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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.

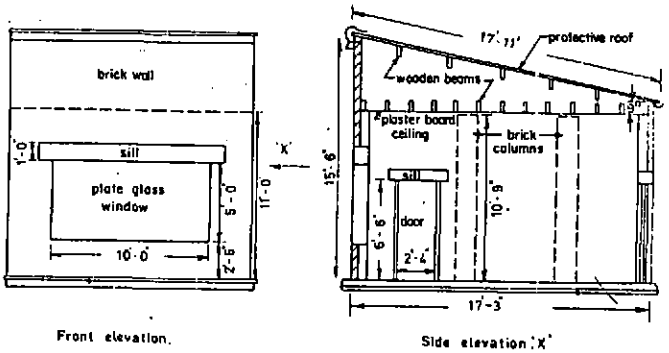
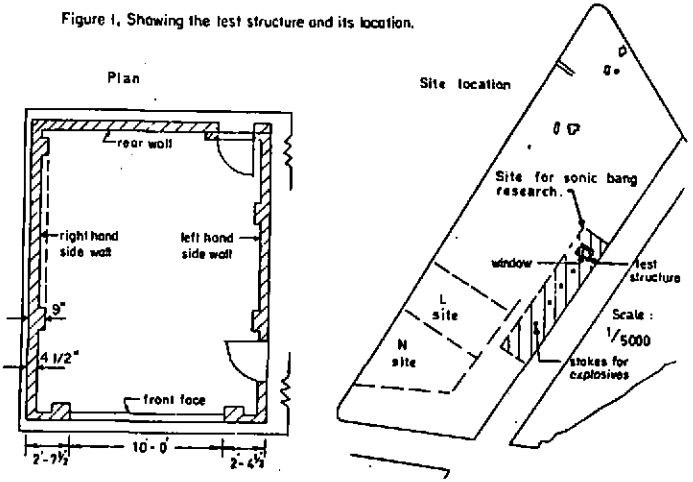


Figure 1. Showing the test structure and its location.



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

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

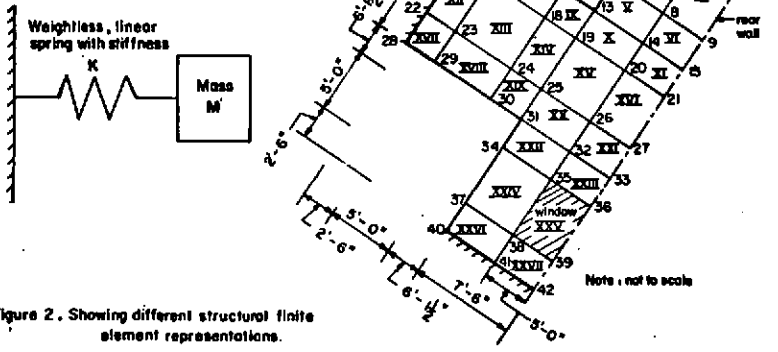


Figure 2. Showing different structural finite element representations.

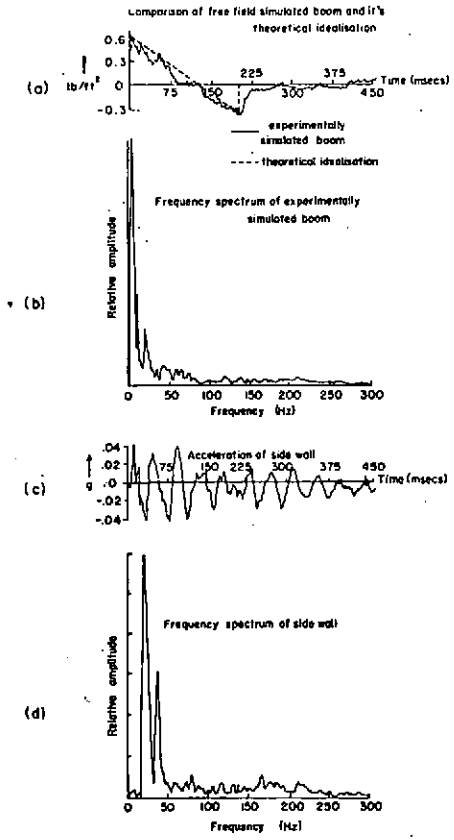


Figure 3. Showing free field booms and side wall's actual acceleration with their experimental frequency spectra.