Bridge Vibrations Excited Through Vibro-Compaction of Bituminous Deck Pavement

R. Cantieni
rci dynamics, Structural Dynamics Consultants, Duebendorf, Switzerland

M. Langenegger
Robert Aebi AG, Regensdorf, Switzerland

ABSTRACT: Vibratory rollers are used to dynamically compact asphalt or bituminous layers of more than 100 mm thickness. The paper deals with the question whether or not such machinery should be allowed to compact pavement on a bridge deck. As no experimental or analytical data related to this problem could be found tests were performed on a reinforced concrete bridge exhibiting a 5 Hz fundamental natural frequency. Two types of vibratory rollers with forcing frequencies in the 35…70 Hz range were used to compact the pavement and the resulting bridge vibrations were monitored. The bridge vibration velocity was smaller than 15 mm/s for both rollers. No sign of resonance between the rollers and the bridge superstructure was to be observed. Therefore, no reason could be found to ban vibratory rollers from compacting pavement on bridges.

1 THE PROBLEM

To compact bituminous pavement layers of more than 100 mm thickness vibratory rollers are usually used. An informal investigation yielded that the problem of whether or not this technology be allowed for the compaction of pavements on bridge decks is not dealt with consistently in Switzerland. Some bridge owners do not allow the use of any vibratory compaction device on bridges. Others allow the use of so-called automatic but not of conventional vibratory rollers.

Automatic rollers continuously adapt the vibration frequency and amplitude to the increasing stiffness of the pavement layer. Conventional rollers allow manual adaptation of these parameters in narrow limits only. No experimental or analytical data could be found which the respective policy could have been based on.

Therefore, to get a rational decision basis tests were performed on a reinforced concrete highway bridge. An automatic and a conventional roller were used for the compaction of the pavement in the two bridge lanes respectively. The induced bridge vibrations were continuously monitored. In case of the peak vibration velocity surpassing $v = 20$ mm/s the test was to be stopped immediately and pavement compaction was to be finished using static rollers. There was hence a slight safety margin versus the $v = 24$ mm/s being acceptable according to (VSS 1992) for the conditions given.

2 THE BRIDGE

The tests were performed on a reinforced concrete highway bridge with spans of 17, 20 and 16 m. The cross section is a massive slab with a 0.9 m thickness and an overall (variable) width of roughly 14 m. The intermediate supports are two circular columns clamped at both ends, the abutments are basically horizontally free line bearings (Figs 1, 5, 6).

Figure 1. View of the bridge.

3 THE BRIDGE DYNAMIC PROPERTIES

The natural bridge vibrations were identified using ambient vibration technology. Two highly sensitive accelerometers PCB 393B31, 10 V/g, a data conditioning and acquisition device OROS OR25, a laptop computer and the ARTeMIS software package were used. One of the accelerometers was placed in a fixed reference point whereas the other sensor was roved over the structure covering a total of 14 additional measurement points. The two abutment lines were not measured. 15 bridge natural modes with frequencies in the range f = 5.00…134.0 Hz could thus be identified. As examples, Figures 2 and 3 show the results for two of the modes identified.

The frequencies of the modes No. 7 to 11 (27.0, 39.75, 56.6, 63.25 and 68.65 Hz) lie in the range of dynamic forces exerted by the rollers. The reason why this fact was found not be critical is described later.

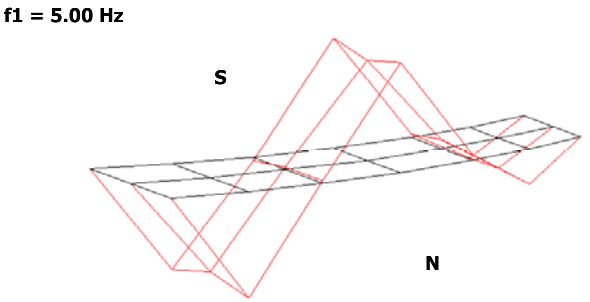

Figure 2. First natural mode of the bridge without pavement.

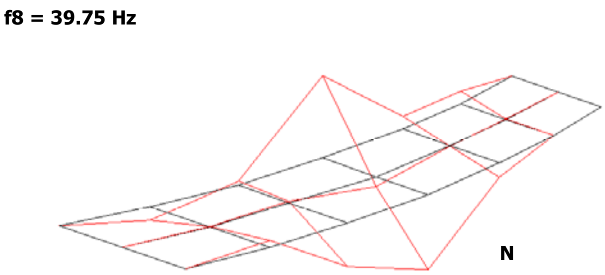

Figure 3. Bridge mode No. 8 for the bridge without pavement.

4 THE VIBRATORY ROLLERS

4.1 *Automatic Roller Ammann AV95*

This roller has an operating mass of 9.5 t, a variable vibration frequency f = 25…50 Hz, a respective vibration amplitude h = 0.62…0.1 mm and a respective centrifugal force per drum F = 52…7 kN. (The vibration amplitude is related to the drum's jump height when operated on a rigid surface). In this paper, the roller is designated as "AV95" (Fig. 4).

Figure 4. The rollers DY52/70 (left) and AV95 (right).

4.2 *Conventional Roller Dynapac CC232*

This roller has an operating mass of 8.0 t, a vibration frequency of either f = 52 Hz or f = 70 Hz, a respective vibration amplitude of 0.5 mm and 0.22 mm and a respective centrifugal force per drum of F = 89 kN and F = 65 kN. In this paper the roller is designated as "DY52" and "DY70" respectively. In case of the vibration frequency not being an asset, the designation used is "DY52/70" (Fig. 4).

5 THE TESTS

5.1 *Instrumentation, Data Acquisition*

Eight accelerometers PCB 393A03 (sensitivity 1 V/g) were installed on the bridge deck undersight. Four of them were located in the bridge lane A covered by the roller AV95, four in the bridge lane B covered by the roller DY52/70 (Figs 5, 6). Signal conditioning and capture were provided by an OROS OR25 front end and a laptop computer. The sampling rate was s = 512 Hz, the range of the signal processing in the frequency domain f = 0…200 Hz. These parameters were chosen with considering the vibration frequencies of the rollers.

5.2 *Data Processing*

Three different modes of operation are offered by the OR25 software package:

On-line analysis. The signals can be treated arbitrarily in the frequency and time domains. In the present case the measured acceleration signals were integrated once to get vibrational velocity. In this mode, the treated signals can be monitored concerning specific values like e.g. peak values. These peak values can be monitored visually and/or stored on disk. It is however not possible to store treated signals continuously on disk.

Recorder. In this mode, the untreated signals can be stored continuously on disk.

Off-line analysis. In this mode, the untreated signals having been stored on disk can subsequently be analyzed in the frequency and time domains.

As a consequence, the on-line analysis mode was activated with first priority to monitor the velocity peak values and to hence allow stopping of the tests if necessary. With second priority, acceleration signals were streamed to the disk to allow subsequent analyses in the off-line analysis mode.

6 THE RESULTS

6.1 *Time Domain Analysis*

As a first priority result: The peak velocity values observed during all on-line analysis monitoring phases never surpassed v = 15 mm/s. Therefore, the tests had not to be stopped due to occurrence of excessive bridge vibrations.

Maximum velocity values observed are:

- AV95: 12.7 mm/s
- DY52: 14.0 mm/s
- DY70: 11.1 mm/s

For the sake of completeness, the maximum acceleration values determined from the recorded acceleration signals (not directly relatable to the peak velocity values given above) are also given here:

- AV95: 3.7 m/s2
- DY52: 3.3 m/s2
- DY70: 3.8 m/s2

6.2 *Frequency Domain Analysis*

To allow interpretation of the processes controlling the events, the recorded acceleration signals were processed in the frequency domain.

As characteristic examples, two test sequencies are discussed in more detail here.

6.3 *Automatic roller AV 95*

Figure 7 gives an acceleration time signal recorded in measurement point No. 2 (Fig. 6). The averaged, logarithmically scaled frequency spectrum calculated from the relevant part of this signal is shown in Figure 8. What can be seen from this spectrum?

a) Four bridge natural frequencies lying in the range f = 4.5…16.75 Hz can be distinguished. These frequencies are Δf = 0.5…1.0 Hz lower than those determined for the bridge without pavement. This indicates that, as a consequence of the continuously increasing mass of the pavement placed on the deck the bridge natural frequencies are subject to continuous decrease.

b) Vibrations induced by the roller are in the range f = 40…51 Hz plus the respective higher harmonics.

c) The vibration at f = 55.5 Hz was first thought to be related to the bridge mode No. 9, f = 56.6 Hz. However, due to the existence of the related higher harmonics this interpretation had to be abandoned. This vibration could later be related to forces generated by the roller's Diesel engine.

6.4 *Conventional roller DY70*

Figure 9 gives an acceleration time signal recorded in measurement point No. 6. The averaged frequency spectrum calculated from the relevant part of this signal is shown in Figure 10. What can be seen from this spectrum?

a) Four bridge natural frequencies lying in the range f = 4.5…16.5 Hz can be distinguished. These frequencies are Δf = 0.5…1.0 Hz lower than those determined for the bridge without pavement.

b) Vibrations induced by the roller are f = 66 Hz plus the respective higher harmonics.

c) The Diesel engine induced vibration f = 55.5 Hz plus harmonics can also be identified.

6.5 *Stability of the roller's forcing frequency*

Finally, the question of whether or not the forcing frequency of a roller would be a function of the forcing amplitude was investigated into. A respective investigation revealed that this is not the case. The rollers' forcing frequency is absolutely stable and independent of the forcing amplitude. This means that no transient resonance effects while increasing the roller's force intensity from zero to maximum is to be accounted for.

6.6 *Results of the Frequency Domain Analysis*

Interpretation of the frequency spectra based on the knowledge concerning bridge natural frequencies and roller vibrational frequencies revealed that three sources of vibration can be distinguished:

- bridge natural vibrations,
- roller forced vibrations,
- vibrations forced by the roller's Diesel engine, operating in the range f = 55 Hz.

Obviously, the bridge dynamic response to the operation of the vibratory rollers is dominated by vibrations forced by the rollers. Although the bridge exhibits natural frequencies in the range of the roller's dynamic forces' frequencies, no sign of dynamic interaction between bridge and rollers could be identified. Why?

One reason is the lacking stability of the bridge natural frequencies due to the mass effect of the pavement layer. With estimated damping ratios of the bridge natural vibrations of 1…2 % of critical, resonance occurs with exact coincidence of natural and forcing frequencies only.

A further reason is the fact that the distance between the first couple of natural bridge modes' frequencies and the roller's forcing frequencies is high. Resonance can therefore only occur for a very complicated bridge mode shape and a limited amount of time (…the roller needs to cross the region of modal amplitudes being significantly different from zero). The consequences of such an effect can hence be limited an very local only.

7 CONCLUSIONS

The question whether or not application of vibratory rollers to compact pavement layers on bridge decks would lead to excessive bridge vibrations was investigated into. Tests performed on a reinforced concrete highway bridge lead to the result that this seems not to be the case. Although the test results cannot simply be generalized, there are some effects to be reported:

Although the bridge tested exhibits some higher modes with frequencies in the range of the rollers' dynamic forcing frequencies, the maximum bridge vibrations did not exceed v = 15 mm/s.

Simple and therefore dangerous resonance effects did not occur. There are two reasons for this:

First of all, the bridge natural frequencies are not stable because of the mass effect of the pavement placed.

Furthermore, the distance between the first couple of bridge mode frequencies and the rollers' forcing frequencies is large.

8 REFERENCES

VSS 1992. *Erschütterungen, Erschütterungseinwirkungen auf Bauwerke. Norm SN 640 312 a.* Zürich: Herausgegeben von der VSS, Vereinigung Schweizerischer Strassenfachleute.

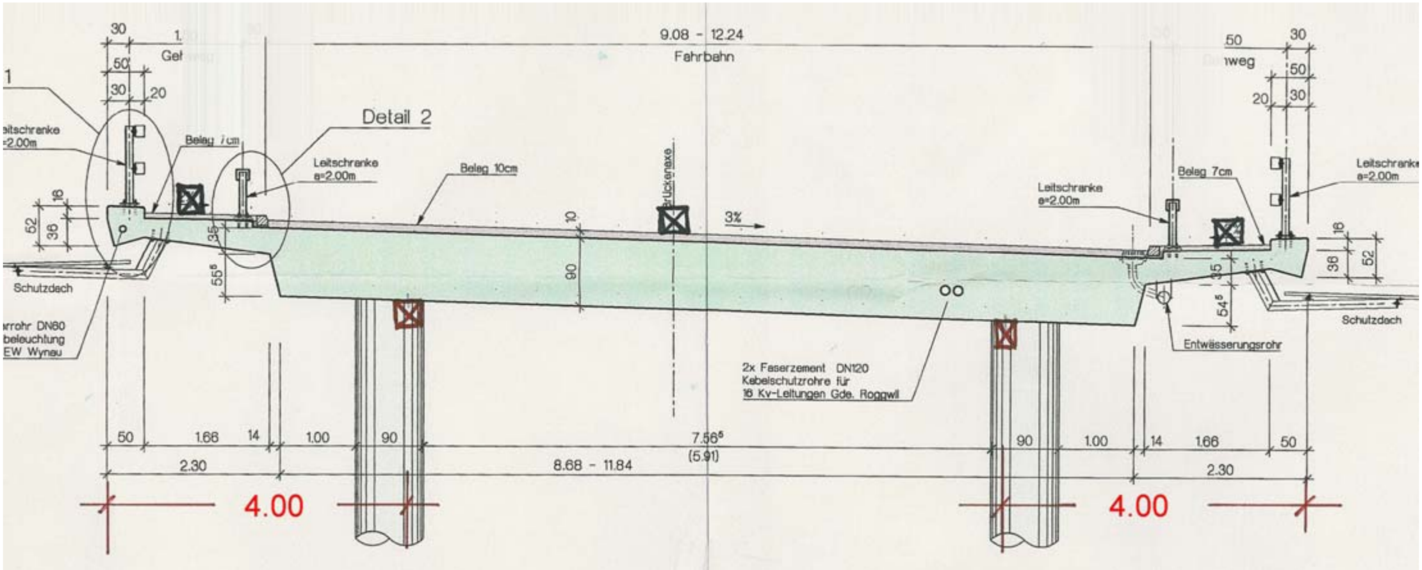

Figure 5. Bridge cross section. The lateral position of the three sensors per cross section used to determine the bridge natural dynamic properties is indicated on the bridge deck. Similarly, the position of the two sensors per cross section used to monitor the bridge vibrations during pavement compaction is indicated on the bridge slab undersight.

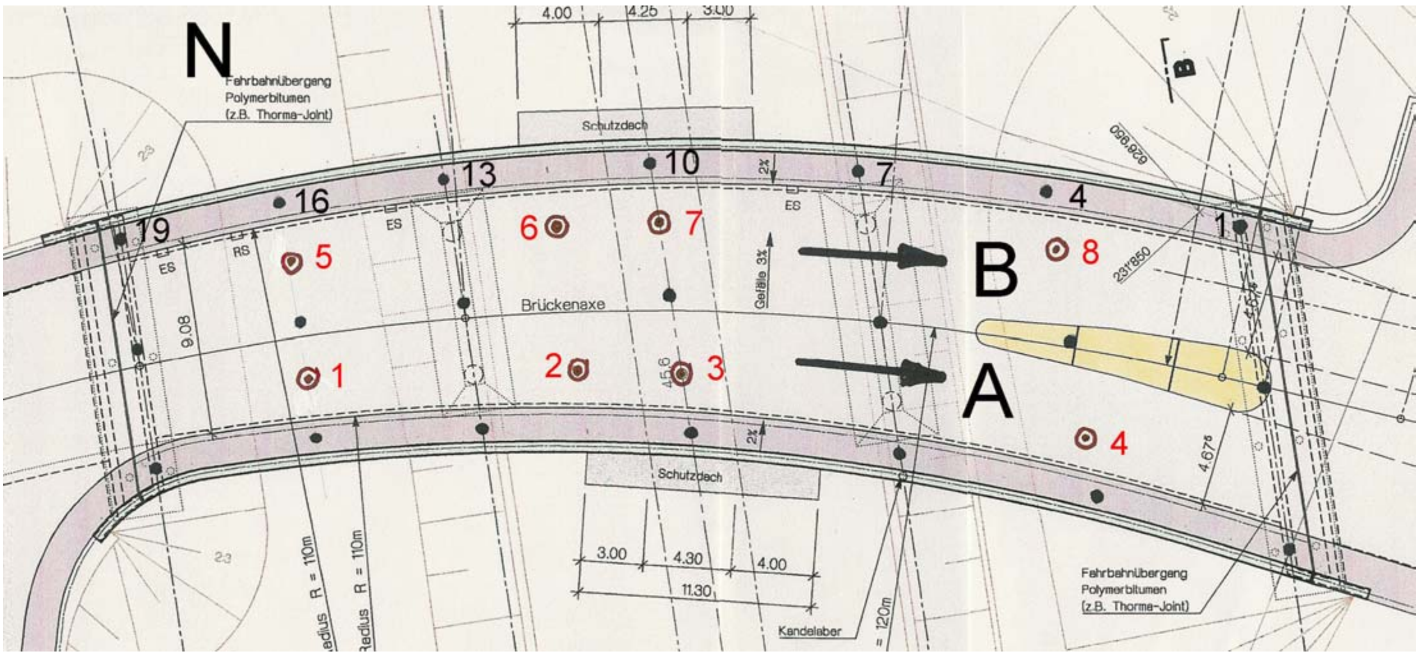

Figure 6. Bridge plan view. Indicated are the North side of the bridge (N), the lanes of the rollers (A) and (B), the 21 points of the measurement point grid used for the determination of the bridge natural dynamic properties (numbers given on one bridge curb only; No. 10 = reference point) and the measurement points used during the compaction tests (1 to 4 in lane A, 5 to 8 in lane B).

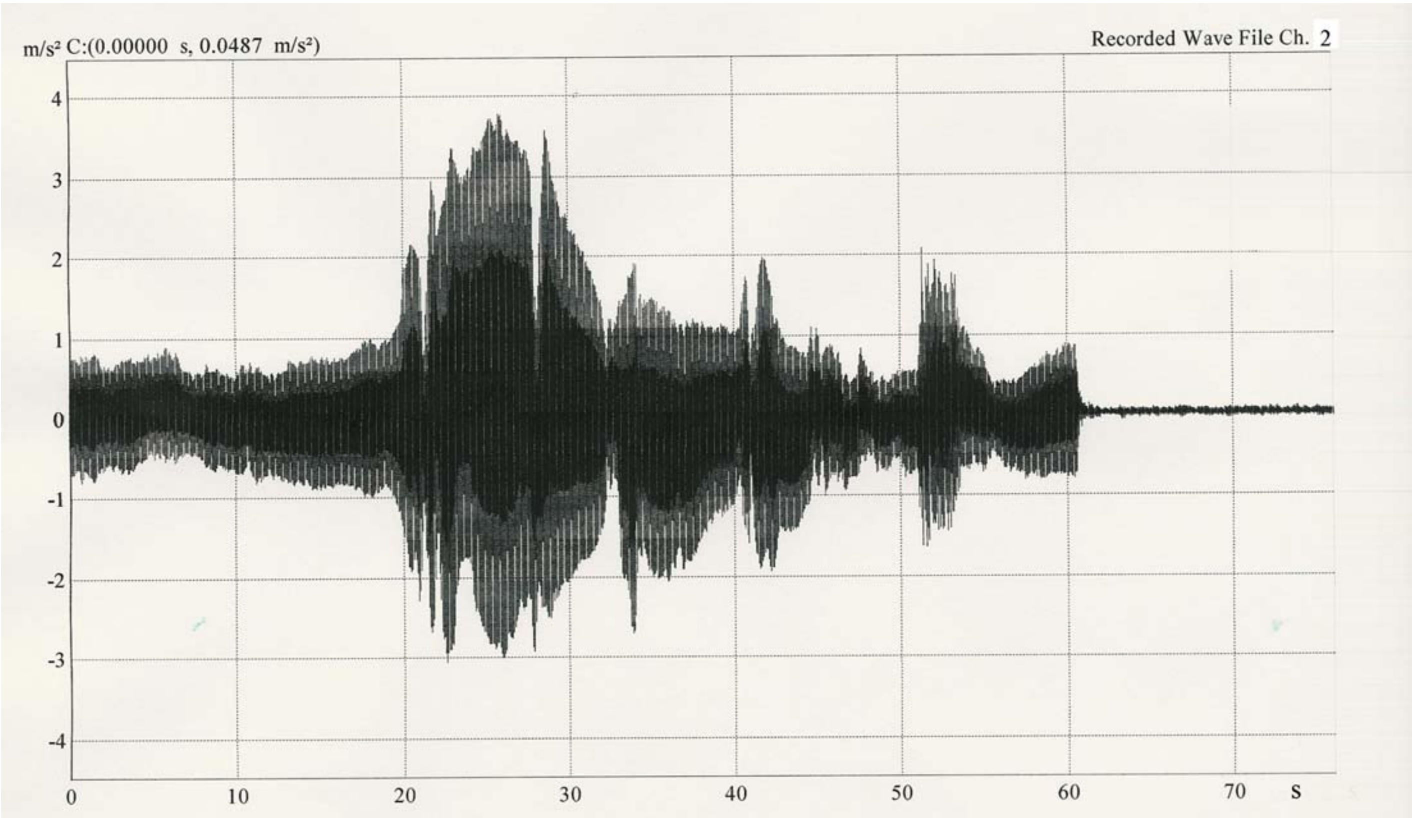

Figure 7. Acceleration time signal measured in point No.2 during compaction with roller AV95.

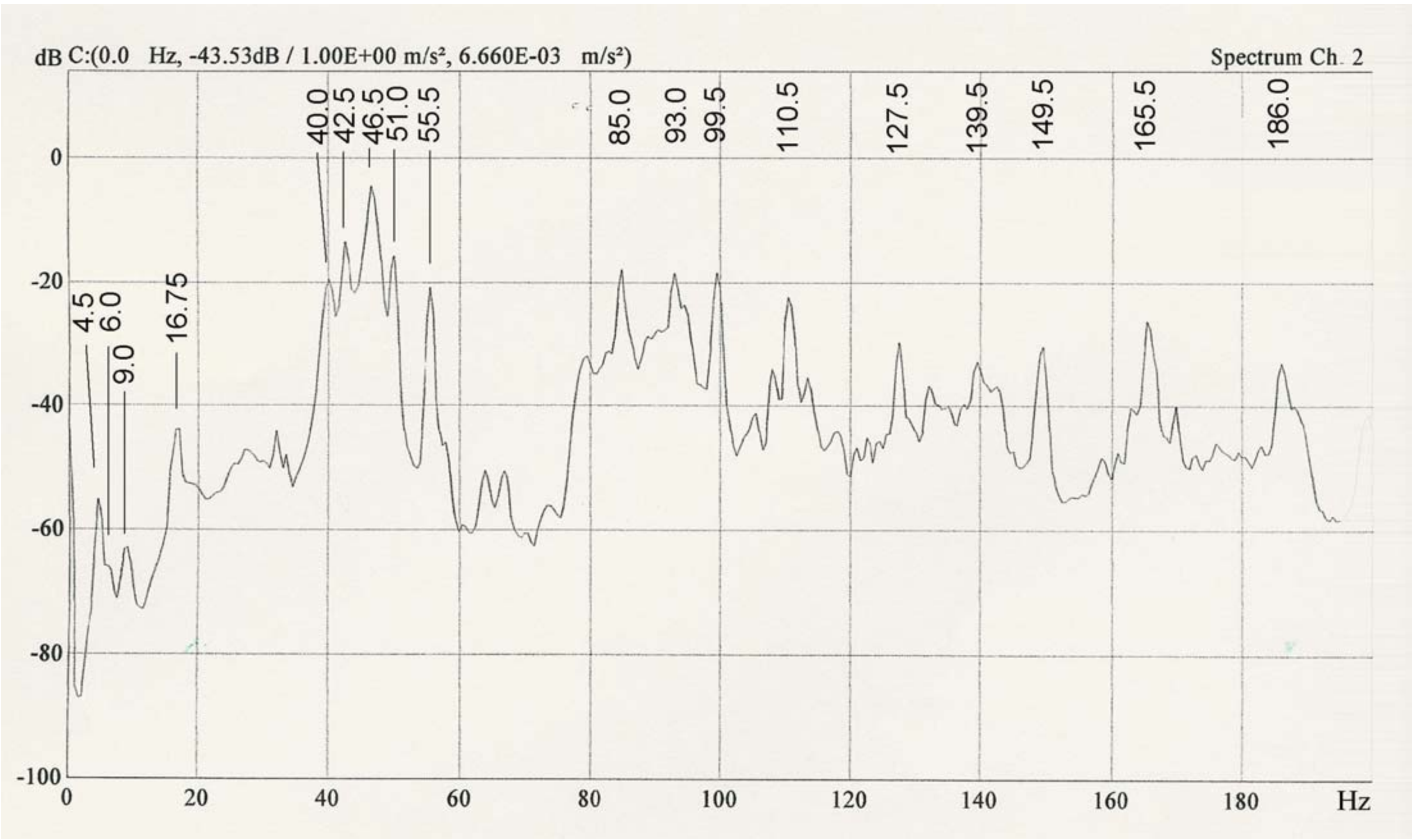

Figure 8. Frequency spectrum of the relevant part of the time signal shown in Figure 7.

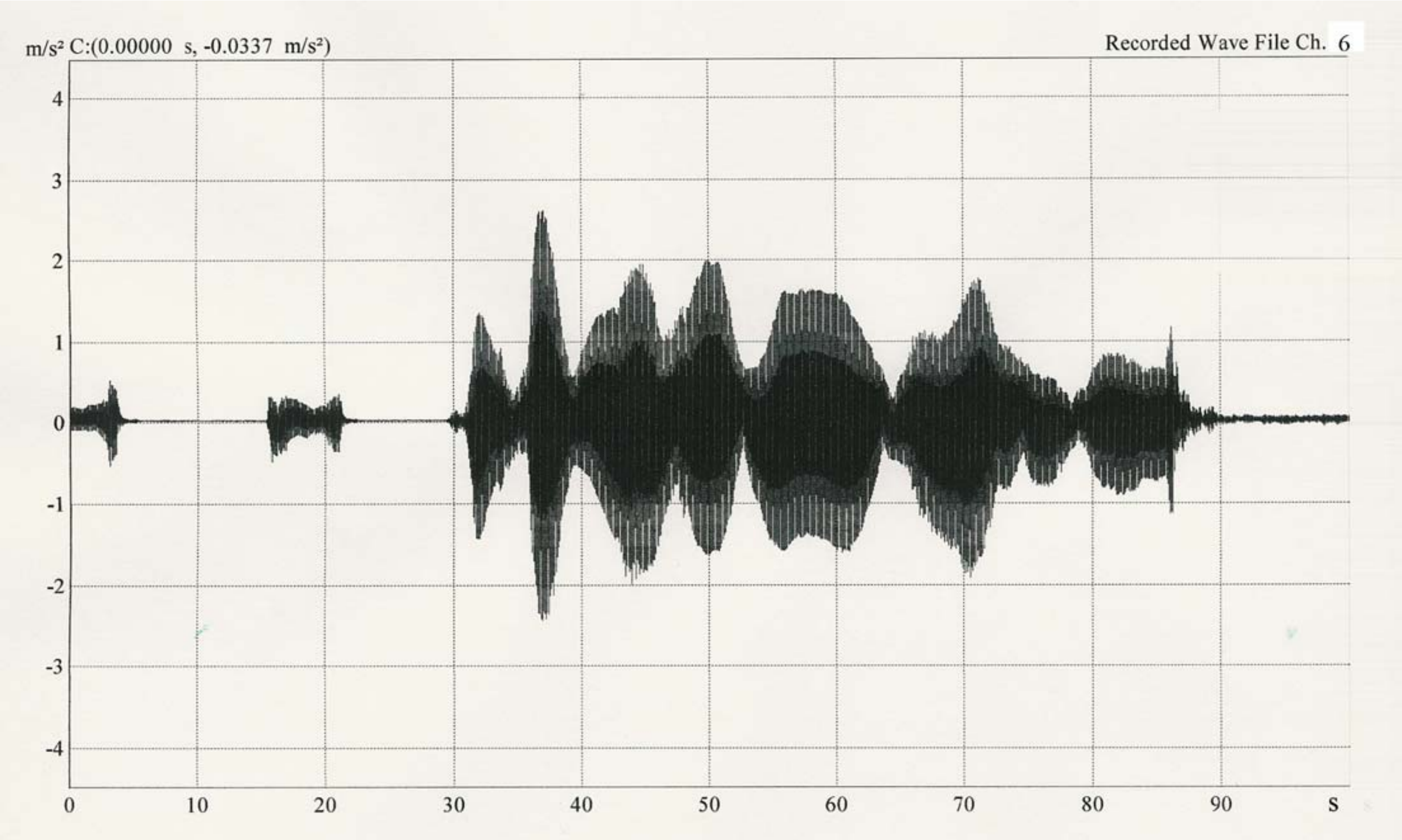

Figure 9. Acceleration time signal measured in point No. 6 during compaction with roller DY70.

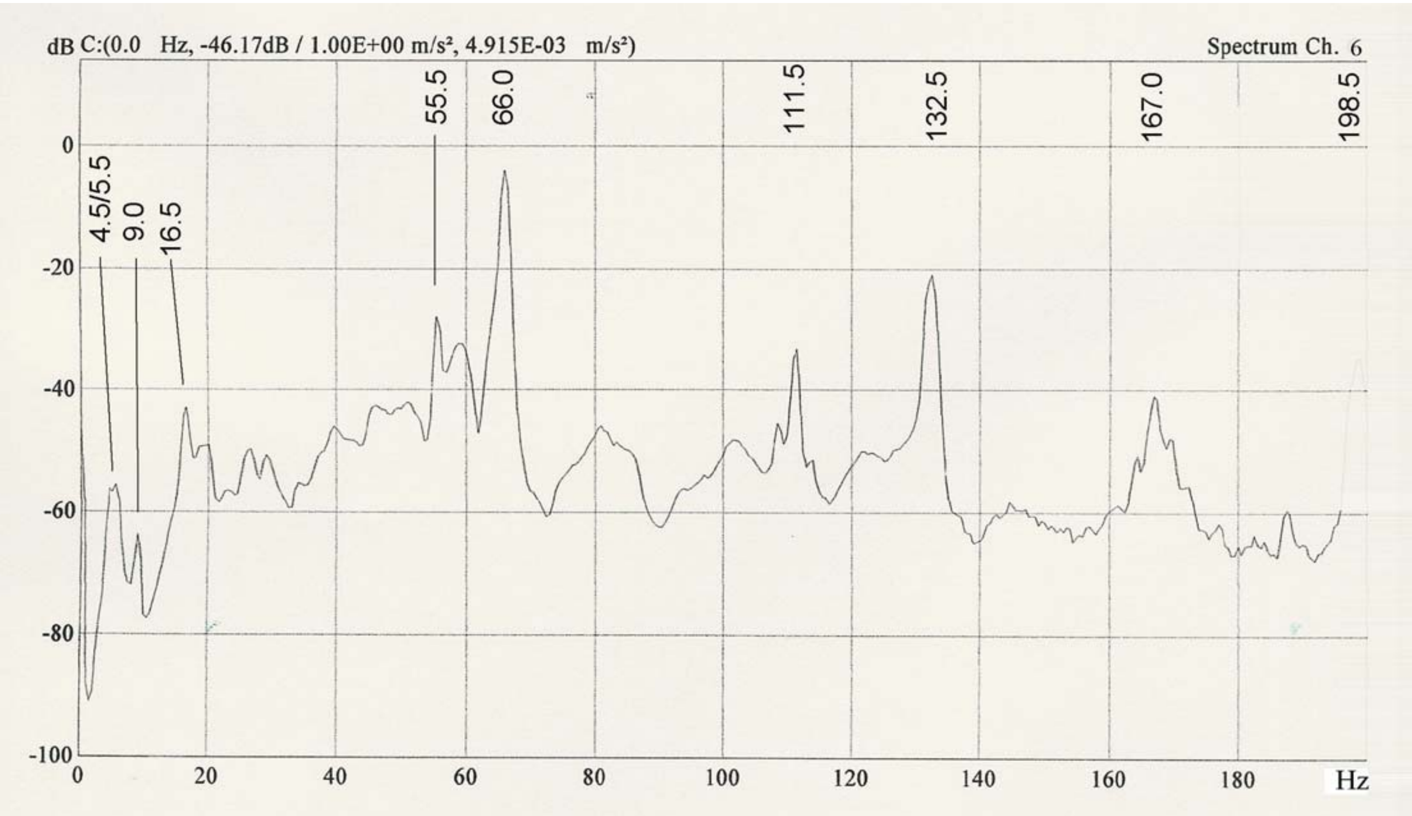

Figure 10. Frequency spectrum of the relevant part of the time signal shown in Figure 9.