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INVESTIGATION OF REBUILD REPEATABILITY ISSUES IN LABORATORY IMPACT TESTING

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ABSTRACT

Materials such as floor coverings, screeds, and resilient matting are commonly applied on top of a floor-ceiling assembly to improve the impact noise insulation. Since the test measures the insulation of the entire assembly, it can be difficult to isolate the effect of these top-side components from the base structural assembly. The authors previously reported on a laboratory test program to evaluate the repeatability in the laboratory when rebuilding assemblies (1). As a continuation of that program, assemblies and products from historical tests were retested, and the resulting repeatability was poor. Investigation determined that the cause of the discrepancies was variation in the base assemblies, not the top-side materials. The techniques and results are discussed, and the effect on the interpretation of laboratory testing is evaluated.

Keywords: Sound, Insulation, Transmission

1. INTRODUCTION

Acoustical testing characterizes the acoustical performance of materials and assemblies. Testing is intended to evaluate assemblies with respect to building code or other requirements, to compare materials or assemblies with each other, and to research and develop new materials or assemblies. In order for acoustical testing to provide useful information to complete these goals, the characterization must be independent of environmental and other factors that are not directly related to the material, installation or construction. The uncertainties of the test methods must be small compared to the differences being evaluated, and the uncertainties must be well known and stable. If these conditions are not met, not only is the data unreliable, but the results can be misleading. For example, if two competing assemblies have similar actual performance, but the test results for the assemblies differ by a significant amount for reasons unrelated to the assembly, an observer will be led to the incorrect conclusion that one product is superior to the other.

Unfortunately, it is our experience that such misleading results are common. The problem is not the variation in the acoustical test results *per se*, but the fact that these uncertainties are large compared to the differences that are desired to be evaluated. Worse than the size of the uncertainties is the fact that the uncertainties are often not known or are inadequately measured and reported.

In this paper we report airborne and impact insulation testing of floor-ceiling assemblies that demonstrate the undocumented and unreported uncertainties associated with re-installing and re-building assemblies, and how the uncertainty affects both manufacturers of acoustical products and the acoustical engineers who depend on the data to make design decisions.

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2. STATE OF STATISTICAL CONTROL

In North America, most acoustical testing is performed according to standard methods published by ASTM International. ASTM E177 (2) defines the use of the terms “precision” and “bias” in other test methods, and discusses the underlying statistical understanding. In most building acoustics testing, the “true value” is defined by the test method results, so there is no bias by definition. However, the precision is a vital concept. Precision refers to the closeness of independent results performed under stated conditions.

E177 states bluntly that, “The measurement process must be in a state of statistical control; else the precision of the process has no meaning.” A process is in a state of statistical control if the variation between independent measurements (under the stated conditions) can be attributed to “chance causes,” sometimes called “common causes.” Chance causes refer to all of the unknown sources of variation, presumably numerous but small in magnitude, that result in variation of a repeated measurement. Chance causes represent a stable degree of variability and is generally normally distributed around the mean.

Lack of statistical control is the situation when the variation exceeds that expected from the stable, normal distribution of chance causes. E177 describes this condition as including “unassignable trends, cycles, abrupt changes, excess scatter, or other unpredictable variations” as determined by statistical methods. The presence of outliers, data points outside of the normal distribution of chance causes, “may indicate a weakness in the test method or its documentation.” One possible cause of lack of statistical control is variation due to “special causes” or “assignable causes” that have not been identified. Special causes result in a non-random distribution of results.

3. Testing program

3.1 Assembly description

The assemblies under consideration include gypsum concrete topping slab or screed over resilient sound mat. The gypsum concrete screed and sound mat are considered floor coverings in the sense that they are not an integral part of the structural design and can hence be installed on any structural system, or “base assembly.” Here we consider two base assemblies, one with 300 mm deep wood I-joists and one with dimensional timber joists (nominal 2 by 10 in., approximately 38 by 240 mm). For both joist types, the base assembly included fiberglass insulation in the cavity, and a gypsum board ceiling supported on resilient channels.

Since testing must be performed with numerous finish floors on numerous structural assembly types, the number of permutations is large. To facilitate testing, the laboratory constructs the base assemblies in large frames which can be moved into and out of the test chamber relatively quickly. The base assemblies are stored on site and the floor coverings are installed on the assemblies outside of the chamber. A picture of the finish floor on the base assembly installed in the test chamber is shown in Figure 1.

Figure 1 – Assembly installed in chamber.

3.2 Repeatability conditions

"Repeatability" refers to the variation of independent test measurements performed under the stated repeatability conditions. Per ASTM E177, the preferred repeatability conditions are those involving the same laboratory, by the same operator using the same equipment in as short a time as possible. E177 is aimed at more traditional measurements of properties of samples taken from a lot of materials. The repeatability conditions must be modified for acoustical testing, where only a single assembly is available to test in a short amount of time. Therefore, acoustical test methods define repeatability as testing the same sample repeatedly by the same operator using the same equipment in as short a time as possible.

However, many other repeatability conditions are possible. In previous papers (1,3,4), the authors evaluated additional repeatability conditions. *Re-install repeatability* is measured when the specimen is removed from the chamber and later re-installed without modification. *Re-build repeatability* is measured when the specimen is completely or partially demolished and rebuilt.

ASTM E492 (5) section 14 reports repeatability standard deviations under several repeatability conditions. One is a re-build repeatability condition for a wood joist floor, and another is a re-install repeatability condition for a concrete slab.

3.3 Previous Results

In the previously published study (1), the re-install and re-build repeatability were measured. To summarize, the re-install repeatability was consistent with the values reported in E492, although higher at high frequencies, and consistent across finish floors and assemblies. The re-build repeatability standard deviations were small in terms of single number ratings, but the third-octave data showed significant discrepancies. One of the rebuilt assemblies showed only small changes compared to the original, but the other assembly showed a systematic difference in both airborne and impact isolation.

3.4 Current Testing

The gypsum concrete topping and sound mat were installed on the wood I-joist base assembly. The result, in particular the impact insulation class (IIC) rating, was significantly lower (roughly 4–5 points) than expectations based on historical testing of the same products. Additional tests were performed to investigate the discrepancy.

The assemblies were re-installed and re-tested, which did not result in significant changes. This was expected, as the re-install repeatability had been measured to be small. Next, the ceiling was removed and re-installed (partial re-build repeatability). Second, the base assembly was removed and re-installed 90 mm (3.5 in.) higher in the test opening.

In another series of tests, the gypsum concrete topping and sound mat were installed on the dimensional timber base assembly. Again the results were lower than expectations. This assembly was also raised in the test opening. Finally two modifications were made to the base assembly.

The single number ratings are shown in Table 1. The rationale for these changes and the results are described in the following section.

Table 1: Summary of test results

Base Assembly	Condition	Finish	IIC	STC
I-joist	First test	Bare	43	59
		5.5 mm LVT	52	60
	Ceiling rebuild	Bare	44	60
		5.5 mm LVT	53	60
	Raised in opening	Bare	49	58
		5.5 mm LVT	56	58
Dimension timber	First test	Bare	42	57
	Raised in opening	Bare	44	54
	Frame reduced	Bare	43	56
	Lag screws removed	Bare	46	55

4. RESULTS AND DISCUSSION

4.1 Re-build repeatability

As described above, for the I-joist assemblies, the ceiling was removed and re-built, which resulted in an improvement of 1 IIC point for both finish floors. Figure 2 shows the change in impact insulation (positive values indicate improvement, i.e., lower impact sound levels) in third octaves. There was a consistent improvement, which might imply that the original assembly had errors or issues in construction.

In Figure 3, the absolute value of the differences is compared to the 95% repeatability limit based on the re-build repeatability condition reported in E492. The change from the ceiling re-build is therefore smaller than previously documented changes, and well within the expected uncertainty for this repeatability condition per the standard. The airborne transmission loss (not shown) did not have a large or systematic change. It was therefore concluded that errors (if any) or other variation in the ceiling construction were not sufficient to explain the results.

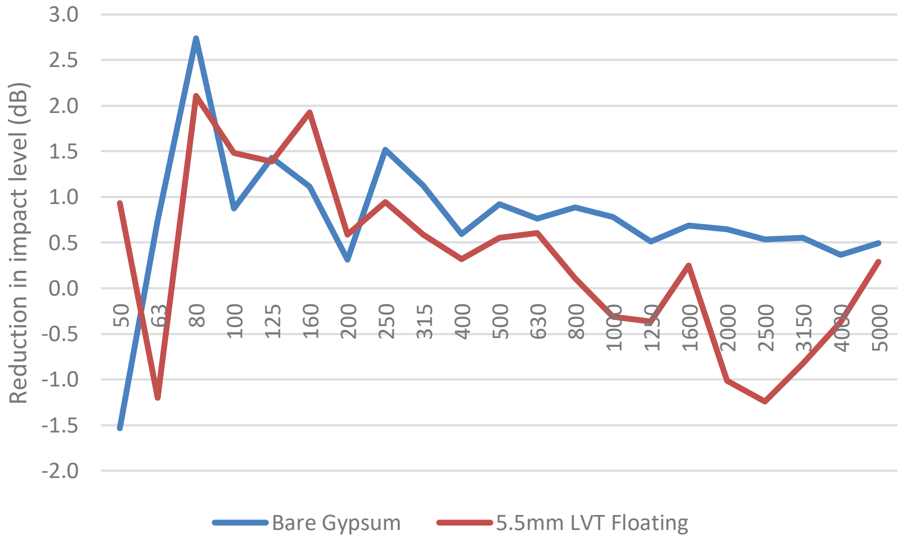

Figure 2 – Reduction in impact sound level due to partial re-build of the assembly.

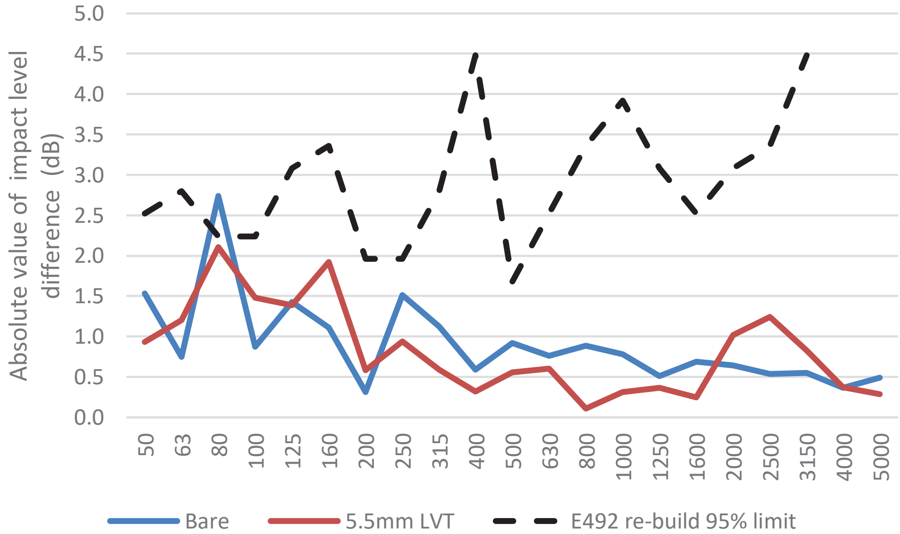

Figure 3 – Absolute value of difference between partially re-built assemblies compared to the 95% limit for re-build repeatability per E492.

4.2 Position within opening

The opening between the top and bottom chambers in the test laboratory has a depth that is set by the overall construction of the chambers. The thickness of the base assemblies varies, so there is an ambiguity in the test method regarding the exact position of the specimen within the opening. The specimens are generally positioned such that the floor of the specimen is flush with the floor of the top chamber. However, this is not always the case, and the position is not documented in the test report.

Both the I-joist and dimensional timber assemblies were raised about 90 mm (3.5 in.) in the opening and re-tested. The resultant improvement in impact insulation is shown in Figure 4. The differences at mid and high frequencies are large, and the single number ratings increased by 2-5 points. For comparison, Figure 5 compares the absolute value of the differences to the 95% repeatability limit based on the re-install repeatability measured previously (1). The results are clearly outside the expected variation.

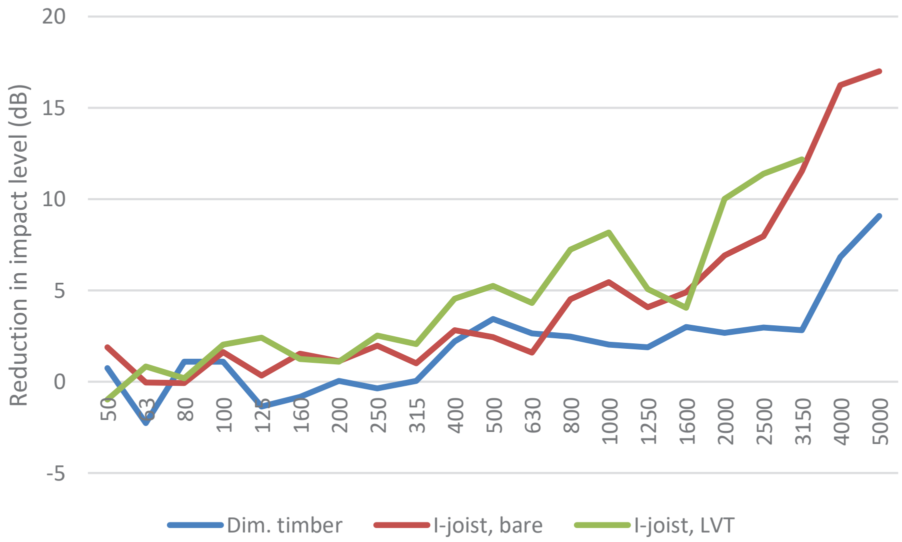

Figure 4 – Reduction in impact sound level due to moving the specimen within the test opening.

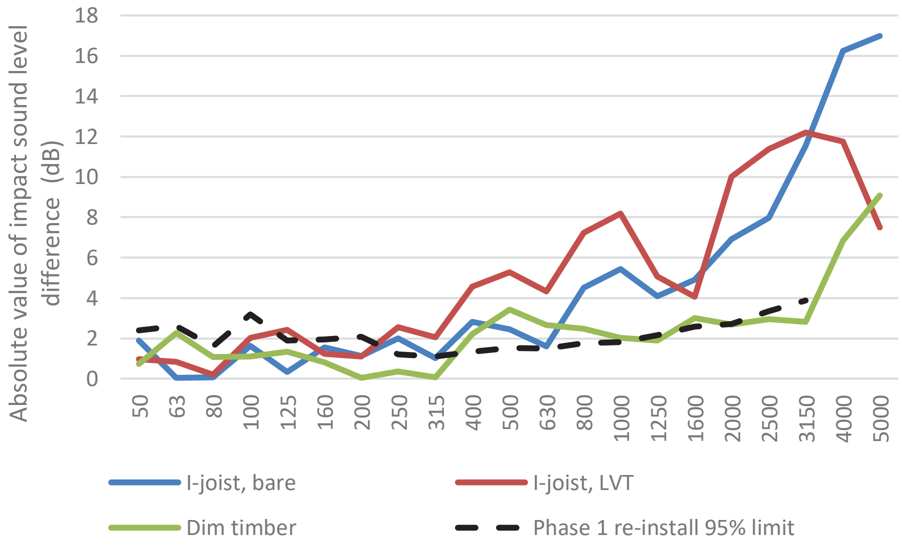

Figure 5 – Absolute value of differences due to re-installing the assembly at a different position in the test opening, compared with the 95% limit for re-install repeatability previously established.

The position of the specimen within the opening has a large effect of the test result, yet this parameter is not recorded or documented in the test report. Tests of otherwise identical assemblies will exhibit abrupt and unexpected shifts in measured values depending on their position. An observer who was not aware of the effect of the position might include such variations within re-install repeatability. In fact, the position of the specimen within the opening appears to be a "special cause" and failing to control or document this parameter means that the test process is not in a state of statistical control.

4.3 Frame construction

For the dimensional timber system, investigation revealed that changes had been made to the base assemblies. As mentioned, the base assemblies are stored at the laboratory and used to test a wide variety of floor covering products. In an effort to stiffen the base assemblies to make them easier to move, newly-constructed base assemblies were not identical to assemblies that had been used in the past. The new base assemblies had been reinforced with additional pieces of lumber around the bottom of the frame, and large lag screws had been added to help to support the joists.

To determine if these changes to the base assembly affected the results, several tests were performed. First the new assembly with modifications was raised within the chamber opening as described in section 4.2, resulting in an increase of 2 IIC points. Second, the additional lumber used to stiffen the frame was removed from the dimensional lumber assembly, so that the floor level was equal to the baseline test (low, flush with top chamber floor) but with the assembly supported on a non-rigid base. This resulted in a slight decrease in IIC rating. Finally, half of the lag screws were removed, one from the end of each joist. The change in impact and airborne isolation is shown in Figure 6. The individual changes are shown; that is, the curves should be summed to determine the overall change.

Removing the lumber from the frame resulted in a large increase in airborne isolation, while the effect on the impact isolation is smaller. Removing the lag screws reduced the transmission loss slightly, but significantly increased the impact insulation.

Changes to the base structural assemblies are not included in existing definitions of re-rebuild or re-install repeatability conditions. It appears that changes to the base assembly are a special cause that is causing a significant, non-random change in the test results, and that the test method is not in a state of statistical control. The changes to the base assemblies were not documented or described to the laboratory's clients. It is not known how much testing the laboratory performed when constructing a new base assembly to verify that the performance compared to the existing base assemblies.

It may be possible to reasonably define repeatability conditions that include the variation in base assembly. This would require measurement and documentation of the variation among nominally identical base assemblies. To our knowledge this work has not been performed.

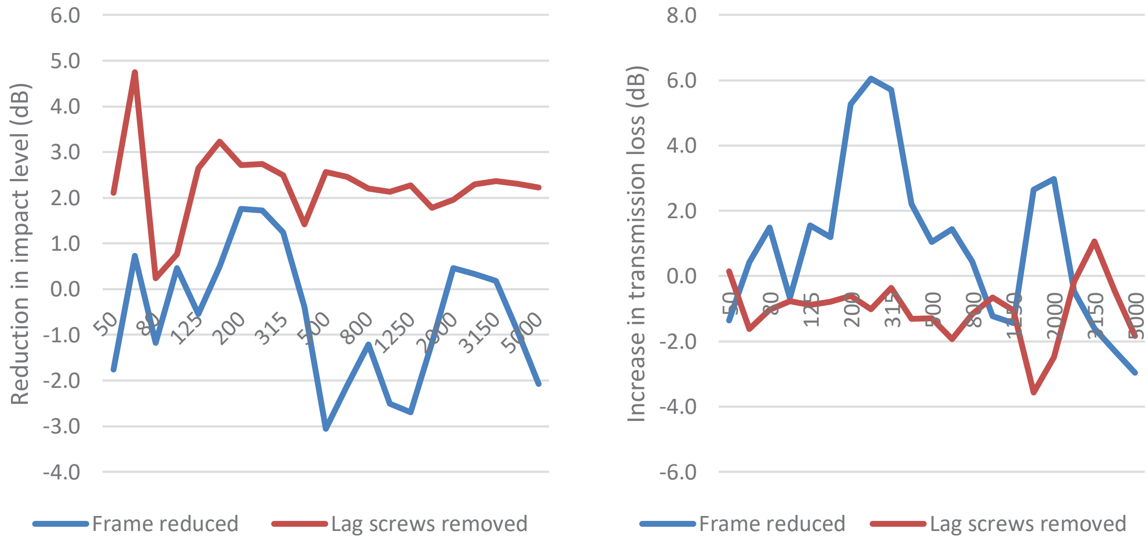

Figure 6 – Improvement in impact isolation (left) and airborne isolation (right) for the changes to the base assembly described in the text.

5. CONCLUSIONS

The nature of acoustical laboratory testing is such that numerous repeatability conditions occur that may be uncommon in other types of testing. Some of these conditions have been documented previously (1,3,4) and reported here. Measuring the variation under various repeatability conditions is a critical task, and determines how well the test method can resolve differences between assemblies and products.

More importantly, we have determined that some of the variations in laboratory test results cannot be assumed to be statistical (common cause) variation. This work documents several special causes of variation within acoustical testing that are not reported and have not been suitably investigated by the test laboratories. Since these special causes are not controlled as part of the repeatability conditions, the test method is not in a state of statistical control, and the repeatability is not defined. Further, the size of the variations calls into question whether the test method can provide the desired level of precision.

It is in the interest of all parties that the testing be performed in as fast and efficient a manner as possible. However, this study shows that the testing paradigm of building, storing, and installing base assemblies has more parameters than then laboratories are currently tracking and reporting, or that customers are specifying as part of their test programs. Additional testing is required to demonstrate the reliability of the base assemblies and the statistical control of the test method.

Since the acoustical testing results are part of building codes and required by law, a top priority of the community should be the research, analysis, and protocols required to bring the method into a state of statistical control and to properly document the uncertainty. Without this work, the market will continue to be inundated with misleading and uninformative test data. The test method must match the needs of the community.

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