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Compaction performance of vibratory and oscillatory rollers on poorly compacted soils

Performances de compactage des rouleaux vibrants et oscillants sur des sols peu compactés

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ABSTRACT: Dynamic roller compaction has become the common method for near-surface compaction since it is significantly more efficient compared to static rollers. Furthermore, dynamically excited drums allow the use of Continuous Compaction Control (CCC) systems, which enable a reliable assessment of the state of soil compaction, based on an analysis of the motion behaviour of the dynamically excited drum interacting with the soil. The most popular dynamically excited drum in earthworks is the vibratory drum followed by the oscillatory drum. These two types of excitation do not only differ in their setting and modes of operation but also in their impact on the soil. The investigations performed in the scope of large-scale in situ tests were part of a research project of the German roller manufacturer HAMM AG in cooperation with TU Wien. The paper presents setup, procedure and results of the experimental field tests with the main target to outline the differences in compaction performance of vibratory and oscillatory rollers on poorly compacted soils.

RÉSUMÉ: Le rouleau compacteur dynamique est devenu la méthode commune pour effectuer un compactage superficiel puisqu'il est plus efficace que les rouleaux compacteurs statiques. Par ailleurs, les tambours activés dynamiquement permettent l'utilisation de systèmes CCC (Continuous Compaction Control), qui évaluent de manière fiable l'état de compactage du sol en se basant sur le mouvement du tambour. Les rouleaux compacteurs dynamiques les plus utilisées sont les rouleaux vibrants et les rouleaux oscillants. Ces machines ont non seulement des principes d'utilisation distincts mais aussi un impact différent sur le sol. Une campagne d'essais in-situ à grande échelle a été réalisé en coopération avec la fabricant allemand HAMM AG et TU Wien. Cet article présente la procédure et les résultats d'essai in-situ en mettant l'accent sur les différences de l'impact des rouleaux vibrants et oscillants sur des sols peu compactés.

Keywords: Dynamic roller; soil compaction; vibratory roller; oscillatory roller

1 INTRODUCTION

For several civil engineering structures dynamic rollers are used for near-surface compaction. The quality of the earth structures highly depends on the compaction state of fill layers. Thus, both compaction equipment and compaction procedure needs to be selected carfully taking into account the used fill material. The layer thickness has to be assessed considering material properties such as grain size distribution, maximum grain size and degree of non-uniformity, water content, and water permeability, bearing in mind the roller type and machine parameters.

The concept of vibratory excitation for drums was implemented for the first time in 1958 and has become – together with its further developments like rollers with directed vibration and feedback controlled rollers – the commonly used type of excitation for dynamic drums in earthworks. The major benefit of vibratory rollers compared to static rollers is their significantly higher vertical loading due to dynamic excitation, wich results in a better compaction at depth.

A second type of dynamically excited drums are oscillatory drums. The principle of oscillatory roller compaction was developed by the Swedish company Geodynmaik AB in the early 1980s (Geodynamik AB 1982). The dominant direction of compaction of oscillatory rollers (horizontal) results in a lower compaction depth compared to vibratory rollers of the same size and weight. This has to be taken into consideration on site by reducing the thickness of filled layers. Asphalt construction – which uses significantly smaller layer thicknesses compared to earthworks – is an ideal field of application for oscillatory rollers. The characteristic motion of an oscillatory drum results in very homogenous and smooth surfaces, which is a crucial advantage in asphalt compaction. Another advantage of oscillatory rollers, which makes their application a considerable option in earthworks, is given by the significantly reduced ambient vibrations caused by oscillatory rollers (Pistrol et al. 2013). Therefore, oscillatory rollers can also be used in sensitive areas, such as inner city construction sites or on and near bridges. Further information on the characteristics of vibratory and oscillatory rollers, their settings, modes of operation and the applicability of CCC systems can be found in (Pistrol and Adam 2018), for example.

In the scope of a research project of the German roller manufacturer HAMM AG in cooperation with the Institute of Geotechnics at TU Wien, large-scale in situ tests were performed to investigate the compaction performance of vibratory and oscillatory rollers, especially on poorly compacted soils.

2 EXPERIMENTAL FIELD TESTS

The experimental field tests were conducted in a gravel pit near Vienna in July and August 2016.

2.1 Compaction devices

For a direct comparison of vibratory and oscillatory compaction dynamic rollers equiped with so called VIO drums were used for the experimental field tests. The shafts carrying the eccentric masses of a VIO drum are mounted eccentrically but point symmetric to the drum axis.

One of the shafts can be rotated seperately by 180°. If the eccentric masses of both shafts point and rotate in the same direction, they cause a cyclic translational motion of the drum – vibratory compaction. The same sense of rotation of both shafts but with the eccentric masses pointing in the opposite direction (by rotating one shaft by 180°) results in a sinusoidal torque around the drum axis and a torsional motion in terms of a fast forward-backward-rotation of the drum – oscillatory compaction.

Two single-drum rollers were used for the field tests. A smaller and lighter HAMM H7i VIO (6,325 kg total mass) which is mainly used for inner city construction sites and a typical single-drum roller for earthworks, the HAMM H13i VIO (12,610 kg total mass). Further details and data sheets of the rollers can be found in (HAMM AG 2018).

2.2 Test layout 1 – variable layer thickness

The differences of vibratory and oscillatory rollers in loading the soil result in different compaction depths, which have to be considered on site for choosing the right thickness of filled layers. Test layout 1 was designed to investigate the influence of the layer thickness on the compaction work.

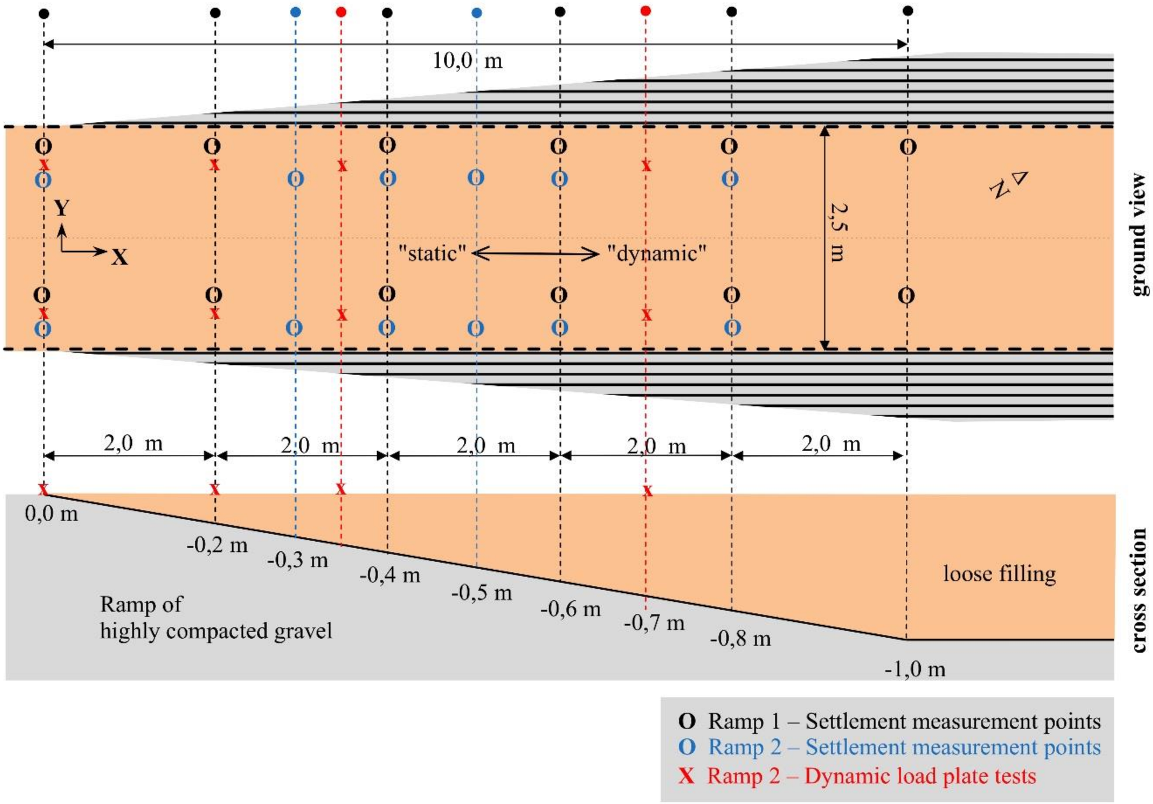

Figure 1 Test layout 1 for experimental field tests with variable layer thickness

Two lanes with a width of 2.5 m were marked on the highly compacted subgrade of the gravel pit and excavated over a length of 20 m. The depth of the excavations was increased continuously over the first 10 m to a final depth of 1.0 m after 10 m (see Figure 1). The remaining 10 m of both lanes were excavated to a depth of 1.0 m. Both excavations were filled with loose sandy gravel ($C_U = 40.2$, $C_C = 1.327$, $G = 185.75$ cm^2) afterwards. The described ramp setup enabled an investigation of the compaction performance for a layer thickness ranging from 0.0 m to 1.0 m during each test run.

Numerous test runs were performed on each ramp using static compaction (no dynamic excitation of the drum), vibratory compaction and oscillatory compaction with both rollers. The excitation frequency (vibratory and oscillatory) and the roller speed were kept constant for all ramp tests at $f = 30$ Hz and $v = 3$ km/h.

For ramp 1 six sets of four roller passes each were performed (see Table 1).

Table 1. Roller passes on ramp 1

Roller	Excitation	Number of passes
H7i	none (static)	4
H13i	none (static)	4
H7i	oscillatory	4
H13i	oscillatory	4
H7i	vibratory	4
H13i	vibratory	4

After filling the ramp and after each set of roller passes geodetic measurements were performed at layer thickness 0 m, 0.2 m, 0.4 m, 0.6 m, 0.8 m and 1.0 m to evaluate the settlements.

For ramp 2 seven sets of roller passes were performed according to Table 2.

Table 2. Roller passes on ramp 2

Roller	Excitation	Number of passes
H7i	oscillatory	6
H13i	oscillatory	4
H13i	oscillatory	4
H13i	oscillatory	4
H13i	vibratory	4
H13i	vibratory	4
H13i	oscillatory	2

Geodetic measurements for evaluating the settlements were performed at layer thickness 0 m, 0.3 m, 0.4 m, 0.5 m, 0.6 m and 0.8 m after filling the ramp and after each set of roller passes. Additionally, dynamic load plate tests were perfomed after filling the ramp and after every second test run at layer thickness 0 m, 0.2 m, 0.35 m and 0.7 m.

2.3 Test layout 2 – compaction above weak spots

The quality and achievable stiffness of compacted layers highly depends on the subgrade conditions. Poorly compacted zones in the subgrade may result in areas of unsufficient compaction in a filled layer. The influence of poorly compacted subgrades depends on the layer thickness and number of layers or the depth of the poorly compacted zone, respectively.

Test layout 2 was intended for an investigation of the influence of poorly compacted zones in the subgrade with increasing layer thickness.

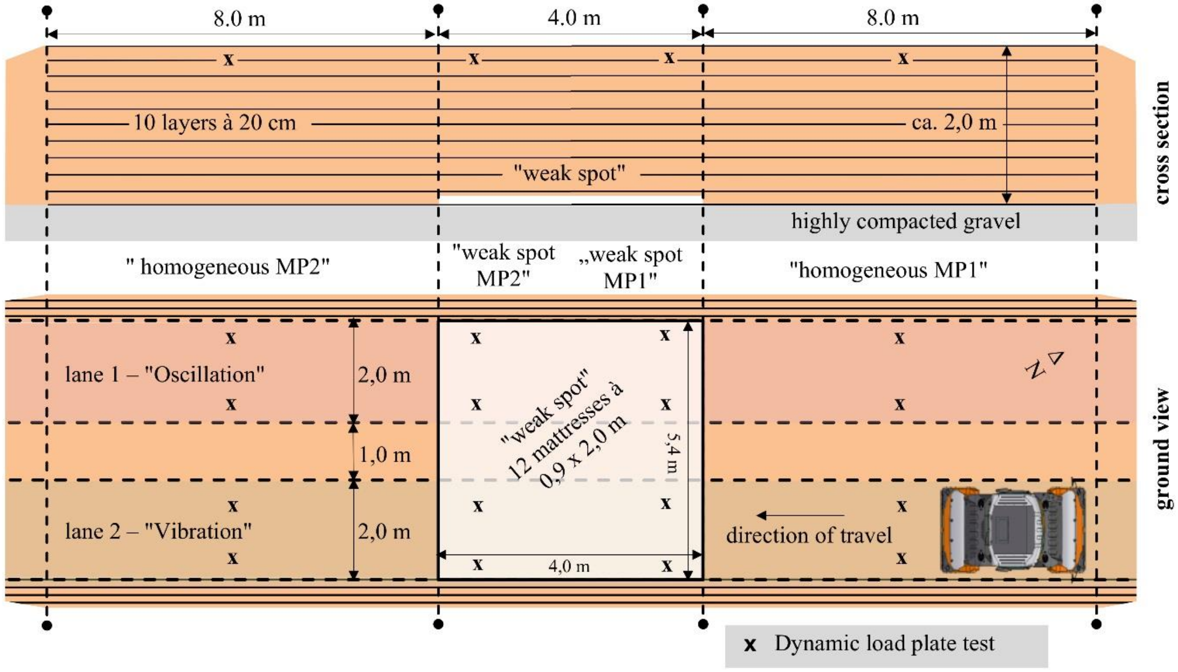

Figure 2 Test layout 2 for experimental field tests on poorly compacted soils

Twelve mattresses of 0.15 m thickness were placed on the highly compacted subgrade to cover an area of 5.4 m by 4.0 m and wrapped in a non-woven geosynthetic layer to create an artificial weak spot. The mattresses could be compacted and acted like an elastic spring.

A dam with 5.0 m width and 20.0 m was built, filling ten layers of sandy gravel with 0.2 m thickness each (see Figure 2). Each layer was compacted on two lanes – lane 1 for oscillatory compaction, lane 2 for vibratory compaction – by four passes of the H13i roller at f = 30 Hz and v = 3 km/h. After four passes, two dynamic load plate tests were performed in the areas "Homogenous MP1", "Weak Spot MP1", "Weak Spot MP2" and "Homogenous MP2" of each test lane (marked in Figure 2). The dynamic load plate tests were followed by a single pass of the H7i roller to ensure a smooth and well compacted surface before filling the next layer.

Continuous Compaction Control (CCC) was not used in the scope of this investigation.

3 RESULTS

3.1 *Test layout 1, Ramp 1 – Settlements*

The results of the geodetic measurements on ramp 1, which have been performed to quantify the settlements at different layer thicknesses after each set of roller passes, are depicted in Figure 3. As expected, there was nearly no observable increase of settlements at the top of the highly compacted subgrade at the beginning of the ramp (0 cm) throughout the whole test series. After filling the excavated trench with loose sandy gravel, the series started with eight static roller passes. After the first four static passes with the light oscillatory roller H7i, nearly 80% of the total settlements had been already gained up to a depth of about 60 cm. The subsequent roller passes only had a minor impact on the measured settlements up to a layer thickness of 60 cm. The additional test runs with the vibratory roller caused considerable increases in settlements at measure points with depths of 80 cm up to 100 cm and induced minor loosening near the surface at the beginning of the ramp.

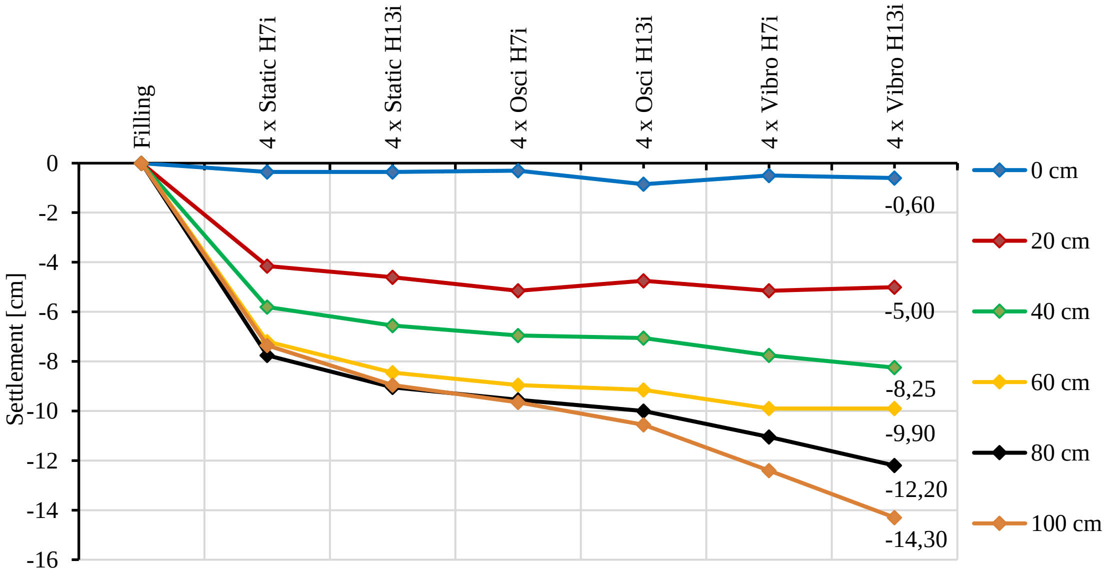

Figure 3 Results of the geodetic measurements performed on test layout 1, ramp 1

3.2 *Test layout 1, Ramp 2 – Settlements*

Figure 4 shows the settlements measured in the scope of test series 2 (Table 2) at different layer thicknesses along ramp 2. Near the ground level of the terrain, all noticeable settlements are reached after the six roller passes with the light oscillatory roller H7i. The subsequent passes with the vibratory roller only yield to near-surface loosening. The oscillatory passes with the H13i roller caused additional settlements for depths larger than 30 cm. For a depth of 40 cm and larger, a significant increase in settlements is noticeable due to the subsequent passes with vibratory excitation. It becomes more significant the bigger the layer thickness is. The final passes with the oscillatory roller did not gain any further settlements.

In summary, the results from test layout 1 could be confirmed, with one interesting fact and difference. The total settlements measured on ramp 2 were roughly 50% smaller compared to those on ramp 1. This fact is rooted in the static passes performed on ramp 1, while the test runs on ramp 2 started with oscillatory excitation and thus generated a highly dense package on the surface, which prevented a further increase in settlements.

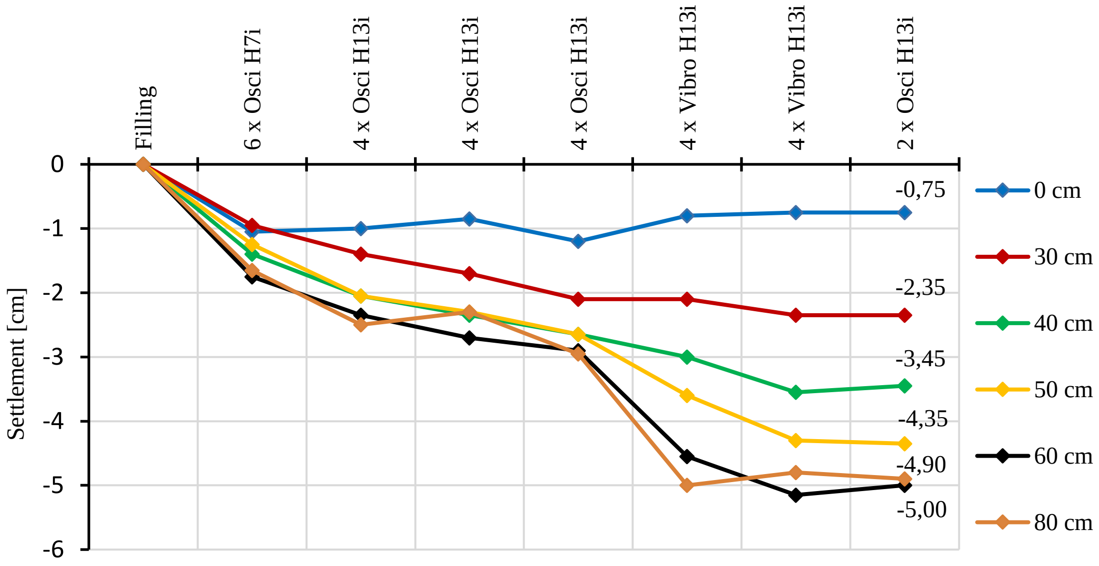

Figure 4 Results of the geodetic measurements performed on test layout 1, ramp 2

3.3 *Test layout 1, Ramp 2 – Stiffness*

The development of the dynamic deformation modulus E_{vd} over all sets of roller passes with two test runs each, measured at different layer thicknesses along the ramp, is illustrated in Figure 5. The first six passes with the light oscillatory roller H7i at the beginning of the test series yield to a steady compaction increase at each measuring point. The following test runs with the heavy oscillatory roller H13i did not result in a recognizable increase in E_{vd} values, since at this time a near-surface “rigid plate” already had been created by the oscillatory passes of the H7i roller, which prevented further compression by oscillation. However, the subsequently performed eight sets of two roller passes each, with the heavy vibratory roller H13i caused a significant increase in E_{vd} values all over the ramp (excluding the highly compacted subgrade at the top of the terrain), due to the better compaction depth of vibratory rollers. The final two oscillatory passes were performed to compensate the near-surface loosening as a consequence of the previous accomplished vibration rides. The shearing forces thus taking effect in the ground, in combination with the kneading of the near surface soil, caused an additional increase in soil bearing capacity at all measuring points by the oscillating drum.

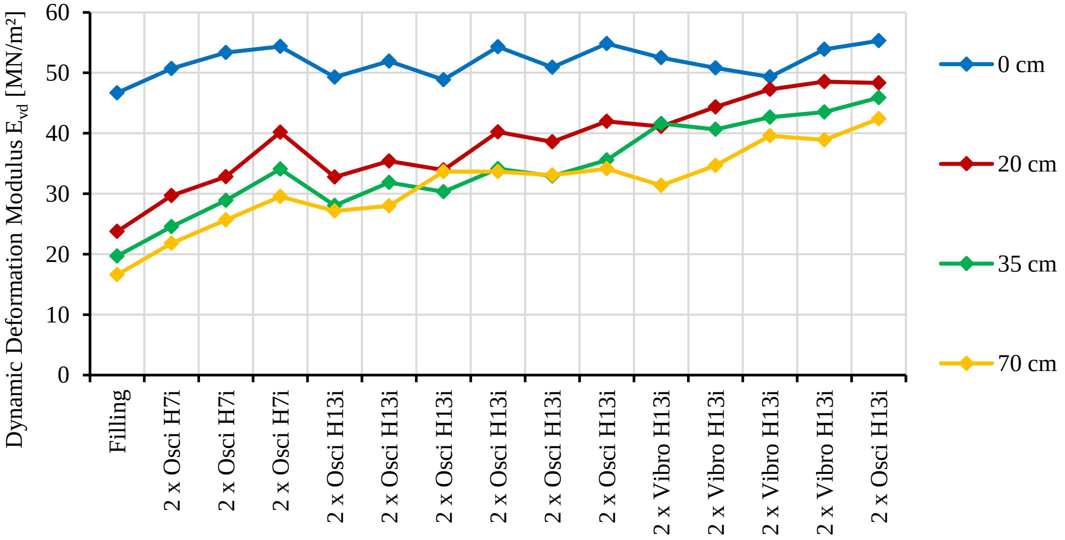

Figure 5 Development of the dynamic deformation modulus E_{vd} on test layout 1, ramp 2

3.4 Test layout 2 – Stiffness

Figure 6 illustrates the development of the dynamic deformation modulus E_{vd} in soil areas with different stiffnesses on both test tracks (osci-lane: dash-dotted line; vibro-lane: solid line).

The artificially created weak spot in the middle of the test field is recognized very clearly on both lanes up to a layer thickness of approximately 60 cm by a blatantly reduced measured value. The E_{vd} values measured above the weak spot on the vibration track are well above those on the oscillation track up to this layer thickness.

With increasing layer thickness (layers 4 and 5) the weak spot on the oscillation track is no longer detected and the determined E_{vd} values approach those of the homogeneous areas.

On the vibratory test lane, however, even with larger layer thicknesses of approx. 80-100 cm, a drop in measured E_{vd} can still be registered above the weak spot, although the weak spot is certainly already below the measuring depth of the dynamic load plate.

The reason for this is as follows: The larger and deeper, since predominantly vertically directed, compression effect of the vibratory excited drum causes a near-surface loosening of the grain structure on the one hand and an activation of the mattresses on the other hand, which act as an elastic spring according to the compression effect just described and, thus, makes a compaction of the layer package in this area almost impossible. In other words: “the hammer is working without an anvil”.

The gentle kneading effect of the oscillatory drum, which predominantly results in shear forces in the soil, provides significantly higher

E_{vd} values above the weak spot with increasing layer thickness and therefore is much better suited for compaction work in areas of poorly compacted soil.

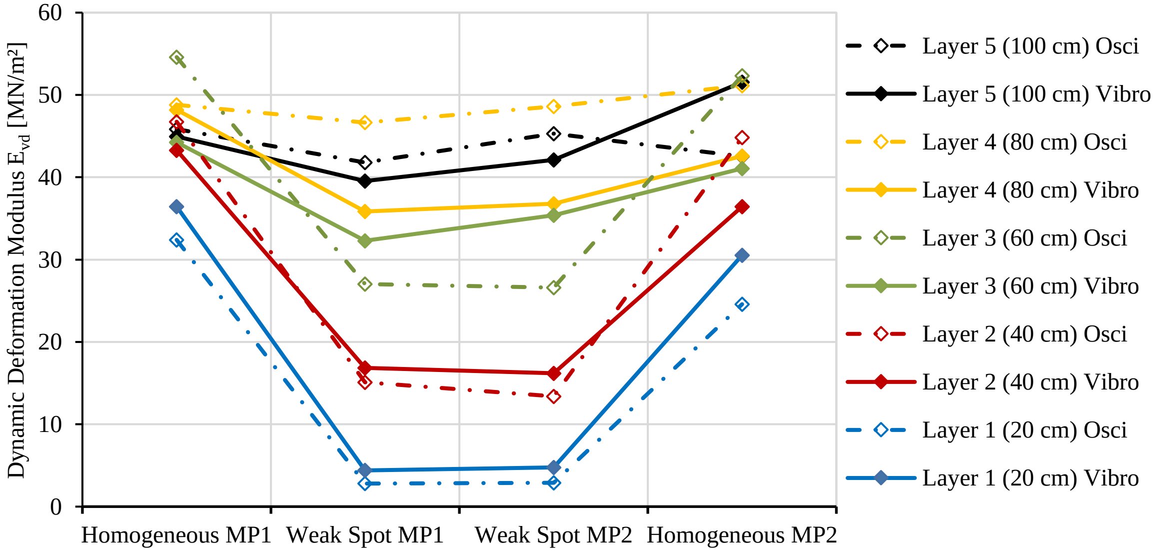

Figure 6 Results of dynamic load plate tests on both tracks and areas with different soil stiffnesses up to a layer thickness of 100 cm on test layout 2.

4 CONCLUSIONS

Experimental field tests were conducted to investigate the compaction performance of vibratory and oscillatory rollers on poorly compacted soils.

Tests performed on ramps (test layout 1) confirmed a better compaction depth of vibratory rollers. Additional settlements and an increase in soil stiffness were gained within the vibratory roller passes. However, it is recommended to start with vibratory passes (larger amplitudes) for practical engineering to ensure a sufficient compaction in greater depths. Additional oscillatory passes yield to good near-surface compation and prevent grain crushing and loosening. Tests on artificial weak spots (test layout 2) highlighted that oscillatory rollers can ideally be used for compaction of layers on poorly compacted subgrades. The vibratory roller lacks subgrade resistance and is not able to compact the overlying layers, while the oscillatory roller is able to compact these layers by mainly taking effect of shear forces in the soil. The layer thickness has to be adapted in practical engineering, when using oscillatory rollers. The presented findings are very likely applicable to other fill materials. However, further field tests are recommended.

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