inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 7.6

PREDICTION OF THE AUDIBLE EFFECTS IN A BROADCASTING STUDIO, CAUSED BY A NEWLY PLANNED METRO LINE - PART I: ESTIMATION OF DESIGN VIBRATION SPECTRA ON THE STUDIO WALLS AND FLOORS

P. Forián Szabó*, É. Arató-Borsi, F. Augusztinovicz*****

* Consulting Engineer, Lánchíd u. 23., H - 1013, Budapest, Hungary

** Hungarian Radio, Bródy S. u. 5/7, H - 1088, Budapest, Hungary

*** Technical University of Budapest, Dep. of Telecommunications, Stoczek u.2., H - 1111, Budapest, Hungary

Tel.: 36-1-202-4517 / Fax: 36-1-202-4517 / Email: fszp@mail.datanet.hu

Keywords:
INDOOR NOISE PREDICTION, BUILDING NOISE CONTROL, RADIATED UNDERGROUND NOISE, NOISE AND VIBRATION FROM UNDERGROUND OPERATION

ABSTRACT
A new metro line is being planned near to the Hungarian Radio in Budapest. The task was to predict, whether or not audible disturbances in consequence of the train passby are to be expected, and if this is the case, what kind of control measures are necessary. Two types of prediction models were elaborated and verified. Each model development consists of essentially two major steps: (1) Development of a vibration prediction model, on the basis of measurements on existing situations adaptation of the calculation method for sound level prediction from vibration data and verification of the calculations; (2) Transferring the measured and validated results from the existing situation to the planned one. This lecture deals with step (1), and Part 2 of this contribution deals with step (2) as well as with the conclusions of the whole investigation.

1 - PROBLEM EXPOSITION
Studio 6 is one of the oldest studios of the Hungarian Radio. It was designed by Gy. Békésy and inaugurated in 1935. It is still the rehearsal room for the Symphony Orchestra of the Hungarian Radio and frequently used studio for high quality sound recordings.
A new (underground) metro line is currently being planned crossing the Danube River and the city centre of Budapest. The proposed tunnel path was planned close to the Radio buildings. The horizontal distance from the nearest cross-section of the tunnel to the centre point of Studio 6. was not more than 54 m. The depth of the tunnel centre from the ground surface was about 21,5 m at this cross section. The soil structure around the tunnel is saturated grain deposit with sand or silt inclusions.
Our task was to predict, whether or not audible disturbances in consequence of the train passby in the tunnel are to be expected, and if this is the case, what kind of control measures are necessary and feasible (e.g. determination of minimum separation distance in the ground between the new tunnel and the radio studios, vibration isolation in, and construction of, the tunnel etc.).
In broadcasting studios the maximum permitted airborne noise levels are very low. Examining the current background noise of Studio 6. it can be seen that the measured background noise is hardly under the acceptable noise level. Therefore, it was very important to find a correct solution, which has no further disturbing effect.

2 - COMPARATIVE SOUND AND VIBRATION MEASUREMENTS ON SOME EXISTING BUILDINGS NEAR TO A SIMILAR OPERATING METRO LINE
There is a similar metro line (M3) in operation not far from the site of our investigation. The soil conditions are practically the same for both tunnels. Our first step was to find some existing buildings

near to this existing M3-tunnel, and to make comparative sound and vibration measurements. The aim of these measurements was the following:

- to survey the disturbing indoor noise effects in other buildings with similar conditions,
- to collect input noise and vibration data from train passby,
- to prove and validate the calculation models under existing circumstances.

On Fig. 1 one can see that the radiated indoor noise was considerably higher in these buildings than the maximum allowed noise spectrum in radio studios.
A cellar room in a five-storeyed reference building was chosen near to line M3 for model validation. The spatial distance between this room and the closer M3-tunnel centre was about 27,1 m. The following quantities has been measured in this cellar room:

- horizontal and vertical vibration spectra of the wall-, floor-, and ceiling elements due to train passby,
- natural frequencies of these structural elements
- the radiated indoor noise in the cellar room due to train passby, and the background noise as well
- vertical eigenfrequency of the whole building embedded in the soil structure.

Furthermore, vertical vibration spectra on another neighbouring building's wall and in the M3 tunnel were also measured.

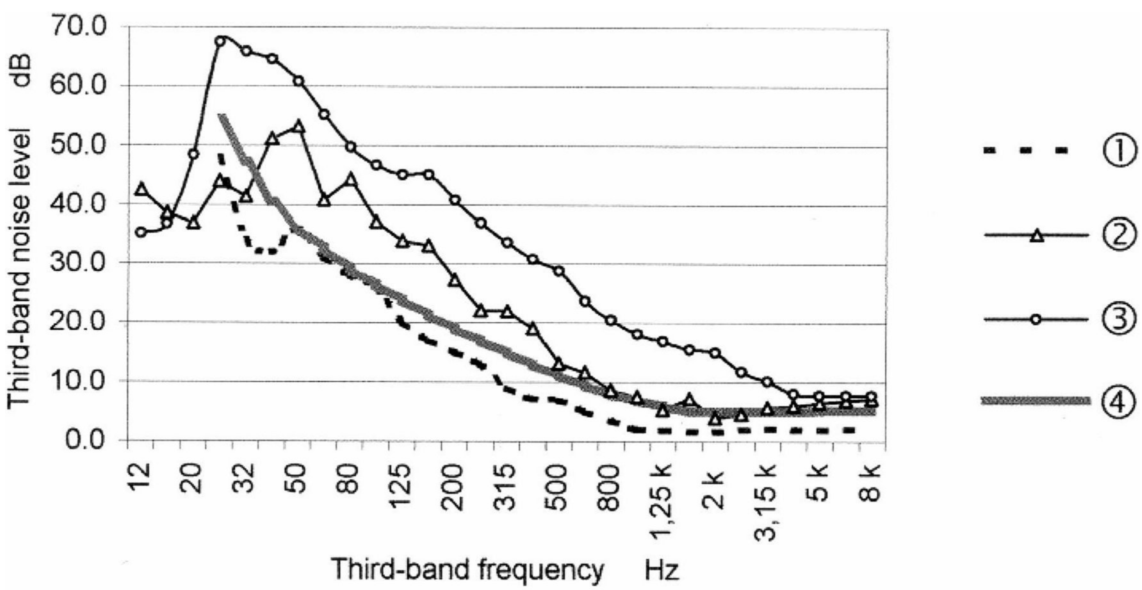

Figure 1: Measured indoor noise in some buildings near to the planning area; (1) background noise in Studio 6, (2) reference building's cellar near to the M3-line, (3) cellar in St. Stephen's Cathedral near to the M3-line, (4) limit spectrum in radio studios.

3 - METHODS FOR PREDICTION OF INTERIOR NOISE LEVELS

Two types of prediction methods were applied. For the frequency range where numerical calculations are feasible a combined structural FE / acoustical BE method was applied. At frequencies where the numerical approach is no longer appropriate, a statistical method based on modal average and estimated radiation efficiency was used.

3.1 - Coupled FEM/BEM calculations

The room has been treated as a closed box-form structure, consisting of shell elements of different thickness and material characteristics. First the structural modes of the box were derived and a linear response analysis has been carried out, while it was assumed that the structure is excited by uniformly distributed unit load-excitation, acting on the bottom surface only, in unique direction. The displacements of the walls were calculated and a linked FEM/BEM calculation was carried out, resulting in calculated sound pressures for an arbitrary number of field points in the room as a function of excitation frequency. Eventually, the obtained results are linearly scaled to obtain the measured wall displacements or velocities.

3.2 - Statistical noise radiation approach

The statistical method is based on the assumption that the walls vibrate as baffled finite panels. The average velocity of the wall is derived from the procedure as given below, the frequency-average radiation efficiency can be calculated from theoretical considerations [1], [2]. The total sound pressure in the room is obtained from energy summation of the radiation of each vibrating wall, summed for third-octave bands.

For both estimation methods, one of the most important tasks is to predict the design velocity spectra of the surface-elements properly. To do this, all wall, floor and ceiling elements of the room can be treated as independent, generalised vibration systems with little degree of freedom [3]. The design velocity third octave band spectra were estimated on the point of each structural element, on which the maximal vibrating amplitude is expected.

These procedures are followed by the validation of the model. In the cellar of the five-storeyed reference building near to the M3-line, all of the previously mentioned FEM/BEM and statistical calculations have been made using pink-noise unit dynamic load. The real dynamic load spectrum generated by train passby and acting on the cellar surface through the soil is unknown, and probably differs from the pink-noise shape. Nevertheless, from the unity, pink-noise shaped dynamic load FEM response and from operational acceleration-measurements one can calculate a "weighting function" for each discrete frequency step. Using these weighting functions, the above mentioned pink-noise shape excitation can be validated, and with this validated excitation one can calculate a "validated response" of the structure. A comparison of the measured and the validated response in the five-storeyed reference building's cellar in the middle of the ceiling is shown in Fig. 2. The measured and the calculated response spectra show rather good coincidence.

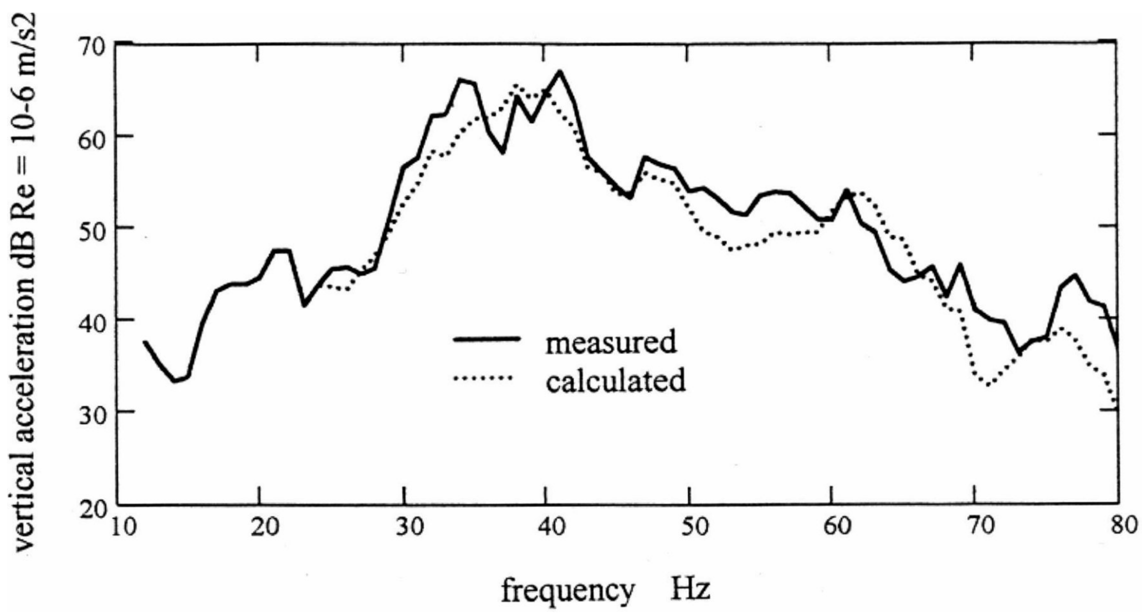

Figure 2: Measured and calculated vertical acceleration spectra caused by a typical train passby on the ceiling of a five-storeyed reference building's cellar.

4 - PREDICTION OF THE REFERENCE VIBRATION SPECTRA FOR FURTHER INVESTIGATIONS

Vertical vibration spectra due to train passby were measured on the basement walls of two buildings near to the existing M3-line. Assuming generalised linear SDOF systems, the influences of the spectral magnification of these SDOF systems were subtracted from the measured vibration spectra. Two influences were subtracted in this way: the first horizontal modal shape of the basement wall, and the first

vertical mode shape of the whole building embedded in the soil structure [4]. The eigenfrequencies and damping coefficients of these SDOF systems were identified using artificial impulse excitation near to the two buildings.
The acceleration spectra measured on the two buildings' walls were transformed to a common reference distance $d_0 = 27{,}0$ m, by using the vibration attenuation law in soil structure [5], [6]:

$$C = K \cdot \log \frac{d}{d_0} - 8,7 \cdot \frac{\pi \cdot f \cdot \eta}{c} \cdot (d - d_0)$$

where

- K: Geometric damping constant depending on the source and wave type ($K = -20$ for line-type source and body-waves),
- d: spatial distance in m between the source and the measurement point,
- d_0: reference distance in m,
- f: frequency in Hz,
- η: damping coefficient in the soil (for this type of soil $\eta = 0{,}1$)
- c: wave attenuation-velocity in the soil in m/s (for this type of soil $c = 200$ m/s)

Fig. 3 shows both of the transformed acceleration spectra, measured on two building's wall. The arithmetic mean of them was accepted as "reference vibration spectrum" for further calculations.

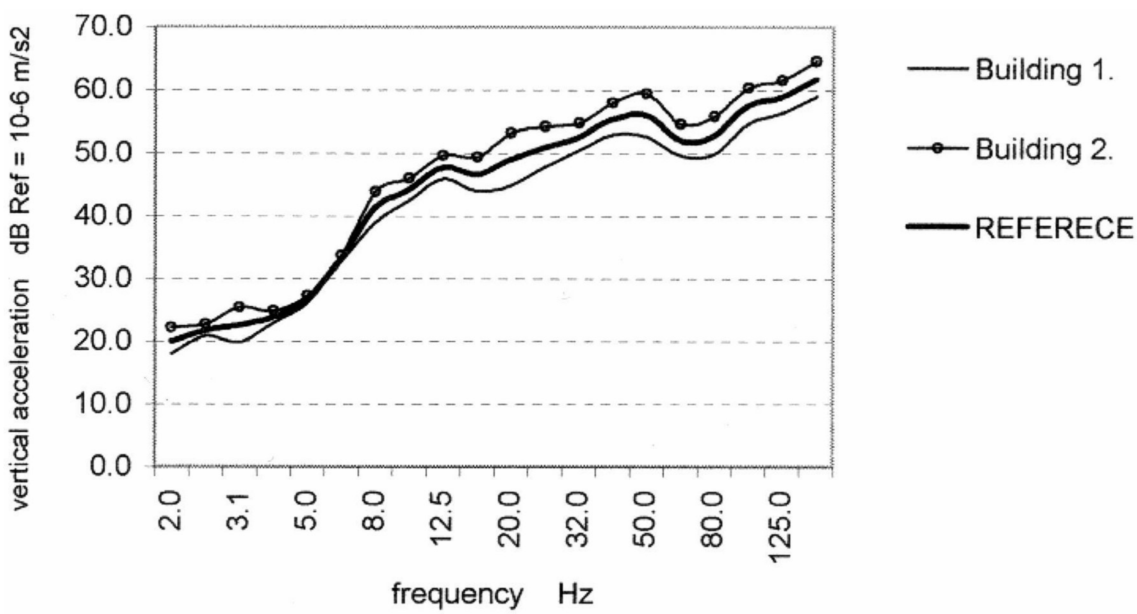

Figure 3: The reference vibration spectrum is the arithmetic mean of two acceleration spectra, measured on two different buildings near to the existing M3-line, subtracted their dominant magnification properties, and transformed to a common reference distance.

The transfer of the measured data from the environment of the existing M3-line to the radio studio and the planned new metro-line will be detailed in Part 2 of this paper [7].

REFERENCES

1. **F. Fahy**, *Sound and Structural Vibration*, Academic Press, 1985
2. **I.L. Vér**, *Interaction of Sound-Waves with Structures in: Noise and Vibration Control Engineering Chap. 9*, John Whiley Inc. New-York, 1992
3. **R.W. Clough, J. Penzien**, *Dynamics of Structures*, McGraw-Hill Inc., 1975

4. **L. Auersch**, Berechnung des Schwingungsverhaltens von Gebäuden bei Einwirkung von Schwingungen, *Bauingenieur*, Vol. 59, pp. 309-317, 1984

5. **T.G. Gutowski, C.L. Dym**, Propagation of Ground Vibration: a Rewiew, *Journal of Sound and Vibration*, Vol. 49(2), pp. 179-193, 1976

6. **J. Melke**, *Ausbreitung technisch erregter Erschütterungen - Probleme der Vorhersage zum Immissionsschutz* , VDI-Berichte/VDI Vg. Düsseldorf, pp. 89-96, 1977

7. **É. Arató-Borsi, P. Forián Szabó, F. Augusztinovicz**, Prediction of the audible effects in a broadcasting studio, caused by a newly planned metro line - Part 2. Transferring the measured and validated results from the existing situation to the planned one, In *Proc. of Inter-Noise'2000*, 2000