P07

Application of Surface Wave Method to Confirm Compaction of a Refurbished Embankment - Case Study

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SUMMARY

In 2002 two extreme floods damaged the embankments of the river Kamp in Lower Austria nearby Vienna, because some parts of the dams are more than 100 years old. In 2009 it was decided to refurbish these embankments with the Impulse Compaction Method. To control if this compaction is successful surface wave seismic and dynamic probing was performed before and after the compaction. Results from refraction seismology indicate an improvement of the dam body after the compaction, but are not very accurate. Seismic surface wave results, which have a higher resolution near the ground surface, show a velocity inversion zone in 3-4m depth. This zone corresponds with the native soil upon which the dam was constructed. Furthermore there are in average higher velocities after the compaction down to the depth of 4m and no velocity changes below. Nevertheless the 2D-results of the seismic surface waves analysis indicates that the improvement of the packing density is laterally changing und goes locally deeper than the 4m depth. This is corroborated by the dynamic probing. Generally, it was demonstrated that the seismic surface wave analysis is a valuable tool to confirm the success of compaction and its penetration depth.

Introduction

In August 2002 two extreme floods devastated the surroundings of the river Kamp near the confluence with the river Danube in Lower Austria, about 70km east from Vienna (Figure 1). At these days the precipitation reached from 160 up to more than 200 mm/m^2 (Godina, et al., 2004). The high-water level combined with the bad condition of the embankments, some parts of the dams are more than 100 years old, lead to dam failures at several locations which caused that several townships were flooded and more than 400 houses were damaged (Figure 2a).

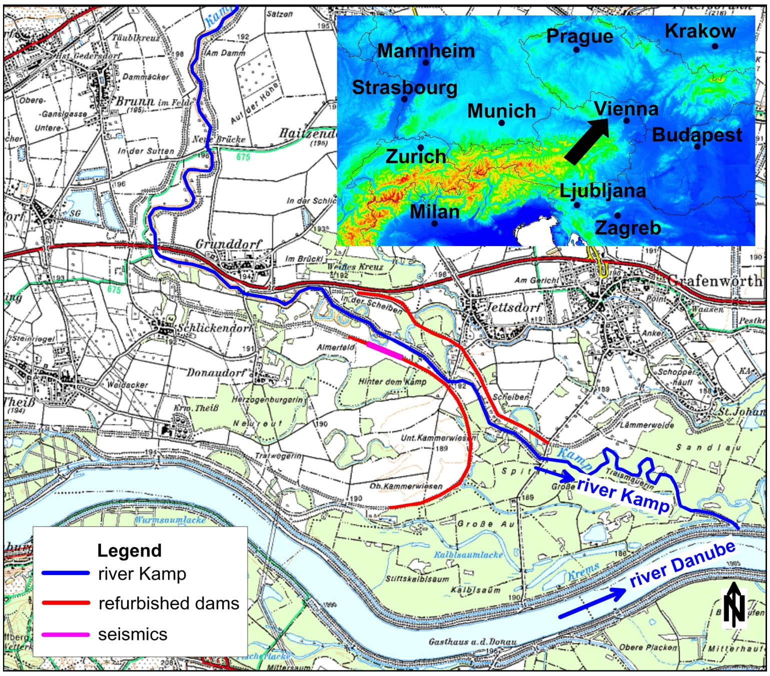

Figure 1 Map view of the investigation area; inset shows the location of the investigation area on small scale; see legend for main features, modified from (Amap Austria)

After a feasibility study it was decided to refurbish the embankments with possible overtopping areas along both banks with a total length of 4.9 km (Figure 1). The construction started in summer 2009 with the Impulse Compaction method by the company "Terra-Mix GmbH" (Figure 2b). The Impulse Compaction method generates an impulse by a falling weight impacting on a plate placed on the ground surface. For this project a falling weight of 9 tons and a falling height of about 1.2 m were used. This cylinder is about 1.5 m in diameter and has a weight of three tons. According to previous experience with compaction work for road projects, an effective compaction depth of up to 7 m can be expected. Compaction depth of sandy soils should be larger than for cohesive soils.

Figure 2 Picture of the flood 2002 near Jettsdorf (2a) and of the Impulse Compaction on the trial section (2b)

A drilling at the dam crest showed that the texture of the subsurface is fine sand down to 3m, silty sand from 3-6.5m and alternately medium and coarse gravel from 6.5-12.5 depth. The upmost sandy layer is interpreted as the dam itself constructed on the native soil which is overlaying the gravel created by the river Kamp or Danube.

To determine if there is an improved packing of the dam body, seismic measurements besides dynamic penetration tests were carried out before and after the Impulse Compaction. Figure 1 shows the area of the seismic measurements with a total length of about 300m. This area was chosen because the river Kamp is close to the levee and the embankment condition was rather poor which was confirmed by low blow numbers of the dynamic probing.

Method

Because of the need of high resolution near the ground surface it was chosen to determine the packing of the dam with the seismic surface waves. We used the Multichannel Analysis of Surface Wave (MASW) method which mainly consists of the following steps (Park, 2007):

- Acquisition of a multiple number of multichannel records along a linear survey line by use of the roll-along mode
- Processing all acquired records independently to produce a dispersion curve and a 1-D S-wave velocity-depth profile for each record
- Creating the 2-D S-wave velocity map through spatial interpolation by assigning each 1-D S-wave velocity-depth profile at the surface coordinate to the middle of the receiver spread

To achieve appropriate surface waves the generation of seismic waves was done by a sledgehammer with 8 kg weight. The recording of the seismic waves took place along a line on the dam via 48 receiver arrays, which were planted in equal spacing of 2 m. Each receiver array consisted of four single geophones with a natural frequency of 10 Hz. The signals of the geophones were stored in a portable registration unit (Summit Compact) with a record length of 3s. The seismic measurements were carried out according to the roll-along acquisition method, where the source was at the first receiver. The whole seismic arrangement moved step by step from one geophone station to the next.

Each record was processed with the software SurfSeis (KGS Kansas Geological Survey). The data quality was rather good which was confirmed by nice dispersion amplitudes for almost all shots and therefore no further signal processing was needed. The range of frequency between 10-30Hz for picking the dispersion curve and the parameters for the inversion to achieve the S-wave velocity-depth profile was chosen identically for all data.

Results

Although our main interest was on the surface waves, there are additional results from the refraction seismology worth to show. Figure 3 shows a common offset stack of all records before and after the compaction, which can be seen as an average shot for the whole seismic line. The P-wave refraction layer with a velocity of 2000 m/s is interpreted as the groundwater level in about 5 m depth. Near the source, the direct wave is observed which propagates as a body wave along the ground surface. The velocity of the direct wave, which is valid from the ground surface to the depth of the refracting layer represents the dam density.

The comparison of direct P- and S-waves before and after compaction points to an increase of the average velocity for both wave types. The average velocity of P-waves increases from 346 m/s to 394 m/s and the velocity of S-waves from 142 m/s to 173 m/s, which indicates increased density after the compaction.

Even though the refraction seismic analysis shows an increase of the seismic velocity for the direct wave, because of few picks of the direct wave and the validation of the seismic velocity down to 5m there is a lack of resolution near the ground surface. Nevertheless, it is a first advice for an improved compaction.

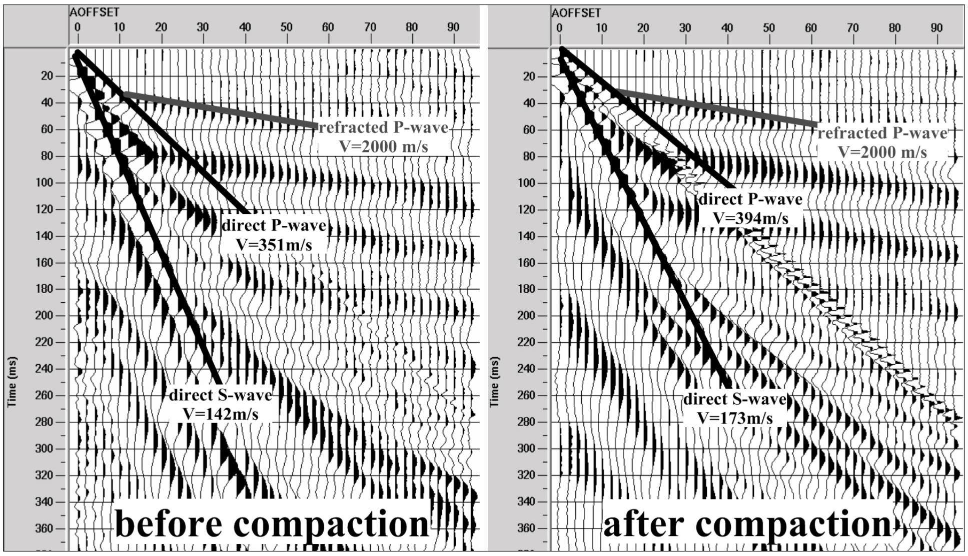

Figure 3 *Common offset stack of all shots before and after the compaction and the interpretation of the direct and refracted P- and S-waves*

Analysing the surface waves result in higher resolution for the dam body. Figure 4 shows the 2D S-wave velocity contribution for the whole seismic line before and after Impulse Compaction calculated with MASW method.

Comparing both measurements it can be clearly seen that there is an inversion zone between 3-4 m depth which corresponds with the upmost of the silty sand layer representing the native soil before the dam construction. Generally, the S-wave velocity increased after compaction near the surface and including the dam body down to 5 m depth, which is confirmed by the dynamic probings. It looks like that the compaction was more efficient from 20-145m (see the green zones in Figure 4).

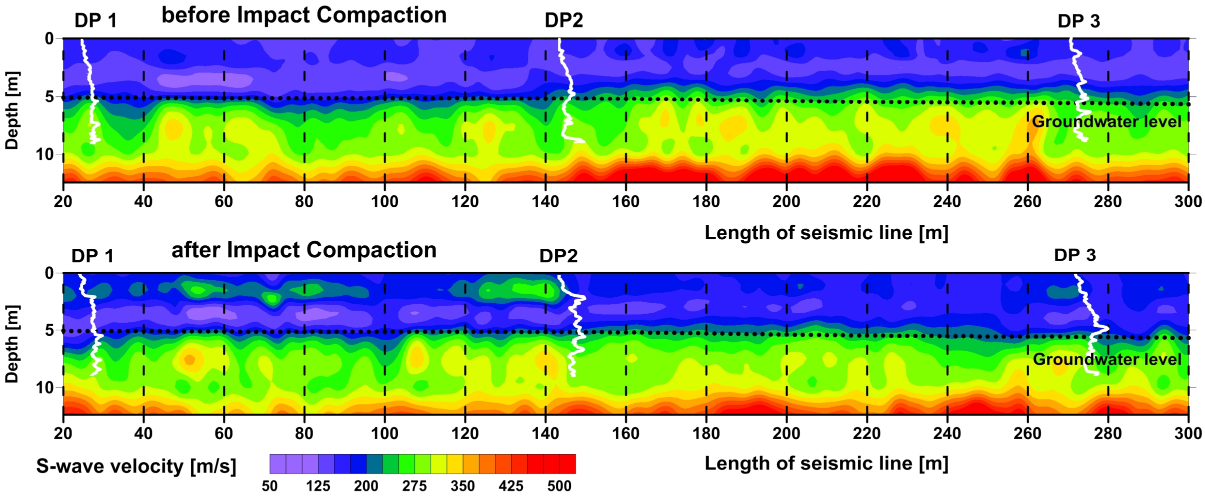

Figure 4 *2D S-wave velocity contribution before and after compaction; dynamic probings (DP1-3) and groundwater level are inserted*

To make the difference more qualitative an average S-wave velocity-depth profile before and after the Impulse Compaction over the whole seismic line was calculated (Figure 5a**).** Figure 5a clearly shows an inversion zone in 2-4m depth and that the S-wave velocity increased near the surface down to 3.5m depth after compaction. The inversion zone corresponds with the native soil upon which the dam was constructed. Below 4 m there is no apparent difference in the seismic velocity.

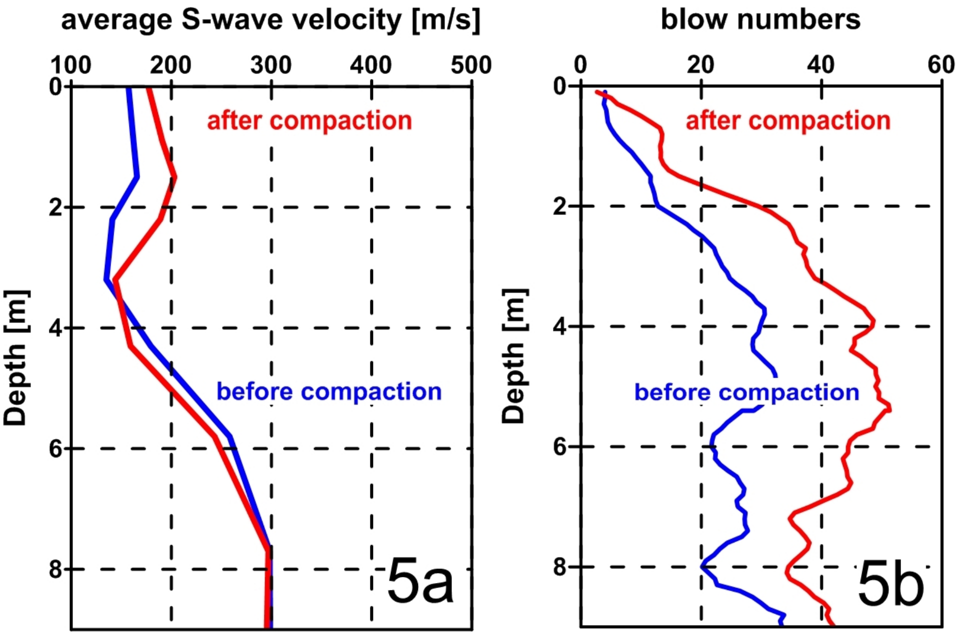

Figure 5 a) *Average seismic S-wave velocities calculated from 2D-results; b) Average blow numbers of dynamic probing DPL*

Figure 5b shows the averaged blow numbers of the three dynamic probings. Generally, the blow numbers are higher after compaction in all depths. A qualitative interpretation of the shape of these curves shows an increase of blow numbers down to 2.5 m and then a flat increase between 2.5 - 3.5 m depth, matching the inversion zone in the S-wave velocity.
Below there is an area of high blow numbers between 4-6m depth corresponding to silty sand and a decrease from 6-9m depth corresponding to medium and coarse gravel.

Conclusions

Impulse Compaction, which is said to have an effective compaction depth of up to 7 m, was applied for refurbishing embankments. The improvement of the packing density of the dam, after the compaction, was confirmed by the results of the seismic surface wave analysis with measurements before and after the compaction. These results, in average higher velocities down to 4 m depth, show that the surface wave analysis has a much higher resolution near the ground surface than e.g. the refraction seismology, which also indicates an increase in the seismic velocities near surface but not so accurate. In certain areas it seems that the improvement of the packing density is laterally changing und goes deeper than the 4 m depth, which is corroborated by the dynamic probings.
Hence the surface wave analysis provides an attractive method for compaction control. As compared with the conventional methods, e.g. dynamic probing, the surface seismic analysis has the advantage of being continuous and fast. With surface waves the weak spots within the embankment with very low density can be easily localized, while for dynamic probing this is often a matter of chance.

References

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Park, C.B., Miller, R.D., Xia, J., and Ivanov, J. [2007] Multichannel analysis of surface waves (MASW) - active and passive methods: The Leading Edge, January 2007