HOLOGRAPHIC INTERFEROMETRY IN SOIL DYNAMICS

INTERFEROMETRIE HOLOGRAPHIQUE EN DYNAMIQUE DU SOL

ГОЛОГРАФИЧЕСКАЯ ИНТЕРФЕРОМЕТРИЯ В ДИНАМИКЕ ГРУНТОВ

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SYNOPSIS. Holographic interferometry has been successfully used to study the vibratory displacement of a sand surface. Double exposure holograms have been obtained containing fringes which represent contours of equal displacement amplitude. Using this technique, criteria for cylindrical hole barriers for screening elastic waves have been developed.

INTRODUCTION

The effectiveness of trench barriers for isolation of structures and foundations from ground transmitted vibrations has been studied by several investigators including Barkan (1962); Dolling (1970); and Richart, Hall and Woods (1970); and Woods (1968). These studies have established the applicability of wavelength scaling and some of the limiting dimensions for effective barriers.

One of the most critical dimensions of isolation barriers is the depth. All evidence indicates that the depth must be a large fraction of the wavelength of the energy being screened. Practical soil mechanics considerations limit the depth to which an open, unsupported trench can be excavated. These considerations limit the application of trenches in isolation problems where moderately long wavelengths, 40-100 feet, (12-30 meters) must be screened.

As an alternative to a trench, a row of cylindrical holes has been suggested. This kind of barrier would be stable for considerable depth with no support or with only a thin-walled liner. In the study reported here, the overall effectiveness of unlined cylindrical hole barriers has been studied, and some guidelines have been established for predicting the isolation effectiveness of rows of cylindrical holes.

Earlier studies of screening indicated some of the difficulties of accumulating and displaying vibration data. Previous studies, both model and full scale, were accomplished by point by point measurements of ground motion. A new tool, holographic interferometry, has been applied in this study to determine the vertical surface displacement of a half-space model. Holographic interferometry provides a method of recording vibration amplitudes at every point on any vibrating surface.

PRINCIPLES OF HOLOGRAPHIC INTERFEROMETRY

Holograms are formed by capturing the interference pattern of intersecting wave fronts in a photographic emulsion, see Leith and Upatnieks (1965). To make a hologram, coherent light from a laser is split into two beams, object beam and reference beam, Fig. 1a. The object beam is diffused by a lens to illuminate an object. Part of the object beam reflects off the object and impinges on the same photographic plate. The object beam and the reference beam intersect at the photographic plate forming an interference pattern. This interference pattern is stored in the photographic emulsion. The developed plate is a hologram.

The stored wavefront interference pattern is a complex pattern of small light and dark zones which show no obvious relationship to the object when viewed in normal light. However, when the hologram is re-illuminated by the reference beam, Fig. 1b, the original wavefronts are reconstructed and a virtual image of the object is visible to an observer looking through the hologram. The virtual image will be visible even if the object has been removed.

Using holography, it is possible to store a wave front and at any later time, reconstruct that wave front with or without the original object. This stored wave front can later be re-created in the same optical setup and interfere with a new wave front from the same object which has been deformed, Fig. 1c. Now the virtual image stored in the hologram will not exactly coincide with the deformed object beam and the interference of these two slightly different wave fronts will cause dark and bright fringes to appear on the object. These fringes are essentially contours of equal displacement and may be viewed by eye or photographed by conventional photography. This process is called "real-time" holographic interferometry.

Figure 2 is a photograph of a hologram with real-time fringes. First a hologram was made of a footing on sand with no load applied. Then a static load was applied to the footing and the real footing was observed and photographed through the hologram. The nearly parallel fringes on the footing in Fig. 2 represent rigid body rotation while the concentric fringes around the footing represent contours of ground surface displacement. Each fringe represents an elevation difference equal to about 1/2 of the wavelength of the laser light (1/2 x

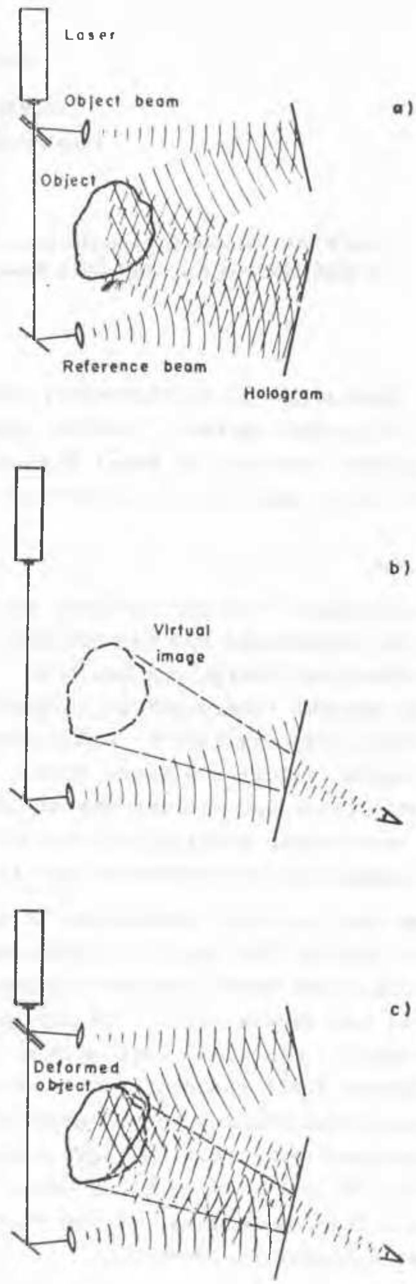

Fig. 1 Holographic process

Fig. 2 Hologram of statically loaded footing

5145 Å, about 0.00025 mm or about 10 x 10^{-6} inch).

With modifications the above holographic procedure can be used to measure vibrating displacements of objects, see Sampson (1970). As in Fig. 1a, the photographic plate can be exposed with the object at rest but the plate is not yet developed. Next a harmonic force can be applied to the object and the laser pulsed stroboscopically at the same frequency as the harmonic force (stop motion technique), and the plate re-exposed. Now the initially stored static wavefronts interfere with stroboscopically stopped wave fronts in a "double exposure" hologram. This process captures interference fringes permanently in the double exposure hologram. The plate can then be developed and when re-illuminated with the laser reference beam as in Fig. 1b, an observer can see a virtual image of the object with fringes representing contours of equal displacement superimposed. With this technique the displaced shape of the entire object can be obtained in one record.

For the investigations described here, the stroboscopic, double exposure technique was used and the object observed was the surface of a model half-space. This model consisted of a box about one meter square and 30 cm deep filled with fine sand (Agsco #16 crushed quartz), Figs. 3 and 4. The sand in the half-space model was kept moist ($10\% < w < 20\%$) to develop apparent cohesion. The apparent cohesion permitted excavation of open holes without support and also permitted upward particle accelerations near the vibrating footing to exceed 1g. A zone of loose sand at all boundaries about 8 cm wide acted as an energy absorber and eliminated reflections.

Making holograms of the vibrating surface of this model required the optical and physical arrangements shown in Figs. 3 and 4.

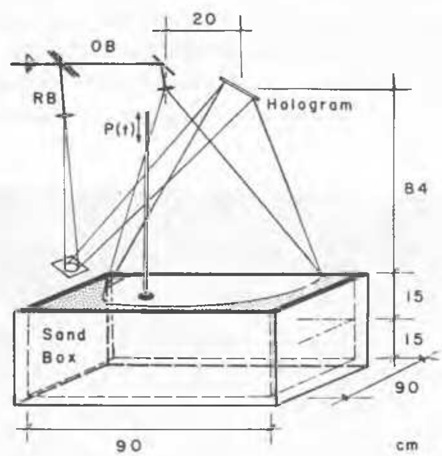

Fig. 3 Schematic of half-space model and holography setup

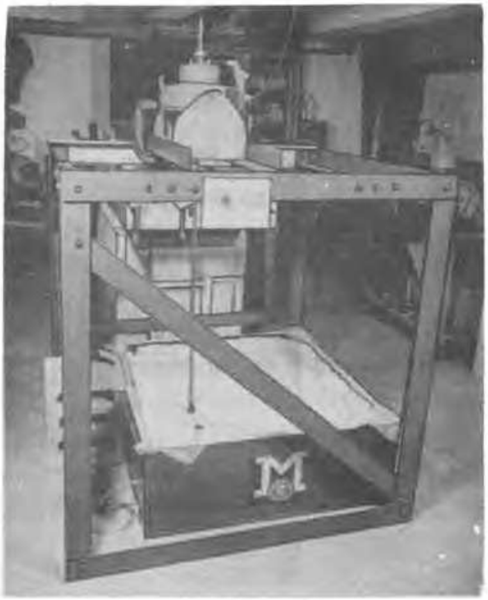

Fig. 4 Photograph of model facility and holography apparatus

ISOLATION TESTS

To study the screening effects of rows of cylindrical holes, first a double exposure hologram was made of undisturbed traveling waves generated by a vibrating circular footing, Fig. 5a. The wave field hologram obtained in this way consisted of concentric fringes representing the normal decay of Rayleigh waves with distance from the source. Next, a barrier consisting of vertical cylindrical holes of pre-selected depth, diameter and spacing was excavated. Finally, a second double exposure hologram was made of the diffracted and reflected wave field caused by the barrier, Fig. 5b. By comparing pairs of holograms as in Fig. 5, the influence of the barrier could be evaluated both qualitatively and quantitatively. A total of 45 barriers were studied this way.

The most satisfactory frequency found for tests in this model facility was 1400 Hz. This produced wavelengths of about 7.5 cm.

The variables influencing the isolation effectiveness of barriers that were studied included: depth of holes (H), diameter of holes (D), spacing of holes (S), number of holes in a row and distance from the source to the barrier. All variables were normalized on the wavelength at the Rayleigh wave (λ_R = 7.5 cm).

CONCLUSIONS

The results of these tests regarding the depth of effective barriers confirmed earlier

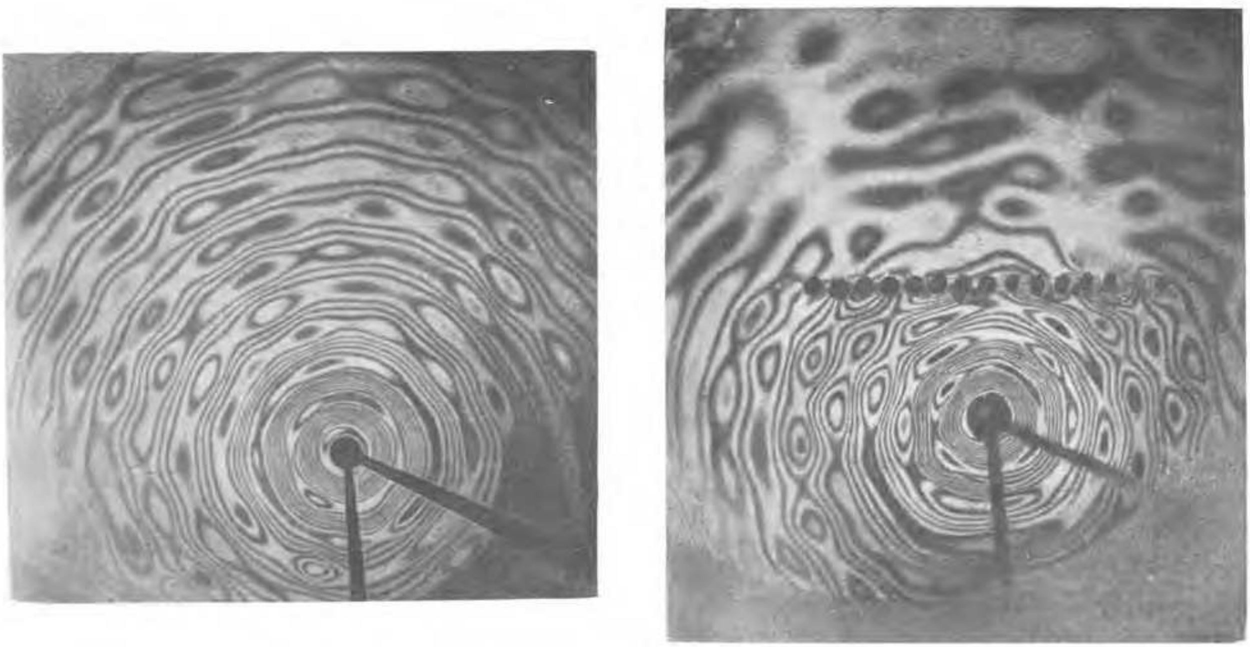

Fig. 5 Surface displacement pattern; a) without wave barrier, b) with wave barrier

results of Woods (1968) and Dolling (1970). The depth of an effective cylindrical hole barrier must be greater than 2/3 the wavelength of the Rayleigh wave ($H > 2/3\ \lambda_R$).

After eliminating depth as a variable, two other variables were identified as the key variables for cylindrical hole barriers. These were diameter of the holes and spacing center to center of the holes.

Practical considerations for isolation of long wavelengths led to the selection of a range of diameters to be tried. A diameter equal to 1/3 wavelength ($D = \lambda_R/3$) was taken as the maximum feasible diameter. These studies indicated, however, that for diameters less than 1/6 of the wavelength, extremely close spacing was required to provide adequate isolation. Close spacing also presents a problem for excavation and stability.

The net space, (S-D), available for energy to penetrate the barrier was found to be the key spacing parameter. Figure 6 shows the relationships between net scaled spacing $(S-D)/\lambda_R$, scaled diameter (D/λ_R) and isolation effectiveness $(1 - F_A')$. The factor F_A' represents the reduction in vertical surface displacement amplitude caused by a barrier.

$$F_A' = \frac{\text{amplitude with barrier}}{\text{amplitude without barrier}}$$

Barrier depth, H, was not included in Fig. 6 because all barriers had approximately the same depth, $1.5\ \lambda_R$.

It was found that for barriers with hole diameters between 1/3 and 1/6 wavelength, no difference in isolation effectiveness was observed for constant net scaled spacings.

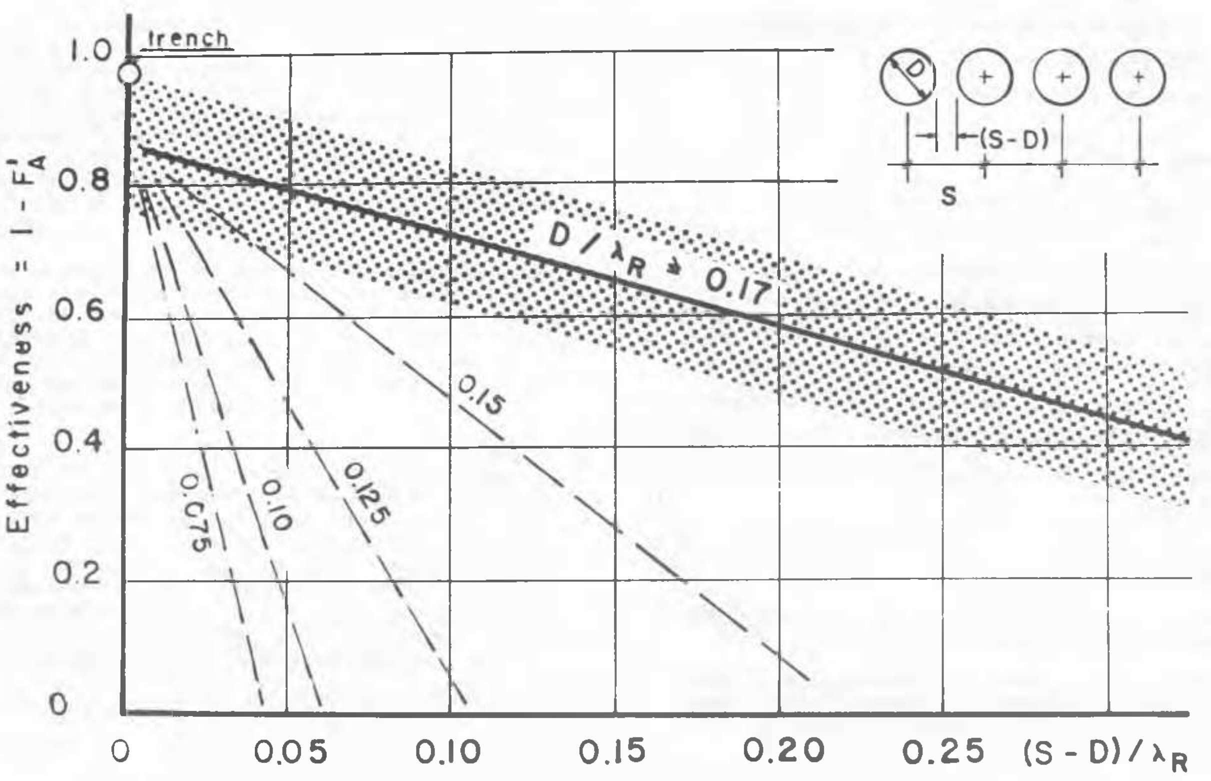

Fig. 6 Isolation effectiveness as a function of hole diameter and spacing

But, for hole diameters less than 1/6 wavelength, the effectiveness drops off quickly at all hole spacings. The shaded zone on Fig. 6 was well established by many tests, however, the dashed lines for $D/\lambda_R < 0.17$ are speculative and are based on only a few tests. As a practical matter, it was very difficult to excavate barriers consisting of closely spaced, small diameter holes. However, the general trend showed that as D/λ_R decreases, $(S-D)/\lambda_R$ must also decrease to accomplish satisfactory isolation.

SUMMARY

It has been shown that double exposure, stroboscopic, holographic interferometry can be used to study vibrations of sand model surfaces. Using the holographic interferometry technique, criteria for effective cylindrical hole wave barriers have been established. The hole diameters should be at least 1/6 of the wavelength of the Rayleigh wave and the net hole spacing (S-D) should be less than 1/4 wavelength.

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