A MEASUREMENT METHOD FOR DETERMINATION OF STRUCTURE-BORNE NOISE SOURCE FOR BUILDING SERVICE EQUIPMENT

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ABSTRACT

A pilot project with an inter-laboratory comparison (round robin) has been performed, where a modified heavy duty washing machine has been circulated for tests among 7 laboratories. The main goal of this pilot project was to find out whether a simple substitution method could be applied to determine the structure-borne sound source strength of typical building service equipments. The vibration levels from a machine are compared to levels obtained on the same floor with the standardized tapping machine. These vibration level differences may be used to estimate the characteristic power according to prEN 12354-5. The standard also describes how sound pressure levels in a nearby room may be deduced from the source power. The vibration level differences are assumed to correspond to sound pressure level differences obtained with measurements according to ISO 140-8, but this is not validated yet. If they are found to correspond, they can be used to predict reduction of impact sound in nearby rooms according to EN 12354 part 2 in the same way as for floorings on a heavy slab. Some tests were also performed in order to enable comparisons to sound power obtained by the draft standard prEN 15657-1, where the source strength is determined by a reception plate method. However, it was not possible to determine the structural reverberation time and point mobilities of the slabs accurately, thus the comparison could not be made.

1. INTRODUCTION

Structure-borne sound from building service equipment is today an important issue for the manufacturers of such equipment. Structure borne sound excitation is in many cases the source of indoor noise problems in modern apartment buildings and public spaces. These problems might even increase in the future because of the increased use of light-weight wooden structures in the Nordic countries, where normal structure-borne noise insulation solutions become complicated. The common method of today is to add sound insulation to walls and slabs (linings) to prevent vibrating structures to radiate sound. The lack of reliable source data and prediction methods has the consequence, that constructions are not optimized but either exaggerated or underperforming. The expense of these linings has been estimated to more than 0,1 million EUR in each of some common dwelling houses built over the last 5 years. This cost can be reduced considerably with improved solutions near to the sources of structure borne sound, i.e. vibration insulation. However, for practical and security reasons, such solutions must be developed and integrated by the manufacturers and should not be added at the building site. Several manufacturers as well as some large Nordic contractors participate in a parallel project, focused on finding efficient solutions to various kinds of problem related to structure borne sound.

There are not yet any standardized methods to determine the source strength of structure-borne noise sources, nor to predict the propagation and radiation of sound in nearby rooms. This is a major drawback for the building industry, particularly to manufacturers of installation equipment such as HVAC systems, elevators, laundry machines, sanitary equipment and kitchen furniture. However, a detailed test method has been proposed in an European draft standard (prEN 15657-1, [1]). Another draft standard has been developed, describing methods for the prediction of noise in nearby rooms as well as principles for simplified measurements of the source strengths (prEN 12354-5, [2]). Both drafts have been circulated for comments among the European standardization bodies. The comments have been somewhat critical; the proposed methods have been regarded as complicated and uncertain. They both need to be tested under realistic conditions. Initial studies implicate that the proposed 'substitution method' in prEN 12354-5 may be robust enough to serve as a field method (survey grade), but this has to be verified. The manufacturers are now waiting for a common measurement method in order to continue the work on reducing the source strength of their products and to document the properties in a common way.

Another question is whether the detailed method described in prEN 15657-1 gives results that may be applied outside the laboratories. The source strength determined either by comparison to a tapping machine (standardized in EN ISO 140) or determined by a so called reception plate method (prEN 15657-1), could be strongly affected by different modal vibrations of the supporting floor. If so, this may alter the source strength in a building, as compared to the strength determined in the laboratory. This translation of lab data to in situ must be robust in order to make the test results applicable in practice. Therefore, it is vital to perform a round robin test, and the tests should be made both in dedicated impact sound laboratories as well as in realistic buildings with a variety of constructions.

Thus, one source has been circulated for tests at 5 Nordic and 2 European laboratories, to evaluate a characteristic spread of results among various laboratories, particularly to study whether the rank order between different sound sources would alter or remain stable.

2. TEST OBJECT

The source used for this inter laboratory comparison is a modified Electrolux Laundry Systems 465H, intended for 6,5 kg dry load. This heavy duty laundry machine is intended for common laundry spaces in apartment buildings. The machine has 4 speeds and a variable structural impedance (c.f. figure 1). It may be regarded as a typical source of vibration in this context, i.e. the results would be applicable to other types of equipment with similar framed structures and operating frequencies, e.g. HVAC units, elevators etc. .The machine is somewhat larger than typical household machines (HDW 112 x 69 x 72 cm, weight 154 kg). In the tests, the drum is loaded by a steel plate (1,5 kg), fixed to one side of the drum (c.f. figure 1d). The drum and driving motor is internally suspended on steel springs. The machine is placed on three different foundations, in order to change the source mobility, see figures 1a-1c. This is achieved by hand operated jacks that make the change of footings efficient. The machine is operated at four speeds: 720, 840, 960 and 1080 rpm (12, 14, 16, 18 Hz).

Figure 1. Washing machine Electrolux Laundry Systems type Wascator 465H, on a) the framed base with a MDF plate on 4 hand-operated jacks, b) the concrete filled steel plate base (200 kg) resting on*

massive steel cylinders, c) the same concrete base resting on Sylomer® soft polymer cylinders (f0 12 Hz), d) the eccentric load, a 1,5 kg steel plate fixed to the side of the drum

3. TEST FLOORS

In some laboratories, tests were made on several floors. The floors used for tests are listed in a random order compared to the list of laboratories:

A. 14 cm massive concrete floor, 4,0 x 3,4 m^2, supported on 3 masonry walls (340 kg/m^2), one side free (with a light weight stud-and-plasterboard wall beneath). Thin linoleum carpet laid on floor (without foam layer and without glue). Reverberation room under the plate, intended for impact sound reduction tests according to ISO 140-8 (ref 6)

B. 10 cm massive concrete floor, 2,8 x 2 m^2, 4 free sides. The plate is supported by elastic pads to serve as a 'reference plate' according to the draft standard prEN 15657-1 (ref 1)

C. 10 cm massive concrete floor, 250 kg/m^2, 3,3 x 3,3 m^2, on 40 cm concrete frame and walls. Reverberation room under the plate, intended for impact sound reduction tests according to ISO 140-8 (ref 6)

D. 2x2 cm OSB floor boards on 45x145 mm wooden joists spaced 0,8 m, no ceiling under the joists, joists supported by 40 cm concrete frame and walls. Reverberation room under the plate, intended for impact sound reduction tests according to ISO 140-11

E. 10 cm massive concrete slab with tile flooring, supported by 20 cm EPS thermal insulation on a crushed rock ballasting on soil bed, 9 x 7 m^2.The edges of the plate have an increased thickness (30 cm) to carry the load of the light weight walls and roof

F. 30 cm massive concrete floor on 50 cm concrete beams spaced 5,6 m, the overall plate size being> 600 m^2. Tests were made in the middle of one floor section (between the beams, 7,4 x 5,6 m^2

G. 15 cm massive concrete floor, 3,2 x 4,2 m, on a 30 cm concrete frame and concrete walls, the room being supported by steel springs (with a low loss factor). Reverberation room under the plate, intended for impact sound reduction tests according to ISO 140-8 (ref 6),without any structural connection to the test floor

H. 10 cm massive concrete floor, 7,5x5,7 m, 4 free edges, suspended on cork/rubber vibration insulation (f_0 <<20 Hz), light weight walls and roof load carried by the edges of the floor

I. 15 cm massive concrete floor (360 kg/m^2) on 4 masonry walls. Reverberation room under the plate, intended for impact sound reduction tests according to ISO 140-8 (ref 6)

J. 15 cm massive concrete slab on a heavy concrete frame. Reverberation room under the plate, intended for impact sound reduction tests according to ISO 140-8 (ref 6)

K. 20 cm massive concrete slab 4,5x4,5 m^2, cast on a sand bed on soil, with 4 free edges

L. 2,2 cm particle board screwed (not glued) to wooden joists 45x195 mm, spaced 600 mm, width 2,4 m, length 3,6 m.

M. 2,2 cm particle board screwed (not glued) to wooden joists 45x195 mm, spaced 600 mm, width 2,4 m, length 2,5 m. Floor M was accomplished by adding a third joist support to the floor L (a wooden lath between the joists and the concrete floor)

4. MEASUREMENTS

Measurement setup

In the inter-laboratory tests, the washing machine was operated at 3 positions (except for 4 positions on floors A and B, 2 positions on floors C and D). One source position was located close to a corner of the test floor and the others were placed asymmetrically in the middle of the test floor (except for floor E where all source positions were in the middle region of the large floor since there were no corners available). The standardized tapping machine was placed in 2 positions in the center of each position used for the washing machine, the 2 positions being at right angles following its diagonal lines. The accelerometers (4 positions) were placed in the middle of the floor, avoiding symmetry lines and diagonal lines, on at least 0,5 m distance from each other and at least 0,2 m away from the any source position. On floors A and B, 7 positions were used for the accelerometers. Figure 2 shows the floor H setup:

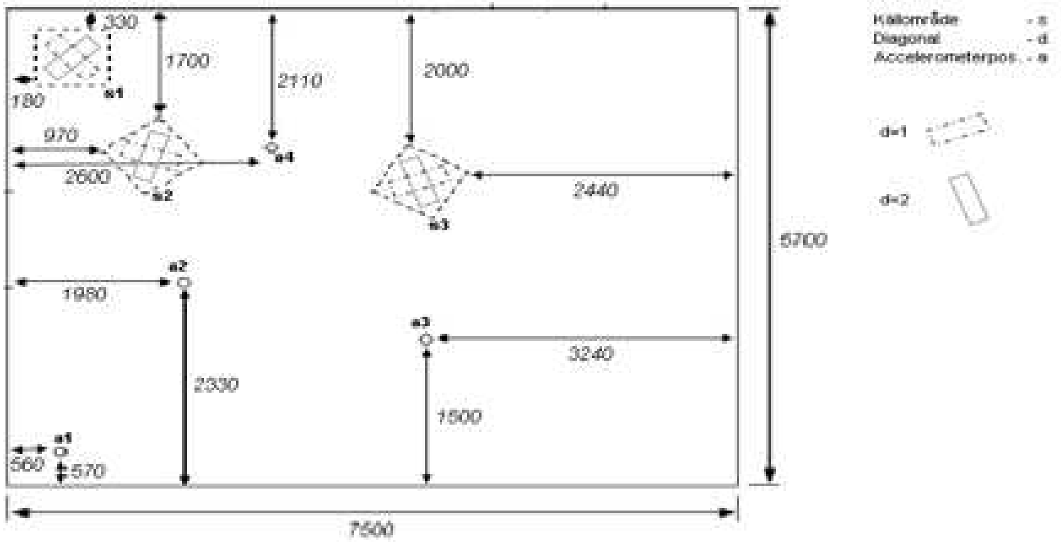

Figure 2. Example of test setup (floor H). sX denotes source positions, aY denotes accelerometer positions, d1 and d2 shows orientation of tapping machine on the diagonals of each source position

Measurements

- Measurement equipment: 2-8 accelerometers fixed to the floor surface and connected to third octave band sound level meters (real time analyzers) that comply with requirements in ISO 140-4 and ISO 10848-1
- The velocity levels of the background (no source in operation) and for maximum excitation (with tapping machine) were determined and compared to the vibration levels with the source operating, to determine the upper and lower limits of measurement (effective dynamic range)
- Test object and modes of operation, c.f. clause 1
- Measurement time: 32 seconds after 30-60 seconds starting and settle time for the washing machine, i.e. each measurements was made at a constant speed
- All data presented for the interlaboratory comparison below refer to logarithmic averages of 4 speeds

5. RESULTS

The results of the inter-laboratory measurements are summarized and discussed below. For anybody who is interested in the detailed results, the authors may forward an MS Excel file with all vibration levels of each floor and each test object. Please direct such a request to the authors, with a short explanation of the purpose.

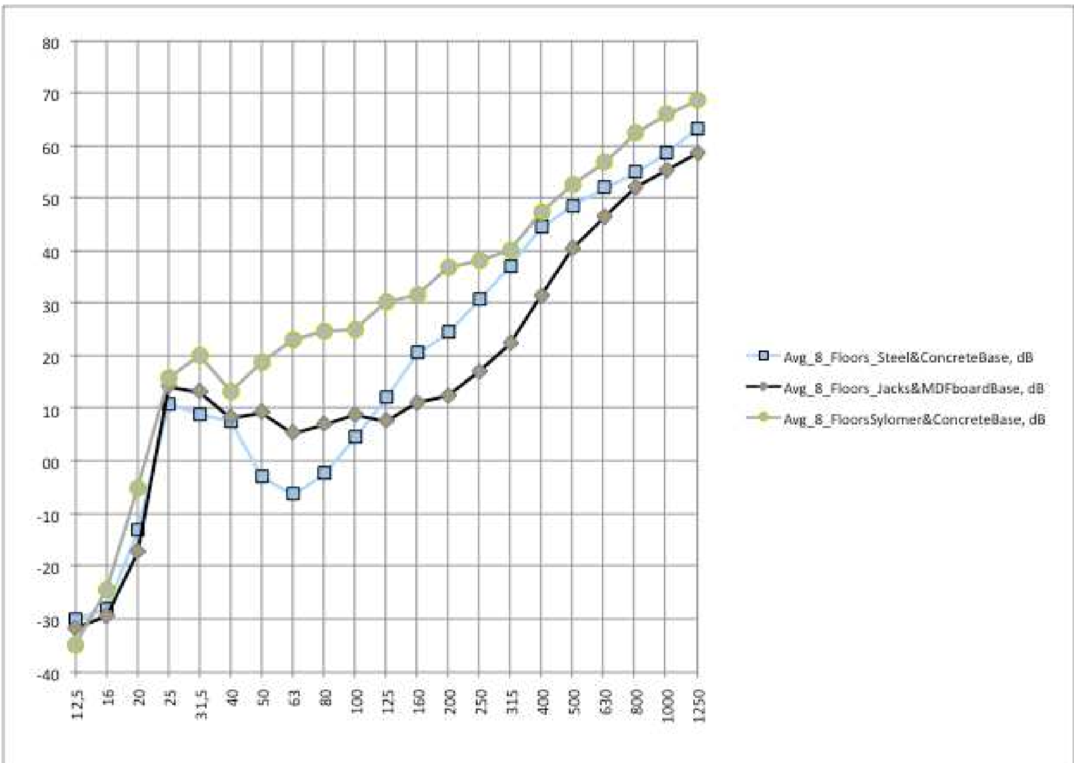

Figure 3a)

: Differences between the spatially averaged vibration levels of the standardized tapping machine and the washing machine, put on three types of base, on 10 concrete floors. Average of 4 speeds 720-1080 rpm (12-18 Hz).

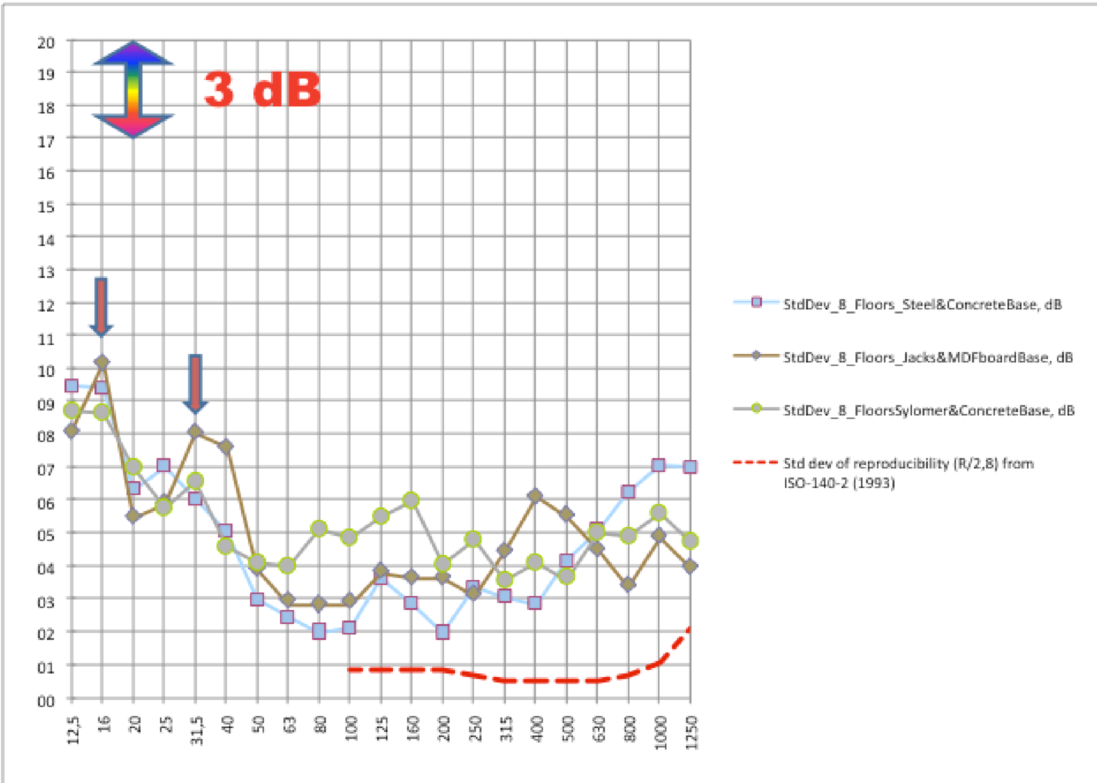

Figure 3 b): Standard deviation of differences in figure 3 a.

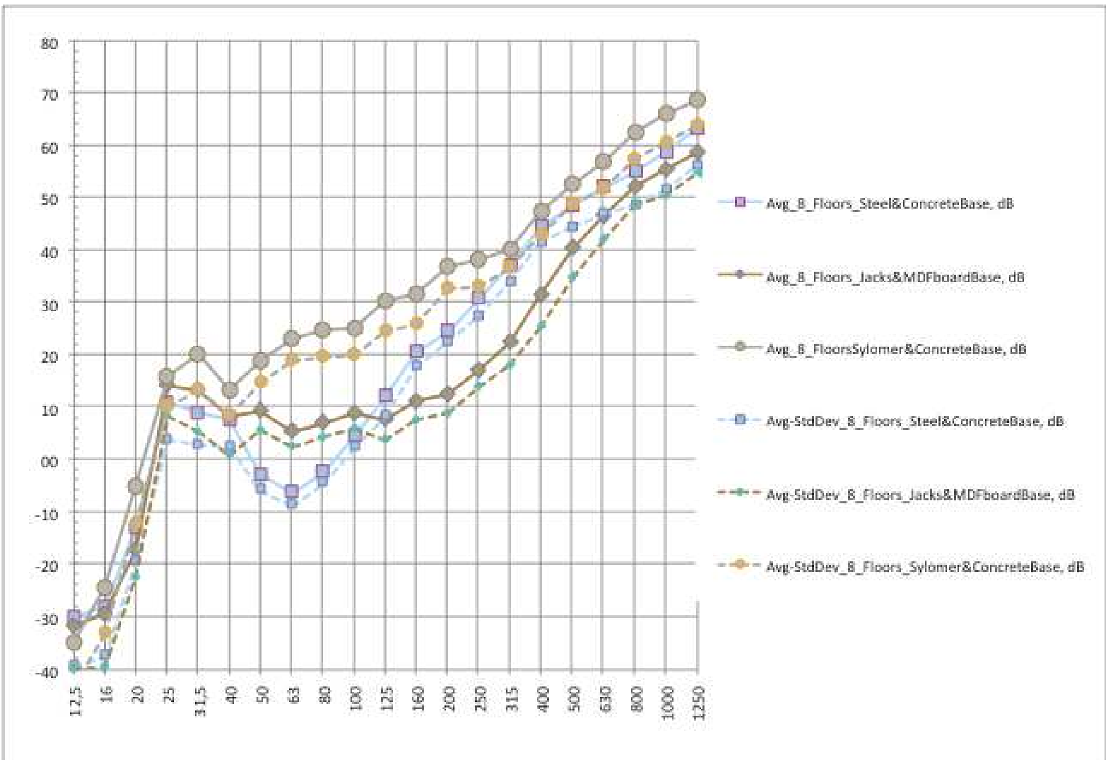

Figure 3c. (—) from figure 3a, (- - -) vibration level difference reduced by one standard deviation (from figure 3b)

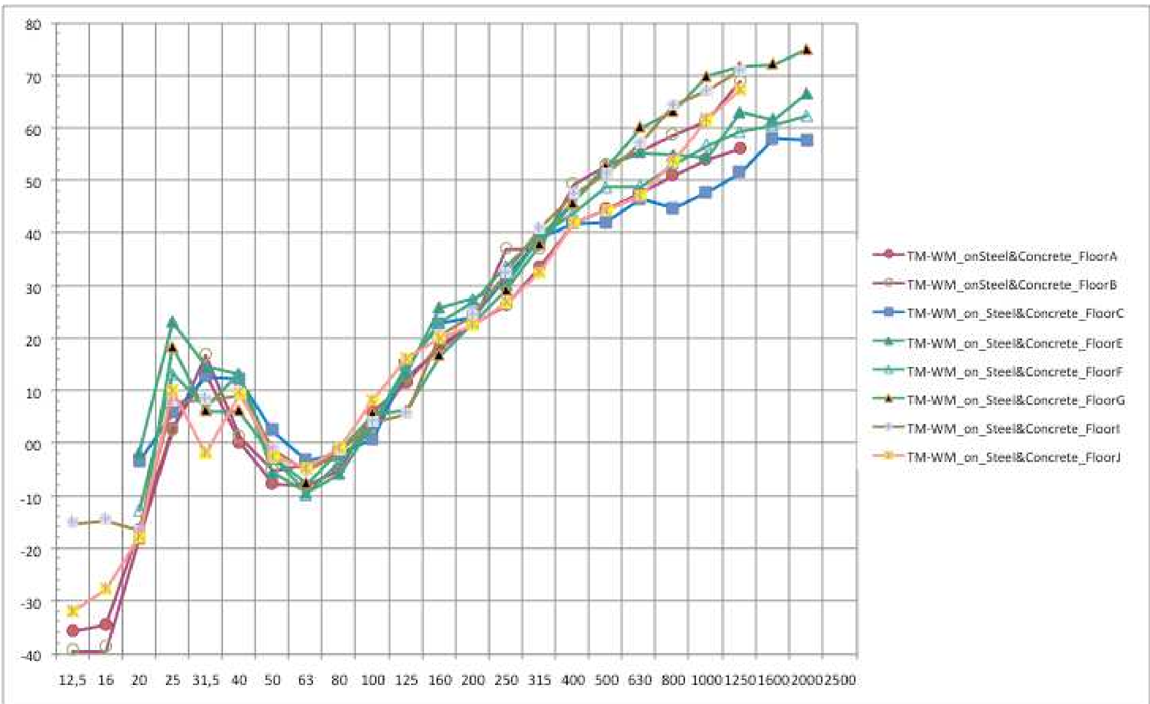

Figure 4a. Differences between the spatially averaged vibration levels of the standardized tapping machine and the washing machine, put on the steel&concrete base on steel footings, measured on 10 concrete floors. Average of 4 speeds 720-1080 rpm (12-18 Hz).

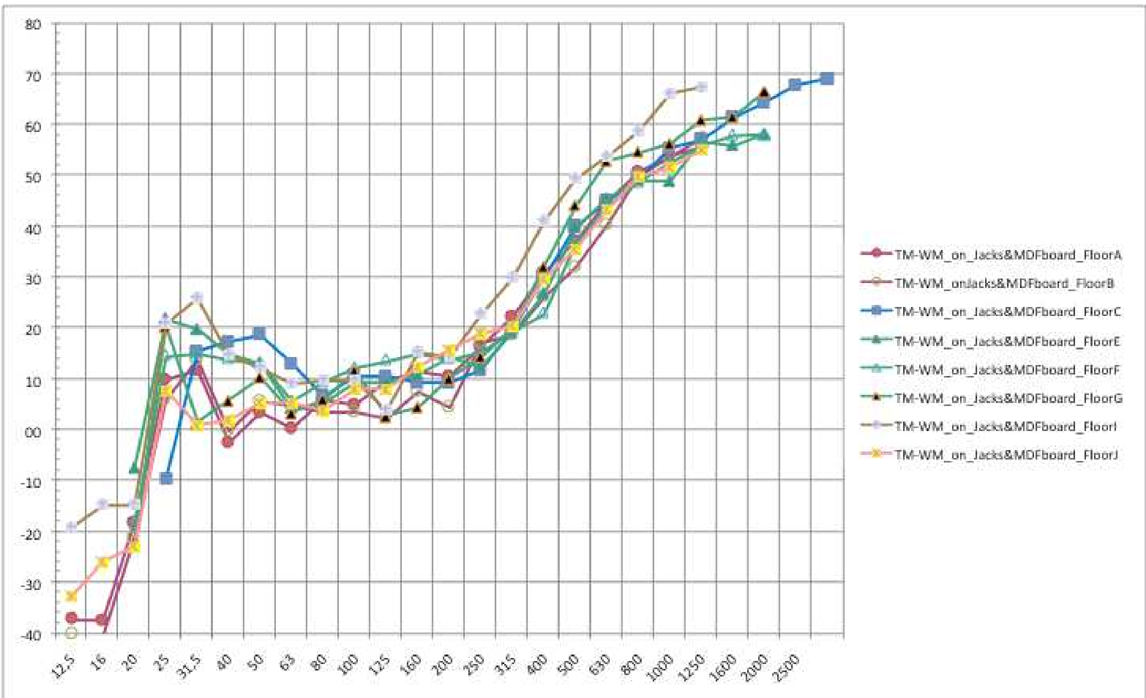

Figure 4b. As for 4a, washing machine put on the MDF-board base on 4 screw jacks

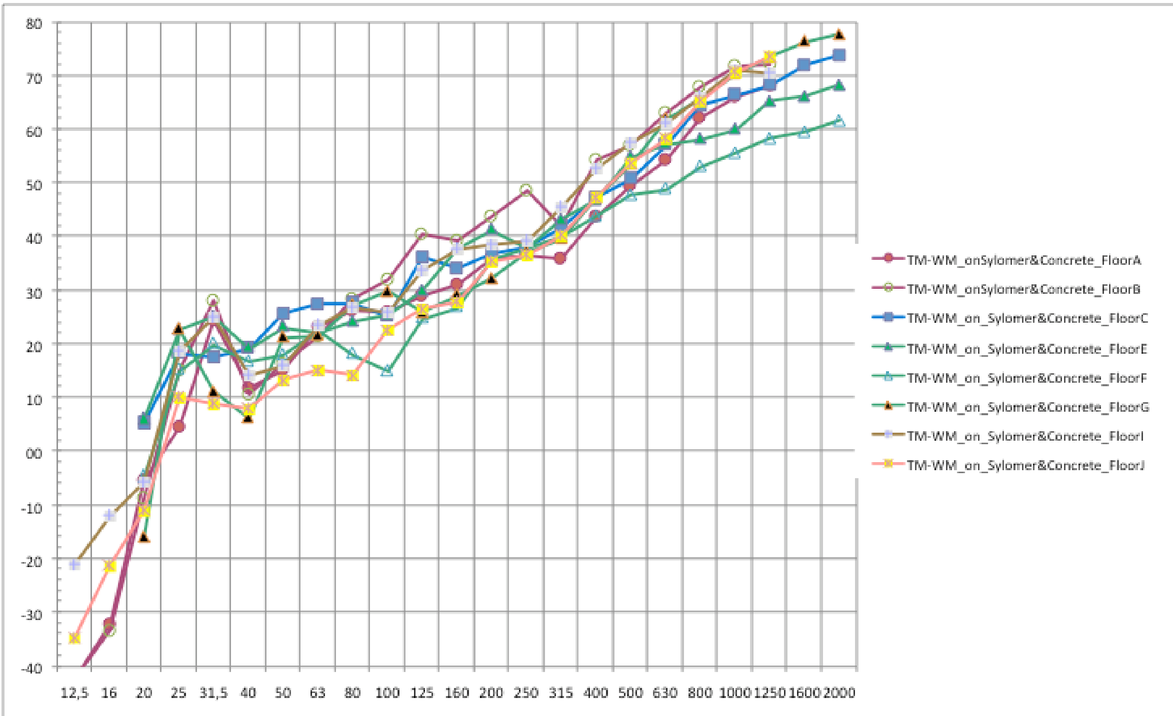

Figure 4c. As for 4a, washing machine put on the steel&concrete base on Sylomer® footings

6. CONCLUSIONS

The results are encouraging with respect to the possibility to establish a field method for the determination of structural sound source strength. The spread of results call for some statistical analysis to be applied to a measurement result, such that the final result represent e.g. the 15% highest level that may be expected on any kind of floor of the same type as being measured. For light weight floors, separate measurements must be made and the difference in vibration levels may only be referred to for similar types of floor.

The measurement method will be proposed as a Nordtest method for field measurements of structure borne source strength of building service equipment and the results will be used as basis for future standardization on this topic.

7. REFERENCES

[1] Draft European standard prEN 15657-1: Acoustic properties of building elements and of buildings - Laboratory measurement of airborne and structure borne sound from building equipment - Part 1: Simplified cases where the equipment mobilities are much higher than the receiver mobilities, taking whirlpool baths as an example

[2] Draft European standard prEN 12354-5: Building acoustics — Estimation of acoustic performance of building from the performance of elements — Part 5: Sounds levels due to service equipment. CEN/TC 126/WG 2, April 2008.