

FINITE ELEMENT IDEALISATIONS OF A FULL-SCALE BUILDING

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The historical development of finite element representations of structures is outlined from the viewpoint of determining the transient response to a particular type of impact loading known as the sonic boom. This is the pressure disturbance observed on the ground when an aircraft flies overhead at a speed greater than that of sound. Three finite element models - a simple oscillator, a plate and a box - are discussed in detail and their applicability in determining the free and transient response of the full scale structure shown in Figure 1 is considered.

In general, both the computational effort and accuracy of results are proportional to the finite element model's degree of sophistication. Hence it is advisable to use the simplest model commensurate with an acceptable level of accuracy. The decision whether a theoretical model is likely to be sufficiently accurate is based in part on previous experience. Consequently it is useful to present even a limited comparison of different models' predicted responses with experimental data.

The building in Figure 1 has single thickness brick walls with supporting columns, a plaster board ceiling suspended from equally spaced wooden beams and a large window in one of the walls. A sloping roof was constructed over the ceiling to protect it from the weather. Different finite element representations of this structure are illustrated in Figure 2. A simple rectangular geometry is used for the box idealisation in order to economize computational effort. In view of this simplification, it is reasonable to reduce the complexity of the analysis even further by neglecting the effects of columns, sills and doors; assuming symmetry about the vertical central plane at right angles to the window; and idealising the ceiling's beam-plaster board as a homogeneous isotropic plate with the plaster board contributing additional mass to the beams. Even with these simplifications, however, the effort required to compute the free and particularly the transient response can be great. The effort is reduced significantly if joints of interconnecting structural members have high rigidity so that walls, ceiling and windows can be idealised as independent plates and analyzed individually. Further, if the response of any of these components is dominated by a single mode then it is equivalent to the simplest representation of all - the single degree-of-freedom oscillator.

Resonance tests conducted on a single brick wall established that it behaved like a homogeneous plate and was approximately linear for small deformations. Then the building shown in Figure 1 was excited to determine its natural frequencies and normal modes. It was found that the modal density was extremely high, there being on average a mode every 2.4Hz. There was also a variation of up to 10% in the value of any one frequency which seemed to depend on the water content of the brick walls. The profusion of modes together with their frequency variation created enormous practical difficulties. Consequently only a qualitative estimate of the mode shapes was undertaken.

Table 1 compares the natural frequencies predicted by the finite element models with those experimental frequencies which noticeably affect the side walls. It is seen that the box model gives a higher modal density than either of the plates; no model has a density as high as that actually measured for the complete structure.

Subsequently, the transient response of the side walls to a simulated sonic boom was determined experimentally and theoretically. Figure 3 shows the boom and the resulting acceleration of the side wall together with their frequency spectra. It is seen that this acceleration is dominated by two low frequency modes with higher frequency modes having little effect. Hence a realistic, yet economical approximation to the free field simulated boom, is obtained by using the idealised pulse shown in Figure 3(a) as the dashed straight lines. When this wave travels over a structure, its pressure-time variation will be modified. The changes are caused by rarefaction, diffraction and reflection of the boom and the formation of vortices at the edges of the structure. However, a simplified loading description is used in all theoretical models which neglects edge effects and assumes no energy transfer to the structure. The plate and box models, unlike the oscillator, take the wave's motion over the structure into consideration. The shape of the pulse exciting the oscillator is obtained by assuming that the boom's direction of travel is normal to the side wall.

Significant differences are found in the accelerations predicted by the various models although there is a relatively smaller variation in the displacements.

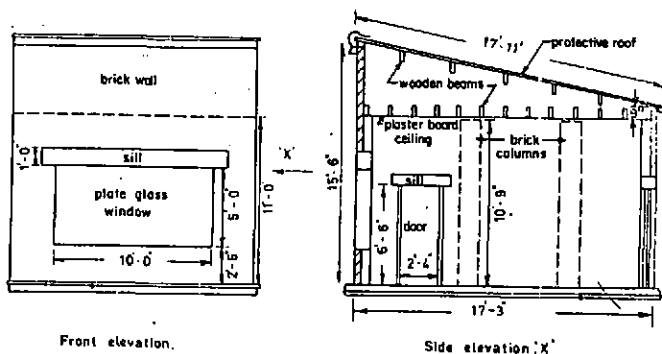
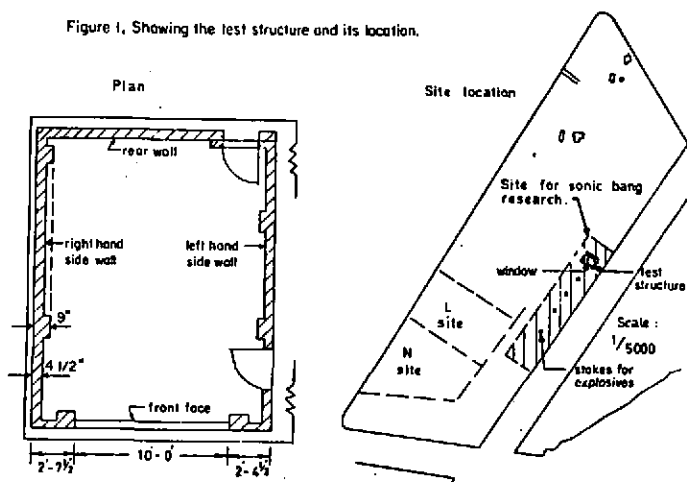


Figure 1. Showing the test structure and its location.



(a) One degree of freedom system with lumped mass and stiffness.

(b) Box with distributed mass and stiffness assuming one plane of symmetry.

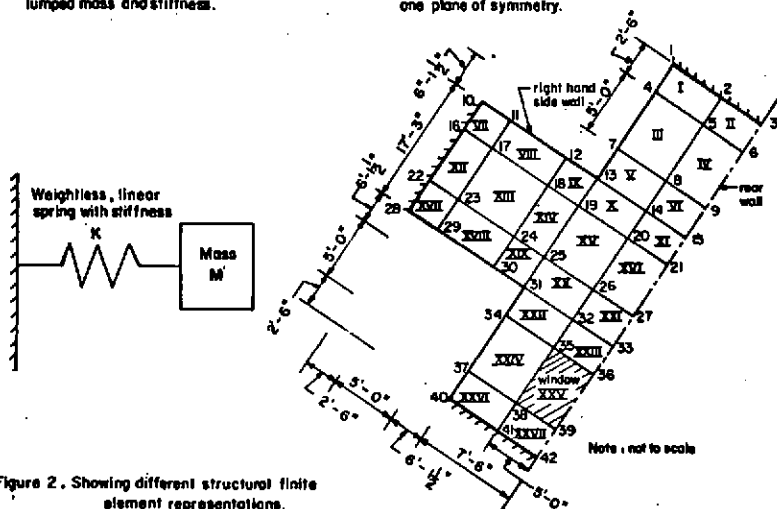


Figure 2. Showing different structural finite element representations.

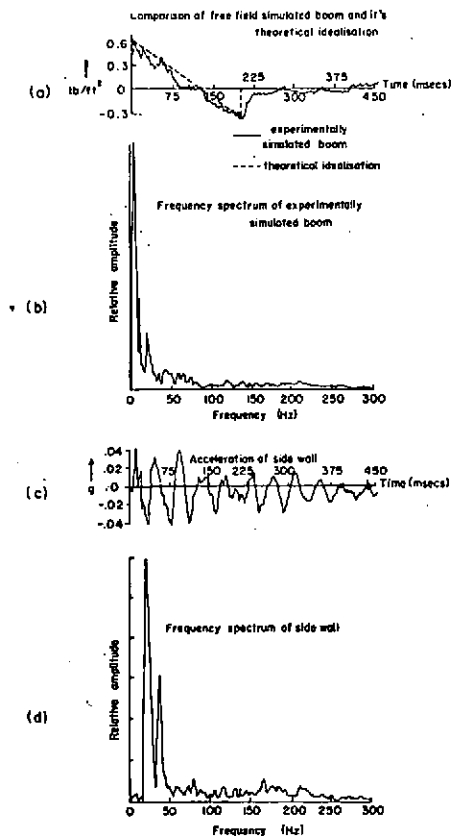




Figure 3. Showing free field booms and side wall's actual acceleration with their experimental frequency spectra.

Experimental Frequencies (cps)		Theoretical Frequencies (cps)	
Right hand side wall	Left hand side wall	Box theory 	Open theory 
25"	12.5 25"	22.0 22.0	22.2
30"	15 30"	27 27.2	28.0
36"	18 36"	32.2 32.2	32.6
42"	21 42"	37.5 37.5	42.2
48"	24 48"	42.8 42.8	42.8
54"	27 54"	48.1 48.1	48.1
60"	30 60"	53.4 53.4	53.4
66"	33 66"	58.7 58.7	58.7
72"	36 72"	64.0 64.0	64.0
78"	39 78"	69.3 69.3	69.3
84"	42 84"	74.6 74.6	74.6
90"	45 90"	79.9 79.9	79.9
96"	48 96"	85.2 85.2	85.2
102"	51 102"	90.5 90.5	90.5
108"	54 108"	95.8 95.8	95.8
114"	57 114"	101.1 101.1	101.1
120"	60 120"	106.4 106.4	106.4
126"	63 126"	111.7 111.7	111.7
132"	66 132"	117.0 117.0	117.0
138"	69 138"	122.3 122.3	122.3
144"	72 144"	127.6 127.6	127.6
150"	75 150"	132.9 132.9	132.9
156"	78 156"	138.2 138.2	138.2
162"	81 162"	143.5 143.5	143.5
168"	84 168"	148.8 148.8	148.8
174"	87 174"	154.1 154.1	154.1
180"	90 180"	159.4 159.4	159.4
186"	93 186"	164.7 164.7	164.7
192"	96 192"	170.0 170.0	170.0
198"	99 198"	175.3 175.3	175.3
204"	102 204"	180.6 180.6	180.6
210"	105 210"	185.9 185.9	185.9
216"	108 216"	191.2 191.2	191.2
222"	111 222"	196.5 196.5	196.5
228"	114 228"	201.8 201.8	201.8
234"	117 234"	207.1 207.1	207.1
240"	120 240"	212.4 212.4	212.4
246"	123 246"	217.7 217.7	217.7
252"	126 252"	223.0 223.0	223.0
258"	129 258"	228.3 228.3	228.3
264"	132 264"	233.6 233.6	233.6
270"	135 270"	238.9 238.9	238.9
276"	138 276"	244.2 244.2	244.2
282"	141 282"	249.5 249.5	249.5
288"	144 288"	254.8 254.8	254.8
294"	147 294"	260.1 260.1	260.1
300"	150 300"	265.4 265.4	265.4
306"	153 306"	270.7 270.7	270.7
312"	156 312"	276.0 276.0	276.0
318"	159 318"	281.3 281.3	281.3
324"	162 324"	286.6 286.6	286.6
330"	165 330"	291.9 291.9	291.9
336"	168 336"	297.2 297.2	297.2
342"	171 342"	302.5 302.5	302.5
348"	174 348"	307.8 307.8	307.8
354"	177 354"	313.1 313.1	313.1
360"	180 360"	318.4 318.4	318.4
366"	183 366"	323.7 323.7	323.7
372"	186 372"	329.0 329.0	329.0
378"	189 378"	334.3 334.3	334.3
384"	192 384"	339.6 339.6	339.6
390"	195 390"	344.9 344.9	344.9
396"	198 396"	350.2 350.2	350.2
402"	201 402"	355.5 355.5	355.5
408"	204 408"	360.8 360.8	360.8
414"	207 414"	366.1 366.1	366.1
420"	210 420"	371.4 371.4	371.4
426"	213 426"	376.7 376.7	376.7
432"	216 432"	382.0 382.0	382.0
438"	219 438"	387.3 387.3	387.3
444"	222 444"	392.6 392.6	392.6
450"	225 450"	397.9 397.9	397.9
456"	228 456"	403.2 403.2	403.2
462"	231 462"	408.5 408.5	408.5
468"	234 468"	413.8 413.8	413.8
474"	237 474"	419.1 419.1	419.1
480"	240 480"	424.4 424.4	424.4
486"	243 486"	429.7 429.7	429.7
492"	246 492"	435.0 435.0	435.0
498"	249 498"	440.3 440.3	440.3
504"	252 504"	445.6 445.6	445.6
510"	255 510"	450.9 450.9	450.9
516"	258 516"	456.2 456.2	456.2
522"	261 522"	461.5 461.5	461.5
528"	264 528"	466.8 466.8	466.8
534"	267 534"	472.1 472.1	472.1
540"	270 540"	477.4 477.4	477.4
546"	273 546"	482.7 482.7	482.7
552"	276 552"	488.0 488.0	488.0
558"	279 558"	493.3 493.3	493.3
564"	282 564"	498.6 498.6	498.6
570"	285 570"	503.9 503.9	503.9
576"	288 576"	509.2 509.2	509.2
582"	291 582"	514.5 514.5	514.5
588"	294 588"	519.8 519.8	519.8
594"	297 594"	525.1 525.1	525.1
600"	300 600"	530.4 530.4	530.4
606"	303 606"	535.7 535.7	535.7
612"	306 612"	541.0 541.0	541.0
618"	309 618"	546.3 546.3	546.3
624"	312 624"	551.6 551.6	551.6
630"	315 630"	556.9 556.9	556.9
636"	318 636"	562.2 562.2	562.2
642"	321 642"	567.5 567.5	567.5
648"	324 648"	572.8 572.8	572.8
654"	327 654"	578.1 578.1	578.1
660"	330 660"	583.4 583.4	583.4
666"	333 666"	588.7 588.7	588.7
672"	336 672"	594.0 594.0	594.0
678"	339 678"	599.3 599.3	599.3
684"	342 684"	604.6 604.6	604.6
690"	345 690"	609.9 609.9	609.9
696"	348 696"	615.2 615.2	615.2
702"	351 702"	620.5 620.5	620.5
708"	354 708"	625.8 625.8	625.8
714"	357 714"	631.1 631.1	631.1
720"	360 720"	636.4 636.4	636.4
726"	363 726"	641.7 641.7	641.7
732"	366 732"	647.0 647.0	647.0
738"	369 738"	652.3 652.3	652.3
744"	372 744"	657.6 657.6	657.6
750"	375 750"	662.9 662.9	662.9
756"	378 756"	668.2 668.2	668.2
762"	381 762"	673.5 673.5	673.5
768"	384 768"	678.8 678.8	678.8
774"	387 774"	684.1 684.1	684.1
780"	390 780"	689.4 689.4	689.4
786"	393 786"	694.7 694.7	694.7
792"	396 792"	700.0 700.0	700.0
798"	399 798"	705.3 705.3	705.3
804"	402 804"	710.6 710.6	710.6
810"	405 810"	715.9 715.9	715.9
816"	408 816"	721.2 721.2	721.2
822"	411 822"	726.5 726.5	726.5
828"	414 828"	731.8 731.8	731.8
834"	417 834"	737.1 737.1	737.1
840"	420 840"	742.4 742.4	742.4
846"	423 846"	747.7 747.7	747.7
852"	426 852"	753.0 753.0	753.0
858"	429 858"	758.3 758.3	758.3
864"	432 864"	763.6 763.6	763.6
870"	435 870"	768.9 768.9	768.9
876"	438 876"	774.2 774.2	774.2
882"	441 882"	779.5 779.5	779.5
888"	444 888"	784.8 784.8	784.8
894"	447 894"	790.1 790.1	790.1
900"	450 900"	795.4 795.4	795.4
906"	453 906"	800.7 800.7	800.7
912"	456 912"	806.0 806.0	806.0
918"	459 918"	811.3 811.3	811.3
924"	462 924"	816.6 816.6	816.6
930"	465 930"	821.9 821.9	821.9
936"	468 936"	827.2 827.2	827.2
942"	471 942"	832.5 832.5	832.5
948"	474 948"	837.8 837.8	837.8
954"	477 954"	843.1 843.1	843.1
960"	480 960"	848.4 848.4	848.4
966"	483 966"	853.7 853.7	853.7
972"	486 972"	859.0 859.0	859.0
978"	489 978"	864.3 864.3	864.3
984"	492 984"	869.6 869.6	869.6
990"	495 990"	874.9 874.9	874.9
996"	498 996"	880.2 880.2	880.2
1002"	501 1002"	885.5 885.5	885.5
1008"	504 1008"	890.8 890.8	890.8
1014"	507 1014"	896.1 896.1	896.1
1020"	510 1020"	901.4 901.4	901.4
1026"	513 1026"	906.7 906.7	906.7
1032"	516 1032"	912.0 912.0	912.0
1038"	519 1038"	917.3 917.3	917.3
1044"	522 1044"	922.6 922.6	922.6
1050"	525 1050"	927.9 927.9	927.9
1056"	528 1056"	933.2 933.2	933.2
1062"	531 1062"	938.5 938.5	938.5
1068"	534 1068"	943.8 943.8	943.8
1074"	537 1074"	949.1 949.1	949.1
1080"	540 1080"	954.4 954.4	954.4
1086"	543 1086"	959.7 959.7	959.7
1092"	546 1092"	965.0 965.0	965.0
1098"	549 1098"	970.3 970.3	970.3
1104"	552 1104"	975.6 975.6	975.6
1110"	555 1110"	980.9 980.9	980.9
1116"	558 1116"	986.2 986.2	986.2
1122"	561 1122"	991.5 991.5	991.5
1128"	564 1128"	996.8 996.8	996.8
1134"	567 1134"	1002.1 1002.1	1002.1
1140"	570 1140"	1007.4 1007.4	1007.4
1146"	573 1146"	1012.7 1012.7	1012.7
1152"	576 1152"	1018.0 1018.0	1018.0
1158"	579 1158"	1023.3 1023.3	1023.3
1164"	582 1164"	1028.6 1028.6	1028.6
1170"	585 1170"	1033.9 1033.9	1033.9
1176"	588 1176"	1039.2 1039.2	1039.2
1182"	591 1182"	1044.5 1044.5	1044.5
1188"	594 1188"	1049.8 1049.8	1049.8
1194"	597 1194"	1055.1 1055.1	1055.1
1200"	600 1200"	1060.4 1060.4	1060.4
1206"	603 1206"	1065.7 1065.7	1065.7
1212"	606 1212"	1071.0 1071.0	1071.0
1218"	609 1218"	1076.3 1076.3	1076.3
1224"	612 1224"	1081.6 1081.6	1081.6
1230"	615 1230"	1086.9 1086.9	1086.9
1236"	618 1236"	1092.2 1092.2	1092.2
1242"	621 1242"	1097.5 1097.5	1097.5
1248"	624 1248"	1102.8 1102.8	1102.8
1254"	627 1254"	1108.1 1108.1	1108.1
1260"	630 1260"	1113.4 1113.4	1113.4
1266"	633 1266"	1118.7 1118.7	1118.7
1272"	636 1272"	1124.0 1124.0	1124.0
1278"	639 1278"	1129.3 1129.3	1129.3
1284"	642 1284"	1134.6 1134.6	1134.6
1290"	645 1290"	1139.9 1139.9	1139.9
1296"	648 1296"	1145.2 1145.2	1145.2
1302"	651 1302"	1150.5 1150.5	1150.5
1308"	654 1308"	1155.8 1155.8	1155.8
1314"	657 1314"	1161.1 1161.1	1161.1
1320"	660 1320"	1166.4 1166.4	1166.4
1326"	663 1326"	1171.7 1171.7	1171.7
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1386"	693 1386"	1224.7 1224.7	1224.7
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1404"	702 1404"	1240.6 1240.6	1240.6
1410"	705 1410"		