18
8-31-81
1500-2 NTS
SAND80-2667

UNLIMITED RELEASE

①
B6814

MASTER

AN APPROACH FOR ESTIMATING SOIL ATTACHMENT DURING PENETRATION EVENTS

R. L. McNEILL

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87185
and Livermore, California 94550 for the United States Department of
Energy under Contract DE-AC04-76DP00789.

PRINTED AUGUST 1981

Sandia National Laboratories

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors or subcontractors.

SAND80-2667
Unlimited Distribution

An Approach for Estimating Soil Attachment
During Penetration Events

by

R. L. McNeill

DISCLAIMER
This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ABSTRACT

It is not presently known if significant soil attachment occurs during a penetration event. If attachment occurs, the penetrator may thereby experience increased decelerating forces and the design loads on the penetrator body may be different from the nonattached case. A method is developed to identify when attachment may occur and to estimate the resulting loads on the penetrator. The important parameters are the weight and dimensions of the penetrator, the velocity of the penetrator, and the stiffness of the soil. The method is intended to guide the design of definitive experiments to identify if attachment occurs and to assess the significance of attachment to the design of penetrators.

ED
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

	<u>PAGE</u>
1. Introduction.	1
2. Postulated Mechanism.	2
3. Parametric Evaluation of Attachment Process.	7
4. Suggested Further Work.	13
4a. Experiments for the General Effect	13
4b. Experiments for Quantitative Effects	15
4c. Measurement of Attachment Stresses	15
5. Closure	15

An Approach for Estimating Soil Attachment
During Penetration Events
SAND80-2667

Robert L. McNeill
Sandia National Laboratories

1. Introduction

As a penetrator moves through the soil, its nose must split and move aside the soil materials. The nose must do this with great violence, because in many cases penetrators are recovered with the paint on their body sections practically intact. What is usually observed is: (1) the paint on the pointed nose is gone, and sometimes the metal is eroded; (2) the paint on the body is intact, or lightly scratched, aft of the body's junction with the nose; (3) the paint on the aft section of the body is often gone; and (4) the radius of the final hole is less than the radius of the penetrator. Thus it appears, at least for part of some penetration events, that the soil is thrust violently aside by the nose, so that the radius of the hole is greater than the radius of the penetrator. In that case there is no soil attachment, and therefore no skin friction just aft of the nose. It is clear that the soil recovers and springs back, and it may do that before the penetrator has passed. Thus there could be some attachment of the soil, and therefore skin friction, to the aft end of the body of the penetrator. Loads could be appreciable, possibly on the order of the loads transmitted through the nose (Ref. 1). Recently, C. W. Young, of Sandia National Laboratories, proposed that the water near the nose of the penetrator may flash to steam, generating an envelope of hot, high-pressure gas around the body of the penetrator (Ref. 1). Presumably this situation would lead to small or negligible friction between the soil and the body of the penetrator. The hypothesis is based on deductive reasoning from diverse observations on recovered penetrators which impacted at high velocities.

Clarification of this situation is important to the designers of penetrators who must estimate the distributions of the loads. Clarification is also important to researchers studying the proposition of calculating soil shear strengths from the decelerations recorded

by a penetrator.

The purpose of this paper is to present a physical mechanism for the attachment phenomenon. The model is purposely simple and approximate, so that it can be adjusted based on field experiments. The model does not presently account specifically for the complete lack of attachment due to steam pressure; but it can be accommodated to that condition if experimental results show that the steam pressure is a controlling factor. The paper also presents some suggestions for appropriate field experiments.

2. Postulated Mechanism

The sketches of Figure 1 will be used to illustrate the postulated mechanism.

It is postulated that the penetrator nose splits the soil, and transports it outward and upward as an annular cylinder. If there is no attachment, as in Figure 1(a), the loads on the penetrator are on the nose, resulting from splitting and transporting of the soil, and from the shear strength, S , of the soil acting on the periphery of the annulus. For convenience, the length of the annulus is expressed as a proportion, β , of the body length, H , of the penetrator; and the radius of the sheared zone is expressed as a proportion, λ_s , of the radius, R , of the penetrator. For the case shown in Figure 1(a), $\beta > 1$, and there is no attachment. For the case of $\beta \leq 1$, Figure 1(b), there is attachment, and friction loads on the aft end of the body. The friction stress on the aft end depends on the normal stresses acting, but these are not known. For this reason, those frictional stresses will be expressed as a proportion, η_b , of the soil shear strength, S . While this formulation of the frictional stress = $\eta_b \cdot S$ ignores the fundamentals of frictional behavior, it does allow application of geotechnical experience with piles. That experience indicates (reference 2) that the values of η_b should lie in the range of about 0.7 to 1.0 for very soft soils, to about 0.5 to 1.0 for harder soils. Thus the first part of the postulated mechanism is that there is an upward moving annulus of soil which is thoroughly sheared and remolded, and which may or may not be attached to the aft end of the body. The amount of attachment

(a) NO ATTACHMENT
NO FRICTION LOAD
ON BODY

(b) ATTACHMENT
FRICTION LOAD ON
BODY, TAKEN TO BE
PROPORTIONAL TO
SHEAR STRENGTH

FIG. 1: Postulated Mechanisms
for no attachment ($\beta > 1$)
and for attachment ($\beta \leq 1$)

depends on the value of β , which will be formulated below. It seems reasonable to expect that β will decrease as the penetrator slows, and that the attachment will therefore increase.

A second part of the postulated mechanism is that the impacting nose generates a dilatational wave which propagates radially into the soil mass, and returns to relieve the outward particle velocity on the inside particles of the annulus, allowing those particles to spring back to cause the attachment. One possible cause for the return of the dilatational wave would be its tendency to reflect from the acoustic-impedance boundary at the edge of the soil stressed by the event, as will now be developed. Figure 2 shows a stress-strain curve for a typical soil, along with the wave-velocity/strain curve obtained by calculating the square root of the derivative of the stress-strain curve divided by the soil's density. The latter curve is steep at low strains, and horizontal at high strains (reference 3). The implications of the slope of the wave-velocity curve will be discussed using Figure 3. That figure shows, in the top sketch, the penetrator surrounded by: the sheared and remolded plastic zone (1), which corresponds to the peak of the stress-strain curve of Figure 2; a variable zone (2), which corresponds to the curved part of the stress-strain curve of Figure 2; and an unaffected zone (3) in which the added stress is negligible. The sketches at the bottom of Figure 3 show the added stress and the corresponding acoustic impedance, from the wave-velocity curve. As the limit between the variable zone and the unaffected zone is approached, the acoustic impedance must increase sharply, and possibly could act as a reflecting boundary for the dilatational wave. As the wave-velocity curve shows, the dilatational velocity will be low at high strains and high at low strains. For simplicity, let the average dilatational velocity through the zones 1,2,3 of Figure 3 be,

$$\bar{C} = \epsilon C_d \dots \dots \dots (1)$$

where C_d is the seismic (near-zero stress) dilatational velocity, and ϵ is a factor which has been shown in laboratory wave-propagation

FIG. 2: Wave Velocity in Soils at High Stress Levels

FIG. 3: Zones Around Penetrator
not to scale

experiments to lie between 0.2 and 0.7 (reference 4). The distance from the penetrator centerline to the edge of the unaffected zone is taken to be a proportion, λ_w , of the penetrator radius, R . The theory of plasticity indicates that for materials with properties typical of soils, λ_w has a value of about 20 (reference 5). Thus the time it takes the dilatational wave to propagate to the unaffected zone, reflect, and return to allow the hole to spring back, is approximately

$$\delta t = \frac{2R(\lambda_w - 1)}{\epsilon C_d} \dots \dots \dots (2)$$

During this time, the penetrator will have traveled a distance βH , at the average velocity V_p over that time. That is,

$$\delta t = \frac{\beta H}{V_p} \dots \dots \dots (3)$$

Eliminating δt from Equations (2) and (3) and solving for, β

$$\beta = 2(\lambda_w - 1) \left(\frac{R}{H} \right) \left(\frac{V_p}{\epsilon C_d} \right) \dots \dots \dots (4)$$

Equation (4) is proposed as an initial approximation for the value of β , for the purposes of preliminary parametric evaluation of the attachment effects, and for planning and interpreting experiments.

3. Parametric Evaluation of Attachment Process

The value of β calculated from Equation (4) suffers in some aspects of fundamental mechanics, and depends on choices of λ_w and ϵ . Therefore the values to be calculated are highly approximate, intended only to help to scope the situation, and to guide the planning of experiments.

Using the guideline values from theoretical considerations for λ_w , and from laboratory experiments for ϵ , a base case will be considered

$$\lambda_w \approx 20$$

$$\epsilon \approx 0.2$$

On this basis, Equation (4) becomes:

$$\beta \approx 190 \left(\frac{R}{H} \right) \left(\frac{v_p}{c_d} \right) \dots \dots \dots (4a)$$

Taking as one limit a small, semi-portable Marine Sediment Penetrator (MSP) (R = 1.5 in., H = 53 in.), and as another limit a large Research Earth Borer (REB) (R = 4.38 in., H = 91 in.), the appropriate β -values appear to be in the range of,

$$\beta_m = 5.4 \left(\frac{v_p}{c_d} \right)$$

$$\beta_r = 9.1 \left(\frac{v_p}{c_d} \right)$$

Thus, because these values do not differ greatly, and considering the approximations involved, a first attempt at evaluating the attachment effect will be based upon

$$\beta \approx 7 \left(\frac{v_p}{c_d} \right) \dots \dots \dots (4b)$$

For purposes of this parametric evaluation, three classes of soils of differing hardnesses, taken to be defined approximately by their dilatational velocities, will be considered:

<u>Soil</u> <u>Hardness Class</u>	<u>Dilatational</u> <u>Velocity, fps</u>
Soft	1,000
Medium	5,000
Hard	12,000

The results, using the approximate form of Equation (4b), are given in Figure 4. The following tentative conclusions seem reasonable: (1) for soft soils, attachment may occur at penetrator velocities of a few hundred feet per second; (2) for medium soils, attachment may occur at penetration velocities of several hundred feet per second; (3) for hard soils, attachment may occur at penetrator velocities of a thousand or so feet per second; and (4) for all soils, attachment may involve over 90 percent of the body length ($\beta < 0.1$) when the velocity is only a few tens of feet per second.

The basic form of Equation (4) indicates that attachment should increase as the penetration slows. To determine how attachment increases with depth, it is necessary to know the velocity-depth profile, which results from integrations of the deceleration records. A typical example is given in Figure 5. The change in velocity typically increases with depth, with a somewhat parabolic shape. For the purposes of this parametric study only, that velocity-depth profile was fitted to a cubic parabola, which is the relationship used to calculate the velocity-depth profiles in Figure 6, as will now be discussed.

According to Figure 4, there should be some critical velocity, V_c , at which $\beta = 1$, and below which there is some attachment. The soft-soil case has been chosen for the calculations of Figure 6, and two impact velocities have been studied: 200 fps, which should

FIG. 4: Approximate Dependence of Attachment on Soil Hardness and Penetrator Velocity, based on Eqn. (4b)

— DATA, TEST MSP2A-8, $V_0 = 85$ fps, SOFT SOIL

○ CALCULATED $V_z = V_0 - \left[\frac{V_0}{Z_f^n} \right] Z^n$, $n = 3$

FIG. 5: Typical Shape of Velocity Depth Data

FIG. 6: Velocity - and β - Profile, Soft Soil

be greater than V_c , according to Figure 4; and 85 fps, which should be below V_c . For the case of $V_0 = 200$ fps, attachment only occurs in the last one-third of the trajectory. For this case, the situation sketched in Figure 1(a) would apply for the upper 32 feet of the trajectory; while the situation sketched in Figure 1(b) would apply for the lower 18 feet of the trajectory. Thus, it is clear from these approximate calculations that a theoretical study of the penetration process probably will have to handle both situations. For the case of $V_0 = 85$ fps, attachment exists throughout the trajectory.

For simplicity, the calculations above were based on Equation 4(b), which in effect ignores the effects of penetrator geometry. The original formulation of β , Equation (4), allows for the effects of penetrator geometry. Using Equation (4), the results shown in Figure 7 were calculated. Penetrator A has been used for research on the strength of rocks under penetrator loadings. In one experiment, it impacted at about 1500 fps, and penetrated 16 feet, as shown in Figure 7. Calculations using Equation (4) indicate that attachment commenced at about 12 feet. Penetrator B has been used to study the strength properties of offshore soils. For these calculations, it was hypothesized that it would penetrate about the same as Penetration A. Under that hypothesis, the results of Figure 7 show that attachment would exist throughout the entire trajectory of Penetration B. Thus the behavior and fundamental penetration mechanisms of these two penetrators would be expected to be different.

4. Suggested Further Work

4a. Experiments for the General Effect

These experiments will not be instrumented, and the only measured result will be final depth. Each set of experiments will require four identical penetrators, except that two will have smooth bodies and two will have roughened bodies. A pair then would be one smooth and one roughened body. One pair of each set would be impacted at about 60 fps, and the other at about 200 fps.

The first set, Set A, would be turned from solid steel billet to 3 inches in diameter, and of length appropriate to make the sectional

FIG. 7: Effects of Penetrator Geometry

- Hard soil or rock
- Penetrators sketched to common scale

pressure about 15 psi ($H \approx 60$ inches). Each pair should be dropped at the same time from the same platform. Succeeding Sets B and C should be done only if the impact velocities can be controlled to duplicate those of Set A, and if impact accuracy is such that all three sets will be close to each other.

The penetrators of Set B should be substantially longer than those of Set A (e.g., $H \approx 90$ inches), but the penetrators of Set B should be bored out so that their sectional pressures are the same as those of Set A. The penetrators of Set C should be substantially shorter than those of Set A, but the penetrators of Set A should be bored out and refilled with lead so that their sectional pressures are the same as those of Set A.

4b. Experiments for Quantitative Effects

These experiments will involve the expense of instrumented penetrators, and therefore should not be planned until the results of the noninstrumented general effects experiments above have been analyzed. The general idea would be to instrument the penetrators with axial and lateral accelerometers, to instrument to measure the nose loads, and to instrument to measure the attachments to the body, all in real time.

4c. Measurement of Attachment Stresses

The University of New Mexico (reference 6) has developed an acceleration-compensated gauge which simultaneously measures the normal stress and two perpendicular components of shear stress on its sensing face. This gauge should be studied for its applicability to penetrator experiments designed to define the fundamental normal and friction mechanisms of the attachment event.

5. Closure

A simple method for estimating attachment and its effects has been presented in Equation (4). Calculations using that equation and the properties of existing penetrators indicate that the mechanism of penetration changes throughout the penetration event. When the penetrator velocity is greater than the critical velocity for that penetrator in that particular soil, there is no attachment, and the loading is only on the nose. When the penetrator velocity is less than the critical velocity, partial attachment occurs on the aft end of the penetrator, and loading is on both the nose and the aft end of the body. As the penetrator slows further, the attachment increases, becoming complete as the penetrator stops.

References

1. Young, C.W.: "The Earth Penetrator--A Steam Generator?", Letter to C.E. Daltony - 5621, Sandia National Laboratories, Albuquerque, New Mexico, 20 Nov, 80.
2. Tomlinson, M.J.: Foundation Design & Construction, Wiley, New York, 1969.
3. McNeill, R.L.: "A Study of the Propagation of Stress Waves in Sand", AFWL-TR-65-180, Weapons Laboratory, USAF, Albuquerque, New Mexico, 1966.
4. Anderson, D.G.: "Dynamic Modulus of Cohesive Soils", UMEE-74RZ, Univ. Mich., Ann Arbor, June, 1974.
5. Esrig, M.I., R.C. Kirby, R.G. Bea., and B.S. Murphy: "Initial Development of a General Effective Stress Method for the Prediction of Axial Capacity for Driven Piles in Clay," Paper 2943, Proc., OTC, 1977.
6. Pickett, S.F.: "Development and Evaluation of a Triaxial Interface Stress Transducer," AFWL-TR-77-90, Weapons Laboratory, USAF, Albuquerque, New Mexico, 1977.

DISTRIBUTION

Dr. R. M. Beard
C. E. Laboratory
Naval Construction Battalion
Center
Port Hueneme, CA 93043

Dr. T. R. Chari
Faculty of Engr. and Applied
Science
Memorial University of Newfoundland
St. Johns, Newfoundland
Canada A1B 3X5

Dr. Umesh Dayal
CE Department
Indian Institute of Technology
Kampur 208-016
U.P. India

Dr. Bruce Denness
Professor of Ocean Engr.
Queen Victoria Rd.
Newcastle-upon-Tyne NE1 7RU
England

U.S. Department of Energy
Acting Deputy Assist. Secretary
for Oil and Gas Tech.
MS D107
Washington, DC 20545

Los Alamos Scientific Laboratory
P. O. Box 1663
LosAlamos, NM 87544
Attn: W-D0

Lawrence Livermore Laboratory
P. O. Box 808
Livermore, CA 94551
Attn: Tech. Info. Division

U. S. Geological Survey
Box 25046, MS903
Federal Center
Denver, CO 80225
Attn: Dr. H. Olsen

U.S. Geological Survey
National Center MS 915
Reston, VA 22092
Attn: Dr. T. Edgar

U.S. Geological Survey
Woods Hole, MA 02545
Attn: Dr. D. Folger

U.S. Geological Survey
P. O. Box 6732
Corpus Christi, TX 78411
Attn: Dr. L. Garrison

Deep-Sea Drilling Project
Scripps Inst. of Oceanography
La Jolla, CA 92093
Attn: Mr. V. F. Larsen, MCA-031

MOAA
15 Rickenbacker Causeway, ADML-MGGL
Virginia Key
Miami, FL 33149
Attn: Dr. R. Bennett

U.S. Army Engineers
Waterways Experiment Station
Vicksburg, MI 39180
Attn: Mr. J. G. Jackson

University of California
Civil Engineering
440 Davis Hall
Berkeley, CA 94720
Attn: Dr. J. Mitchell

University of California
Civil Engineering
440 Davis Hall
Berkeley, CA 94720
Attn: Dr. H. Seed

California State University
Civil Engineering
Long Beach, CA 90840
Attn: Dr. B. Yen

Texas A&M University
College Station, TX 77843
Attn: Dr. W. Dunlap

University of New Mexico
Albuquerque, NM 87131
Attn: Mr. D. Calhoun

Lehigh University
Marine Geotechnology Lab.
Bethlehem, PA 18015
Attn: Dr. A. Richards

Carnegie-Mellon Institute
Civil Engineering Dept.
5115 Margaret Morrison St.
Pittsburgh, PA 15213
Attn: Dr. D. Sangrey

Dames and Moore
500 Sansome St.
San Francisco, CA 94111
Attn: Mr. R. Darragh

Fugro Gulf, Inc.
8181 Commerce Park Dr.
Suite 712
Houston, TX 77036
Attn: B. Grubbs

McClelland Engineers
6100 Hillcroft
Houston, TX 77081
Attn: Mr. B. McClelland

Converse Ward Davis Dixon
P. O. Box 22680
Pasadena, CA 91105
Attn: Mr. J. Ward

Woodward-Clyde Consultants
600 Montgomery St.
30th Floor
San Francisco, CA 94111
Attn: Mr. D. C. Moorhouse

4000 A. Narath
4700 J. Scott
4750 V. Dugan
4752 R. Prindle
4752 R. McNeill
4536 R. Anderson
4536 D. Talbort
4536 J. Lipkin
5500 O. Jones
5530 W. Herrmann
5532 B. Butcher
5533 A. Chabai
5541 W. Luth
5541 J. Rundle
5620 M. Newsom
5621 C. Dalton
5621 A. Foster
5621 K. Grube
5621 G. Reis
5621 W. Young
4752 H. Dodd
3141 L. J. Erickson (5)
3151 W. L. Garner (3)
DOE/TIC (25 - for Unlimited
Release)
3154-4 J. Hernandez

[illegible]