U.S. Department of Agriculture
Soil Conservation Service
Engineering Division

Soil Mechanics Note No. 9

Permeability of Selected Clean Sands and Gravels

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PERMEABILITY OF SELECTED CLEAN SANDS AND GRAVELS

I. Purpose

This study was made at the Soil Mechanics Laboratory to determine the permeability characteristics of fifteen clean sands and gravels for use in design.

II. Symbols and Abbreviations

The symbols and abbreviations used in this paper conform to those in Soil Mechanics Note No. 6, Parts B and C. Definitions are given in Part A of that note.

A	=	area, sq ft
ASTM	=	American Society for Testing and Materials
C_u	=	coefficient of uniformity = D_{60}/D_{10}
C_z	=	coefficient of curvature $(D_{30})^2/(D_{10} \times D_{60})$
Dr	=	relative density, percent
fpd	=	feet per day
h	=	hydraulic head, ft
i	=	hydraulic gradient = h/L
k	=	coefficient of permeability, fpd
L	=	length normal to flow, ft
min	=	minimum (referring to relative density)
No. 78	=	coarse aggregate size number 78 listed in ASTM Designation D448
pcf	=	pounds per cubic foot
q	=	rate of flow, cubic feet per day
γ_d	=	dry unit weight (density), pcf

III. Materials tested

The fifteen gradations are shown in Figure 1. They vary from fine sands to fine gravels and classify as SP, SW, GP, and GW soils. Gradations 3 and 7 are the fine and coarse limits respectively of fine aggregate (sand) in ASTM Designation C33. Gradations 12 and 14 are the fine and coarse limits respectively of gravel size number 78 in ASTM Designation D448. Frequently, C33 sand and size 78 gravel are used in the Soil Conservation Service (SCS) as filter and drain materials.

Two series of tests were run on these four gradations (i.e., numbers 3, 7, 12, and 14)--one series consisting of rounded particles of alluvial river sand and the other consisting of angular particles of hard, crushed limestone.

Only rounded particles were used in the other eleven gradations.

IV. Test procedures

Generally, three specimens of each gradation (and each particle shape, where applicable) were tested, both at minimum (or near minimum) and at approximately 70 percent relative densities (D_r). A few relatively broadly graded gravels that segregated readily when compacted were tested at less than 70 percent relative density to avoid particle segregation. Relative densities were determined by the procedures in ASTM Designation D2049.

Fine and medium sands were tested in an 8-inch diameter permeameter of the type described in Designation E13, Earth Manual, Bureau of Reclamation. In order to obtain more accurate head readings, the permeameter was modified by placing piezometers at the base and top of the 3-inch high test specimens. Appendix A contains the procedure for making these tests.

Coarse sands and gravels were tested in a high capacity 8-inch diameter permeameter designed in the Soil Mechanics Laboratory. Eight-inch high specimens were used with water flowing upward through specimens. The test procedure and a sketch of the permeameter are given in appendix B.

V. Test results

Average results of hydraulic gradient ($i = h/L$) versus velocity ($v = q/A$) for each gradation are shown in figures 2 and 3. Figure 2 is for relative densities of approximately 70 percent, whereas figure 3 is for minimum relative densities. When rounded and angular particles were used, test series consisting of rounded particles carry the gradation number and suffix A, whereas angular particles carry the gradation number and suffix B.

Permeability coefficients (k) changed very little with increasing hydraulic gradients for gradations 1 through 10; thus, k values are shown on the curves in figures 2 and 3. However, permeability rates generally decreased with increasing hydraulic gradient in the coarser soils--the flow apparently becoming nonlaminar. In these latter cases, a permeability coefficient is not shown; thus, the required cross sectional area of a drain must be calculated using the hydraulic gradient and the rate of flow (q) that will exist in the drain.

The basic data for each specimen tested are presented in appendix C. Each figure contains the gradation, particle shape, unified classification symbol, relative density values, test dry densities, and arithmetic plots of values of i vs. q/A.

VI. Use of test results

Test results can be used in two ways: (1) to estimate size of drains or (2) to estimate the rate of flow in natural clean sands and gravels. Gradation of the material being considered can be plotted on a copy of figure 1 or an overlay of figure 1 using Form SCS-ENG-130A "Drain Materials." Then, an interpolation can be made of gradation number or numbers that best fit this material. Using the best-fit number(s) in figures 2 or 3 will give either a k value or a q/A value for the appropriate hydraulic gradient (i).

It is suggested that figure 2 ($D_r \approx 70\%$) be used for drain fill material and that figure 3 ($D_r \approx$ min) be used for inplace materials. The basic data in appendix C can also be used to estimate the desired information for a given gradation, but interpolation between two gradations is more difficult.

An example to illustrate use of figure 2 follows:

Given: design discharge (q) = 1,900 cfd and drain slope = 2%.
Find: cross sectional area of drain if materials similar to gradations No. 13 (GW) and No. 14 (GP) are available.

Assume that drain materials will be placed at about $D_r = 70\%$.

1. <u>Gradation No. 13</u>

   a. From figure 2 with i = 0.02, q/A = 130 fpd

   b. A = q/130 = 1,900/130 = 14.6 sq ft

2. <u>Gradation No. 14</u>

   a. From figure 2 with i = 0.02, q/A = 800 fpd

   b. A = q/800 = 1,900/800 = 2.4 sq ft

Thus, cross sectional areas vary between about 15 and 3 square feet, depending on materials. BUT, these areas do not provide for a factor of safety to account for the uncertainties of the design discharge, variations in drain material permeability, and other factors. The actual size of the drain must be decided by the designer. In addition, he must check the compatibility of drain and base materials in accordance with Soil Mechanics Note No. 1. A filter may be required around the drain to prevent movement of surrounding soil into the drain material.

Form SCS 130
5-65

MATERIALS TESTING REPORT

U.S. DEPARTMENT of AGRICULTURE
SOIL CONSERVATION SERVICE

DRAIN MATERIALS

PROJECT and STATE: Project Study No. 101

DESIGNED AT

BY: SML

DATE

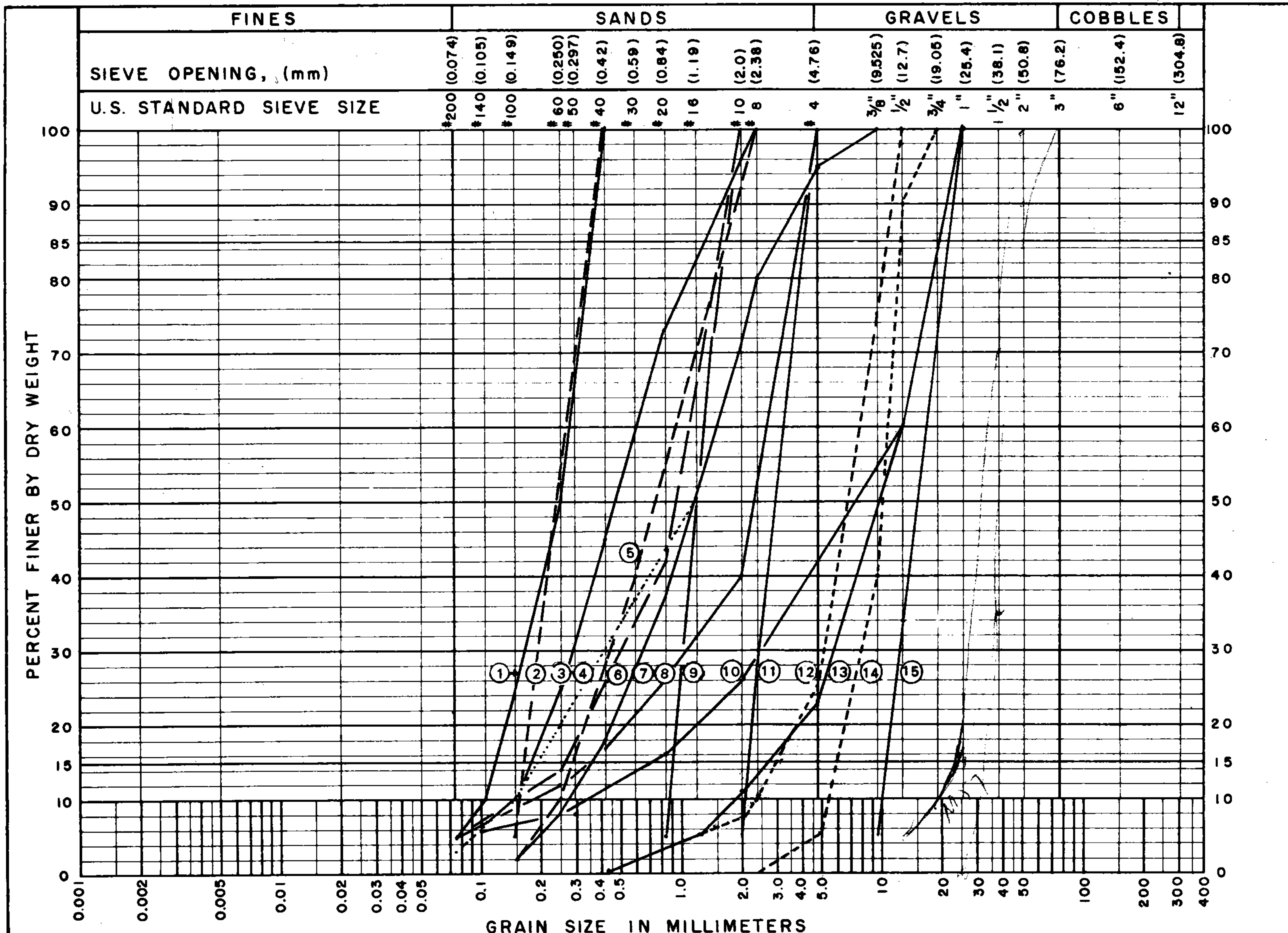


Figure 1. Gradations of sands and gravels tested

REMARKS 1. Gradations No. 3 and 7 represent the fine and coarse limits of fine aggregate sand (ASTM Designation C33).

2. Gradations No. 12 and 14 represent the fine and coarse limits of gravel size No. 78 (ASTM Designation D448).

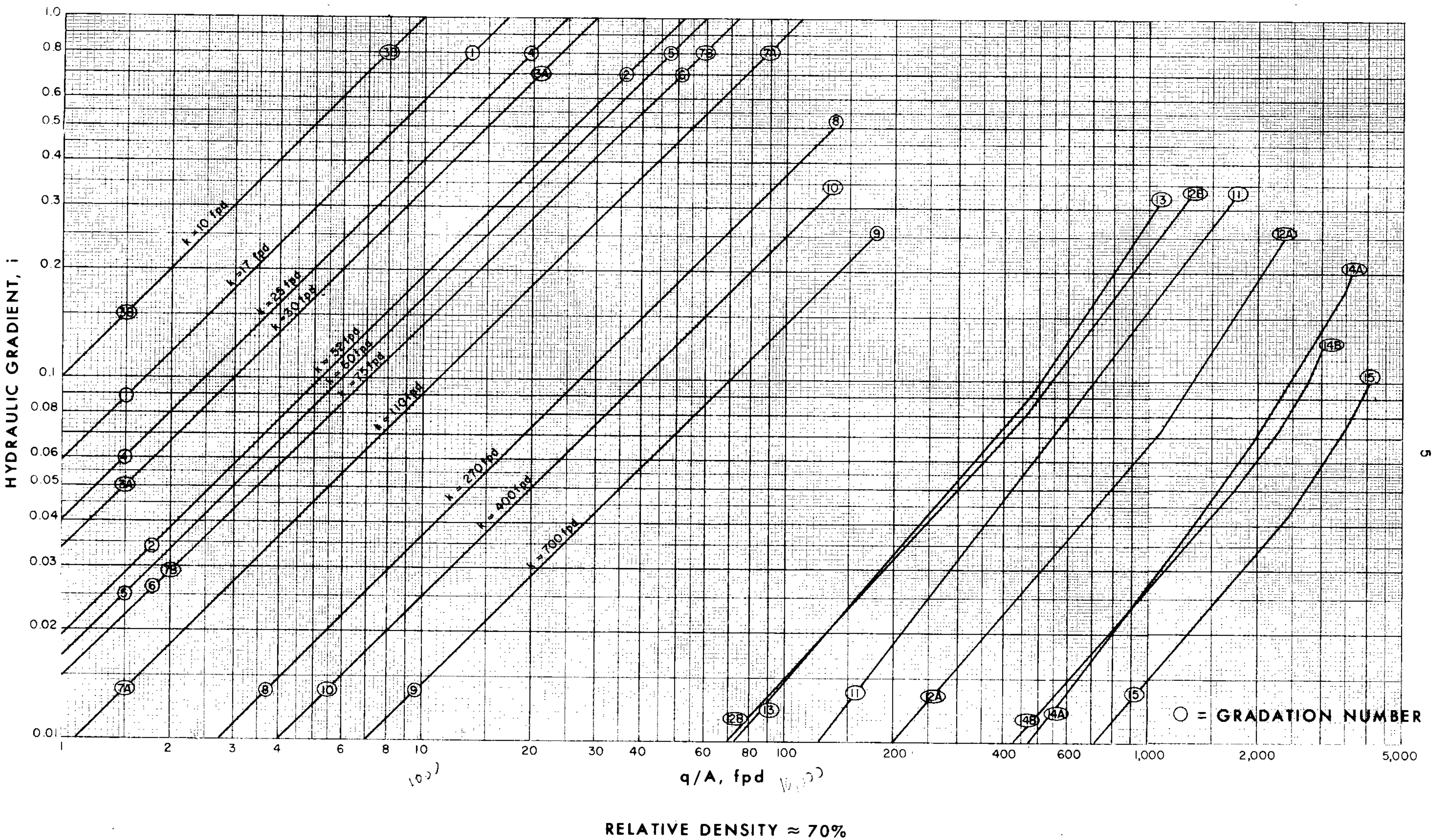
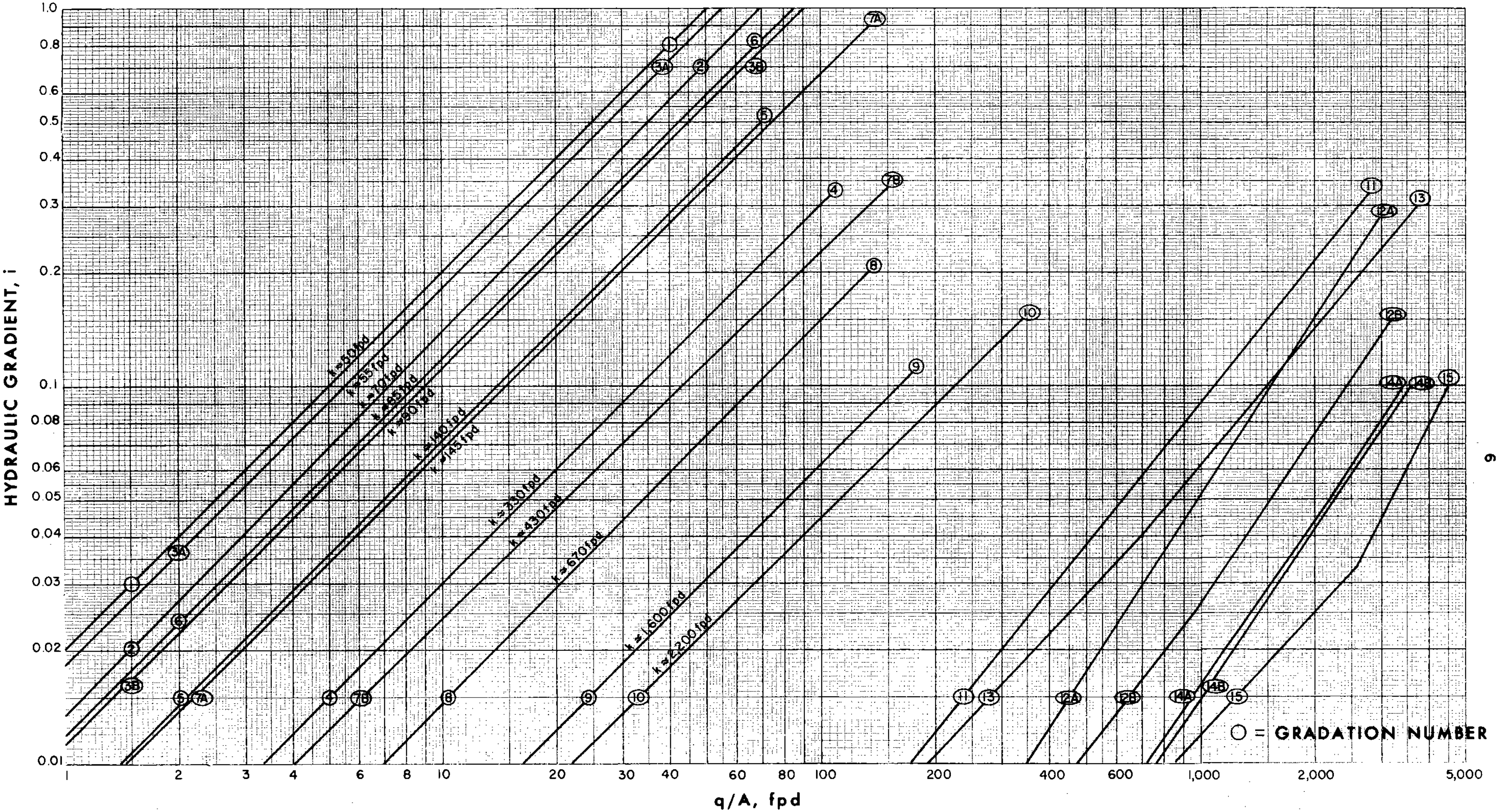


Figure 2. RELATIONSHIP BETWEEN i AND q/A FOR 15 GRADATIONS OF CLEAN SANDS AND GRAVELS



RELATIVE DENSITY ≈ MIN.

Figure 3. RELATIONSHIP BETWEEN i AND q/A FOR 15 GRADATIONS OF CLEAN SANDS AND GRAVELS

APPENDIX A

PERMEABILITY TEST PROCEDURE FOR SOILS CONSISTING OF FINE TO MEDIUM SAND

1. Sieve sufficient material of the fractions desired to provide 15,000 grams or more of the gradation that is to be tested.

2. Calculate amount of each size fraction needed to obtain the desired gradation. Weigh out the appropriate amounts and mix fractions thoroughly using sample splitter.

3. Make relative density tests on the gradation to be tested using the regular SML procedure (see ASTM D2049).

4. Calculate the volume of the permeameter for a test specimen 3 inches long.

5. Select the percent relative density to be tested; i.e., 70% D_r or minimum D_r.

6. Calculate the total weight of the test material (obtained in step 2) needed to produce the volume calculated in step 5 for one permeability test specimen (set up three test specimens for each gradation to be tested).

7. Weigh out the amount calculated in step 6.

8. Determine extensiometer readings for the 8-inch permeameter with a 3-inch calibration spacer between the porous stones to be used in the test. Center the spacer in the permeameter and hold it in place with a folded towel. Orient base plate and top stone on index mark so that they can be placed in the same position for subsequent readings. Place the two extensiometers to measure height of base plate arms and orient the gages to face the outlet tube of the permeameter so that the same relative placement of gages can be obtained in subsequent readings.

9. Place dry test material in the permeameter using a tremie (10-inch funnel) to avoid segregation and unwanted compaction. Place material in a spiral pattern starting from the center and working outward to outside edge and then back to the center. Hold spout within 1 inch of top of sample.

10. Place top stone and base plate with overhang arms to check sample height. Line up index marks on plate and permeameter so that reference arms are in the same position each time that the extensiometers are placed in position.

11. Compact sample as necessary to obtain the 3-inch sample height (L). Vibratory table may be needed for the specimens that do not compact easily. Compaction should not be necessary for the minimum density tests.

12. Attach water supply to permeameter. Open supply tank valve slightly to allow sample to wet up slowly to avoid sample disturbance from water rushing in. Fill permeameter until water passes through overflow. Open supply tank valve fully when sample is saturated to avoid constriction of flow from the supply tank at the higher rates of flow.

13. Record amount of water (Q) in milliliters passing through sample for any given time period (t) in hours for various elevations of the head tank. Record differential between piezometers (h) to use in calculating permeability rate of the sample.

14. Area (A) of 8-inch diameter specimen = $\frac{\pi d^2}{4} = \frac{\pi(8)^2}{4} = 50.3 \text{ in}^2$

15. Darcy's law: $q = \frac{Q}{t} = kiA$ or $k = \frac{q/A}{i} = \frac{q/A}{h/L}$

Convert test units so q/A is in feet per day (fpd)

$$\frac{q}{A}\text{ (fpd)} = \frac{\frac{q \text{ ml}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{\text{liter}}{1{,}000 \text{ ml}} \times \frac{\text{cu ft}}{28.32 \text{ liters}}}{50.3 \text{ in}^2 \times \frac{\text{ft}^2}{144 \text{ in}^2}}$$

$$= \frac{(24 \times 144)q}{(1{,}000 \times 28.32 \times 50.3)}$$

$$= 0.00243\ q \text{ where } q = \text{ml/hr}$$

16. Plot q/A (fpd) vs. i (Appendix C).

APPENDIX B

PERMEABILITY TEST PROCEDURE FOR

COARSE SANDS AND GRAVELS[1/]

1. Sieve sufficient amounts of aggregate for gradation desired.

2. Mix carefully and run relative density tests.

3. Weigh the amount of aggregate needed for the desired length and density of specimen to be tested.

4. Carefully place aggregate in permeameter using a long-snout tremie to avoid segregation during placement. Use circular motion to fill permeameter and limit free fall of aggregate to 0.5 inch.

5. Vibrate the permeameter as needed to obtain sample density. Avoid excessive vibration of broadly graded materials which will segregate readily.

6. Pass water up through bottom of sample at selected rate until flow becomes steady.

7. Measure water passing through permeameter, Q, in milliliters keeping track of time.

8. Measure head causing water flow using the piezometers at the top and bottom of the test specimen.

9. Increase flow through sample and take a new set of readings, etc.

10. Area (A) of 8-inch diameter specimen $= \frac{\pi d^2}{4} = \frac{\pi(8)^2}{4} = 50.3 \text{ in}^2$

11. Convert test units so q/A is in feet per day (fpd)

$$\frac{q}{A}\text{ (fpd)} = \frac{q\ \frac{\text{ml}}{\text{hr}} \times \frac{24\text{ hr}}{\text{day}} \times \frac{\text{liter}}{1{,}000\text{ ml}} \times \frac{\text{cu ft}}{28.32\text{ liters}}}{50.3\text{ in}^2 \times \frac{\text{ft}^2}{144\text{ in}^2}}$$

$$= \frac{(24 \times 144)\ q}{(1{,}000 \times 28.32 \times 50.3)}$$

$$= 0.00243\ q \text{ where } q = \text{ml/hr}$$

12. Plot q/A (fpd) vs. i (Appendix C).

[1/] See sketch of permeameter in figure B-1.

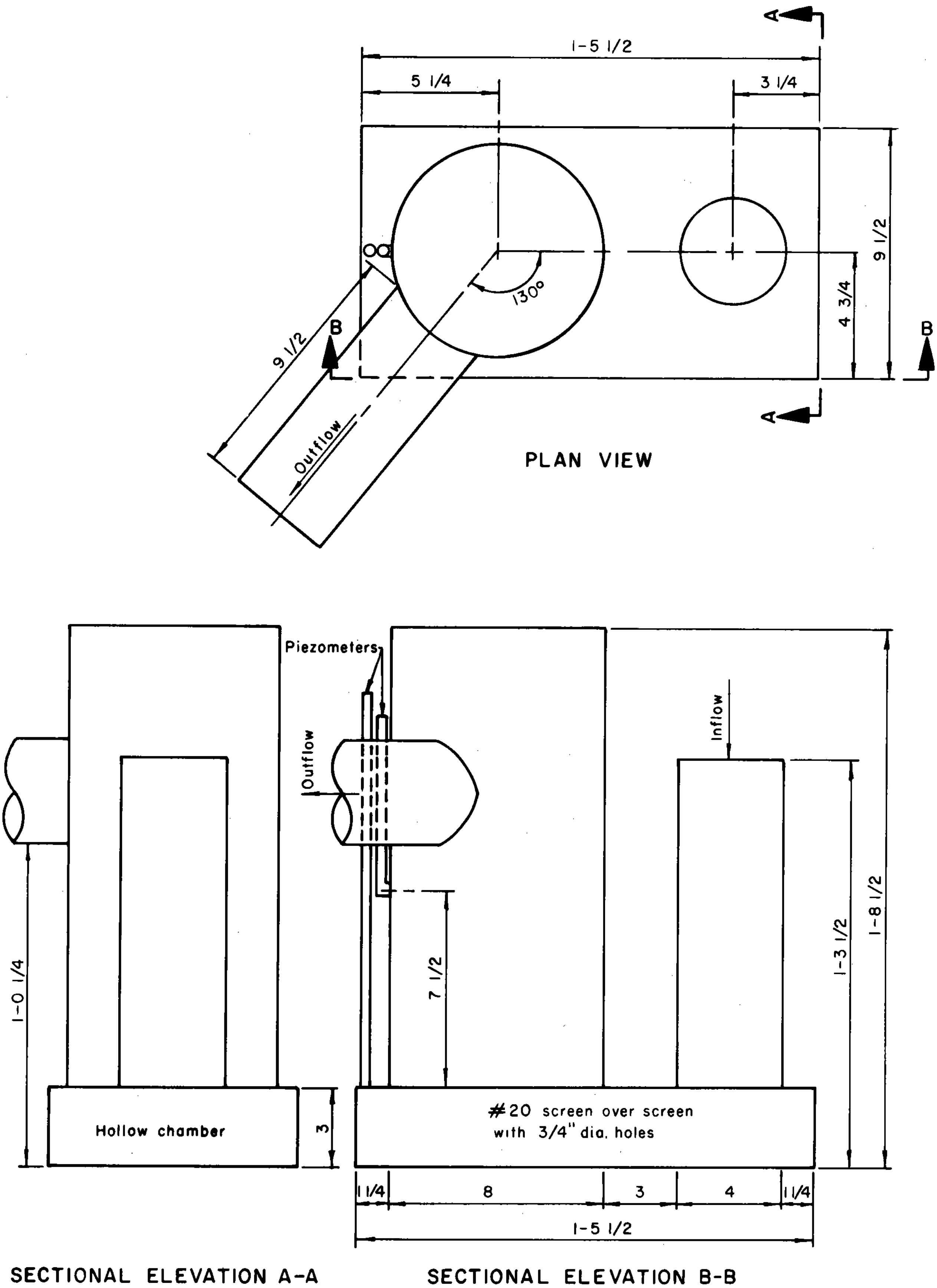
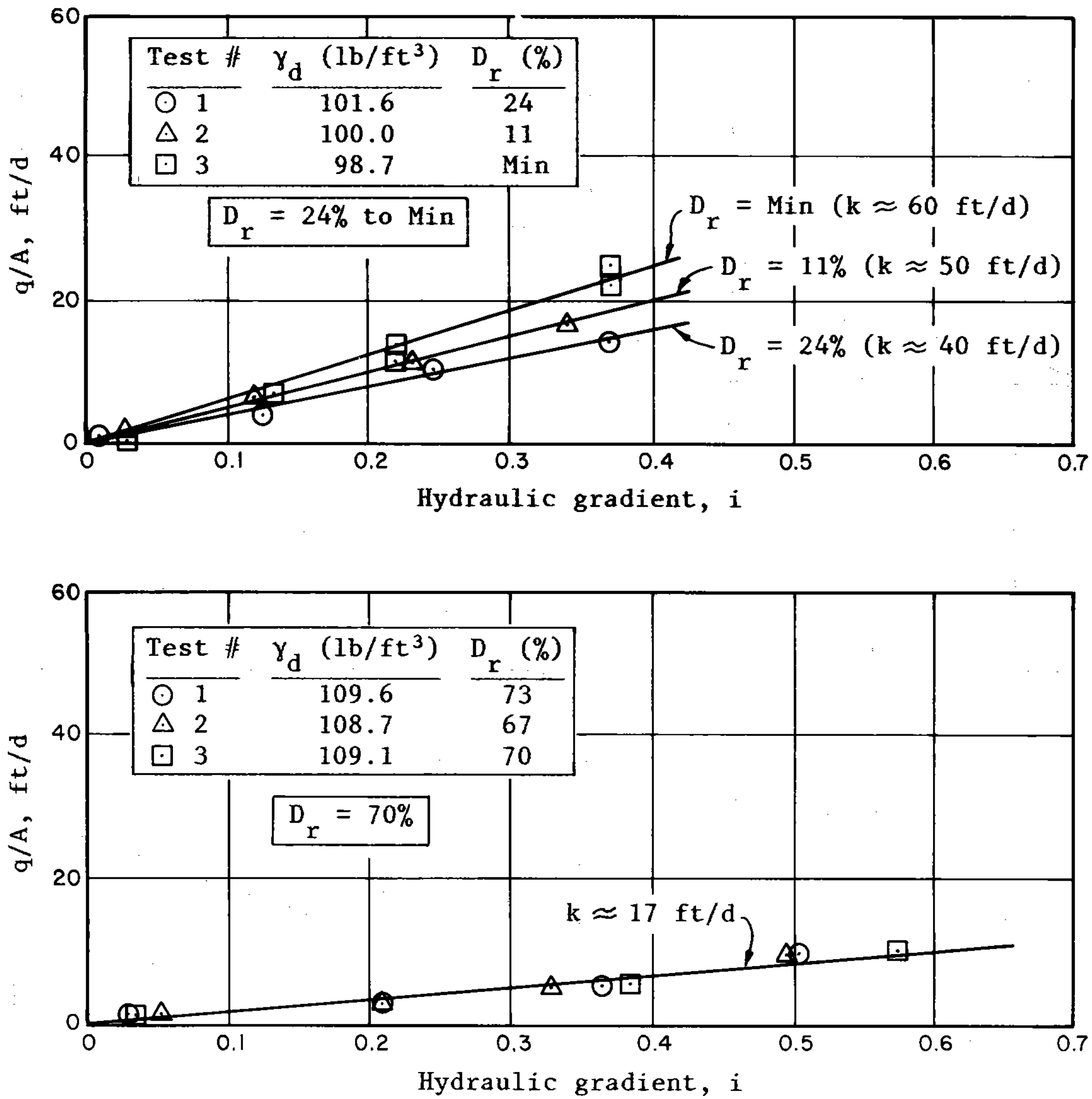


Figure B-1 PERMEAMETER USED FOR GRAVELS AND COARSE SANDS.

APPENDIX C

BASIC TEST DATA

Data from tests at $D_r \approx$ minimum and $D_r \approx 70\%$ relative densities are presented in figures C-1 through C-15. The lines representing i vs. q/A are "eyeball" averages that, in turn, are shown in figures 2 and 3.



GRADATION #1

SP (rounded particles)

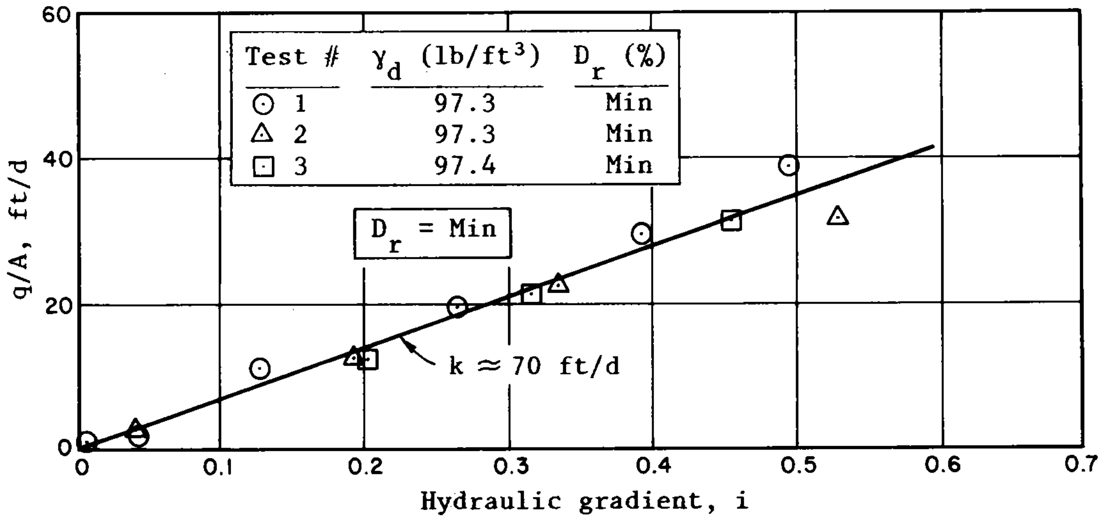
$C_u = 2.7$; $C_z = 0.9$

Sieve #	% Passing
40	100
60	50
100	24
140	10
200	5

Relative Density, D_r

Min γ_d = 98.5 lb/ft³
Max γ_d = 114.5 lb/ft³

Figure C-1. Relationship between q/A and i for Gradation No. 1 (SP, rounded)



GRADATION #2
SP (rounded particles)
$C_u = 1.7$; $C_z = 0.9$

Sieve #	% Passing
40	100
60	55
100	5

Relative Density, D_r

Min γ_d = 97.5 lb/ft³
Max γ_d = 111.3 lb/ft³

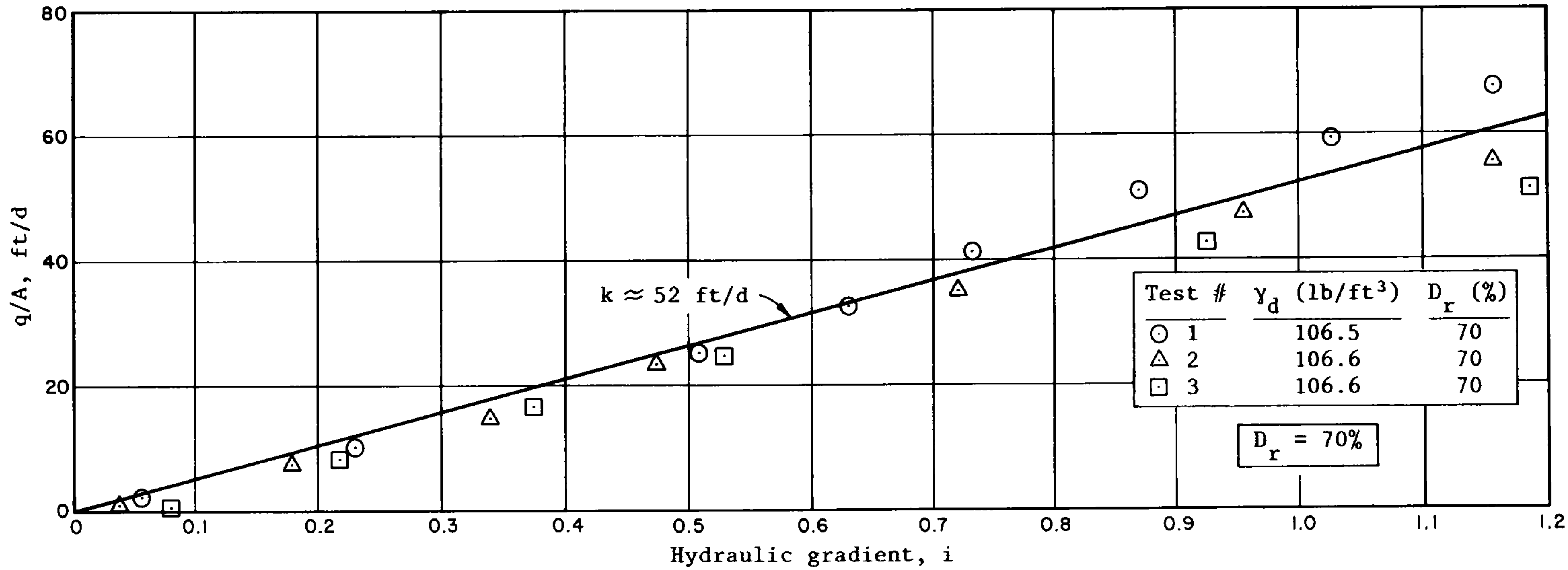


Figure C-2. Relationship between q/A and i for Gradation No. 2 (SP, rounded)

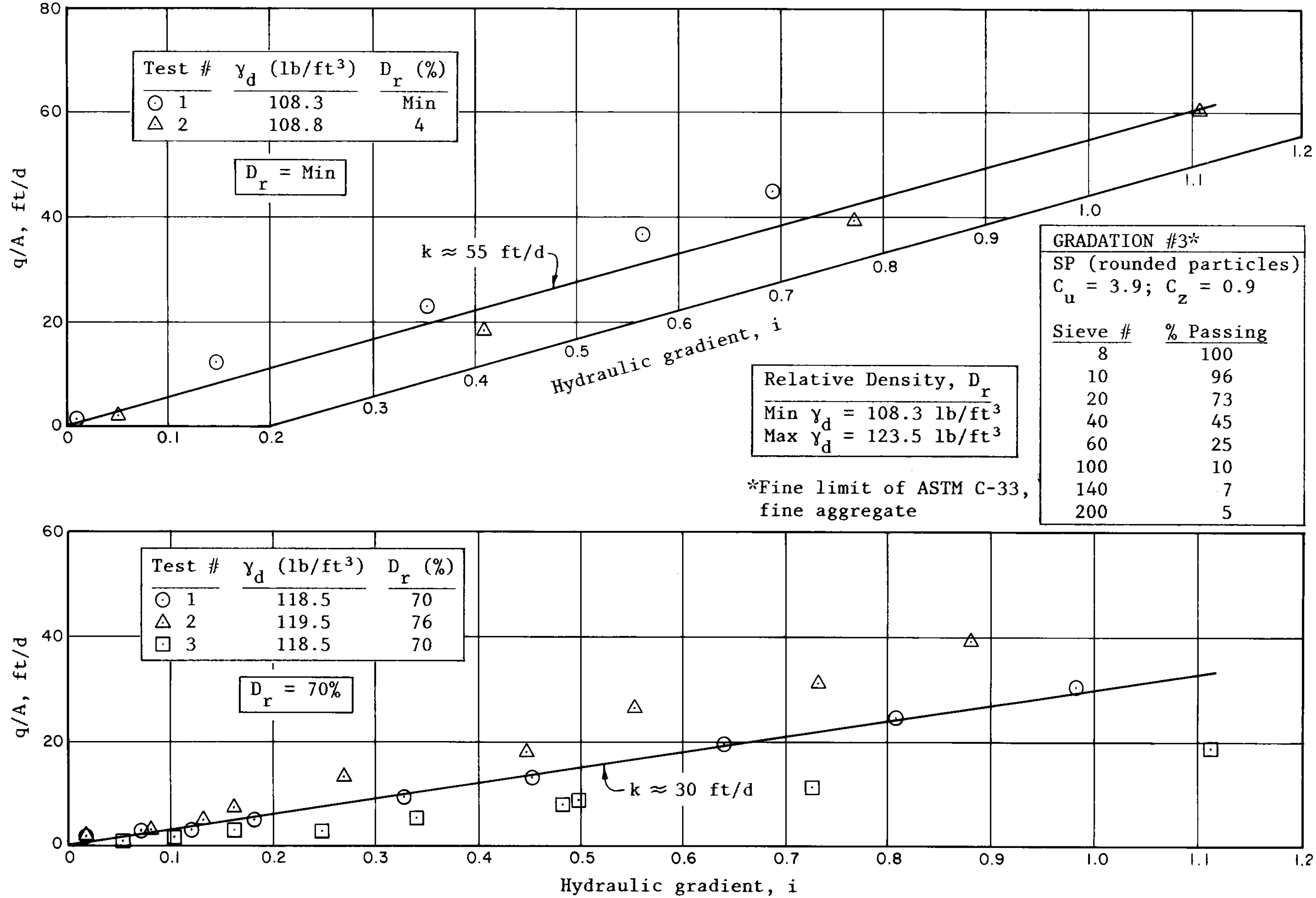
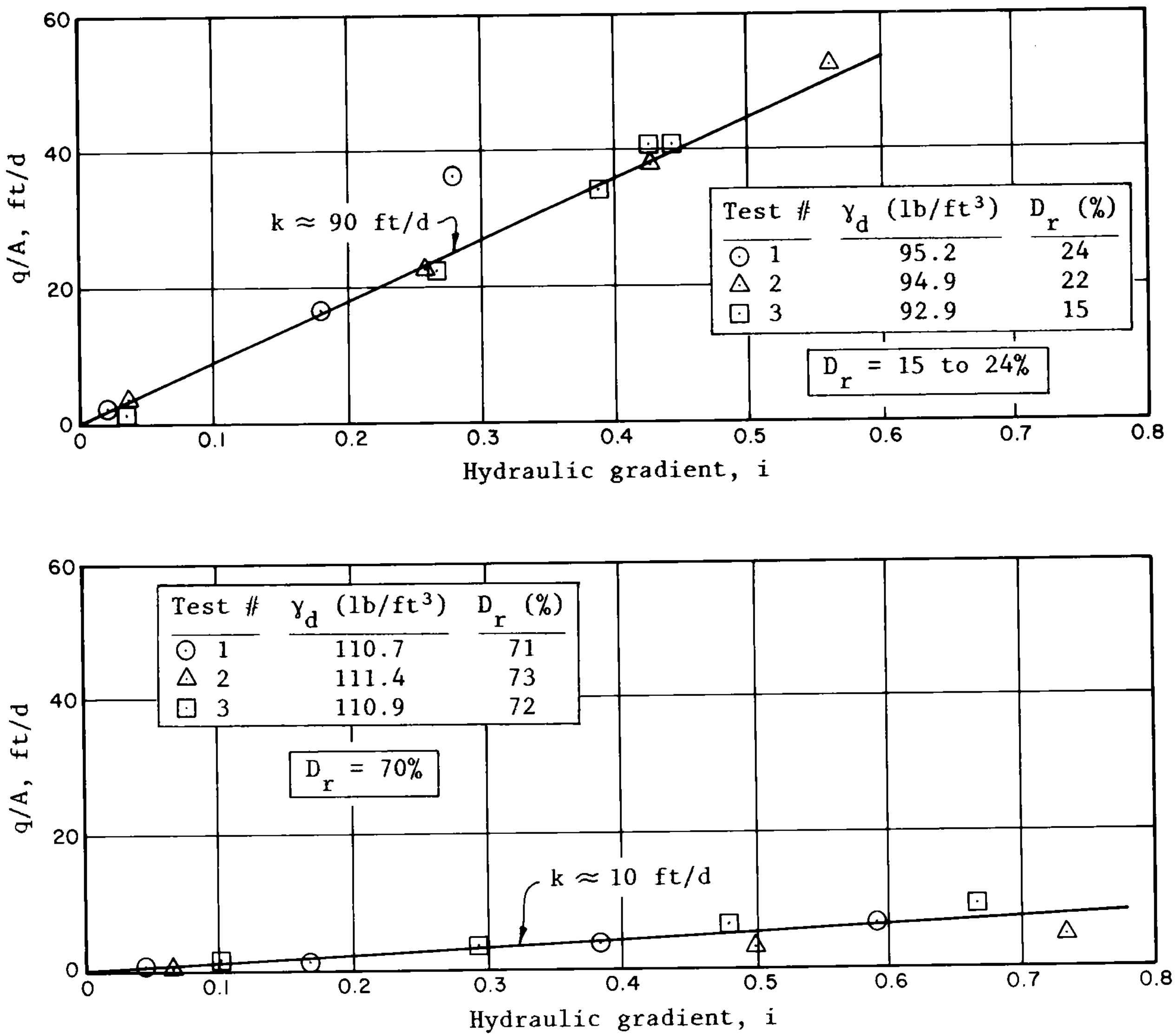


Figure C-3A. Relationship between q/A and i for Gradation No. 3 (SP, rounded)



GRADATION #3*	
SP (angular particles)	
C_u = 3.9; C_z = 0.9	
Sieve #	**% Passing**
8	100
10	96
20	73
40	45
60	25
100	10
140	7
200	5
Relative Density, D_r	
Min γ_d = 89.0 lb/ft³	
Max γ_d = 123.0 lb/ft³	

*Fine limit of ASTM C-33, fine aggregate

Figure C-3B. Relationship between q/A and i for Gradation No. 3 (SP, angular)

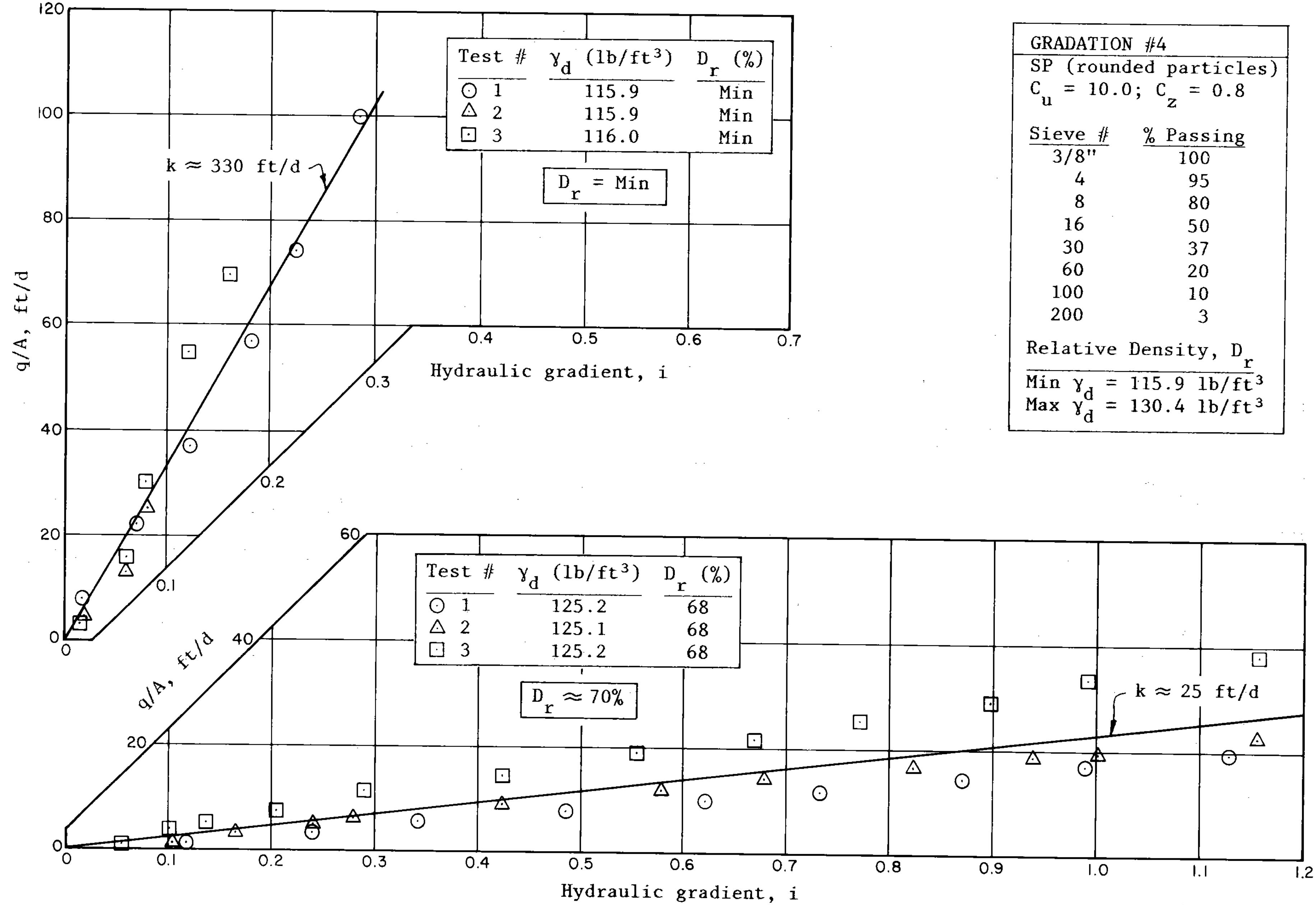


Figure C-4. Relationship between q/A and i for Gradation No. 4 (SP, rounded)

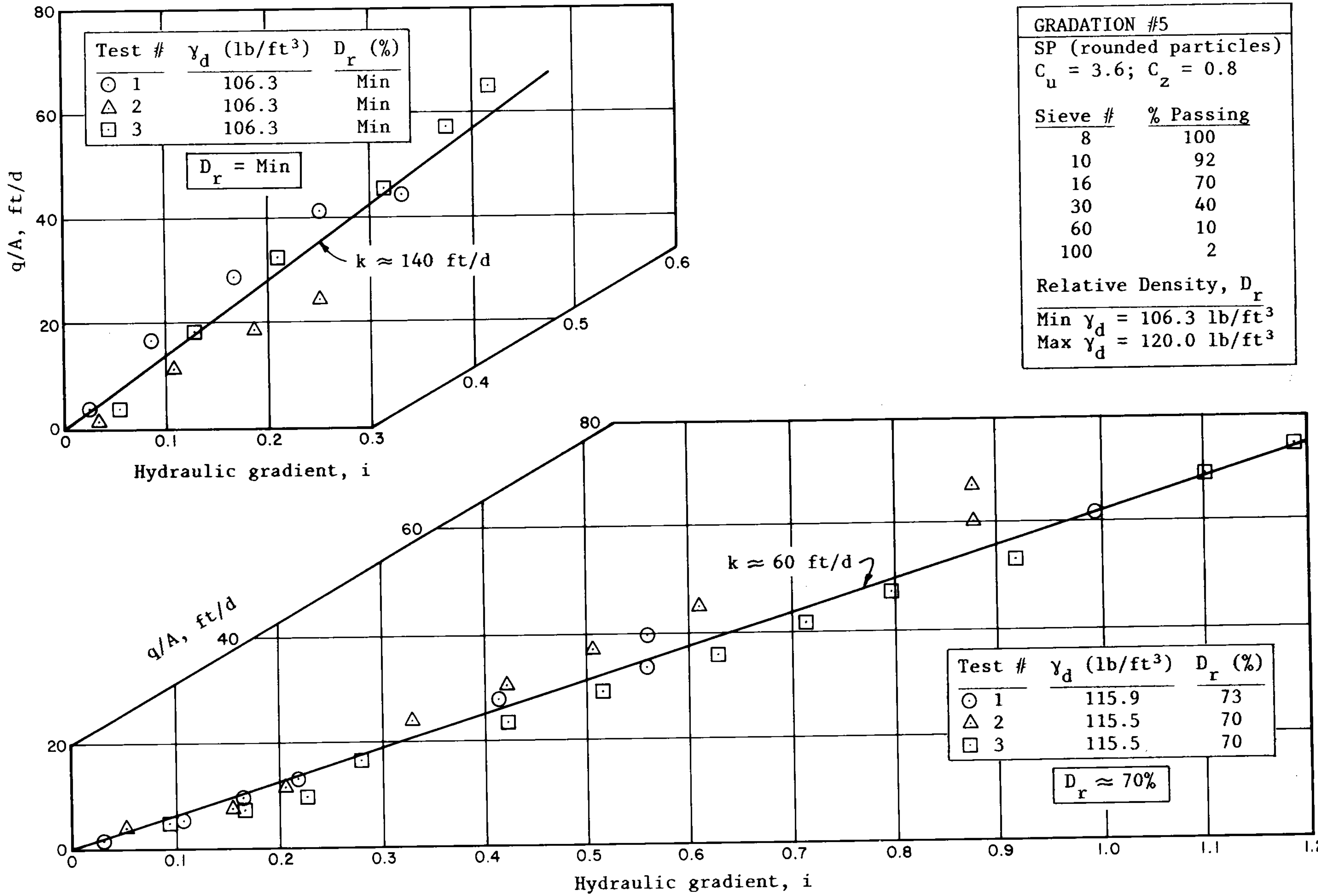


Figure C-5. Relationship between q/A and i for Gradation No. 5 (SP, rounded)

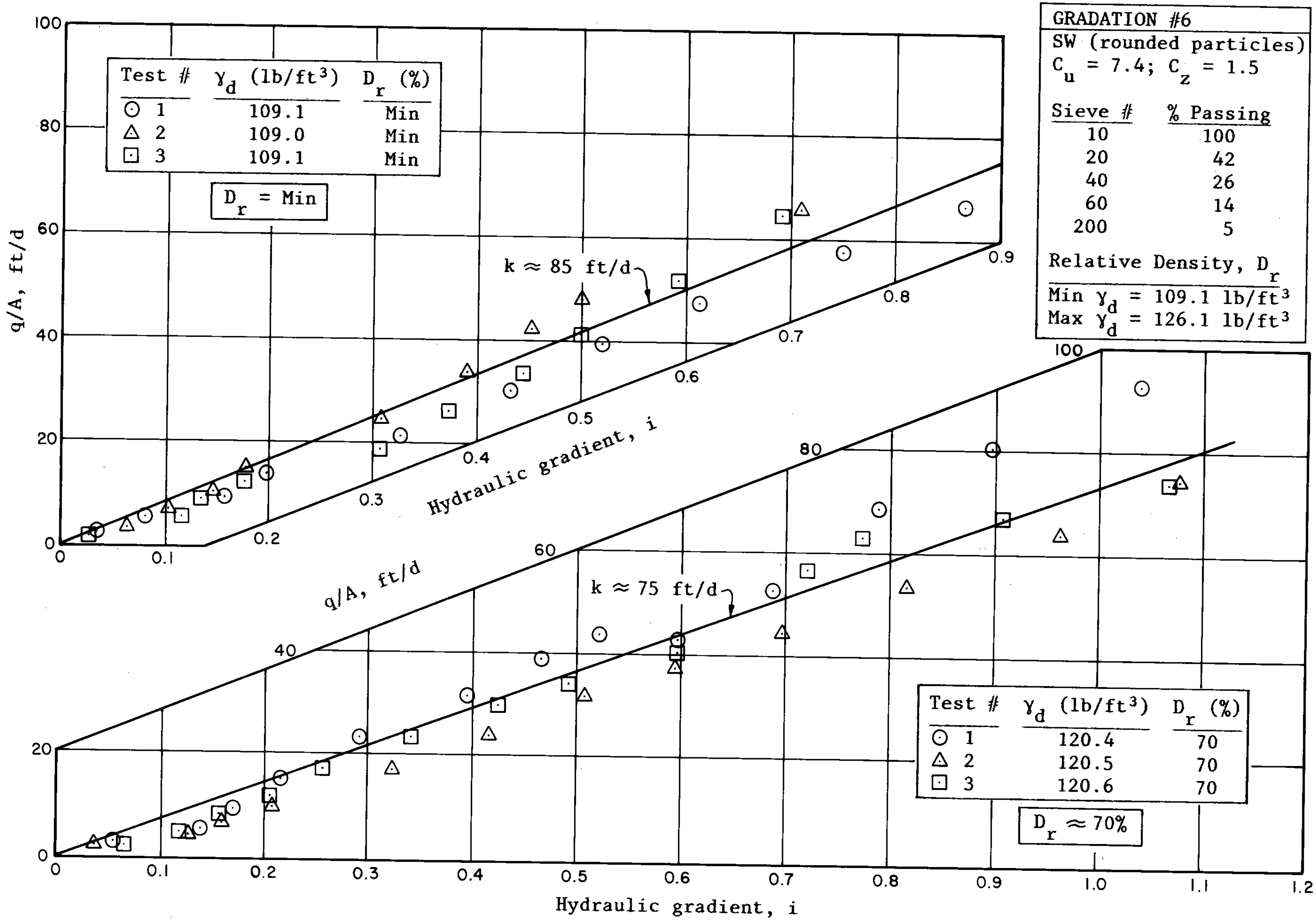


Figure C-6. Relationship between q/A and i for Gradation No. 6 (SW, rounded)

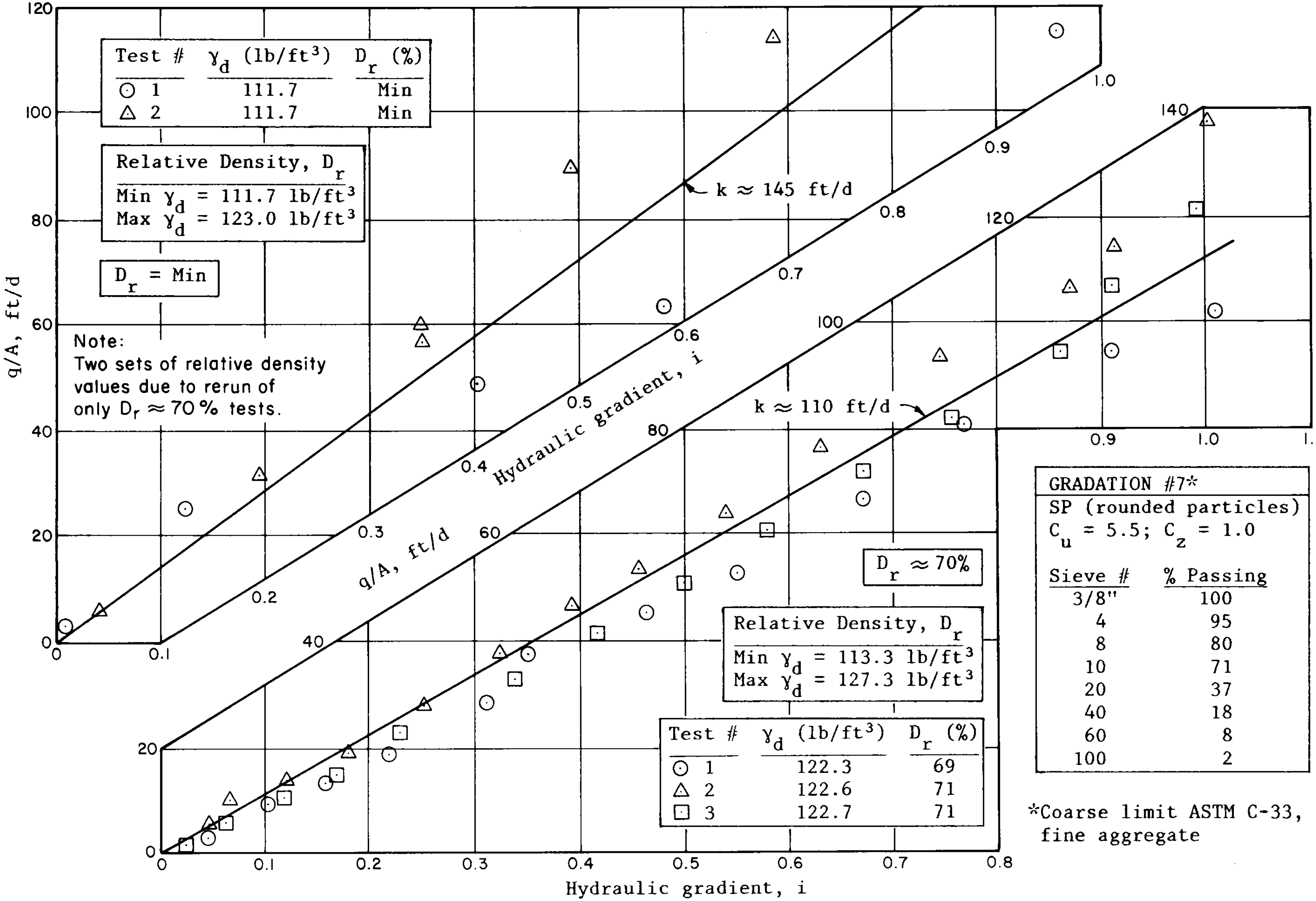


Figure C-7A. Relationship between q/A and i for Gradation No. 7 (SP, rounded)

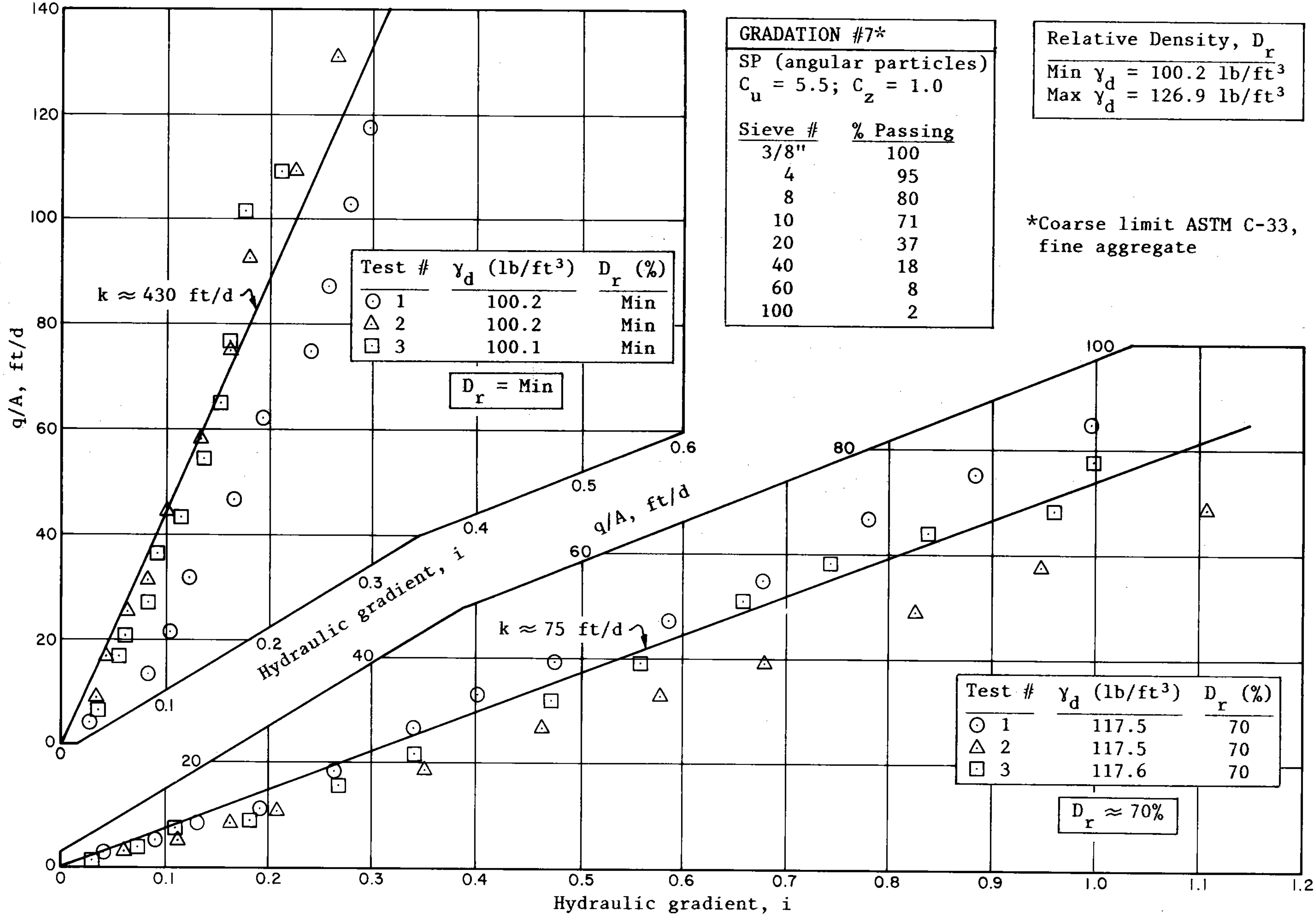


Figure C-7B. Relationship between q/A and i for Gradation No. 7 (SP, angular)

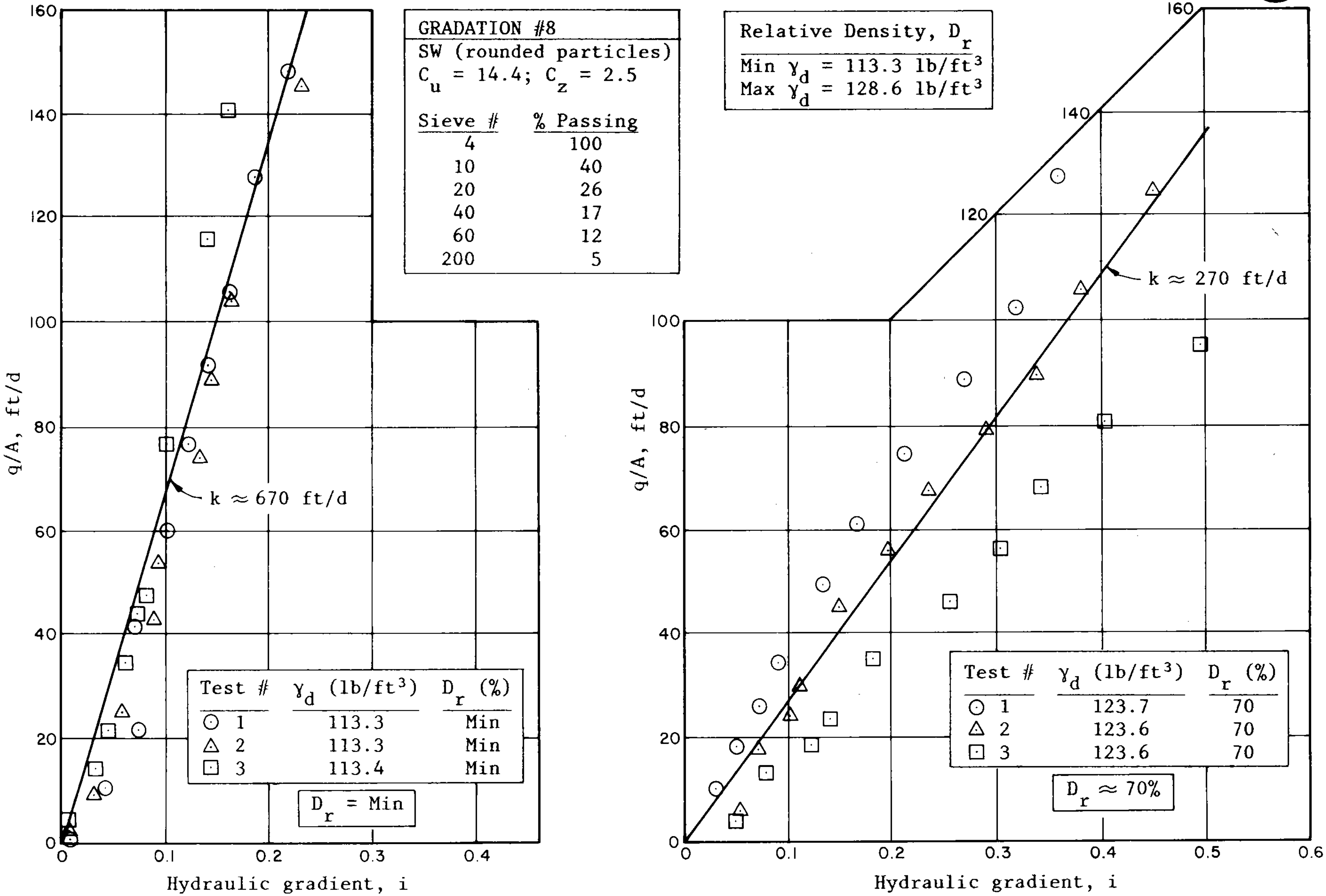
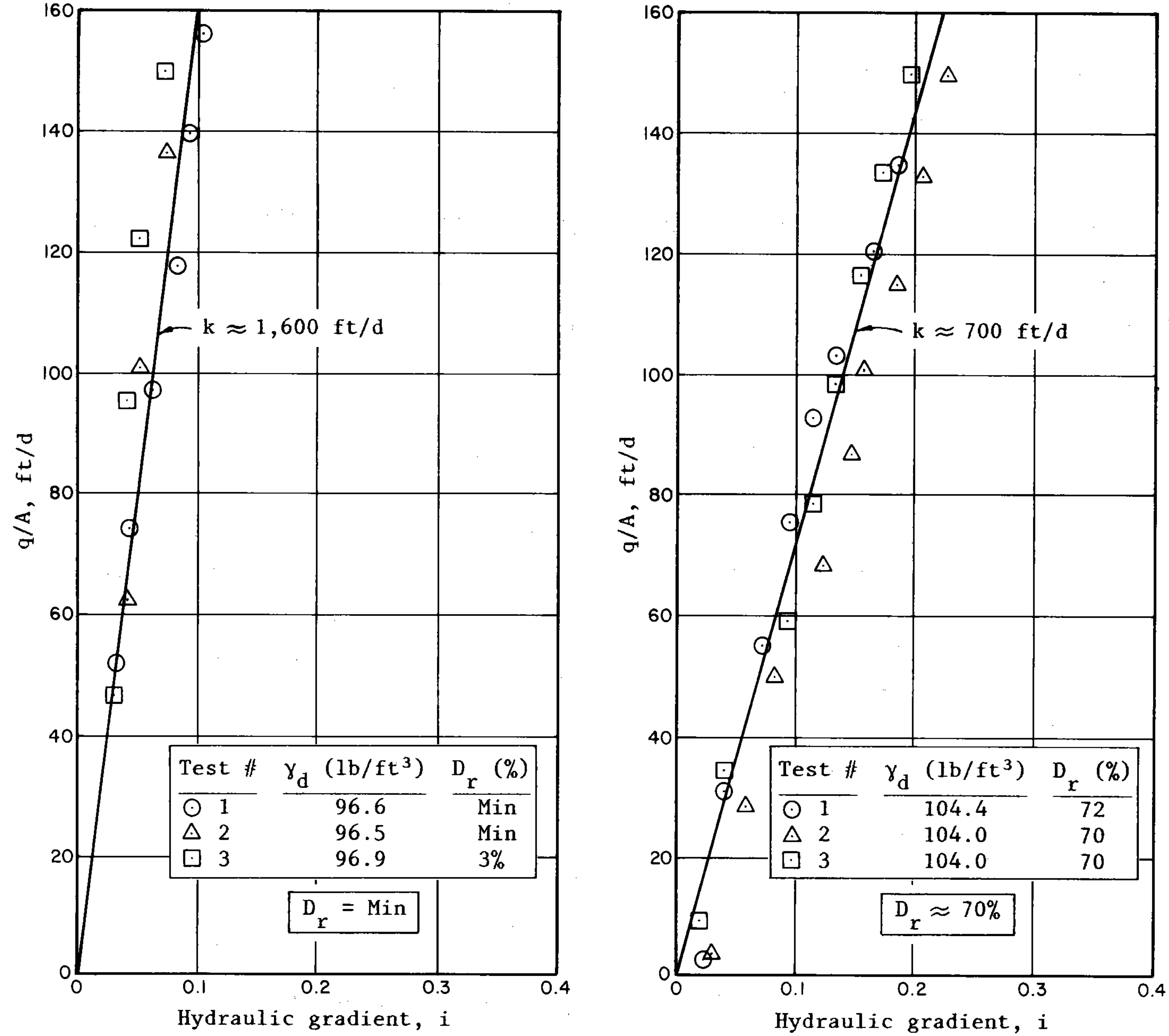


Figure C-8. Relationship between q/A and i for Gradation No. 8 (SW, rounded)



GRADATION #9

SP (rounded particles)

C_u = 1.4; C_z = 0.8

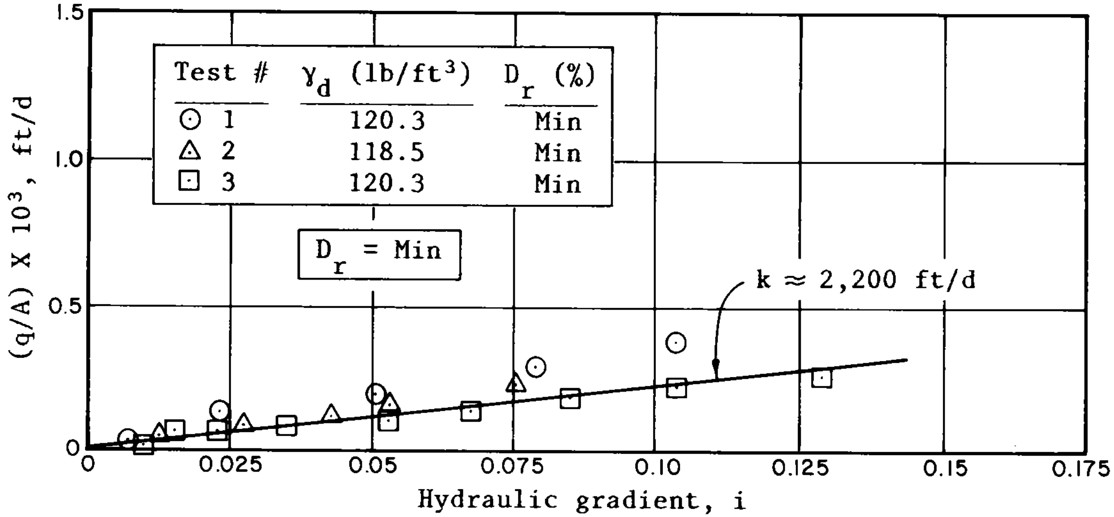
Sieve #	% Passing
10	100
16	50
20	5

Relative Density, D_r

Min γ_d = 96.6 lb/ft^3

Max γ_d = 107.8 lb/ft^3

Figure C-9. Relationship between q/A and i for Gradation No. 9 (SP, rounded)



GRADATION #10	
GW (rounded particles)	
C_u = 37.3; C_z = 1.5	
Sieve #	**% Passing**
1"	100
1/2"	60
4	42
10	26
20	16
60	8
200	5

Relative Density, D_r
Min γ_d = 120.3 lb/ft³
Max γ_d = 133.3 lb/ft³

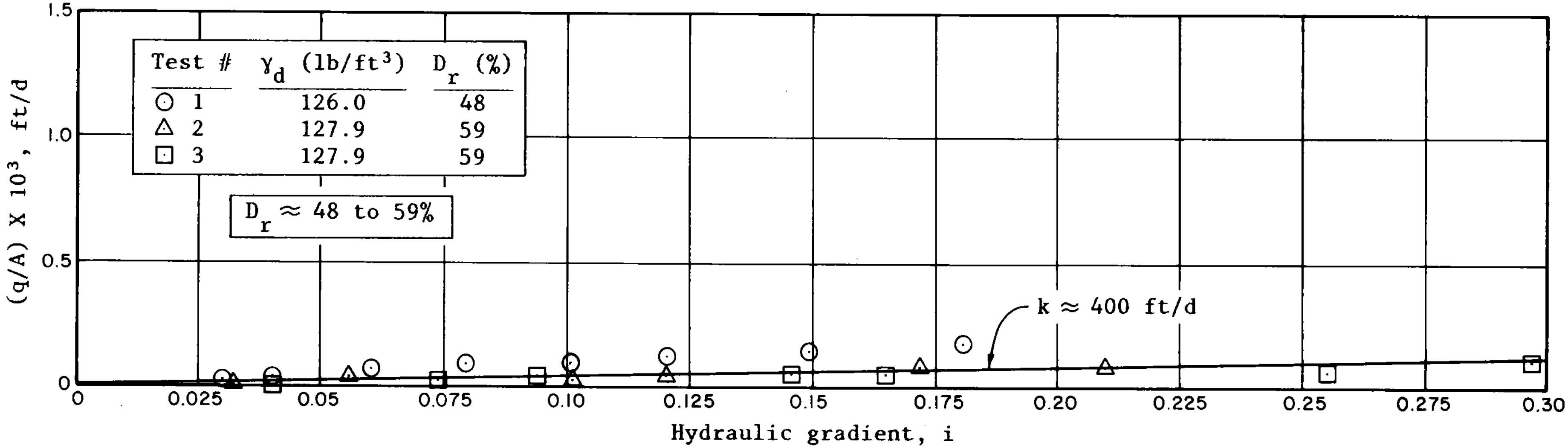


Figure C-10. Relationship between q/A and i for Gradation No. 10 (GW, rounded)

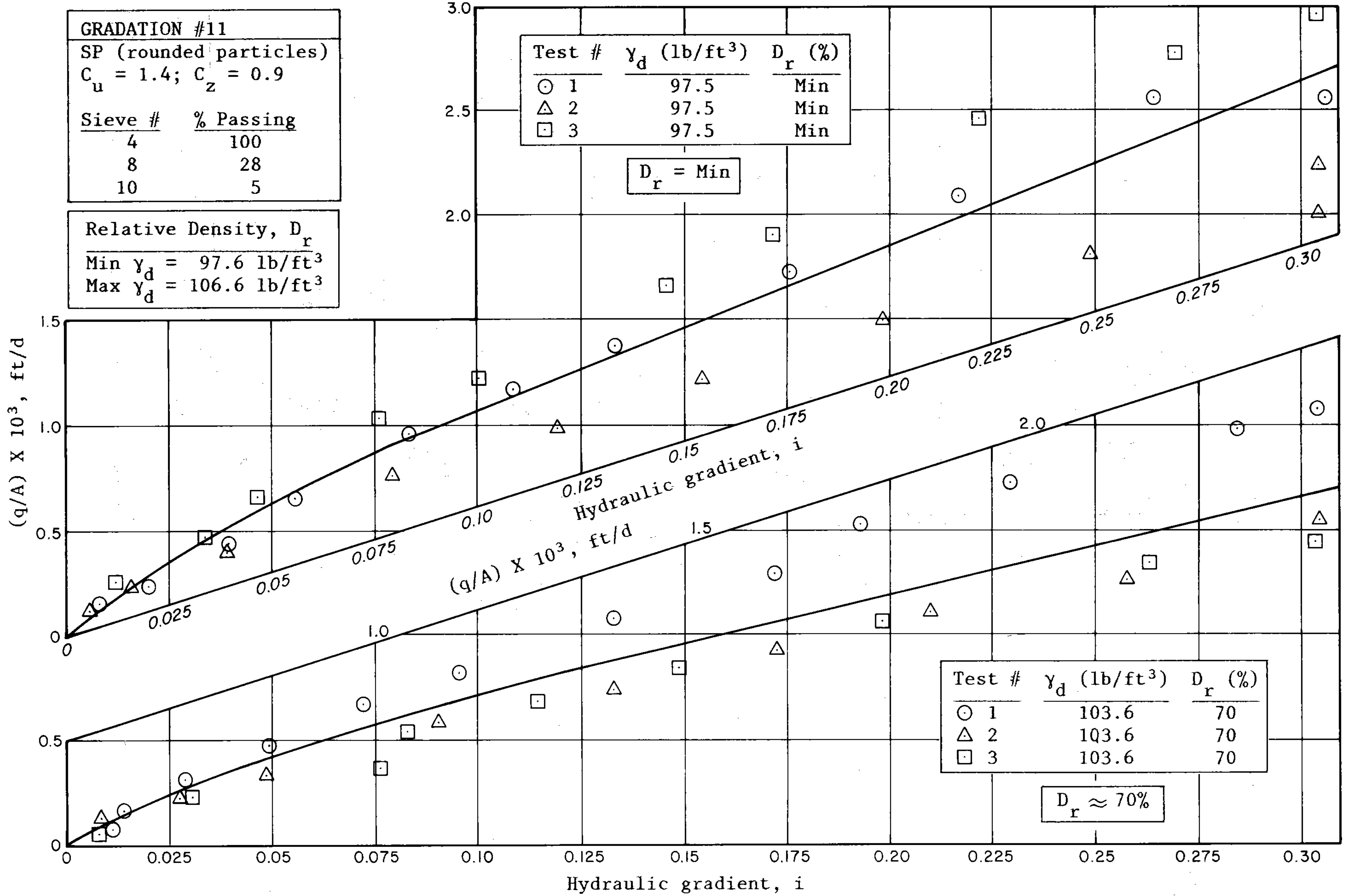


Figure C-11. Relationship between q/A and i for Gradation No. 11 (SP, rounded)

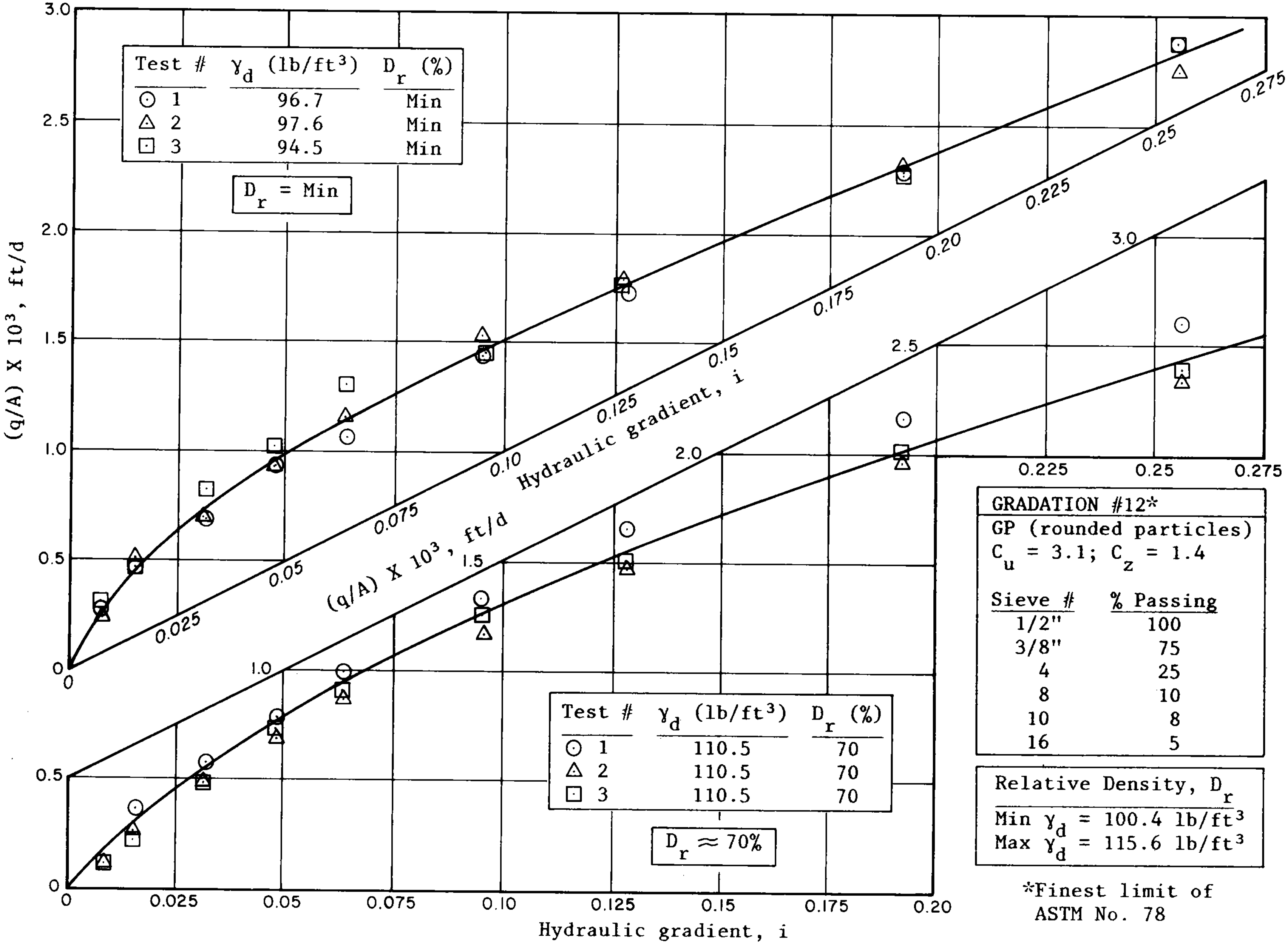


Figure C-12A. Relationship between q/A and i for Gradation No. 12 (GP, rounded)

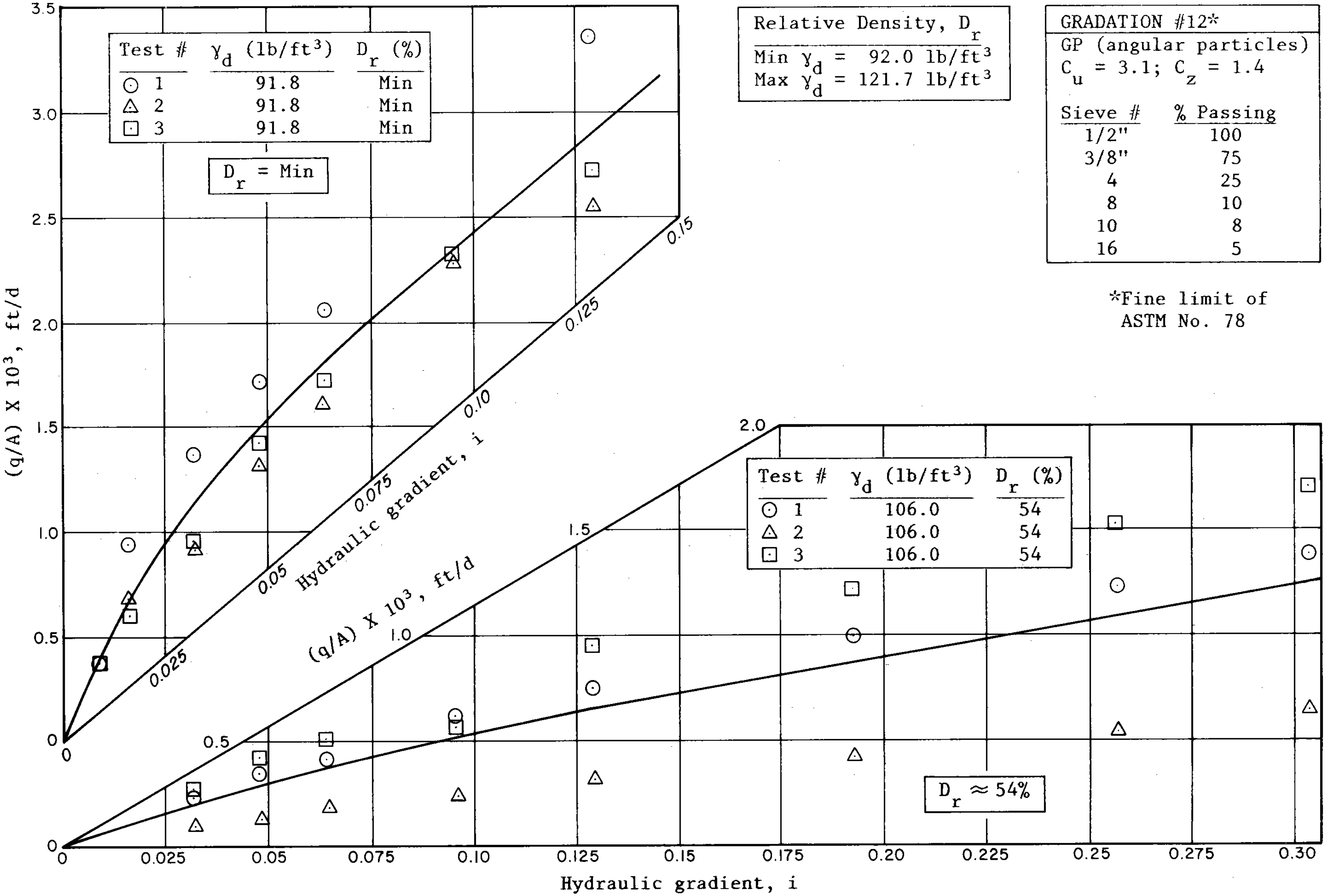


Figure C-12B. Relationship between q/A and i for Gradation No. 12 (GP, angular)

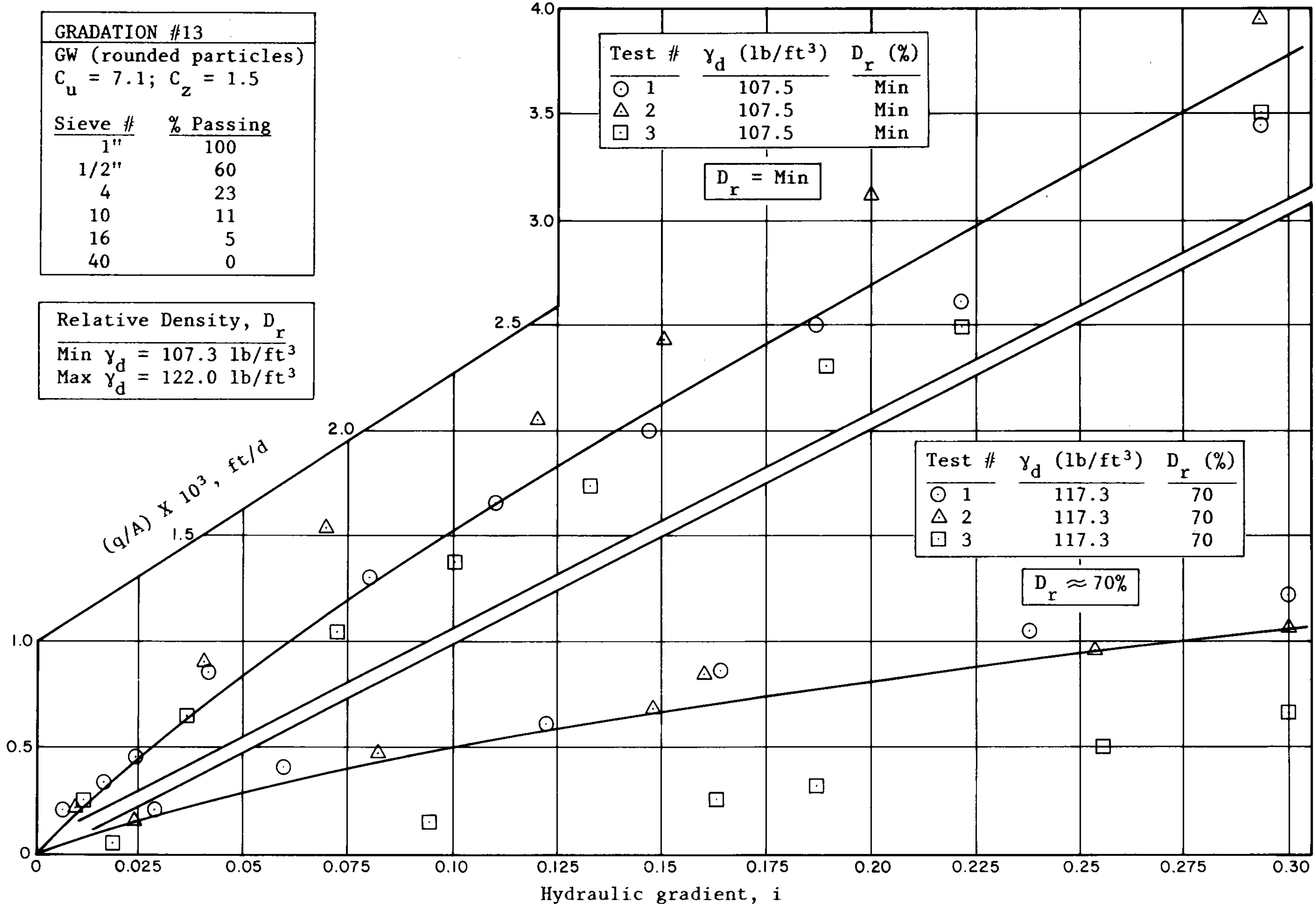


Figure C-13. Relationship between q/A and i for Gradation No. 13 (GW, rounded)

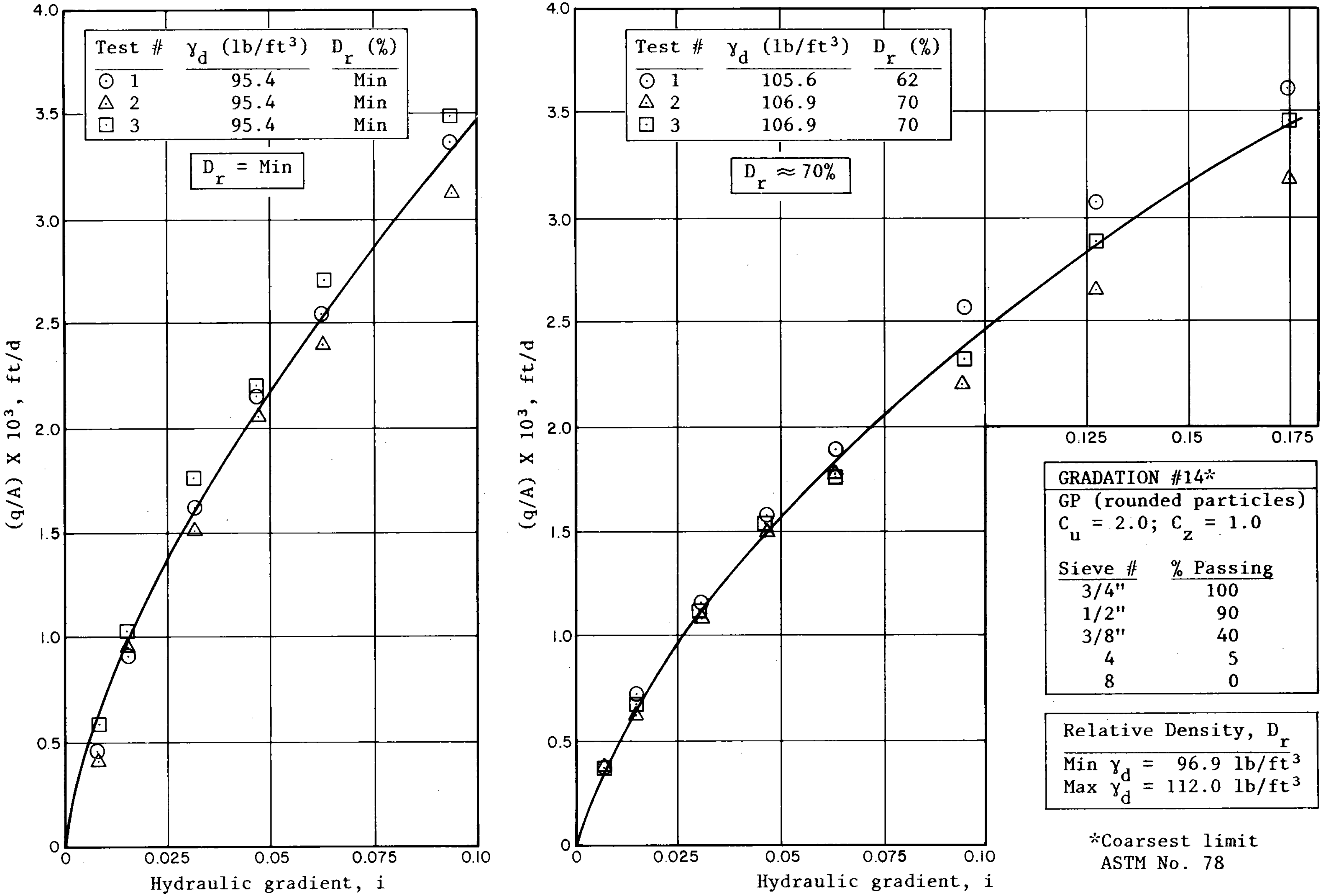


Figure C-14A. Relationship between q/A and i for Gradation No. 14 (GP, rounded)

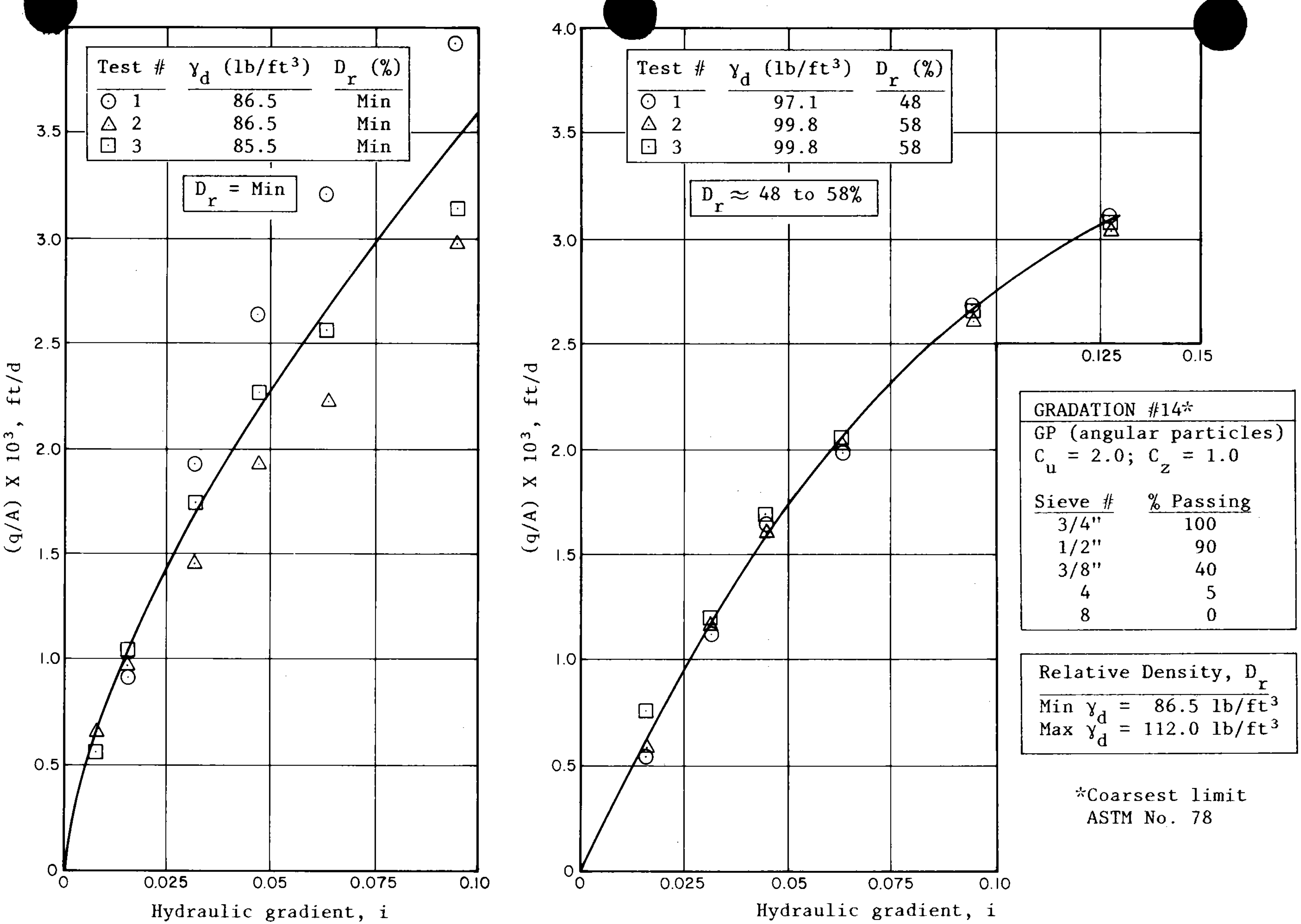


Figure C-14B. Relationship between q/A and i for Gradation No. 14 (GP, angular)

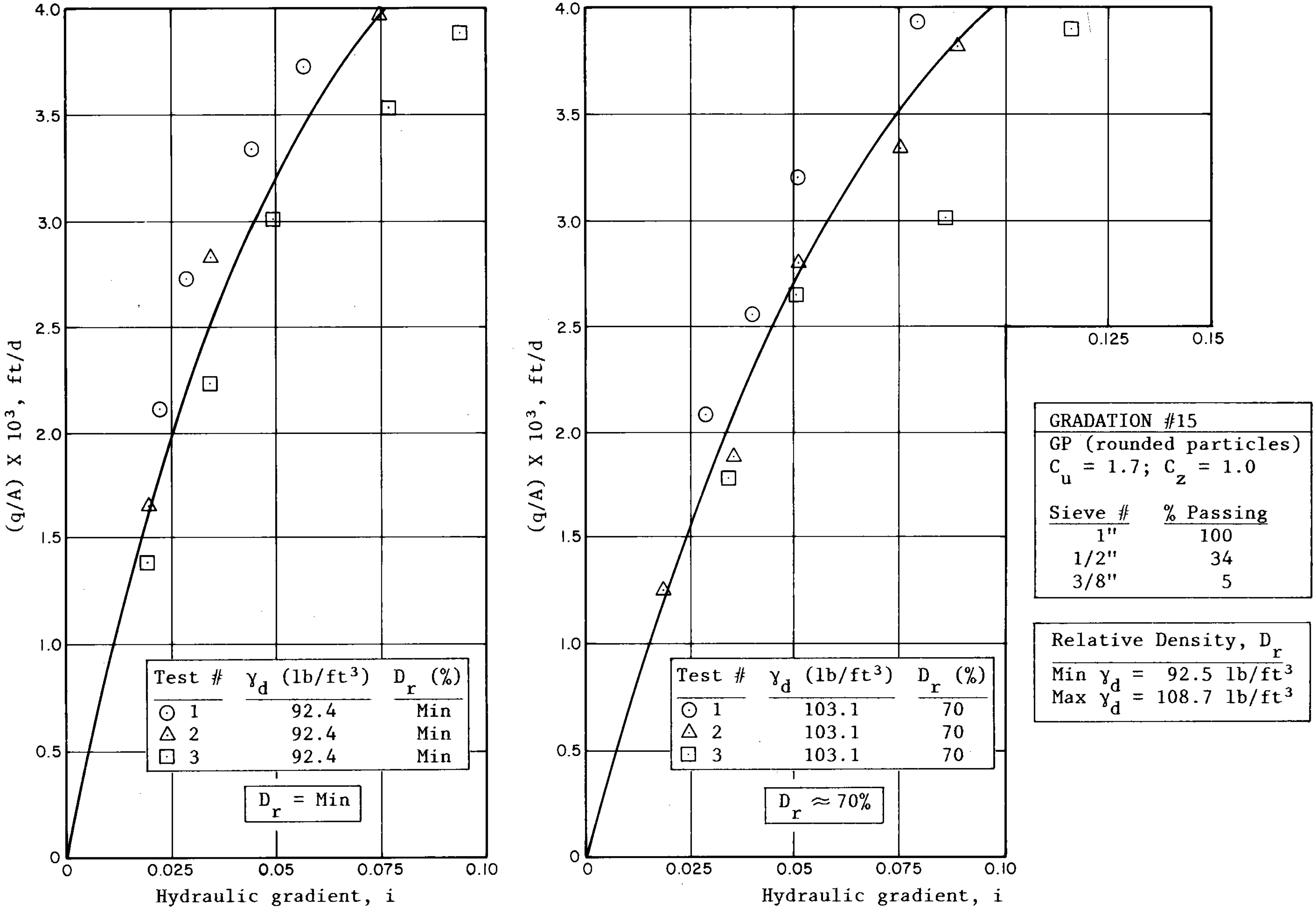


Figure C-15. Relationship between q/A and i for Gradation No. 15 (GP, rounded)

*U.S. GOVERNMENT PRINTING OFFICE : 1984 0-420-951/SCS-628