DETERMINATION OF SEISMIC WAVE VELOCITIES USING METRO-VIBRATIONS

H. Wenzel[1]

[1] *Managing Director, VCE Holding GmbH, Hadikgasse 60, A-1140 Vienna*
Email: wenzel@vce.at

ABSTRACT:

The knowledge of wave velocities helps in the process of microzonation. A metro running in tunnels in urban areas emits vibrations, which can be monitored. Applying a time synchronous monitoring campaign wave velocities in the well-known soil conditions in the vicinity of metro tunnels can be extracted. The idea has been developed from Earthquake Engineering Methodologies.

The present paper reports about measurements done under almost perfect conditions and describes the results. For the evaluation of the data new concepts were developed and tested in the Austrian capital Vienna. If this methodology turns out to be successful, the final target would be to take records at approximately 10.000 points covering the complete area of the city out of which a velocity map for Vienna will be computed.

KEYWORDS: shear wave velocity, transient signal processing, autocorrelation, energy content

1. INTRODUCTION

The subsoil conditions are of crucial importance for the estimation of a location as regards the load from earthquake on the construction. The different wave propagation in the ground should be taken into account according to bedding, material, granulometry, compactness of the ground, water content etc. of the subsoil. The average speed of transversal waves from the surface area up to a depth of approx. 30 m is a relevant parameter for the estimation of dynamic subsoil conditions.

Methods that can efficiently and reproducibly determine the wave propagation in the subsoil as well as the local speed of transversal waves under the urban circumstances of Vienna have been examined as a basis for microzonation of Vienna, which should be done in the scope of the SEISMID project.

There are different methods for the determination of the speed of transversal waves. Some of them take advantage of the measurement of the artificially generated surface waves to enable the evaluation of the subsoil conditions. Other methods use the dynamic ground stimulation in depth (e.g. detonations in the borehole) to measure the wave propagation in the ground (e.g. in the borehole) and on the surface and to directly define the dynamic subsoil conditions from it. The measurement and estimation of artificially generated surface waves was intensively followed in the SEISMID project and was also a part of measurements in Grossfeldsiedlung on Wednesday, October 3 2007. This part is already contained in another separate report whereas the current report deals with dynamic ground stimulation in the depth of a subsoil.

As an overall, dynamic survey of the subsoil by means of boring seismics in a tight grid implies unjustifiably high costs, the idea was born of using dynamic stimulation of the subsoil by the use of underground railway lines for the analysis of wave propagation. Measurements in Grossfeldsiedlung served for the verification of this idea.

2. CRITERIA FOR A TESTING LOCATION

The method was to be checked under ideal conditions to be able to make quite explicit statements. The following criteria were given special emphasis in the search for a suitable location for the measurements:

- The surface area should have a suitable size and should be located directly above an underground railway route.
- The underground railway should have a constant speed in this area (not in the braking or accelerating track).
- The underground railway line should run as straightly as possible in the observed area.
- The surface area should be freely accessible and an undisturbed measurement should be guaranteed.
- The surface area should be as flat and horizontal as possible and the underground railway line should not have any significant longitudinal slope.
- The ground composition in the examined region should not be too heterogeneous.

The results presented in this paper are based on measurements which were done at Grossfeldsiedlung (A-1210 Vienna, Bubergasse, Wassermanngasse, Uhlitzgasse), where the above criteria were fulfilled to a great extend.

3. MEASUREMENT DETAILS

3.1. Location

The selected location is placed directly above the underground railway line U1, which runs towards the outskirts of the city (Leopoldau), and towards the centre of the city (Reumannplatz).

The beginning of the platform of the station Grossfeldsiedlung is at a distance of 168.7 m from the next measurement sensor, a distance at which underground railway trains have already achieved and still hold their final speed. The terrain is flat and horizontal, the sensors were placed on non-sealed positions directly on the ground.

3.2. Sensor System

Three measurement locations directly above the underground railway route, with distances of 30 m each, were specified and marked from north to south with S1, S2 and S3 respectively (cf. Figure 1). Normal to this line, two measurement locations, starting from S2 towards the east were defined at a distance of 25 m (S4) and further 15 m (S5). At all measurement locations an acceleration sensor (Epi-Sensor) and a sensor for oscillation speeds (Walesch-Sensor) were installed.

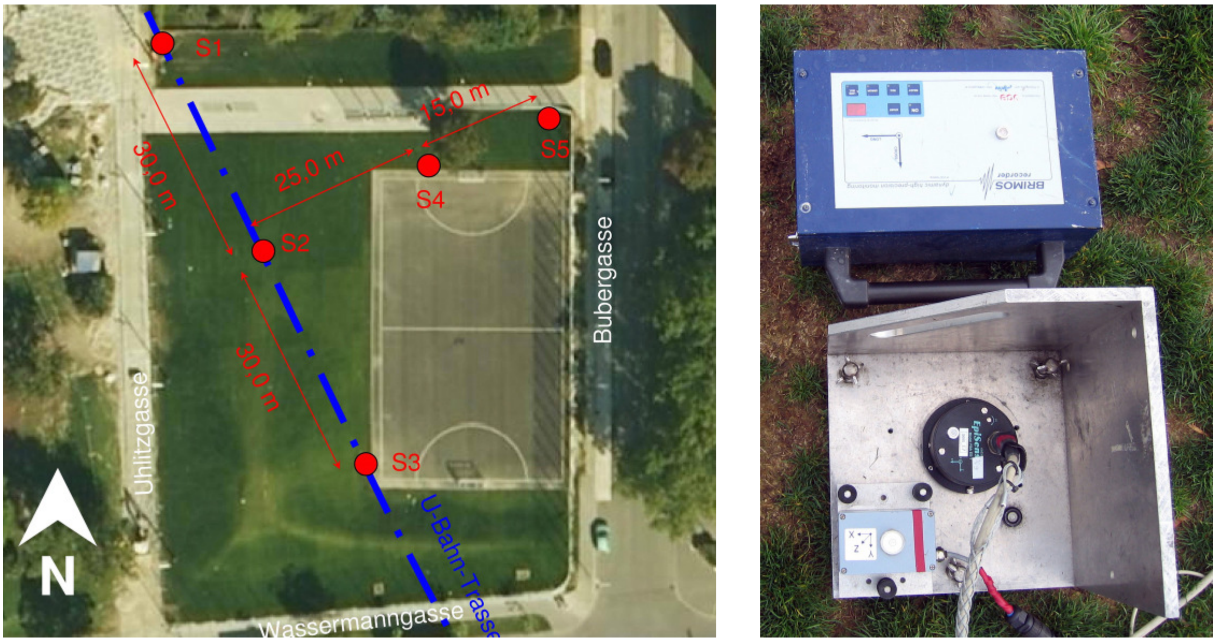

Figure 1 Location of measurement sensors (left) and the sensors at Measurement location S2: Walesch-Sensor (grey), EPI-Sensor (black) and BRIMOS-Recorder (blue)

Additionally, the BRIMOS-Recorder, a self-sufficient measurement device, which records accelerations, was positioned on the measurement location S2. It recorded the ground accelerations over the whole duration of the test.

All sensors registered in three directions, with the X-direction determined by the straight line from S3 to S1. The Y-direction was defined normal to this towards the east and the Z-direction ran vertically.

The measurement values were generally recorded with a sampling rate of 1000 Hz. The sampling rate of the Brimos-Recorder was adjusted to 200 Hz.

3.3. Measurement Procedure

The recording of the measurement values resulted on October 3 2007 in the period from 10.13 to 11.45 am. In this period all evident events which can have an influence on the measurements (e.g. disruption by the bus in Wassermanngasse) were documented. Furthermore the times when the first carriage of the arriving underground railway train towards Lepoldau reached the beginning of platform and when the last carriage of the train left the platform towards Reumannplatz respectively were recorded in the station Grossfeldsiedlung.

The old (grey) underground railway trains (three double-railcars) were indicated with U, whereas the designation V relates to the new, continuously walkable six-carriage-trains.

4. EVALUATIONS

The recorded signals of the acceleration and oscillation speed sensors were systematically viewed and tested for pecularities, which are regarded as appropriate for the registration of wave velocities and the assessment of wave propagation characteristics.

In the measurement record below (Figure 2), the vertical accelerations at sensor position S2 are represented. The signals caused by underground railway trains are clearly recognisable. Thus the train U 3231 has considerably higher acceleration amplitudes than the train U 3040 in both directions although both trains are of the old design. New trains (e.g. V 3807) cause considerably lower vibrations then those of the old design.

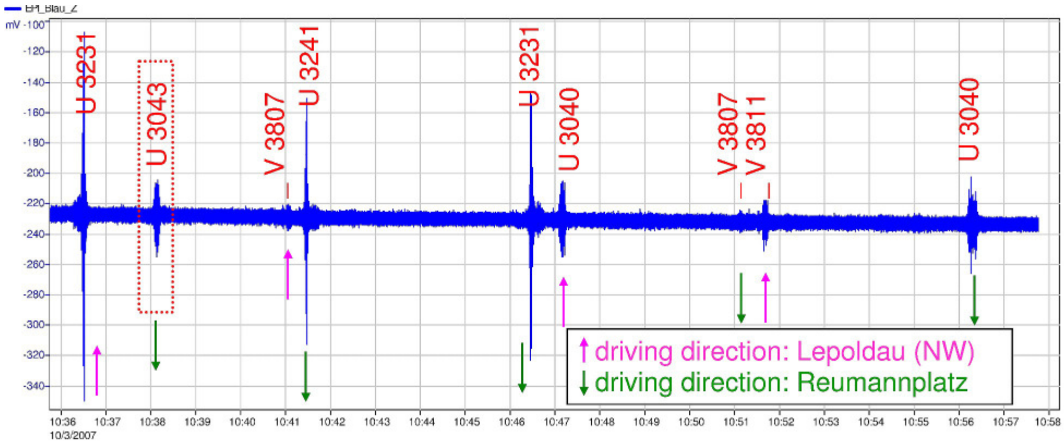

Figure 2 Measurement record 10.36 – 10.58 am, vertical acceleration S2

Below the evaluation of the passage of train U 3043 at 1038 in direction Reumannplatz is shown. In Figure 2 this passage is marked with a red dotted rectangle. This train was chosen because it showed one marked flat spot (at least) of a wheel tyre, whose periodic impulses during the passage seemed advantageous for the determination of wave propagation.

5. RESULTS

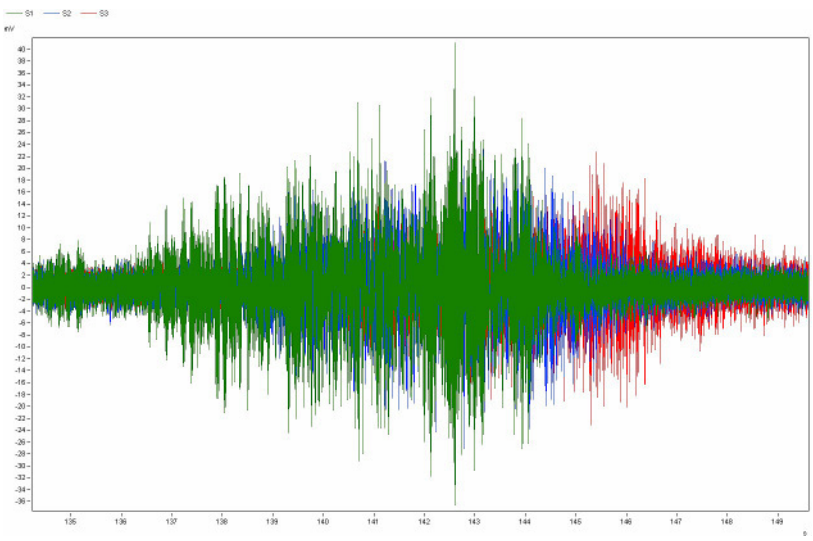

Figure 3 Vertical acceleration signals on the measurement locations S1, S2 and S3

In Figure 3 the train towards Reumannplatz can be identified first in sensor location S1 (green), then in the central sensor location S2 (blue) and finally in sensor location S3. In order to enable the measurement of the driving speed of underground railway trains the signals were squared and integrated. In this way the “energy content” contained in the signal adds up and the time, when half of the total energy content is reached, is when the train centre passes the sensor position (Figure 4).

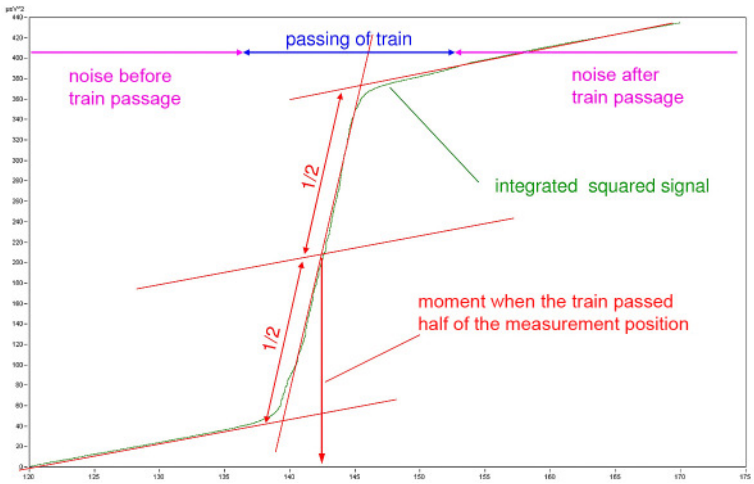

Figure 4 Basic sketch for the determination of the moment of the train passage

The driving speed of the underground railway train can be calculated with 70km/h (19.4 m/s) at this position by means of the time differences and the known sensor distance of 30 m. This evaluation was also carried out at the oscillation speed signals. Differences in the results show that this method is just sufficiently accurate for the determination of the driving speed but it is not appropriate for the observation of wave propagation periods due to inaccuracy. With the known wheel diameter of 0.90 m (circumference of 2.827 m), the frequency of excitation can be estimated at 6.9 Hz by means of the flat spot on the wheel tyre, which is clearly visible as a small peak in the frequency analysis of the three signals (Figure 5).

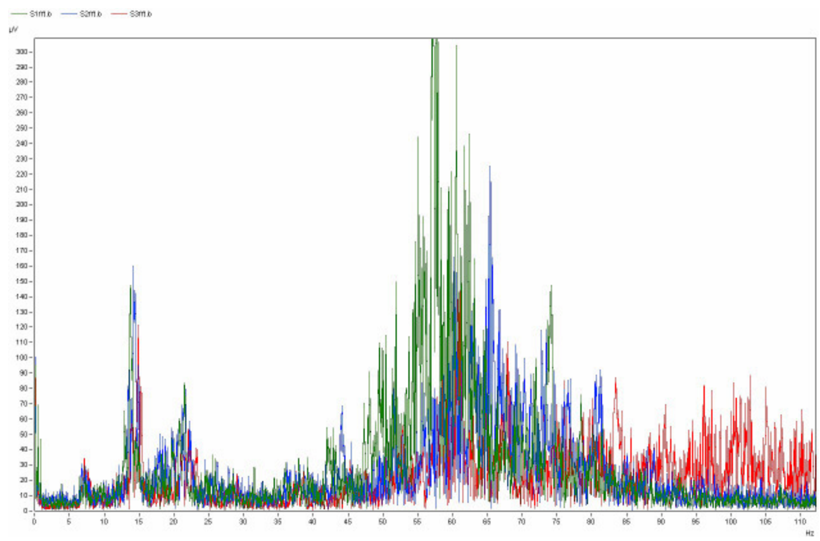

Figure 5 Frequency analysis of vertical accelerations in S1, S2 and S3 by means of FFT

Special attention is attached to these signals with approx. 7 Hz on the flat spot(s) of the wheel tyre during the evaluation. The periodical impulses during the passage of the train should be visible earlier at the nearest sensors than at the sensors farther away according to the current position of the axis(es) on the underground train route. The propagation speed could be calculated from the time difference.

To separate periodic impulses and to establish time displacements from overall acceleration signals, these were processed as follows:

- The absolute values of the acceleration data were smoothed (Figure 6, blue line)
- A band-pass filter (Butterworth 6.3 – 8.3 Hz) was applied on these signals (Figure 7)
- To reach a better comparability, these signals were brought to a uniform amplitude by dividing them through their own strongly smoothed absolute values
- These signals were used in sections (different windows in different train positions) to calculate time displacement by means of cross correlation (Figure 8).

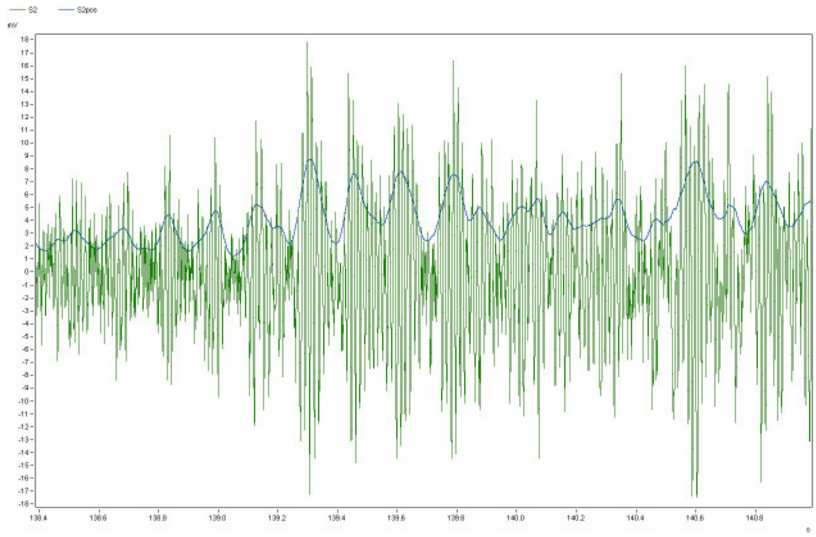

Figure 6 Section of vertical acceleration S2 (green) and absolute values smoothed (blue)

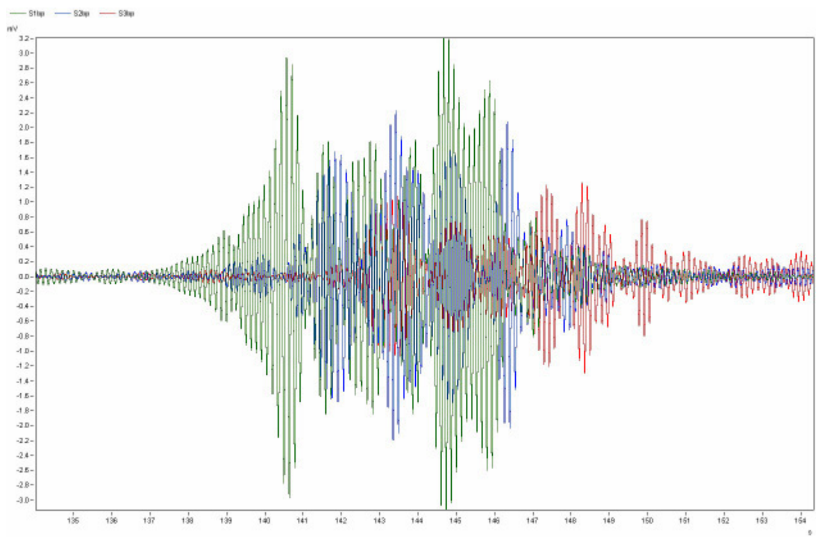

Figure 7 Band-pass filter (6.3 – 8.3 Hz) of smoothed absolute values

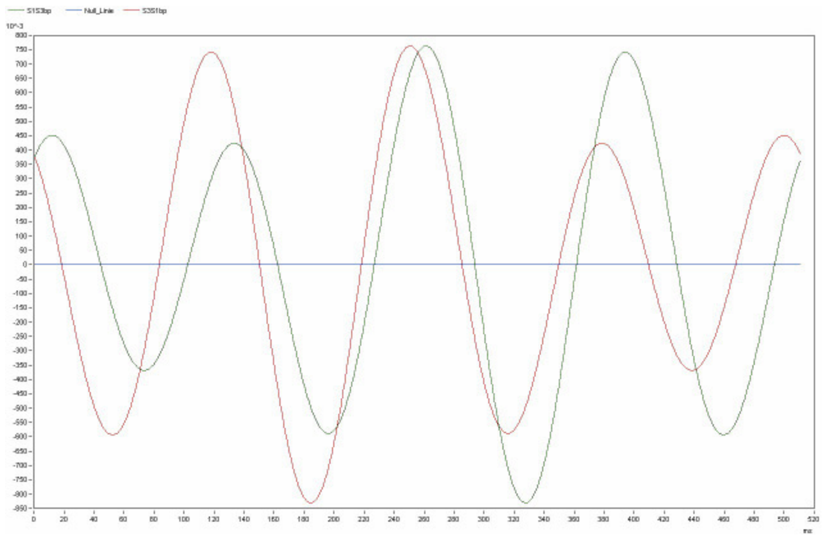

Figure 8 Cross-correlation of reprocessed signals of S1 and S2 for a time window of 0.7 sec with the centre of train passage at S1, green: basis S1, red: basis S3

Additionally in Figure 9, the band-pass filtered beginning of visibility of the underground railway is illustrated in the measurement signals. The hope to observe an undisturbed run of wave propagation in driving direction was not achieved.

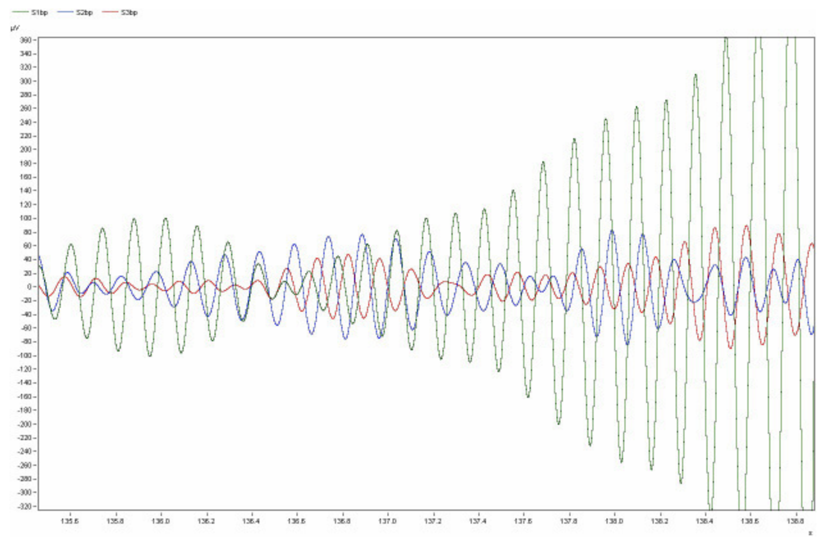

Figure 9 Beginning of visibility of the underground railway in the measurement signals (band-pass filtering)

6. CONCLUSIONS

The tested method, which explores the wave propagation in the subsoil, needs subterranean, dynamic stimulation and is therefore linked to the underground railway network. This concept is not sufficient by itself for the planned global analysis within Vienna's urban area.

In the process of searching for appropriate measurement locations it became evident that there are only few places which offer optimal measurement conditions. As the method is not easily applicable despite optimal position and calm conditions, success is rather improbable at less appropriate positions.

The length of a train (111 m) is relatively large in comparison to the reasonably chosen distances of sensors (60 m). The more concentrated dynamic stimulation is carried out, the better can the data measured at a defined distance be interpreted. In case of a "linear" dynamic load, which is longer than the sensor distance, mixed effects that can be only interpreted with difficulty inevitably occur. An underground railway train has 24 axes. Due to overlapping of many simultaneous single events, place and type of the single stimulations cannot be clearly identified.

Impulses of a flat spot on a wheel tyre can only yield results when the flat spot is the only one at the train and the remaining axes of the train run relatively smoothly.

Even measurement data determined under the described optimal conditions as well as a specific choice of a promising data sequence in combination with an evaluation specifically adjusted to the local circumstances, do not deliver satisfying results.

Therefore standardisation of the method does not seem productive.

ACKNOWLEDGEMENTS

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