, coefficient of curvature $C_c = 3$ and specific gravity $G_s = 2.696$. The maximum density, determined by modified Proctor test, was 2230 kg/m^3. The roller had a standard operating frequency of 31 Hz but modification of the equipment facilitated a variable frequency setting. Tests were conducted at two frequencies – the standard operating frequency of the roller, 31 Hz, and 20 Hz, which is slightly above the coupled resonant frequency. The resonant frequency was 17 Hz, determined in the previous study. Both tests were repeated, resulting in 2 test cycles per frequency, i.e. 4 in total. In each test, the material was loosened down to 60 cm using an excavator, followed by one preparatory static pass of the roller and 16 vibrated passes, with intermediate measurements. The base below the gravel layer that was loosened consisted of 0.5 m of the same material and then a rock fill layer. The properties of the rock fill are unknown but the material can be assumed to be very well-compacted considering that compaction tests have been conducted at the same location for more than 30 years.

The relative compaction between the two frequencies was quantified using three different measurement techniques. All measurements were conducted after 2, 4, 8, 12 and 16 passes. As in the previous study, settlement was measured by laser levelling and density was estimated by means of a horizontal nuclear density gauge (NDG) that measured nuclear decay between a transmitter and three adjacent boreholes. SPL tests were also conducted. Settlements were measured at 30 points spread evenly across the surface (10 longitudinally along the surface and 3 transversally along the width of the drum). NDG tests were conducted in 3 locations with measurements from 40 mm to 500 mm depth at an interval of 20 mm. The water content was measured at each NDG measurement location from 0 to 500 mm depth. During all tests the average water content was 3.3% with a coefficient of variation, COV, of 3% while the maximum and optimum water content was approximately 6%. Since the material is free-draining, it is not particularly sensitive to variations in water content. As in the previous tests, however, it was considered more important to have a constant water content than to be close to the optimum, based on previous results. The soil was covered with plastic between each pass to minimize evaporation and the samples obtained after each cycle, 5 days apart, showed no variation in water content, which was also confirmed by intermediate samples during the tests. The SPL tests were performed in 4 locations with a 300 mm diameter plate using the roller as the loading device [15]. In the SPL tests, the deformation versus deflection is measured in 2 loading cycles, where the deformation modulus of the second cycle, E_{v2}, represents the stiffness of the subgrade and the ratio between the moduli in the second and first cycles, E_{v2}/E_{v1}, is considered a measure of the degree of compaction. The roller, material properties and measurement techniques (excluding SPL tests) have been described in more detail in [18]. Table 1 summarizes the number of tests conducted at each frequency and pass.

Results and discussion

The settlements after 2, 4, 8, 12 and 16 passes are shown as probability density functions (PDFs) in Fig. 2 for the two test frequencies. Each PDF is based on 60 settlement measurements (Table 1) with the respective variation in the sample. The variability with respect to the COV of the sample is overall low, but decreases significantly from 5.5% for 31 Hz to 3.8% for 20 Hz (Table 2). The variability is also relatively constant over the range

Fig. 1. Test bed and roller in operation.

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