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PREDICTION OF THE AUDIBLE EFFECTS IN A BROADCASTING STUDIO, CAUSED BY A NEWLY PLANNED METRO LINE - PART III: VERIFICATION OF THE PREDICTION METHOD, COMPARISON OF MEASUREMENTS AND CALCULATIONS

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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 (2) and with the conclusions of the whole investigation. Step (1) has been discussed in Part 1.

1 - CALCULATED AND MEASURED INDOOR NOISE RESULTS IN AN EXISTING FIVE-STOREYED BUILDING

In Part 1 of this contribution [1] two types of prediction models have been introduced:

1. Coupled FEM/BEM calculation
2. Statistical noise radiation approach

For each type of models, first a number of in-situ measurements in an existing five-storeyed reference building near to an existing, operational metro-line (M3-line) have been made. The comparison of these measurements with the calculated results has revealed the applicable frequency range and reliability of the two models.
Fig. 1 shows the average third-octave band indoor noise spectrum, measured in the cellar room of a five-storeyed reference building near to the M3-line due to train passby. The upper curve shows the calculated radiated noise using the statistical prediction method (2). As input of these calculations we used the actual vibration spectra, measured in the centre-points of the floor-, wall- and ceiling-elements in the cellar room. One can see that this prediction model results in higher noise-level predictions in the cellar, but it gives no data in the lower frequency range. The reason of that is the following: The radiated sound level was calculated from the measured spectra of the most vibrating point of each surface element. Therefore, the calculated noise overestimates the one. Under 40 Hz frequency, this method is turning more and more unrealistic, because of the uncertainty in the radiation efficiency.

The prediction model (1) is usable in the lower frequency range only. The reason of that is twofold: linear FEM models require large computational effort, and the modes are more and more difficult to extract in the higher frequency range. E.g. in this computation the first 45 modes had eigenfrequencies under 100 Hz. It would be advantageous to calculate higher order modes in the frequency range of interest but, unfortunately, the modes are increasingly overlapped.

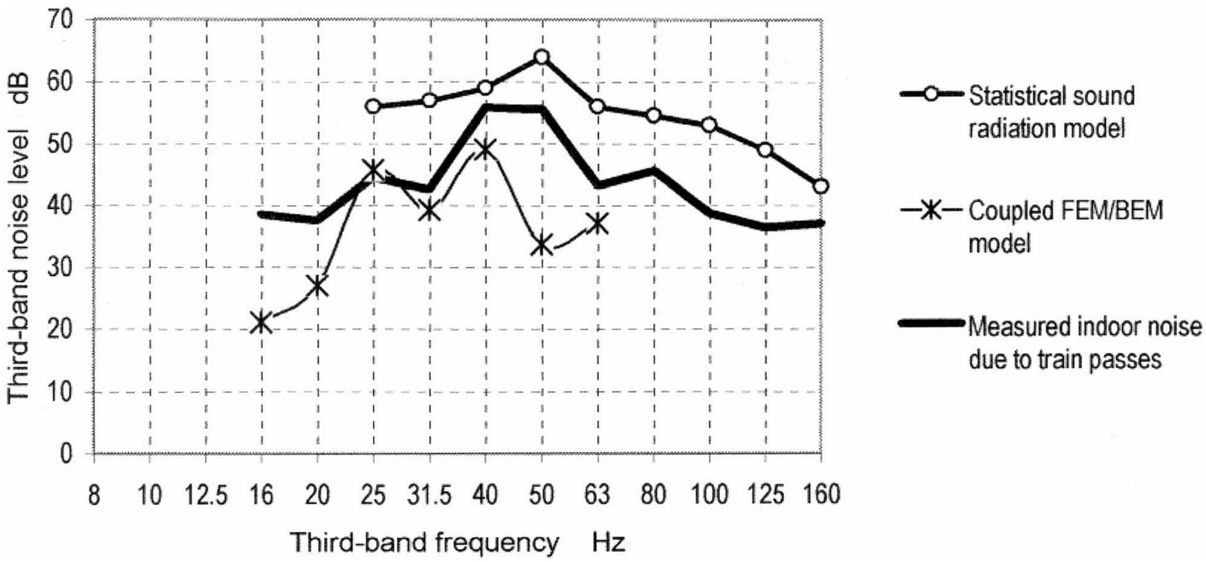

Figure 1: Indoor noise due to metro passby, calculated and measured for a cellar room of a five-storeyed reference building near to the M3 line.

The second observation, which is worth mentioning is, that the numerical FEM/BEM prediction model (1) seems to underestimate the actual indoor noise. The reason could be the following: In this type of prediction model, we used dynamic load acting from the bottom surface of the room only. In the real situation in the cellar-room the excitation through the soil structure arrived in the room most likely not only from the bottom surface but from at least one wall too, and this excitation was not taken into account in the numerical model.

2 - APPLICATION OF THE MODELS TO THE PLANNED METRO LINE AND TO THE RADIO STUDIO

2.1 - Transferring the statistical model to the planned situation

Studio 6 is a one-storeyed building near to the planned metro line. The spatial distance between the centre of the studio and the centre of the closer metro-tunnel is d = 58,1 m. The reference distance was d_0 = 27,1 m. The soil and the tunnel structures are supposed to be the same, as it was at the reference five-storeyed building.

First, the reference vibration spectrum has to be transformed from distance d_0 into d using the attenuation-law. See Part 1 [1]. Further on it was supposed, that the best possible vibration isolation would be applied in the tunnel (in the reference M3 line there was no isolation at all). Nowadays the floating slab track structures are known as the best solution. The insertion loss of this type of isolating system was applied in our calculations [2]. This way we have obtained a "design vibration spectrum" for further calculations of the studio.

As a next step, local vibration measurements have been made on the studio building by using artificial impulse excitation. The aim of those measurements was to establish some dominant eigenfrequencies and damping coefficients of the structural elements of the studio building. This way we could establish the first two horizontal eigenfrequencies of the studio walls, the first two vertical eigenfrequencies of the roof, and the global damping coefficient of the structure.

The room was modelled as a set of independent slabs in horizontal and vertical plane, and they were supported along the corners. Moreover, all of these independent walls, the roof and the floor were treated, as 2 degree of freedom generalised vibration systems [3] and the excitation of those was the same: the aforementioned design vibration spectrum, acting on the supports of the elements. The responses of the structural elements were calculated by taking into account the measured eigenfrequencies and damping.

In this manner, we had independent vibration spectra for all wall- floor- and roof elements, and these spectra were the input for the statistical noise radiation calculations [1]

2.2 - Transferring the numerical model to the planned situation

For this prediction model the Studio 6. was treated as a whole box-structure, and the first 50 eigen-frequencies and modes were calculated using FEM calculations. The room was large; therefore, the modal-density was rather high, resulting in small distances between two successsive eigenfrequencies. E.g. the 49-th calculated eigenfrequency was 32,41 Hz and the 50-th was only 32,68 Hz. That means that the further calculations would have required very large computational effort, in order to span the whole noise frequency range of interest by using this structural finite element method. (Moreover, the reliability of the higher modes is doubtful too.) Therefore, we finished the FEM-modal analysis at the first 50 modes.

After this we have calculated the response of the structure to an uniformly distributed unit load excitation, which acts on a part of the bottom surface only, has unique oriented direction, and in low frequency band pink-noise spectrum. Than a coupled BEM calculation has been carried out by using the former calculated response, and as a result one could calculate the spatial noise-level distribution inside of the box in each dominant eigenfrequency.

After this procedure, the response spectrum-lines were weighted similar as it was calculated on the reference building [1].

3 - FINAL RESULTS AND PROPOSALS FOR THE PROJECT INVESTMENT

Results of the two model-type calculations are shown in Fig. 2.

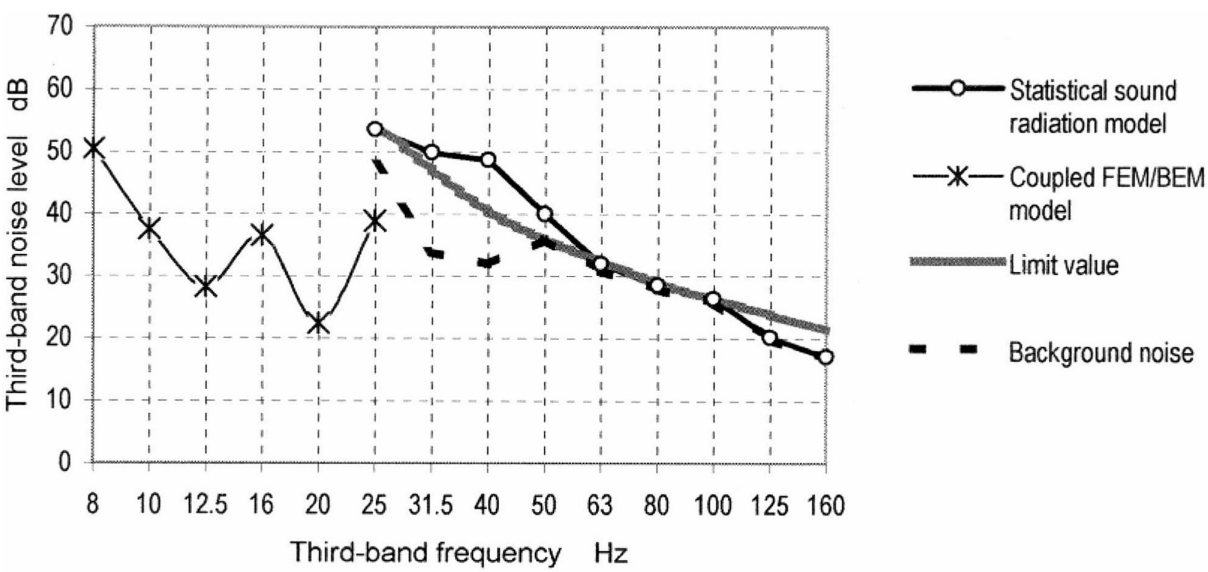

Figure 2: Estimated indoor noise spectra from train passby in the planned tunnel.

Results of two approaches:

1. Coupled FEM/BEM calculations
2. Statistical noise radiation approach

One can see from the Fig. 2 that the frequency range of the two model-type investigations has been separated. Probably the model (1) calculations underestimate, and model (2) calculations overestimate the really expected spectrum.

The model-type (1) cannot be used for the indoor noise prediction in the studio in the frequency range of interest; it is suitable only for controlling the results of the calculations obtained from model (2).

The prediction model of the statistical noise radiation approach method has shown that the expected indoor noise spectrum exceeds the maximum permissible curve.

Therefore, we suggested modifying the layout of the tunnel to the project investment. The calculations have shown that the indoor noise disturbances in the Studio 6 could be avoided by removing the tracks at about 25 m farther from the planned position.

4 - SUMMARY AND CONCLUSIONS

Based on calculations and measurements on a five-storeyed building close to an existing metro line downtown in the Hungarian capital, a prediction method for the estimation of interior noise levels caused by underground train passby was developed. The method includes the calculation of vibration propagation in the soil from the tunnel to the building, as well as the vibration response and calculation of the interior noise level of the building itself. Two models of different complexity of the building were used: a more detailed, but rather cumbersome numerical structural model, and a simplified statistical noise radiation model. The calculation models were compared to real-life measurements and reasonable agreement for the reference building was found: for the frequency range where both methods resulted in meaningful data, the statistical approach has overestimated and the numerical method underestimated the measured noise spectrum.

After having earned sufficient confidence in the method, we have attempted to apply it for the building in question, i.e. Studio 6 of the Hungarian Radio, too. It was established that the numerical method is applicable for the very low frequency range only, and the statistical method suggested that the resulting noise levels would most likely exceed the maximum allowable noise levels. Based on these findings, the new Budapest metro line was redesigned.

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