International Conference on Case Histories in Geotechnical Engineering

(2004) - Fifth International Conference on Case Histories in Geotechnical Engineering

16 Apr 2004, 4:30pm - 6:30pm

Performance of a Steel Sheet-Pile Barrier against Ground Vibration Originating in Railway Traffics

Tadanori Nishimura
Kozo Keikaku Engineering Inc., Tokyo, Japan

Masahiro Shoji
Kozo Keikaku Engineering Inc., Tokyo, Japan

Kiyoshi Hayakawa
Ritsumeikan University, Shiga, Japan

Recommended Citation

Nishimura, Tadanori; Shoji, Masahiro; and Hayakawa, Kiyoshi, "Performance of a Steel Sheet-Pile Barrier against Ground Vibration Originating in Railway Traffics" (2004). *International Conference on Case Histories in Geotechnical Engineering*. 5.
https://scholarsmine.mst.edu/icchge/5icchge/session04/5

Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

Performance of a Steel Sheet-Pile Barrier against Ground Vibration Originating in Railway Traffics

Tadanori Nishimura
Kozo Keikaku Engineering Inc.
Tokyo, Japan

Masahiro Shoji
Kozo Keikaku Engineering Inc.
Tokyo, Japan

Kiyoshi Hayakawa
Ritsumeikan University,
Shiga, Japan

ABSTRACT

In order to develop an effective and practical isolation method against ground vibrations caused by running trains, the authors tried to apply sheet pile walls beside of real railway tracks. Field tests were carried out to evaluate the effectiveness of this countermeasure for reducing the ground vibrations. An estimation method for vibration reduction by sheet pile walls is presented, being based on FEM simulation analysis

1. INTRODUCTION

Because conventional railway lines often run through areas densely packed with housing, noise and ground vibration generated by a passing train, causing a considerable discomfort to the neighbors in such areas, has become one of the major environmental hazards needing urgent attention. Furthermore, the need is one of the rise for railway companies, as work has recently been in progress to expand the existing railway network, and also to operate trains at a higher speed than ever on both conventional and Shinkansen lines, so as to cope with the ever growing social demands.

A large number of studies, (for examples, Nelson, J. T. and H. J. Saurenman [1983] and Verhas, H. P.[1979] has been conducted to date on the mechanism through which noise and vibration originating in a running train propagates or is transmitted, bringing about quite a few ways to effectively solve the resulting problems. The mechanism, however, can not be said to have been fully understood, because of its complexity involving such factors as the dynamic characteristics of a running train, the rigidity with which the track is borne, as well as the response of the soil to vibration. Consequently, steps are yet to be developed further that are effective and practical enough to counter such ground vibration.

Measures that have been developed to date against ground vibration arising from a running train can be sorted out into a number of categories; (i)those which can be taken at its origin, including a) the train itself, b) the track, c) the structure supporting the track, and d) the foundation. (ii) those that can be applied to its path or propagation, and (iii) those which can be adopted at the receiving end. In this study, it was decided to address one of such measures as included in category (iv) as they appeared to provide ample room for further development from technical and economical viewpoints.

Reports (Ahmad, S. and T. M. Al-Hussaini[1991], Hayakawa, K. et. al.[1991] and Haupt, W. A.[1977], [1995]) are available from past studies on the performances of underground barriers against ground vibration built of such materials as concrete, foamed styrene and urethane in its path of propagation. Despite providing some advantages over the others, however, these barriers have their shortcomings: concrete barriers need to be built to a thickness greater than 5 m to be really effective, according to a wave penetration theory, and with those made of formed plastics, steps should be taken to keep them from floating out of the ground. It was therefore decided to address an underground barrier made of steel sheet-piles as a means of keeping ground vibration from propagating, mainly because of the ease with which it can be built in a usually narrow strip of spare land along a railway line. Reports have been published on the performance, as observed along the Japan Rail operated Tsugaru Strait line, of this type of barriers against ground vibration arising a running train. There effects, however, were not fully identified or analyzed.

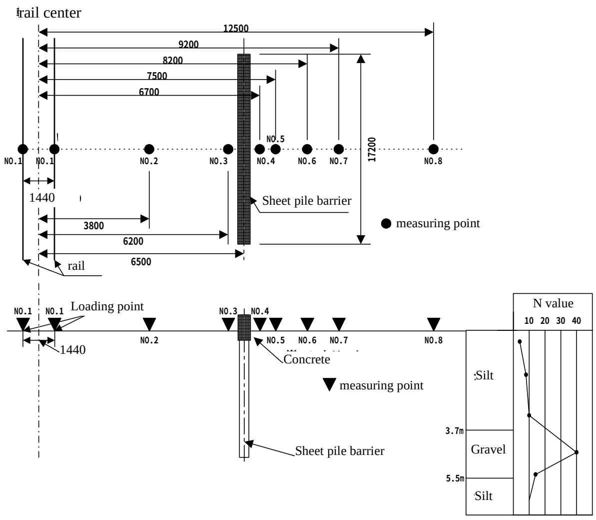
In this study, a steel sheet-pile wall was built as a barrier against ground vibration originating in a running train, and its performance was identified by using data taken of such vibration at each stage of the work to built it. A numerical simulation analysis was subsequently conducted by using a tri-dimensional model, assuming that the vibration addressed is of a forced type. The method was then verified against measured data for conformance, to see whether it is capable of predicting the performance of a similar barrier with a reasonable accuracy.

2. FIELD TESTS

(1) Test set-up

Shown in Fig.1 is the set-up for the tests, including the relative positions between the railway track, the barrier and the points at which measurement was taken of vibration, including the composition of soil there and the distribution of its N-value. The barrier was 17.2 m long and built of SPll type steel sheet-piles in direction parallel to the railway track. The piles were driven by pressure in two stages, first to a depth of 2 m, and subsequently to 4.5 m, so that data could be taken with the barrier built to a depth above, and also into the gravel stratum having a N-value greater than 30, as identified through a preliminary soil survey, and assumed to be capable of bearing the sheet piles and reflecting the ground vibration.

Vertical acceleration of ground vibration generated by passing train was measured at seven points (No.2 through to No.8) along a line normal to the track and intersecting a joint with a clearance between two rails, the nearest being at 3.8 m, and the farthest at 12.5 m, from the center of the track. As shown in Table 1, data were taken in each of the four phases of the work to built the barrier, offering different conditions.



（upper：top view　lower：cross section）

Fig.1 The set-up for the tests, including the relative positions

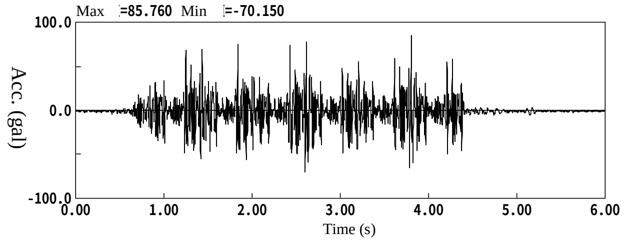
Table1 Test case

CASE	COUNTERMEASURE
STEP1	No barrier
STEP2	Steel Sheet-pile(length 2.0m)
STEP3	Steel Sheet-pile(length 4.5m)
STEP4	Steel Sheet-pile(length 4.5m) + Concrete

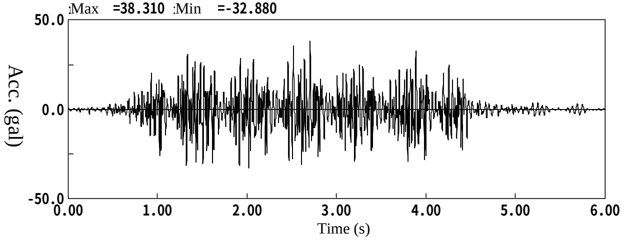
(2) Results and analysis

a) Acceleration

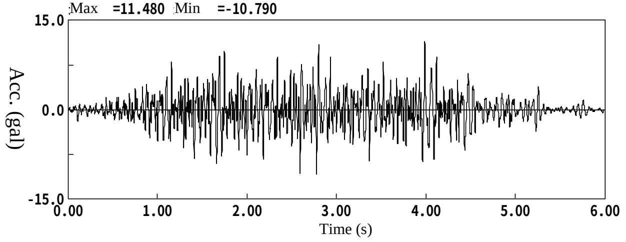
Reproduced in Fig. 2 are three typical acceleration waveforms as observed with no barrier, and recorded just by the track at Point No.5 and No.8 (7.5 m and 12.5 m distant from the center of the track) respectively. In the recorded taken by the track, predominant components are seen at relatively higher frequencies whose maximum acceleration (α max) falls between 70 to 86 gal. These can be assumed to have arisen from the dynamic interaction between the wheels of the passing train and the rails. It is seen, however, that the maximum acceleration rapidly dropped to about 33 to 38 gal and then to 11 gal as the distance increased from the 7.5 m to 12.5 m. Overall, predominance is seen of the acceleration components originating in the shocks generated as each pair of wheels passed over the rail joints with the clearance.



No Barrier (No.2)



No Barrier (No.5)

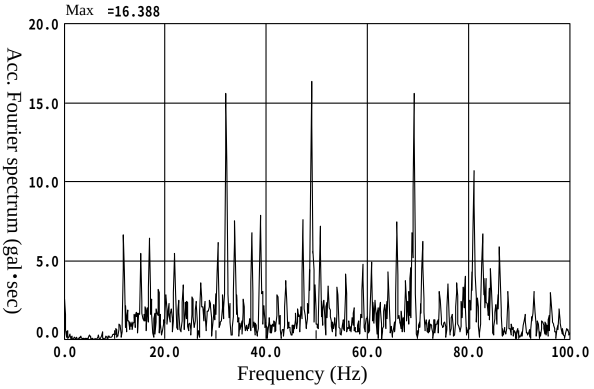


No Barrier (No.8)

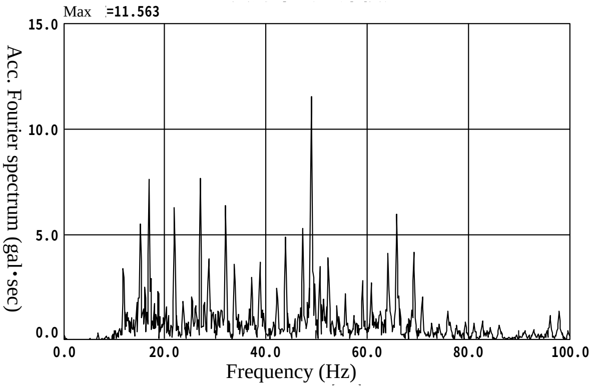
Fig. 2 Wave form of acceleration

b) Fourier spectrum

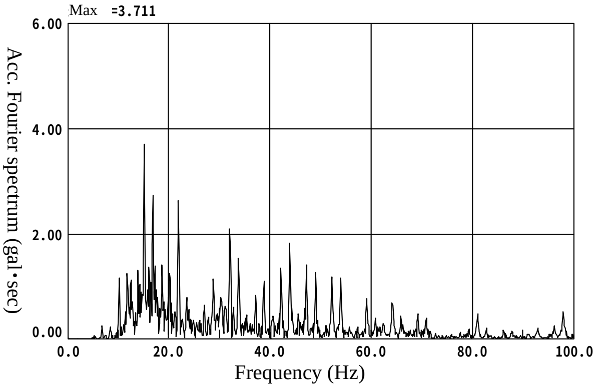
Presented in Fig. 3 (a), (b) and (c) are the Fourier spectra of the accelerations as recorded at three respective points. In (a) showing the spectrum corresponding to the record taken by the track, predominant components are observed at about 70 Hz, 50 Hz and 30 Hz. In the spectrum of the data recorded at Point 4 and 7.5 m away from the track, as shown in (b), however, predominant components are found at around 50 Hz, 25 Hz and 15 Hz, while those which were predominant at around 70 Hz in the data taken by the track are observed to have decreased in magnitude. At Point No.8, 12.5 m away from the track, predominant components are concentrated around 15 Hz, while those found at frequencies higher than 20 Hz have all rapidly decreased in magnitude. From the above, it can be seen that, as the distance increases from the track, components become more predominant at lower frequencies while those which were predominant at higher frequencies rapidly decrease in magnitude.



No Barrier (No.2)



No Barrier (No.5)



No Barrier (No.8)

Fig. 3 Fourier spectra of the accelerations

c) Effect of the barrier

Plotted in Fig. 4 are acceleration levels as recorded during each of four different phases shown in Table 1 as a train was passing by to show how they decreased with distance under four different conditions. The data shown are "all-pass values" (general values without having been filtered through a band-pass) of the averages of several records generated by as many trains passing by. Furthermore, certain correction was made on the data taken at Point No.2 during Phase ll through lV to make them coincide with those recorded at the same point during Phase l with no barrier, so as to facilitate their comparison. It is seen that, with the barrier driven to a depth of 2 m, the level was reduced by about 6 dB at a point just behind it, and with the barrier further driven to 4.5 m, by about 12 dB, as compared with that recorded at the same point with no barrier. Under the former condition, however, the level is seen to have grown again to a similar value to that resisted with no barrier, as the distance increased from the barrier, providing no effect at Point No.5 behind the barrier. It can be observed that the positive effect of the barrier as driven to 4.5 m deep was particularly noticeable just behind it, and the effect further increased, albeit slightly, as a concrete crown was built on top of it. With the data taken in front of the barrier some effect is also noted of reflection, which was reduced as the crown was built. At Point No.8, 12.5 m away from the barrier, all the data are seen to converge to the level as recorded with no barrier. These phenomena are as corroborated through a series of experiments conducted on a model by Yoshioka et al[2000].

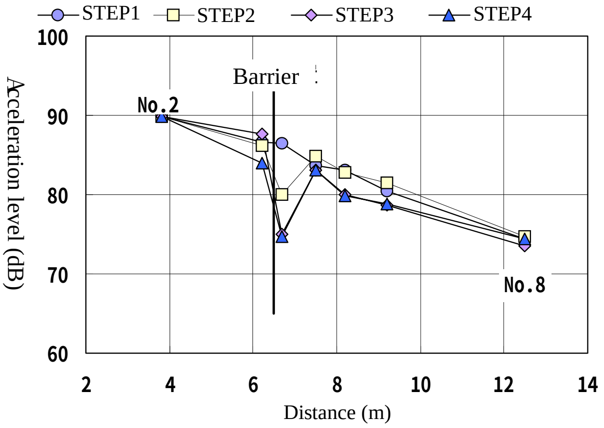


Fig.4 Acceleration levels as recorded

3. NUMERICAL SIMULATION ANALYSIS

A numerical simulation analysis was conducted by using the data presented above to see whether it was capable of predicting the performance of the barrier as herein addressed in reducing ground vibration.

(1) The method

On conducting analysis, due account was taken of; (i) the response of the barrier when subjected to a vibration, consistent with its width made up with a number of steel sheet-piles, (ii) combined effect of the predominant vibration resulting from the shock load at the joint with a clearance between rails and secondary one induced by the varying force along the rails and (iii) tri-dimensional characteristics of the ground vibration exhibits as it propagates through the soil.

A tri-dimensional model comprising the soil and barrier is proposed to calculate their response to a forced vibration imparted to the track. The soil was divided into a number of strata commensurate with an thin-layer element method, and a tri-dimensional finite element method was applied to the barrier to work out its model.

The continuity of the force in soil and barrier, their displacements, and the response of the former to the forced vibration, were assessed based on a dynamic substructure method, and in accordance with the solution with respect to the acceleration imparted onto the rail joint as worked out by applying a thin-layer element method. The analysis was of a liner type using a complex response method.

During the actual analysis, vertical acceleration was calculated at each measuring point by assuming that the track was subjected to a forced vibration in vertical direction. The force inducing vibration to the track, on the other hand, was calculated in reference to the acceleration wave-form as observed at Point No.2, by assuming that it was equal to the sum between the force acting at the joint ant that on the tracks, both including vibration at the source (Point 1).

As already mentioned in Section 2 (2), the force acting on the joint is the major cause generating the ground vibration, while that acting on the rails exerts a relatively minor effect. It was then assumed that the two are acting on the track in a synchronous manner, though continuously varying in amplitude at a ratio 1:10. It was further assumed that the latter is acting on the track over a total length of 20 m, 10 m in each direction from the joint. Fig. 5 is a schematic diagram illustrating the method to calculate the combined force including the vibration by using the data as measured on acceleration, and Fig. 6 is the Fourier spectrum of the acceleration as observed at Point No.2, and used for the calculation

$$M(\omega)=A(\omega)/R1(\omega) \qquad (1)$$

$R1(\omega)$:Frequency transmitting function

(Response ratio of the assumes point of input vibration with respect to the unit motive force at the assumed point) (Data taken at Point No.2 with the barrier driven to 4.5 m depth and a concrete crown added on its top. These are the data used to calculate the vibration including force.)

(2) The model

The velocity (Vs) at which the S-wave propagates through the soil was calculated by substituting an appropriate N-value as identified through a soil survey into following formula:

$$V_s = 80N^{1/3} \quad \text{(for sandy soils)}$$
$$V_s = 100N^{1/3} \quad \text{(for clayey soils)} \qquad (2)$$

The velocity of the P wave assumed to be 1500 m/s in every case because underground water was present close to the ground surface.

Given in Table 2 are the elements of the model used, and their particulars. The soil was finely divided into eight layers, every one of them thinner than 1/6 of the wave length consistent with velocity Vs at which a S wave propagates through it at frequencies up to 100 Hz. In conformance with the tri-dimensional FEM; the model of the barrier was worked out into shell elements composing a plate having an isotropic stiffness against bending towards its outer surface. The subsequent analysis was conducted with a Super FLUSH/3D program.

Table 2 Soile ploperty

Layer	Soil	Unit Weight (kN/m3)	S-Wave speed (m/sec)	Damping ratio (%)	Thickness (m)
1	Silt	16.66	170.0	5.00	0.60
2	Gravel	16.66	170.0	5.00	0.80
3	Silt	16.66	170.0	5.00	0.40
4	Silt	16.66	180.0	5.00	1.40
5	Silt	16.66	220.0	5.00	0.50
6	Gravel	16.66	270.0	5.00	1.80
7	Silt	16.66	150.0	5.00	1.00
8	Silt	16.66	180.0	5.00	1.50
Base		16.66	300.0	5.00	

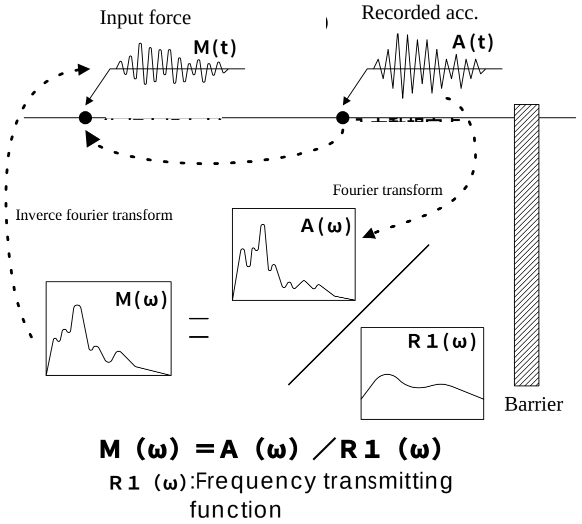
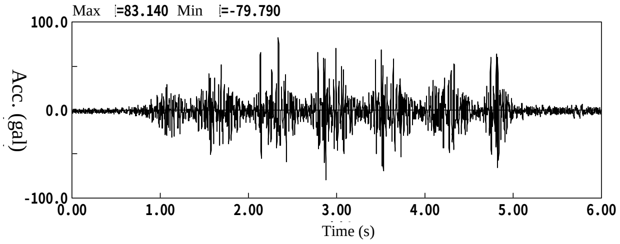
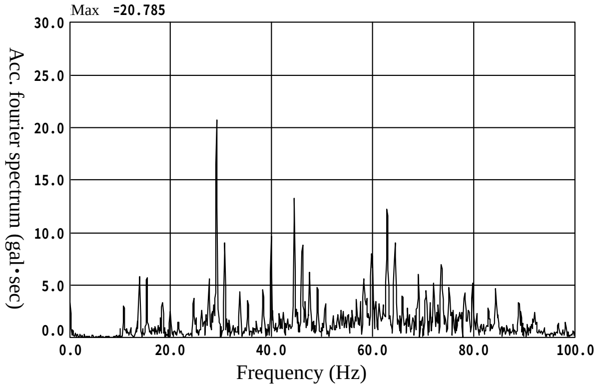


Fig.5 A schematic diagram illustrating the method to calculate the combined force



Wave form of acceleration



Fourier spectrum

Fig .6 The Fourier spectrum of the acceleration as observed at Point No.2
(Test case:STEP4)

(3) Result and Consideration

Fig. 7 shows the reduction in acceleration level with distance from the track as calculated. Data are also shown as measured for comparison. Fig. 8 presents the distribution over the addressed range of frequency of acceleration level as recorded in front and behind the barrier. Presented in Fig. 9, is the distribution over a range of frequency of the level of acceleration transmitted from Point No.2 to Point No.5, the left side diagram showing the data as measured, while the sight side on, those as calculated in terms of all-pass values. To facilitate comparison, the calculated levels corresponding to Point No.2 were corrected so that they should coincide with those as measured at the same point. The acceleration levels as calculated whose distribution is shown were duly processed over an 1/3 octave band.

a) Reduction on acceleration level with distance

With no barrier, the result from the analysis are seen to generally agree well with the measured data, though discrepancy tends to grow to a maximum of about 3 dB as the distance increases from the track. With the barrier in place acceleration level at Point No.4, just behind it, is seen to have been substantially lower than with no barrier. Some effect can be identified of the barrier in the results as calculated as well as those as measured, although the effect with former is seen to be slightly smaller than that by the latter. An increase is seen in the level as calculated at Point No.5, which is particularly noticeable with the barrier driven to 4.5 m deep, and in very good agreement with the measured data. Similar tendencies are observed of the data as calculated as well as those as measured under different conditions. In addition, at every point behind the barrier, the data calculated under any of the conditions are seen to be in excellent agreement with those as measured.

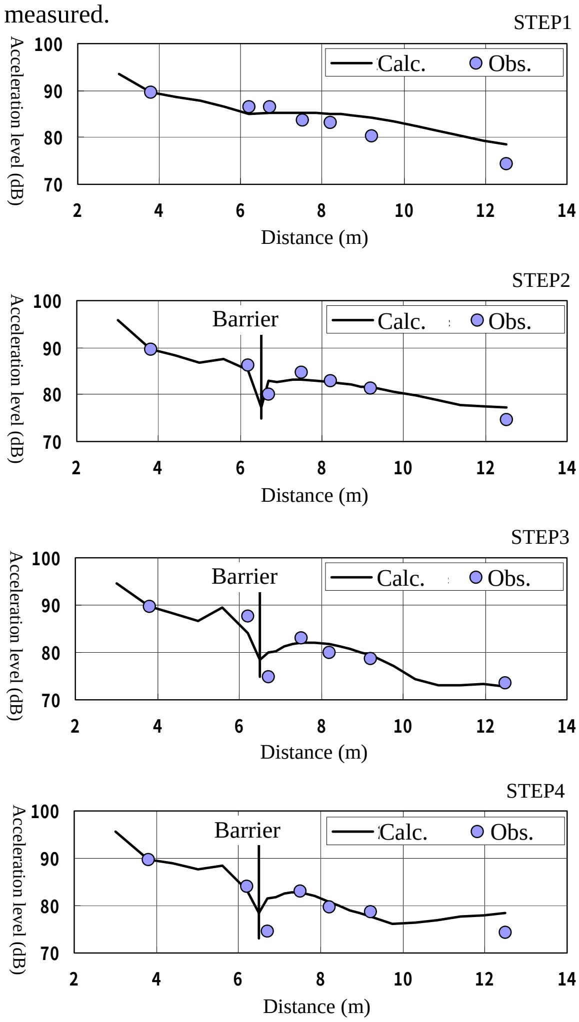
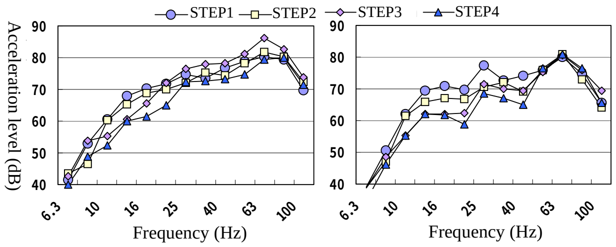


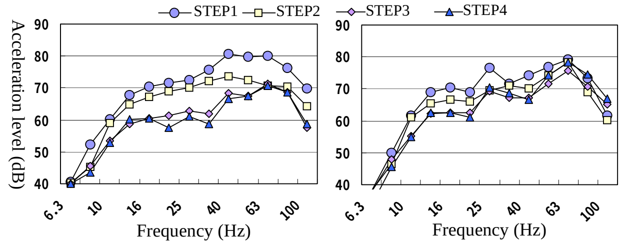
Fig. 7 reduction in acceleration level with distance

b) Distribution of acceleration level

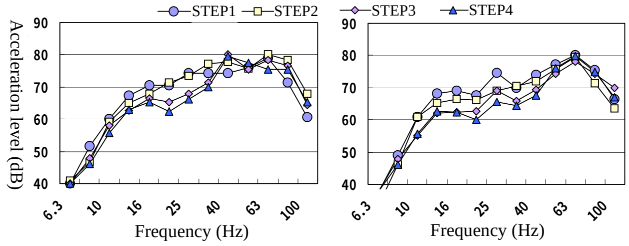
In every case shown in Fig. 8, prominent peaks are observed of acceleration level at frequencies between 40 and 63 Hz, as identified with the measured data. In addition, a relatively good agreement is generally seen between the calculated and measured data. The reduction by about 10 dB in level as measured at Point No.4 with the barrier 4.5 m depth, and observed over a range of frequency between 10 and 63 Hz, is represented by the corresponding reduction as calculated over a range of frequency between 10 and 40 Hz, which is about 8 dB, slightly smaller than the former. Overall, the result from the analysis seem to reproduce well, in a qualitative manner, the effect of the barrier at its various stages, although in general the calculated values are slightly smaller than measured ones. A particularly good agreement can be noted between the acceleration level as calculated and those as measured at Point No.5 at which a noticeable increase is observed in that level. The rather abnormal increase in level as noticed in the measured results at around 40 Hz is not as noticeable in the calculated data. The increase can therefore be taken for a local anomaly. The effect of the barrier to reduce vibration at its various stages can be summed up as follows: As driven to 2.0 m depth, it provides little effect, the reduction in level being very small from that as observed with no barrier; When further driven to 4.5 m depth, a substantial reduction in level is achieved at frequencies greater than 10 Hz, as can be corroborated with the measured data which are in good agreement with those as calculated.



measuring point No.3



measuring point No.4



measuring point No.5

Fig. 8 Acceleration level at frequencies
（Left：Obs. Right：Calc.）

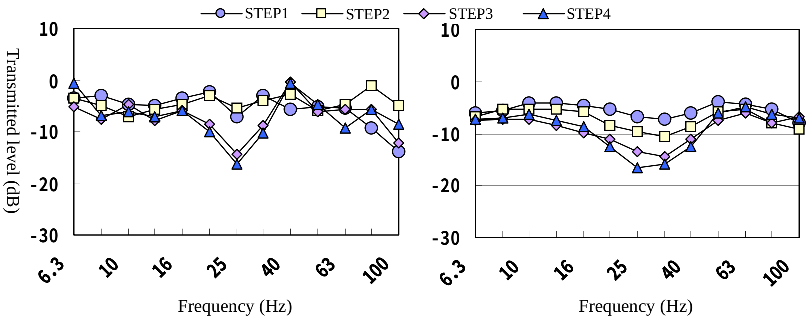


Fig. 9 Transmitted level of acceleration
（Left：Obs. Right：Calc.）

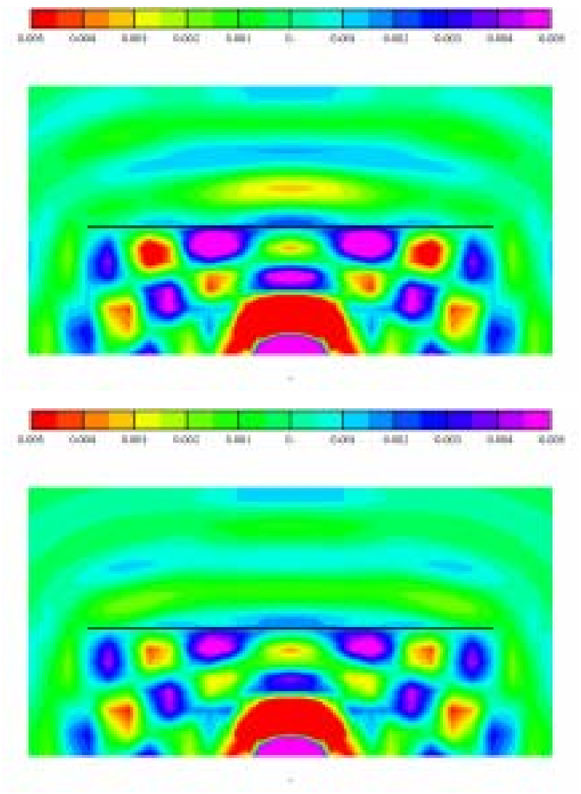


Fig. 10 Distribution of vertical acceleration
Upper:The result as worked out by taking into account the bending
Lower:The result with no such bending taken into account

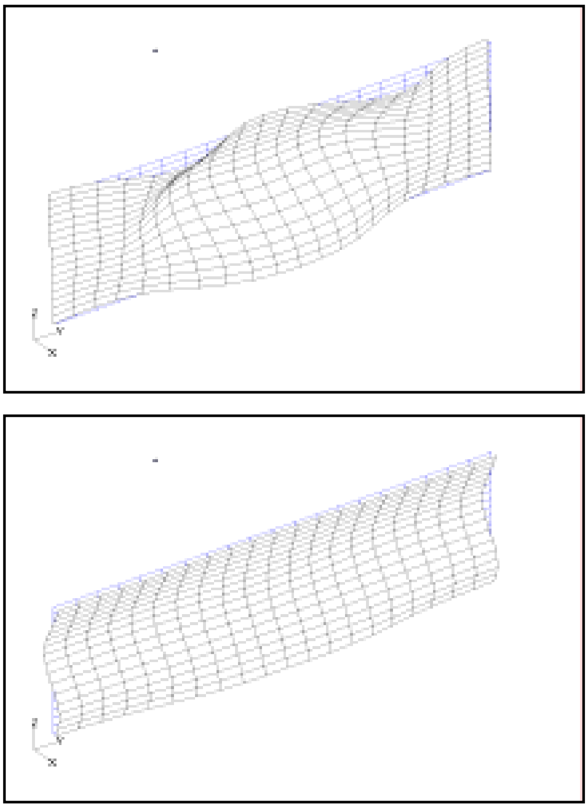
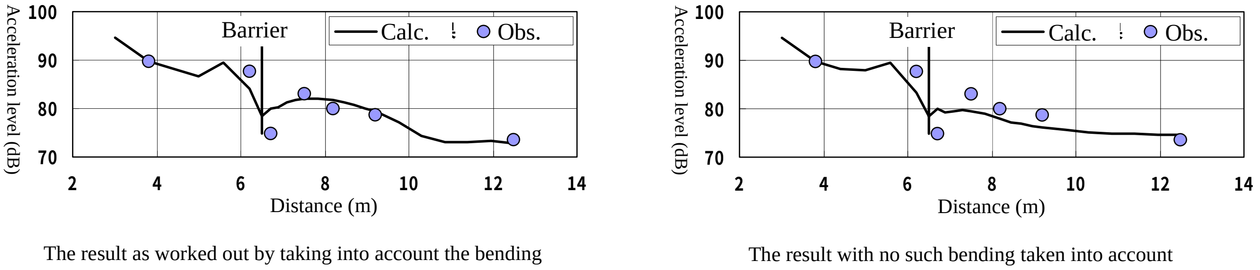


Fig. 11 Different modes in which the barrier
Upper:The result as worked out by taking into account the bending
Lower:The result with no such bending taken into account



The result as worked out by taking into account the bending

The result with no such bending taken into account

Fig. 12 The reduction in acceleration level with distance

c) Transmitted level of acceleration

The simulation is not fully capable of accurately reproducing the rapid increase in the level of acceleration as observed in the data measured at Point No.5 over the range of frequency between 40 Hz and 63 Hz with the barrier driven to a depth of 4.5 m. Overall, however, the result from the simulation appears to be in fairly good agreement with the measured data, despite slight local deviations as can be observed with the data of reduction in vibration at Point No.4, just behind barrier, and their distribution over a frequency range. It can therefore be conducted that the simulation method presented is capable of qualitatively, if not quantitatively, reproducing the performance of such a barrier as herein addressed in reducing ground vibration.

d) Effect of possible bending of the barrier

Shown in the two diagrams in Fig. 10 is the distribution of vertical acceleration as worked out by using the simulation method with a sine wave having a frequency of 60 Hz imparted as input for a period of 8 seconds, and assuming that the barrier was 4.5 m depth. The upper diagram presents a result as worked out by taking into account the bending the barrier may suffer when subject to vibration, while the lower one is the result with no such bending taken into account. In the former the acceleration is seen to have been amplified to some extent while propagating to a point just behind barrier. In the latter, however, no such phenomenon is observed.

Shown in Fig.11 are two different modes in which the barrier is assumed to bend, and in Fig. 12, the reduction in acceleration level with distance, as worked out for each mode. The data shown indicate that the increase in acceleration just behind the barrier can be simulated more accurately by taking into account the possible bending the barrier may suffer than otherwise. They further suggest that some additional steps may be needed to limit the deformation the barrier may suffer in longitudinal direction to further improve the performance of this type of vibration barrier.

4. CONCLUSIONS

In this study, field tests were carried out on a barrier built of steel sheet-piles to identify its performance in reducing ground vibration arising from a running train. A simulation analysis was subsequently conducted by using a tri-dimensional model to quantitatively establish the mechanism through which the barrier was capable of reducing such vibration. From the results of conclusions were drawn as follows:

(1) The maximum acceleration as observed of ground vibration was from 70 to 86 gal by the track, 33 to 38 gal and about 11 gal at point 7.5 m and 12.5 m away from the latter, respectively.

(2) Prominent peaks were observed at around 70 Hz, 50 Hz and 30 Hz in acceleration as recorded by the track, and at about 50 Hz, 25 Hz and 15 Hz in that observed at a point 7.5 m away from it. Around a point 12.5 m distant, father way from the track than the former, the peaks observed at around 15 Hz remained still prominent while those that were prominent at higher frequencies than 20 Hz all tended to disappear.

(3) At point just behind the barrier driven to 2 m and 4.5 m, vibration level was reduced by about 6 dB and 12 dB, respectively from that recorded at the same point with no barrier. The effect was particularly noticeable of the barrier as driven to 4.5 m depth, which was found to increase further, albeit slightly, as a concrete crown was added on top of it.

(4) With the results from the simulation analysis, peaks were found in acceleration over a range of frequency between 40 Hz and 63 Hz as was the case with the data as measured. Remarkable effect was identified of the barrier against vibration over a range of frequency from 10 to 31.5 Hz, although acceleration was found to be amplified to some extent at a frequency around 40 Hz.

(5) The effect of the barrier to amplify the level of acceleration behind it was clearly verified through an analysis incorporating the effect of bending the barrier may have suffered. This suggests that steps may need to be taken to keep the barrier from bending in longitudinal direction to further improve its performance against vibration.

The analytical method used in this study was found to be capable of qualitatively reproducing the performance against vibration of a barrier built with steel sheet-piles. Quantitatively, however, the method still leaves much to be desired. Further study is being planned to improve the method by working out a new model to accurately represent both the soil and the barrier.

REFERENCES

Ahmad. S. and T. M. AL-Hussaini[1991],"Simplified Design for Vibration Screening by Open and In-filled Trenches", Journal of the Geotechnical Engineering Division, ASCE, Vol. 117, No.1, pp.67-88.

Hayakawa, K., M. Sawatake, H. Murata, R. Goto and T. Matsui[1991], "EPS Mat Protection Against Ground Vibration Caused by Trains", International Symposium of Active Control of Sound and Vibration, Tokyo, pp.403-408.

Haupt, W. A[1977],"Isolation of Vibration by Concrete Core Walls", Proceedings of 9th International Conference on Soil Mechanics and Foundation Engineering, Volume 2, Tokyo, pp.251-256.

Haupt, W. A[1995],"Wave Propagation in the Ground and Isolation Measures", Proceedings of Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Volume 2, St. Louis, Missouri, pp.985-1016.

Nelson, J. T. and H. J. Saurenman[1983],"State-of -the Art Review, Prediction and Control of Ground-borne Noise and Vibration from Rail Transit Trains", UMTAMA, 83-3, pp.5.1-5.53.

Verhas H. P.[1979],"Prediction of the Train-induced Ground Vibration", Journal of Sound and Vibration, 66(3), pp.371-376. pp.985-1016.

Yoshioka,O.[2000], "Basic characteristics of Shinkansen-induced ground vibration and its reduction measures", Proceedings of the International Workshop WAVE 2000, pp.219-237