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Roller Compaction - Impact of Dynamic Drums in Comparison

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Abstract. In the presented study two different types of excitation for the dynamic roller drum are compared in terms of their impact on soil, the vibratory drum and the oscillatory drum. Their differences in functioning, mode of operation and loading the soil are outlined. First results of large-scale in-situ tests are presented in which the vertical earth pressure, deformations and tri-axial accelerations have been measured. Moreover, the influence of the type of excitation on ambient vibrations is discussed.

Keywords: Soil Dynamics; Compaction; Vibration; Oscillation; Ambient Vibration, Measurement.

1 INTRODUCTION

The commonly used method for near-surface compaction is dynamic roller compaction, since it is much more efficient compared to static roller compaction. Two types of excitation are included in the majority of rollers used in the field: rollers with vibratory drums and rollers with oscillatory drums. The two types of excitation differ not only in their composition but also in their mode of operation and loading the soil and the material to be compacted. While the vibratory drum is capable of compacting in larger depths, the oscillatory drum reduces ambient vibrations significantly and is therefore used in sensitive areas like inner city construction sites.

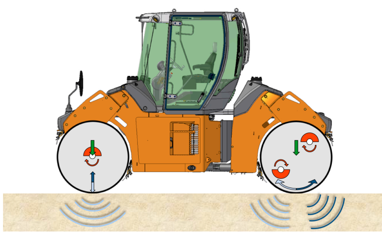

Figure 1. Forces and moments of dynamic drums: vibrating drum (left), oscillating drum (right).

2 VIBRATION VS. OSCILLATION

The eccentric masses of a vibrating drum are shafted concentrically to the drum axis resulting in a significantly higher vertical loading but also increased ambient vibration.

The torsional motion of an oscillatory drum is caused by two opposed, rotating eccentric masses, which shafts are mounted eccentrically but point symmetric to the drum axis. Soil is dynamically loaded horizontally by the drum motion (see Fig. 1) and statically loaded in vertical direction by the dead weight of drum and roller. Mainly tangential forces are transmitted into the soil by shear waves, the volume decreases while the stiffness increases.

3 EXPERIMENTAL FIELD TESTS

3.1 Test layout and measuring equipment

A test area was prepared and equipped in a gravel pit near Vienna for the experimental field tests. The test area comprised four parallel test lanes of loose sandy gravel (to be compacted) with a length of 20 m and a thickness of 0.5 m. The test field was filled on the highly compacted plane of the gravel pit. The typical layer thickness for compaction ranges from about 15 cm to 25 cm. However, the thickness was chosen larger to be able to run more tests without over-compacting the layer. The four test lanes were intended for static, vibratory, oscillatory, and combined vibratory and oscillatory compaction. Two ramps at the beginning and at the end of the test lanes served for roller handling, speeding up and down the roller as well as for lane changes.

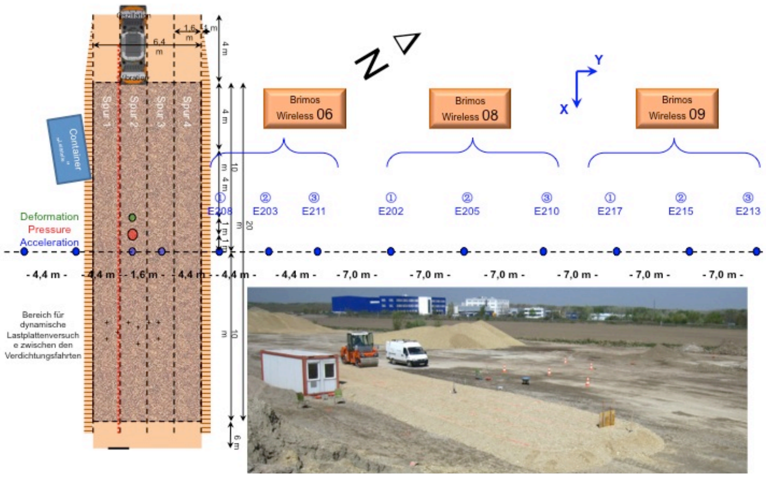

Figure 2. Test layout of the experimental field tests.

Two tri-axial accelerometers were buried in the test field by installing them on lanes 2 and 3 before filling the test area. Moreover test lane 2 was equipped with an earth pressure cell to measure the vertical earth pressure under the static and dynamic loading of the roller in a depth of 0.5 m.

The dynamic vibration displacements can easily be calculated from the measured ground accelerations using a two times integration of the signal. However, it is not possible to identify the elastic and plastic parts of the deformation caused by the roller and to evaluate the plastic deformations, which are of great interest in compaction work. To account for the plastic deformations a special displacement-measuring-device was installed in lane 2 of the test area (Fig. 2). The fixed part of this device comprises a tubing shafted to a circular plate both made of brass. The circular plate was used as an anchorage in the ground and therefore was buried in the highly compacted subsoil under the compacted layer. An inductive displacement transducer was placed inside the tubing and extended by a wire. A Bowden cable protected the wire inside the compacted layer. A second circular plate made of brass was installed on the surface of the compacted soil layer, where the wire was fixed. The top layers surface also represented the measurement level. When the upper plate moved in vertical direction (which can be expected during compaction work), the displacements were detected by the inductive displacement transducer inside the buried part of the displacement-measuring-device. A detailed description of the device is provided in (Adam 1996, Kopf 1999).

Numerous tri-axial accelerometers were positioned along a line perpendicular to the direction of compaction in the centre of the test area on the highly compacted subgrade to measure the propagation of ambient vibrations.

3.2 Compaction device

A HAMM HD+90 VO tandem roller was used as compaction device. The roller comprises a total mass of 9,380 kg and two drums of about 1,900 kg vibrating mass each. The typical speed during compaction work for this type of roller is 4 km/h and was used throughout all tests.

Depending on the rotational direction of the eccentric masses the vibratory drum at the front of the roller operates with a vertical amplitude of 0.34 mm or 0.62 mm respectively. For the smaller amplitude a frequency of 50 Hz was used, while 40 Hz was the standard frequency for vibratory compaction with the large amplitude.

The drum on the rear of the roller is an oscillatory drum that uses a tangential amplitude of 1.44 mm. The standard frequency for the oscillatory compaction is 39 Hz for this type of roller.

4 FIRST RESULTS OF THE EXPERIMENTAL FIELD TESTS

Subsequently first results of the experimental field tests are presented, which primarily focus on the differences between the vibratory and the oscillatory drum. Unless otherwise noted, the parameters for the small vibration amplitude were used for the vibratory drum. Each test run comprised a forward motion with one dynamically excited drum (vibration or oscillation) and a static backward motion.

4.1 Vertical earth pressure

The vertical earth pressure was measured between the level of the highly compacted subgrade and the compacted layer of loose sandy gravels and therefore in a depth of 0.5 m beneath the roller. Fig. 3 shows the vertical earth pressure for two test runs. On the left hand side the measured pressure over time for a test run with an active vibratory drum is depicted. The vibrating drum is clearly visible as significant first peak, which is followed by a smaller peak caused by the inactive oscillatory drum. The roller stops at the end of the test lane (after around 32 seconds) and moves backwards without any excitation of the drums (two smaller peaks at 46 and 49 seconds in Fig. 3).

The measured earth pressure is very similar for the oscillatory test run (Fig. 3 right) with a significant second peak caused by the dynamically excited oscillatory drum.

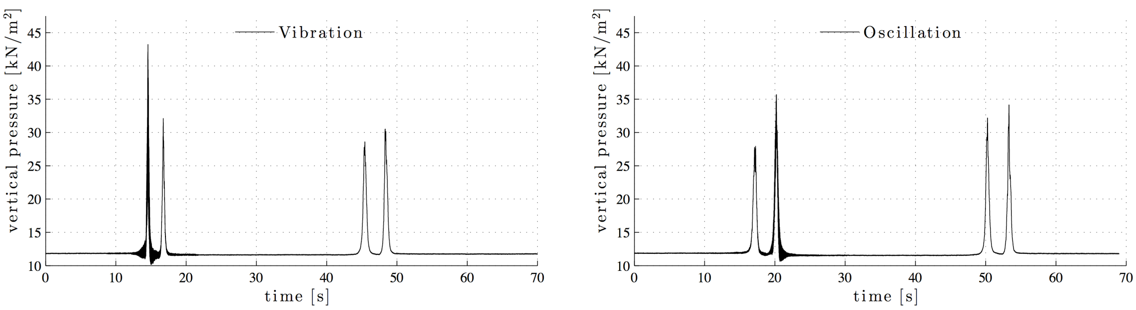

Figure 3. Vertical earth pressure: vibratory test run (left), oscillatory test run (right).

To point out the differences between the two types of excitation, the dynamic part of the vertical earth pressure for the vibratory and oscillatory test run is depicted in Fig. 4. The static part of the vertical earth pressure is filtered for this comparison. Both curves oscillate around zero and show the frequency of excitation.

The earth pressure over time of the vibratory test run increases as the vibratory drum approaches the pressure cell, has its maximum when the drum is situated exactly above the pressure cell and decreases after the drum has passed over (Fig. 4 left).

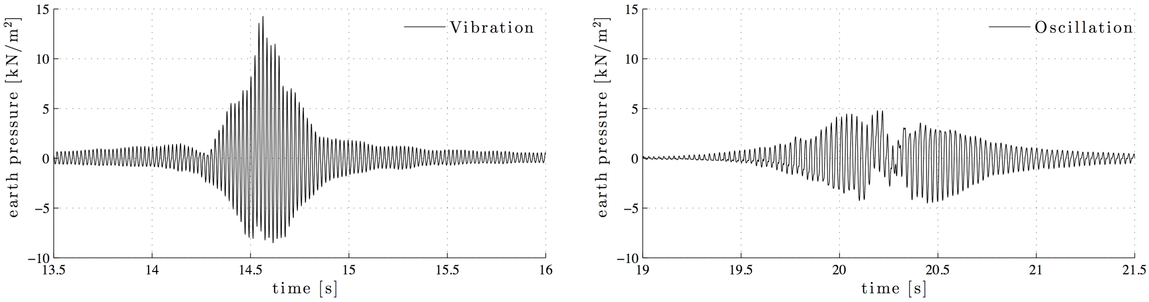

Figure 4. Dynamic part of the vertical earth pressure: vibratory test run (left), oscillatory test run (right).

In contrast to the earth pressure progression of the vibratory test run with its maximum at the passing time of the drum, the curve of the oscillatory test shows a node at the same time. The maximum values were measured shortly before and after the node, while the phase changes in the node. The fast forward-backward-rotation of the oscillatory excitation forces the drum to move forward and backward in its self-produced settlement depression. In each period of the oscillatory movement the drum rolls onto the bow wave in front of the drum and causes a vertical pressure component. This vertical component increases as the drum approaches the pressure cell, but decreases to a node in the pressure curve when the drum is situated exactly above the pressure cell. A similar behaviour as for the approach can be observed when the drum moves away from the pressure cell. However, with a phase change and caused by the rear wave.

4.2 Deformation measurements

The settlements or differential deformations of the compacted soil layer respectively were measured during the whole test runs with the deformation-measuring-device described in section 3.1. The measured settlement curves are depicted in Fig. 5 for the vibratory drum (on the left) and the oscillatory drum (on the right). The plate made of brass on the surface of the compacted soil layer has passed four times by one of the drums during each test run. The passing drums are noticeable as four negative peaks in the settlement curves. However, the peaks are almost elastic and therefore they denote reversible deformations. To evaluate the plastic part of the deformations, the values at the beginning and the end of a test run are compared. The curve of the vibratory test run shows a ground-heave after the dynamically excited forward motion of the roller. Such a heaving may be caused by an inclination of the plate on the surface. However, especially vibratory compaction work may cause disaggregation close to the surface. Inclinations of the plate as well as disaggregation are usually compensated by the static pass during the backward motion of the roller.

The measured curve of the oscillatory drum represents an ideal case. A primarily elastic deformation caused by the inactive vibratory drum is followed by a plastic deformation caused by the oscillating drum. The oscillatory test was performed well before the vibratory test run, resulting in higher values in case of the oscillatory test run. The actual compaction process of the test lane was largely finished when the vibratory test run was performed.

For both excitation types a pass of the drum starts with an elastic upheaval (the bow wave) which the drum pushes ahead of itself. The bow wave is followed by a significant depression caused by the drum. The soil is unloaded when the drum moves on and the elastic part of the deformation is released. In most cases a certain resilience and a small rear wave can be observed. Similar results were presented by (Adam 1996, Kopf 1999).

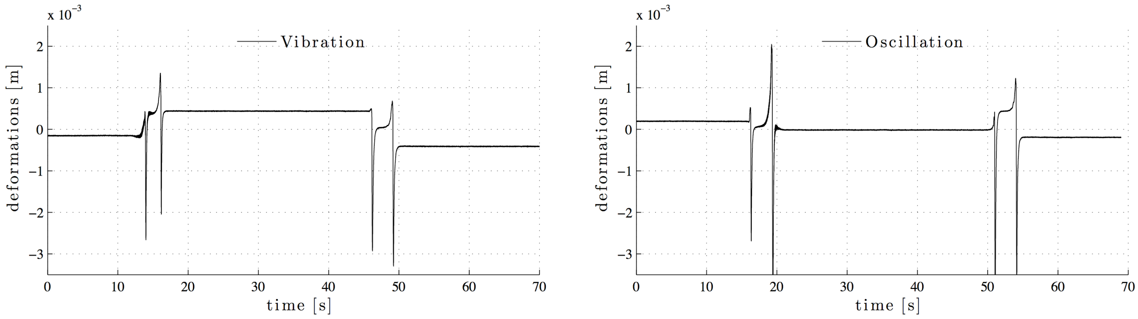

Figure 5. Deformation measurements: vibratory test run (left), oscillatory test run (right).

4.3 Soil accelerations

The soil accelerations were measured in three axes as described in section 3.1. The horizontal accelerations in Fig. 6 correspond to the accelerations measured in the direction of compaction ("x" in Fig. 2). The horizontal accelerations perpendicular to the direction of compaction ("y" in Fig. 2) are not depicted. The positive sign is defined downwards.

The comparison of accelerations of both types of excitation in Fig 6 shows higher values in vertical direction for the vibratory drum. The reasons for that are the type of excitation and the periods when the tests were performed. The vibratory test run was performed subsequently when the layer of sandy gravel was already compacted and therefore showed a stiffer reaction. For the vibratory drum the direction of dynamic loading matches the direction of the measured vertical accelerations, resulting in larger values in vertical direction. The vertical acceleration has its maximum when the drum is exactly above the accelerometer, while the horizontal component of the soil acceleration shows a node and a phase change at the same time. The dominant frequency of both components is the frequency of excitation (50 Hz).

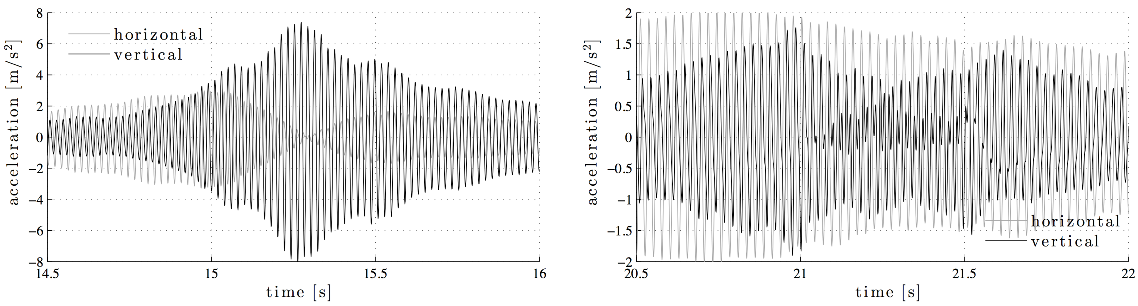

Figure 6. Soil accelerations: vibratory test run (left), oscillatory test run (right).

The fast forward-backward-rotation of the oscillating drum causes mainly horizontal accelerations in the direction of compaction (Fig. 6 right). The horizontal accelerations with an almost constant amplitude show the excitation frequency. The vertical accelerations show a different behaviour. A continuous phase change can be observed as the oscillatory drum passes the accelerometer. The curve of the horizontal acceleration shows the formation of a secondary vibration as the drum approaches the sensor, which increases until the frequency of the vertical acceleration is twice the frequency of the horizontal acceleration or the excitation acceleration respectively. The secondary vibration decreases and disappears after the drum pass and the vertical and horizontal accelerations show the same dominant frequency again, however, with a reversed phase of the vertical accelerations. The explanation for the observed phenomena is the settlement depression under the oscillatory drum and the formation of bow wave and rear wave. One forward-backward-rotation corresponds to one period of horizontal movement and acceleration. Because of the upward movement of the drum onto the bow wave during the forwards motion and the upwards 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 of the horizontal acceleration.

4.4 Vibration propagation

Usually the vibration velocity is used for the evaluation of the vibration propagation. Therefore, the signals of the tri-axial accelerometers (as described in section 3.1) are integrated to calculate the magnitude of the peak velocity according to the Austrian Standard ÖNORM S 9020 (Eq. 1).

$$v_{R,\max} = \left| \sqrt{v_x^2(t) + v_y^2(t) + v_z^2(t)} \right|_{\max} \tag{1}$$

The peak velocity magnitudes of two vibratory test runs with small and large amplitude and an oscillatory test run are depicted in a double logarithmic scale in Fig. 7. The measured ambient vibrations decrease linearly for all types of excitation in the double logarithmic scale. Therefore, the decrease of ambient vibrations in dependence of the distance *r* from the source can be written as:

$$v_{(r)} = v_{(1)} \cdot r^{-D} \tag{2}$$

The allowable peak velocity magnitude for long lasting excitations of sensitive structures is 4 mm/s according to Austrian Standard ÖNORM S 9020. This limit is added as horizontal line in Fig. 7. If the limit of the Austrian Standard applies, a minimum distance of 2.3 m between the sensitive structure and an oscillating roller is necessary to avoid damages in the sensitive buildings structure. In case of a vibratory roller the minimum distance has to be doubled (small amplitude) or even tripled (large amplitude). These measurements highlight the applicability of oscillating rollers in sensitive areas like inner city construction sites and on and near bridges.

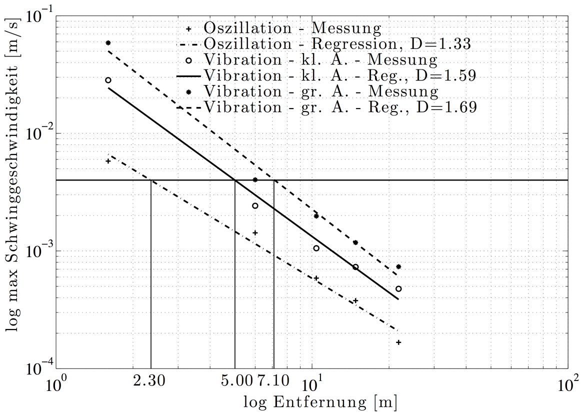

Figure 7. Comparison of ambient vibrations caused by vibrating and oscillating drums.

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