A STUDY OF POLYVINYL-CHLORIDE PIPE AS WELL CASING

by

Dinh Huu Dao

Diploma in Civil Engineering
National Institute of Technology
Saigon, Vietnam
1962

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Approved by:

Wayne W. Williams
Major Professor

TABLE OF CONTENTS

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Water plays one of the most important roles in the life of mankind, animals, and plants on the earth. Deny man foods, he can sustain life for days, but deny him water, he will die within hours. The foods the soil produces also depend upon water for their growth and their nutritional value, since the soil minerals must be in solution before they can be used by plant life.

The need for potable water for both domestic and irrigation uses has greatly increased during the past decades. The water can be taken from rivers and used after mechanical and chemical treatment through a plant, but it is expensive for local use, and sometimes there is no dependable available river source. The water is then taken from the aquifers under ground through deep wells using metal pipe for the most part as casing. Due to the geological formation of the soil, the producing water soil layer varies from one place to another and the cost of the well increases with its depth and diameter. Also the problem of corrosion due to chemical reaction on the well screen and casing limits the useful life of the well. For an area that contains corrosive water with high iron content, a galvanized steel pipe, in most cases, needs to be replaced in four to five years.

The seriousness of the premature well failure due to corrosion may be judged by the costs involving the rehabilitation or replacement of the well casing and the inconveniences resulting from interruption of water supply during the time that the well is out of order.

Today, through technical development in the plastics industry, many well companies are turning to polyvinyl-chloride (PVC) along with other plastic materials for well casing, but still on an experimental basis with the limitations of size and depth for this application unknown at this time.

In order to insure the proper use and design of PVC for well casing, knowledge concerning the forces and reaction of the PVC pipe must be acquired. This knowledge will enable manufacturers and contractors to use the plastic pipe as the most economical material for well casing by its low cost of installation, the elimination of iron bacteria, and the elimination of electrolytic action on the well casing giving almost unlimited well life expectancy.

PURPOSE OF THE STUDY

The purpose of this study was to determine the suitability and limitation of large diameter polyvinyl chloride pipe used as well casing for water wells.

SCOPE OF THE STUDY

The scope of the study included a determination of the theoretical forces on a well casing using the most reasonable and accepted theories. The attempt was then made to determine the validity of these theories by laboratory and field data.

The study consists of a thorough review of the literature including the early studies of flexible conduits used for drainage, early studies of stresses on cylindrical bodies, and the more recent studies of pressure on well casing.

Experimental data was collected from laboratory testing of 8" and 10" PVC pipe.

Field data was collected from a test well on the Vernon Rechke farm at Iuka, Kansas. A 16" PVC pipe with a wall thickness of 0.50" was installed to a depth of 155 feet in this well and the deflection of the pipe noted.

LITERATURE REVIEW

Any structure surrounded by soil is subjected to earth pressure. The magnitude of earth pressure depends on the method of burial, the position of burial, the physical properties of the soil and its interaction with the structure, and the amount of absolute and relative deformation. The problem of magnitude and distribution of earth pressure is statically indeterminate.

The following review of literature begins with a search for a rational expression for the buckling and failure of long tubes, then to the method for determining the failure of a flexible conduit, and finally to the literature concerning polyvinyl-chloride pipe and well casing.

BUCKLING AND FAILURE OF TUBES

In 1848 Fairban (10) reported the collapsing pressures of tubing, based on experimental data.

Since then, a rational expression for critical collapse pressure has been the concern of many investigators.

In 1884 M. Levy (14) developed an expression for the collapse of long cylinders under external pressure which was:

$$P = \frac{2E}{1 - \mu^2} \times \frac{1}{\left(\frac{D}{t} - 1\right)^2} \quad . \; . \; . \; . \; . \; . \; . \; .$$

where

P = external pressure

E = Young's Modulus

μ = Poisson's ratio

D = outside diameter

t = wall thickness

In 1888, Bryan (4) developed a similar formula for collapse pressure of long, thin tubes;

$$P = \frac{2E}{1-\mu^2} \cdot \left(\frac{t}{D}\right)^3, \qquad \sigma = \frac{E}{1-\mu^2} \cdot \left(\frac{t}{D}\right)^2$$

P = external collapsing pressure, σ = circumferential stress

Stewart (24) found an empirical equation for elastic collapse following his experiments on lap-welded steel tubes.

$$P = 1{,}000 \left[1 - \sqrt{\left(1 - \frac{1600}{\left(\frac{D}{t}\right)^2}\right)}\right] \; . \; . \; . \; . \; . \; . \; .$$

This equation becomes imaginary for $\frac{D}{t}$ less than 40.

Another expression for elastic collapse was given by him as equal to;

$$P = \frac{50.2(10^6)}{\left(\frac{D}{t}\right)^3} \; . \; . \; . \; . \; . \; . \; . \; .$$

This can also be written

$$P = \frac{2CE}{1-\mu^2} \cdot \frac{1}{\left(\frac{D}{t}\right)^3} \; . \; . \; . \; . \; . \; . \; .$$

where C is an empirical constant.

Sturm (25), in his doctorate dissertation, investigated the effect of the length to diameter ratio $\frac{L}{D}$ on collapse and gave an expression:

$$P = \frac{2E}{1-\mu^2} \cdot \frac{1}{\left(\frac{D}{t}\right)^3} \cdot \left[\frac{N^4 - N^2 + a^4 \left(\frac{\Pi}{2}\frac{D}{L}\right)^4 + a^2 \left(\frac{\Pi}{2}\frac{D}{L}\right)^2 (2N^2 - \mu)}{3N^2}\right]$$

where

L = length of the tube

N = number of lobes in which the tube collapses, taken as 2 for long tubes.

a = a parameter for end conditions, taken as 1 for long tubes as $\frac{L}{D}$ increases the factor in brackets approaches 1 as limit.

For long tubes, the factor may be given the value of unit, and

$$P = \frac{2E}{1 - \mu^2} \cdot \frac{1}{(\frac{D}{t})^3} \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot$$

Clinedinst (5) by the derivation of collapsing pressure for long tubes based upon the elastic theory basis and both linear and hyperbolic distribution of stress that occurs with the neutral axis located at the *outside diameter* of the tube, arrived at these expressions for collapsing pressure;

- Assuming a hyperbolic stress distribution

$$P = \frac{2E}{1-\mu^2} \cdot \frac{3\lambda}{\frac{D}{t}}$$

with $\lambda = -1 + \frac{\frac{D}{t} - 1}{2} \ln \frac{\frac{D}{t}}{\frac{D}{t} - 2}$

- Assuming a linear stress distribution

$$P = \frac{2E}{1-\mu^2} \cdot \frac{1}{\frac{D}{t}\left(\frac{D}{t} - 1\right)^2}$$

BUCKLING AND FAILURE OF FLEXIBLE CONDUITS

The first generally available theoretical study of earth forces on buried flexible conduits was made by Anson Marston and A. O. Anderson in 1913 (15) which was reported to ASTM Committee C.6 in 1914 (6). In the early 1900's, engineers in northern Iowa reported widespread structural failure in pipe lines used for drainage with large diameter and deep soil cut. They turned to Marston for help. Through investigation, Marston found that the load due to the weight of the soil column above a buried conduit is modified by arch action with the result that in some cases, the load on the pipe may be less than the weight of overlying columns of soil. The basic equation which Marston gave for the computation of the maximum load or rigid conduit was:

$$Wc = Cd\gamma Bd^2$$

where

Wc = load on conduit in pounds per linear foot

γ = unit weight of soil (pcf)

Bd = width of ditch in feet

Cd = load coefficient which is

$$Cd = \frac{1 - e^{-2Ka\mu'(H/Bd)}}{2Ka\mu'}$$

e = natural log base

Ka = coefficient of active pressure which is

$$Ka = \mathrm{Tan}^2\left(45° - \frac{\phi}{2}\right)$$

μ' = coefficient of friction between ditch wall and interior fill

H = height of fill to top of conduit

A cross section of a ditch conduit is presented in Fig. 1. The values of Cd vary with the ratio H/Bd for several kinds of filling materials having different coefficients of internal friction.

For the case of a flexible ditch conduit, the above equation should be multiplied by the ratio of the width of the conduit to the width of the ditch (Bc/Bd) which results in the equation

$$Wc = Cd\gamma BdBc$$

The theoretical and experimental investigations were continued at Iowa State University as reported by Marston in 1930 (17), Schlick in 1932 (19), and Spangler in 1941 (20).

Spangler developed the first theory of predicting deflections for buried flexible conduits (21). This theory resulted in a formula known

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

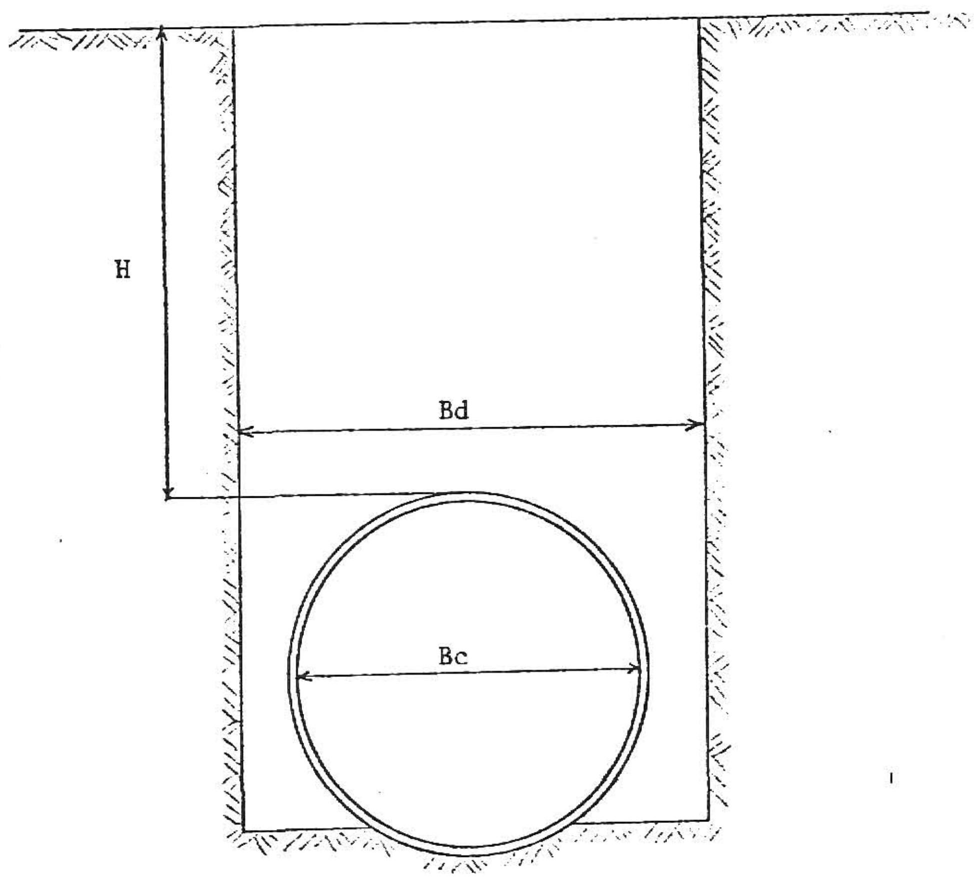

Fig. 1. Cross section of a ditch conduit

as the Iowa Formula;

$$\Delta x = \frac{D1KWcr^3}{EI + .06er^4}$$

when

Δx = horizontal deflection in inches

D1 = deflection time lag factor

K = bedding factor

Wc = vertical load in pounds per inch

r = mean radius of conduit in inches

E = modulus of elasticity of conduit material in pounds per square inch

I = moment of inertia in $(\text{inch})^4$ per inch

e = modulus of passive resistance of soil in pounds per square inch per inch

The deflection time lag factor "D1" in the above equation usually ranges between 1.25 and 1.50.

"K" or bedding factor is subject to the bedding angle shown below (1).

Bedding Angle (degree)	K constant
0	0.110
30	0.108
45	0.105
60	0.102
90	0.096
120	0.090
180	0.083

The modulus of passive resistance "e" is the measure of rate of change of lateral pressure with respect to lateral displacement (26). It describes the relationship between the horizontal pressure on the pipe and the horizontal displacement of that pipe, and it is similar to Westergaard's modulus of subgrade reaction (29).

The modulus of passive resistance is a function of the density of the soil. For a heavy clay in natural state, Spangler (22) found that the modulus of passive resistance varied from 4 to 8 pounds per square inch. But when the clay was pneumatically packed, the value of "e" increased up to 51 pounds per square inch. Early experimental works showed that the modulus of passive resistance "e" varied proportionally with the density of the soil and depended on soil properties.

The method of analysis and the "Iowa Formula" are widely used and accepted today. Furthermore, it was found that flexible tubing was practical and in some ways superior to rigid conduit since it mobilized the soil strength to prevent the deflection of the pipe.

The studies of Holmquist and Nadai (11) and Clinedinst (5) were excellent in outlining the forces on deep oil well casing, subject only to hydrostatic pressure stress without a consequent support of the tubing by the surrounding earth since oil well casing is often placed in oversized holes in bedrock and is not afforded any lateral support.

When the loading of a conduit is greater than the supportive strength available to the structure, failure will occur. Flexible conduits will not fail by rupture because of their ability to deform to a certain extent without structurally damaging themselves. Flexible conduit failures are usually defined as deflections ranging from 5 to 20 percent based on the ratio of the vertical deflection to the diameter of the conduit according to Watkins and Smith (28).

When a vertical load is applied to a flexible conduit, the vertical diameter decreases, while the horizontal diameter increases. With continuous increase in vertical load, the top of the conduit becomes flattened and the curvature of the conduit will become reversed or inverted. At the occurence of this stage, the sides of conduit will be pulled in toward the center, thus negating the passive earth pressure in the adjacent soil. The available source of supportive strength of the conduit is now its own inherent strength that is not sufficient to resist the load, and the conduit collapses. Figure 2 illustrates the different stages of failure of a flexible conduit under vertical load.

BUCKLING AND FAILURE OF PVC CONDUITS

Through advancement in the plastics industry, conduits now can be made of a wide variety of material. The polyvinyl-chloride (PVC) pipe is a thermo plastic pipe.

Research has indicated that PVC has desirable characteristics for well casing. The PVC retains its flexibility at -40° F. and its rigidity at +150° F. (8). It also retains a tensile strength of 3000 psi at 212° F., has a modulus of elasticity of 400,000 to 480,000 psi, and is highly resistant to many chemicals (2).

Howard and Selander (13) found that plastic and steel pipe deflected the same amount in high density backfill. They found that PVC pipes with ring stiffness value of 7.0 psi and steel pipe would deflect similarly.

Watkins and Smith (27) concluded that ring stiffness is more important in loose than in dense soil and that wall thickness has a minimal effect in high density soil. Howard (12) found that flexible pipe with moderate ring stiffness factor (RSF > 10 psi) failed eliptically while those with low ring stiffness factors (RSF = 2 psi) failed in rectangular fashion.

Moser, Watkins, and Bishop (18) tested PVP pipe in size from 12" to 24" diameter and reported a strange phenomena. Pipe with a diameter

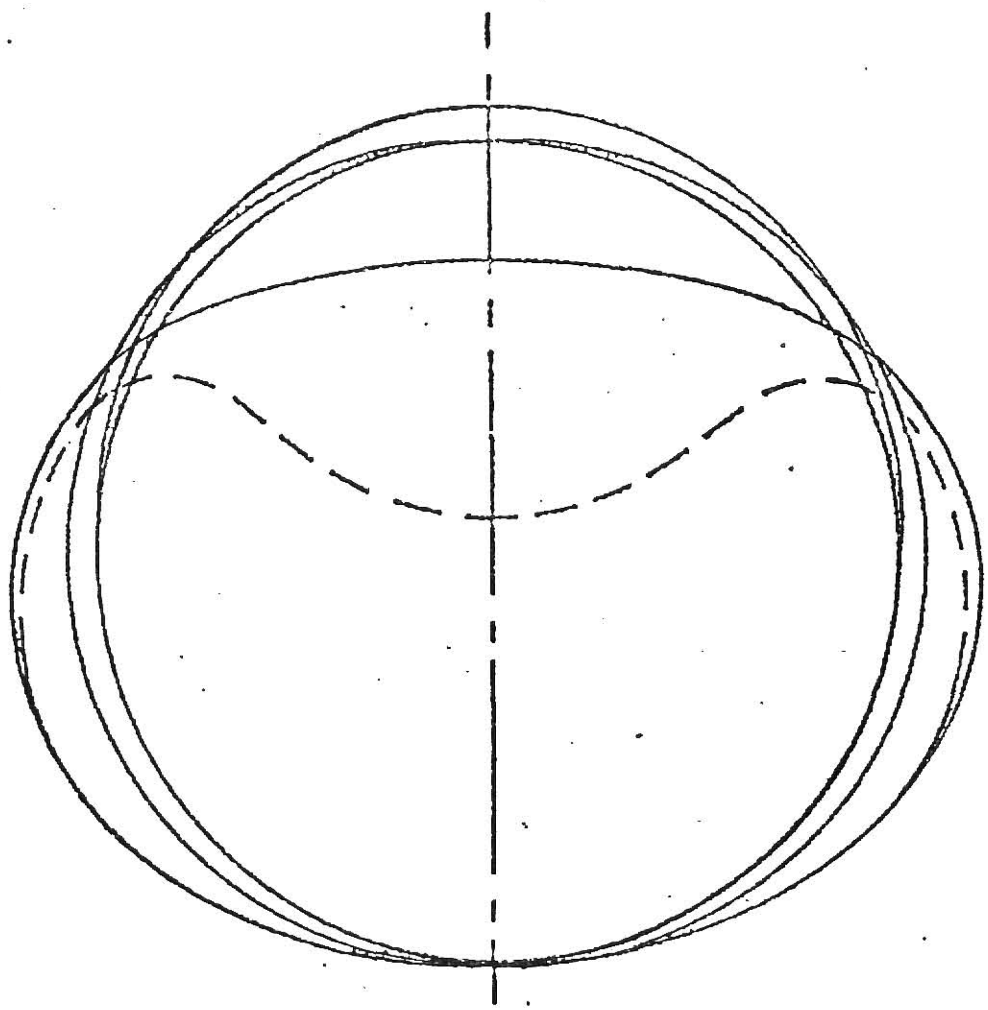

Fig. 2. Stages of deformation of a flexible conduit, (Taken from Spangler and Handy (23).)

to thickness ratio (D/t) of 37 to 38 deflects less than pipe other with other SDR values at constant soil pressure or overburden load. This result is illustrated in Fig. 3, which shows that the strain (or percentage deflection) in the PVC pipe walls decreases with an increasing D/t ratio until the curve reaches a ratio of 37 to 38, the strain then increases with increasing D/t ratio. The authors explained this by stating that a stiff pipe would act as a rigid body concentrating pressures while a more flexible pipe would yield to the hard and soft spot in the soil, thus losing the ideal elliptical shape but in turn mobilizing all the available soil reaction to prevent further failure.

In 1975, an investigation by Erikson (9), using a sand with an angle of internal friction of 40.5°, found the adhesion between PVC pipe and sand to be 3.4° radially. From this it was concluded that the soil surrounding the pipe is free to move peripherally around the pipe to adjust hard and soft spots much more effectively than would be possible with rough pipe.

Duryee (7), in a companion study found that the soil particle relative movement in deflection is directly proportional to the density of the soil and the size of the pipe. This study was carried out to deflection $\frac{Dy}{D}$ of 0.14 with no failures of PVC pipes of various ring stiffness.

It was concluded from these studies that plastic pipe is superior to steel in poor bedding conditions, since the soil can adjust more readily due to the low adhesion between pipe and soil and furthermore that large diameter plastic pipes are much superior to large diameter steel pipes.

BUCKLING AND FAILURE OF A WELL CASING SUBJECTED ONLY TO EARTH PRESSURE

A well casing is a vertical buried pipe subjected to lateral earth pressure.

The earth pressure on cylindrical surface was computed by Beresantzev (3)

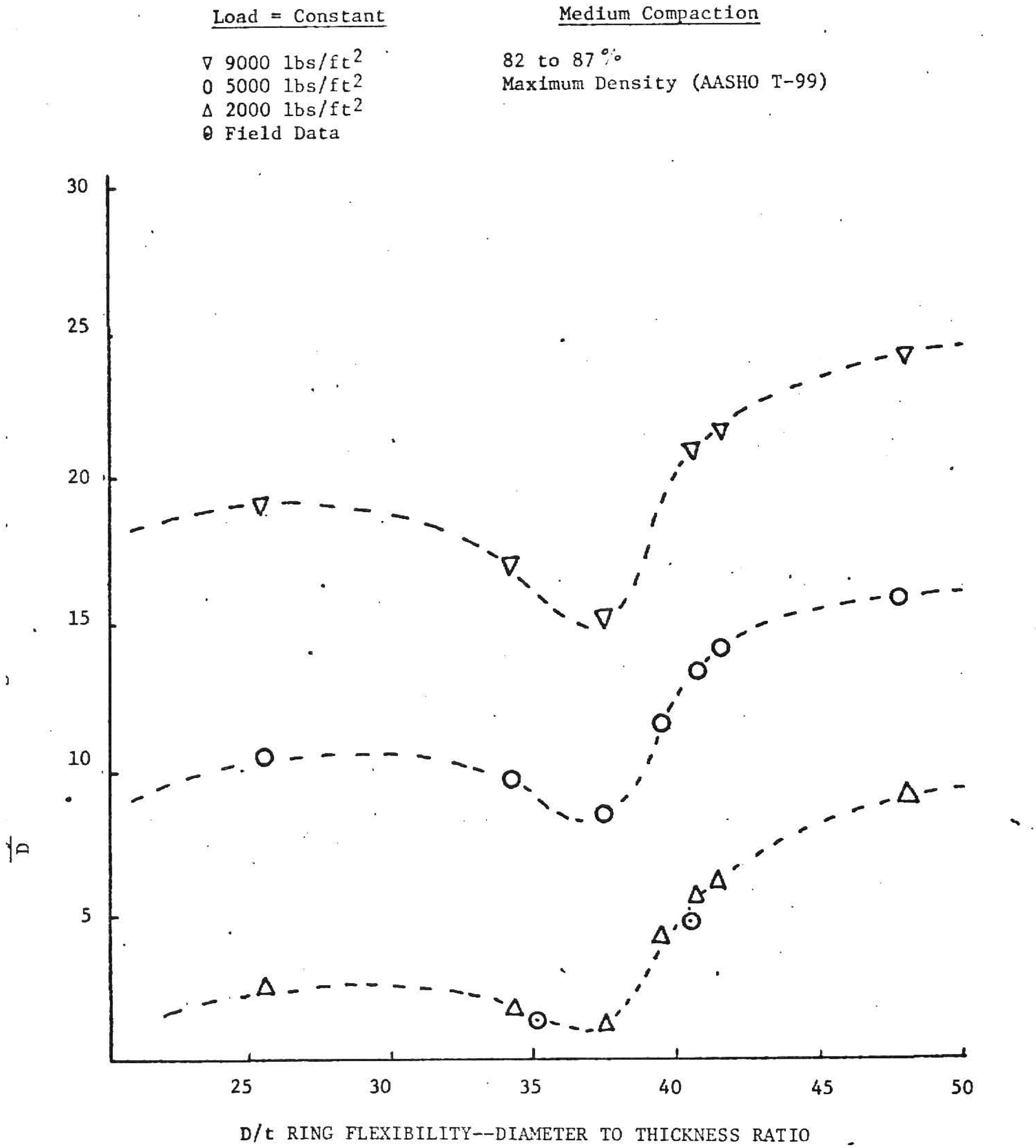

Fig. 3. Plots of Vertical Ring Deflection of PVC pipe as a function of D/t for a constant vertical soil pressure in medium compacted sand.

[Taken from Moser, Watkins and Bishop (18)] in 1958 by the formula:

$$\sigma_r = r\gamma\sqrt{\frac{Ka}{\lambda - 1}}\left[1 - \left(\frac{r}{rb}\right)^{\lambda-1}\right] + q\left(\frac{r}{rb}\right) + C \cot \phi \left[\left(\frac{r}{rb}\right)^{\lambda} Ka - 1\right]$$

where

σ_r = horizontal radial stress

r = radius of pipe

γ = unit weight of the soil

Ka = coefficient of active earth pressure - $\tan^2\left(45° - \frac{\phi}{2}\right)$

rb = $r + z\sqrt{Ka}$

λ = $2 \tan \phi \tan\left(45° + \frac{\phi}{2}\right)$

ϕ = friction angle of the soil

q = uniform surcharge

c = cohesion

Using the formula of Beresantzev, it is found that the vertical and horizontal stress on well casing increases downward in a parabolic fashion and that below a relatively shallow depth the stress becomes a constant. The horizontal radial stress on a well casing is dependent upon the friction angle of the soil as shown in Fig. 4.

At a depth of some 2 or 3 times the radius of the casing, the change is insignificant for most sands used in a gravel packed well.

The earth pressure on a 16-inch diameter well casing in sand having a friction angle of 40° does not exceed 12 psf which is insignificant.

It is concluded from these investigations that a well casing with a reasonable ring stiffness cannot fail by horizontal earth pressure alone.

HYDRAULIC PRESSURE ON WELL CASINGS

During the drilling of a well, drilling mud is generally used to prevent the hole from collapsing. After the installation of the well casing pipe, water or drilling mud fills the inside of the casing and equilibrium is still maintained. Compressed air is generally used to develop fresh water

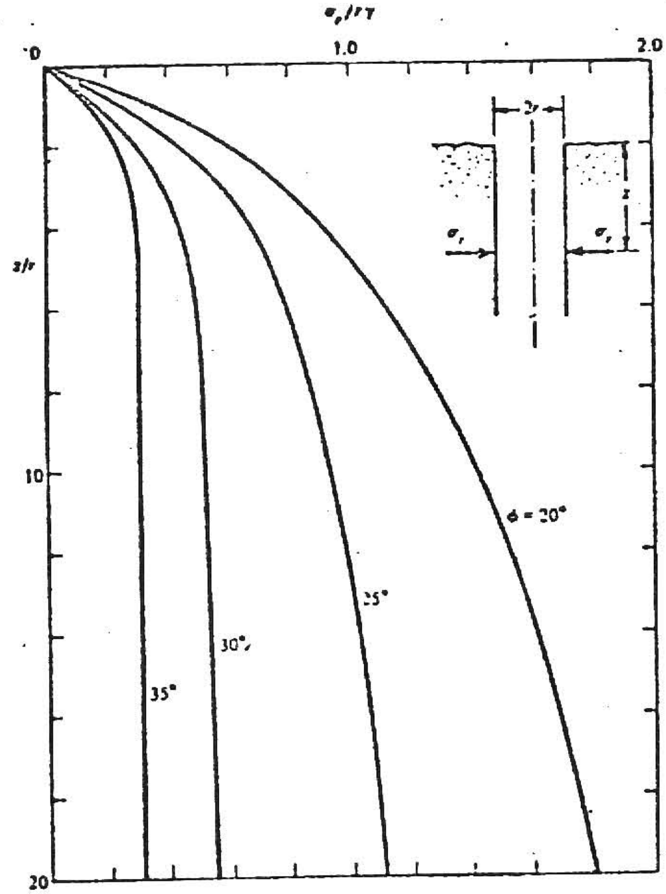

Fig. 4. Horizontal radial stresses acting on a cylindrical surface in active case.

[Taken from Winterkon and Fang (31)]

in small diameter wells. The compressed air mixed with the water at the bottom of the well reduces the specific gravity of the fluid and makes it rise to the ground surface. In large diameter wells the well is cleaned by pumping. The F-17 Committee on Plastic Piping Systems (6) considered two limits for collapsing pressure.

The first limit is when the drilling mud is in near liquid state and there is no support of the gravel pack around the well casing, then the critical collapse pressure is given by the equation:

$$Pc = \frac{2E}{1-\mu^2} \cdot \frac{1}{\frac{D}{t}\left(\frac{D}{t} - 1\right)^2}$$

or

$$Pc = \frac{2E}{1-\mu^2} \cdot \frac{1}{SDR(SDR - 1)^2}$$

Pc = critical collapsing pressure, in psi

E = modulus of elasticity, psi

μ = Poisson's ratio

D = outside diameter of the well casing pipe, in.

t = thickness of the well casing pipe, in.

SDR = standard dimension ratio = $\frac{D}{t}$

This is an expression given by Clinedinst assuming a linear stress distribution.

The second limit is when support of the gravel to the well casing pipe is considered. Due to its flexibility, any decrease in diameter of the well casing pipe at any point due to a collapse is accompanied by an increase in the diameter of the pipe at right angles and the well is prevented from collapsing by the passive pressure of the soil. The ultimate resistance to collapse is obtained when the gravel pack around the well casing holds firmly the well casing pipe from getting out of round.

The critical collapsing pressure is then equal to the crushing strength of the wall of the well casing pipe and is equal to:

$$Pc = \frac{2t \times 2000}{D}$$

or

$$Pc = \frac{2 \times 2000}{SDR}$$

Pc = critical collapsing pressure, psi

t = wall thickness, in.

2000 = design of stress of thermo plastic material from PPI - TR4, August, 72

SDR = standard dimension ratio = $\frac{D}{t}$

Due to the insignificant value of the active earth pressure, the critical collapsing pressure here is equal to the difference of head of fluid between outside and inside of the well casing.

DESIGN OF EXPERIMENT

The design of the experiments for this thesis had to be within the constraints of limited funds for testing procedures and the urgency of obtaining practical information that could be used immediately for writing specifications to govern the use of plastic tubing for well casing. During the preparation of this thesis the States of Nebraska, Colorado, and Kansas accepted the use of PVC well casing with certain limitations while at least Illinois and Arkansas rejected its usage. In February, 1976 the matter was considered in San Diego, California by the American Society for Testing Materials and a national standard for plastic well casing has been tentatively approved by that group.

The design of experiment for this thesis consisted of three distinct phases:

1. To find and verify reasonable formulas that could be used to determine the forces on well casings from a purely mathematical-mechanical standpoint.

2. To test large diameter, high SDR ratio pipe in the laboratory for ultimate strength and to establish a reasonable deflection to be used as failure criteria.

3. To install and check large diameter PVC wells in the field measuring their performance and the problems of installation.

The first part of the study was completed by Williams & Dao (30) which was presented at San Diego and after careful study was accepted by ASTM as a guide for forces on plastic well casing.

The laboratory study of the PVC pipe was limited to pipe that could be obtained in thin wall and large diameter sizes. The pipe tested consisted of twelve pieces of PVC pipe produced by Peerless Plastics Company of Garden City, Kansas. There was an equal number of pieces of eight and ten inch outside diameter pipe with SDR of 42. The pipe was tested in a soil bin as shown in Fig. 5.

Four load-deflection determinations were made for each size of pipe. A single test well was emplaced to a depth of 155' using 16" SDR 32 pipe at Pratt, Kansas. Data from three experimental wells was furnished by Jet Stream Plastics, Siloam Springs, Arkansas.

ILLEGIBLE

THE FOLLOWING DOCUMENT (S) IS ILLEGIBLE DUE TO THE PRINTING ON THE ORIGINAL BEING CUT OFF

ILLEGIBLE

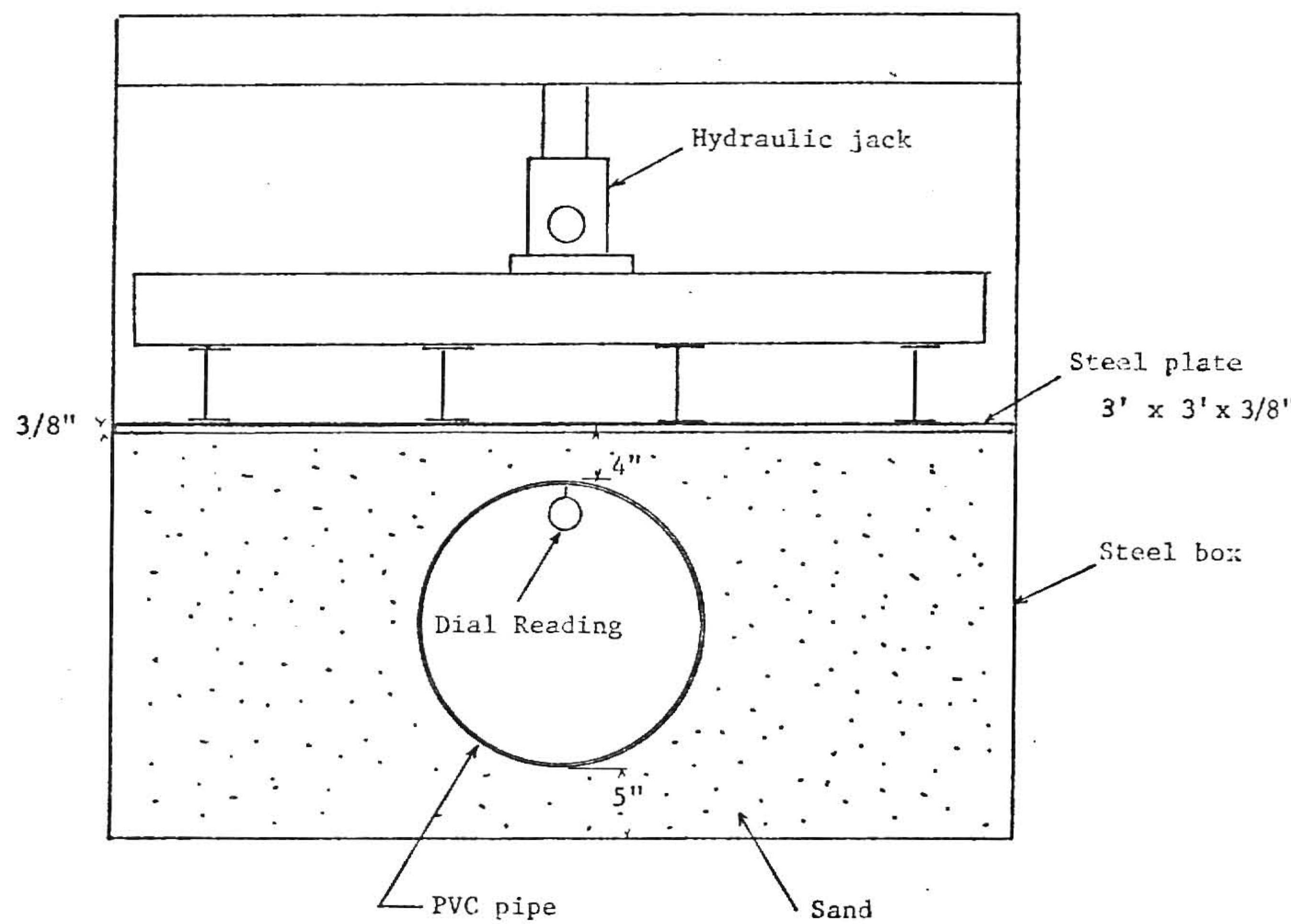

Fig. 5. Load Testing Device

PRESENTATION OF DATA

LABORATORY TESTING

Load testing of the PVC pipe in the soil bin was conducted with a single type of soil; a river sand from the Kansas River Valley at Manhattan, Kansas. This sand had the following physical characteristics:

Natural Moisture content (w):	3%
Specific Gravity (G_s):	2.62
Atterberg Limits:	Non-Plastic
Cohesion (c):	0.0
Internal Angle of Friction (ϕ):	38°
Maximum Dry Density (ASTM D-698):	113.5 Pcf
Optimum Moisture:	11.5%
Classification:	AASHO A1a Unified SW

The laboratory data sheets for these tests may be found in Appendix A.

The PVC pipe embedded in this sand was loaded in the soil bin with four replications for each test. The results of these load tests are shown in Figs. 6 and 7.

The laboratory data collected is shown in Appendix B.

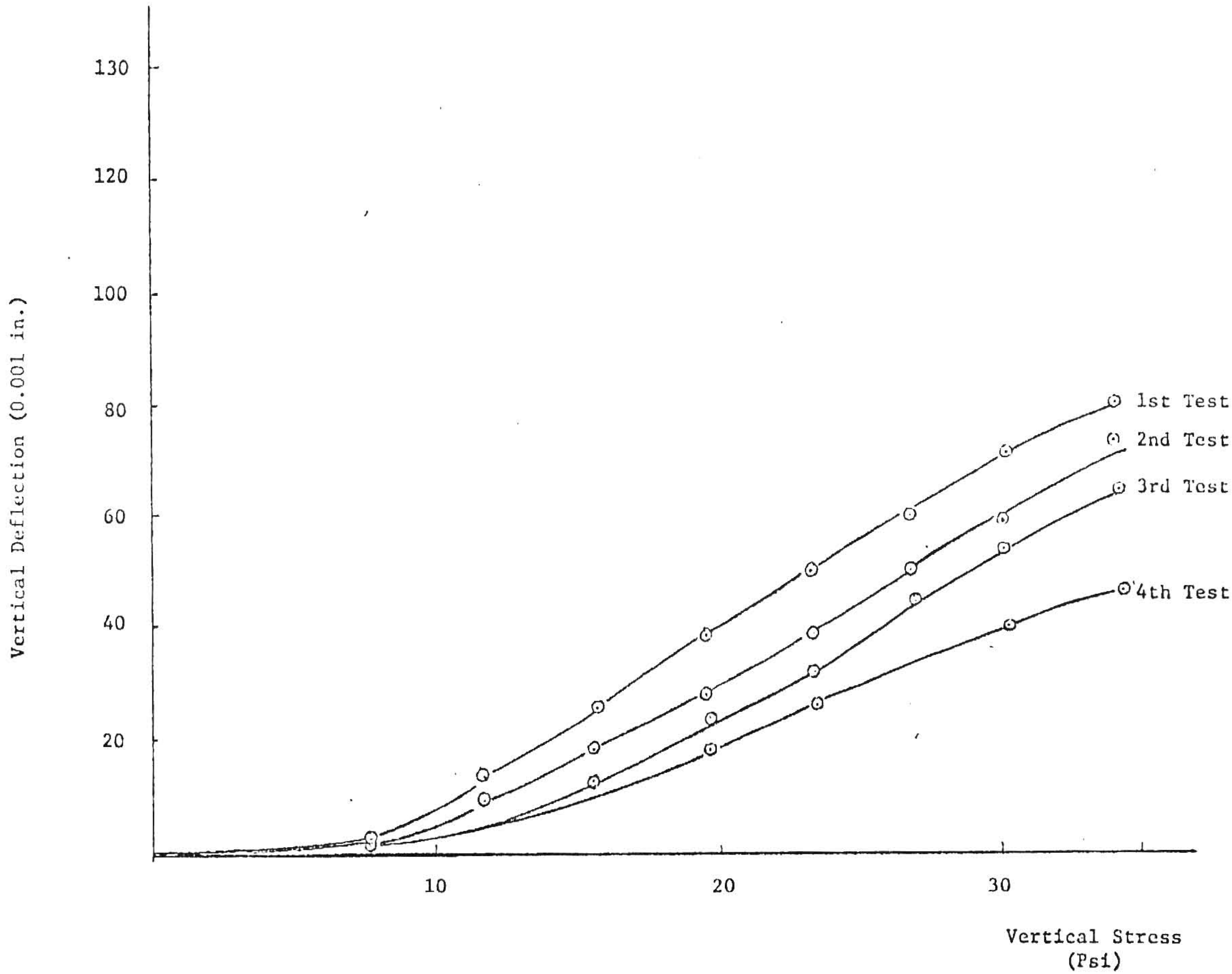

Fig. 6. Load test result on 8" PVC pipe SDR 42.

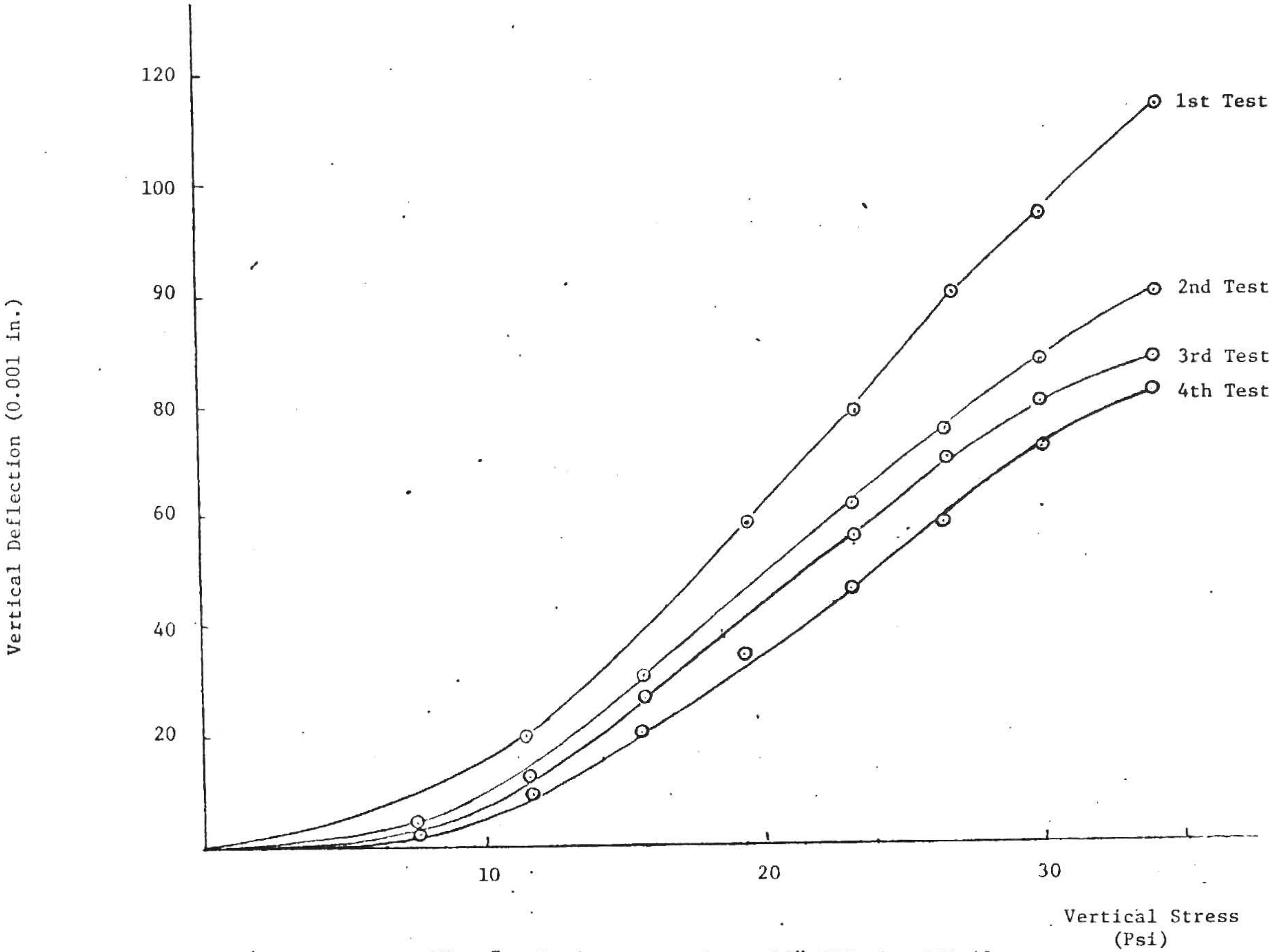

Fig. 7. Load test result on 10" PVC pipe SDR 42.

FIELD TEST

PEERLESS PLASTICS TEST WELL

The irrigation test well was drilled on the Vernon Rechke farm, Iuka, Pratt County, Kansas, on June 15, 1976. The well was drilled with a 28-inch diameter drag bit with reverse circulation and mudded with bentonite to prevent the wall of the hole from collapsing.

The total depth of the hole was 155 feet and the stratum is as followed:

Depth	Description
Ground to 4 feet	Top soil
4 to 80 feet	Brown clay
80 to 90 feet	Sand & Gravel - medium coarse
90 to 100 feet	Sand & Gravel - with white clay bands
100 to 120 feet	Brown & White clay
120 to 150 feet	Sand & Gravel
150 to 155 feet	Brown clay & shale

The bore hole was cased with the 16" polyvinyl-chloride pipe with a 0.5 inch wall thickness imprinted 1120 SCH-D-1785. This pipe has a SDR 32. The well screen consists of two 20' perforated pipe casings. The perforations consist of sawed slots 1/8 inch wide that are 3.75 inches wide inside and 4.00 inches long outside of the pipe. The slots are arranged in horizontal rows around the pipe with eight slots per row. The rows of slots are 3/4 inch apart measured vertically.

The drilling contractor elected to set a twenty foot screen with the end closed by a plastic cap, then a twenty foot unslotted pipe followed by the second twenty foot perforated screen.

The pipe was joined by an eight inch coupling with two coats of sol-weld cement applied to both male and female surfaces. Each joint was then fastened by three 3/4 inch screws and allowed to set for 5 minutes before the pipe was lowered. The well was immediately packed with the gravel from the bottom to a point 20 feet below the ground surface.

Samples of gravel pack and water producing sand were taken for grain size analysis with the results given in Appendix C.

The well was cleaned and put into production on June 22, 1976 by pumping with a 12", 4 stage turbine pump. The water became clean after 20 minutes of pumping and there was no noticeable sand.

The static water level was 53 feet before pumping and the following record was found for the Test Well over 1 1/2 hour of pumping.

Gallon per Minute	Drawdown
0	0 feet
600	17 "
700	18 "
800	20 "
1000	25 "
1200	29 "
1400	35 "

The pump was cycled several times from 0 to 1400 GPM to check the external static pressure on sudden drawdown and no adverse effects were noted. The well was grouted on June 24, 1976 with 4.5' thick collar of ready-mix 3000 psi concrete emplaced at the 20' level, then with well cuttings up to 4' level. The top 4' was grouted with concrete, and a 4' x 4' x 0.5' slab was cast around the head above the ground surface.

The heat of hydration of cement is 50 calories/gm cement. This will theoretically raise the temperature of the pipe 14.14° during the grouting.

Drilling tools lowered into the completed well indicated that the pipe casing is plumb and there is no deflection at the present time.

A cross section of the test is shown in Fig. 8.

JET STREAM PLASTICS EXPERIMENTAL IRRIGATION WELLS

The Jet Stream Plastics started its experimental program on large diameter PVC pipe for well casing in March, 1975. Three experimental wells were put down in Nebraska, and two have the following characteristics:

Experimental Irrigation Well #1

Date installed	March 5, 1975
Site	4 Miles NE Bartley, Nebraska
Augafier (water bearing strata)	Medium gravel
Diameter of bore hole	26"
Depth Cased	196'
Slotted	30'
Solid	166'
Type casing	PVC
Slotted	1/8" slot 7 1/2% total opening
Solid	15.3 OD 14.48ID .410 wall
SDR	37
Gravel pack	Class "A" road gravel

The well was test pumped with turbine power and produced 2356 GPM. A drawdown of 42' was observed after testing was completed.

Experimental Irrigation Well #3

Date installed	May 1, 1975
Site	5 Miles east of Atkinson, Nebraska
Augafier	Fine, Ogalalla sand.
Diameter of bore hole	28"
Depth cased	342'
Slotted	120'
Solid	222'

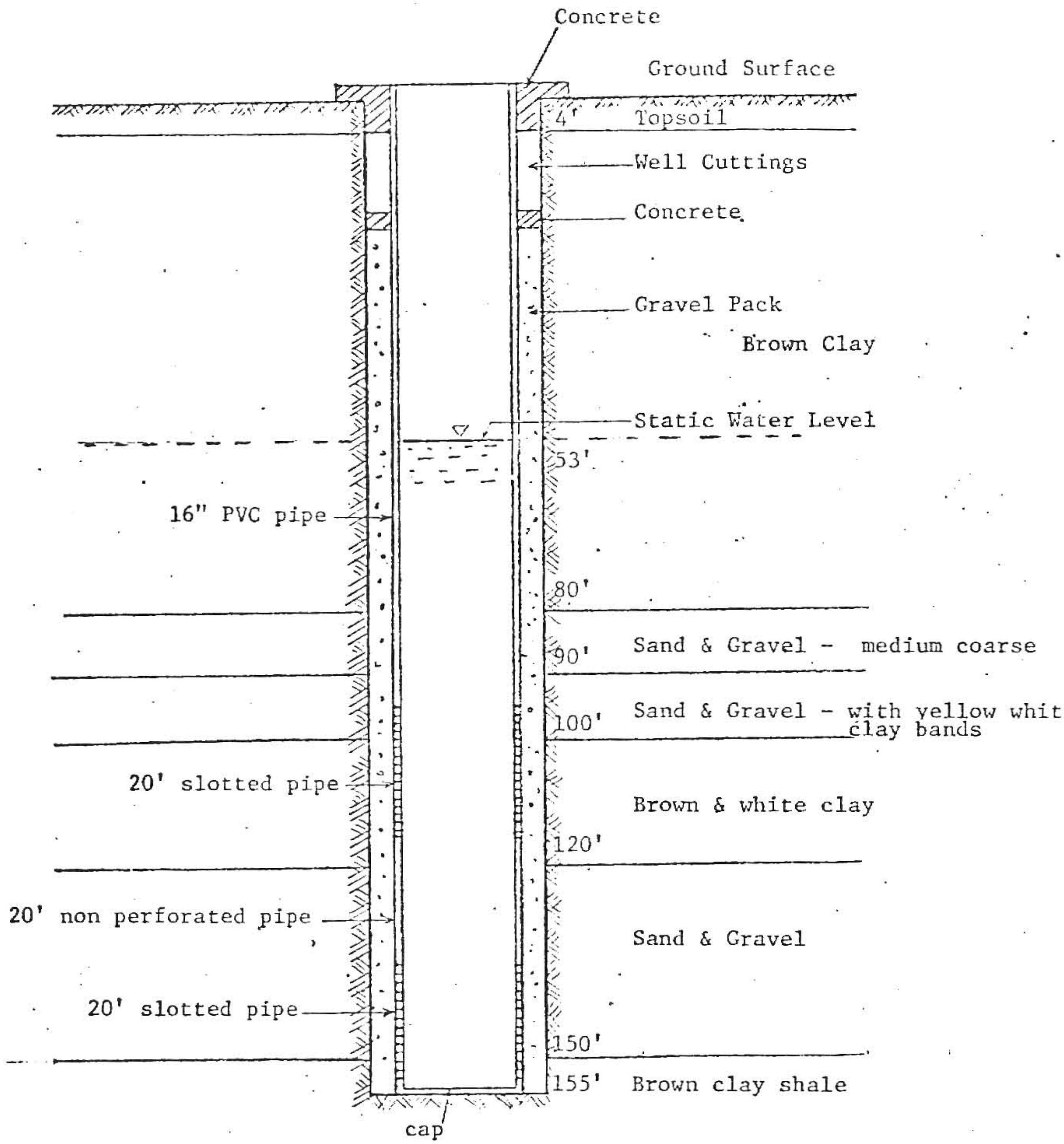

Fig. 8. Peerless Plastic test well.

Experimental Irrigation Well #3

Type Casing	PVC
Slotted	1/8" slot 7 1/2% total opening
Solid	15.3 OD 14.48 ID .410 wall
SDR	37
Gravel Pack	Class "A" road gravel

The well produced 1100 GPM with 88' of drawdown and 1600 GPM with 103' of drawdown. The pump was cycled several times from 0 to 1000 GPM to check the lateral static pressure on sudden drawdown and no adverse effects were noted.

The third Experimental Irrigation Well was a 100' depth well put down at Wayne, Nebraska. The well was reported quite successful and produced 675 GPM when completed, but no new information was obtained from it.

The Jet Stream Plastics reported an excess of 300 successful installations with 15" and 16" PVC casing by some 25 different drillers with depths ranging down to 480' and an average of 200'.

ANALYSIS OF DATA

(A) LOAD TEST

From the results of Load test, the 8" PVC and 10" PVC SDR 42 pipe surrounded by sand and under a uniform vertical pressure of 34.72 psi would deflect about 0.01 or 1 percent. Each time the test was repeated, the sand got denser and the PVC pipe deflected less than the previous time. The test also showed that these 8" and 10" PVC pipe surrounded by dense sand could support adequately a pressure of 35 psi.

(B) FIELD TEST

The Peerless Plastics and the Jet Stream Plastics tests used 16" PVC pipe with a SDR 32 and 37. Field test data showed that these pipes performed successfully for water well casing.

The depth of the wells varied from 100 feet to 342 feet, the drawdown was 35 feet at a production of 1400 GPM with Peerless Plastics Test Well and 103 feet at a production of 1600 GPM with Jet Stream Plastics Experimental Irrigation Well.

From the results of these test wells, an important role in the supporting strength of the pipe must be given to the gravel pack and the surrounding soil around the pipe. The radial active earth pressure on pipe as pointed out by Beresantzev, was insignificant. The lateral earth pressure formula for lateral constraint for retaining wall key is, however, quite large and is computed by the formula

$$Ep = \frac{\gamma H^2}{2} \tan^2(45° + \frac{\phi}{2})$$

thus, a well casing in granular soil has a radial compression restraint that increases considerably with depth and prevents the deformation of the pipe which is required for any type of failure except crushing of the pipe.

This allows a differential head of water in excess of 288 feet with a 16" PVC SDR 32 pipe and 249 feet with a 16" PVC SDR 37 pipe, using the formula

$$Pc = \frac{2 \cdot 2000}{SDR}$$

before significant strength is introduced into the pipe.

The differential head of water caused by sudden drawdown during the above pumping tests were far below the critical collapsing pressure of the well casing pipes.

CONCLUSION

It is concluded that Polyvinyl-chloride pipe is useful as a water well casing to unlimited depth from the stand point of earth pressure.

The soil surrounding the well is expected to offer significant strength to restrain deflection of the pipe, but the gravel pack must be well graded and installed with caution to avoid bridging.

The sudden difference in hydraulic head inside and outside the casing is of prime importance but when the passive resistance of the earth is considered, acceptable values for practice use are obtained.

A large 16" PVC SDR 41 pipe will perform adequately to a depth of some 500 feet.

RECOMMENDATION FOR FURTHER STUDY

Although the successful result of the use of large diameter polyvinyl-chloride pipe for well casing, it is strongly urged that careful instrument well casing be emplaced and tested. The study should be continued and that a 16" PVC SDR 41 pipe be tested.

It is anticipated that a national standard for plastic pipe used as well casing will soon be accepted.

ACKNOWLEDGMENT

I wish to express my most sincere appreciation and gratitude to Professor Wayne W. Williams for financial support, encouragement, precious advice and guidance for all steps of study and various forms of assistance for my family.

To Dr. Robert Snell, for making it possible for me to enter Graduate School.

To Dr. Edwin C. Lindly for reviewing the manuscript.

To Peerless Plastics Co. of Garden City, Kansas for financial support of the research.

Appendix A

Physical Characteristics of the Sand
Used in the Soil Bin

TABLE I

MOISTURE CONTENT

Determination No.	1	2	3
Weight of can plus wet sand, in grams	248.11	207.24	200.15
Weight of can plus dry sand, in grams	241.83	202.82	195.63
Weight of can, in grams	52.47	50.49	49.83
Weight of water, in grams	6.28	4.42	4.52
Weight of sand, in grams	189.36	152.33	145.80
Moisture content (percentage)	3.00	2.90	3.10

Moisture Content = 3.00%

TABLE II

SPECIFIC GRAVITY

Determination No.	1	2	3
Bottle No.	6	8	5
Weight of Bottle + water + soil, W_1, in grams	705.09	715.29	704.25
Temperature, T, in °C	30° C	30° C	30° C
Weight of Bottle + water, W_2, in grams	674.00	684.35	673.27
Weight of Soil, W_s, in grams	50.00	50.00	50.00
Specific Gravity of water at T°, G_T	.9957	.9957	.9957
Specific Gravity of soil, G_s	2.63	2.61	2.62

$$G_s = \frac{G_T W_s}{W_s - W_1 + W_2} \qquad G_s = 2.62$$

TABLE III

SIEVE ANALYSIS

Sieve No.	Weight Soil Retained (in grams)	Percent Retained	Cumulative Percent Retained	Percent Finer
1st Determination				
4	15.48	2.0	2.0	98.0
10	83.45	11.6	13.6	86.4
20	192.27	26.7	40.3	59.7
40	240.55	33.4	73.7	26.3
60	125.99	17.4	91.1	8.9
140	59.17	8.3	99.4	0.6
200	1.88	0.3	99.7	0.3
pan	2.84	0.3	100	0.0
2nd Determination				
4	16.32	2.3	2.3	97.7
10	61.4	8.6	10.9	89.1
20	163.01	22.9	33.8	66.2
40	248.48	34.9	68.7	31.3
60	143.40	20.2	88.9	11.1
100	72.72	10.2	99.1	0.9
200	2.66	0.4	99.5	0.5
pan	3.47	0.5	100	0.0
3rd Determination				
4	19.58	2.4	2.4	97.6
10	102.04	12.5	14.9	85.1
20	238.99	29.5	44.2	55.8
40	276.70	34.0	78.2	21.8
60	119.32	14.6	92.8	7.2
100	55.05	6.7	99.5	0.5
200	1.75	0.2	99.7	0.3
pan	2.29	0.3	100	0.0

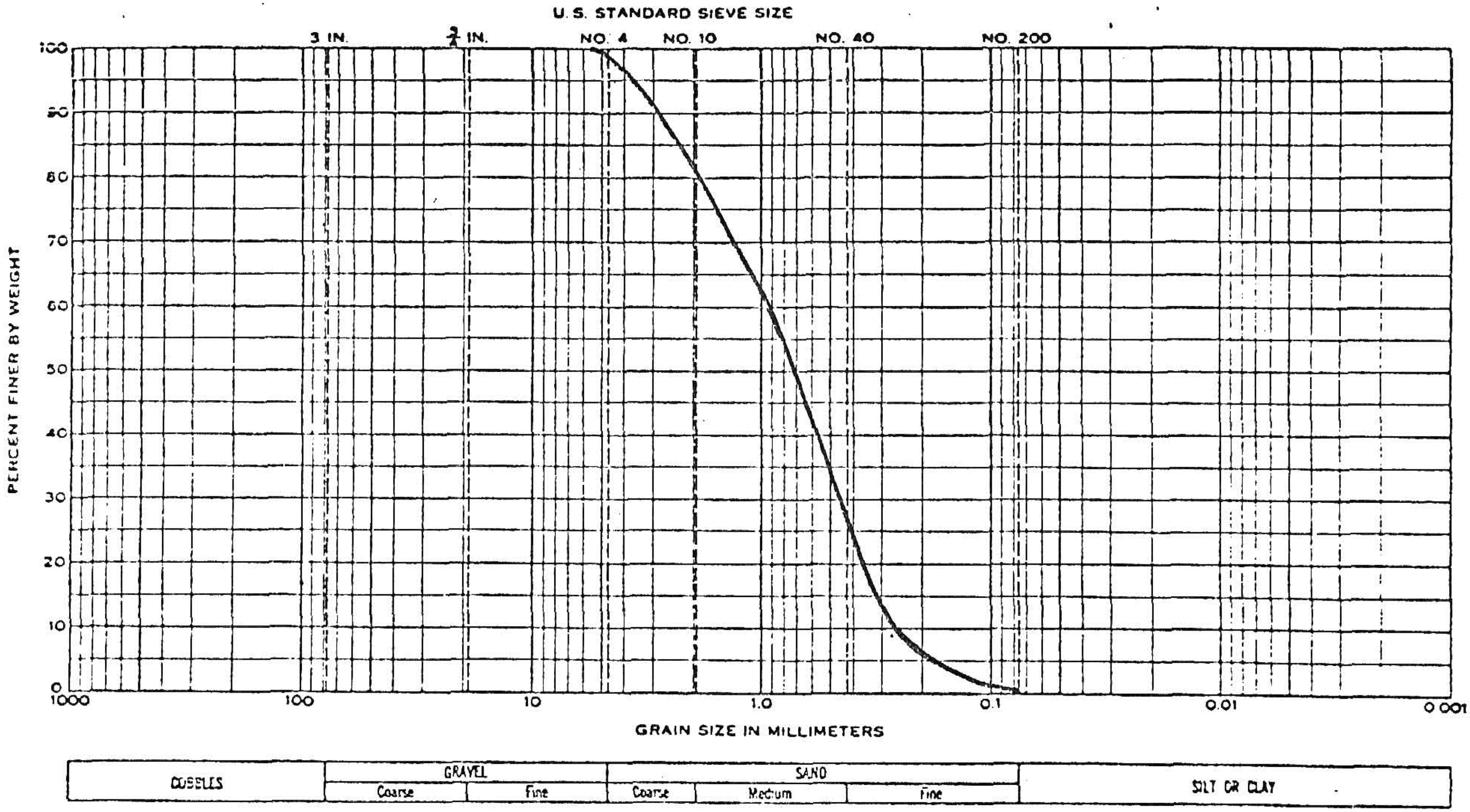

Fig. 9. Sieve Analysis
1st Determination

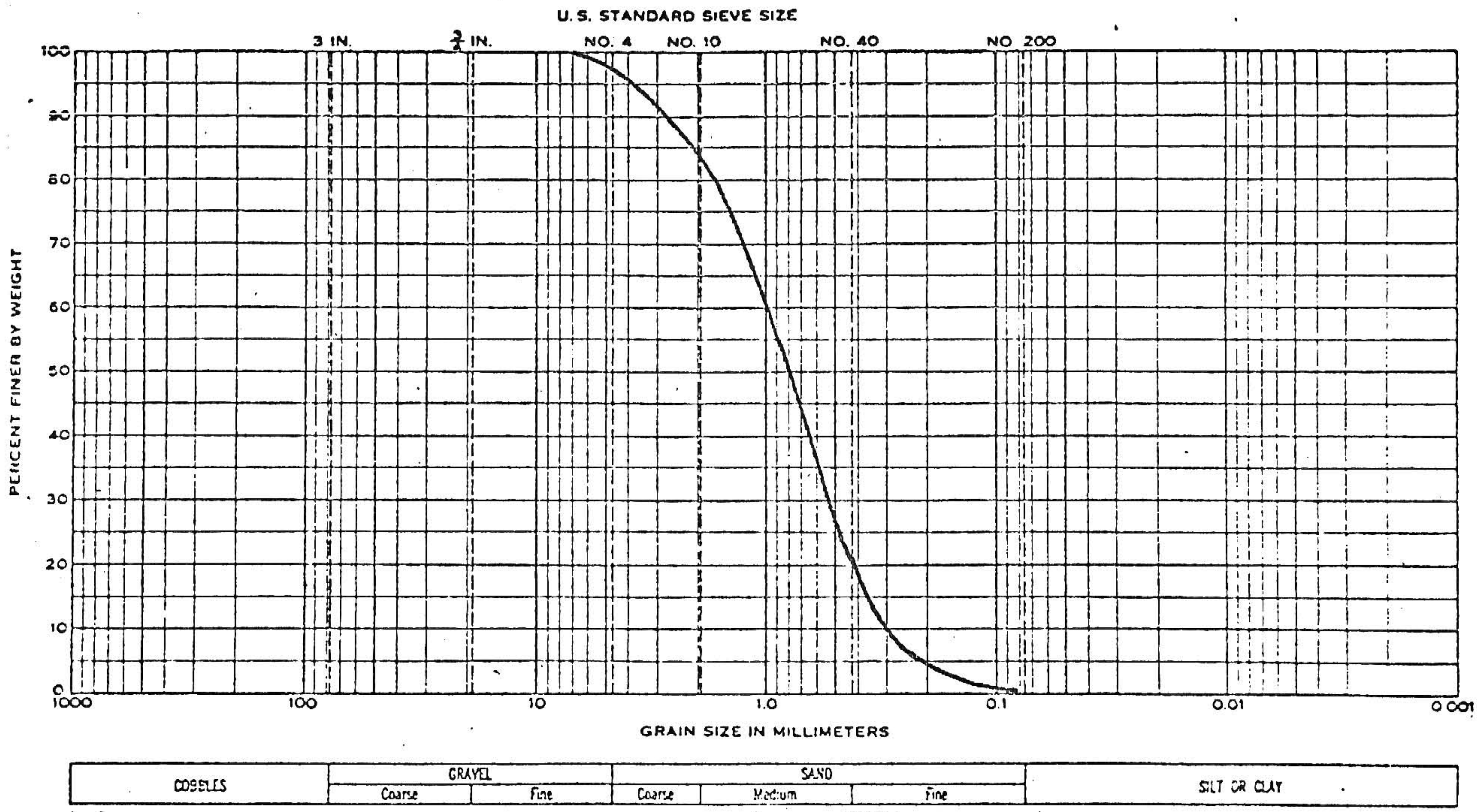

Fig. 10. Sieve Analysis
2nd Determination

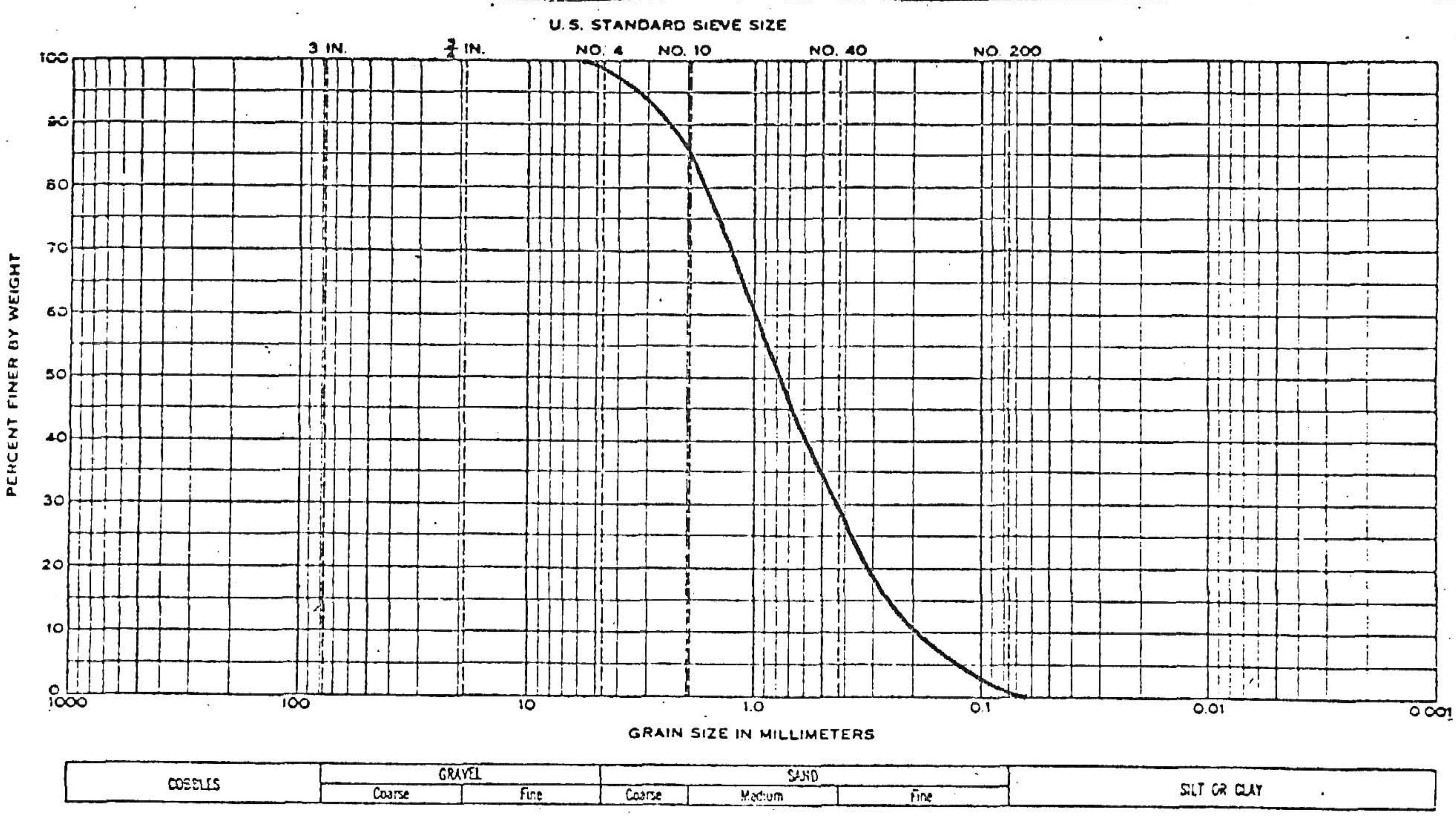

Fig. 11. Sieve Analysis
3rd Determination

TABLE IV

COMPACTION TEST

Density

Determination No.	1	2	3	4	5
Wt. mold in lb.	9.78	9.78	9.78	9.78	9.78
Weight mold + compacted sand in lb.	13.61	13.75	13.82	13.92	14.00
Weight compacted sand in lb.	3.83	3.97	4.04	4.14	4.22
Water content	5%	7%	8%	10.4%	11.4%
Wet density, psi	115.00	119.00	121.00	124.00	127.00
Dry density, psi	109.00	111.00	112.00	113.00	114.00

Water Content

Determination No.					
Weight in grams	21.71	20.42	21.62	21.61	21.23
Weight can + wet sand in grams	75.85	65.21	83.88	108.62	149.17
Weight can + dry sand in grams	73.18	62.15	79.28	100.45	137.09
Weight water in grams	2.67	3.06	4.60	8.17	13.09
Weight dry sand in grams	57.47	41.73	57.66	78.84	114.86
Water content	5%	7%	8%	10.4%	11.4%

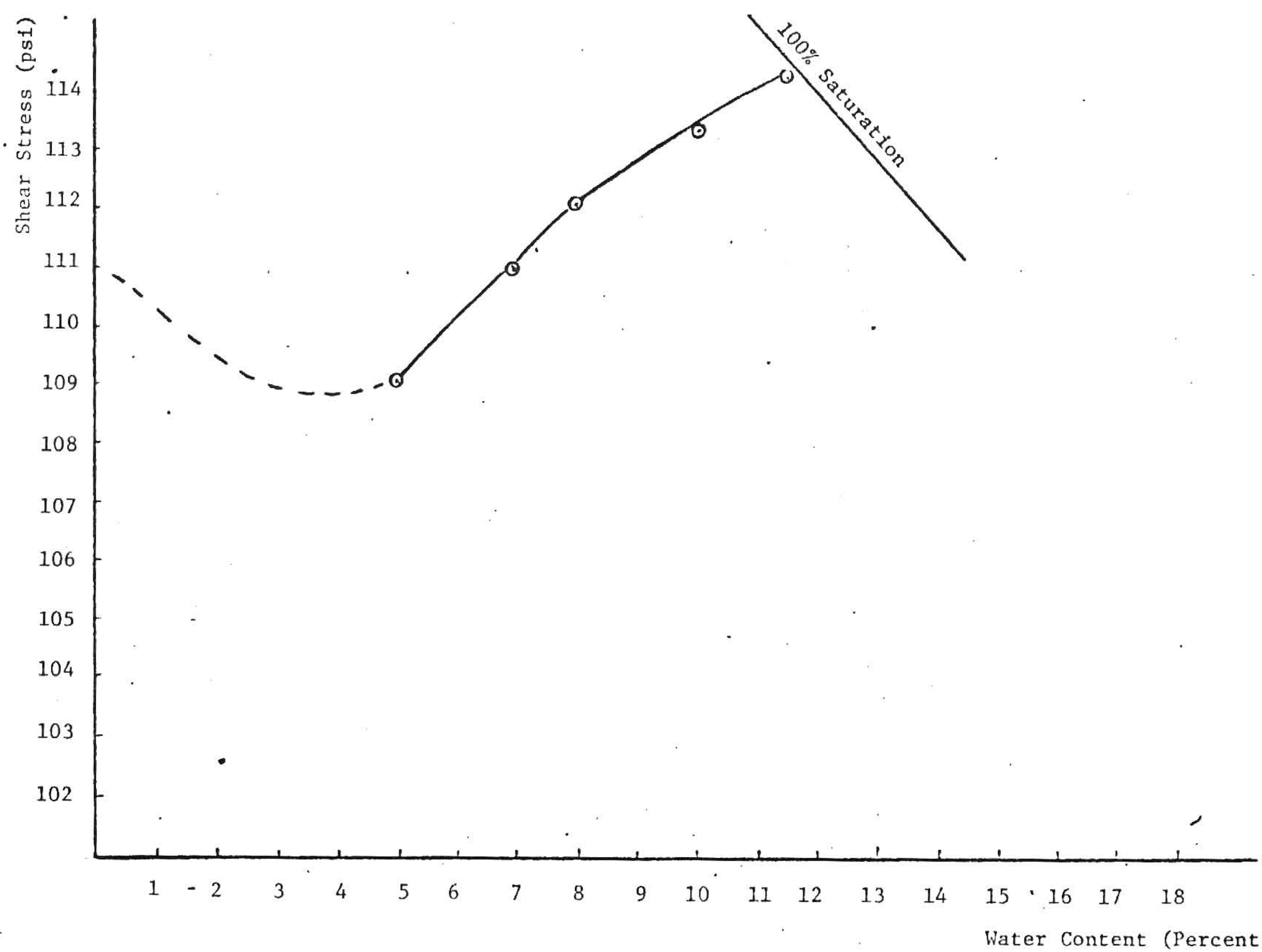

Fig. 12. Compaction test.

TABLE 5

DIRECT SHEAR

Original proving ring reading: 0 10^{-3} in. lbs.

Proving ring calibration factor: 0.323 10^{-3} in.

Cross section area: $\frac{\pi D^2}{4} = 0.7854D^2 = 4.91\ \text{in.}^2$

Normal Load Kg.	Normal Stress (psi)	Load Ring Dial Reading	Horizontal Shear Force lbs.	Shear Stress (psi)
4.44 Kg.	1.99	25	8.08	1.64
20.44 Kg.	9.16	108	34.88	7.10
36.44 Kg.	16.33	205	66.22	13.49

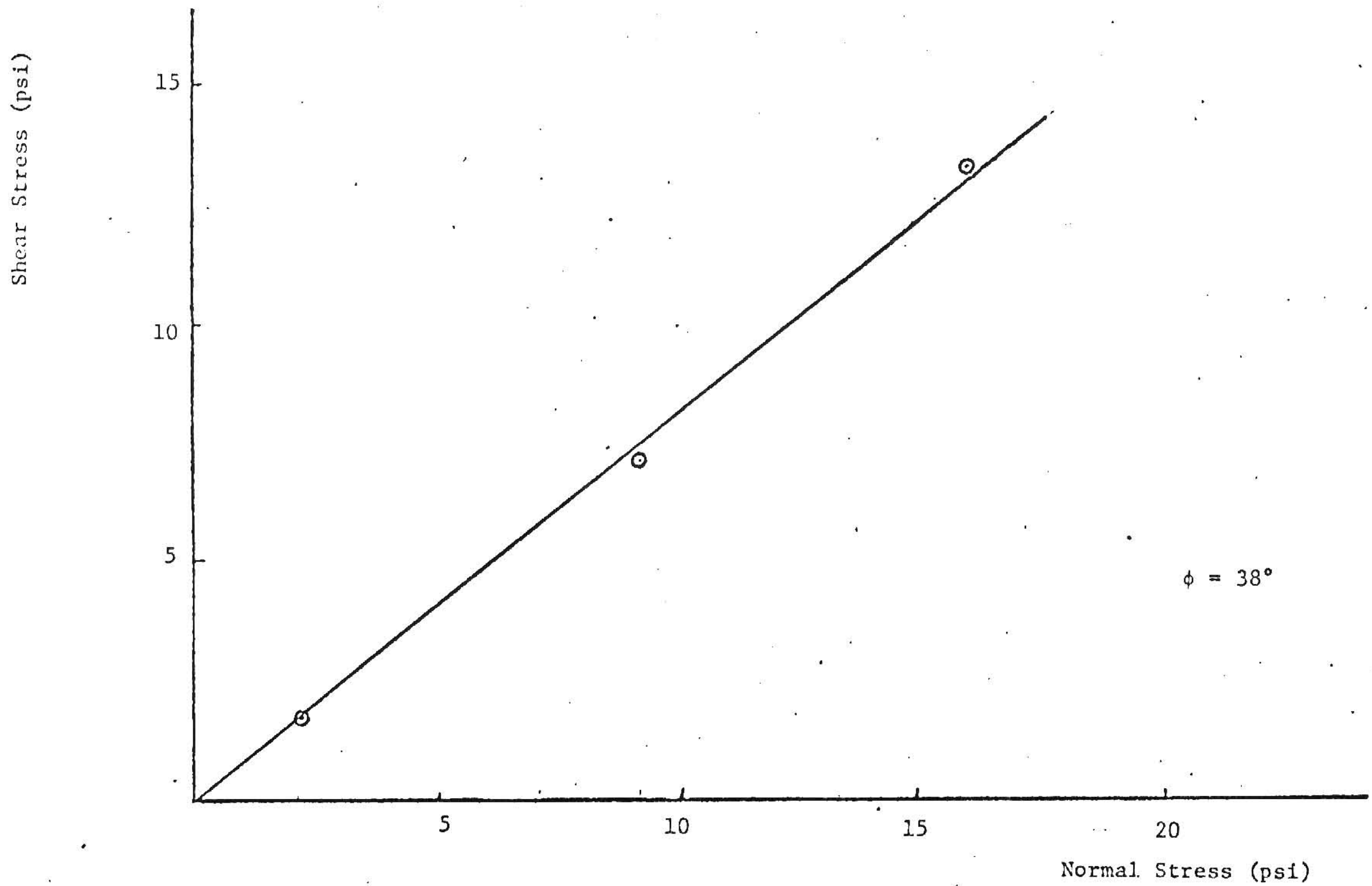

Fig. 13. Direct Shear

Appendix B

Results of Load Tests

TABLE 6

LOAD TEST ON 8" PVC PIPE SDR 42

Vertical Load (lbs.)	Vertical Stress (psi)	Vertical Deflection (in.)			
		1st Test	2nd Test	3rd Test	4th Test
0	0	0	0	0	0
5,000	3.86	0.001	0.004	0	0
10,000	7.72	0.005	0.006	0.002	0.006
15,000	11.57	0.015	0.012	0.003	
20,000	15.43	0.027	0.018	0.012	0.012
25,000	19.29	0.038	0.026	0.023	
30,000	23.15	0.049	0.038	0.033	0.025
35,000	27.01	0.060	0.050	0.044	
40,000	30.86	0.070	0.060	0.053	0.040
45,000	34.72	0.080	0.075	0.062	0.045

TABLE 7

LOAD TEST ON 10" PVC PIPE SDR 42

Vertical Load (lbs)	Vertical Stress (psi)	Vertical Deflection (in.)			
		1st Test	2nd Test	3rd Test	4th Test
0	0	0	0	0	0
10,000	7.72		0.005	0.005	0.005
15,000	11.57	0.018		0.015	0.013
20,000	15.43		0.025	0.023	0.020
25,000	19.29	0.058	0.040		0.035
30,000	23.15	0.075	0.055	0.005	0.50
35,000	27.01	0.100	0.065	0.064	0.058
40,000	30.86	0.115	0.085	0.078	0.074
45,000	34.72	0.133	0.093	0.087	0.081

Appendix C

Grain Size Distribution of Gravel Pack
And Water Producing Sand

TABLE 8
SIEVE ANALYSIS-GRAVEL PACK

Sieve No.	Weight Soil Retained in Grams	Percent Retained	Cumulative Percent Retained	Percent Finer
1st Determination				
4	262.33	35.5	35.5	64.5
10	319.42	43.3	78.8	21.2
20	136.46	18.5	97.3	2.7
40	15.54	2.1	99.6	0.6
60	2.00	0.3	99.7	0.3
140	1.37	0.2	99.9	0.1
200	0.26	0.05	99.95	0.05
pan	0.74	0.05	100.0	0
2nd Determination				
4	184.00	28.2	28.2	71.8
10	296.15	45.4	73.6	26.4
20	143.61	22.0	95.6	4.4
40	20.98	3.2	98.8	1.2
60	3.35	0.5	99.3	0.7
140	3.15	0.5	99.8	0.2
200	0.54	0.1	99.9	0.1
pan	0.81	0.1	100.0	0

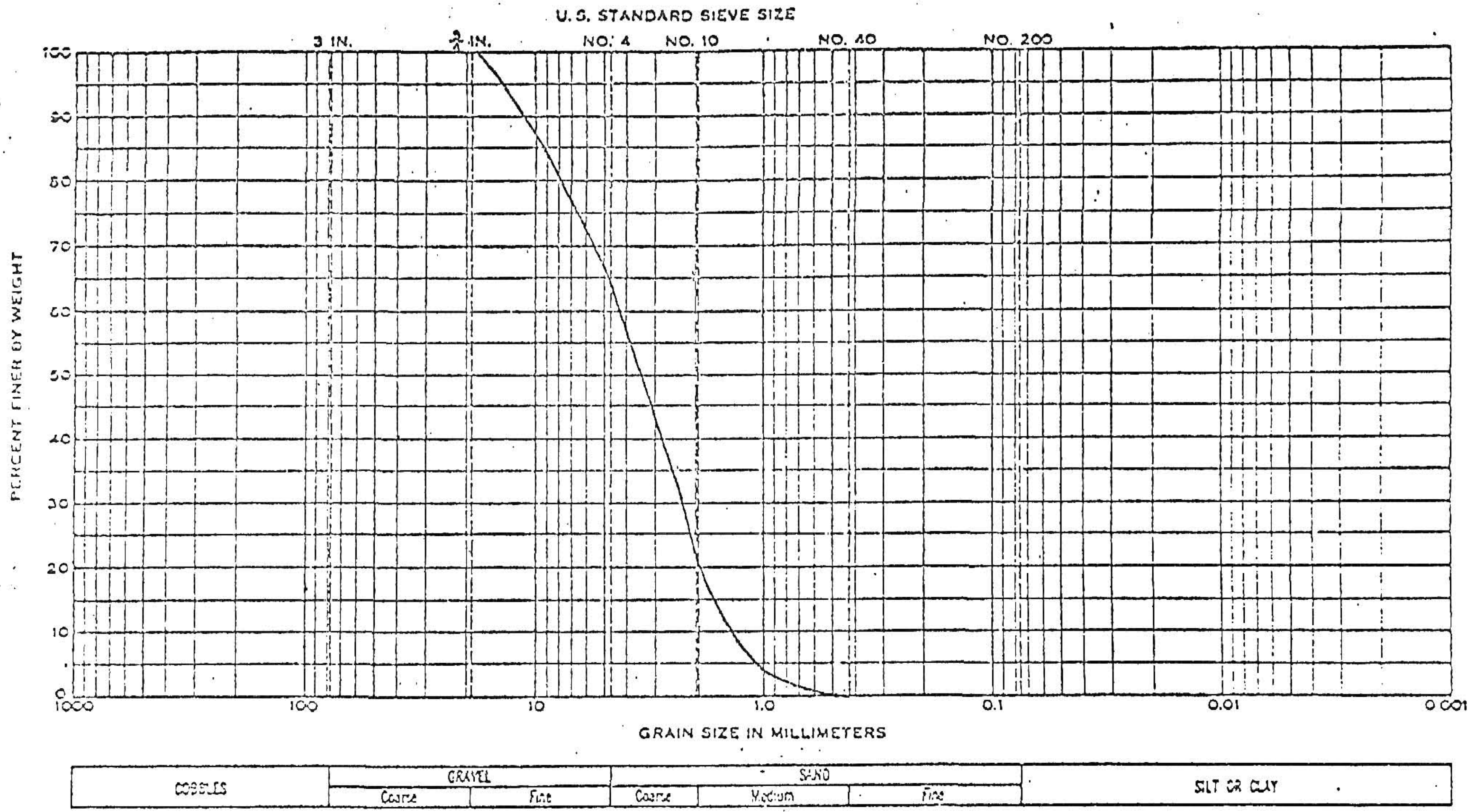

Fig. 14. Gravel pack sieve analysis
1st Determination

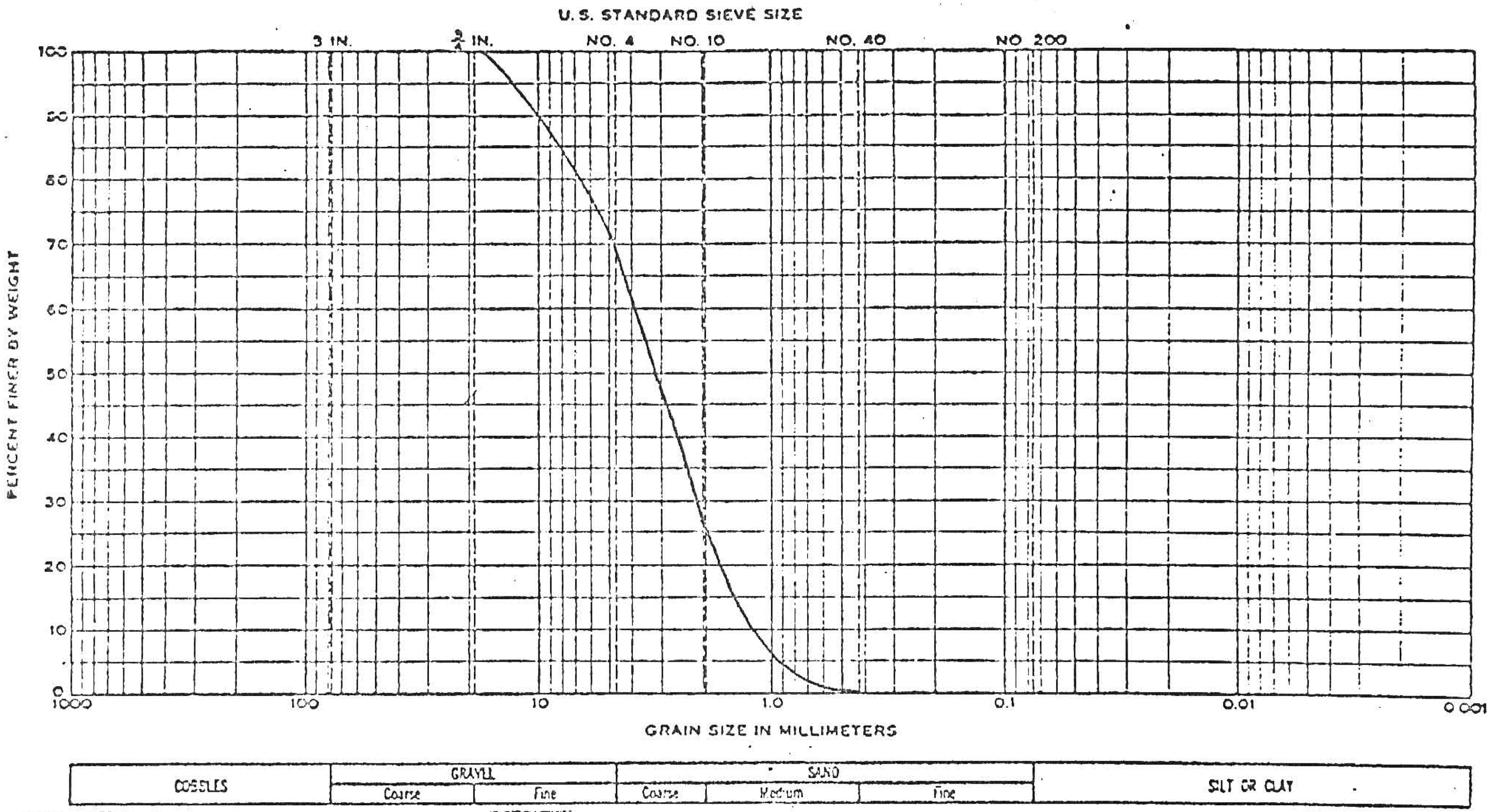

Fig. 15. Gravel pack sieve analysis
2nd Determination

TABLE 9

SIEVE ANALYSIS-WATER PRODUCING SAND

Sieve No.	Weight Soil Retained in Grams	Percent Retained	Cumulative Percent Retained	Percent Finer
1st Determination				
4	70.62	7.6	7.6	92.4
10	249.28	26.8	34.4	65.6
20	380.22	40.9	75.5	24.7
40	187.81	20.2	95.5	4.5
60	33.94	3.6	99.1	0.9
160	6.39	0.7	99.8	0.2
200	0.42	0.1	99.9	0.1
pan	1.08	0.1	100	0
2nd Determination				
4	39.86	7.4	7.4	92.6
10	138.75	25.9	33.3	66.7
20	225.5	42.1	75.4	24.6
40	111.52	20.8	96.2	3.8
60	17.12	3.2	99.4	0.6
160	2.21	0.4	99.8	0.2
200	0.12	0.1	99.9	0.1
pan	0.23	0.1	100	0

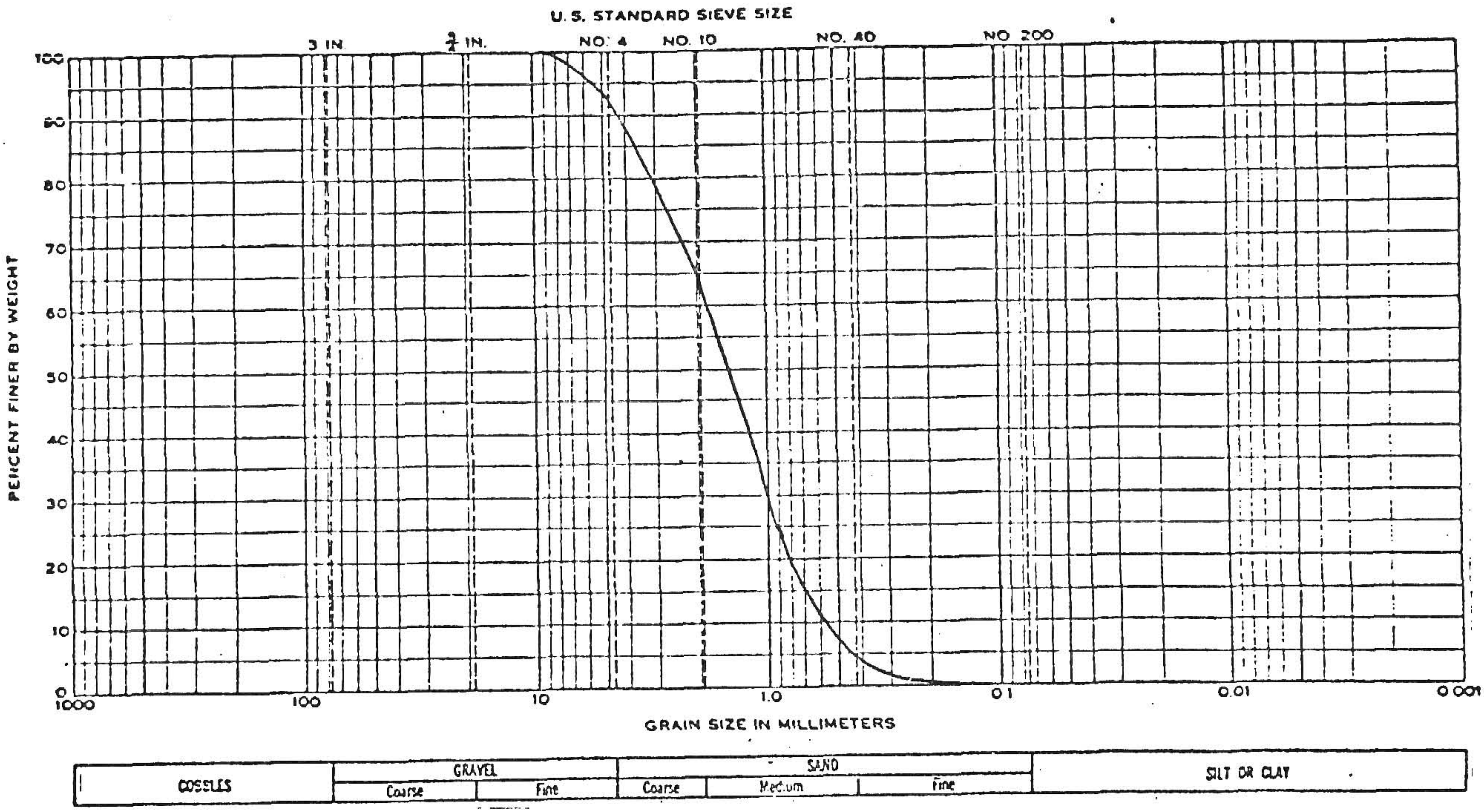

Fig. 16. Water producing sand sieve analysis
1st Determination

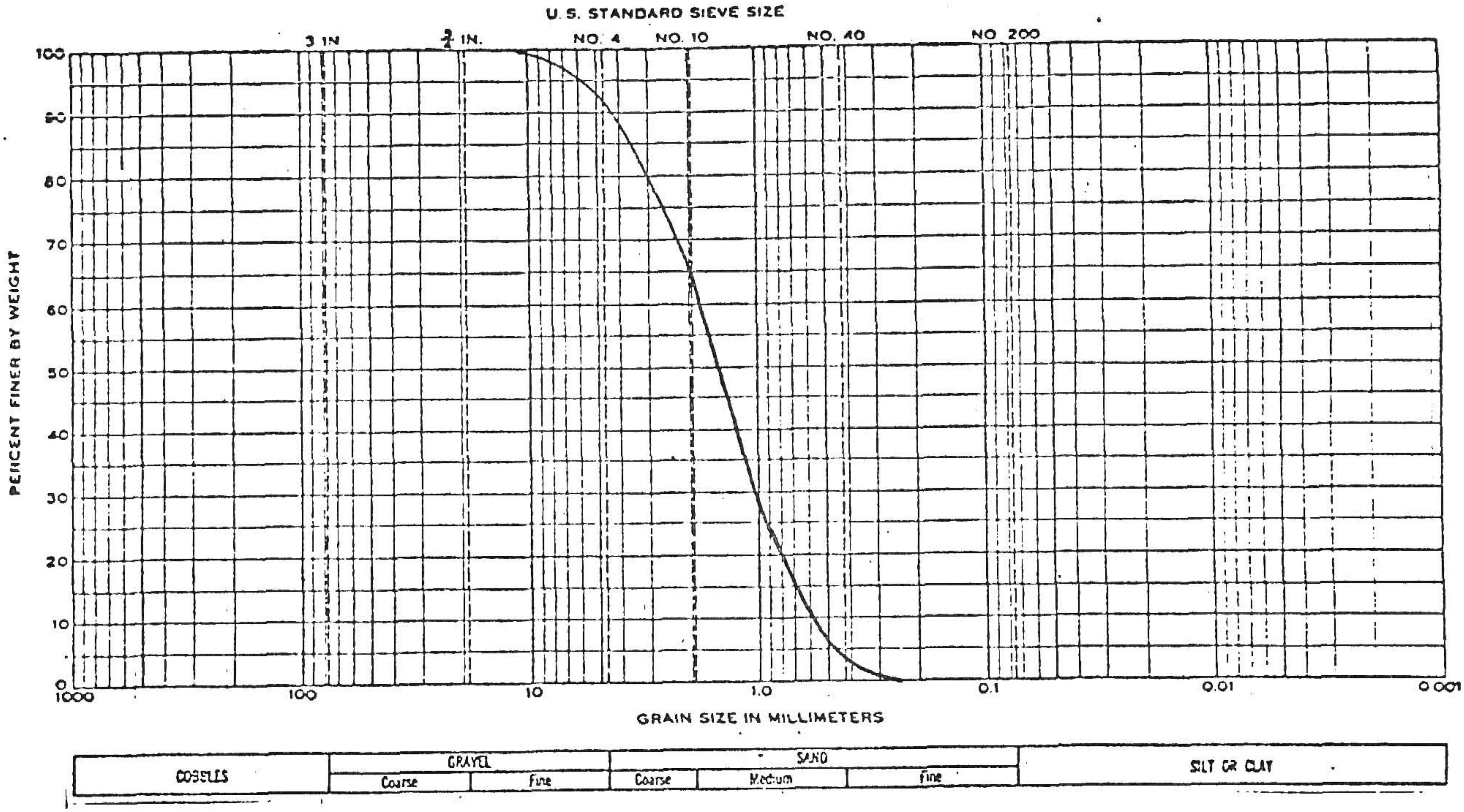

Fig. 17. Water producing sand sieve analysis
2nd Determination

BIBLIOGRAPHY

1. American Society of Civil Engineers, "Design and Construction of Sanitary Storm Sewers," Manual of Engineering Practice, No. 37, 1967, p. 208.

2. Arnold, L. K., "Introduction to Plastics," Iowa State University Press, 1968.

3. Beresantzev, V. G., "Earth Pressures on Cylindral Retaining Walls," Proc. Brussel Conf. on Earth Pressure Problems, 1958.

4. Bryan, G. H., "Application of the Energy Test to the Collapse of Long Thin Pipe Under External Pressure," Proc. Cambridge Phil. Soc., 6, 1888.

5. Clinedinst, W. O., "A Rational Expression for the Critical Collapsing Pressure of Pipe Under External Pressure," Material 20th Annual Meeting, Chicago, 1939.

6. Committee F 17 on Plastic Piping Systems, "Proposed Standard for Thermo-Plastic Well Casing Pipe, Couplings, and Screens Made in Standard Dimension Ratio (SDR)", ASTM, Jan., 1976.

7. Duryee, W. A., "Peripheral Movement of Soil Around a Buried Flexible Pipe," M. S. Thesis, Kansas State University, 1975.

8. Editors of the Modern Plastics Encyclopedia, "Guide to Plastics," McGraw-Hill, 1968-1969.

9. Erickson, F. E., "A Study of Adhesion Between PVC Pipe and Sand," M. S. Thesis, Kansas State University, 1975.

10. Fairban, Wm., "The Resistance of Tube to Collapse," phil Trans, 148, 1848.

11. Holmquist, J. L., and Nadia, A., "A Theoretical and Experimental Approach to the Problem of Collapse of Deep Well Casing," Material 20th Annual Meeting, Chicago, 1939.

12. Howard, A. K., "Laboratory Test on Buried Flexible Pipes," American Water Work Association Journal, Oct., 1972.

13. Howard, A. K., and Selander, C. E., "Laboratory Tests on Reinforced Thermo Setting, Thermoplastic, & Steel Pipe," 28th Technical Conf., Reinforced Plastics/Composites Institute, 1973.

14. Levy, M., "J. Math, Pure and Application," 1884.

15. Marston, Anson, and Anderson, A. O., "The Theory of Load on Pipes in Ditches and Tests of Cement and Clay Drain Tile and Sewer Pipe," Iowa Engineering Station Bulletin 31, Ames, Iowa, 1913.

16. Marston, Anson, and Stewart, J. T., "Report of the Investigation on Drain Tile of Committee C-6 on Standard Tests and Specifications for Drain Tile," ASTM 1914 and Iowa Engineering Experiment Station Bulletin 36, 1914.

17. Marston, Anson, "The Theory of External Loads on Closed Conduits," Iowa Engineering Experiment Station Bulletin 108, 1932.

18. Moser, A. P., Watkins, R. K., and Bishop, R. R., "Structural Response of Buried PVC pipe," Modern Plastics, Nov., 1973.

19. Schlick, W. J., "Loads on Pipes in Wide Ditches," Iowa Engineering Experimental Station Bylletin 108, 1932.

20. Spangler, W. J., "The Structural Design of Flexible Pipe Culverts," Iowa Engineering Experiment Station Bulletin 153, 1941.

21. Spangler, M. G., and Donovan, J. C., "Application of the Modulus of Passive Resistance of Soil in the Design of Flexible Pipe Culverts," HRB Prog., Vol. 36, 1957, pp. 371-381.

22. Spangler, M. G. and Handy, R. L., "Soil Engineering," International Textbook Co., 1951, pp. 409-449.

23. Spangler, M. G. and Handy, "Soil Engineering", Interest Press, 1973.

24. Stewart, R. T., Trans. Am. Soc. Mech. Engrs., 1906.

25. Sturm, R. G., Doctorate Thesis submitted to Department of Theoretical and Applied Mechanics, Coll. Engg, University of Illinois, 1928.

26. Watkins, R. K. and Spangler, M. G., "Some Characteristics of the Modulus of Passive Resistance of Soil, A Study in Similitude," Highway Research Board Proceedings, Vol. 37, 1958, pp. 576-583.

27. Watkins, R. K. and Smith, A. B., "Ring Deflection of Buried Pipes," Journal of American Water Works Association, Vol. 59, March, 1967.

28. Watkins, R. K. and Smith, A. B., "Deflection of Buried Pipes," Journal of American Water Work Association, Vol. 65, Sept., 1973, pp. 588-593.

29. Westergaard, H. M., "Computation of Stress in Concrete Roads," Highway Research Board Proceedings, 5, Pt. 1, 1925, pp. 90-112.

30. Williams, W. W. and Dao, D. H., "The Analysis of Flexible Well Casing," Report presented to the ASTM Committee F. 17-61-05 Water Well Casing Section, San Diego, California, Feb., 1976.

31. Winterkorn, H. F., and Fang, H. Y., Foundation Engineering Handbook, Van Nostrand Reinhold Co., New York, 1975.

A STUDY OF POLYVINYL-CHLORIDE PIPE
AS WELL CASING

by

Dinh Huu Dao

Diploma in Civil Engineering
National Institute of Technology
Saigon, Vietnam
1962

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

ABSTRACT

A well casing is a buried structure subjected to earth and hydraulic pressure. The purpose of this study is to analyze these forces on and reaction of plastic pipe well casing, and to suggest the suitability of the polyvinyl-chloride pipe with large diameter for deep well casing.

Laboratory tests gave an expression of the supportive strength of an 8" and 10" polyvinyl-chloride pipe when surrounded by dense sand.

The Field Test wells recorded the performance of the 16" polyvinyl-chloride pipe used for well casing with different depths varying from 100' to 342'.

With the success of these experimental wells and the continuous progress in the plastics industry, the polyvinyl-chloride pipe with larger diameter will be used as well casing, giving to the well contractors an economical material due to its low cost of installation, the convenience in the handling, and its long life expectancy.