MEASUREMENT OF STRUCTURAL REVERBERATION TIMES FOR CALCULATION OF ASTC IN UPCOMING NBCC

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1 Introduction

The 2015 edition of the National Building Code of Canada (NBCC) will likely see a change from acoustic requirements of element performance to system performance. It is anticipated that there will be three paths for compliance : field measurements in the finished building, look-up tables with representative assemblies, and a detailed design procedure using laboratory test data and prediction methods. For monolithic construction such as concrete or concrete masonry buildings, the prediction is based mainly on ISO 15712-1 [1]. In this international standard, the structural reverberation time of building elements is an important input parameter for the transfer of laboratory data to *in-situ* values.

The measurement of structural reverberation times (RTs) is similar but more difficult than the measurement of room reverberation times. ISO 10848-1 [2] describes the procedure, and more comprehensive descriptions can be found in the literature [3,4]. For this paper, the measurement of structural RTs was investigated in two case studies, for a 190 mm concrete block wall and for a 203 mm hollow-core concrete floor. Due to space constraints, only the floor measurements are presented here. Common challenges are highlighted, and various options regarding the measurement and evaluation of structural impulse responses are investigated.

2 Determination of structural reverberation times by backwards integration

The most common method of determining structural RTs uses backwards-integration of impulse responses [5]. Impulse responses are obtained by either exciting the structure under test with a hammer and recording the response directly, or by exciting the structure using a shaker with a sweep or noise signal, and subsequent signal processing. ISO 10848-1 gives guidance on the number and location of excitation and response positions.

Once the impulse responses have been obtained, a series of signal processing steps are performed to estimate the structural RTs. The impulse response is filtered into (octave or third-octave) frequency bands, and an exponential time window is applied. At this point, it is recommended but not required to remove the noise floor in the impulse responses [6]. In a last step, the energy decay curves (EDCs) are calculated by backwards-integration of the squared impulse response, and the RTs are estimated by linear regression.

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3 Measurement setup

Measurements were performed on a 203 mm thick hollow-core concrete floor of size 4.70 m×3.80 m, installed in the floor testing facility at NRC. The impulse responses were obtained using two different shakers, a small Wilcoxon F3 shaker and a large PCB K2007E01 shaker, driven with an exponential sweep of length 40 s, and also using two impact hammers. Three excitation positions were used, and four different response positions each. The location of the positions was according to ISO 10848-1. For the hammer measurements, three repeats were recorded for each excitation point, and as required by ISO 10848-1 different hammer tips were used in order to excite a wider frequency range.

The responses were recorded using accelerometers type PCB 320C03 with a sensitivity of 1 mV/m/s^{-2}. The sensors were magnetically connected to metal tabs which were epoxied to the surface of the floor specimen. The small shaker was threaded directly to a metal tab which was also epoxied. The larger shaker required to be supported and, in order to prevent rotational excitation, it was connected using a flexible stinger reinforced with a metal sleeve. An impedance head (PCB 288D01) monitored the input force and acceleration.

4 Evaluation of the impulse responses

The measured impulse responses were evaluated using an inhouse software tool implemented in MATLAB. The software calculates the EDCs using the procedure described above, and estimates the RTs using a default evaluation range between −5 dB and −15 dB. It rejects invalid estimates based on a minimum signal-to-noise ratio (>25 dB), correlation coefficient between EDC and regression line (>95%), and BT product (>8 for forward filtering, >4 for reverse filtering). The regression lines can be adjusted manually. Given the large amount of data (# of EDCs = # of excitation positions × # of response positions × # of repeats × # of frequency bands), manual adjustment is very time-consuming.

Several evaluation parameters were investigated :

- Noise truncation limits the impact of background noise on the determined RTs [6].
- Traditional forward-filtering limits the lowest measurable RT more severely than reverse filtering [7]. The parameter of interest is the product of filter bandwidth B and RT T (BT product).

5 Results

The effect of forward and reverse band filtering is considered first. Figure 1 shows the mean values of the determined RTs for the hollow-core floor, measured with the large shaker. Also shown are the limits for the lowest measurable RTs. For this case study, the type of filtering did not have a significant effect, as the structural RTs were above the limits of both forward and reverse filtering. For structures with higher losses these limits will come into play, and therefore the BT products of the RTs should always be checked. If they are below the limit, reverse filtering should be used, or the frequency resolution should be decreased (octave bands instead of third-octave bands).

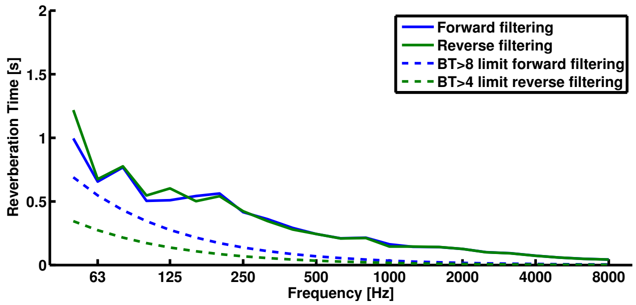

Figure 1: Comparison of forward and reverse frequency band filtering, for hollow-core floor measurements using the large shaker

The influence of noise truncation is considered next. Figure 2 shows the RTs of the hollow-core floor, this time measured with the small shaker. The initial RT estimate (blue line) shows considerable deviations below 400 Hz. Manual adjustment of the fitted regression lines to the EDCs (green line) removes the outliers and yields acceptable standard deviations. However, compared with the automated results with enabled noise truncation (red line), the values are still systematically higher at low frequencies. This is because the noise floor in the impulse responses is integrated in the calculation of the EDCs, resulting in skewed values for the RTs. Manual adjustment of the red line (not shown) had only very little effect on the RT values. From Figure 2 it is concluded that the use of some noise removal algorithm can be highly beneficial. However, it should also be noted that the effect of noise truncation was significantly less pronounced for the large shaker. The reason is that the signal-to-noise ratio for the large shaker was much higher, so noise in the impulse responses had less influence. The small shaker is not strong enough to excite the specimen properly at low frequencies.

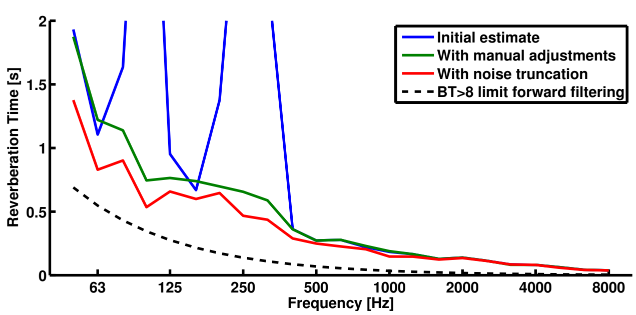

Figure 2: Effect of noise truncation for hollow-core floor measurements, using the small shaker

Finally, the influence of the type of excitation is considered. Figure 3 shows the RTs of the hollow-core floor, measured with different excitation sources. Reverse filtering was used, noise truncation was applied, and the regression lines were manually adjusted. Despite these provisions, the RTs deviate considerably below 500 Hz, in particular between shaker and hammer measurements. This discrepancy has been observed before in other laboratories [8]. One reason may be found in the significant difference in exerted force, pointing to possible non-linear behaviour of the structure under test. More research is required on this issue.

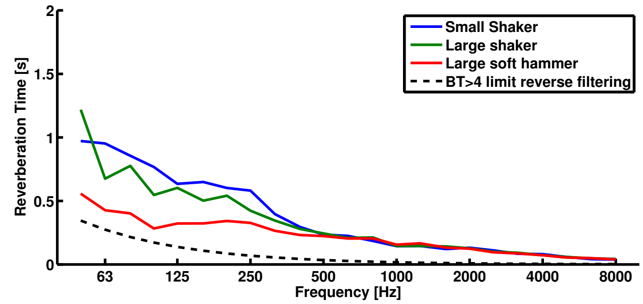

Figure 3: Comparison of RTs obtained with different excitation sources, for concrete hollow-core floor

6 Conclusions

In the cases studied, it was found that there can be systematic differences between RTs obtained with hammers and shakers, respectively. This confirms previous research [8]. Until more research has been conducted on these deviations, it is recommended to use a shaker, because the forces exerted by the shaker closer resemble the forces exerted by airborne excitation. Furthermore, it is recommended that noise truncation techniques [6] be used, as they can significantly improve the RT estimates. In the cases studied, the differences between forward or reverse filtering were not significant. For structures with higher losses it is recommended to use reverse filtering.

References

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