IX. Appendix B: Acoustics Breadth Calculations

ACOUSTICS BREADTH

SOUND TRANSMISSION CLASS - ARCHITECTURAL ACOUSTICS BY DAVID EGAN
- 4" REINFORCED CONCRETE SLAB 44
- 6" REINFORCED CONCRETE SLAB 55
- INTERPOLATE/EXTRAPOLATE TO OBTAIN OTHER VALUES $y=55x+22$
- VALID FOR SPEECH FREQUENCIES OF 125 TO 4000 HZ, DOES NOT INCLUDE RATINGS BELOW 125 HZ WHICH MAY BE ACHIEVED BY MUSIC, OKAY AS MOST EVENTS OCCUR IN THE LATER EVENING HOURS OR ON THE WEEKEND
- EXISTING STEEL STRUCTURAL SYSTEM SOUND TRANSMISSION CLASS
  5" CONCRETE ON 6" COMPOSITE STEEL DECK
  ASSUMING ONLY 3" CONCRETE TOPPING PARTICIPATES IN REDUCTION OF SOUND TRANSMISSION
  3" REINFORCED CONCRETE SLAB 39 - ALL FLOORS
- PROPOSED CONCRETE STRUCTURAL SYSTEM SOUND TRANSMISSION CLASS
  12" REINFORCED CONCRETE SLAB 88 - 1st - 4th, 6th FLOORS
  14" REINFORCED CONCRETE SLAB 99 - 5th FLOOR
- STRUCTURAL SYSTEM COMPARISON
  STC STEEL = 39 << STC CONCRETE = 88

REVERBERATION TIME - ARCHITECTURAL ACOUSTICS BY DAVID EGAN
- LECTURE & CONFERENCE ROOMS 0.7 s - 1.1 s
- DANCE & ROCK BANDS 1.0 s - 1.2 s
- GOAL REVERBERATION TIME 1.1 s
- 125 Hz $1.3(1.1s) = 1.43s$
  500 Hz $1.0(1.1s) = 1.10s$
  4000 Hz $0.77(1.1s) = 0.85s$
- REVERBERATION TIME TO BE CALCULATED FOR BOTH FULL & HALF OCCUPANCY

$$T = 0.05\frac{V}{a} = 0.05\frac{V}{\sum Soc}$$

$V = 2(46.83')(40.34')(7.5') + (46.83')(33.34')(12.5') = 47853\ FT^3$

i Sound Transmission Class Comparison

Sound Transmission Class Data from Architectural Acoustics by David Egan

Building Construction	Transmission Loss (dB) 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC Rating	IIC Rating†
31. Construction no. 30 with 5/8-in gypsum board screwed to resilient channels spaced 24 in oc perpendicular to joists	30	35	44	50	54	60	47	39
32. Construction no. 31 with 3-in glass-fiber insulation in cavity	36	40	45	52	58	64	49	46
33. 4-in reinforced concrete slab (54 lb/ft²)	48	42	45	56	57	66	44	25
34. 14-in precast concrete tees with 2-in concrete topping on 2-in slab (75 lb/ft²)	39	45	50	52	60	68	54	24
35. 6-in reinforced concrete slab (75 lb/ft²)	38	43	52	59	67	72	55	34
36. 6-in reinforced concrete slab with 3/4-in T&G wood flooring on 1 1/2 by 2 wooden battens floated on 1-in glass fiber (83 lb/ft²)	38	44	52	55	60	65	55	57
37. 18-in steel joists 16 in oc with 1 5/8-in concrete on 5/8-in plywood under heavy carpet laid on pad, and 5/8-in gypsum board attached to joists on ceiling side (20 lb/ft²)	27	37	45	54	60	65	47	62
Roofs[2]								
38. 3 by 8 wood beams 32 in oc with 2 by 6 T&G planks, asphalt felt built-up roofing, and gravel topping	29	33	37	44	55	63	43	
39. Construction no. 38 with 2 by 4s 16 in oc between beams, 1/2-in gypsum board supported by metal channels on ceiling side with 4-in glass-fiber insulation in cavity	35	42	49	62	67	79	53	
40. Corrugated steel, 24 gauge with 1 3/8-in sprayed cellulose insulation on ceiling side (1.8 lb/ft²)	17	22	26	30	35	41	30	
41. 2 1/2-in sand and gravel concrete (148 lb/ft³) on 28 gauge corrugated steel supported by 14-in-deep steel bar joists with 1/2-in gypsum plaster on metal lath attached to metal furring channels 13 1/2 in oc on ceiling side (41 lb/ft²)	32	46	45	50	57	61	49	
Doors[2]								
42. Louvered door, 25 to 30% open	10	12	12	12	12	11	12	
43. 1 3/4-in hollow-core wood door, no gaskets, 1/4-in air gap at sill (1.5 lb/ft²)	14	19	23	18	17	21	19	
44. Construction no. 43 with gaskets and drop seal	19	22	25	19	20	29	21	
45. 1 3/4-in solid-core wood door with gaskets and drop seal (4.5 lb/ft²)	29	31	31	31	39	43	34	
46. 1 3/4-in hollow-core 16 gauge steel door, glass-fiber filled, with gaskets and drop seal (7 lb/ft²)	23	28	36	41	39	44	38	
Glass[1,2]								
47. 1/8-in monolithic float glass (1.4 lb/ft²)	18	21	26	31	33	22	26	
48. 1/4-in monolithic float glass (2.9 lb/ft²)	25	28	31	34	30	37	31	
49. 1/2-in insulated glass: 1/8- + 1/8-in double glass with 1/4-in airspace (3.3 lb/ft²)	21	26	24	33	44	34	28	
50. 1/4- + 1/8-in double glass with 2-in airspace	18	31	35	42	44	44	39	
51. Construction no. 50 with 4-in airspace	21	32	42	48	48	44	43	
52. 1/4-in laminated glass, 30-mil plastic interlayer (3.6 lb/ft²)	25	28	32	35	36	43	35	
53. Double glass: 1/4-in laminated + 3/16-in monolithic glass with 2-in airspace (5.9 lb/ft²)	25	34	44	47	48	55	45	
54. Double glass: 1/4-in laminated + 3/16-in monolithic glass with 4-in airspace (5.9 lb/ft²)	36	37	48	51	50	58	48	
55. Double glass: 1/4-in laminated + 1/4-in laminated with 1/2-in airspace (7.2 lb/ft²)	21	30	40	44	46	57	42	

† IIC (*impact isolation class*) is a single-number rating of the impact sound transmission performance of a floor-ceiling construction tested over a standard frequency range. The higher the IIC, the more efficient the construction will be for reducing impact sound transmission. INR (*impact noise rating*) previously was used as the single-number rating of impact noise isolation. To convert the older INR data to IIC, add 51 to the INR number.

‡ A wide range of TL and STC performance can be achieved by gypsum wallboard constructions. Refer to ASTM E 90 laboratory report and literature from manufacturers for specific details such as type of gypsum board; gauge, width, and spacing of steel studs; glass-fiber or mineral-fiber insulation thickness and density; and complete installation recommendations.

ii. Reverberation Time Comparison

Existing Steel Structural System Reverberation Time- Half Occupancy				
Surface	α 125 Hz	α 500 Hz	α 4000 Hz	S (ft^2)
Walls				
5/8" Gypsum Wall Board	0.55	0.08	0.11	954.20
Painted Concrete Block	0.10	0.06	0.08	515.10
Heavy glass	0.18	0.04	0.02	1309.40
Floors				
Glazed tile	0.01	0.01	0.02	1561.31
Heavy Carpet on Concrete	0.02	0.14	0.65	3778.24
Ceilings				
1/2" Gypsum Wall Board	0.29	0.05	0.09	1561.31
3/4" Acoustical Board Suspension System	0.76	0.83	0.94	3778.24
Seating & Audience				
Fabric Well-Upholstered Seats	0.19	0.56	0.59	62.97
Audience	0.39	0.80	0.87	230.00
Surface	ΣSα 125 Hz	ΣSα 500 Hz	ΣSα 4000 Hz	
Walls				
5/8" Gypsum Wall Board	524.81	76.34	104.96	
Painted Concrete Block	51.51	30.91	41.21	
Heavy glass	235.69	52.38	26.19	
Floors				
Glazed tile	15.61	15.61	31.23	
Heavy Carpet on Concrete	75.56	528.95	2455.86	
Ceilings				
1/2" Gypsum Wall Board	452.78	78.07	140.52	
3/4" Acoustical Board Suspension System	2871.47	3135.94	3551.55	
Seating & Audience				
Fabric Well-Upholstered Seats	11.96	35.26	37.15	
Audience	89.70	184.00	200.10	
a (sabins)	4329.10	4137.46	6588.76	
T (s)	0.55	0.58	0.36	

Existing Steel Structural System Reverberation Time- Full Occupancy				
Surface	α 125 Hz	α 500 Hz	α 4000 Hz	S (ft^2)
Walls				
5/8" Gypsum Wall Board	0.55	0.08	0.11	954.20
Painted Concrete Block	0.10	0.06	0.08	515.10
Heavy glass	0.18	0.04	0.02	1309.40
Floors				
Glazed tile	0.01	0.01	0.02	1561.31
Heavy Carpet on Concrete	0.02	0.14	0.65	3778.24
Ceilings				
1/2" Gypsum Wall Board	0.29	0.05	0.09	1561.31
3/4" Acoustical Board Suspension System	0.76	0.83	0.94	3778.24
Seating & Audience				
Fabric Well-Upholstered Seats	0.19	0.56	0.59	125.94
Audience	0.39	0.80	0.87	460.00
Surface	ΣSα 125 Hz	ΣSα 500 Hz	ΣSα 4000 Hz	
Walls				
5/8" Gypsum Wall Board	524.81	76.34	104.96	
Painted Concrete Block	51.51	30.91	41.21	
Heavy glass	235.69	52.38	26.19	
Floors				
Glazed tile	15.61	15.61	31.23	
Heavy Carpet on Concrete	75.56	528.95	2455.86	
Ceilings				
1/2" Gypsum Wall Board	452.78	78.07	140.52	
3/4" Acoustical Board Suspension System	2871.47	3135.94	3551.55	
Seating & Audience				
Fabric Well-Upholstered Seats	23.93	70.53	74.31	
Audience	179.40	368.00	400.20	
a (sabins)	4430.76	4356.72	6826.01	
T (s)	0.54	0.55	0.35	

Proposed Concrete Structural System Reverberation Time- Half Occupancy				
Surface	α 125 Hz	α 500 Hz	α 4000 Hz	S (ft^2)
Walls				
5/8" Gypsum Wall Board	0.55	0.08	0.11	954.20
Rough Concrete	0.01	0.04	0.10	515.10
Heavy glass	0.18	0.04	0.02	1309.40
Floors				
Glazed tile	0.01	0.01	0.02	1561.31
Heavy Carpet on Concrete	0.02	0.14	0.65	3778.24
Ceilings				
Rough Concrete	0.01	0.02	0.02	1561.31
1/2" Gypsum Wall Board Suspension System	0.15	0.05	0.09	3778.24
Seating & Audience				
Fabric Well-Upholstered Seats	0.19	0.56	0.59	62.97
Audience	0.39	0.80	0.87	230.00
Surface	ΣSα 125 Hz	ΣSα 500 Hz	ΣSα 4000 Hz	
Walls				
5/8" Gypsum Wall Board	524.81	76.34	104.96	
Rough Concrete	5.15	20.60	51.51	
Heavy glass	235.69	52.38	26.19	
Floors				
Glazed tile	15.61	15.61	31.23	
Heavy Carpet on Concrete	75.56	528.95	2455.86	
Ceilings				
Rough Concrete	15.61	31.23	31.23	
1/2" Gypsum Wall Board Suspension System	566.74	188.91	340.04	
Seating & Audience				
Fabric Well-Upholstered Seats	11.96	35.26	37.15	
Audience	89.70	184.00	200.10	
a (sabins)	1540.84	1133.28	3278.26	
T (s)	1.55	2.11	0.73	

Proposed Concrete Structural System Reverberation Time- Full Occupancy				
Surface	α 125 Hz	α 500 Hz	α 4000 Hz	S (ft^2)
Walls				
5/8" Gypsum Wall Board	0.55	0.08	0.11	954.20
Rough Concrete	0.01	0.04	0.10	515.10
Heavy glass	0.18	0.04	0.02	1309.40
Floors				
Glazed tile	0.01	0.01	0.02	1561.31
Heavy Carpet on Concrete	0.02	0.14	0.65	3778.24
Ceilings				
Rough Concrete	0.01	0.02	0.02	1561.31
1/2" Gypsum Wall Board Suspension System	0.15	0.05	0.09	3778.24
Seating & Audience				
Fabric Well-Upholstered Seats	0.19	0.56	0.59	125.94
Audience	0.39	0.80	0.87	460.00

Surface	ΣSα 125 Hz	ΣSα 500 Hz	ΣSα 4000 Hz
Walls			
5/8" Gypsum Wall Board	524.81	76.34	104.96
Rough Concrete	5.15	20.60	51.51
Heavy glass	235.69	52.38	26.19
Floors			
Glazed tile	15.61	15.61	31.23
Heavy Carpet on Concrete	75.56	528.95	2455.86
Ceilings			
Rough Concrete	15.61	31.23	31.23
1/2" Gypsum Wall Board Suspension System	566.74	188.91	340.04
Seating & Audience			
Fabric Well-Upholstered Seats	23.93	70.53	74.31
Audience	179.40	368.00	400.20
a (sabins)	1642.51	1352.55	3515.51
T (s)	1.46	1.77	0.68

SOUND ABSORPTION DATA FOR COMMON BUILDING MATERIALS AND FURNISHINGS

Material	Sound Absorption Coefficient 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC Number*
Walls[1-3, 9, 12]							
Sound-Reflecting:							
1. Brick, unglazed	0.02	0.02	0.03	0.04	0.05	0.07	0.05
2. Brick, unglazed and painted	0.01	0.01	0.02	0.02	0.02	0.03	0.00
3. Concrete, rough	0.01	0.02	0.04	0.06	0.08	0.10	0.05
4. Concrete block, painted	0.10	0.05	0.06	0.07	0.09	0.08	0.05
5. Glass, heavy (large panes)	0.18	0.06	0.04	0.03	0.02	0.02	0.05
6. Glass, ordinary window	0.35	0.25	0.18	0.12	0.07	0.04	0.15
7. Gypsum board, 1/2 in thick (nailed to 2 × 4s, 16 in oc)	0.29	0.10	0.05	0.04	0.07	0.09	0.05
8. Gypsum board, 1 layer, 5/8 in thick (screwed to 1 × 3s, 16 in oc with airspaces filled with fibrous insulation)	0.55	0.14	0.08	0.04	0.12	0.11	0.10
9. Construction no. 8 with 2 layers of 5/8-in-thick gypsum board	0.28	0.12	0.10	0.07	0.13	0.09	0.10
10. Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02	0.00
11. Plaster on brick	0.01	0.02	0.02	0.03	0.04	0.05	0.05
12. Plaster on concrete block (or 1 in thick on lath)	0.12	0.09	0.07	0.05	0.05	0.04	0.05
13. Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03	0.05
14. Plywood, 3/8-in paneling	0.28	0.22	0.17	0.09	0.10	0.11	0.15
15. Steel	0.05	0.10	0.10	0.10	0.07	0.02	0.10
16. Venetian blinds, metal	0.06	0.05	0.07	0.15	0.13	0.17	0.10
17. Wood, 1/4-in paneling, with airspace behind	0.42	0.21	0.10	0.08	0.06	0.06	0.10
18. Wood, 1-in paneling with airspace behind	0.19	0.14	0.09	0.06	0.06	0.05	0.10
Sound-Absorbing:							
19. Concrete block, coarse	0.36	0.44	0.31	0.29	0.39	0.25	0.35
20. Lightweight drapery, 10 oz/yd², flat on wall (*Note:* Sound-reflecting at most frequencies.)	0.03	0.04	0.11	0.17	0.24	0.35	0.15
21. Mediumweight drapery, 14 oz/yd², draped to half area (i.e., 2 ft of drapery to 1 ft of wall)	0.07	0.31	0.49	0.75	0.70	0.60	0.55
22. Heavyweight drapery, 18 oz/yd², draped to half area	0.14	0.35	0.55	0.72	0.70	0.65	0.60
23. Fiberglass fabric curtain, 8 1/2 oz/yd², draped to half area (*Note:* The deeper the airspace behind the drapery (up to 12 in), the greater the low-frequency absorption.)	0.09	0.32	0.68	0.83	0.39	0.76	0.55
24. Shredded-wood fiberboard, 2 in thick on concrete (mtg. A)	0.15	0.26	0.62	0.94	0.64	0.92	0.60
25. Thick, fibrous material behind open facing	0.60	0.75	0.82	0.80	0.60	0.38	0.75
26. Carpet, heavy, on 5/8-in perforated mineral fiberboard with airspace behind	0.37	0.41	0.63	0.85	0.96	0.92	0.70
27. Wood, 1/2-in paneling, perforated 3/16-in-diameter holes, 11% open area, with 2 1/2-in glass fiber in airspace behind	0.40	0.90	0.80	0.50	0.40	0.30	0.65
Floors[9, 11]							
Sound-Reflecting:							
28. Concrete or terrazzo	0.01	0.01	0.02	0.02	0.02	0.02	0.00
29. Linoleum, rubber, or asphalt tile on concrete	0.02	0.03	0.03	0.03	0.03	0.02	0.05
30. Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02	0.00
31. Wood	0.15	0.11	0.10	0.07	0.06	0.07	0.10
32. Wood parquet on concrete	0.04	0.04	0.07	0.06	0.06	0.07	0.05
Sound-Absorbing:							
33. Carpet, heavy, on concrete	0.02	0.06	0.14	0.37	0.60	0.65	0.30
34. Carpet, heavy, on foam rubber	0.08	0.24	0.57	0.69	0.71	0.73	0.55
35. Carpet, heavy, with impermeable latex backing on foam rubber	0.08	0.27	0.39	0.34	0.48	0.63	0.35
36. Indoor-outdoor carpet	0.01	0.05	0.10	0.20	0.45	0.65	0.20
Ceilings[5, 8-10] †							
Sound-Reflecting:							
37. Concrete	0.01	0.01	0.02	0.02	0.02	0.02	0.00
38. Gypsum board, 1/2 in thick	0.29	0.10	0.05	0.04	0.07	0.09	0.05
39. Gypsum board, 1/2 in thick, in suspension system	0.15	0.10	0.05	0.04	0.07	0.09	0.05
40. Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03	0.05
41. Plywood, 3/8 in thick	0.28	0.22	0.17	0.09	0.10	0.11	0.15
Sound-Absorbing:							
42. Acoustical board, 3/4 in thick, in suspension system (mtg. E)	0.76	0.93	0.83	0.99	0.99	0.94	0.95
43. Shredded-wood fiberboard, 2 in thick on lay-in grid (mtg. E)	0.59	0.51	0.53	0.73	0.88	0.74	0.65

Material	Sound Absorption Coefficient 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC Number*
44. Thin, porous sound-absorbing material, 3/4 in thick (mtg. B)	0.10	0.60	0.80	0.82	0.78	0.60	0.75
45. Thick, porous sound-absorbing material, 2 in thick (mtg. B), or thin material with airspace behind (mtg. D)	0.38	0.60	0.78	0.80	0.78	0.70	0.75
46. Sprayed cellulose fibers, 1 in thick on concrete (mtg. A)	0.08	0.29	0.75	0.98	0.93	0.76	0.75
47. Glass-fiber roof fabric, 12 oz/yd²	0.65	0.71	0.82	0.86	0.76	0.62	0.80
48. Glass-fiber roof fabric, 37 1/2 oz/yd² (*Note:* Sound-reflecting at most frequencies.)	0.38	0.23	0.17	0.15	0.09	0.06	0.15
49. Polyurethane foam, 1 in thick, open cell, reticulated	0.07	0.11	0.20	0.32	0.60	0.85	0.30
50. Parallel glass-fiberboard panels, 1 in thick by 18 in deep, spaced 18 in apart, suspended 12 in below ceiling	0.07	0.20	0.40	0.52	0.60	0.67	0.45
51. Parallel glass-fiberboard panels, 1 in thick by 18 in deep, spaced 6 1/2 in apart, suspended 12 in below ceiling	0.10	0.29	0.62	1.12	1.33	1.38	0.85
Seats and Audience[1, 5, 7, 9]‡							
52. Fabric well-upholstered seats, with perforated seat pans, unoccupied	0.19	0.37	0.56	0.67	0.61	0.59	
53. Leather-covered upholstered seats, unoccupied§	0.44	0.54	0.60	0.62	0.58	0.50	
54. Audience, seated in upholstered seats§	0.39	0.57	0.80	0.94	0.92	0.87	
55. Congregation, seated in wooden pews	0.57	0.61	0.75	0.86	0.91	0.86	
56. Chair, metal or wood seat, unoccupied	0.15	0.19	0.22	0.39	0.38	0.30	
57. Students, informally dressed, seated in tablet-arm chairs	0.30	0.41	0.49	0.84	0.87	0.84	
Openings[9]¶							
58. Deep balcony, with upholstered seats			0.50–1.00				
59. Diffusers or grilles, mechanical system			0.15–0.50				
60. Stage			0.25–0.75				
Miscellaneous[3, 9, 11]							
61. Gravel, loose and moist, 4 in thick	0.25	0.60	0.65	0.70	0.75	0.80	0.70
62. Grass, marion bluegrass, 2 in high	0.11	0.26	0.60	0.69	0.92	0.99	0.60
63. Snow, freshly fallen, 4 in thick	0.45	0.75	0.90	0.95	0.95	0.95	0.90
64. Soil, rough	0.15	0.25	0.40	0.55	0.60	0.60	0.45
65. Trees, balsam firs, 20 ft² ground area per tree, 8 ft high	0.03	0.06	0.11	0.17	0.27	0.31	0.15
66. Water surface (swimming pool)	0.01	0.01	0.01	0.02	0.02	0.03	0.00

*NRC (noise reduction coefficient) is a single-number rating of the sound absorption coefficients of a material. It is an average that only includes the coefficients in the 250 to 2000 Hz frequency range and therefore should be used with caution. See page 50 for a discussion of the NRC rating method.

†Refer to manufacturer's catalogs for absorption data which should be from up-to-date tests by independent acoustical laboratories according to current ASTM procedures.

‡Coefficients are per square foot of seating floor area or per unit. Where the audience is randomly spaced (e.g., courtroom, cafeteria), mid-frequency absorption can be estimated at about 5 sabins per person. To be precise, coefficients per person must be stated in relation to spacing pattern.

§The floor area occupied by the audience must be calculated to include an *edge effect* at aisles. For an aisle bounded on both sides by audience, include a strip 3 ft wide; for an aisle bounded on only one side by audience, include a strip 1 1/2 ft wide. No edge effect is used when the seating abuts walls or balcony fronts (because the edge is shielded). The coefficients are also valid for orchestra and choral areas at 5 to 8 ft² per person. Orchestra areas include people, instruments, music racks, etc. No edge effects are used around musicians.

¶Coefficients for openings depend on absorption and cubic volume of opposite side.

Test Reference

"Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method," ASTM C 423. Available from American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103.

Sources

1. L. L. Beranek, "Audience and Chair Absorption in Large Halls," *Journal of the Acoustical Society of America*, January 1969.
2. A. N. Burd et al., "Data for the Acoustic Design of Studios," British Broadcasting Corporation, BBC Engineering Monograph no. 64, November 1966.
3. E. J. Evans and E. N. Bazley, "Sound Absorbing Materials," H. M. Stationery Office, London, 1964.