- DTIC FILE COPY

(2)

AD-A204 973

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) PR 88:041:363	5. MONITORING ORGANIZATION REPORT NUMBER(S) PR 88:041:363
6a. NAME OF PERFORMING ORGANIZATION Naval Ocean Research and Development Activity 6b. OFFICE SYMBOL (If applicable) 363	7a. NAME OF MONITORING ORGANIZATION Ocean Science Directorate
6c. ADDRESS (City, State, and ZIP Code) Stennis Space Center, MS 39529-5004	7b. ADDRESS (City, State, and ZIP Code) Stennis Space Center, MS 39529-5004
8a. NAME OF FUNDING/SPONSORING ORGANIZATION NORDA 6.1 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Stennis Space Center, MS 39529-5004	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61153N PROJECT NO. 03105 TASK NO. 330 WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Duomorph Sensing for Laboratory Measurement of Shear Modulus

12. PERSONAL AUTHOR(S)
Samatha Breeding and Dawn Lavoie

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Proceedings	FROM ________ TO ______	November 1988	5

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Duomorph, Shear Modulus, geotechnical properties, reprints.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The shear modulus of a sediment is directly related to shear wave velocity, and essential geoacoustic parameter not easily measured in the laboratory. Further, both shear modulus and shear wave velocity are a function of the effective stress on a sediment. The objective of this research is to develop a simple laboratory test prodedure to measure the shear modulus of a sediment under controlled loading conditions. To do this, a Duomorph has been constructed similar to ones designed by Briar et al. (1). Compressional wave velocity has been measured using the NORDA compressional wave transducers before and after consolidation to validate the Duomorph results. Initial results indicate that the concept is feasible and continued testing is planned.

DTIC ELECTE FEB 1989 S E D

(1)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Dawn Lavoie	22b. TELEPHONE (Include Area Code) 601-688-4659 22c. OFFICE SYMBOL 363

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

REPRINTED FROM

OCEANS '88

A Partnership of Marine Interests

PROCEEDINGS

Baltimore, Maryland
October 31–November 2, 1988

IEEE Catalog Number 88-CH2585-8

Reprinted from PROCEEDINGS OF THE OCEANS '88 CONFERENCE
Baltimore, Maryland, October 31-November 2, 1988

DUOMORPH SENSING FOR LABORATORY MEASUREMENT OF SHEAR MODULUS

*Samantha K. Breeding
+Dawn Lavoie

*SYNTEK Engineering & Computer Systems, Inc.
+Naval Ocean Research and Development Activity - Code 363
Stennis Space Center, Mississippi 39526

ABSTRACT

The shear modulus of a sediment is directly related to shear wave velocity, an essential geoacoustic parameter not easily measured in the laboratory. Further, both shear modulus and shear wave velocity are a function of the effective stress on a sediment. The objective of this research is to develop a simple laboratory test procedure to measure the shear modulus of a sediment under controlled loading conditions. To do this, a Duomorph has been constructed similar to ones designed by Briar et al. (1). Compressional wave velocity has been measured using the NORDA compressional wave transducers before and after consolidation to validate the Duomorph results. Initial results indicate that the concept is feasible and continued testing is planned.

INTRODUCTION

The United States Navy is interested in the measurement of shear wave velocity and shear modulus of marine sediments for acoustic and engineering purposes. Shear wave velocity and shear modulus are both a function of effective stress. To produce results close to in situ values, a laboratory procedure that reproduces the estimated effective stress state of the in situ sediment should be used, such as consolidation testing. Currently, the bender element shear wave transducers used by the Navy are only designed to operate under ambient pressure. Therefore, Duomorph sensors designed to measure shear modulus have been fabricated based on ideas originated by Briar et al. (1).

The Duomorphs as originally designed by Briar, et al. were used as in situ sensors to measure the dynamic modulus of solid propellants, but this new technology has potential for use in other applications and materials. The need for an accurate laboratory method for determining the dynamic shear modulus of carbonate sediments under varying pressures led to the application of the Duomorph technique in sediments.

DUOMORPH SENSING AND LABORATORY METHODS

The Duomorph sensor, app. 2.54 cm diameter, consists of a thin steel plate sandwiched between two peizoceramic crystals with a metallic strain gage adhered to the center of each crystal (Figure 1). The peizoceramic crystal is a low power electromechanical transducer capable of converting electrical energy to mechanical energy and vice versa. The application of an alternating current across the individual layers of the peizoceramic crystals causes one layer to expand while the other contracts. The deflection of the crystals is in a dish-shaped manner.

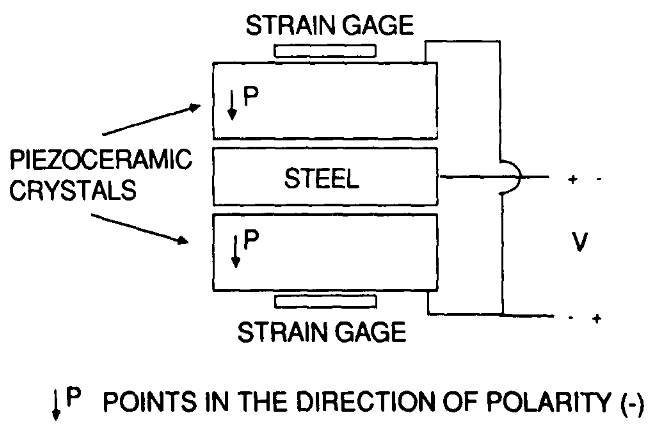


Figure 1. Schematic of a Duomorph wired in parallel.

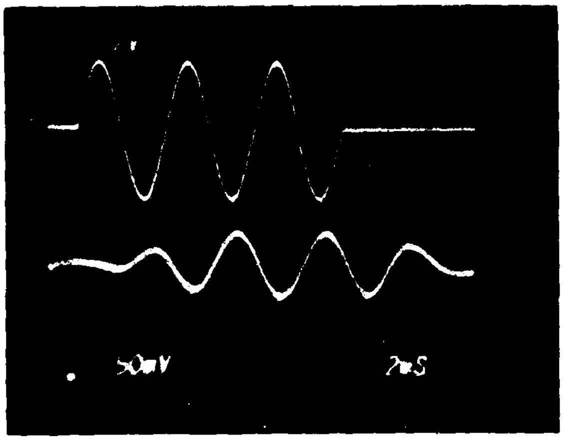


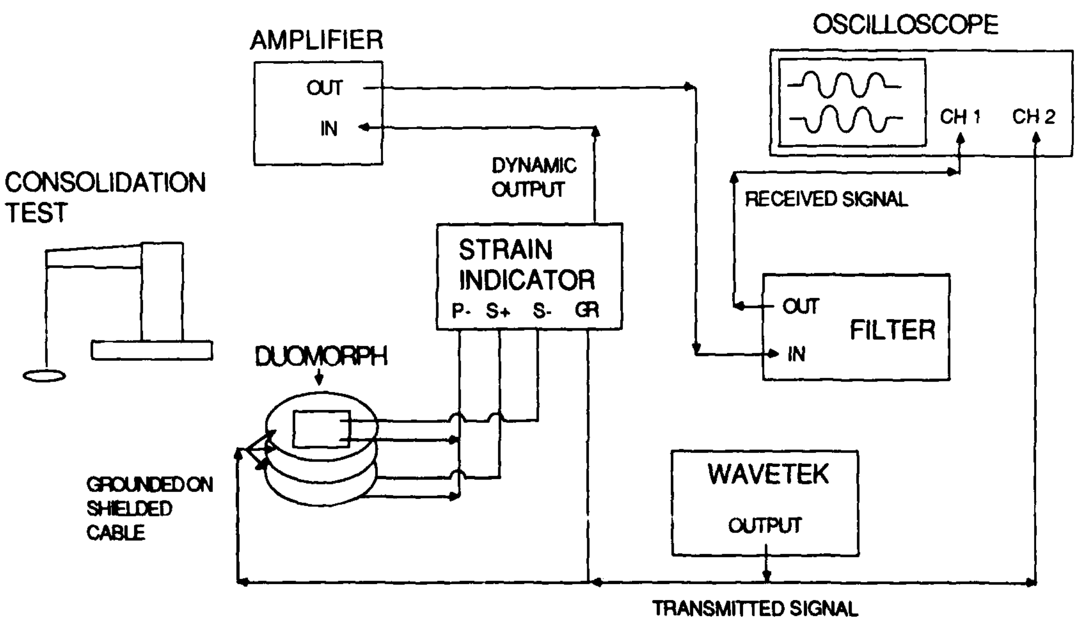
Figure 2. Photograph from the oscilloscope of the transmitted signal to the Duomorph (top) and the received signal from the Duomorph (bottom) after being processed.

The deflection of the Duomorph changes the resistance of the strain gages which are connected to a wheatstone bridge in a strain indicator, in a half bridge configuration. The dynamic output from the strain indicator is amplified, filtered and passed to an oscilloscope to obtain a photograph of the dynamic strain (Figure 2). This laboratory setup is depicted in Fiqure 3.
To use the Duomorph, the strain gage reading of the Duomorph is obtained in air as a reference point. The Duomorph is then embedded in sediment and placed in a consolidation chamber. As loads are added, the consolidation of the sediment is noted according to standard procedures (2). Duomorph strain measurements are made after completion of consolidation under each load increment and used in calculations to determine the shear modulus of the sediment at each load increment.

DESIGN

Two prototypes were built, one with a .020 cm thick steel plate and one with a .008 cm thick steel plate. Both prototypes used 350 ohm resistance metallic strain gages with a .152 cm gage length, a .254 cm grid width, an overall length of .381 cm, and an overall width of .254 cm. They are an "EA" type which measures up to 5% strain. The piezoceramic crystals used were a G-1278 type, fired silver with a thickness of .279 cm and a diameter of 2.54 cm.

After the strain gages were carefully adhered to the crystals, the crystals were adhered to the steel plate forming a sandwich. Thin wires were carefully soldered to the crystals, the steel plate, and to the tabs on the strain



Fiqure 3. Diagram of the laboratory setup for obtaining the dynamic strain from the Duomorph.

gages. This configuration constitutes the instrument called a Duomorph. The Duomorph was then coated with a combination of Resin 184 and 186 to protect the wires and gages from moisture when embedded in sediment.

DATA REDUCTION OF DUOMORPH DATA

Reduction of the Duomorph data follows the method devised by Briar et al. (1). The wave form displayed on the oscilloscope represents the amount of dynamic strain detected by the strain gages. This strain was used in the following equation to determine the modified moment ratio:

$$\frac{M_c}{M_o} = \frac{(e/e_a) - k}{1 - k}, \qquad (1)$$

where:

e is the strain in sediment under a load,
e_a is the strain in air, and
k is a constant dependent on disk design (for the Duomorph with a .020 cm steel plate, $k = -.664$)

$$\frac{1}{k} = \frac{1 - 3\beta h_z(h_z + h_m)(2 + E_m h_m/E_z h_z)}{h^2 [1 + (E_m/E_z - 1)(h_m/h)^3]}, \qquad (2)$$

where:

h_z is the thickness of the PZT crystals,
h_m is the thickness of the steel plate,
E_z is the tensile modulus of the PZT crystals,
E_m is the tensile modulus of the steel plate,
h is the thickness of the entire sandwich, and

$$\beta = (1/2)(1 + h_m/h_z). \qquad (3)$$

The modified moment ratios are used to determine the modulus, M, from a nomograph generated from quasi-static analysis (1). The elastic modulus, E', is calculated by the following equation:

$$E' = M D / a^3, \qquad (4)$$

where:

a is the radius of the Duomorph, and
D is the disk flexural rigidity,

$$D = \frac{h_m^3 (E_m - E_z) + E_z h^3}{12(1 - v^2)}, \qquad (5)$$

where: v is Poisson's ratio for the Duomorph (v =.495 for the Duomorphs used in this research).

The shear modulus, G, is calculated from (5):

$$G = \frac{E'}{2(1 + v)} \qquad (6)$$

The shear wave velocity, Vs, is calculated from (4):

$$V_s = [G / \rho]^{-1/2} \qquad (7)$$

METHOD USED TO CHECK DUOMORPH RESULTS

The values of shear moduli calculated from the Duomorph data are compared to values obtained from a standard method of determining shear modulus to check the validity of the Duomorph results (4).

The standard method used to determine the shear modulus of a sediment involves measuring the compressional wave velocity before and after consolidation. The compressional wave velocity can then be interpolated for intermediate load increments. The specific gravity is determined by a weight/volume technique (3). From the specific gravity, the dry density can be calculated, assuming a fully saturated condition. After a sample has been consolidated (2), the results of the void ratio versus log of effective stress graph are used to calculate a_v, the coeffiecient of compressibility, for each load increment (Figure 4):

$$a_v = \Delta e / \Delta p, \qquad (10)$$

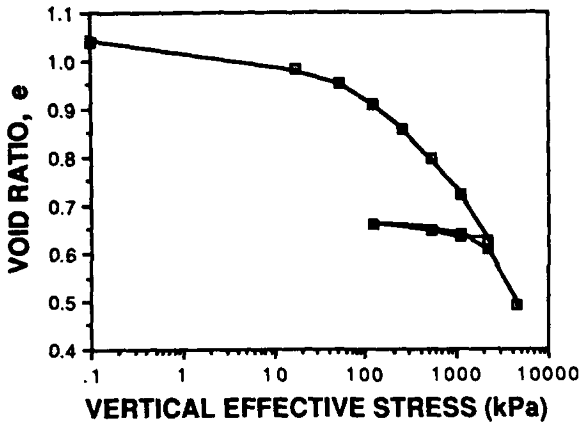
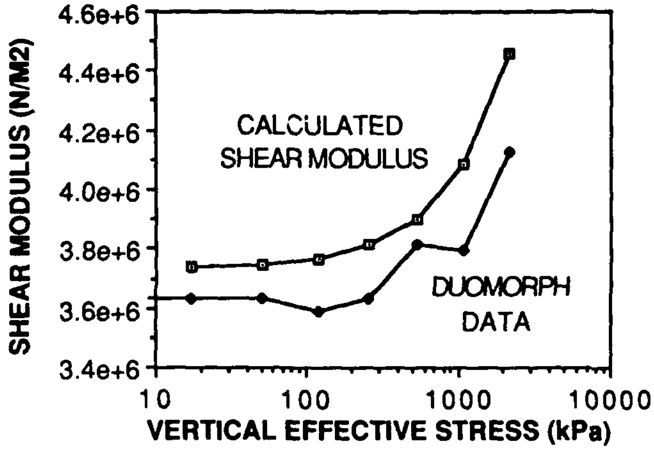


Figure 4. The void ratio versus log of vertical effective stress curve generated from consolidation data.



Fiqure 5. Graph of shear modulus obtained from Duomorph experiment compared to shear modulus calculated from a standard method.

where:

Δe is the change in the void ratio between two load increment, and
Δp is the change in the pressure between two load increment.

The bulk modulus, κ, is calculated from a_v and the initial void ratio, e_o (2,4).

$$\kappa = a_v \left[1 / (1 + e_o) \right] \qquad (11)$$

The shear modulus, G, is calculated from (5):

$$G = (\rho V_p^2 - \kappa) (3/4), \qquad (12)$$

where:

G is the shear modulus,
ρ is the dry density,
V_p is the compressional wave velocity at a load, and
κ is the bulk modulus.

RESULTS

The shear moduli determined from the measured Duomorph data and the shear moduli calculated from the standard method using ρ, V_p, and κ are graphed versus the vertical effective stress in Figure 5. The values from

Table 1. Listing of values calculated from consolidation test and compressional wave transducer tests.

P kN/m^2	e -	a_v $1/kN/m^2$	κ $1/kN/m^2$	V_p m/s	G N/m^2
0.0	1.0398	-	-	1629	-
17.1	.9808	3.45E-3	1.69E-3	1630	3,730,000
51.4	.9528	8.15E-4	4.00E-4	1632	3,740,000
119.9	.9093	6.36E-4	3.12E-4	1637	3,770,000
257.0	.8584	3.71E-4	1.82E-4	1646	3,810,000
531.2	.7941	2.35E-4	1.15E-4	1666	3,900,000
1079.0	.7197	1.36E-4	6.65E-5	1704	4,080,000
2175.0	.6264	8.52E-5	4.18E-5	1781	4,460,000
4605.0	.4892	4.89E-5	2.39E-5	1951	5,350,000

Table 2. Shear wave velocities calculated using the shear modulus from the Duomorph data and the standard method.

Standard Method G (N/m^2)	Standard Method V_s (m/s)	Duomorph Technique G (N/m^2)	Duomorph Technique V_s (m/s)	Percent Difference G %	Percent Difference V_s %
3,740,000	44.6	3,630,000	44.0	2.7	1.4
3,750,000	44.7	3,630,000	44.0	3.0	1.5
3,770,000	44.8	3,590,000	43.8	4.8	2.5
3,820,000	45.1	3,630,000	44.0	4.7	2.4
3,900,000	45.6	3,810,000	45.1	2.3	1.1
4,090,000	46.7	3,790,000	45.0	7.2	3.7
4,460,000	48.8	4,190,000	47.0	7.5	3.8

the consolidation test and the compressional wave velocity tests that were used to calculate the shear moduli using the standard method are listed in Table 1. The shear wave velocities calculated using the shear moduli from both methods are listed in Table 2.

DISCUSSION

The values of shear modulus and shear wave velocity determined from the Duomorph experiment are within 2.3% to 7.5% and 1.2% to 3.8%, respectively, of the values calculated from the standard method. The Duomorph data has slight fluctuations in the data. Fluctuations occur because the strain wave from the oscilloscope isn't always a stable wave; sometimes, it has a tendency to fluctuate due to background laboratory noise. The camera speed was set to 1/15 of a second in attempt to capture a clear wave. In spite of the fast shutter speed, the signal photographed was not always at the same point of fluctuation; and, therefore, the strain measurements varied slightly.

CONCLUSIONS

The values of shear modulus and shear wave velocity obtained from the Duomorph technique are within the range of values determined from the compressional and shear wave velocity techniques. Therefore, Duomorph sensing provides a valid method of determining shear modulus and shear wave velocities of sediments under effective stresses of interest to geotechnical engineers. The advantage of the Duomorph sensor is that it can be placed directly into a consolidation test, whereas, the NORDA bender element transducers for measuring compressional and shear wave velocity are limited to testing samples before and after consolidation testing.

ACKNOWLEDGMENTS

This project was supported by Naval Ocean Research and Development Activity funding at Stennis Space Center, Mississippi. The contribution of Messrs David Young who built the Duomorphs and John Burns who provided electronics support is gratefully acknowledged.

REFERENCES

(1) Briar, Herman P., Bills, Kenneth W., and Schapery, Richard A., "Design and Test of the Operational In-Situ Gage for Solid Propellant Surveillance", Air Force Rocket Propulsion Laboratory, 1976.

(2) Bowles, Joseph E., Engineering Properties of Soils and Their Measurement, McGraw Hill Book Company, third edition, 1986, pp. 107-128.

(3) Lambe, T. William, Soil Testing for Engineers, John Wiley & Sons, Inc., 1951, p.15-21.

(4) Hamilton, Edwin L., "Elastic Properties of Marine Sediments", Journal of Geophysical Research, Vol. 76, No. 2, January 10, 1971, p. 581.

(5) Timoshenko, S., and Goodier, J. N., Theory of Elasticity, McGraw Hill Book Company, Inc., 1951, p. 9.