APPLICATION COMPANION

SEISMIC EXPLAINED!

YOUR PARTNER ON THE ROAD AHEAD!

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Dear Readers,

Welcome to our third “Application Companion” Bulletin. In this issue we cover Dynapac´s latest innovation within the compaction area, namely the revolutionary SEISMIC system. We try to describe how SEISMIC was invented, the natural phenomena that SEISMIC benefits from and what advantages one can expect from a machine equipped with the SEISMIC feature.

COMPACTION USING DYNAPAC'S REVOLUTIONARY SEISMIC SYSTEM

The SEISMIC system aimed for Dynapac's soil rollers has been around for a couple of years with a proven and well documented performance. We claim that, from a roller equipped with SEISMIC, you can expect the following advantages compared to a "standard machine":

- Reduced vibration power and energy consumption with 20-30 %
- Lifetime fuel consumption reduction by approx. 15 % (35 % in combination with ECO-mode)
- Reduction of the number of compaction passes with up to 30 %
- Possibility to omit final static passes
- Elimination of bouncing (double jumping)
- Lower noise levels due to lower vibration frequency
- Reduced machine wear and tear

But how are all these benefits possible without a major redesign of the complete vibrating mechanism and drum? In this number of the Application Bulletin we will take a closer look into the SEISMIC system and how it works. Let us start from the beginning.

BASICS OF VIBRATORY COMPACTION

Soil compaction is the most common ground improvement method and it is often necessary to utilize compaction to reduce settlement, increase stability and stiffness of the subgrade, control swelling and creep, lower the risk of liquefaction and decrease the permeability. It implies densification of the soil by reducing its pore volume. In most soils, this is normally achieved by vibration or impact, producing stress-waves that rearrange the soil particles into a denser state, see figure 1.

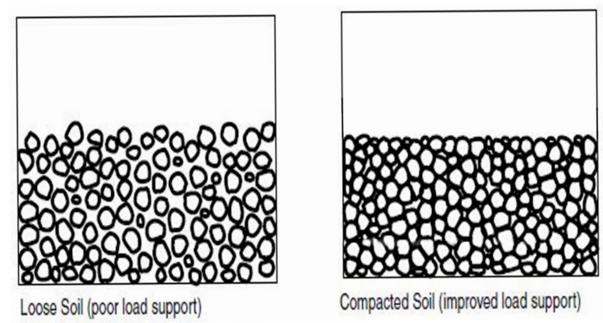

Figure 1. A compacted soil has a reduced amount of air voids and an increased number of contact points between the individual grains.

A pressure wave with a high amplitude and a great portion of energy will reach greater depths in the soil and rearrange the particles to a greater extent compared to a wave with a low amplitude before it is attenuated, see figure 2.

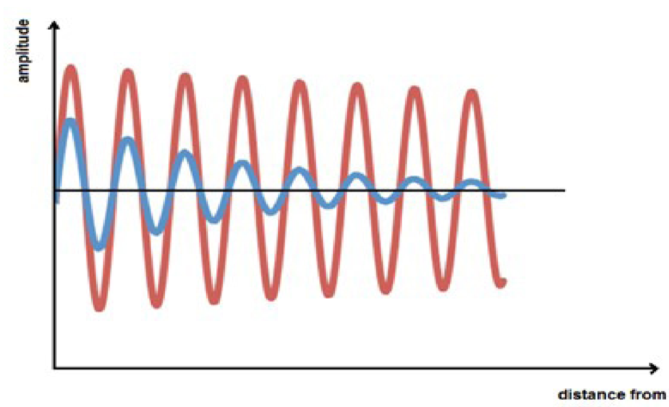

Figure 2. Soil wave attenuation. A wave with a high amplitude (red curve) will create higher soil stresses, and is thus much more effective, compared to a wave with a low amplitude (blue curve).

Thus, we can conclude that the compaction device will be effective if it is able to create waves with high amplitudes and great portions of energy. This can of course be done by installing "big" eccentric weights in the drum that creates a high drum amplitude. However, these big weights will require a high amount of power to be propelled, they will create a lot of heat in the bearings and the complete eccentric arrangement will have to be redesigned to account for the higher loads. In these days where environmental impact, fuel consumption and energy efficiency are important factors to consider, the compaction device must operate in the most sustainable and energy efficient way. To understand how a high drum amplitude can be generated in a smart way, one first needs to know a few details about dynamics!

SOME DRUM AND SOIL DYNAMICS

As vibratory rollers became popular around the 1950s, the optimum compaction procedure became a topic of research. One fundamental property that was investigated was the compaction frequency. All vibrating rollers operate with rotating eccentric masses that produce an increasing centrifugal force with an increased frequency. Historically, most soil rollers has been operating at a fixed frequency (or at a fixed frequency selected by the operator within a quite narrow frequency range). But is this really the most optimum way of creating vibrations?

GREAT ANSWERS ARE FOUND IN NATURE!

Many of our engineering problems can be solved by studying the nature around us. This holds true even in the SEISMIC case! All dynamic systems show a phenomena called a ”resonant frequency” where vibrations are greatly amplified. Consider the simple mass-spring system in figure 3. The mass, denoted m, represents the drum of the roller, and the spring, denoted k, represents the soil.

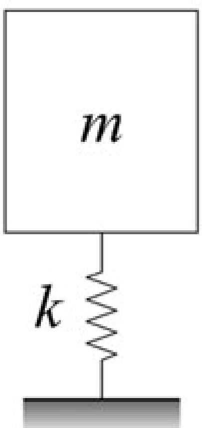

Figure 3. A mathematical representation of a roller drum with mass, m, operating on a soil with a stiffness k.

Let us now investigate what happens to the amplitude of the mass (the roller drum) and the force in the spring i.e., the stress in the soil, when the exciter inside the drum is allowed to vary its frequency from a low to a high value. The amplitude of the mass, m, that represents the drum, shows its highest value for a specific frequency, see figure 4. This frequency is called the resonant frequency (or natural frequency) of the spring-mass (drum-soil) system. Note that the centrifugal force is increasing with increased frequency, but the amplitude is decreasing when the frequency is increased beyond the ”resonance peak”. Based on the previous conclusion, that the compaction process is most effective if the amplitude is maximized, it is clearly shown that the centrifugal force is not a good measure of the compaction performance. What matters is the amplitude of the drum and a correct correlated compaction frequency.

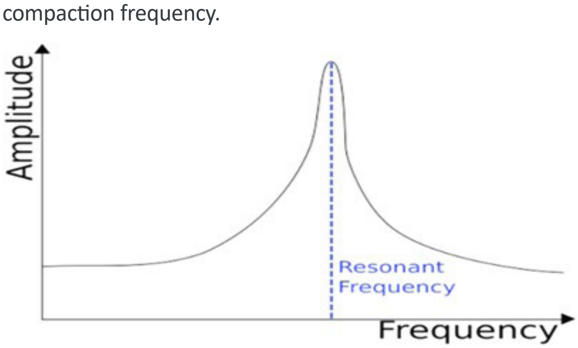

Figure 4. Drum amplitude as a function of vibration frequency.

As is shown in figure 4, the vibration amplitude is a function of the compaction frequency. To maximize the amplitude, and thereby maximizing the compaction performance, one needs to adjust the compaction frequency to a value that is very close to the resonant frequency. This is the ”tricky part”, since all different combinations of a drum with a certain mass, m, and a soil with a certain stiffness, k, show different values of the resonance frequency. It becomes even trickier, since when the stiffness of the soil changes with an increased number of passes, the resonant frequency changes as well. A soil with a high stiffness yields a higher resonant frequency compared to a soil with a lower stiffness. It is clear though, that if one can adjust the compaction frequency in such a way that the machine always operates close to the resonant frequency, the amplitude will be greatly increased and so will the compaction performance.

SEISMIC DOES IT FOR YOU

From the theory above, it is clear that it is more or less impossible to manually monitor and continuously tune the vibration frequency to a value that is always kept close to the resonant frequency. Bear in mind that the stiffness of the soil changes over the area to be compacted and that ”soft spots” might be present that requires the frequency setting to quickly adapt to the weaker soil conditions. However, with the introduction of the Dynapac unique SEISMIC system, there is no need for manual adjustments of the compaction frequency. The SEISMIC system will take care of the adjustments for you, and thanks to the intelligent built-in logics, SEISMIC will continuously monitor the soil conditions and adjust the compaction frequency accordingly to make sure that both amplitude, compaction performance and energy efficiency is maximized at all times.

DOES SESIMIC REALLY IMPROVE THE COMPACTION PERFORMANCE?

The increase in performance has been proven in an extensive test program carried out by Dr. Carl Wersäll at KTH Royal Institute of Technology. Dr. Wersäll has compared compaction performance with the SEISMIC-system turned on and off respectively. Comparisons have been made both in a controlled laboratory environment, as well as in several field trials. All the results are published in a number of articles, reports and theses on this topic. The test program revealed several benefits with the SEISMIC system.

INCREASED STIFFNESS WITH LESS NUMBER OF PASSES

Results from Static Plate Load Tests are shown in figure 5 below. A higher value of Ev2 indicates that the soil stiffness is greater and thus that the compaction effort has been more effective. The results show that the same stiffness is achieved after 11 passes at 20 Hz, which was the optimum compaction frequency found by the SEISMIC-system in this case, compared to 16 passes at 31 Hz, implying a reduction in the required number of passes of approximately 30%! This saves a lot of time, money and fuel. In addition, the energy consumption during operation for a machine equipped with the SEISMIC system is less compared to a conventional machine, since the compaction frequency is significantly lower when the machine operates in SEISMIC-mode.

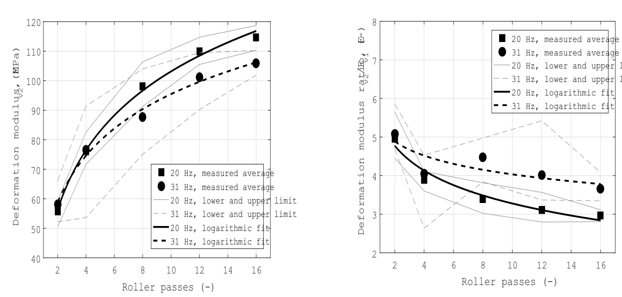

Figure 5. With the SEISMIC system active, one can expect a stiffness increase around nearly 30 % for granular materials, compared to a similar machine without the SEISMIC system.

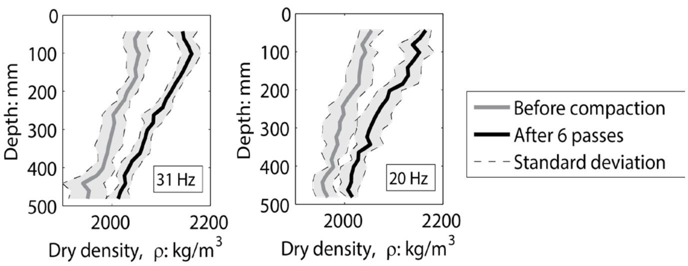

Figure 6. Measured densities (NDG) before compaction and after six vibratory passes with optimum frequency (20 Hz) and conventional fixed frequency (31 Hz).

NO LOOSENING OF THE TOP LAYER

Density measurements (performed with Nuclear Density Gauge) after six passes for optimum and fixed frequency are shown in figure 6 below. The gray lines indicate the initial density before compaction, and the black lines indicate the density after six vibratory passes. Note in figure nr.6 that for optimum frequency, in this case 20 Hz, the decrease in density in the top layer is not as pronounced as for higher frequencies. Loosening of the top layer is a common problem with vibratory compaction of granular materials, but it seems that when the compaction frequency is automatically tuned to an optimum value, the loosening effect is more or less eliminated. This is good news, because loosening of the top layer normally needs to be rectified with one or several static passes towards the end of the compaction work. The results above imply that these static passes may be omitted if the machine operates in SEISMIC-mode and this, in turn, will again save both time, fuel and money!

HARMFUL BOUNCING IS ELIMINATED

Even if the vibration amplitude of a SEISMIC machine is enhanced and thus greater than on a machine operating at a fixed, higher frequency, bouncing (or double jumping) is more or less completely eliminated. Bouncing is harmful to both the machine and the soil being compacted. During bouncing, high forces arise in the machine that might reduce the lifetime of components and create a very uncomfortable environment for the operator. Bouncing normally also means an increased risk of aggregate crushing in the top layer, due to the high forces that arise in the contact between the drum and the soil within every impact. When operating a SEISMIC machine, measurements and experience show that bouncing is very unlikely to occur, even for high contact forces. This is due to the fact that the drum and the soil operate “in pace”, meaning that the drum delivers the high portion of energy and force at the exact right moment, when the soil has the ability to absorb the energy and convert it to compaction work rather than reflecting it back to the machine. This allows a SEISMIC machine to operate with higher amplitude and compaction force and this, in turn, yields a better compaction result.

COMPACTION PERFORMANCE AND CENTRIFUGAL FORCE

Another very important conclusion is that a reduced frequency implies a significant reduction in centrifugal force as this is proportional to the frequency squared. Centrifugal force is often used as a measure of the compaction performance of the roller, but the results above clearly show, that an increased centrifugal force is not equal to an increase in compaction performance. What matters is that a correct compaction frequency is utilized (to boost the amplitude) for the unique conditions on every specific work site, and this is exactly what the SEISMIC-system does.

REDUCED WEAR ON COMPONENTS AND LESS NOISE

Since the optimum vibrating frequency (SEISMIC) normally is lower compared to a fixed frequency (without SEISMIC), this means significantly reduced wear on the components in the vibration powertrain, e.g., hydraulic vibration pump and motor, eccentric shaft, eccentric bearings etc, see figure 7. Lower operating frequencies also means that the emitted noise levels, both inside the cab and in the machine surroundings, are reduced, yielding increased comfort.

Figure 7. The normally lower operating frequencies of a machine equipped with the SEISMIC system, means reduced wear, and thus increased life, on all components in the vibration powertrain.

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WHAT ABOUT FUEL SAVINGS AND CARBON FOOTPRINT?

SEISMIC's performance has been verified by independent sources. Recently, the Swedish National Road and Transport Research Institute (VTI) supervised a series of fuel consumption tests on the Dynapac CA3500D SEISMIC Soil Roller. The roller tested in three different settings over a period of two weeks. The two test weeks were identical regarding procedures and were performed twice to validate that similar test results were reached. The results spoke for themselves. VTI measured a fuel reduction consumption of 35% when using SEISMIC in combination with ECO-mode, compared to conventional compaction (fixed frequency) carried out at full RPM. Moreover, they registered a good alignment with the onboard telemetrics, which reported savings of 34-38%. Operating the SEISMIC system in combination with the engine running at full RPM resulted in a fuel reduction of approx 16 %. Reduced costs from the reduction of passes were not included in the report. This means that under real job site conditions, there is an overall saving of around 55% to complete the job.

Figure 8. Fuel consumption tests carried out under surveillance of the Swedish National Road and Transportation Research Institute, VTI.

Furthermore, customers around the world have noticed the benefits with the SEISMIC system and the reduced fuel burn. Positive reports have been recived from Poland and USA, only to mention a few. The latest report was recieved from a construction company in Varberg on the Swedish West coast. The customer is the main contractor in a large rail road construction project, which involves construction of new tracks, tunneling etc. with the aim to redirect all railroad traffic underneath the city. The contractor uses two CA5000D SEISMIC machines equipped with Dynapac´s CCC (Continuous Compaction Control) system Dyn@lyzer, for a complete quality control and follow up. During compaction of an 0.5 m thick lift of subbase with fraction 0/90 mm, the contractor performed measurements of the fuel consumption. Conventional compaction, carried out at fixed frequency in combination with full engine RPM, was compared with compaction using SEISMIC in combination with ECO-mode. They report a reduction in fuel burn with 35.8 %, which is in perfect agreement with Dynapac´s own results confirmed by VTI.

Figure 9. Proven performance on the field with Dynapac´s SEISMIC system. Contractors report fuel savings of 35.8 %, well in line with Dynapac´s own results confirmed by VTI.

SUMMARY

Finally, Dr Carl Wersäll´s conclusion below speaks for itself. Note that Dr. Carl's work is completely impartial and not influenced by Dynapac in anyway. The results presented above are true, reliable, based on research and thus not "glorified" by any means.

Conclusion

Taking all measurements into account, it is evident that compaction under the conditions presented above is more effective when using the SEISMIC-system compared to conventional compaction carried out at a fixed frequency.

To summarize the findings outlined above we can conclude that:

• Vibratory compaction is most efficient if it is carried out with a compaction frequency close to the resonant frequency (SEISMIC system) of the drum-soil system.
• From tests on crushed gravel, the number of passes until a certain soil stiffness requirement is met, can be reduced with up to 30 %, if compaction is carried out close to the resonant frequency (SEISMIC) compared to conventional compaction at a higher fixed frequency.
• The surface loosening effect that is known in conventional compaction is more or less eliminated on granular soils, meaning that the static passes towards the end of the compaction process for "finish compaction" might be omitted.
• The drum amplitude is greatly amplified when the machine is operated in SEISMIC-mode. This in turn yields much higher stress levels in the soil (compared to conventional compaction), which contribute to an improved compaction.
• Compaction in SEISMIC-mode utilizes lower frequencies compared to conventional compaction. This saves fuel and energy, but also clearly states that centrifugal force is not a good measure of the compaction performance.
• Fuel savings with 36% can be expected when SEISMIC is used in combination with ECO-mode.
• The lower operating frequency also means a significant decrease in machine wear and noise levels.

IN THE NEXT APPLICATION COMPANION:

RECOMMENDATION TOOLS