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INFILL DAMPING TREATMENTS AS A METHOD OF NOISE REDUCTION ON POWER PRESSES AND OTHER STRUCTURES

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INTRODUCTION

The straight-sided type of power press as well as many other types of machinery structures are often constructed as fabrications of steel plates and tubes. Such structures especially when welded together, possess little inherent structural damping which can lead to high levels of noise radiation if excited into vibration by the working or other forces. Conventional damping materials, i.e., stick-on layers, etc., tend to be ineffective on the thick sections of typical machinery structures without resorting to impractically thick damping layers. Many such structures, however, possess numerous internal cavities which, when filled with granular materials such as sand, gravel, lead shot, metal chips, etc., can instill substantial increases in structural damping.

This paper describes theoretical methods developed for predicting the loss factors which can be attained by the use of granular materials, especially in relation to sand as the damping medium. Calculated results are shown compared with measurements on various examples of typical elements of machinery structures and also on a scale model of a power press structure.

THEORETICAL CONSIDERATIONS

The determination of the loss factor of sand-filled structures using classical methods is difficult because the precise mechanism of energy dissipation within the medium is still unknown. However, various relevant properties of sand have been determined [1] including the characteristic impedance, wave speed and internal loss factor. This enables sand to be considered as a medium such as air or water through which waves can propagate and allows the use of the classical equation for radiation from a vibrating surface into a surrounding medium, i.e.,

$$W = \rho c \; s \; \sigma_r \overline{\langle v^2 \rangle}$$

where ρ = density of sand, $\sim$1500 kg/m^2
c = wave speed in sand, $\sim$150 m/s
$\langle v^2 \rangle$ = time and space averaged mean square velocity
s = surface area
σ_r = radiation efficiency

By then assuming a direct analogy of structure to sand space radiation to that of a structure to an air space the theoretical methods of Statistical Energy Analysis (SEA) developed for room acoustics can be utilised. The transmission of vibrational energy into the sand can be predicted and also the effective increase of loss factors of the structure. For a simple two-component system structure/sand it can be shown [2] that the total loss factor measured on the structure is given by:

$$\eta = \eta_1 + \frac{\eta_{12}\eta_2}{\eta_{12}\frac{n_1}{n_2} + \eta_2}$$

where η_1 is the material loss factor of the plate
η_2 is the internal loss factor of sand, $\eta_2 \simeq 0.015$
n_1 and n_2 are the modal densities of the plate and sand space.

The modal density of the sand space can be calculated from the expressions for an equivalent air space [2] by replacing the wave speed and density with those of sand.

η_{12} is the coupling loss factor from the plate to sand and is equal to the ratio of the radiated energy from the plate into the sand to the vibrational energy of the plate per radian, given by [2]:

$$\eta_{12} = \frac{E_{rad}}{\omega M.\langle\overline{v^2}\rangle} = \frac{\rho c \sigma_{rad}}{2\pi\rho_m h f}$$

where ρ_m is the density of the plate
ρ is the density of sand, $\rho \simeq 1500\ kg/m^3$
c is the wave speed in sand, $c \simeq 150\ m/s$
σ_{rad} is the radiation efficiency of the plate into sand.

EXPERIMENTAL WORK

The loss factors of various test pieces (typical of component parts in many machinery structures) were calculated when damped by sand and the results compared with direct measurements. The test pieces are shown in Fig. 1 and consist of a single plate, a double plate, two hollow tubes and a box. Measured and calculated loss factors are shown in Figs. 2 to 6. These show that the analytical methods give good predictions at all but low frequencies where the SEA methods become invalid because of the low modal densities in the structures.

In general the results show that sand can instill high loss factors, approaching $\eta = 0.1$ over a wide frequency band. The loss factors peak broadly around a frequency given by:

$$f_p = \left(\frac{\sqrt{3}.\rho.c^3}{4\pi^2\rho_m h^2.d.c_L.\eta_2}\right)^{0.5}$$

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where ρ - density of sand
ρ_m - density of structure
c - wave speed in sand
c_L - longitudinal wave speed in structure
h - thickness of structure
d - thickness of sand layer
η_2 - loss factor of sand

The effect of sand layer thickness is shown in Fig. 2 for the single plate. The loss factors increase with increasing sand layer thickness up to a sand thickness of around $0.05\lambda_c$ (λ_c = coincident wavelength of plate to sand). This represents roughly a sand layer thickness of between 3 to 4 times the plate thickness. For a thicker sand layer the loss factors then reduce, especially at higher frequencies because of the increasing static pressure restricting the sliding movements of the sand grains near the vibrating surface. This is an important factor for consideration when applying infill damping treatments: it is better not to completely fill large cavities with the damping medium but rather maintain a layer against the sides, possibly with internal baffles.

APPLICATION TO A POWER PRESS STRUCTURE

As part of an investigation into power press noise at ISVR, a scale model of the structure of a 200 tonne power press had been constructed. Models such as this have proved to give good representations of the structural and radiation characteristics of machinery structures. They enable detailed analysis and structural modifications to be made which may be totally impractical on an actual machine. The press model (Fig. 7) is of the structure of a Bret 200 tonne straight-sided power press and was scaled 1/3 on overall dimensions and 1/10 on material thickness. This type of press construction (a welded fabrication from a number of steel plates) possesses little inherent structural damping and thus there exists considerable scope for reducing the radiated noise by increasing damping levels. The structure incorporating a number of internal cavities is ideally suited for infill damping treatments and again for the experiments sand was used as the damping medium.

Measurements of the changes in SPL measured around the model were made as the damping was progressively increased by filling the various hollow sections with sand. This was taken to the ultimate conclusion of completely filling the structure with sand, including damping of the side plates (sand retained by wooden baffles). Although completely filling the model is not possible in practice, it does demonstrate the ultimate noise reductions possible when all the radiating surfaces are treated. Sand was used as the damping medium not only because of its high damping properties but also because of its availability. It is of course not the only damping treatment which could have been used. Other infill materials could be used in practice or alternative damping treatments such as point fixed panels - these would be very applicable to the side panels of the full-scale press.

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Sand can increase typical loss factors of the structure from around $\eta = 8 \times 10^{-3}$ to around 0.1, as is shown in Fig. 8. Thus, theoretically, large reductions > 10 dB are possible by the use of damping treatments; total sound energy being directly proportional to loss factor for ringing noise. In practice, noise reductions may be less than this as loss factors become large, because of the dominance of acceleration noise energy which is not reduced by damping treatments.

Because the press model is a strongly coupled structure, once excited vibrational energy quickly distributes itself throughout the whole of the structure. Thus, all of the larger surfaces of the structure will be radiating significant amounts of noise energy and therefore it is necessary to treat all these parts to achieve a substantial overall reduction in noise. Noise source location measurements on the model have shown that the columns and side plates are the dominant radiating areas. Therefore these are obviously important regions for the application of damping treatments.

Figure 9 shows measurements of sound pressure level (SPL) made as sand was selectively added into the various hollow sections of the model. Results were averaged for a number of blows and at points around the model and are quoted as short term (80 ms) L_{eq} values 'A'-weighted, values being obtained by integration of the measured auto spectrum using a digital spectrum analyser. These show that damping the bed area or the columns alone led only to a small reduction in overall noise (< 2 dB(A)) and to obtain substantial noise reductions it was necessary to damp the whole of the sides of the structure. This gave about 6 dB(A) noise reduction. Completely damping the whole of the structure gave a substantial 8.6 dB(A) noise reduction. Directly comparable or even greater noise reductions would be expected from similar treatments to the full scale press: initial loss factors for the press/model were scaled 1:1 and sand gives greater loss factors at low frequencies for thicker plates due to a reduced plate/sand coincidence frequency [2].

CONCLUSIONS

Sand or other types of granular infill materials can be a very effective method of increasing the structural damping of machinery (or other) structures and hence reducing noise radiation. Loss factors approaching $\eta = 0.1$ can be achieved over a broad frequency range with sand as the damping medium. The loss factors for a plate are maximised when a sand layer thickness of approximately 4 times the plate thickness is used. Above this thickness the loss factor falls because of the static pressure loading restricting the movement of the sand grains.

Infill damping treatments can be an effective method of damping the structure and reducing noise from the fabricated types of power press structure provided all the radiating areas are treated. A reduction of 8 dB(A) was obtained in the noise radiation from the press model structure when damped by sand.

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2. J.C. SUN et al Prediction of total loss factors of structures, II: Loss factors of sand-filled structures (accepted for publication in Journal of Sound and Vibration).

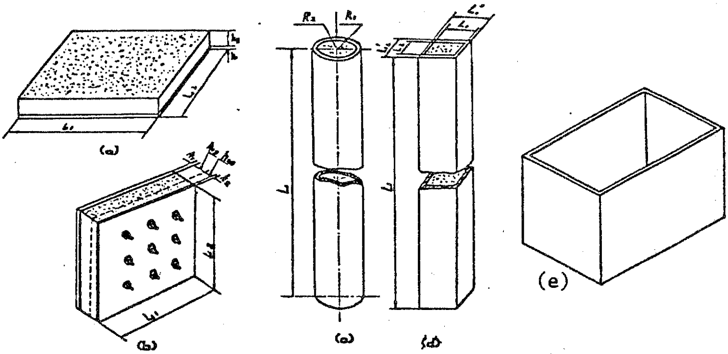

Fig. 1 Configuration of the Sand-Filled Structures
(a) Plate with Added Sand
(b) Bolted Plates with Sand Filled Cavity
(c) Sand Filled Cylinder
(d) Sand Filled Rectangular Tube
(e) Sand Filled Welded Box

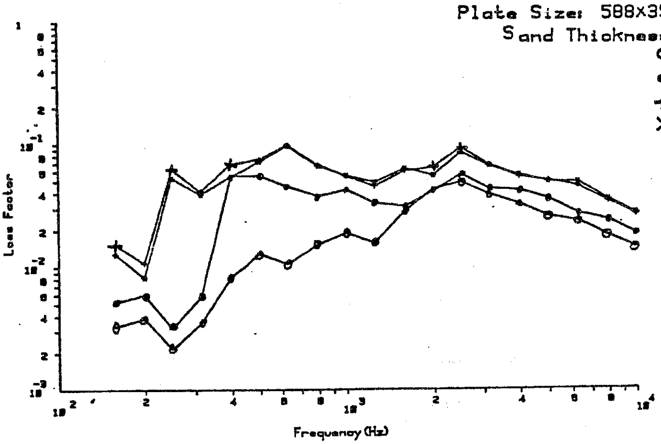

Fig. 2 Relationship between loss factor and sand thickness for plate (a)

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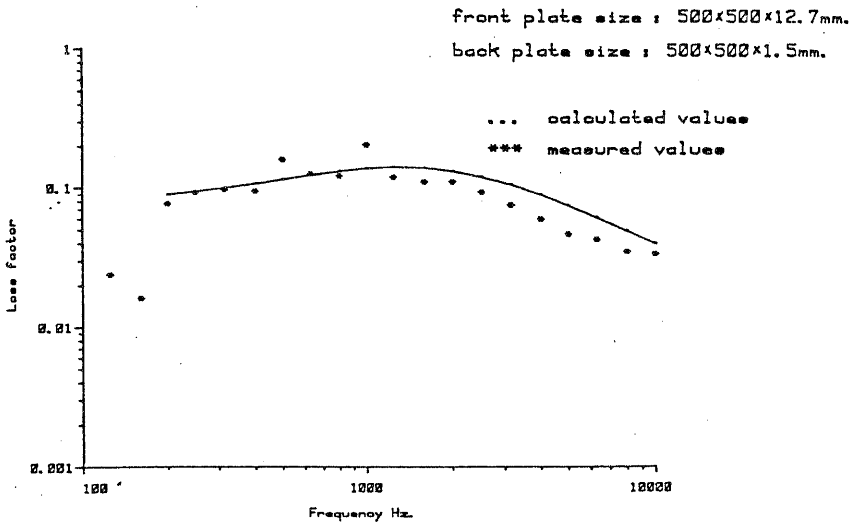

Fig. 3 Loss factors of structure (b)

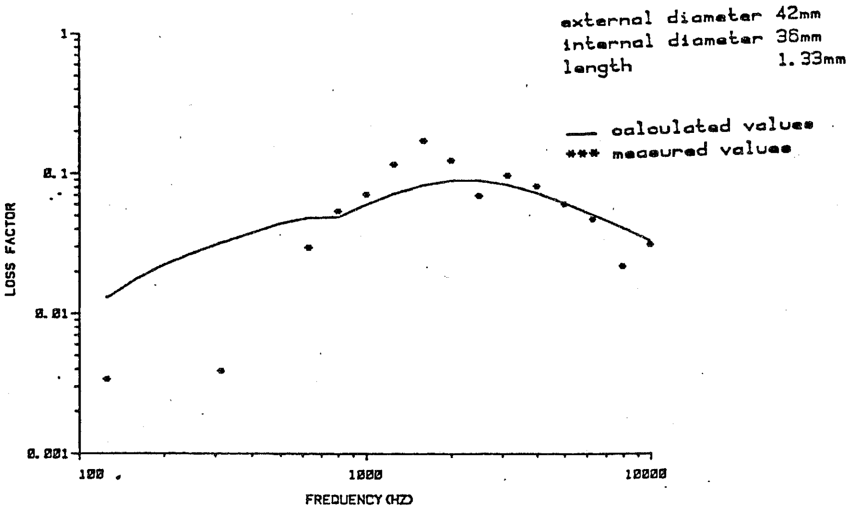

Fig. 4 Loss factors of tube (c)

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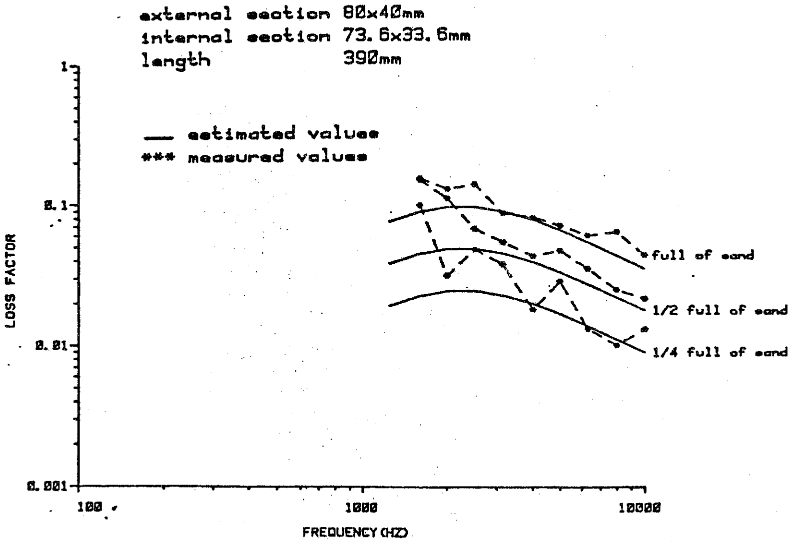

Fig. 5 Loss factors of tube (d)

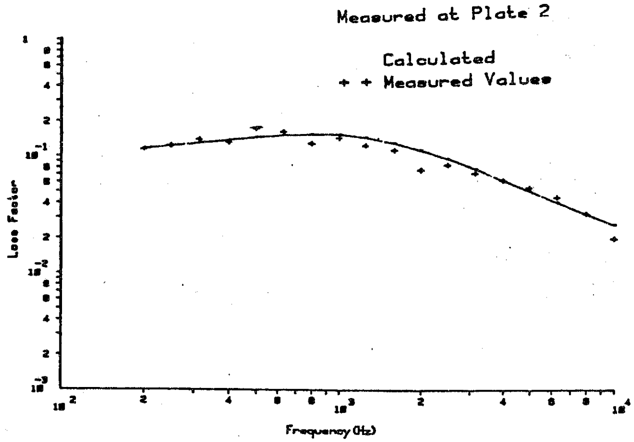

Fig. 6 Loss factors of welded box (e)

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Fig. 7 Press model

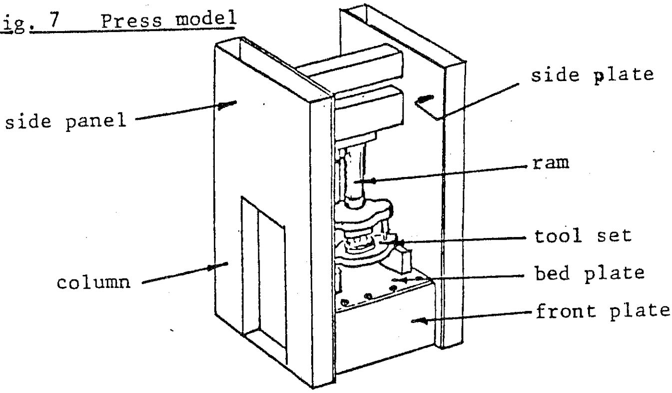
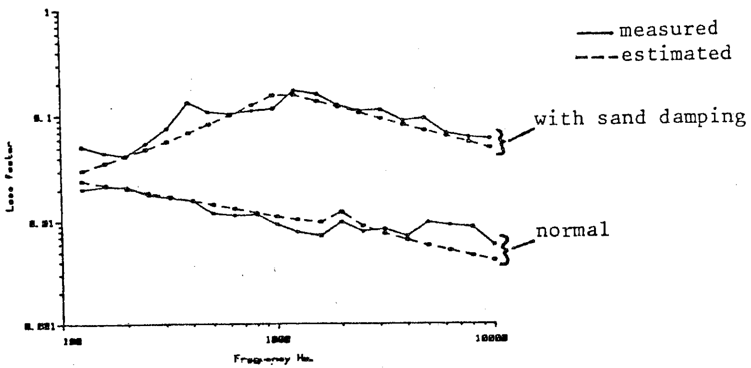


Fig. 8 Loss factors of side plate



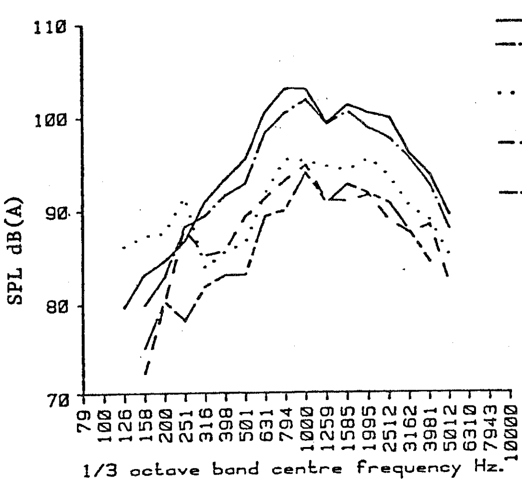


Figure 9. Noise reductions with sand damping