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Since the adoption of the present structural design method in 1951, the design stability of soils, incorporated in the roadway section has been determined from R-Value and expansion pressure measurements on soil specimens which fulfill certain design criteria. The test employs test specimens which are prepared in the Laboratory to simulate the state of moisture saturation and density that is frequently typical of the soil under a pavement after it has been down for a number of years. A mechanical compactor first forms the specimen with a "kneading like" compaction which reproduces an internal structure comparable to that resulting in the roadbed from construction compaction. Kneading compaction is followed by the application of a steadily increasing load with a testing press until the contained water begins to exude. The unit load applied when moisture is squeezed out is called the "exudation pressure" and generally represents a saturated condition in the specimen. Up to the present time, the design R-Value has been determined as the R-Value interpolated to a theoretical specimen which would exude water under 400 psi pressure, except in cases where highly expansive materials are encountered. In the latter instance, the design R-Value is modified in accordance with expansion pressure measurements to provide additional cover as required for stability.



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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

# A REPORT ON AN INVESTIGATION CONCERNING THE EFFECT OF LOWERING THE EXUDATION PRESSURE INTERPOLATION POINT IN THE R-VALUE TEST
## TEST METHOD NO. CALIF. 301-B

59-05

May 20, 1959

MATERIALS & RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways
Materials and Research Department

May 20, 1959

Mr. J. W. Trask
Assistant State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

A REPORT ON

AN INVESTIGATION

CONCERNING THE EFFECT OF

LOWERING THE EXUDATION PRESSURE

INTERPOLATION POINT

IN THE

R-VALUE TEST

TEST METHOD NO. CALIF. 301-B

Study Made by--------------------------------Pavement Section
Under the General Direction of-------------Ernest Zube
Supervised by--------------------------------Clyde G. Gates
Report prepared by-------------------------Daniel R. Howe

Very truly yours,

F. N. Hveem
Materials & Research Engineer

cc: G. Langsner
M. Harris
All Districts

59-05

## INTRODUCTION

Since the adoption of the present structural design method in 1951, the design stability of soils, incorporated in the roadway section has been determined from R-Value and expansion pressure measurements on soil specimens which fulfill certain design criteria. The test employs test specimens which are prepared in the Laboratory to simulate the state of moisture saturation and density that is frequently typical of the soil under a pavement after it has been down for a number of years. A mechanical compactor first forms the specimen with a "kneading like" compaction which reproduces an internal structure comparable to that resulting in the roadbed from construction compaction. Kneading compaction is followed by the application of a steadily increasing load with a testing press until the contained water begins to exude. The unit load applied when moisture is squeezed out is called the "exudation pressure" and generally represents a saturated condition in the specimen. Up to the present time, the design R-Value has been determined as the R-Value interpolated to a theoretical specimen which would exude water under 400 psi pressure, except in cases where highly expansive materials are encountered. In the latter instance, the design R-Value is modified in accordance with expansion pressure measurements to provide additional cover as required for stability.

Where design is based upon exudation pressure, the 400 psi value has been assumed to represent the state of density and the greatest amount of water the soil may ultimately attain in the road sometime after completion of construction. However, recent experience has indicated that the original assumption of 400 psi was overly optimistic with respect to conditions which have been observed on many of our highways. Evidence that the road moisture level often exceeds the amount developed in the R-Value test and the frequent indications of high resilience in the subgrade at the moistures found have indicated a need for the lowering of the exudation pressure interpolation point.

In correlating laboratory tests with field performance, it has been found from Benkelman Beam measurements that high pavement deflections are associated with resilient (or springy) materials which have become saturated. Since repeated high deflections under normal highway traffic conditions will often cause fatigue failure of bituminous pavements within a relatively short period, it becomes important to minimize deflections by providing additional cover thickness over resilient soils. Research studies in the Laboratory involving the Resiliometer, have indicated that the degree of resilience in a given soil is generally proportional to the moisture content of the material. Also, soils composed predominately of silt are usually the most resilient and likewise are the most sensitive to moisture content.

While the R-Value test in its present form does not provide for the direct evaluation of the resilience factor in soils, investigation has revealed that a shift to 300 exudation pressure will increase the moisture in the test specimens and cause the greatest lowering of R-Value in the critical silty materials. The consequent substantial increases in cover thicknesses will therefore be made over resilient soils where it is necessary to reduce pavement deflections.

The investigation, which is the subject of this report, was directed at examining the over-all effect of a change in the exudation pressure interpolation point on all classes of soil commonly encountered in the building of highways in California. Particular effort is made to analyze base materials with respect to the lowering of R-Value and possible rejection by limiting R-Value specifications. Primary consideration was given in the collection of data, to the effect of reducing the pressure from the present 400 psi to 300 psi. However, in connection with base materials, examination was also made of the intermediate 350 psi level.

## ANALYSIS OF DATA

Initially the study began with the tabulation of R-Values at 400 and 300 psi exudation pressure for various materials tested in 1953. The reason for utilizing the 1953 data was that up to that time we performed a considerable amount of routine testing of all types of materials for the various districts. Figure 1 illustrates with a scatter diagram, the over-all effect of lowering the exudation pressure to 300 psi. By grouping the R-Values at 400 psi in 10 R-Value increments and tallying the differences between R-Values at 400 and 300 psi, it is possible to obtain a percentile distribution of tests in terms of differences. This is shown in Figure 2 for 100, 90, 70 and 50 percentile, respectively. It is noted that, in general, the greatest difference occurs in the 41 to 60 R-Value (@ 400 psi) range. Figure 3 was constructed to show the increase in gravel equivalents (@ a T.I. of 9.0) needed to accommodate the differences. Also shown in the same figure is a cumulative curve exhibiting the percentage of tests which show R-Value differences equal to or less than the indicated differences. From these two curves, it can be seen, for example, that 90% of the materials tested will require from zero up to 6.4 inches of additional cover. Likewise, maximum changes in cover can be determined for various other proportions. Figure 4 was included to show the distribution of differences, in the 41 to 60 group, in terms of number of tests.

While the 1953 test series included a number of untreated rock base (URB), crusher run base (CRB) and imported base material (IBM) samples, it is felt that an analysis of the effect of a shift in exudation pressure on base materials should be accomplished with more recent test data. Since the 1953 tests were performed, two significant changes have been made in the R-Value test procedure. First, the use of paper baskets in the fabrication of test specimens was made a standard requirement for all coarse textured untreated bases. Secondly, the so-called "locked head" procedure for confining the test specimen before applying the initial 5 psi horizontal pressure was introduced. Both of these items improved the test considerably by minimizing pre-disturbance of the compacted specimen and thereby reduced the spread of test values obtained. In view of the changes in the test procedure and the fact that the URB's and CRB's conformed to the 1949 Standard Specifications, it was concluded that the study of base materials should be made on more recent tests representing the 1954 specification requirements.

Tests performed on untreated base (UB) and imported base material (IBM) samples were therefore tabulated for the years 1955 through 1958. Figures 5 and 6 exhibit the distribution of UB tests for various differences at 300 and 350 exudation pressures respectively. It is noted that the dotted portion of the bars, representing zero difference, encompasses the majority of tests. Figures 7 and 8 are similar charts for IBM. In both of these latter charts the proportion of tests indicating zero difference with respect to the other differences is considerably less than for UB's, thus denoting a greater variation of R-Value for IBM's.

In recent years it has become increasingly evident that the amount of moisture remaining in the specimen under 400 psi exudation pressure is somewhat lower than the level of moisture equilibrium which is often reached in a roadbed during its life span. As was previously pointed out, this is not in accordance with a fundamental concept of the R-Value test and design method which stipulates that the soil be tested under the most unfavorable moisture condition. Records from various failure investigations reveal numerous instances where the inplace field moisture contents of subgrade material have exceeded the values used in the determination of R-Value on the same materials in the Laboratory. This is illustrated in a summary given in Table I, of moisture tests performed on projects at least one year and in some cases as much as 5 years after completion of construction.

Columns (5) and (6), in Table I, exhibit the average moisture contents obtained from field and laboratory tests respectively. As shown there are 11 cases out of 32 where the average field moisture content exceeds that determined in the R-Value test. However, this does not adequately convey the true extent of the discrepancies since higher field moistures in individual tests are not always reflected by the averages. Therefore column (7) is arranged to indicate the number of tests in each case where the field moisture exceeds the laboratory value. Out of 238 tests there are 104 tests, or nominally 44%, which show higher field moisture contents.

## CONCLUSIONS AND RECOMMENDATIONS

From a review of the above data, it appears that lowering the exudation pressure to 300 psi would provide the greatest benefit to design and testing without seriously limiting the use of untreated bases or causing excessive cover thickness increases. As illustrated in Figures 1 through 4 the soils which show the largest change in R-Value and a corresponding increase in thickness requirements fall within the 40 to 60 R-Value range. The materials represented in this group usually contain a high proportion of silt which has been shown by other tests to be a major contributor to high resilience in soils. The provision of additional cover over resilient soils in embankment and subbases is an important step in minimizing high deflections.

With respect to base materials it again appears that the greatest benefit can be derived from a change to 300 psi exudation pressure. Figure 9 displays the proportion of various base materials which fall below 78 R-Value when the exudation pressure is lowered from 400 to 350 and to 300 psi. In the case of UB's it is noted that reductions to either 350 or 300 psi results in only a nominal amount of tests falling below 78 R-Value. On the other hand, the IBM's are more seriously affected particularly with respect to the 300 psi point. The indications are that the 300 psi will eliminate a substantial proportion of borderline base materials.

In general, the over-all reproducibility of the test and the correlation of R-Value with road moisture conditions would be improved by the lowering of the exudation pressure. With some soils, particularly the silty type, the present interpolation point at 400 psi falls in the region of the curve where the R-Value changes quite rapidly with small changes in moisture and likewise in exudation pressure. In these cases minor variations in the plotting of curves or reproduction of exudation pressures often causes R-Value results to vary broadly. While a shift to 350 psi will lower the rate of change of R-Value with respect to exudation pressure somewhat, the 300 psi will more generally place the interpolation point in the "non-critical" portion of the curve and provide a more realistic degree of moisture saturation in the test.

In view of the data and observations given in this report it appears that the exudation pressure interpolation point should be reduced from 400 psi to 300 psi.

TABLE I

COMPARISON FIELD INPLACE MOISTURES WITH LABORATORY DESIGN MOISTURE DETERMINATIONS
Summarized from Data obtained During Pavement Failure Investigations.

| Dist. Co. Rt. & Sec. | Type Material | No. Tests | Lab. R-Value (Average) | Percent Moisture (Average) Field (Inplace) | Percent Moisture (Average) Lab (Test Value) | No. of Tests Where Field exceeds Lab. Moistures |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| XI-SD-2-F | Basement Soil | 11 | 51 | 10.0 | 12.3 | 2 |
| XI-SD-2-F | Crusher Run Base | 3 | 80 | 3.6 | 6.5 | 0 |
| X-Mer-4-A | Silty Sand | 17 | 47 | 14.3* | 11.9* | 17 |
| X-Mer-4-A | Silty Snd & Gravel | 6 | 61 | 9.6 | 10.5 | 2 |
| X-Mer-4-A | Adobe | 25 | 16 | 15.8* | 14.4* | 19 |
| X-Sol-2-E | Silty Snd & Gravel | 8 | 76 | 7.4 | 9.6 | 4 |
| X-Sol-2-E | Silty Sand | 17 | 61 | 17.9* | 16.7* | 10 |
| X-Sol-2-E | Silty Sand & Clay | 1 | 9 | 14.0 | 15.0 | 0 |
| X-SJ-5-A | Subbase Material | 6 | 81 | 13.5 | 15.4 | 0 |
| X-SJ-5-A | Basement Soil | 9 | 42 | 11.5* | 11.0* | 4 |
| VII-Ven-2-C | Crusher Run Base | 3 | 79 | 6.7 | 7.5 | 0 |
| VII-Ven-2-C | Imported Borrow | 4 | 48 | 10.2 | 14.0 | 1 |
| VII-Ven-2-C | Basement Soil | 7 | 21 | 24.2* | 18.7* | 6 |

* Indicates cases where average field moistures shown in Column (5) exceed average lab. moistures shown in Column (6).

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TABLE I (Continued)

COMPARISON FIELD INPLACE MOISTURES WITH LABORATORY DESIGN MOISTURE DETERMINATIONS
Summarized from Data obtained During Pavement Failure Investigations.

| Dist. Co. Rt. & Sec. | Type Material | No. Tests | Lab. R-Value (Average) | Percent Moisture (Average) Field (Inplace) | Percent Moisture (Average) Lab. (Test Value) | No. of Tests where Field exceeds Lab. Moistures |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| VII-LA-4-J | Untreated Rock Base | 4 | 79 | 3.9 | 7.6 | 0 |
| VII-LA-4-J | Imported S.Base Mtl. | 3 | 81 | 5.6 | 7.7 | 0 |
| VII-LA-4-J | Basement Soil | 4 | 53 | 12.6 | 13.6 | 2 |
| VI-Mad-4-A | Clayey Sand | 22 | 44 | 4.4 | 10.8 | 0 |
| VI-Kern-4-A | Imported S.Base Mtl. | 7 | 71 | 11.6* | 10.7* | 3 |
| VI-Kern-4-A | Basement Soil | 14 | 64 | 9.1 | 9.1 | 3 |
| V-Mon-2-Sal | Imported S.Base Mtl. | 2 | 76 | 7.4 | 10.0 | 0 |
| V-Mon-2-Sal | Imported Borrow | 4 | 25 | 21.0 | 23.0 | 1 |
| IV-Nap-8-A | Untreated Rock Base | 6 | 83 | 8.2 | 9.7 | 1 |
| IV-Nap-8-A | Imported S.Base Mtl. | 6 | 80 | 8.3 | 9.8 | 0 |
| IV-Nap-8-A | Basement Soil | 6 | 38 | 17.7* | 15.6* | 5 |
| III-Sac-3-B | Subbase Mtl. | 6 | 75 | 15.2* | 14.4* | 3 |
| III-Sac-3-B | Basement Soil | 10 | 41 | 14.9* | 13.3* | 7 |
| III-Pla-17-A | Subbase Mtl. | 6 | 78 | 15.6 | 15.7 | 3 |
| III-Pla-17-A | Basement Soil | 4 | 30 | 12.1 | 13.1 | 3 |

* Indicates cases where average field moistures shown in Column (5) exceed average lab. moistures shown in Column (6).

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TABLE I (Continued)

COMPARISON FIELD INPLACE MOISTURES WITH LABORATORY DESIGN MOISTURE DETERMINATIONS
Summarized from Data obtained During Pavement Failure Investigations.

| Dist. Co. Rt. & Sec. | Type Material | No. Tests | Lab. R-Value (Average) | Percent Moisture (Average) | | No. of Tests where Field exceeds Lab. Moistures |
|---|---|---|---|---|---|---|
| | | | | Field (Inplace) | Lab. (Test Value) | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| II-Sha-3-B | Imported S.Base Mtl. | 2 | 83 | 8.9 | 10.2 | 0 |
| II-Sha-3-B | Imported Borrow | 3 | 74 | 10.2* | 10.0* | 2 |
| II-Sha-3-B | Basement Soil | 7 | 44 | 16.5* | 16.4* | 4 |
| I-Men-1-D,E | Basement Soil | 5 | 29 | 12.6 | 13.1 | 2 |
| TEST TOTALS | | 238 | | | | 104 |

* Indicates cases where average field moistures shown in Column (5) exceed average lab. moistures shown in Column (6).

## COMPARISON OF R-VALUES at 400 psi WITH R-VALUES at 300 psi EXUDATION PRESSURE

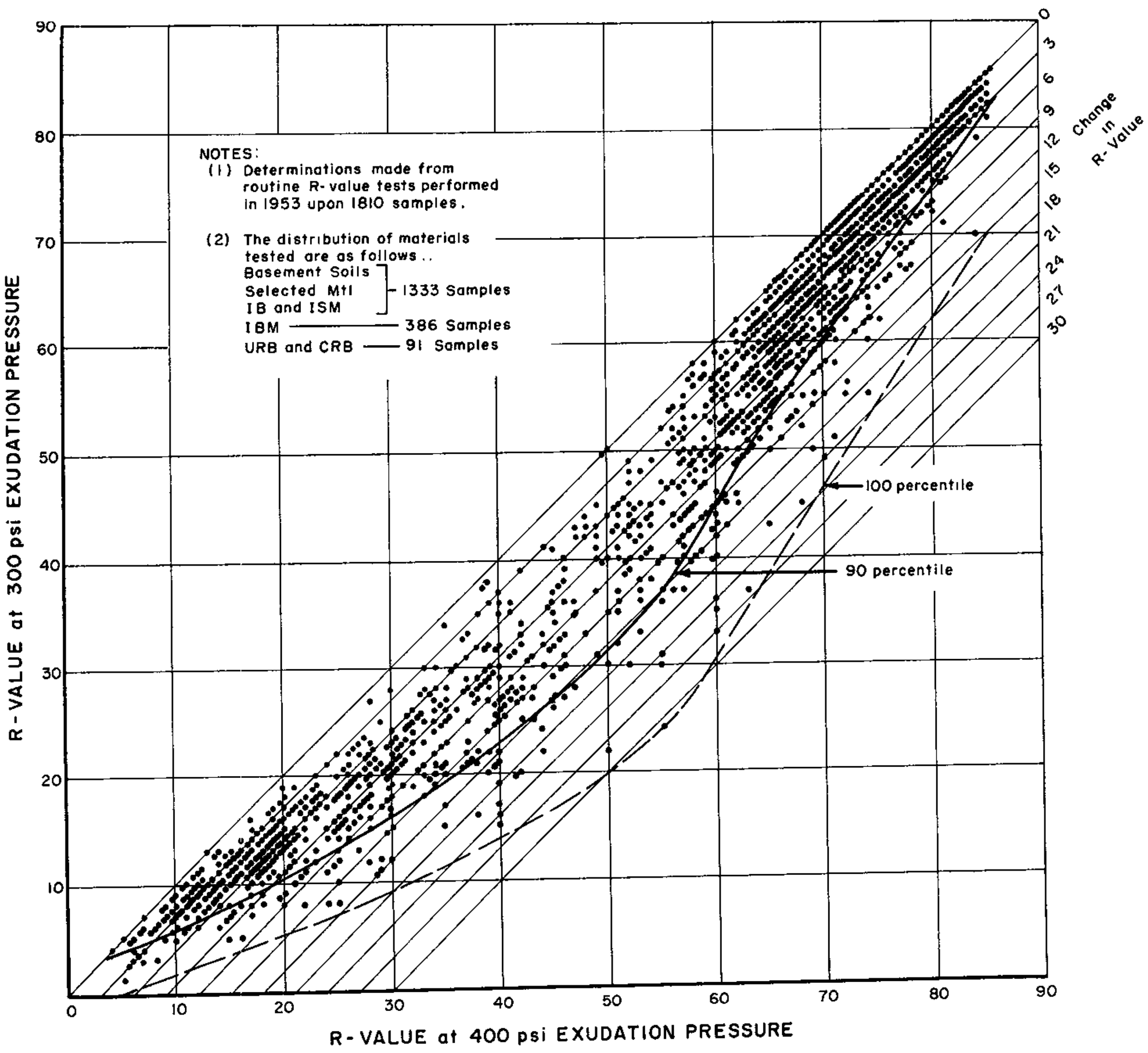


FIGURE I

## DIFFERENCES BETWEEN R-VALUES at 400 & 300 psi EXUDATION PRESSURE FOR VARIOUS GROUPINGS OF R-VALUES at 400 psi

## BASED ON 1810 TESTS PERFORMED IN 1953

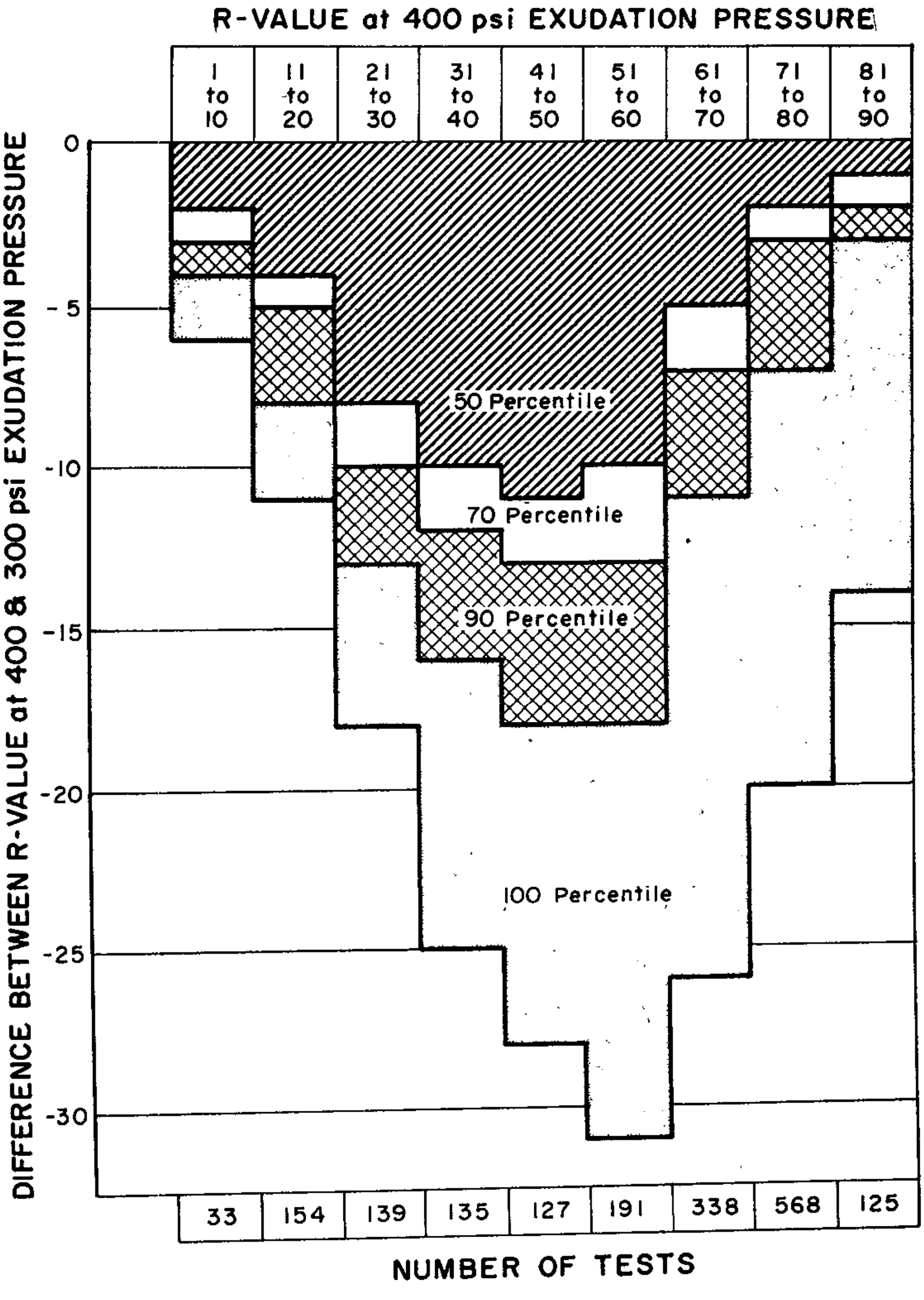


FIGURE 2

# FREQUENCY OF OCCURRENCE & GRAVEL EQUIVALENT CHANGES FOR DIFFERENCES BETWEEN R-VALUES at 400 & 300 psi EXUDATION PRESSURE – 41 to 60 R-VALUE SOILS ONLY

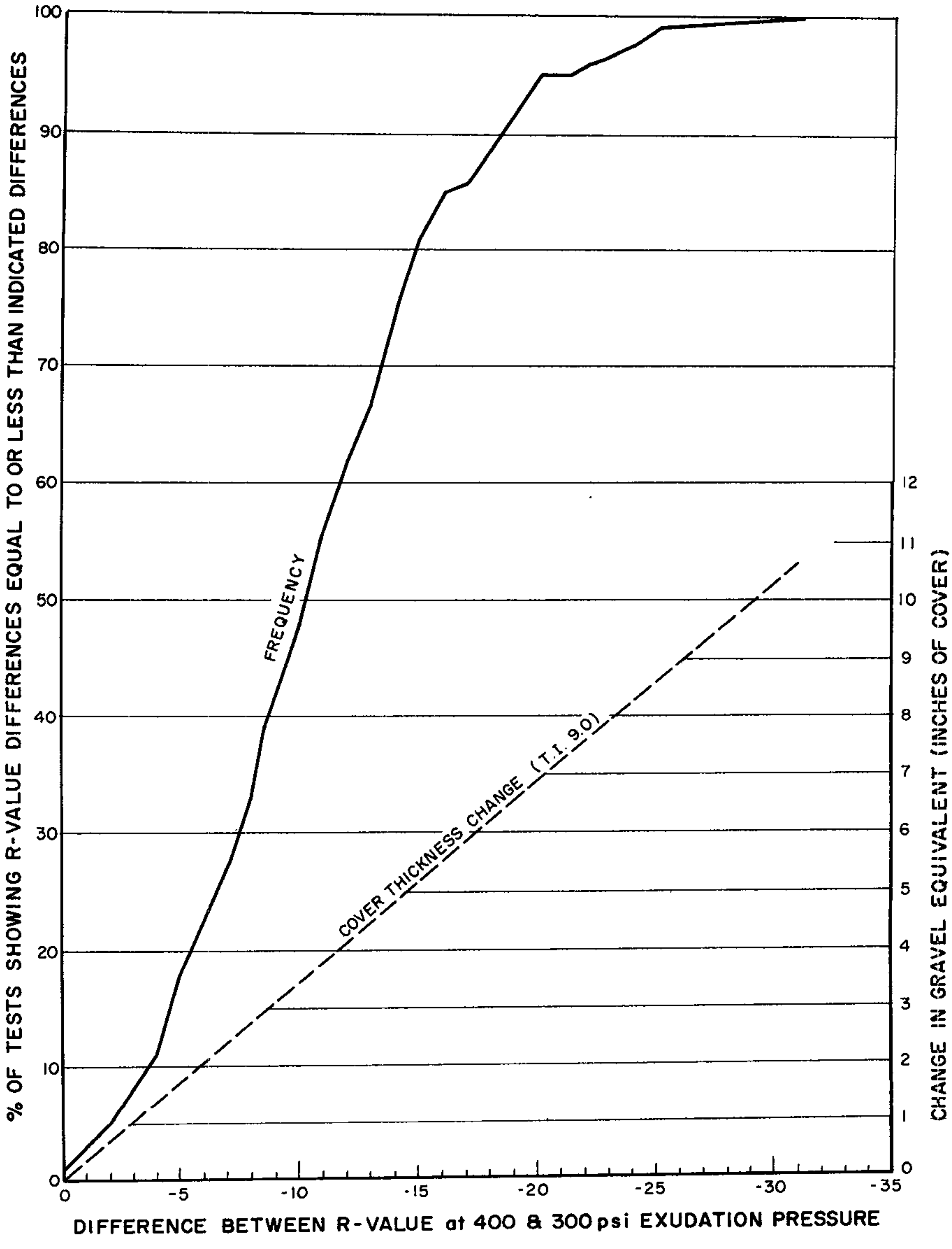


FIGURE 3

## EXUDATION PRESSURE STUDY
## 41 to 60 R-VALUE SOIL

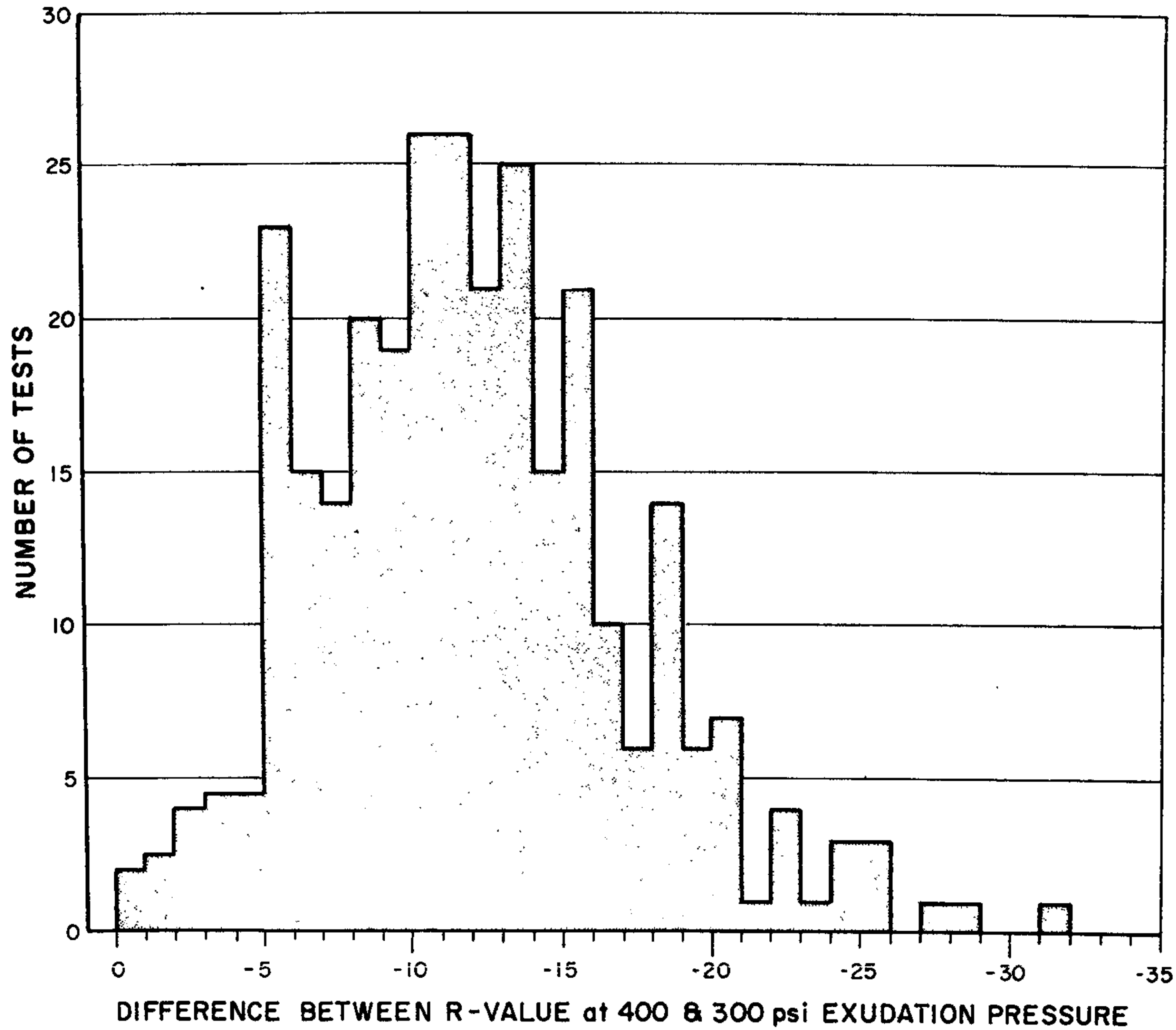


FIGURE 4

# EXUDATION PRESSURE STUDY
# UNTREATED BASES (1955-58)
## 300 psi

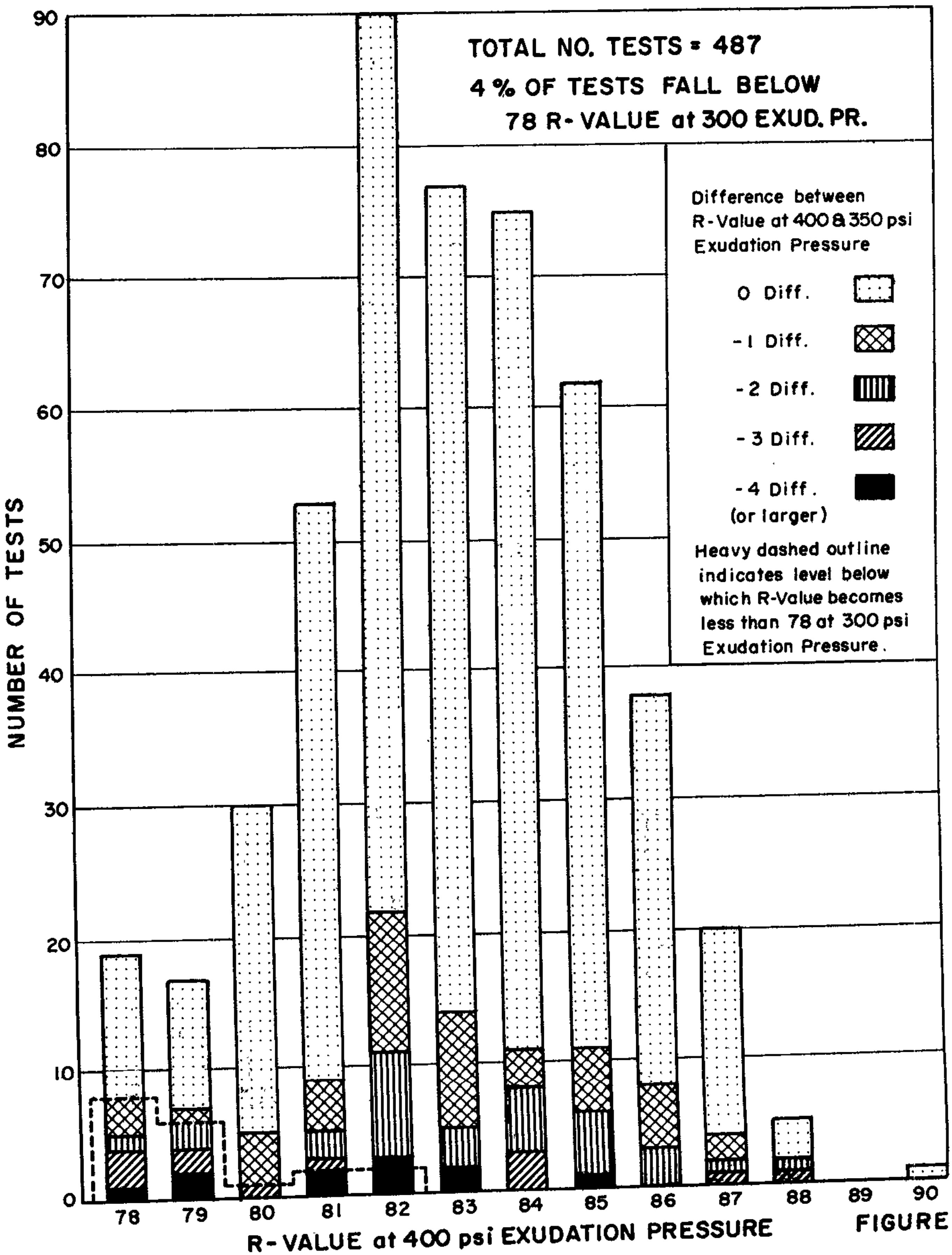


FIGURE 5

# EXUDATION PRESSURE STUDY
# UNTREATED BASES (1955-58)
# 350 psi

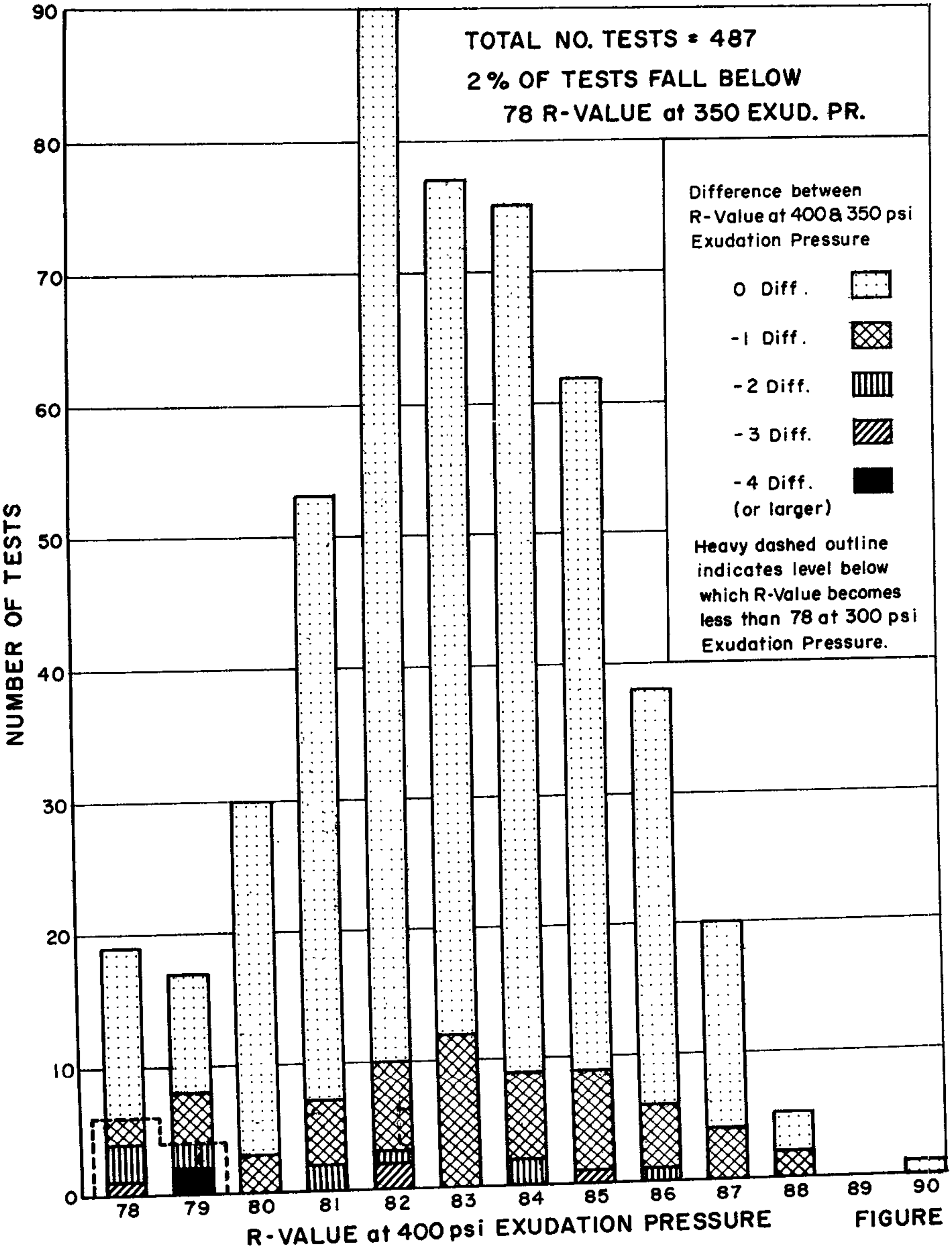


FIGURE 6

# EXUDATION PRESSURE STUDY
# IMPORTED BASE MATERIAL
# 300 psi

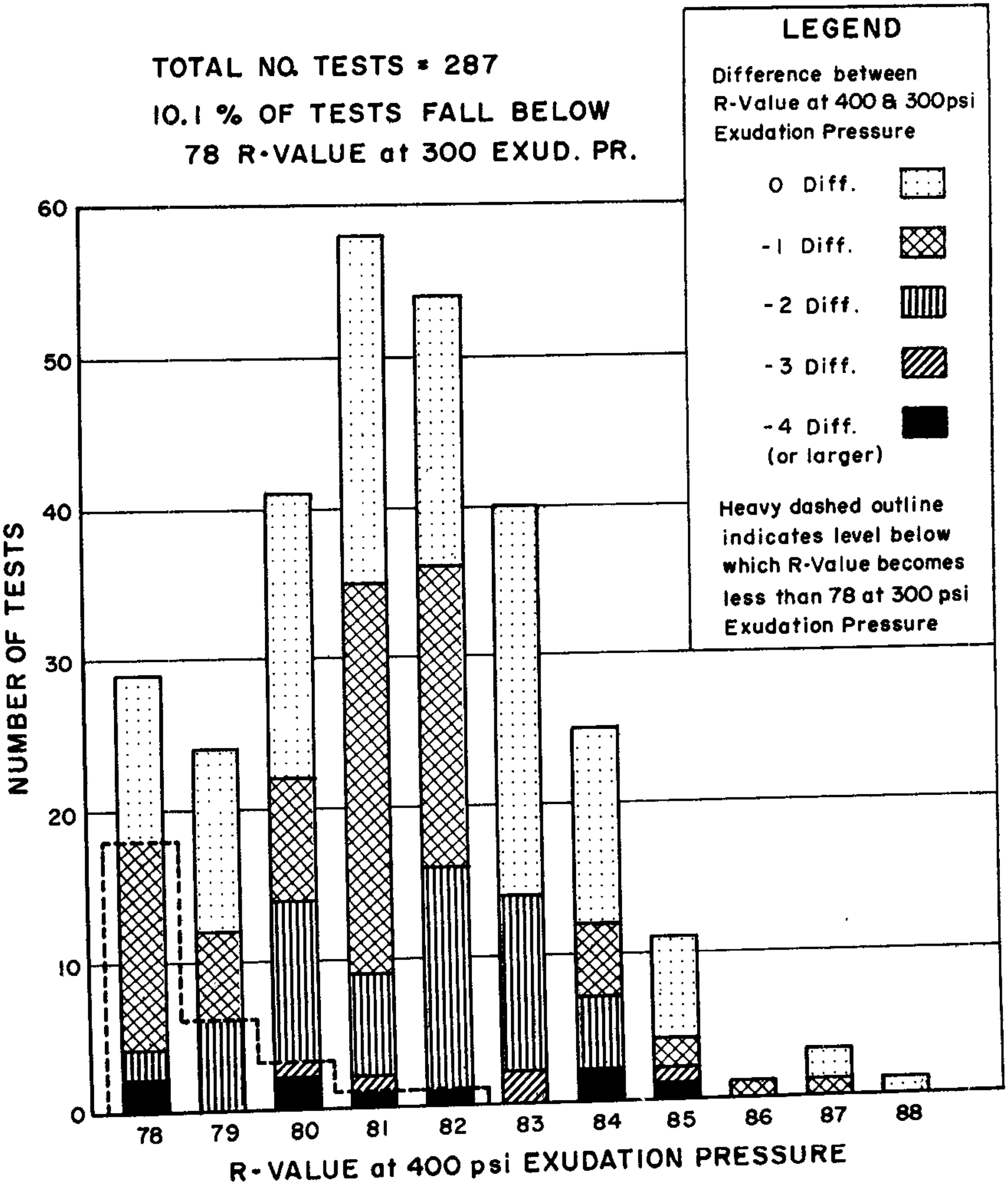


FIGURE 7

# EXUDATION PRESSURE STUDY
# IMPORTED BASE MATERIAL
# 350 psi

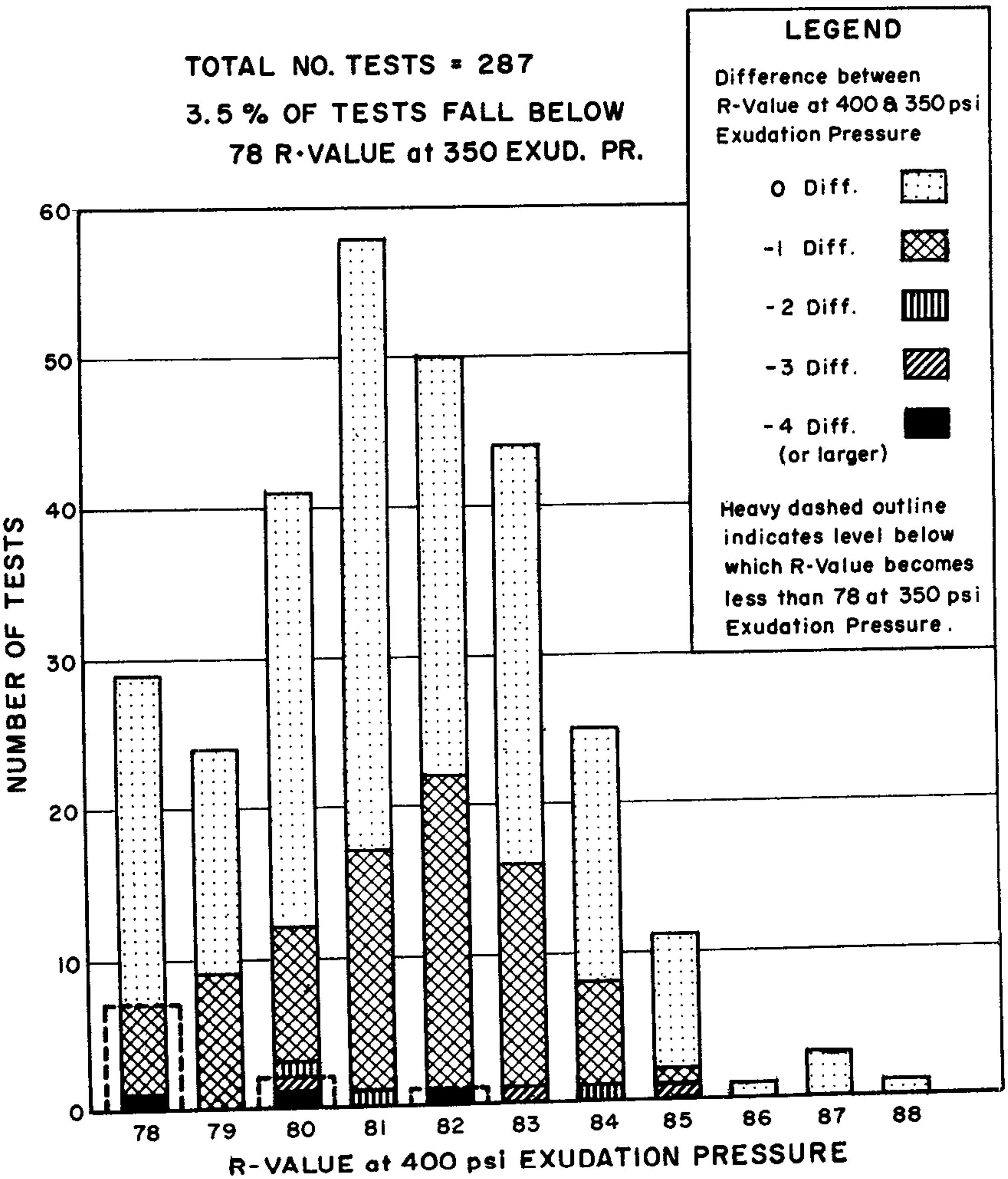


FIGURE 8

# PROPORTION OF VARIOUS BASE MATERIALS FALLING BELOW 78 R-VALUE WHEN EXUD. PR. IS LOWERED FROM 400 to 350 & 300 psi

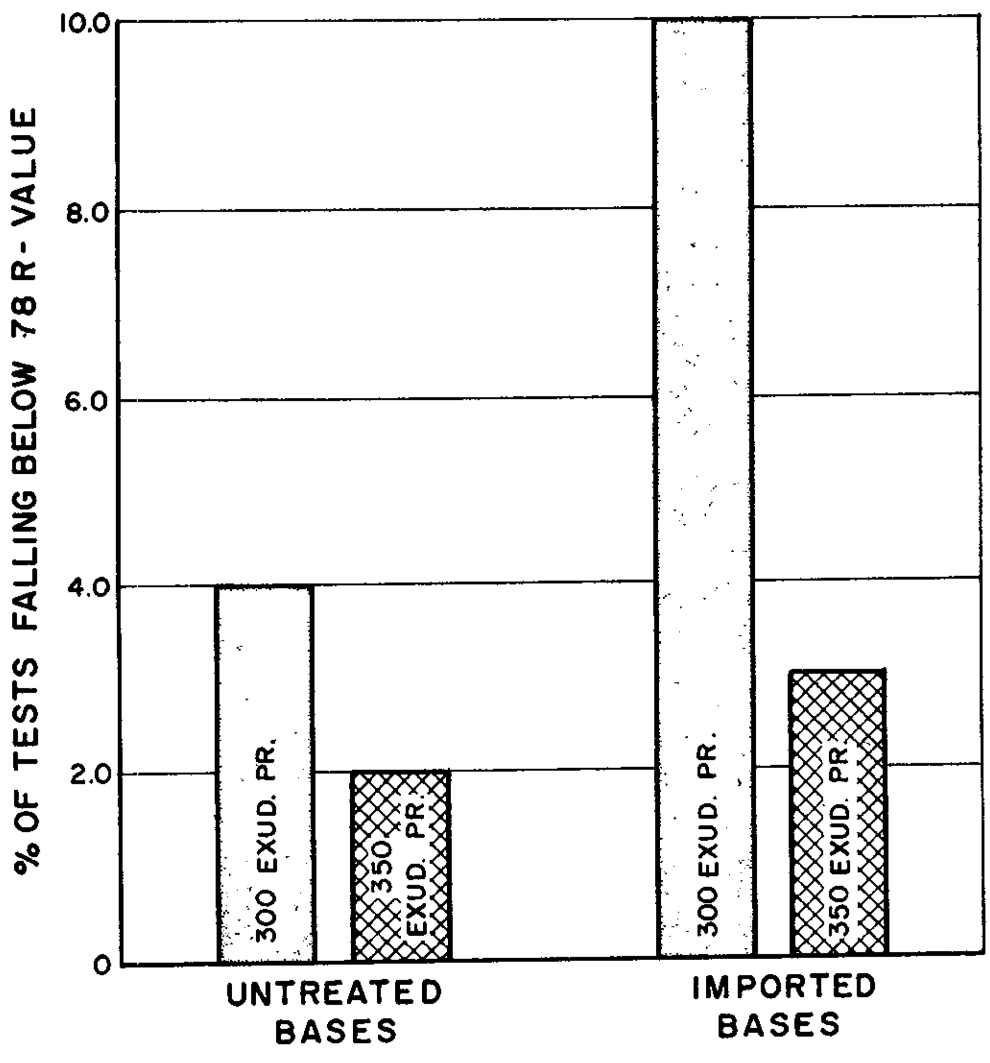


FIGURE 9