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PREDICTING STRUCTURE-BORNE NOISE FROM BUILDING SERVICE EQUIPMENT USING THE IMPACT NOISE CALCULATION MODEL

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This paper describes a way of predicting structure-borne noise from building service equipment following the same approach as for impact noise, assuming both equipment and taping machine acting as force sources, i. e. being installed on heavy building elements. Indeed, European standard EN 12354-2 includes an equation relating the normalized impact noise level of floors to the force level of the standard tapping machine. Knowing the difference between the equivalent blocked force level of the equipment considered – measured according to EN 15657 – and the force level of the standard tapping machine, it is then possible to use standard EN 12354-2 to predict equipment noise in situ, the impact noise result being corrected of the above force level difference. For horizontal supporting elements, databases of normalized impact sound pressure levels already exist; these data bases are also valid for vertical elements made of the same material (concrete for example). For other types of vertical building elements, e.g. masonry walls, the normalized impact sound pressure level must be measured. In this paper, the use of a vertical tapping machine is tested and the prototype characterized in terms of equivalent blocked force level. Results are presented and compared to the blocked force level of the standard tapping machine.
Keywords: Service equipment noise, impact noise prediction

1. Introduction

Standard EN 12354-5:2009 [1] on predicting service equipment noise in buildings is now under revision, mainly for extending its application to lightweight constructions. During the discussions within standardization group CEN/TC126/WG2, which is revising the standard, the idea of using EN 12354-2:2017 [2], which predicts impact noise in buildings, to predict equipment noise in the case of heavy constructions came out. Indeed, both sources act as force sources in this case and in situ impact noise prediction can then be used and corrected of the difference between the blocked force level of the equipment, measured in laboratory according to EN 15657:2017 [3], and the force level of the standard tapping machine given in Annex F of [1]. For floors, databases of normalized impact sound pressure levels already exist; these databases can also be used for vertical elements made of the same material as floors (concrete for example). However, if the equipment is connected to other vertical elements, e.g. masonry walls, then the normalized impact noise of such elements must be measured, which requires a reference vertical tapping machine. Such “tapping machine adapted for walls where the multiple impacts are mechanically controlled to be repeatable” has been mentioned in ISO 10848-1:2017 [4], and has already been built and used at CSTB to measure the vibration level difference of junctions. This source is described in section 2 of this paper, characterized in terms of force source according to [3] and compared to the standard ISO tapping machine in section 3.
It should be added that such a reference vertical source is also required for characterizing isolated heavy stairs or lightweight stairs connected to receiving vertical heavy building elements. Indeed,

according to Annex F of [2], the performance of such stairs is expressed, like any floor covering, as a reduction of impact sound pressure level ΔL between the impact sound level of the receiver without the stairs and the impact sound level of the receiver with the stairs, when the stairs are excited.

2. Description of the CSTB vertical tapping machine

The vertical tapping machine made at CSTB is composed of five arms that can rotate around a horizontal axis, all being equipped with hammers that fulfil the requirements of ISO 10140-5 [5] Annex E in terms of weight and profile. Eccentric wheels driven by an electrical engine are used to rotate the arms up alternatively until the hammers can fall freely and hit the wall under test. The falling angle is adjusted so that the horizontal speed of the hammers – and thus their amount of motion – before impact equals that of the hammers of the ISO tapping machine. The engine rotating speed is set to ensure impacts every 0.1 s.

Unlike the ISO tapping machine, the vertical tapping machine is rigidly fixed to the wall under test using two lateral brackets that need to be screwed into the wall (see Fig. 1).

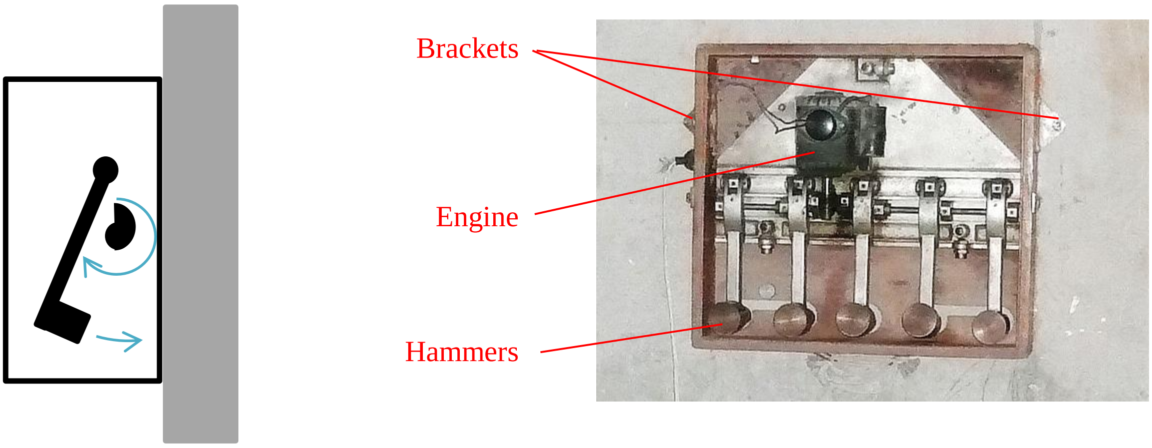

Figure 1: CSTB's vertical tapping machine. Left: schematic cut view. Right: actual machine installed on a concrete wall.

3. Laboratory characterization

The CSTB source has been characterized in laboratory according to [3] and its performance expressed as equivalent blocked force level. The indirect characterization method was applied, using the power substitution method in order to determine the structural power injected by the source installed on a heavy supporting structure. The spatial average of the supporting structure vibration velocity level $L_{v,source}$ is estimated from measurements in different – randomly chosen – positions. Knowing the vibration velocity level $L_{v,cal}$ corresponding to a source (impact hammer) of known power level $L_{Ws,cal}$, it is then possible to estimate the structural power level $L_{Ws,source}$ of the source under test following:

$$L_{Ws,source} = L_{v,source} + 10\lg\left[\frac{1}{N}\sum_{i}^{N} 10^{\left(L_{Ws,cal,i} - L_{v,cal,i}\right)/10}\right] \tag{1}$$

Assuming that the mobility of the wall is much lower than that of the source, the following simplified relationship can be used to estimate the blocked force level:

$$L_{Fb,eq} \approx L_{Ws,source} - 10\lg\left[\mathrm{Re}\left(Y_{R,eq}\right)\right] \tag{2}$$

In Eq. (2), $L_{Fb,eq}$ is the equivalent blocked force level in dB ref. 10^{-6} N, $L_{Ws,source}$ is the installed power in dB ref. 10^{-12} W and $Y_{R,eq}$ is the equivalent mobility of the wall in m/(Ns). $Y_{R,eq}$ can be obtained by averaging the point mobilities of the wall at the contact points.

All measurements are performed in third octave bands in the range 50-5000 Hz.

3.1 Vertical source characterization

The CSTB vertical tapping machine is tested according to the method described above. The supporting structure is a 18 cm thick solid concrete wall. Vibration velocity measurements are performed in 12 different positions. The wall mobilities were measured only at the two fixing points, while it could be argued that the five impact points of the hammers are also contact points. However, the variation in the wall mobility is not expected to vary much with location, provided that the considered points are away from edges and corners. Consequently, considering only these two points is appears to be a reasonable simplification for determining the wall equivalent mobility.

Measurement results of the wall mobility are presented in Fig. 2. As expected, little difference is observed between the two contact points. These mobility values are very close to the characteristic mobility of a 18 cm concrete plate (equal to 1.78 10^{-6} m/(Ns)). Note: at 5000 Hz, one of the measurements was subject to low signal-to-noise ratio. Consequently, only the other result is considered in the determination of the equivalent mobility.

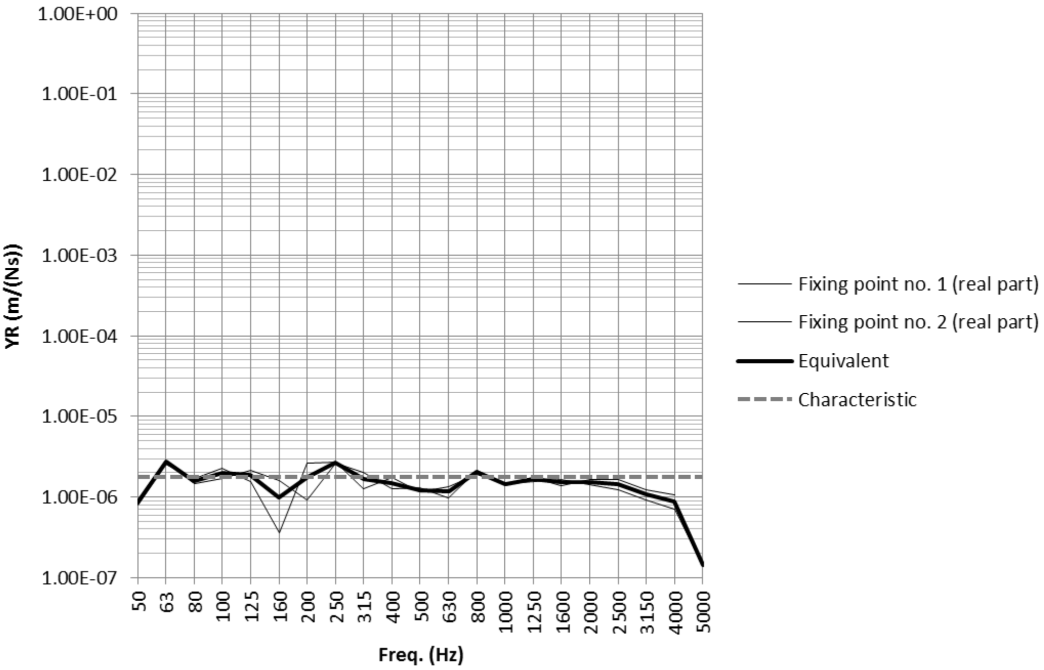

Figure 2: Mobility of the supporting concrete wall.

The estimated equivalent blocked force level of the vertical tapping machine is represented in Fig. 3 in both third octave and octave bands. The absence of value at 5000 Hz is due to low signal-to-noise ratio when measuring $L_{Ws,cal}$ (see Eq. (1)). Consequently, the 4000 Hz octave band value cannot be calculated.

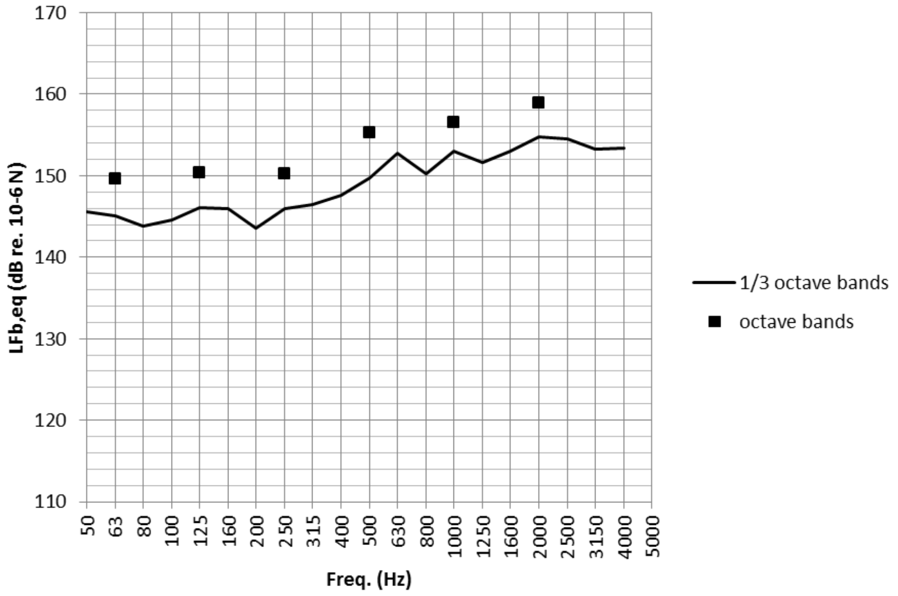

Figure 3: Equivalent blocked force level of the vertical tapping machine.

3.2 Comparison with standard tapping machine

3.2.1 Experimental results

The standard tapping machine (named ISO TM below) has also been characterized in laboratory according to [3] and its performance expressed as equivalent blocked force level. The low mobility reception plate is a 18 cm thick solid concrete slab.

The results are represented in Fig. 4 together with those obtained for the vertical tapping machine (VTM). These results show both tapping machines have very similar activity, except below 100 Hz where the equivalent blocked force level is higher by around 4 dB for the vertical tapping machine. This difference might be due to unwanted excitation generated by the engine and transmitted through the rigid contacts on both sides of the vertical tapping machine.

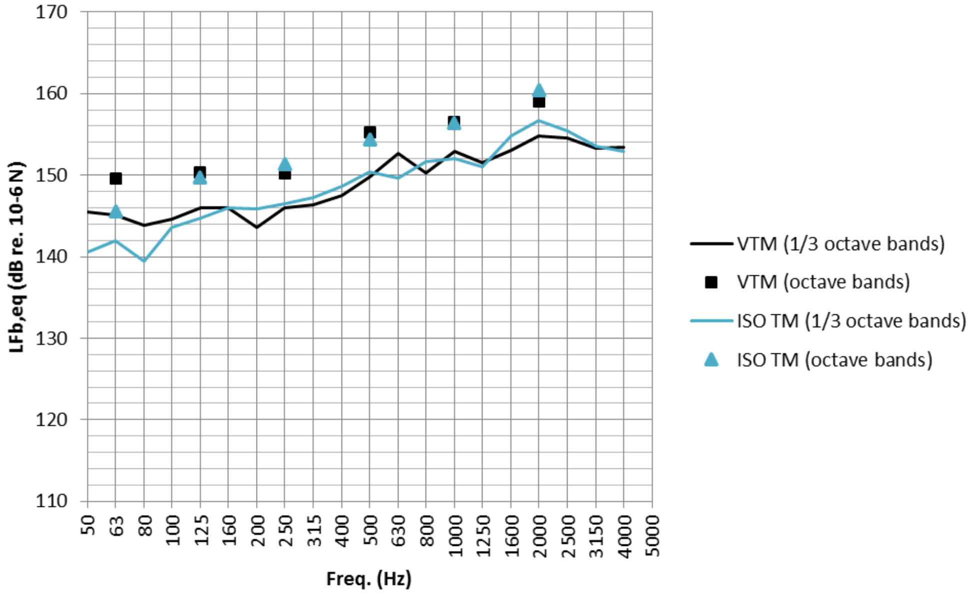

Figure 4: Measured equivalent blocked force levels of the standard and vertical tapping machine.

3.2.2 Comparison with calculated values

The standard tapping machine force level can also be theoretically calculated according to the relationships given in [6]. Following these relationships, the applied force $F_{\Delta f}$ (in N) in a given frequency band of width Δf (in Hz) can be expressed as:

$$F_{\Delta f}^2 = 2 I_H^2 f_H \Delta f \tag{3}$$

In Eq. (3), $I_H \approx 0.626$ Ns is the impulse transmitted by one impact and $f_H = 10\ s^{-1}$ is the number of impacts per second.

Force levels calculated according to Eq. (3) were calculated in octave bands 63-4000 Hz. Theoretical values are also tabulated in EN 12354-5 Annex F.

The calculated, tabulated and measured values of the standard tapping machine blocked force level are represented in Fig. 5. Very good agreement is found between calculated and measured values. However, a 3 dB offset is observed between the calculated and tabulated values. A maximum value of 156 dB is also applied in the tabulated values over 1000 Hz. It should be noted that no reference to this limitation was found in [6] and that EN 12354-5 Annex F refers to a previous edition [7] without giving further details about the calculation method.

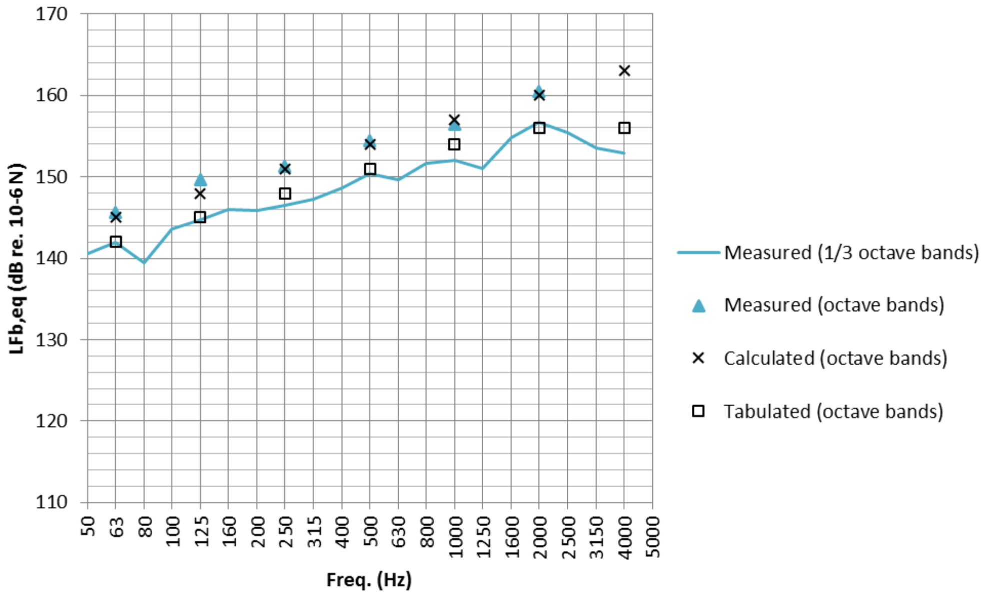

Figure 5: Measured, calculated and tabulated equivalent blocked force levels of the standard tapping machine.

4. Conclusion

The results presented in section 3 in terms of blocked force levels show that:

- The vertical tapping machine built at CSTB has a similar blocked force level to the force level measured on a standard tapping machine, except in octave band 63 Hz where it is 4 dB higher. The excess of power at low frequencies is probably due to the rigid contacts between source frame and receiving wall, problem to be solved.
- The measured values obtained for the standard tapping machine agree well with theoretically calculated values.
- The values given in EN 12354-5 Annex F are underestimated and should be corrected; this correction can be made in the frame of the on-going revision of the standard.

The vertical tapping machine can be used as a reference impact source for characterizing vertical heavy elements in the laboratory (at least from 100 Hz). The resulting normalized impact sound pressure level can then be used to predict equipment noise according to EN 12354-2 by applying a correction term to account for the difference in blocked force level between the tapping machine and the considered equipment. This method shall however be limited to equipment installed in heavy constructions.

5. Acknowledgements

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3 Revised EN 15657 (expected in 2017): Acoustic properties of building elements and of buildings – Laboratory measurement of structure-borne sound from building service equipment for all installation conditions.

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