PROBABILISTIC APPROACH TO SELECTING A REASONABLE MINIMUM SAMPLE OF ROOMS FOR ASTM E-336 TESTING

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1 Introduction

Large buildings or multi-building complex designs include a multitude of partition performance requirements, construction types, and floor plan configurations. One may therefore be faced with potentially assessing hundreds of wall and ceiling design variations with varying sound reduction performance requirements. For one recent project, the RWDI design team was faced with helping a client design and assess performance of approximately 10,000 rooms within a multi-building complex.

Partition constructions varied between STC 45 and STC 60+. Testing was carried out on the STC 50, 55 and 60+ constructions, with the intention that STC 45 walls would typically be built using STC 50 rated constructions. The project specifications required testing of a large sample of the partitions to verify their performance, however the standard of acceptable performance was not well defined. The biggest issue with the testing requirements was a lack of applicable validation criteria to provide confidence in the tested partitions being representative of the remaining partitions in the complex. As a result, RWDI proposed using a statistical approach to minimizing the number of total rooms tested, while providing a specified level of confidence in partition performance for the whole building.

2 Method

2.1 Acoustical testing method

There are three main metrics for evaluating the sound transmission performance of a partition. These include STC (Sound Transmission Classification), FSTC (Field Sound Transmission Classification) and ASTC (Apparent Sound Transmission Classification).

STC is a laboratory rating under ideal conditions, typically used for selecting partition constructions during design. FSTC was not chosen due to the minimum room size for testing and the stringent requirements necessary to control flanking paths before proper testing can be conducted. ASTC was used as it includes the effects of flanking paths under normal usage while allowing the removal of flanking sounds through doorways by means of door plugs. This approach allowed testing to be conducted during construction before all finishes were complete or doors were installed.

The testing method required for this project was to follow ASTM E-336 [1] as applicable.

2.2 Statistical method

The project specification originally required that 5% of all partitions be tested. For a project this size with approximately 10,000 rooms, the number of partitions to be tested was estimated to be between 500 and 1000, which was not practical. A new confidence method/criteria needed to be designed for this size of project to provide confidence to the client and owner that the partitions were constructed to the proper standard.

Thus, a probabilistic approach based on Bayes' Theorem was developed. Bayes' Theorem was applied to calculate the probability that a given percentage of all rooms fail, based on test results of a random sample of partitions. The solution is a continuous distribution that is directly proportional to the hypergeometric distribution (Gregory [2]). The approach took in several factors that included:

- The tolerance for risk is given by the percentage of the credible region (95%), which can be adjusted based on the risk tolerance.
- The failure rate (the percent of rooms permitted to fail the test) was set at 10%, but can be adjusted.
- The failure threshold is incorporated via the specified variance tolerance, which was set at 5 STC points below the specified laboratory STC rating.

The hypergeometric distribution requires as input the sample size, the measured failure rate in the sample, the total number of partitions, and the acceptable failure rate. The limit of the credible region is determined from the area underneath the probability distribution. The statistical approach provides a means of estimating the overall expected "Pass/Fail" rate for all partitions in the project. The goal of the testing and remediation program was to achieve at least 95% probability (tolerance for risk) that no more than 10% (failure rate) of the entire population of partitions are below the targeted ASTC rating (failure threshold). In other words, through this analysis, we can state that we are 95% confident that at least 90% of the partitions in the building will achieve the desired performance level.

For this statistical approach to work, the selected partitions must meet the following conditions:

- Randomly sampled (i.e. not selected by those involved with the construction);

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- Representative of different wall types, room types, and wall configurations (i.e. with different mullion and penetration conditions, column locations, duct layouts, recessed panels, etc.); and
- Relatively evenly distributed throughout the complex (i.e. from various stages of construction, different construction crews, variations in materials or construction practices, etc.).

Another advantage of the statistical approach is the ability to assess a small sample of tests while partitions are being constructed, and to compare the results to previous testing rounds. This method was used to correct construction practices and ensure continual improvement throughout construction. This feedback allowed the contractors to understand the faults during construction and fix all similar and future constructions. When failing partitions were fixed, the resolved issues were retested and re-incorporated into the statistical model. This process requires close communication and cooperation among the acoustics consultant, the construction manager and the construction teams. Nevertheless, the alternative is significant re-work and post-construction mitigation.

The example below for a population size of 450 partitions total shows several rounds of testing and continuous improvement until the statistical requirements above were met.

Table 1: Example of statistical analysis applied to population of 450 partitions.

Activity	Partitions Tested	Failed	Median Failure Rate	Upper 95% Confidence Failure Rate
First round of tests	8	1	--	--
Cumulative	**8**	**1**	**18%**	**43%**
Second round of tests	12	1	--	--
Cumulative	**20**	**2**	**12%**	**27%**
Mitigation for one partition type	--	-1	--	--
Cumulative	**20**	**1**	**8%**	**20%**
Third round of tests	20	1	--	--
Cumulative	**40**	**2**	**6%**	**14%**
Mitigation for one partition type	--	-1	--	--
Cumulative	**40**	**1**	**4%**	**11%**
Fourth round of tests	20	0	--	--
Cumulative and Final	**60**	**1**	**2%**	**7%**

3 Acoustical testing

3.1 Initial visit

An initial site visit was completed by RWDI staff during early construction of partitions, with only a few rooms constructed and no finished ceilings, doors, or furnishings within the room. The testing identified construction deficiencies for the contractors to improve. The main deficiencies observed were typical flanking paths at penetrations and perimeter joints (i.e. at slab and window mullions), with little attention to construction of proper acoustic details. The client was informed of the deficiencies, and these were corrected in both the existing partitions and in all future partitions. This was part of the continual improvement aspect of the testing plan to help the client improve construction quality while striving to meet the new testing criteria.

3.2 Follow-up visits

Several more site visits were made to the site to conduct further sample testing to populate the statistical model and eventually satisfy the testing program criteria. These tests were usually completed after confirmation that the client had attempted to rectify any earlier failures so that the statistical model could be updated. As before, the results of the testing were provided to the client so that failures could be investigated and corrected as construction of the complex progressed.

4 Results

In the end, far fewer than 5% of the rooms required testing. Meeting the above statistical model parameters required a total of 243 tests conducted on 196 different partitions. These numbers illustrate that re-testing of several partitions was required. The total breakdown included:

- 120 partitions with a design rating of STC 50;
- 60 partitions with a design rating of STC 55;
- 14 partitions with a design rating of STC 60+; and
- a check of 2 partitions with a STC 45 target.

The majority (169) of the partitions passed on their first test. Of the remaining, 22 partitions required very minor remediation before passing on their second test. Finally, there were 5 partitions that required multiple tests and deeper investigation into their reduced ASTC performance.

5 Discussion

The above statistical method resulted in a significantly reduced sample of partition tests to meet the client's requirements, and provided sound statistical evidence that untested rooms would be expected to meet the design requirements. The testing procedure also allowed for continual improvements to construction practices to be implemented.

One drawback to this statistical method for testing, is that until sufficient passing tests have been completed, the total number of tests required to meet the statistical validation is not known. Therefore, we found that scoping and planning the proper timing and number of site visits was quite difficult. However, the probabilistic approach provides a statistically based response for an acceptable number of partitions to be tested in a large building or complex with varying STC requirements, wall types, and wall configurations. Weighting these benefits versus the drawback, we found this approach to be superior to agreeing on a fixed sample size (number of partitions to be tested) prior to testing.

References

[1] ASTM E-336: Standard Test Method for Measurement of Airborne Sound Attenuation between Rooms in Buildings

[2] Gregory, P.C., 2005: Bayesian Logical Data Analysis for the Physical Sciences. A Comparative Approach with Mathematica Support. Cambridge University Press.