EVALUATION OF THE COHESIOMETER TEST FOR ASPHALTIC CONCRETE

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Synopsis

The investigation reported herein is a supporting study to a larger project concerned with the modification of the AASHO Road Test findings for use under conditions found in the State of Texas. It was the objective of this special study to determine whether cohesiometer test results are significantly related to factors known to affect the performance of asphaltic concrete, to modify the equipment or procedure if necessary, and to evaluate the test for use in the parent project.

The cohesiometer used by and available to the Texas Highway Department was modified slightly and a load-deflection recorder was attached to the unit. The data obtained from the evaluation program have shown that the cohesiometer test results are affected by and are sensitive to mixture variables that exist in asphaltic concrete pavements. An equation defining the cohesiometer's response to a test specimen was derived and verified by test data. Also for use in the parent project a specimen height correction chart was established.

Introduction

Since the completion and reporting of the AASHO Road Test, highway engineers have recognized the necessity of translating the findings for local conditions. It is primarily for the above reason that project HPS-1-(27) E was initiated in the State of Texas. A special phase of this program is concerned with the determination of the surfacing coefficient for use in the Road Test performance equation and with the cohesiometer test for arriving at a value for this coefficient.

The cohesiometer test was developed by the California Highway Department for use in designing asphaltic mixtures and pavements; however, the cohesiometer test has not been used as a specification requirement for asphaltic surfacings. Several districts of the Texas Highway Department employ a cohesiometer of Texas design for evaluation of pavement materials. It is this type of cohesiometer that was selected for use in this study; however, certain modifications to the standard apparatus were made.

A major modification to the standard cohesiometer was the addition of a load-deflection recorder. The recorder is a mechanical one in which a paper tape moves at a rate of 18 inches per minute and a pen attachment linked to the cohesiometer beam traces a curve on the tape as the beam deflects under load. The cohesiometer is illustrated in Figure 1. Other changes from the standard are slight ones, such as (a) the beam is allowed to deflect up to 1-1/2 inch and (b) the variation in the gap distance between the clamp down plates has been reduced from that of previous models.

Prior to performing some preliminary testing with the new cohesiometer several machine characteristics were noted and considered in the testing procedure. These are listed and discussed as follows:

1. On the specimen deck of the cohesiometer a circle 4 inches in diameter was inscribed for aid in centering 4-inch diameter test specimens.

2. Specifications for the cohesiometer required that the gap variability between the specimen clamping plates be restricted to close tolerances.

3. The manufacturer's recommended torque of 25 in-lb for securing the specimen was found to be excessive for asphaltic concrete specimens. The maximum torque used was 20-in-lb, and, in some instances, lower torque values were found to be necessary to avoid damaging test specimens.

4. The fixed location of the thermometer for determining cabinet temperature is not considered to be proper. Generally, during usage the test temperature is reached sooner at the elevation of the fixed thermometer than at the elevation of the test specimen. For this reason it was necessary to place a thermometer on the fixed-side clamping plate as shown in Figure 1 for determining and controlling the test temperature.

5. The present design of the cohesiometer utilizes a cam for supporting the loaded end of the cohesiometer beam. The beam deflection recorder responds to the bending of the beam due to its own weight when the end cam support is released. Future designs should eliminate this type of deflection from the load-deflection graph. A typical curve is shown in Figure 2.

6. Personnel opinion indicates a preference for sturdier or more rigid construction of the cohesiometer.

As mentioned previously the cohesiometer test was developed by the California Highway Department. The available literature on this test is limited to procedure and to values obtained for different mixture studies. The common procedure calls for testing a specimen generally 4 inches in diameter, 2 to 2-1/2 inches high, at a temperature of 140° F. and using a rate of loading of 1800 grams per minute. The loading is stopped when the end of the beam deflects 1/2 inch. The load corresponding to the 1/2 inch deflection is corrected for specimen height to obtain the cohesiometer value.

The asphaltic mixture characteristic evaluated by the cohesiometer may be related to flexural strength of the material and it is generally recognized that information on this property of asphaltic concrete is required for mixture design and evaluation. Use of the cohesiometer under existing procedure has shown that for normal asphaltic concrete there is no visual evidence of failure of the specimen and that the available height correction factors are not adequate for thin specimens. An objective of this study was to determine a method for transforming the test value of specimens of different heights to that value of a specified height.

Because of the lack of information on the theory originally hypothesized for the response of the cohesiometer to test conditions, an hypothesis was stated for the present study and a model equation for cohesiometer response was obtained for verification. The hypothesis is based on the flexural nature of the test. The test conditions of a test specimen are illustrated and defined in Figure 3. It can be seen that the external moment due to W is given by Equation 1, where c is the rate of loading in gm/sec and t is the period of loading in seconds. The resistance to the external moment comes from the material in the wedge OAB and is taken to be some function of the original wedge dimensions (H, m, w), of some parameter K representing all properties of the material, and also of the instantaneous angular velocity $d\theta/dt$ at which the deformation occurs in order to account for rate of loading effects. This resistance is represented by Equation 2.

As a first approximation it is assumed that the resisting moment is directly proportional to the instantaneous angular velocity and that dimensions m and w (w=4") will not be varied for the present; also the length a (a=30") will be a constant. Under the above conditions Equation 2 is written in the form of Equation 3. Neglecting the momentum of moving parts, the external and resisting moments are equated in Equation 4.

Separation of variables (Equation 4a) and integration yields Equation 5. Substitution of y/a for $\sin\theta$ and W/c for t results in Equation 6, which can then be written in the form of Equation 7 by changing the base of the logarithm and collecting terms. Equation 7 indicates that its graph on coordinates of $\log \frac{a+y}{a-y}$ vs W^2 should be a straight line of slope A. Preliminary test data have shown the initial portion of this graph to be a straight line (see Figure 4) and thus it is indicated that there is agreement between the test data and the model equation presented. In Figure 4 the deflection value y is used instead of log $\frac{(a + y)}{(a - y)}$ to simplify the plotting operation and yet still show the general shape of the graph for the Equation 7. It can be shown that for the values of y considered, a practical linear relationship exists between log $\frac{(30 + y)}{(30 - y)}$ and y. Failure of the model and of the specimen is assumed to occur when the plotted data cease to lie on the initial straight line of the graph. It is interesting to note that the apparent failure of specimens represented in Figure 4 is occurring at a deflection of 0.25 inch (compare with original procedure in which 0.50 inch deflection is the failure criterion).

Preliminary testing with the cohesiometer was done on specimens of three different heights and at three different rates of loading. A regression analysis of these data indicated a reliable relationship ($r^2 = 0.915$) between the logarithm of specimen height (H) and the logarithm of the product of the slope of the straight line of the proposed model (A) and the rate of loading (c), that is, $\log (cA) = \log a_o - b \log H$ (See Appendix A). This relationship suggests Equations 8 to 10 and Equation 10 is taken as the basic equation for representing a specimen's strength in terms of mixture characteristics ($\log a_o$) and specimen height (H).

The preliminary work discussed above was done on specimens made from an actual construction paving mixture in which component variables could not be controlled.

In planning the experiments for evaluation of the cohesiometer, it was deemed desirable to investigate the effects of the following factors which are believed to exist and influence the performance of asphaltic concrete surfacings:

1. Aggregate gradation

   a. dense graded
   b. gap graded

2. Aggregate surface texture (of -#8 sieve size in which 100 percent passes 1/2" sieve).

   a. rough
   b. smooth

3. Asphalt content (80-100 penetration)

4. Specimens

   a. height
   b. density

The basic aggregate blends are identified as Combinations 1, 2, 3 or 4 and are described as follows:

(a) Combination No. 1 - dense graded and rough surface texture
(b) Combination No. 2 - gap graded and rough surface texture
(c) Combination No. 3 - dense graded and smooth surface texture
(d) Combination No. 4 - gap graded and smooth surface texture

The coarse textured aggregate blends were obtained by combining a rounded gravel and a hard limestone screening. The limestone screening furnished most of the minus #8 size particles.

The smooth textured aggregate blends were made by blending the same gravel as in the previous aggregate mixture, concrete sand and field sand. In order to facilitate the duplication of gradations for both rough and smooth textured aggregates, it was thought that the use of the gravel for the plus #8 size for all combinations would not greatly minimize the surface texture effect on test values. Table 1 shows the gradations of the various blends obtained by computation for blending the different aggreates, and Figure 5 shows graphically the size distribution obtained after actual blending for the dense and gap graded combinations of rough textured aggregates.

Evaluation of the different asphalt aggregate combinations was made according to the Texas Highway Department method in which specimens are formed by gyratory shear compaction. The results of these tests are presented in Table 2. The cohesiometer values were obtained by the original method of testing. All asphaltic mixtures contained an 85-100 penetration grade asphalt which met the state's specifications.

Experimental Work

Three experiments were set up for studying the response of the new cohesiometer to the different variables considered.

The first experiment involved primarily the effects of temperature on the strength of test specimens. The variables in this testing program were as follows:

(a) Temperature - 74°, 90°, 105°, 120° and 140° F.
(b) Asphalt Content - 5.0 and 5.5 percent and
(c) Specimen height - 1.5 and 2.0 inches.

For these specimens, aggregate Combination No. 1 was used, and the rate of loading with the cohesiometer was the standard rate of 30 grams per second. Results of test and analyses of data are shown in Appendix B.

The next experiment performed included the following variables:

(a) aggregates - 4 combinations
(b) asphalt content - 4.5, 5.0 and 5.5 percent and
(c) compactive effort - 3 levels.

In view of the background experience had with the cohesiometer test and study of the first experiment, testing conditions were standardized to a test temperature of 140° F. and a loading rate of 30 grams per second. Data from this series of testing may be found in Appendix C.

The objective of the last experiment was to determine a relationship between a value representing the strength of a specimen and the height of the test sample. The establishment of this relationship is necessary to allow comparison of cohesiometer values for different mixtures. Since it was believed that one curve of the above variables of strength and height would not satisfy the needs, the following variables were incorporated into Experiment 3:

(a) specimen height - 1.50, 1.75, 2.00 and 2.25 inches
(b) compactive effort - 2 levels
(c) asphalt content - 2 levels
(d) aggregate - Combinations 1, 2, 3 and 4

In effect these variables represented sixteen different pavement mixtures with differences other than thickness. The results obtained from the testing for this experiment are shown in Appendix D.

Discussion of Results

It has previously been mentioned that the basic strength equation for the cohesiometer test is represented by Equation 10. It is apparent that the term $\underline{cA}$ can be simplified by the elimination of $\underline{c}$ if a standard rate of loading is specified for the test. Also, from Figure 4 it appears that the load at the end of the straight line portion (representing failure of a specimen) might be correlated with the slope of that line and this suggests the direct use of the failure load instead of the slope of the line in Equation 10. Figure 6 shows that a correlation between failure load W_f and slope A does exist; that is, that specimens having different failure loads are not likely to have the same value for slope A. The constants of the equation $W_f \cong \frac{8000}{A'^{0.600}}$ shown in Figure 6 were determined directly from the graph and do not represent "best-fit" values. The term c is kept in Equation 10 for flexibility, should variations in loading rate be desired in future work. For the present value of slope A instead of failure load W_f will be used since the evaluation of A is felt to be more exact than establishing the location of the end of the straight line portion of curves such as shown in Figure 4. However, it is possible that testing variations may be larger than differences obtained in the use of A or W_f in Equation 10.

The results obtained in the preliminary testing with the cohesiometer are presented in Appendix A. These data have indicated the following relationship,

$$\log (cA \times 10^8) = 3.349 - 4.473 \log H$$

where,

A = the slope of the initial straight line portion of a

$$\log \frac{(30 + y)}{(30 - y)} \text{ vs } W^2 \text{ plot,}$$

y = the deflection in inches at the end of the cohesiometer beam corresponding to load W in grams,

c = the rate of loading in gram/second, and

H = the height of specimen in inches.

As shown, the correlation coefficient, r^2, had a value of 0.915.

The basic data for Experiment No. 1 are shown in Appendix B. For ease in tabulating and use, the symbol A' has been substituted for $30 \times A \times 10^8$. The analysis of variance for these data shows that (a) temperature, (b) specimen height, (c) interaction between asphalt content with height, and (d) interaction between asphalt content with temperature, all had significant effects on the cohesiometer response represented by the value of A'. The lack of significant effect by asphalt content alone can be explained as follows. In regular testing with the cohesiometer, it has been observed that the strength of specimens increases as asphalt content increases but only to an optimum amount of asphalt. Increasing the amount of asphalt above such an optimum value results in a decrease of cohesiometer value. Further, for most asphaltic concrete specimens containing asphalt near the optimum amount, the cohesiometer value is not affected to a significant extent by slight variations of asphalt content. This behavior is illustrated by the cohesiometer values presented in Table 2.

As mentioned above in discussing Experiment No. 1, the effect of temperature was significant; however, a limited study of the comparison between A' and temperature did not show a distinct discontinuity near the softening point temperature of 115° F. for the asphalt used. Also a study of the standard deviations for the different A' values did not indicate differences within these values that could be attributed to test temperatures. Perhaps a more meaningful way of expressing the variations of values is by the coefficient of variation which is the standard deviation divided by the mean value and usually expressed in terms of percent. The coefficients of variation for A' of specimens 2.00 inches high and containing 5.0 and 5.5 percent asphalt averaged 11.7 and 8.5 respectively for the test temperature range from 74° F. to 140° F.; these values for the temperature of 140° F. were 11.4 and 8.7. For the above reasons and because of experience in this area of testing, a temperature of 140° F. was chosen for a standard test.

In Experiment No. 2 the variables considered were aggregate, asphalt content, and compactive effort.

The standard THD method of asphaltic concrete laboratory compaction requires that gyratory-shear be imparted to the mixture until a particular strength of mixture or "end point" is obtained. The end point is reached when one stroke of the standard jack handle raises the ram pressure to 100 psi. In order to achieve a variation in density for different compacted mixtures, the molding procedure was modified in that 50 psi and also 200 psi were set as end points.

Appendix C shows the values of A' obtained in this program. It can be seen that the range of compactive effort used caused significant changes in strength as indicated by A' for all mixtures. A review of Figures 4 and 6 will show that a high value of A' is associated with a weak specimen. These data show that an increase in compactive effort may either increase or decrease the value of A' depending upon the amount of asphalt and the aggregate combination contained in the specimen.

The use of compactive effort for showing the above effects may be questioned by those who would prefer to make the comparison on the basis of void content or asphalt film thickness; however, the density variations were not made to establish a design criterion but to study the cohesiometer's response to changes in density.

The data also show that the aggregate combinations employed affected the results of the test. The dense graded mixtures were generally stronger than the gap graded ones but were more susceptive to decrease in strength at the higher asphalt content with an increase of compactive effort. The use of coarse textured aggregate resulted in specimens that were stronger than those containing smooth textured aggregate. However, a combination of gradation and texture can be found such that a well graded smooth textured aggregated mixture (Combination 3 - 4.5% asphalt - 200 psi end point) can be stronger than a gap graded rough textured aggregate mixture (Combination 2 - 4.5% asphalt - 50 psi end point).

The ultimate desire of the research was to establish a means by which different asphaltic concrete surfacing materials can be compared in terms of some characteristic parameter. Since asphaltic surfacings are of different thicknesses, the method established should evaluate the mixture's characteristic parameter in relation to thickness. And further, since all asphaltic pavements are not made from the same materials, this same method of evaluation should be responsive to differences in mixtures. These considerations were the basis for choosing the variables of Experiment No. 3. It is recognized that compositional variations of the specimens tested were not as great as those found in actual pavements; however, the strength variations created by changes in thickness, asphalt content, and density are considered to be as great as those found in practice.

The results of evaluations from Experiment No. 3 are tabulated in Appendix D.

The molding of mixtures by the Texas Highway Department's method resulted in a simple procedure for obtaining specimens of different height but with equal density. An examination of the slopes (b) obtained from a regression analysis of $\log A' = \log a_o + b \log H$ shows a range of values from -2.6 to -4.2. These extreme values of $\underline{b}$ occur for mixtures that are comparable in strength characteristics and do not represent extremes of strength. A plot of $\log A'$ vs $\log H$ for the sixteen sets of specimens showed that variations in the slope, $\underline{b}$, were not correlated with any of the variables studied, nor with strength. Thus, a constant slope was suggested by the data in this experiment and was obtained by averaging the 16 values of $\underline{b}$. The average value of $\underline{b}$ was -3.658. The standard deviation of individual values of $\underline{b}$ about their average was 0.725.

The transformation of a cohesiometer test value (A') for a specimen of a specific height to a standard height specimen can be done by utilizing the chart of Figure 7.

Figure 7 has logarithmic coordinates of value $\underline{A'}$ and $\underline{H}$. Also shown is an axis labeled $\underline{W_f}$ in which the value corresponds to the failure load located at the end of the straight line portion of the y-W^2 plot (see Figure 4). In addition these are data points for different mixtures. It is of interest to note that although the data from Experiment No. 1 were not used to establish the slope of the guide lines, the two bottom sets do appear to follow the trend presented. The use of this chart will be explained on the basis of entering into it with values of $\underline{H}$ and $\underline{A'}$ and assuming that a standard height H is chosen to be 2.00 inches. As an example, suppose that a specimen 4 inches in diameter and 1.40 inches high yields a test value for $\underline{A'}$ equal to 200. In order to determine the strength of a standard specimen (H = 2.00) of such a mixture, locate on the chart a point described by the two given coordinates. Next, from this point follow parallel to the guide lines and intersect the vertical line representing H = 2.00 inches. The ordinate, $A' = 60$, of this junction point then indicates the strength as represented by $\underline{A'}$ of a standard specimen.

A similar description for height-correction can be made for use of the failure load $\underline{W_f}$.

Summary and Conclusions

The prime objective of this study was to evaluate the cohesiometer test for use in project HPS-1(27)E and secondarily to modify the equipment or procedure to achieve the above objective. In summary, it has been found that the modified cohesiometer test as described herein yields results that are affected by variables found in asphaltic concrete and which are believed to affect the performance on such pavements. Modifications to the cohesiometer test involved the following items:

1. A load-deflection recorder was attached to the apparatus to obtain a record of beam deflections and corresponding loads during a test.
2. A 4-inch diameter circle was inscribed on the specimen deck to aid in centering a test specimen.
3. The specimen clamping plates were modified to minimize the variability of gap opening.
4. The torque applied to secure a specimen was limited to 20 in-lb; however, in some instances this value was reduced to as much as 10 in-lb in order to prevent damaging a test specimen.
5. The free end of the cohesiometer beam was allowed to deflect 1-1/2 inches.

A study of the mechanics of the cohesiometer test led to the derivation of a model equation for defining the cohesiometer's response. Another equation as shown below was found to be suitable for establishing a height-correction chart for reducing test values to strengths of specimens of a standard height:

$$\log A' = \log a_o - 3.658 \log H$$

The symbols are those described in the text of the report.

It is not the intention of this report to set the standard specimen height as 2.00 inches in the evaluation of pavement surfacing to be tested for the parent project entitled "Application of AASHO Road Test Results to Texas Conditions." It is believed that the standard height for pavement samples should be set in consideration of the average thickness of road samples to be tested and the average height of specimens used in this study.

A description of the cohesiometer test procedure used in this study is attached as Appendix E.

Acknowledgement

The research presented in this report was done under sponsorship of the Texas Highway Department and the Bureau of Public Roads. Most of the statistical analysis was done under the guidance of Dr. Donald E. Cleveland of the Texas Transportation Institute. The basic model equation proposed for the cohesiometer test response was derived by Frank Scrivner of the Texas Transportation Institute.

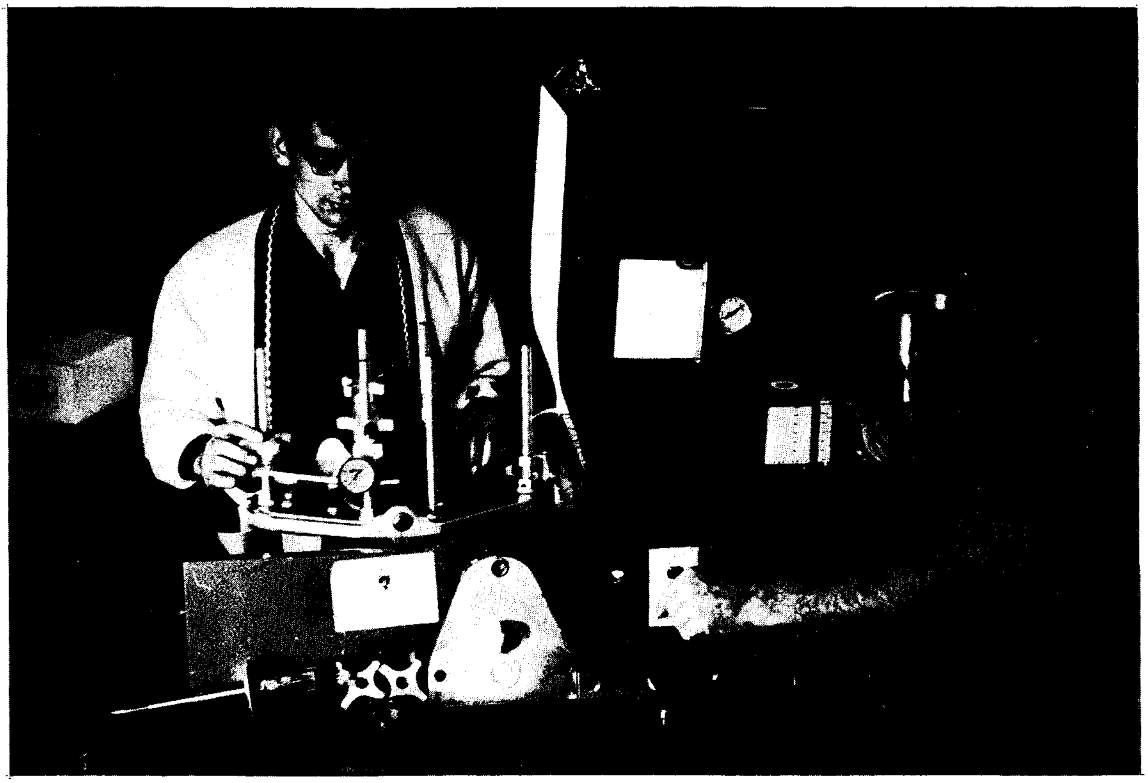


Figure 1. Photograph of cohesiometer.

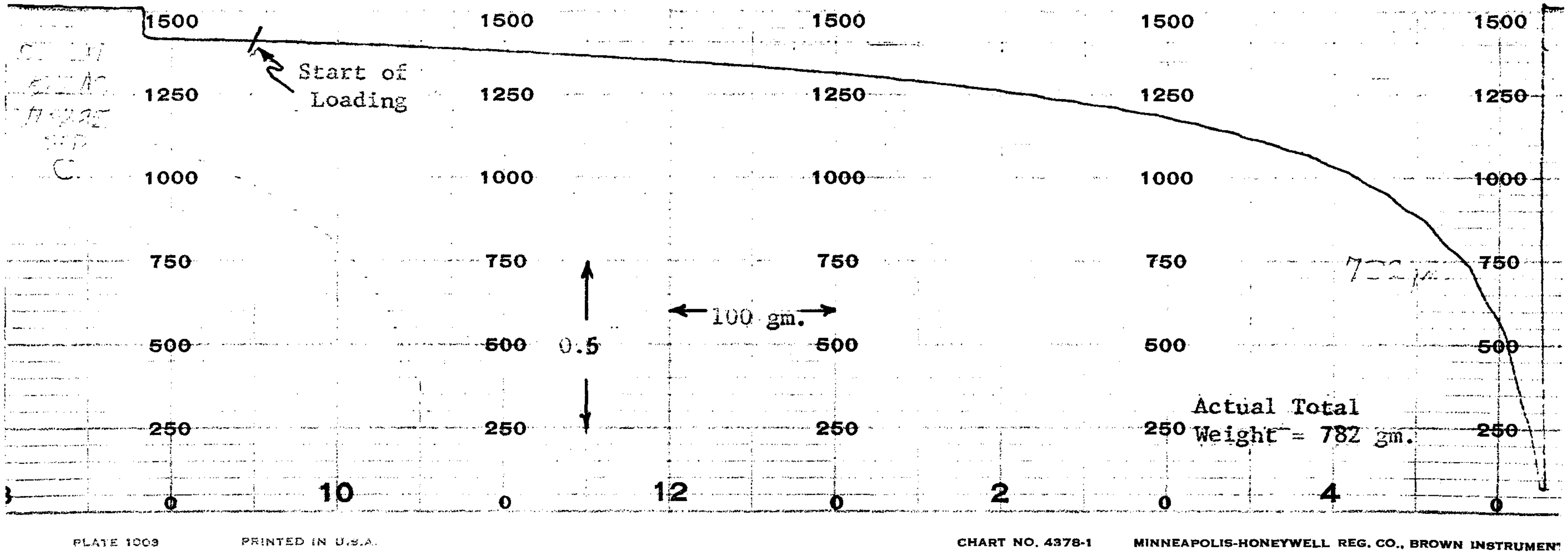
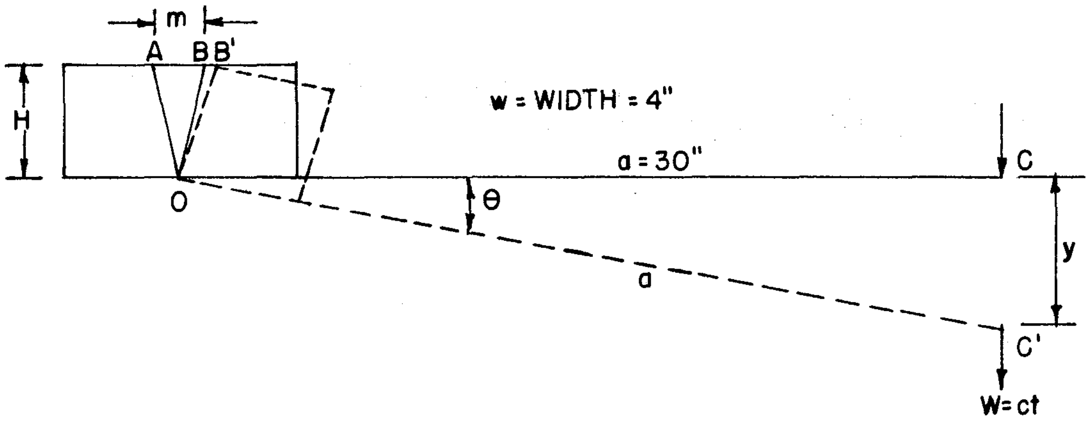


Figure 2. Typical Load-deflection curve from cohesiometer test.



$$M_W = act\cos\theta \tag{1}$$

$$M_r = f(H,m,w,K,d\theta/dt) \tag{2}$$

$$M_r = f(H,K)\,d\theta/dt \tag{3}$$

$$M_W = M_r;\quad act\cos\theta = f(H,K)\,d\theta/dt \tag{4}$$

$$\frac{d\theta}{\cos\theta} = \frac{act\,dt}{f(H,K)} \tag{4a}$$

$$\ln\frac{(1+\sin\theta)}{(1-\sin\theta)} = \frac{act^2}{f(H,K)} \qquad (\ln = \text{Log}_e) \tag{5}$$

Substituting $\frac{y}{a}$ for $\sin\theta$ and $\frac{W}{c}$ for t

$$\ln\frac{(a+y)}{(a-y)} = \frac{a\,W^2}{cf(H,K)} \tag{6}$$

$$\ln\frac{(a+y)}{(a-y)} = AW^2 \qquad ;\ A = \frac{na}{cf(H,K)} \tag{7}$$

Since na is a constant and from equation 7

$$cA = F(H,K) \tag{8}$$

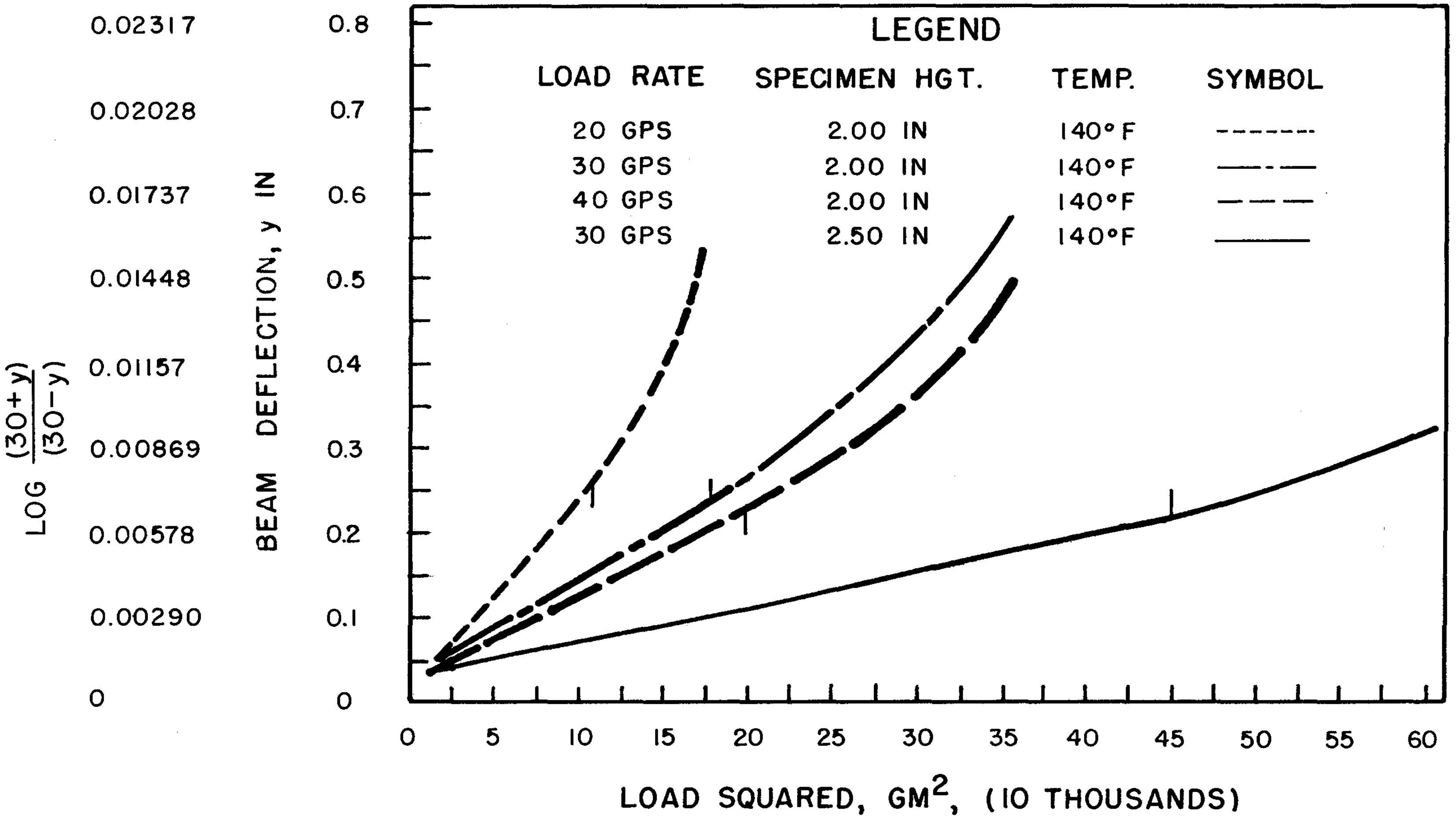
$$cA = H^b f(K);\ (\text{assuming } F(H,K) = H^b f(K))$$

or

$$\text{Log}(cA) = \text{Log} f(K) + b\,\text{Log} H \tag{9}$$

$$\text{Log}(cA) = \text{Log}\, a_0 + b\,\text{Log}\, H \tag{10}$$

Figure 3.



LOAD-DEFLECTION RELATIONSHIP FOR COHESIOMETER TEST

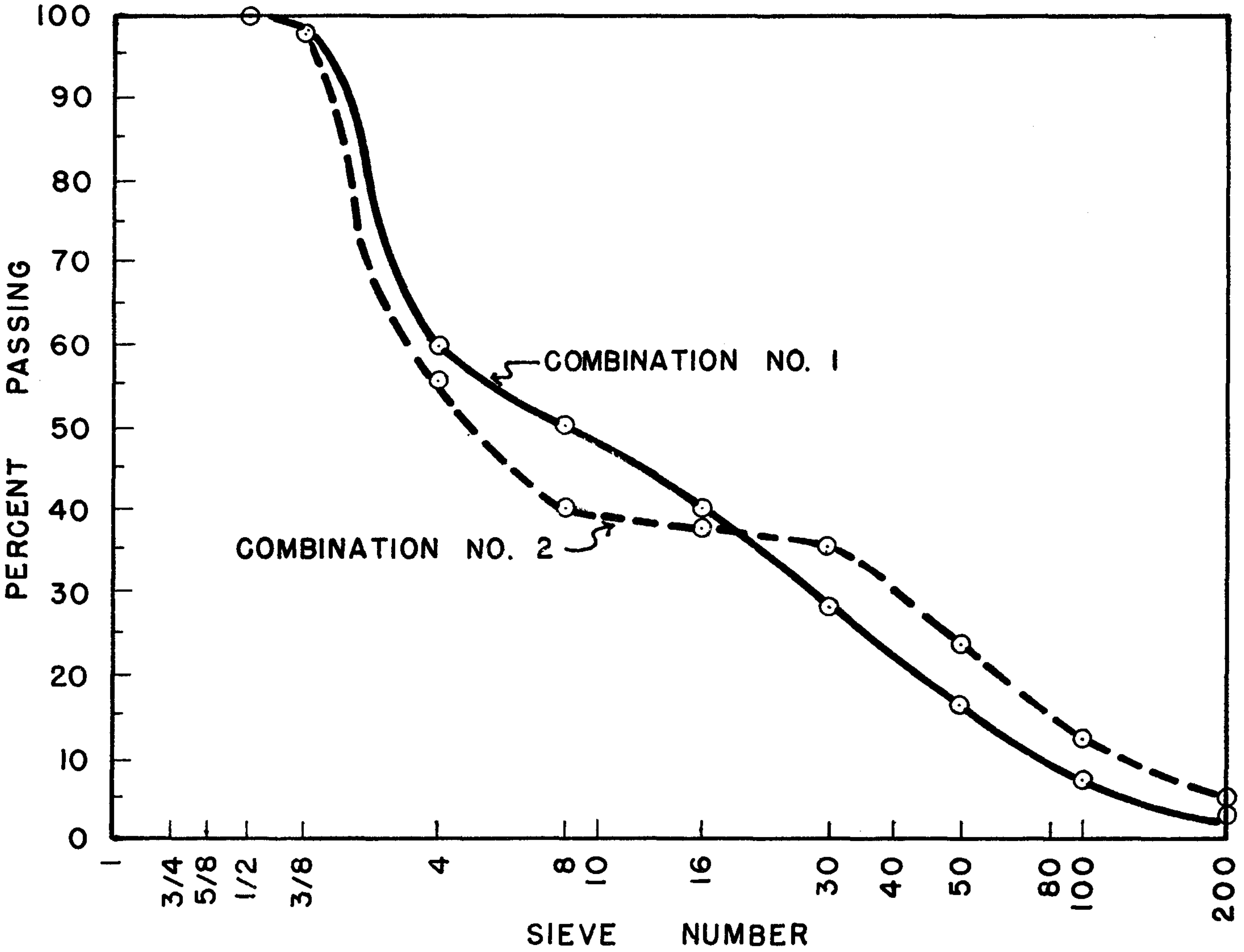
Figure 4.

TABLE 1

Gradation for Aggregate Blends

Percent Passing

Sieve Size	Comb. No. 1	Comb. No. 2	Comb. No. 3	Comb. No. 4
1/2	100.0	100.0	100.0	100.0
3/8	98.4	98.0	98.4	98.0
4	65.3	58.0	65.3	58.0
8	50.0	40.0	50.0	40.0
10	47.5	38.2	47.3	38.6
16	40.0	38.0	38.8	37.7
30	25.0	35.0	25.0	35.0
40	20.0	28.5	20.4	29.0
50	14.4	20.0	17.0	20.7
80	11.0	12.0	12.0	12.3
100	9.5	10.5	10.4	10.9
200	3.5	5.0	3.2	3.3



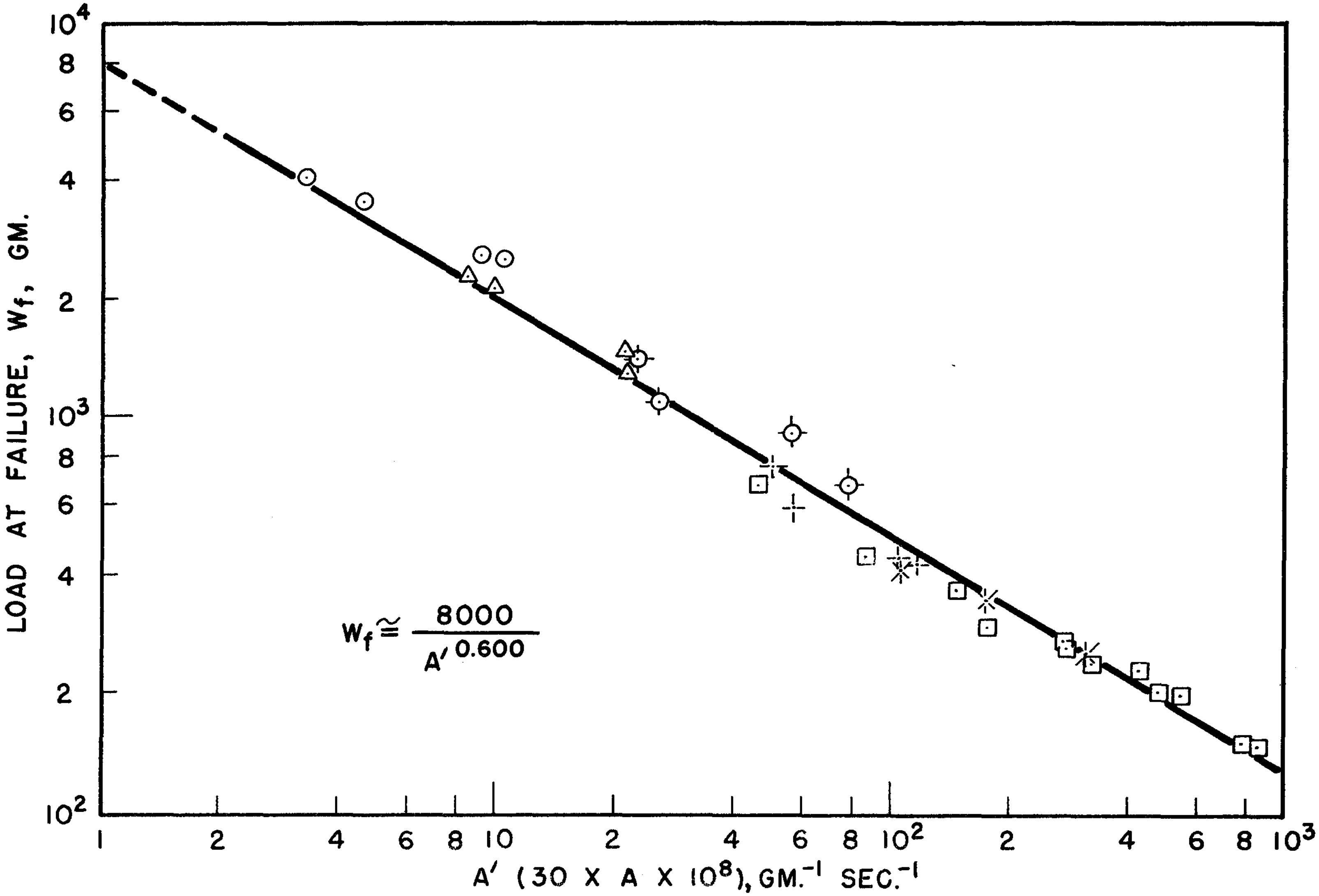
GRADATION CURVES

Figure 5.

TABLE 2

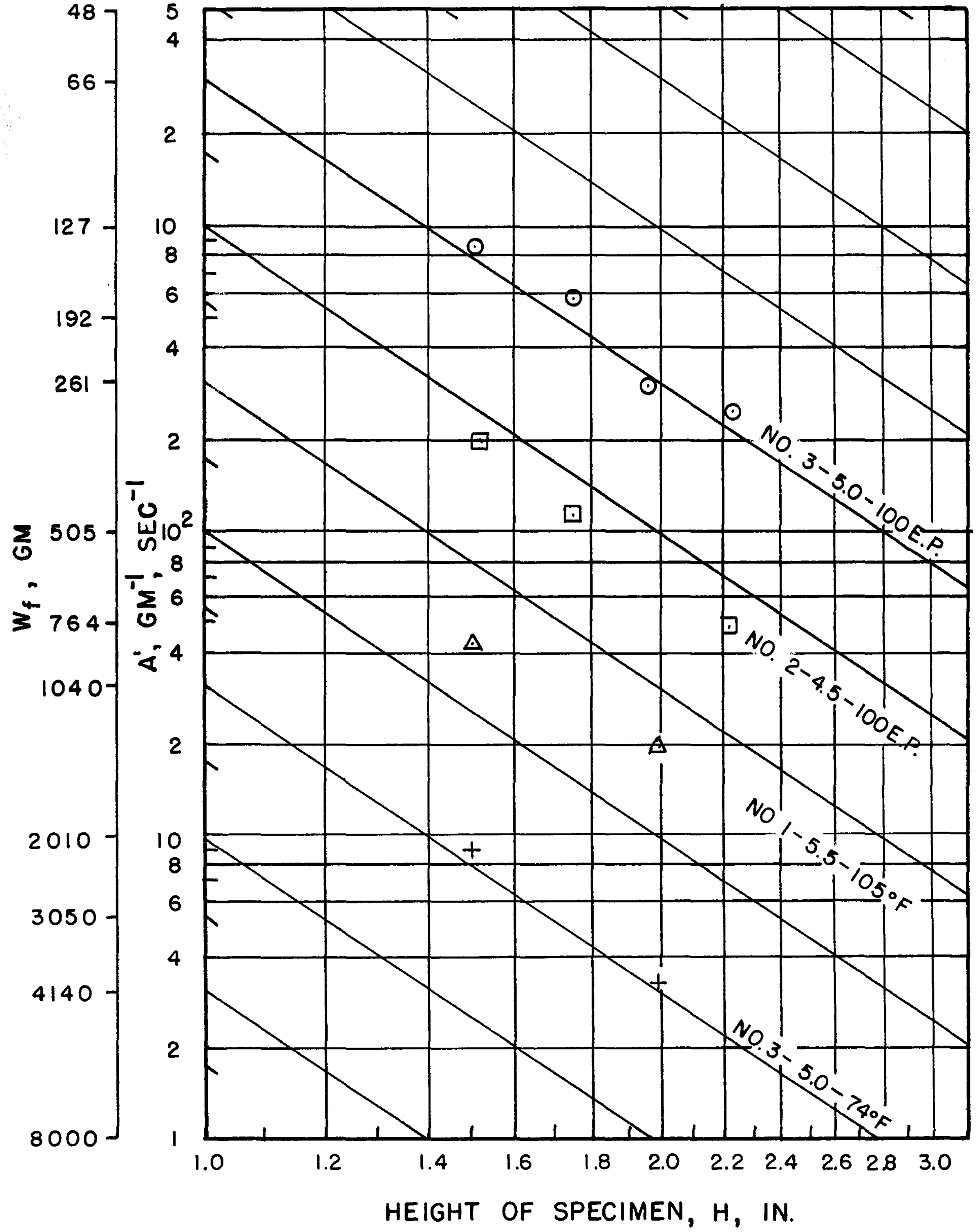
Design Characteristics of Asphaltic Concrete Mixtures with OA-90 Asphalt

Asphalt Content %	Air Content %	Hveem Stability %	Cohesiometer Value gm/in. width/3" height
		Combination No. 1	
4.5%	5.6	61	212
5.0%	3.4	51	293
5.5%	2.5	40	303
		Combination No. 2	
4.5%	6.4	57	177
5.0%	4.3	51	249
5.5%	3.5	33	254
		Combination No. 3	
4.25	4.2	44	127
4.5	3.8	43	150
4.75	3.3	35	114
		Combination No. 4	
4.6	4.7	36	103
4.85	3.5	38	133
5.10	2.9	38	157



RELATIONSHIP BETWEEN LOAD AT FAILURE, W_f, AND A′

Figure 6.



COHESIOMETER HEIGHT CORRECTION CHART

Figure 7.

APPENDICES

APPENDIX A

Results of Preliminary Testing With the Cohesiometer of a Construction Mixture. Test Temperature of 140° F.

Specimen Height H, in.	Rate of Loading c, gm/sec.	Slope $A \times 10^8$ gm^{-2}
1.5	20	24.2 11.7 26.6
1.5	30	13.8 10.5 8.99
1.5	40	7.64 9.09 9.35
2.0	20	5.06 6.38 5.88
2.0	30	2.90 4.56 3.24
2.0	40	2.78 1.44 4.41
2.5	20	1.55 2.16 1.19
2.5	30	0.73 1.54 1.29
2.5	40	1.13 1.12

$$\log (cA \times 10^8) = 3.349 - 4.473 \log H$$

$$r^2 = 0.915$$

APPENDIX B

Values of A' Obtained from Testing in Experiment No. 1- Rate of Loading of 30 gm/sec. $A' = 30 \times A \times 10^8$ gm^{-1} sec^{-1}

	5.0% A.C.		5.5% A. C.	
Temp. °F	1.5 in.	2.0 in.	1.5 in.	2.0 in.
	12.24	2.94	9.63	5.16
74	7.95	3.87	11.37	4.26
	7.26	3.00	10.38	4.53
	20.13	8.64	20.37	9.39
90	20.70	8.79	22.35	9.84
	23.82	8.58	20.28	10.56
	78.00	25.41	48.90	24.87
105	69.00	27.54	64.80	20.94
	87.00	24.06	55.50	22.56
	126.3	49.20	75.30	52.20
120	109.8	57.30	109.2	53.40
	110.4	64.20	130.8	44.40
	223.2	89.70	173.1	104.1
140	309.0	105.0	192.0	123.9
	399.6	112.8	158.1	116.1

APPENDIX B (Cont'd)

Analysis of Variance for Coded Data (1)
Experiment No. 1

Source of Variation	d.f.	Sum of Squares	Mean Square	Variance Ratio
Percent Asphalt, P	1	7,194.15	7,194.15	1.82
Height of Specimen, H	1	2,008,242.15	2,008,242.15	507.91 ***
Temperature, T	4	15,265,164.77	3,816,291.19	965.18 ***
P × H	1	42,400.42	42,400.42	10.72 **
P × T	4	96,064.10	24,016.03	6.07 ***
H × T	4	31,449.10	7,862.28	1.99
P × H × T	4	36,022.49	9,005.62	2.28
Error	39	154,204.67	3,953.97	
Lost Observation	1			
Total	59	17,640,696.85		

Est. Variance = 3953.97 = .00395397

σ = .06288

---

(1) Coded Data = (log 30 × A × 10^8) 1000 - 400

*** Significant at .1% level

** Significant at 1% level

APPENDIX C

Values of A' Obtained From Testing in Experiment No. 2
Test Temperature of 140° F., Rate of Loading of 30 gms/sec., and Height = 2.00 in.
$A' = 30 \times A \times 10^8$ gm^{-1} sec^{-1}

Compactive Effort	E. P. 50			E. P. 100			E. P. 200		
Asphalt Content, %	4.5	5.0	5.5	4.5	5.0	5.5	4.5	5.0	5.5
Aggregate Combination									
	239	200	77	120	90	104	98	86	82
No. 1	253	150	87	134	105	124	114	73	78
	333	161	98	103	113	116	117	97	120
	291	195	155	259	164	155	171	118	132
No. 2	420	204	127	280	151	211	160	76	92
	396	217	147	234	107	149	172	97	125
	666	336	306	---	336	402	266	315	387
No. 3	867	669	303	747	280	420	315	315	494
	624	315	354	600	308	504	290	321	526
	1245	489	336	672	381	345	912	370	339
No. 4	442	342	336	872	687	366	1050	277	453
	1026	570	306	---	513	546	645	479	432

APPENDIX D

Values of Height, H, and A' Obtained From Testing in Experiment No. 3
Test Temperature of 140° F and Rate of Loading of 30 gm/sec.
$A' = 30 \times A \times 10^8\ gm^{-1}\ sec^{-1}$
Statistical Data Based on $\log A' = \log a_o + b \log H$

Combination 1

E. P. 50				E. P. 100			
4.5% AC		5.0% AC		4.5% AC		5.0% AC	
H, in.	A'	H, in.	A'	H, in.	A'	H, in.	A'
1.57	645	1.55	834	1.49	134	1.51	223
	858		834		140		309
	1008		650		146		400
1.81	693	1.75	200	1.75	100	1.74	134
	495		230		100		191
	588		220		102		130
2.01	239	2.01	209	1.97	121	1.96	90
	253		150		134		105
	333		161		103		113
2.25	348	2.25	129	2.21	31	2.21	57
	180		258		37		59
	182		122		37		59
b = -3.906		b = -3.940		b = -4.532		b = -4.233	
r^2 = 0.937		r^2 = 0.759		r^2 = 0.842		r^2 = 0.993	

Combination 2

1.54	810	1.54	594	1.52	237	1.51	174
	830		792		172		200
	822		498		214		207
1.79	327	1.81	439	1.75	103	1.73	174
	514		432		110		124
	420		423		126		172
2.02	291	2.01	195	1.99	259	1.98	163
	420		204		280		151
	396		217		234		107

E. P. 50				E. P. 100			
4.5% AC		5.0% AC		4.5% AC		5.0% AC	
H, in.	A'	H, in.	A'	H, in.	A'	H, in.	A'
2.26	426	2.22	148	2.22	54	2.22	56
	220		146		40		50
	258		150		44		46
b =	-2.620	b =	-4.120	b =	-3.949	b =	-3.142
r^2 =	0.916	r^2 =	0.951	r^2 =	0.994	r^2 =	0.771

Combination 3

1.55	2140	1.54	1410	1.53	1293	1.50	1293
	2200		1410		1500		537
	2100		1460		1245		933
1.79	1540	1.81	1300	1.79	468	1.75	498
	1528		1580		867		696
	1540		756		936		591
1.99	666	1.99	336	2.01	1200	1.96	336
	867		670		747		280
	625		315		600		308
2.24	360	2.22	177	2.28	379	2.23	205
	528		468		291		252
	730		220		---		312
b =	-4.109	b =	-4.932	b =	-3.131	b =	-3.320
r^2 =	0.952	r^2 =	0.882	r^2 =	0.842	r^2 =	0.954

Combination 4

1.54	1720	1.54	1850	1.53	1135	1.52	1310
	2500		1550		1320		1400
	2245		1720		1515		1470
1.79	1340	1.79	707	1.78	1092	1.78	758
	1340		1101		864		780
	1340		431		978		582
2.01	1245	2.01	490	1.98	672	1.98	381
	942		342		870		687
	1003		570		---		513
2.24	1420	2.23	342	2.27	420	2.26	357
	417		368		471		357
	657		378		504		513
b =	-2.604	b =	-4.228	b =	-2.623	b =	-3140
r^2 =	0.992	r^2 =	0.959	r^2 =	0.971	r^2 =	0.961

APPENDIX E

TEXAS TRANSPORTATION INSTITUTE PROCEDURE
FOR
TTI COHESIOMETER TEST OF
ASPHALTIC CONCRETE

The interpretation and analysis of this test were evolved from a study of the cohesiometer which was sponsored by the Texas Highway Department in cooperation with the Bureau of Public Roads.

The purpose of the cohesiometer test as described herein is to obtain a measure of tensile strength of asphaltic concrete.

The testing apparatus is a modified Hveem cohesiometer (Figure A) which has a load-deflection recorder. The cohesiometer must be in calibration with respect to the following:

1. Rate of loading. The present standard rate of loading is 30 grams per second.
2. Test temperature. The test temperature is to be determined and controlled within the cohesiometer cabinet at approximately the same elevation as that of the test specimen. The normal test temperature is 140° F. ± 2° F.
3. The cohesiometer and especially the specimen deck must be level.
4. The load-deflection recorder must be in adjustment. The recorder should indicate twice the deflection at the end of the load beam. The speed of the recorder tape should be 18 inches per minute, thus one inch of travel represents 100 grams for the standard rate of loading.
5. The loading beam, shot bucket, and clamping plates must be balanced so that loading of a test specimen is due only to the flow of No. 12 lead shots.

Test specimens may be either laboratory prepared samples or field samples. The top and bottom surfaces of a test specimen must be fairly smooth and parallel; the thickness generally will vary from about 1 inch to 2.5 inches and the width should be 4.00 inches; rectangular specimens should be at least 4.0 inches long. Measurements will be taken to determine the height, width, and density of a specimen. These are to be recorded in the data sheet, Figure B.

The test procedure is as follows:

1. Place test specimens in a 140° F. ± 2° F. oven for a minimum period of 3.5 hours prior to testing.

2. Center the specimen on the cohesiometer deck and adjust clamping plate supporting nuts so that the bottom surface of the clamping plates are on the plane determined by the upper surface of the test specimen. Tighten clamping plates with the torque wrench using from 10 to 20 inch-pounds to prevent slippage of the plates and yet not damage the specimen. The temperature of the cabinet prior to placing the test specimen should be 140° F. After securing the specimen and closing the cabinet, wait until the test temperature is reached before starting to load the specimen. On the tape of the recorder write the identifying marks of the test specimens.

3. Start the load-deflection recorder, then release the beam support cam, and then start the flow of lead shots. Mark the load-deflection trace at the time when the actual flow of shots started. This is necessary since the deflection of the beam due to loss of support from the cam will appear on the load-deflection curve. The flow of shots continues until the end of the beam deflects 1.5 inches; at this time a solenoid switch will close the outlet of flow and also stop the recorder. Return the load beam to its original position. Figure C shows a typical record.

4. Weigh the shots in the receiver and record this weight on both the recorder tape and data sheet.

5. Tabulate on the data sheet loads corresponding to at least 10 different values of deflection. The range of deflections values is generally from 0.05 inch to about 0.30 inch. This reduction is facilitated by means of a plastic overlay constructed in a form similar to that shown in Figure D. The zero load point of the trace is checked by use of the total weight of shots.

6. Plot corresponding load-deflection values on the chart of Figure E and draw by "eye" the best fitting straight line through the initial points that do establish a straight line. Then connect the other points with a curved line that connects smoothly with the initial straight line portion of the graph. In Figure E the load scale W is set by the W^2 scale, thus, if a change of scale is necessary in order to obtain a clearer plot of the data this is done preferably for the W^2 scale.

The use of y and W in Figure E is for convenience since the desired information is expressed in terms of W^2 and log

$$\frac{30 + y}{30 - y} .$$

7. From two extreme points on the straignt line of the curve, determine the slope, A, of the line.

$$A = \frac{\log\frac{(30 + y2)}{(30 - y2)} - \log\frac{(30 + y1)}{(30 - y1)}}{W_2^2 - W_1^2}$$

Also from the graph determine the value of W corresponding to the point of tangency between the initial straight line and the curved portion; this value is labeled W_f and represents the failure load.

8. Correct the test specimen value for height effect. It has been shown that a relationship exists between failure load W_f and slope A; however, corrections for specimen height will presently be made on the basis of A. The original mathematical model expressing the effects of loading rate, c, Height, H, on slope A is given as

$$\log (cA) = \log a_o - b \log H$$

Since this testing procedure has not been set as statewide standard, the present form of the model given above will be used for data reduction even though the rate of loading is a constant. To simplify height corrections, a value of A' is used so that $A' = 30 \times A \times 10^8$. Enter Figure F with the test specimen's values of A' and H, then extend this point parallel to the guide lines until the vertical line representing H = 2.00 is intersected. The value of A' at this junction is the corrected strength of the specimen. It has been assumed that the standard height of specimen is 2.00 inches. As yet this is not an accepted standard. Also the strength corrections have been made on the basis of a standard specimen width equal to 4.00 inches. Correction for width will be made in direct ratios of widths from the standard.

Figure E shows that W_f can be used to correct for specimen height; however, for the time being it is recommended that the use of W_f serve primarily as a check.

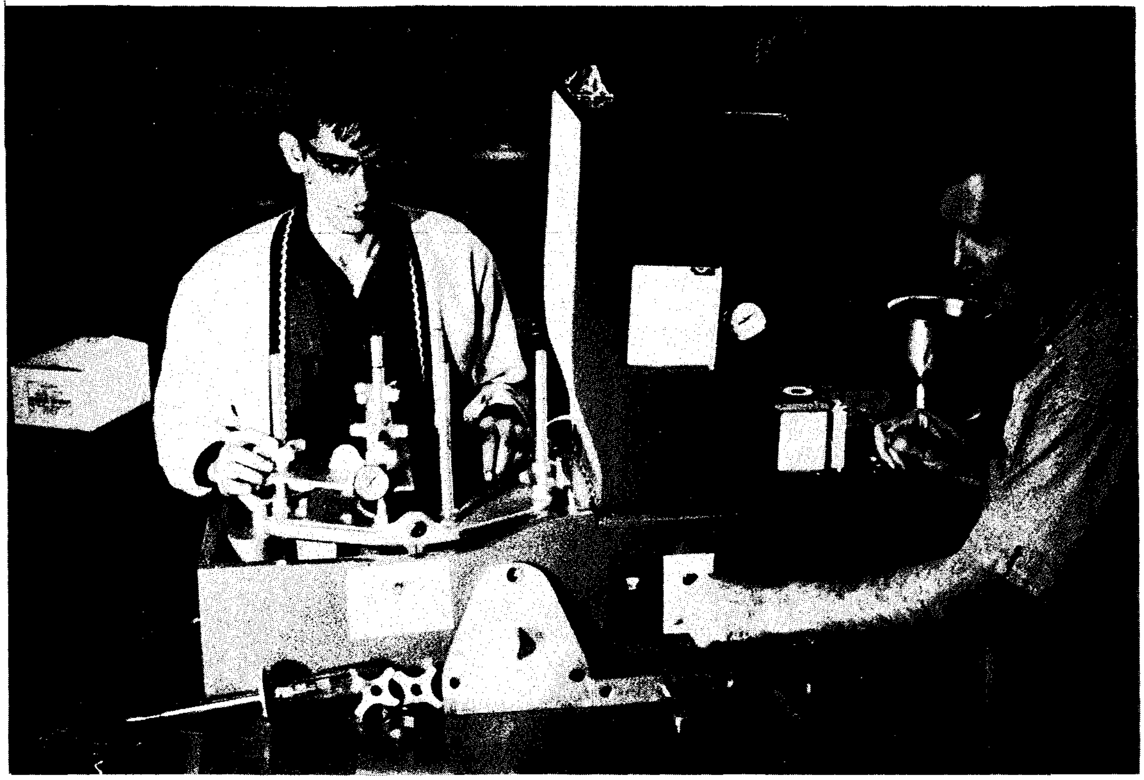


Figure A. Photograph of cohesiometer.

ASPHALTIC CONCRETE RESEARCH

COHESIOMETER EVALUATION

Project____________ Operator____________ Date____________

Material____________ Temp.________°F Rate of load____________gm/min

Remarks__________________________________

____

____

Sample Label	A	B	C	D	E	F
Wt. Sample in Air, gm.						
Wt. Sample in Water, gm.						
Wt. (SSD) Sample in Air, gm.						
Vol. of Sample, cc						
Sp. Gr.						
Sample, Height, in.						
	Test		Load			Gm.
Beam Deflection, in.						
1 0.05						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12 Max. Load						
Sample Load, gm. @ 0.50 in.						
Corr. Cohesiometer for Height						

Figure B

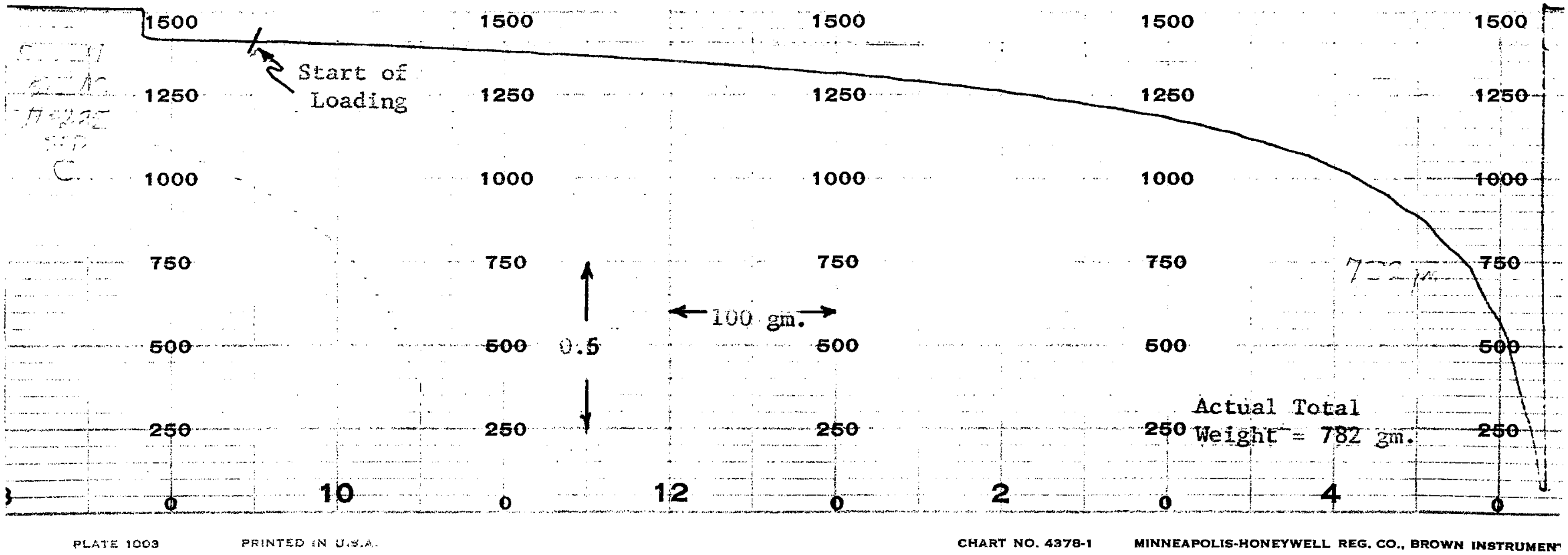
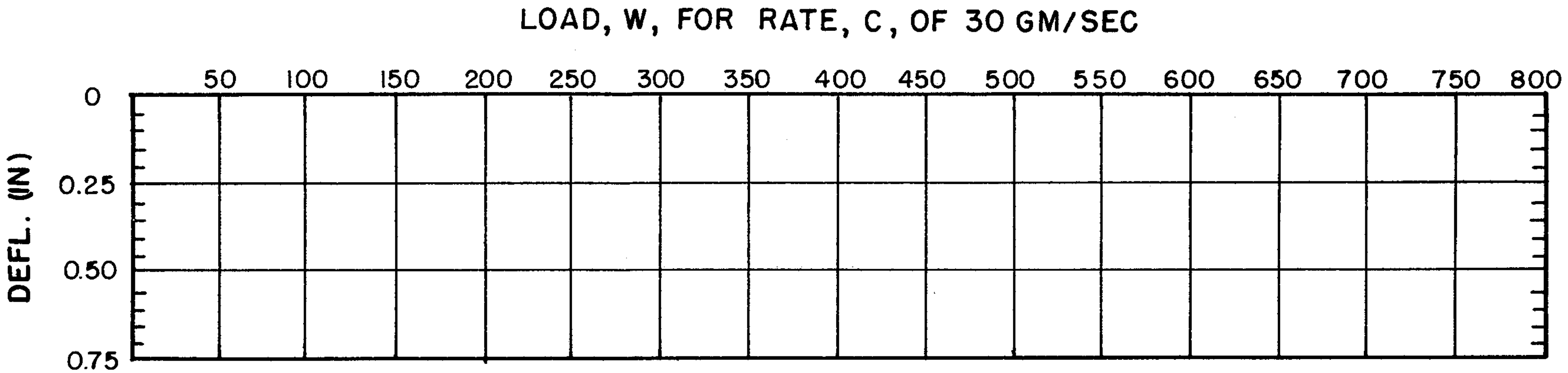
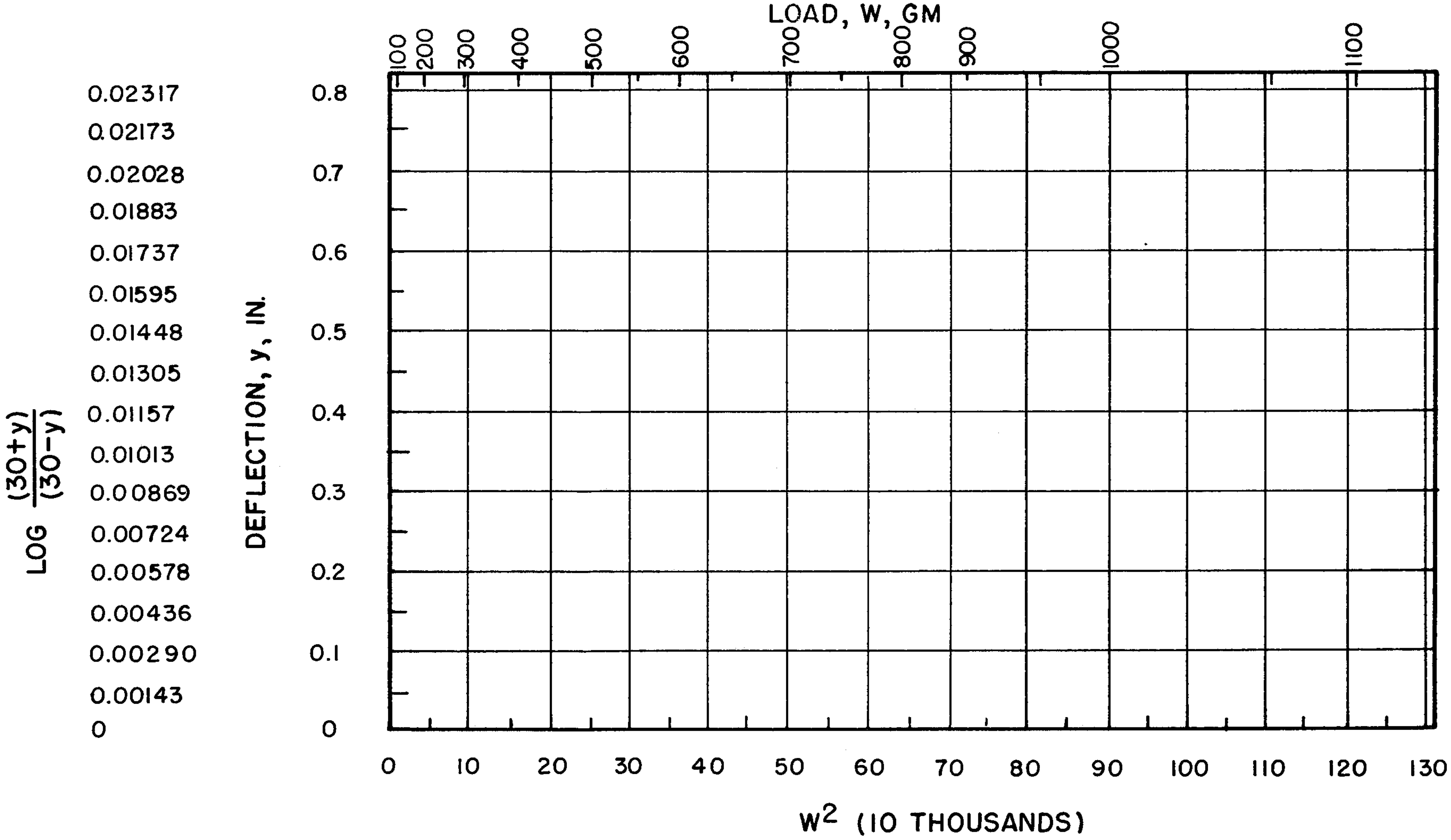


Figure C. Typical Load-deflection curve from cohesiometer test.



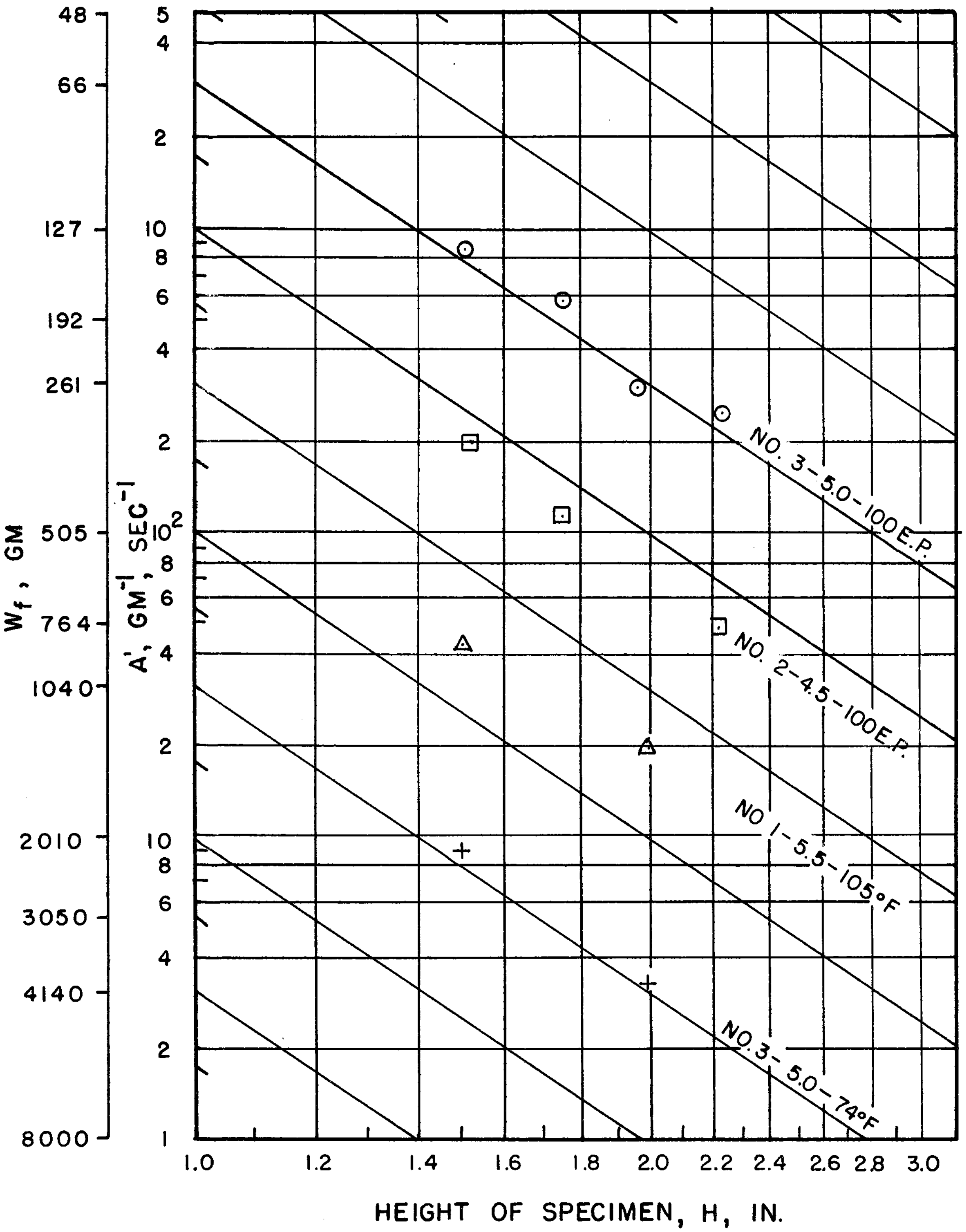
LOAD-DEFLECTION OVERLAY

Figure D.



BEAM DEFLECTION VS LOAD FOR COHESIOMETER TEST

Figure E.



COHESIOMETER HEIGHT CORRECTION CHART

Figure F.