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Anomalous Record of October 15, 1979, Imperial Valley, California, Earthquake from Coachella Canal Engine House No. 4

by

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Open File Report

No. 82-317

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or reviewed for conformity with Geological Survey
standards and nomenclature.

Menlo Park, California

1981

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Abstract

A recording obtained at the Coachella Canal Engine House No. 4 of the October 15, 1979, Imperial Valley earthquake shows a dominant 2 Hz frequency. This feature is very unusual and an attempt has been made to determine if the recording is real or spurious. As the pumping station is a small heavily constructed bunker type of structure located on material of low shear wave velocity it was considered likely that soil-structure interaction might be responsible for the 2 Hz component. However, both an experimental and theoretical investigation fail to establish this. This report describes the theoretical investigation. The experimental investigation is described in a separate open-file report.

Introduction.

Frequently earthquake recordings exhibit non-typical characteristics which may, indeed, be real due to local peculiarities of the terrain or they may be caused by malfunction of the instrument, improper mounting or by soil-structure interaction. Bycroft (1978) discusses the effect of soil-structure interaction on seismograph readings and shows that in certain circumstances the effect can be very significant. The effect is most pronounced for the higher frequencies for massive structures located on a low shear wave velocity terrain.

Fig. 1 shows the record obtained at the Coachella Engine House No. 4 from the Imperial Valley earthquake on October 15, 1979. A dominant 2 Hz component is noted particularly in the 135 degree component. This 2 Hz component shows up more distinctly in the velocity response and Fourier amplitude spectrum shown in Figures 2, 3, 4, and 5. Records obtained at Niland and Calipatria located respectively 10 and 20 km south of Coachella do not show this 2 Hz component. The instrument is located on the floor of a massive bunker-like structure located on very low shear wave velocity terrain leading to the notion that soil-structure interaction may be responsible for the dominant 2 Hz component. The structure is located close to a canal whose proximity could conceivably cause the anomaly. Fig. 2 shows a photo of the engine house. Soil-structure interaction effects may be treated by considering the ground to be an elastic halfspace and by using the impedence or compliance functions of the foundation of the structure on this elastic halfspace. Both rocking and translation of the structure will occur due to the horizontal components of the earthquake. Compliance functions for a rectangular foundation have been calculated by Wong (1975). The compliance functions are the non-dimensionalized ratios of the displacement or notation to the force or moment causing those displacements or notations. In Wong's notation the motion of a foundation excited by a horizontal force and by a couple about a horizontal axis can be expressed by the following equations:

Rocking compliance:

$$(1)\quad C_{mm}(a_o) = \frac{\mu b^3 \phi}{M}$$

where $C_{mm}(a_o)$ is the rocking compliance as a function of the non-dimensional frequency a_o, μ is the shear modulus of the elastic halfspace, 2b is the length of the side of the foundation perpendicular to the axis of rotation, ϕ is the angle of rotation, and $Me^{i\omega t}$ is the exciting moment.

$$(2)\quad a_o = \frac{\omega b}{\beta_s}$$

where β_s is the shear wave velocity.

Horizontal compliance:

$$(3)\quad C_{hh}(a_o) = \frac{\mu b\ \Delta H_1}{Q_1}$$

where ΔH_1 is the horizontal displacement of the foundation and $Q_1 e^{i\omega t}$ is the horizontal exciting force.

Figures 7 and 8 show the values of C_{mm} and C_{hh} as functions of the non-dimensionalized frequency a_o. It is to be noted that these functions are complex because, as well as the inertial and elastic properties of the wave propagation, energy is transmitted to infinity leading to a dissipative component.

Fig. 9 shows a rigid body rocking and translating on the surface of an elastic halfspace and excited by a horizontal force $Qe^{i\omega t}$ resulting in a force $Ae^{i\omega t}$ and a couple $Me^{i\omega t}$ on the base of the structure. A and M are necessarily complex values. The equations of motion of this system are readily shown to be,

$$(4)\quad m\omega^2 Q F_H + mh_1\omega^2 M F_R = Q + A$$

$$(5)\quad I\omega^2 M F_R = M + Q(h_2 - h_1) - Ah_1$$

where m is the mass of the structure, I is the moment of Inertia about the center of gravity and,

$$(6)\quad F_H = \frac{C_{hh}}{\mu b_2}$$

$$(7)\quad F_R = \frac{C_{mm}}{\mu b_1^3}$$

If these equations are solved for A and M it is found that a frequency equation occurs in the bottom line of the functions A and M. This frequency equation has two roots and has the form:

(8) $mh_1^2\omega^2F_R - (I\omega^2F_R-1)(m\omega^2F_H-1) = 0$

Now $F_R(a_0)$ and $F_H(a_0)$ are complex numbers and consequently the two values of ω obtained from equation (8) are also complex showing a damped system due to the propagation of energy to infinity. However, as will be seen later the value of the non-dimensional frequency factor a_0 is relatively small and consequently it will be satisfactory to use only the real parts of F_R and F_H.

The relevant parameters for this structure, where AA is the longitudinal axis and BB the transverse axis, are as follows:

Length = 14 ft
Height = 9 ft
Breadth = 7 ft
Thickness = 8 in
$m = 56{,}500$ lbs
$I_{AA} = 1.072 \times 10^6$ lbxft^2
$I_{BB} = 1.97 \times 10^6$ lbxft^2
$h_1 = 4.5$ ft
$\beta_s = 700$ ft/sec

AA $C_{hh} = -0.28$
BB $C_{hh} = -0.13$
AA $C_{mm} = -0.12$
BB $C_{mm} = -0.31$
AA $F_H = 2.667 \times 10^{-8}$ ft/lb
BB $F_H = 24.74 \times 10^{-9}$
AA $F_R = 18.63 \times 10^{-10}$
BB $F_R = 5.99 \times 10^{-10}$

If equation (8) is solved for these values then the lowest frequency for the two are 19 Hz along the AA axis and 17 Hz along the BB axis. These frequencies check well with the experimental results described in another report. However, although the experimental and theoretical investigations confirm soil-structure interaction theory they do not explain the dominant 2 Hz frequency appearing in the record. The fact that the difference of the two frequencies is indeed 2 Hz is fortuitous. This could only lead to a 2 Hz modulation and not a dominant 2 Hz component.

REFERENCES

(1) Bycroft, G. N. (1978). "The Effect of Soil-Structure Interaction on Seismometer Readings", Bull. Seis. Soc. Am. Vol. 68, No. 3, pp. 823-843

(2) Wong, H. L. (1975). "Dynamic Soil Structure Interaction", Earthquake Engineering Laboratory Cal. Tech. Report No. EERL-75-01.

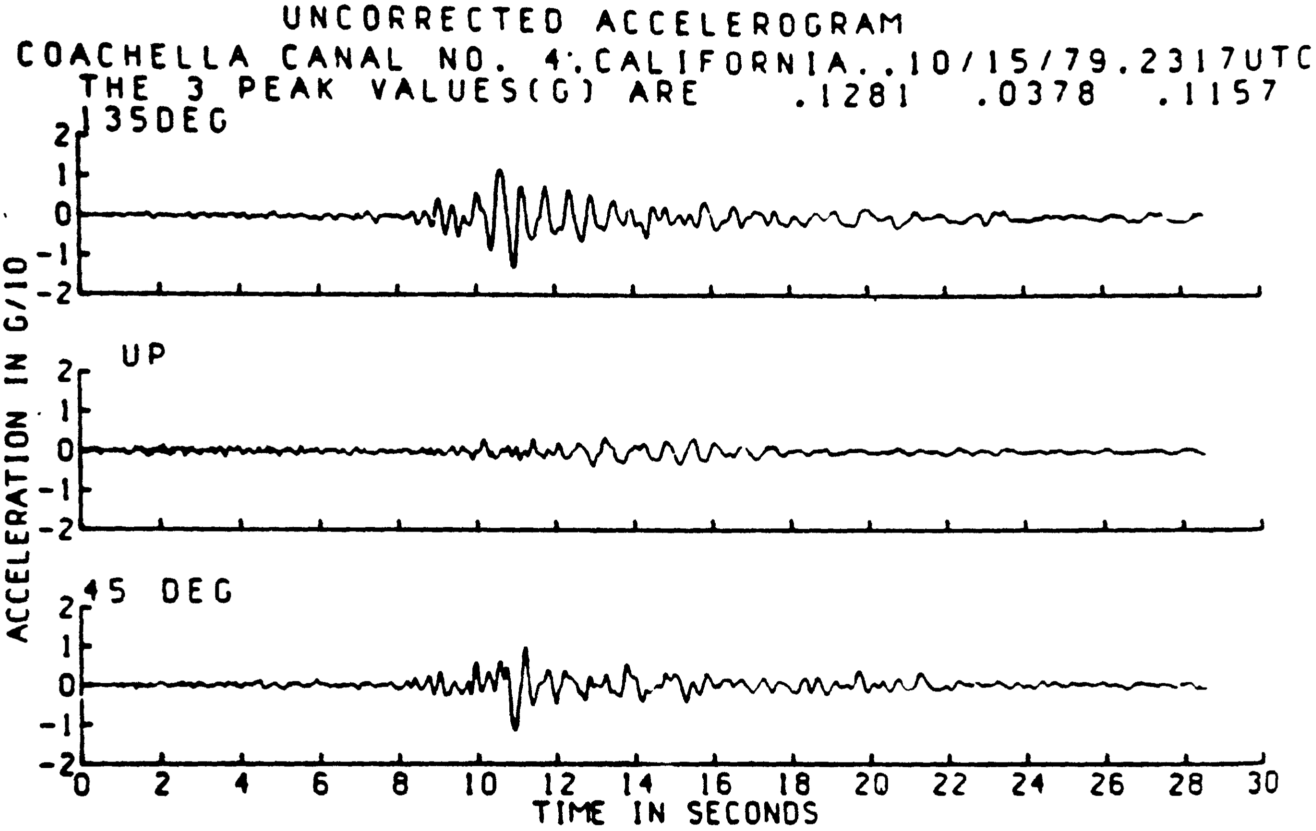


Figure 1.- Accelerogram from Coachella Pumping House No. 4.

Figure 2.

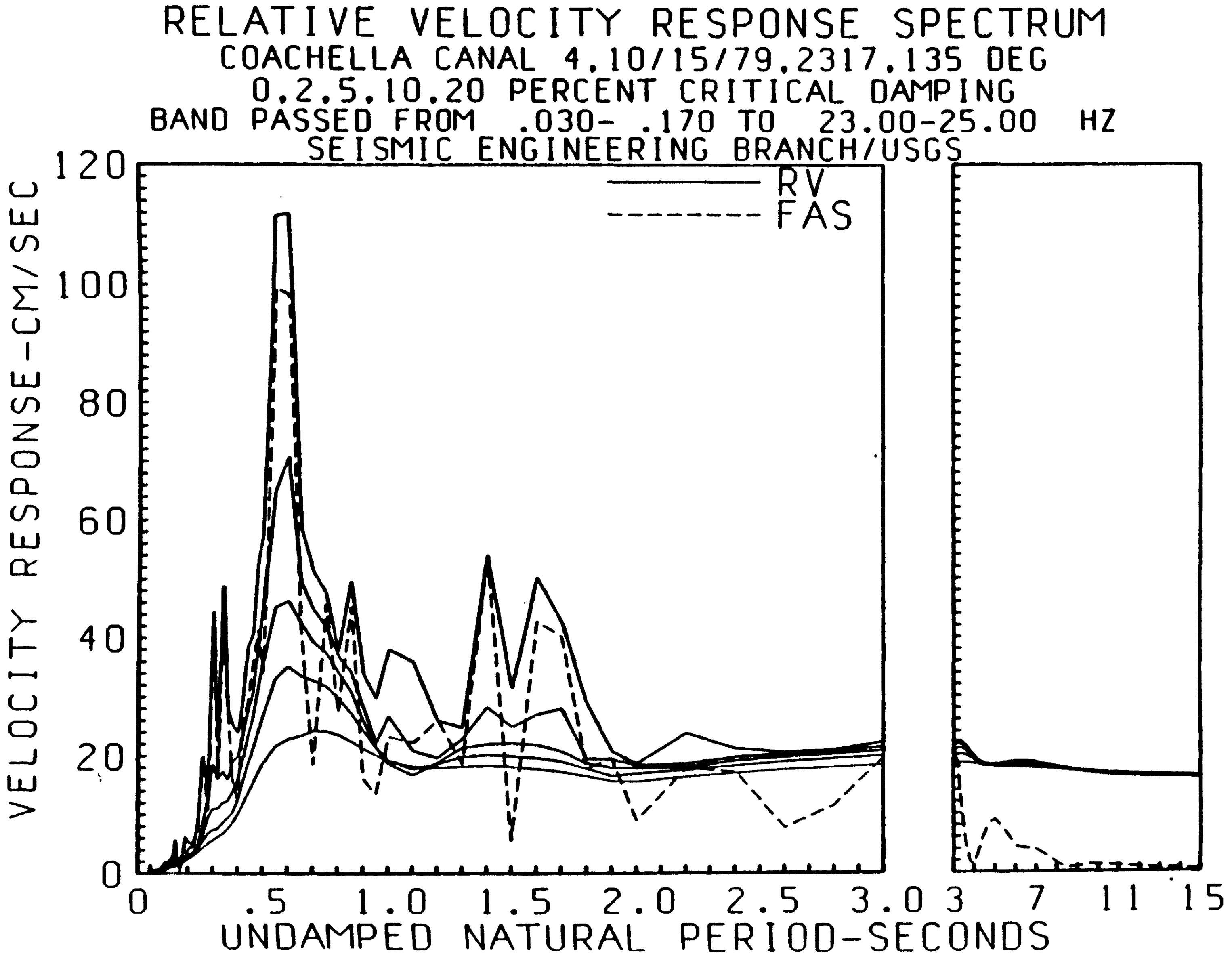

RELATIVE VELOCITY RESPONSE SPECTRUM
COACHELLA CANAL 4.10/15/79.2317.135 DEG
0.2.5.10.20 PERCENT CRITICAL DAMPING
BAND PASSED FROM .030- .170 TO 23.00-25.00 HZ
SEISMIC ENGINEERING BRANCH/USGS
RV
FAS
VELOCITY RESPONSE-CM/SEC
0
20
40
60
80
100
120
0
.5
1.0
1.5
2.0
2.5
3.0
3
7
11
15
UNDAMPED NATURAL PERIOD-SECONDS

Figure 3.

FOURIER AMPLITUDE SPECTRUM OF ACCELERATION
IMPERIAL VALLEY EARTHQUAKE OF OCTOBER 15,1979 - 2317UTC
COACHELLA CANAL NUMBER 4,CALIFORNIA,COMP 135 DEGREES
BAND PASSED FROM .030- .170 TO 23.00-25.00 HZ
SEISMIC ENGINEERING BRANCH/USGS

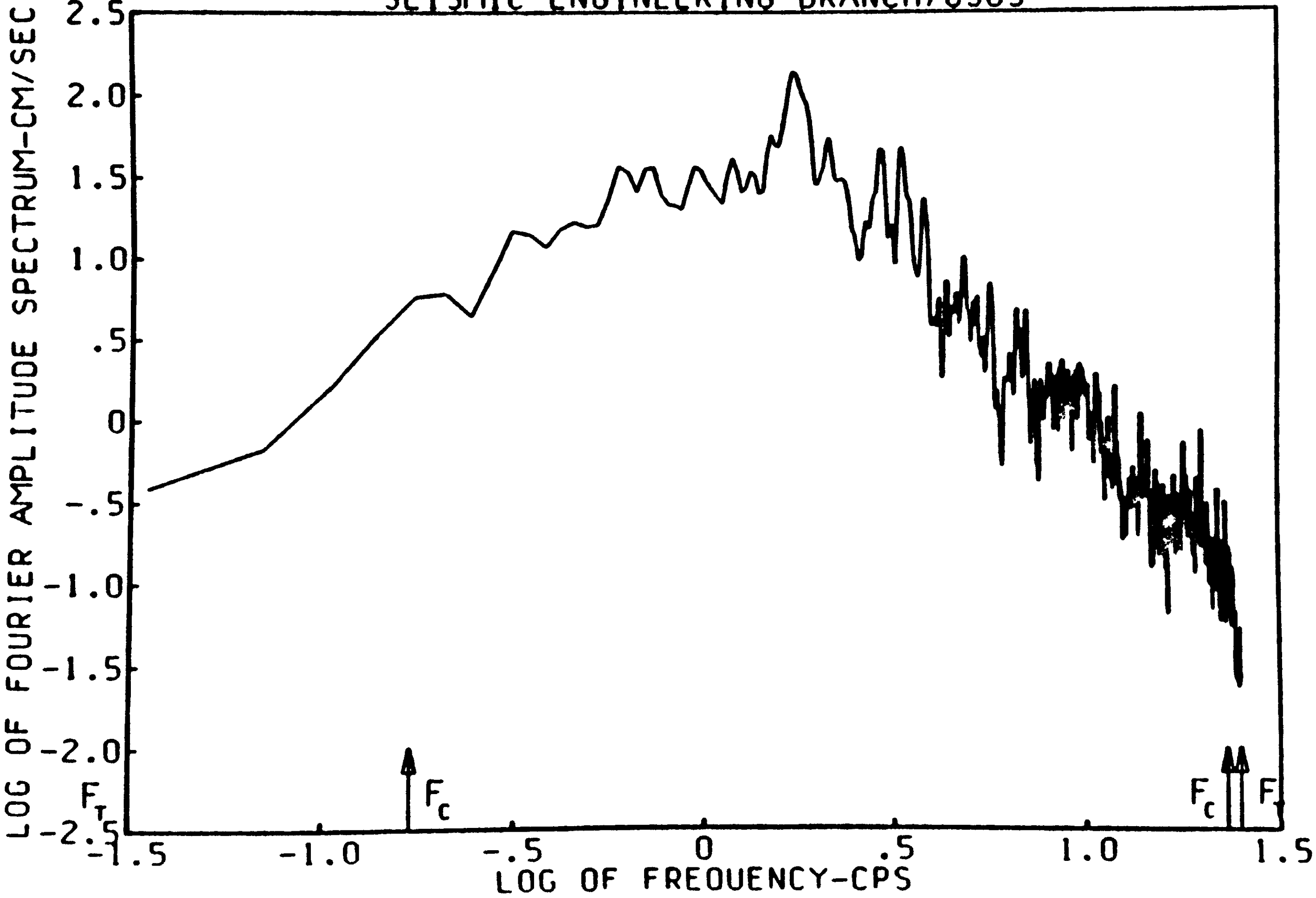


Figure 4.

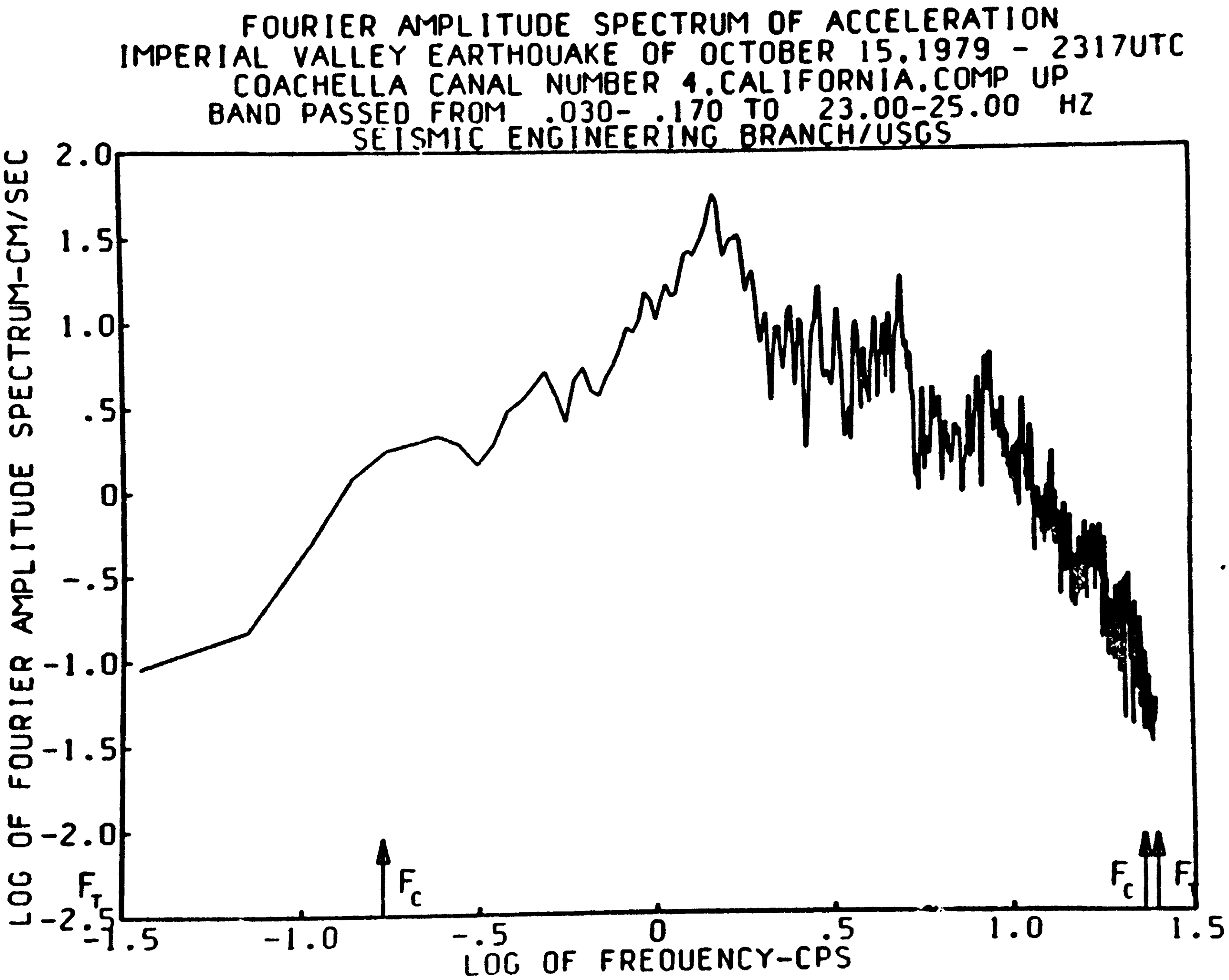
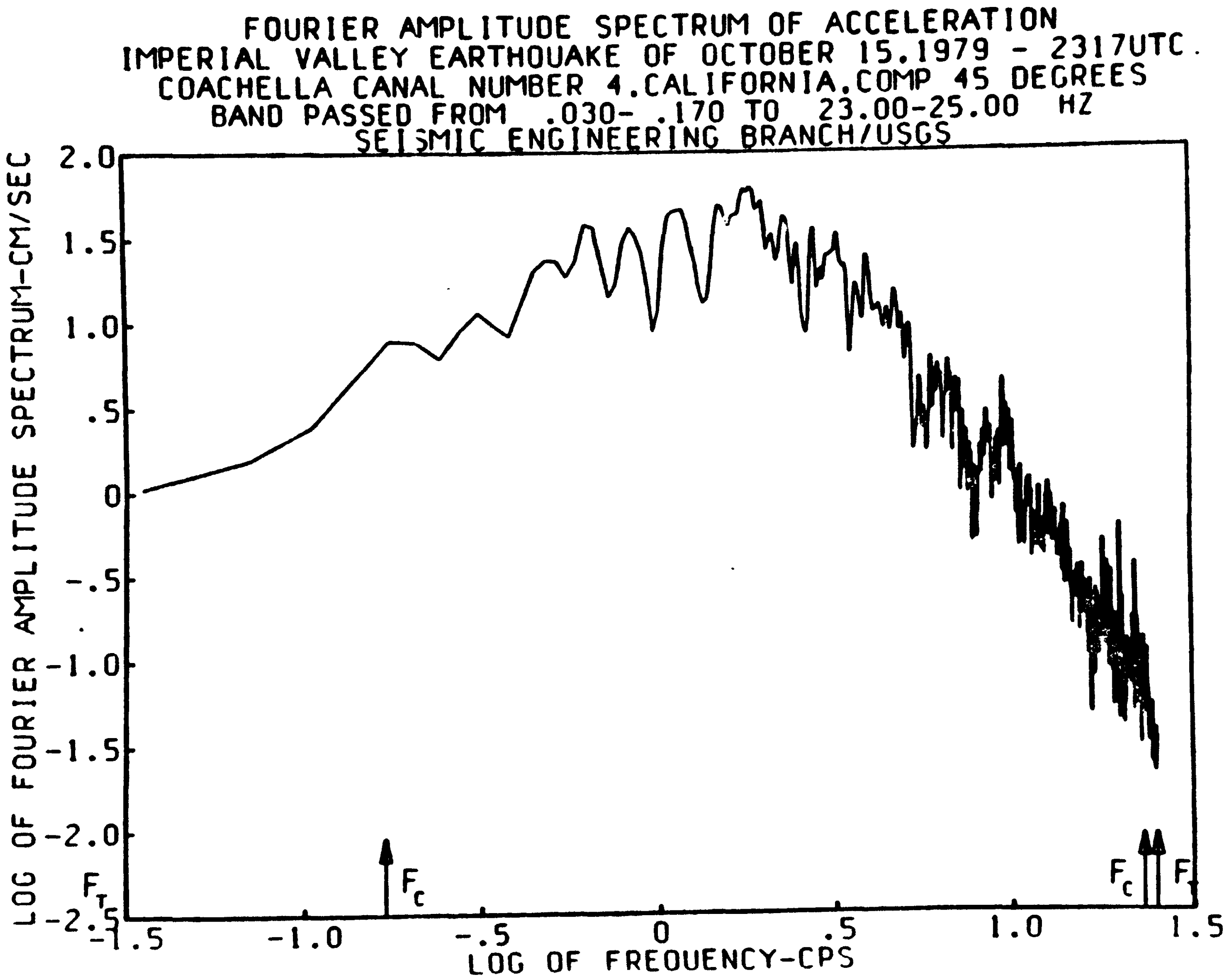
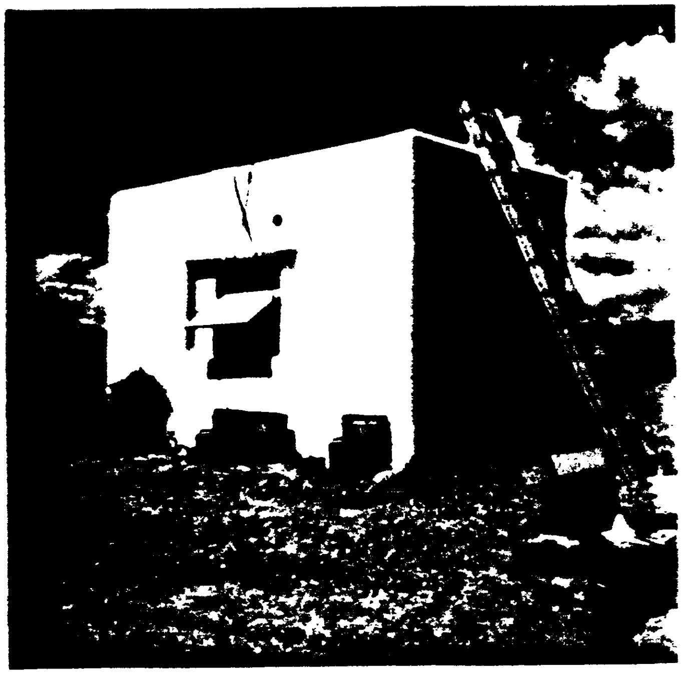

FOURIER AMPLITUDE SPECTRUM OF ACCELERATION
IMPERIAL VALLEY EARTHOUAKE OF OCTOBER 15,1979 - 2317UTC
COACHELLA CANAL NUMBER 4,CALIFORNIA,COMP UP
BAND PASSED FROM .030- .170 TO 23.00-25.00 HZ
SEISMIC ENGINEERING BRANCH/USGS
LOG OF FOURIER AMPLITUDE SPECTRUM-CM/SEC
2.0
1.5
1.0
.5
0
-.5
-1.0
-1.5
-2.0
-2.5
LOG OF FREOUENCY-CPS
-1.5
-1.0
-.5
0
.5
1.0
1.5
F_T
F_c
F_c
F_T

Figure 5.



FOURIER AMPLITUDE SPECTRUM OF ACCELERATION
IMPERIAL VALLEY EARTHQUAKE OF OCTOBER 15.1979 - 2317UTC.
COACHELLA CANAL NUMBER 4.CALIFORNIA.COMP 45 DEGREES
BAND PASSED FROM .030- .170 TO 23.00-25.00 HZ
SEISMIC ENGINEERING BRANCH/USGS



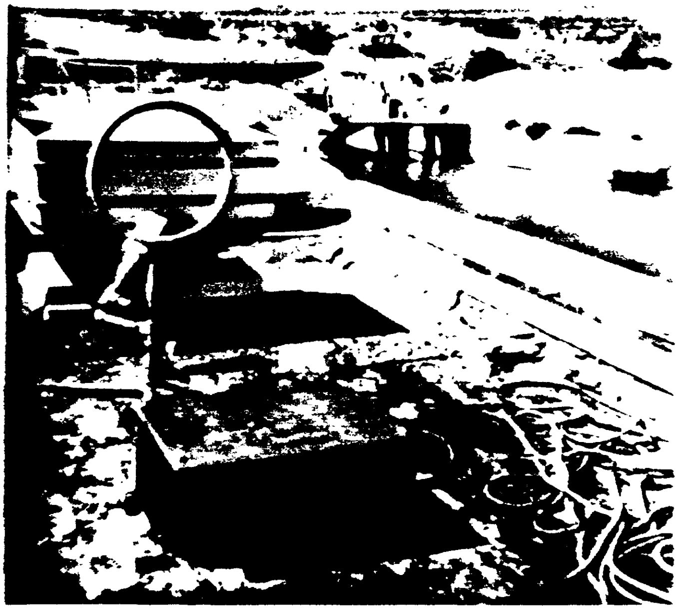


Figure 6.- Engine house and canal.

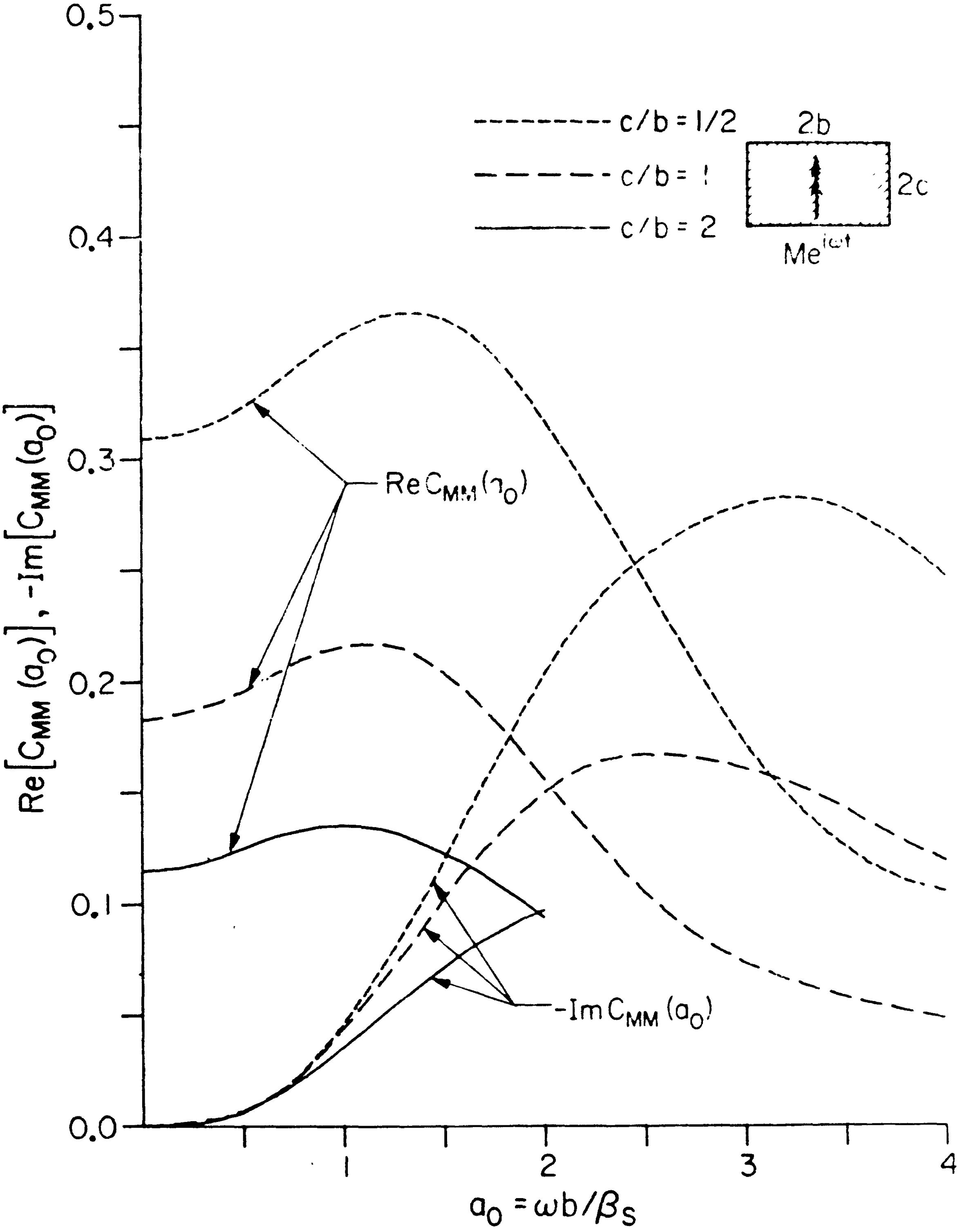


Figure 7.- Rocking compliance for rigid rectangular foundations ($\nu = \frac{1}{3}$).

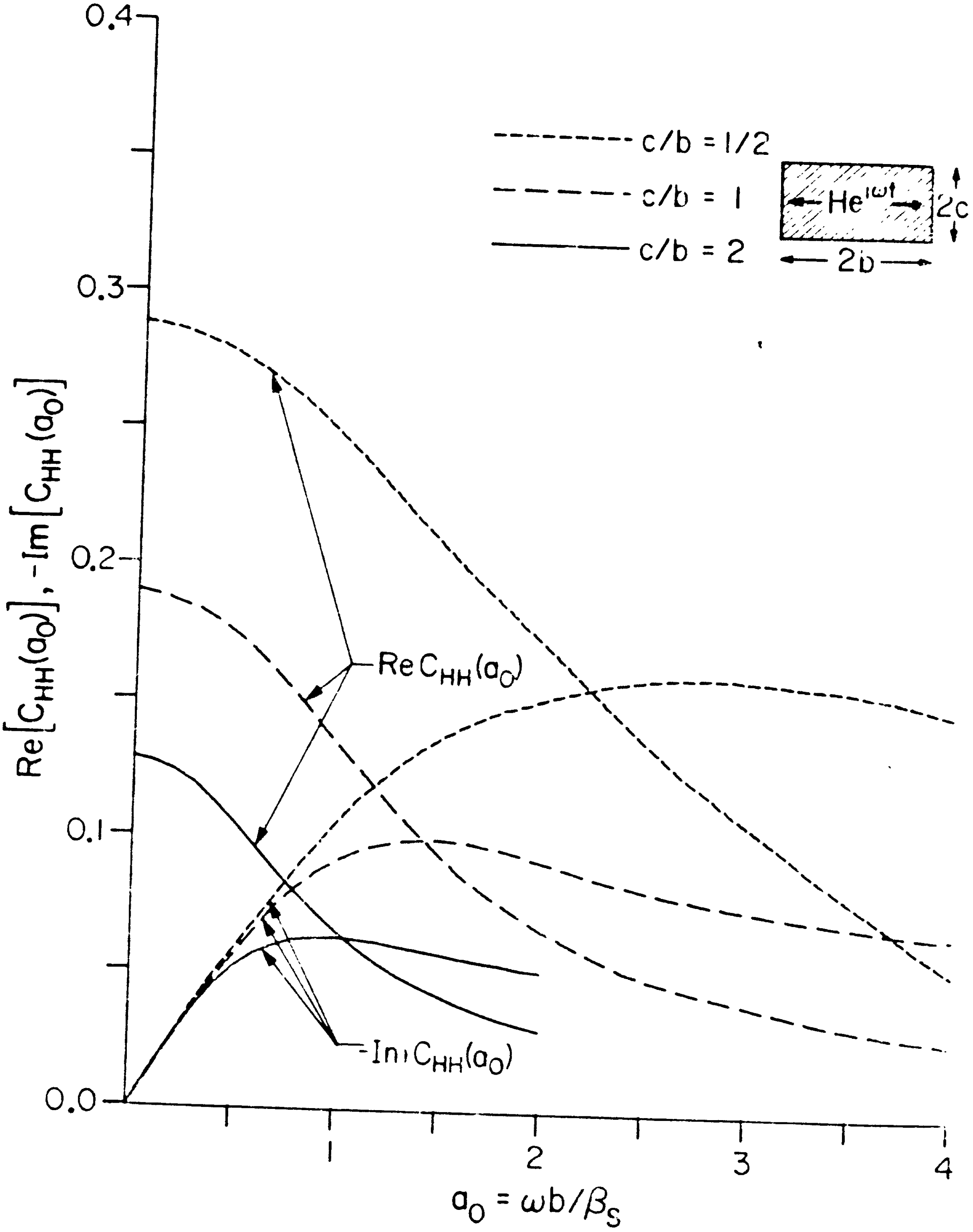


Figure 8.- Horizontal compliance for rigid rectangular foundations ($\nu = \frac{1}{2}$).

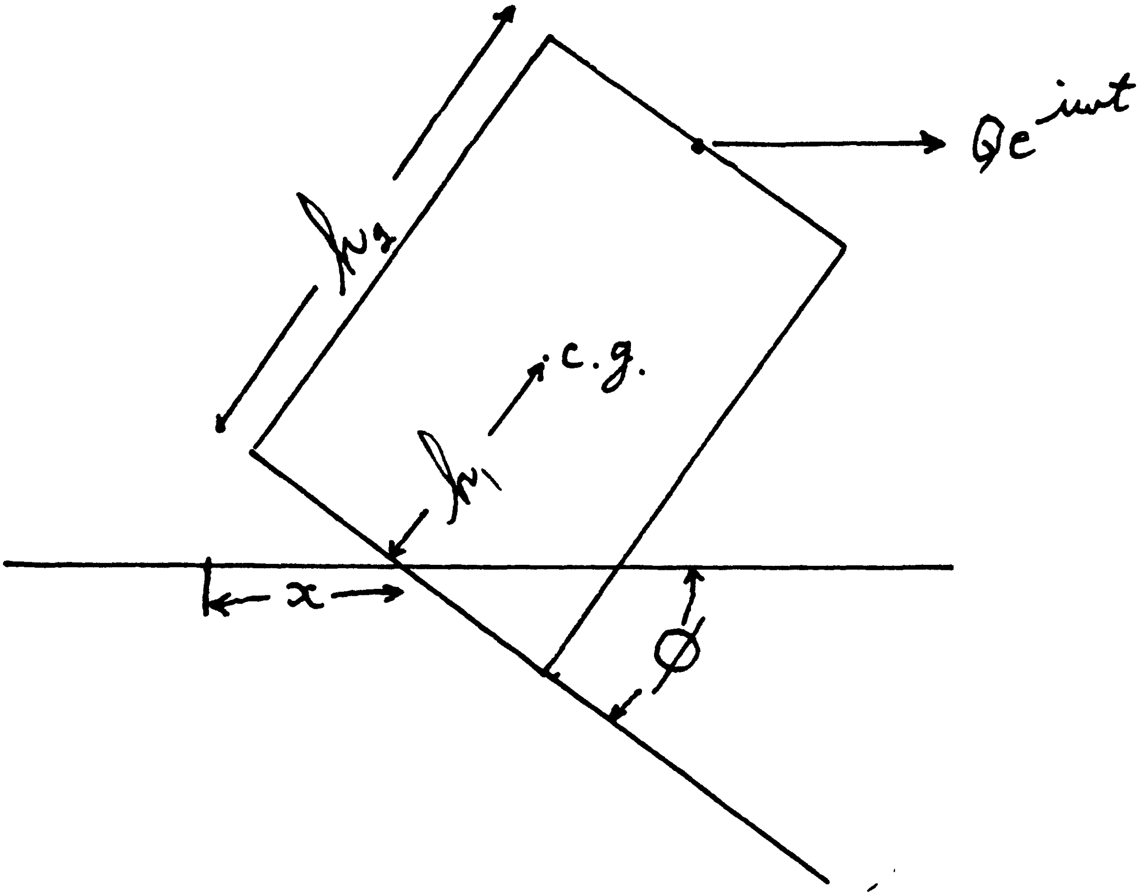


Figure 9.- Rigid body on an elastic halfspace.