THE CORRECTION OF ECHOES AND REVERBERATION IN THE AUDITORIUM AT THE UNIVERSITY OF ILINOIS

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A brief account is given herewith of an investigation of the acoustical defects of the Auditorium at the University of Illinois. This investigation has extended over a period of nearly seven years and was recently brought to a conclusion when materials were installed to correct the reverberation and echoes.[1]

The Auditorium is a large structure nearly hemispherical in shape, with several large arches and recesses which break the regularity of its inner surface. Because of its large size and concreted curved walls, it was afflicted with both a reverberation and echoes. A watch ticking on the pulpit could be heard far away in the balcony. A whisper started by an observer on the stage was returned so that it could be heard distinctly after it had traveled a distance of 225 feet. Echoes were heard from every direction and the reverberation lasted for several seconds. Speakers found their utterances thrown back at them and auditors in every part of the house had difficulty in understanding what was said.

This unfortunate condition proved beneficial in the respect that it allowed tests of faulty acoustics to be made under exceptionally good conditions. A systematic investigation, avoiding "cut-and-dry" methods of cure, was inaugurated first

[1]Detailed accounts of the investigation with numerous drawings and photographs may be obtained in Bulletins Nos. 73 and 87 on "Acoustics of Auditoriums," and "The Correction of Echoes and Reverberation in the Auditorium, University of Illinois." published by the Engineering Experiment Station of the University of Illinois. These bulletins may be obtained on application to the author or to the Director of the Engineering Experiment Station, University of Illinois, Urbana, Ill.

to ascertain what the acoustical defects were and then to investigate the methods of cure and apply them to correct the trouble.[2]

The usual acoustical faults in auditoriums, as pointed out by Professor Sabine[3] in his classical experiments on this subject, are a reverberation, or undue prolongation of sound, and echoes; both of these faults being due to reflection of sound from the walls. Sabine has shown definitely how the reverberation can be corrected by installing sound-absorbing materials. Other defects, such as interference and resonance, may also be present, but they are usually of small consequence compared with the first two mentioned.

The reverberation in the Auditorium at the University of Illinois could therefore have been cured by installing hairfelt on the walls. Experimental tests on the reverberation were conducted by Sabine's method and calculations made to determine the amount of absorbing material needed to reduce the reverberation to a satisfactory point. The greatest annoyance, however, appeared to be due to echoes, so that the main purpose of the investigation was to find the echoes and eliminate them.

If an observer stood on the stage and clapped his hands a veritable chaos of sound resulted and echoes were heard from every direction.This action was too complex to lead to a definite analysis of the trouble, so a simpler method was adopted by which a small beam of sound was to be sent successively in different directions and its paths traced after reflection. A difficulty then arose to find a suitable arrangement of apparatus to carry out the method. A ticking watch backed by a reflector gave definite data, as did also a metronome enclosed in a box so that its sound could escape only through a directed horn. The results were not entirely conclusive. A satisfactory method was finally found by using an arc light at the focus of a parabolic reflector. The arc gave forth an intense hissing sound that traveled with the light so that an observer could see where the sound struck and thus locate the walls that

[2]"Echoes in an Auditorium," Physical Review, Vol. 32, p. 231, 1911. "Air Currents and the Acoustics of Auditoriums," Engineering Record, Vol. 67, p. 265, 1913. "Acoustical Effect of Fireproofed Cotton-Flannel Sound Absorbers," Engineering News, Vol. 71, p. 261, Jan. 29, 1914.

[3]See articles on "Architectural Acoustics," American Architect, 1900.

caused the echoes. Small mirrors attached to the walls assisted in tracing the reflections.

Experiments to improve the acoustics were then carried on in accordance with the results of the analysis. Sounding boards, or more properly, reflecting boards, of various kinds were tested.[4] A flat board about five feet square was placed at an angle over the position of the speaker. This proved to be of small effect, as was also the case when a large canvas sheet 12 by 20 feet was similarly mounted, although speakers said the ease of speaking was increased when they stood under the canvas. A parabolic reflector was then tried and gave much better results, but it had several disadvantages. It was necessary for the speaker to keep closely to the focus of the parabola to have the sound proceed properly. Any movement on his part would diminish the efficiency of the reflector. Also the sound worked both ways, so that noises generated by the audience were focused at the speaker's ears. The reflector was suited only for a single speaker and would not serve for concerts or plays where the entire stage was used. Furthermore it did not reduce the reverberation materially.

A word or two should be added concerning the use of wires in correcting acoustics. Wires attached in an auditorium have practically no effect on the acoustics. Five miles of wire were installed in one church and the acoustics still remained imperfect. Wires have much the same effect on the sound that a fish line in the water has on water waves. To break up the sound, the obstacle must be much larger than a wire; it must have dimensions comparable with the wave length of the sound.[5]

Canvases were then hung in various positions in the hall to determine the effect of cutting off certain walls from the action of the sound. Absorbing materials were also hung at critical points suggested by the analysis. The final provisional cure was brought about when four large canvases were hung in the dome. For the first time speakers could talk with comparative ease without suffering great annoyance from echoes.

[4] "The Use of Sounding Boards in an Auditorium," Physical Review, Vol. 1, 2, p. 241, 1913. Also a more complete article in The Brickbuilder, June, 1913.

[5] "Inefficiency of Wires as a Means of Curing Defective Acoustics of Auditoriums," Science, Vol. 35, p. 833, 1912.

From the acoustical standpoint the Auditorium was then in fairly satisfactory shape. The canvas curtains, however, were unsightly and did not accord with the architectural features of the room. Steps were taken to find an arrangement that would satisfy both the acoustical and architectural requirements. Calculations were made by Sabine's method to determine the amount of hairfelt necessary to cure the reverberation. Unfortunately this amount was not sufficient to cover all the walls producing echoes. It was desirable to eliminate the echoes, but it was risky to install much absorbing material and make the Auditorium too dead for sound.

In the face of this difficulty it was decided to carry on further experiments before attempting the final cure. One of the large curved walls was covered with vertical strips of hairfelt 30 inches wide placed 30 inches apart with bare wall space between them. This arrangement had several advantages. It maintained the curvature of the wall and used only half the material necessary to cover the surface completely. Also, it was theoretically more effective in breaking up the incident sound because the portions of the waves striking the felt strips were strongly absorbed and changed in phase. The results obtained were encouraging, though not as marked in diminishing the echoes as anticipated. Another wall was therefore padded in a similar way except that the felt strips were installed one foot out from the surface. This would allow the felt to act on both the incident and reflected waves and thus more thoroughly modify the regularity of the sound. The dome surface was also treated, the felt being mounted in radial strips placed 18 inches from the ceiling at the edge of the skylight and gradually nearing the wall until it touched at the crown of the arches.

Other changes were made in the Auditorium. A pipe organ was installed, the lighting system was changed and the interior was redecorated. All of these modfications affected the acoustics and were considered when calculating the amount of hairfelt to be used.

The results obtained have been generally satisfactory. The remodeled Auditorium has been used almost continuously under varied conditions for music and speaking and has been found to have acceptable acoustics. A speaker with a mod-

erate voice can be heard and understood by auditors in the most distant seats. According to experts, the music of the pipe organ is satisfactorily rendered. The room is suited also for orchestra music, although for this case the carpet is removed from the stage so as to provide a sounding board for the instruments. The reverberation is not excessive even when no audience is present, so that rehearsals may be conducted under favorable conditions. Several instances of echoes have been reported, but these do not appear to prevent the words of the speaker being understood.

While the best evidence for the improved conditions was furnished by the favorable opinion of the auditors, it was thought desirable to get additional information by experiment. Accordingly, the time of reverberation was determined experimentally and was found to be satisfactorily reduced from what it had been before the correction was made. Echoes were tested by the arc light reflector, and by a special arrangement of megaphones. The padded walls diminished the sound to such an extent that they produced little trouble, but several unpadded walls of comparatively small area produced echoes under particular conditions. For instance, when the speaker faces such a wall so that the auditor can see the profile of his face, an echo is perceptible. This is because the sound coming directly to the auditor is diminished while that reflected from the wall is augmented.

The main conclusions of the investigation are as follows: A room with large volume and hard, nonporous walls with but little sound-absorbing materials will have a reverberation. If the dimensions of the room are great, echoes are likely to be set up, especially if the reflecting walls are curved. Walls responsible for the production of echoes may be located by using an arc light backed by a reflector as a source of sound. Such a room may have its faulty acoustics corrected by installing sound-absorbing material, but this should be placed so as to eliminate echoes as well as to reduce the reverberation.