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SLOPE EROSION CONTROL FOR URBAN FREEWAYS IN ARID CLIMATES

Volume I - Final Report

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16. Abstract

The character and extent of slope erosion damage to urban freeways in the Metropolitan Phoenix, Arizona area was examined. The costs associated with this damage was determined and a reporting program developed to track future erosion damage. A review of existing erosion knowledge and soils within the study area was conducted. As a result of this review a comprehensive testing program was developed to predict the erosion potential of freeway slopes. This existing program incorporates both raindrop impact and overland flow induced stresses on slope surfaces. The effectiveness of vegetation in retarding erosion was also evaluated and found to be marginally effective in arid climates.

Erosion resistance of slope soils was found, in part, to be a function of maximum particle size and the amount of particle larger than 0.18 inches. Using particle size, slope, and resistance to weathering a surface protection scheme was developed that utilized rock fragments. This rock surface acts as an intensely armored surface to protect underlying soils that is effective on slopes as steep as 26 degrees. Maximum particle sizes of up to 1.5 inches with a shape factor larger than 2 were found to provide satisfactory protection.

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SI (Metric) UNIT CONVERSION FACTORS

This report uses both English and SI units with the authors selecting the unit most appropriate. The following factors may be used to convert the measures used in this report to the International System of units (SI):

1 inch = 2.52 centimeters

1 foot = 0.3048 meter

1 pound force = 453.59 grams

1 centimeter per sec = 1.9685 feet per minute

1 gallon per minute = 3.785 liters per minute

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Introduction

The problems presented by erosion to society are both severe and many facetted. The loss in crop production due to erosion will severely restrict long term agricultural capability in this country. The research directed at recognizing soil erosion potential and the development of mitigation measures comes mainly from the concern over food production . The problem of erosion is not limited to agricultural concerns. Erosion along highways represents a major safety concern and produces unsightly conditions for passing motorists. These problems are heightened in urban settings because of the intensification of freeway usage.

Not to be overlooked is the cost associated with erosion along urban freeways. The expenses associated with erosion are enormous because of the diverse activities that are affected by the results. The removal of eroded material from the highway surface is only the beginning. Soil lost from slopes clogs drainage channels. In areas where protective material is used on the slopes, large costs can be associated with the maintenance and repair of that material. An example in the Phoenix Metropolitan area is the granite placed on the slopes. Granite has created excessive pump damage in some areas. Replacement of granite lost from large rills and repair of the cosmetic damage caused by small rills requires the expenditure of many man-hours.

The problem of slope protection is both a short term and a long term one. Three general conditions of the freeway slopes must be considered: 1) Protection of slopes between the completion of the grading operations and final slope protection scheme application. 2) Correction of problems with presently protected slopes that utilize either vegetation or decomposed granite. 3) Protection of all new slopes utilizing the most efficient techniques.

This research report addressed the problems associated with short and long term erosion in the study areas shown in Figure 1. The following objectives provided the initial guidelines for the research.

1. Characterization of soil resistance to erosion. Both original subgrade and plating soils needed to be examined. This characterization had to not only assess erosion potential with respect to slope but with the appropriate freeway environment as well. The latter was especially important since the freeway slopes present unique environments in terms of precipitation, wind turbulence, and solar heating.
2. Development of temporary slope protection measures which were cost effective and compatible with permanent slope protection systems. The temporary systems needed to minimize slope damage for the period of time between the completion of the grading operation and the implementation of the permanent protection systems.
3. Development of the permanent slope protection system or systems. To meet this objective proposed protective systems needed be cost efficient, compatible with freeway

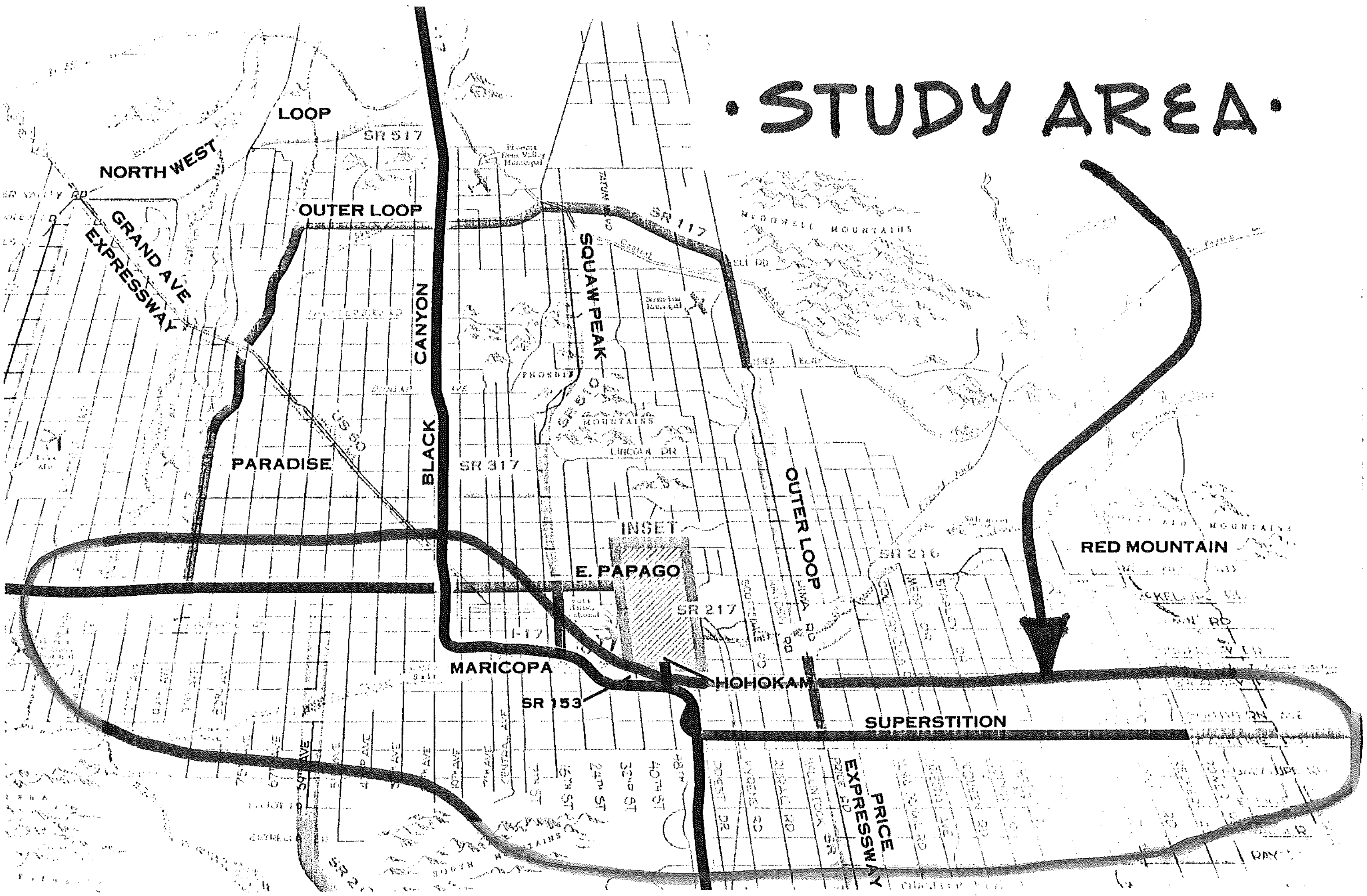

Figure 1. Study Area

ascetics, present no safety concerns to traffic, be resistive to both water and wind erosion, and relatively maintenance free.

4. Review of the existing decomposed granite slope protection material in use. Problems with this material had surfaced, and ADOT wanted to remedy these erosion related difficulties. Decisions concerning whether or not to continue with the granite, find superior alternatives, or rectify the problems by modifying the original material required additional information. Since a considerable amount of granite had already been placed, a reasonable effort needed to be directed towards finding ways to get the maximum return from the granite in place.

5. Development of slope protection systems that restrict the size of soil and granite particles transported to the pumps and drains. To minimize pump damage and reduce rates of drain sedimentation, transport particle sizes needed to be factored into the analysis. Any slope, no matter how well protected, could be expected to yield some sediment during periods of heavy precipitation. Effort needed to be directed to stopping coarse sediment particles. It was not enough to prevent the development of erosion channels on the slope, the water born sediment should also be low in coarse fractions. Proposed protective schemes should produce not only relatively small amounts of erosion, but also particles that were smaller than those brought onto the highway by traffic.

Establishment of Slope Damage

The types and locations of slope damage in the study area were determined through an extensive survey along I-10 and SR 360 during July and August of 1986, After initial assessments, the team developed an inventory for slope erosion damage (Table 1). The inventory was intended to provide information concerning the vegetation, type of slope protection, and extent of slope damage. Areas in the pre-landscaping status were divided into segments based on field observations of rill patterns and vegetation density. Each segment was sectioned by station location. A random station for each segment was evaluated using the inventory sheets.

The landscaped areas were also evaluated using a combination of the inventory sheets and an additional survey. Damage and other conditions related to the granite and plating soils were coded according to a key which had been developed from earlier field observations and is presented in Table 2. Copies of the as-built sheets were used as base maps for recording the damage keys. From these maps specific areas were targeted for inventory.

A total of 64 stations on I-10 and 57 stations on SR 360 were inventoried. Information from the inventory and the based maps containing the coded damage were combined to produce the erosion damage maps. These maps provide an overview of the erosion situation in the study area for a particular time period. Subsequent landscaping activities on I-10 have obliterated the patterns of erosion that appeared in the pre-

Table 1. Inventory Sheet for Slope Erosion Damage.

Freeway ID: I SR Team ______________

Inspection date: __________

Vegetation: Landscaped plants Mulch ______________

Natural vegetation ______________

Recent Disturbance: No Yes: ______________

Slope protection: Granite No protection

Slope facing direction: N S E W

Slope angle ________ degrees Slope length ________ meters

Evidence of erosion:

None Rills Pedistals* Armoring ______________

*Pedistal height: __________ *Fragment size ______________

Other ______________________________

Rill information:

% of slope length containing rills ____________

# of rills = __________ per ________ feet along detail line

Maximum rill width ______________ inches

Maximum rill depth ______________ inches

Comments on erosion pattern:

Table 2. Key For Damage in Landscaped Areas of SR 360.

Code	Description
Granite	
GP -	General designation for granite around plants
GP-1	Plant brushing or sweeping - no erosion
GP-2	Plant brushing or sweeping - erosion
GP-3	Collapse around plant base - no erosion
GP-4	Collapse around plant base - erosion
GP-5	Disturbance caused by maintenance such as foot prints
GO -	General designation for granite in open areas or nonplants areas
GO-1	Collapse perpendicular to dip - no erosion
GO-2	Collapse perpendicular to dip - erosion
GO-3	Shrink-swell cracks - no erosion
GO-4	Shrink-swell cracks - erosion
GO-5	Tire tracks and skid marks
GO-6	Gradation of size down slope
GE -	Erosion around structures
GE-1	Over curbs
GE-2	Light posts
GE-3	Drip emitters
GE-4	Control valves
GC -	Changes in granite characteristics
GC-1	Color differences
GC-2	Amount of fines
GR -	Erosion rills in granite
GR-1	Rills incised into plating material
GR-2	Rills not incised into plating material
Soil	
SP -	General designation for plant areas
SP-1	Rills between plants
SP-2	Crusting between plants
SP-3	Evidence of shrink-swell
SO -	Open areas around plants
SO-1	Rills
SO-2	Crusting
SO-3	Evidence of shrink-swell
SE -	Erosion around structures
SE-1	From emitters
SE-2	Around control valves
SE-3	Over concrete berms
SE-4	Along edges of overpass apron
SA -	Armoring

landscaped surfaces. Future landscaping on SR 360 will destroy the surface recorded in these maps.

The erosion damage maps provide a valuable record that can be used for later comparison of erosional patterns that may develop. For example, differences in the erosional behavior of the granite emplaced along I-10 may be related to the interaction between the granite and the underlying soil. The maps are a historical record of the differences expressed by the soil in the pre-landscaping phase.

Of equal value to the record provided by the maps is the wealth of information that was derived from the careful observation of slope environment. These observations greatly enhanced the understanding of the researchers and influenced the later research effort; therefore, some of these observations warrant discussion.

Although the dominant form of erosion appeared to be sheet erosion from intense rainfall, other sources contributed to the damage in localized areas. The process of overland flow will be discussed in detail in the erosion index testing section. The researchers noted that the slope surfaces immediately adjacent to the concrete base of overpasses often exhibited moderate to deep rills suggesting that undirected runoff was channeling down the slopes. Observation of the rill pattern at the Dysart intersection indicated that the spacing of the rills might be related to the spacing of the bump strips along the side of the highway. Water from the road surface was channeled by the strips. Observation of the deep rills in the granite on the SR 360 overpass for the railroad track each of Country Club suggested that the highway surface on the overpass was acting as a water collection system. Runoff water was cutting a channel parallel to the direction of railroad in the freeway embankment.

Other localized sources of erosion included rills in landscaped areas caused by broken emitters in the drip irrigation lines. Soil in areas with plants but no granite often displayed a rill pattern related to irrigation sprinklers. Observation of the drainage canal along the north side of SR 360 in the vicinity of Stapely Road led to the conclusion that a major portion of the soil in the canal was contributed by the edge of the embankment adjacent to the canal and not from the slope. The upper portion of the south side of the canal embankment was not encased in concrete. Deep cuts in the soil along the unprotected embankment provided evidence of the source.

Although maintenance activities are necessary, some of these activities involve mechanical disturbance of the slopes which may have contributed to conditions conductive to erosion. Traffic on the landscaped slopes was noted as well as frequent tire impacts. Traction from tires may have helped to physically transport granite downslope. It was also noted that some rills in the granite were not filled but were cosmetically repaired by blading. The overall effect was to decrease the thickness of the granite layer for the whole area. The layer may have become too thin to provide sufficient slope protection. This observation was documented in the erosion testing.

Mechanical disturbance in the form of scraping to remove tumbleweed on I-10 may have interfered with the stabilization that was developing in the pre-landscaped areas. The scraping activity removed mulch and the upper layer of soil. Disturbance of the soil destroyed any natural armoring that had occurred and removed dormant seeds that may have provided vegetative cover. Mowing slopes on I-10 scalped existing vegetation and exposed strips of unprotected soil.

The erosion mapping process also provided an opportunity to observe the vegetation in the freeway environment. The grass in the landscaped area in the vicinity of Kyrene Rd. on SR 360 appeared to be stable. No rills were associated with it. With the exception of the bermuda grass, the landscape plants generally did not appear to influence erosion in either a positive or negative manner. Rills that began upslope were traced through plantings of Acacia redolens and appeared to be the same as rills in nearby unplanted soil. In some areas of SR 360 circular depressions in the granite were found. These patterns were always associated with an irrigated landscaped plant. The depressions were apparently related to the response of the underlying soil to wetting. In no instances were any rills in the granite associated with these depressions.

Establishment of vegetation in the pre-landscaped areas altered the erosion pattern and decreased the rill intensity. A good example of this is the grass stand on the railroad overpass between Dysart and Litchfield Roads on I-10. The value of grass in stabilizing slopes is well established and the seeding mix used by ADOT personnel for the pre-landscaped slopes containes several grasses. Observations of the plants along the south side of SR 360 near Greenfield Road indicated that the performance of this mix may be related to the lack of available moisture during the establishment period. In the flat area, adjacent to the slope, the vegetation was growing in the rows created by the seeder. The adjacent south-facing slope contained virtually none of the same plants. Assuming that the soil was similar for each area and that both areas were seeded at the same time, the flat areas was likely to have a higher infiltration rate which would have build up the water storage in the soil. During a dry period, the plants would be able to draw from this stored water. The lower infiltration on the slope would have prevented the increase in plant available water and thus reduced the chances of establishment. The planting date should be timed to allow utilization of stored soil water during early establishment.

Slope observations made in conjunction with the erosion mapping also laid the basis sampling which occurred later in the research. It was noted that the plating soil used in the study area exhibited few differences in surface appearance. The color did not change appreciably nor did the observed texture. Later textural and phosphorus contents confirmed the observed uniformity. Three major types of granite were noted, one at Dysart Rd., one at Val Vista Dr., and one at Gilbert Rd.

Erosion Cost Program

After the extent of erosion had been established, the research team attempted to ascertain the costs associated with it. This effort proved to be time consuming and of little value. The team searched ADOT change orders associated with the study area but found little evidence of erosion related costs. Discussions with the committee overseeing this project led to the conclusion that the most likely source of erosion cost information was the maintenance records stored in the PECOS system. Natalie Rohig, Maintenance Analyst of District 1, identified four activity numbers specifically related to erosion, 169Q (cleaning of erosion material from freeway pumps and drains), 169Z (cleaning of drainage channels), 319F (granite replacement and repair), and 319H (replacement of soil lost from erosion). These descriptions are defined by the 1986-87 Performance Standards/Definitions provided by Highway Maintenance Planning Services.

The costs accumulated in these four activities for the period of March 3, 1985 through June 30, 1986 are presented in Tables 3 through 6. The laborious hand calculations required to obtain the information in these tables indicated a need for a more efficient method of data evaluation. The committee and researchers concluded that a means of accessing the PECOS records was needed. The researchers designed a cost tracking program, which is included in Appendix B. The main concept of the program was based on the realization that many of the costs related to erosion were hidden in acti-

Table 3. Erosion costs listed as dollars per mile for SR 360 Eastbound. Total erosion cost is the summation of costs associated with activities 319 F, 319 H, 169 Q and 169 Z. Slope erosion cost encompasses activities 319 F, 319 H and 169 Q.

Mile Begin	Mile End	Direc-tion	Activity 319 F	Activity 319 H	Activity 169 Q	Activity 169 Z	Total Erosion Cost	Slope Erosion Cost
0.00	1.00	East	1513.73	434.98	0.00	0.00	1948.71	1948.71
1.10	2.00	East	3490.31	436.72	0.00	0.00	3927.03	3927.03
2.10	3.00	East	682.79	223.37	0.00	0.00	906.16	906.16
3.10	4.00	East	0.00	0.00	0.00	0.00	0.00	0.00
4.10	5.00	East	0.00	0.00	0.00	0.00	0.00	0.00
5.10	6.00	East	0.00	0.00	0.00	0.00	0.00	0.00
6.10	7.00	East	0.00	74.33	0.00	0.00	74.33	74.33
7.10	8.00	East	18.29	308.24	0.00	0.00	326.53	326.53
8.10	9.00	East	30.48	501.70	0.00	0.00	532.18	532.18
9.10	10.00	East	12.19	219.51	321.53	0.00	553.23	553.23
10.10	11.00	East	0.00	0.00	562.47	0.00	562.47	562.47
11.10	12.00	East	0.00	0.00	623.39	8462.28	9085.67	623.39
12.10	13.00	East	0.00	0.00	710.75	0.00	710.75	710.75
13.10	14.00	East	0.00	0.00	147.38	0.00	147.38	147.38
14.10	15.00	East	0.00	0.00	81.97	0.00	81.97	81.97
15.10	16.00	East	0.00	0.00	38.36	0.00	38.36	38.36
16.10	17.00	East	0.00	0.00	15.34	0.00	15.34	15.34
			5747.79	2198.85	2501.19	8462.28	18910.11	10447.83

Table 4. Erosion costs listed as dollars per mile for SR 360 Westbound. Total erosion cost is the summation of costs associated with activities 319 F, 319 H, 169 Q and 169 Z. Slope erosion cost encompasses activities 319 F, 319 H, and 169 Q.

Mile Begin	Mile End	Direction	Activity 319 F	Activity 319 H	Activity 169 Q	Activity 169 Z	Total Erosion Cost	Slope Erosion Cost
0.00	1.00	West	3167.67	359.15	0.00	0.00	3526.82	3526.82
1.10	2.00	West	3262.07	365.82	0.00	0.00	3627.89	3627.89
2.10	3.00	West	622.01	150.00	0.00	0.00	772.01	772.01
3.10	4.00	West	0.00	0.00	0.00	0.00	0.00	0.00
4.10	5.00	West	0.00	0.00	0.00	0.00	0.00	0.00
5.10	6.00	West	0.00	0.00	0.00	1304.94	1304.94	0.00
6.10	7.00	West	0.00	74.33	0.00	2224.77	2299.10	74.33
7.10	8.00	West	18.29	899.09	0.00	3287.98	4205.36	917.38
8.10	9.00	West	30.48	1736.97	0.00	9694.70	11462.15	1767.45
9.10	10.00	West	12.19	613.36	321.53	9694.70	10641.78	947.08
10.10	11.00	West	0.00	0.00	562.47	1170.25	1732.72	562.47
11.10	12.00	West	0.00	0.00	623.39	4234.45	4857.84	623.39
12.10	13.00	West	0.00	0.00	710.75	18090.72	18801.47	710.75
13.10	14.00	West	0.00	0.00	147.38	2878.36	3025.74	147.38
14.10	15.00	West	0.00	0.00	81.97	0.00	81.97	81.97
15.10	16.00	West	0.00	0.00	38.36	0.00	38.36	38.36
16.10	17.00	West	0.00	0.00	15.34	0.00	15.34	15.34
			7112.71	4198.72	2501.19	52580.87	66393.49	13812.62

Table 5. Erosion costs listed as dollars per mile for I-10 Eastbound. Total erosion cost is the summation of cost associated with activities 319 F, 319 H, 169 Q and 169 Z. Slope erosion cost encompasses activities 319 F, 319 H, and 169 Q.

Mile Begin	Mile End	Direc-tion	Activity 319 F	Activity 319 H	Activity 169 Q	Activity 169 Z	Total Erosion Cost	Slope Erosion Cost
128.00	129.00	East	0.00	3871.66	0.00	0.00	3871.66	3871.66
129.10	130.00	East	1692.36	5310.05	0.00	0.00	7002.41	7002.41
130.10	131.00	East	0.00	0.00	0.00	0.00	0.00	0.00
131.10	132.00	East	0.00	0.00	0.00	0.00	0.00	0.00
132.10	133.00	East	0.00	0.00	0.00	0.00	0.00	0.00
133.10	134.00	East	0.00	0.00	0.00	0.00	0.00	0.00
134.10	135.00	East	0.00	0.00	950.34	0.00	950.34	950.34
135.10	136.00	East	0.00	0.00	2930.12	0.00	2930.12	2930.12
136.10	137.00	East	0.00	0.00	156.28	0.00	156.28	156.28
137.10	138.00	East	0.00	0.00	1188.92	0.00	1188.92	1188.92
138.10	139.00	East	0.00	0.00	28.02	0.00	28.02	28.02
139.10	140.00	East	0.00	0.00	28.02	0.00	28.02	28.02
140.10	141.00	East	0.00	0.00	56.21	0.00	56.21	56.21
141.10	142.00	East	0.00	0.00	121.98	0.00	121.98	121.98
142.10	143.00	East	0.00	0.00	85.38	0.00	85.38	85.38
			1692.36	9181.71	5545.27	0.00	16419.34	16419.34

Table 6. Erosion costs listed as dollars per mile for I-10 Westbound. Total erosion cost is the summation of cost associated with activities 319 F, 319 H, 169 Q and 169 Z. Slope erosion cost encompasses activities 319 F, 319 H and 169 Q.

Mile Begin	Mile End	Direction	Activity 319 F	Activity 319 H	Activity 169 Q	Activity 169 Z	Total Erosion Cost	Slope Erosion Cost
128.00	129.00	West	0.00	2597.88	0.00	0.00	2597.88	2597.88
129.10	130.00	West	3368.31	2578.50	0.00	0.00	5946.81	5946.81
130.10	131.00	West	0.00	0.00	0.00	2073.93	2073.93	0.00
131.10	132.00	West	0.00	0.00	0.00	3233.65	3233.65	0.00
132.10	133.00	West	0.00	0.00	0.00	7804.20	7804.20	0.00
133.10	134.00	West	0.00	0.00	0.00	1006.71	1006.71	0.00
134.10	135.00	West	0.00	0.00	2651.89	5720.66	8372.55	2651.89
135.10	136.00	West	0.00	0.00	3487.85	1854.17	5342.02	3487.85
136.10	137.00	West	0.00	0.00	1167.98	1078.82	2246.80	1167.98
137.10	138.00	West	0.00	0.00	463.87	0.00	463.87	463.87
138.10	139.00	West	0.00	0.00	1045.00	0.00	1045.00	1045.00
139.10	140.00	West	0.00	0.00	28.02	0.00	28.02	28.02
140.10	141.00	West	0.00	0.00	56.21	0.00	56.21	56.21
141.10	142.00	West	0.00	0.00	121.98	0.00	121.98	121.98
142.10	143.00	West	0.00	0.00	85.38	0.00	85.38	85.38
			3368.31	5176.38	9108.18	22772.14	40425.01	17652.87

vities other than the four mentioned above. To account for these costs, the researchers interviewed various ADOT personnel. The activities selected for the program and the percent of erosion related cost or factor for each activity were based on the consensus of the ADOT personnel. The actual programming was completed by ADOT personnel under the supervision of Mr. John Daru.

The final version of the erosion cost tracking program should prove extremely useful to future users. The program is entitled the PECOS Roadside Activity Costing System Report/File Search Procedure. It is user interactive and utilizes the PC as the accumulator of information pertaining to the data requested. An upload-download procedure accesses the PECOS records. The time efficiency of the program has been enhanced by disk storage of records pertaining to certain activity numbers for the five years previous to the current date. Options within the program allow changes in both the activity list and factors which enable the program to be tailored to the needs of the individual users. In cooperation with the programmers, the research team wrote a User Manual for the procedure. The manual is provided in Appendix C.

Evaluation of Soils in the Study Area

Sampling and chemical analysis

The soils of the study area were examined in order to determine their variability and their limitations as plant growth media. Establishing the variability allowed the researchers to make decisions concerning other aspects of the project. Evaluating the chemical and physical properties of the soils determines what if any factors might be growth limiting to plants. Information on both variability and limiting factors will be needed in selecting test sections which are representative of the area.

Forty-two soil samples were taken in the study area. Samples of shallow depth were collected from a ten inch (25.4 cm) auger hole while deeper samples were taken with a tube sampler which was driven in by hand. The location of and general field observations for each sample are given in Appendix D.

The researchers identified three potential sources of soil variation in the study area. They were route location, soil associations present before construction, and soil environmental types after construction. The route location was selected because of potential differences in construction since the two highways that comprise the study area are not adjacent to each other.

Several soil associations exist in the area. Soil associations as defined by the USDA Soil Conservation Service represent a distinctive and proportional pattern of individual soils in a natural landscape. They are a product of the soil forming factors interacting with parent material and represent the broadest differences present in the area. Although small differences between individual soils may be obliterated by the disturbance that occurs during construction, the researchers felt that the post construction environment might still contain elements of the soil associations.

The associations present along SR 360 are described by the Soil Survey of Eastern Maricopa and Northern Pinal Counties Area, Arizona. The associations are the Laveen Association, the Mohall-Contine association, and the Gilman-Estrella-Avondale association. The associations along I-10 are described in the Soil Survey of Maricopa County, Arizona (central part) and include the Gilman-Estrella-Avondale association, the Carrizo-Brios association, and Laveen-Collidge association.

The concept of soil environment types present after construction developed from field observations and from a general understanding of the interaction of plants and soils. From a vegetation aspect, the freeway environment represents drastically disturbed land. The natural equilibrium between the plants and the soil that existed before construction has been destroyed. A new environment in a state of disequilibrium is now present. Much of what is known in traditional disciplines such as plant science and soil science does not directly apply to that new environment until the equilibrium is reestablished.

Because the drastically disturbed environment does not always conform to the expected responses of a natural landscape, new soil-plant growth units or types must be established. The freeway environment can be classified into three types of materials: plating, fill, and nonfill. Plating soil is synonymous with top soil in surface mine reclamation. It is the upper portion of the natural soil which was removed before disturbance and replaced on the surface as a plant growth medium after disturbance. This procedure recognizes the value of the natural soil and is required by law in the reclamation of lands disturbed by surface mining. The depth of this plating material in the study area is generally about two feet (0.6 meters). The source is the upper four feet (1.2 meters) of material in the excavated region of the freeway according to the as-built plans for SR 360 and I-10. For plants with fibrous root systems, the plating material may be considered the rooting zone; however, many landscape trees and shrubs have a tap root system and would be expected to extend their roots much deeper than two feet unless restricted by impenetrable layers.

The material beneath the plating soil is of two types. Fill material is placed on the existing ground surface and nonfill is the undisturbed material present beneath the ground surface. The fill material is not usually composed of natural soil since soil as a plant growth medium is described as the upper 80 inches (203 cm) of undisturbed sediment. Fill would generally be taken from the areas excavated for the highway or from an unknown source. It is subsurface material that has been mixed and compacted. If the matrix had been cemented, it was partly or completely destroyed during the emplacement process. Since the nonfill material is undisturbed subsurface material, cementation is not likely to be destroyed and may represent a serious impediment to plant roots.

Since this concept of soil environmental type has implications for the landscape design, the properties of the three types needed to be explored along with possible differences due to route location and soil associations. The sampling scheme for the soils was designed to evaluate potential differences in the plating, fill, and nonfill types.

The analysis of the 42 samples was performed on soil material which was air-dried and passed through a 2 mm sieve. The determination of the textural class of each sample was based on the percent sand, silt and clay as measured by the hydrometer method and plotted on the soil textural triangle. The pH was determined in a 1:1 ratio of soil to distilled water and measured with a pH meter. The electrical conductivity (EC) of the saturated paste extract was measured with a Beckman electrical conductivity bridge using a cell constant of 1. The available phosphorus (P) was determined by the sodium bicarbonate method which is the most common phosphorus procedure for alkaline soils in the western United States. The results from the above procedures provide information about the ability of the soils to act as a plant growth medium.

<u>Statistical analysis</u>

The mean value, range, standard deviation, and 95% confidence interval about the mean for the pH, percent sand, percent silt, percent clay, EC and P are provided in Table 7. Although the range for all parameters except pH appears to be wide, the small values for the standard deviation and the narrow confidence intervals indicate that the dispersion of the data about

Table 7. The mean value, range, and the 95% confidence interval for measured parameters of 42 soil samples taken from SR 360 and I-10.

PARAMETER	RANGE	MEAN	STD DEV	95% CONFIDENCE INTERVAL
Sand, %	6 - 66	40	11.97	36.3 - 43.7
Silt, %	19 - 50	32	7.70	30.1 - 34.9
Clay, %	8 - 49	28	9.43	24.6 - 30.4
pH	7.4 - 8.8	8.2	0.27	8.0 - 8.3
EC, dS/m	0.3 - 5.7	1.8	1.11	1.5 - 2.1
P, ppm	1.1 - 17.6	4.9	3.18	3.9 - 5.9

the mean is narrow. It can be deducted that the variability of these parameters in the study area is low; therefore only a few samples are needed to characterize the area.

The lack of variability also appears in the soil textural classes which are determined by the percent sand, silt and clay. The classes are listed in Table 8. along with the raw data. Thirty six percent of the samples were classified as loam, 31% were clay loam, 14% were sandy clay loam, 7% were sandy loam, 5% were clay, 5% were silty clay loam, and 2% were silty clay. The textural classes of loam and clay loam account for two thirds of the samples analyzed. The mean values for percent sand, silt and clay in Table 7 can be used to calculate an "average" soil texture for the area. A soil with 40% sand, 32% silt, and 28% clay would be classified as a clay loam bordering on a loam.

An analysis of variance (ANOVA) was used to evaluate the effect of route location, soil association, and soil environmental type. The percent sand, percent clay, pH, electrical conductivity, available phosphorus were used as dependent variables while location, association and type were independent variables. The design was a factorial but the interactions were not significant and were pooled into the error term. The results for the resulting ANOVA's are provided in Tables 9 through 13. When percent sand was used as the dependent variable, only the soil association was significant at the 0.05 alpha level (Table 9). This may be interpreted that the percent sand in the sample is related to the soil association from

Table 8. Raw data for 42 soil samples collected in study area.

(a) #	(b) Loc.	(c) Type	(d) Soil Assoc.	(e) Tex. Class	(f) % Sd	% St	% Cy	pH	(g) EC dS/m	Avail. P, ppm
1	360	F	E3	CL	31	36	33	8.4	0.3	6.4
2	360	P	E5	CL	39	31	30	8.0	2.0	6.3
3	360	F	E5	CL	39	30	31	8.2	1.2	7.0
4	360	P	E5	L	44	29	27	8.1	2.4	3.2
5	360	F	E5	L	40	36	24	8.0	2.3	5.7
6	360	P	E3	CL	25	38	37	8.3	1.5	3.1
7	360	P	E4	SCL	52	19	29	7.7	3.0	5.4
8	360	F	E4	SCL	49	20	31	7.8	2.8	5.8
9	360	P	E3	C	30	30	40	8.2	2.6	5.8
10	360	F	E3	CL	34	33	33	8.0	1.4	11.2
11	360	P	E4	CL	42	22	36	8.0	1.8	7.0
12	360	F	E4	CL	42	22	36	8.0	1.5	7.0
13	360	P	E4	SCL	42	25	33	8.2	1.4	6.3
14	360	F	E3	C	27	24	49	8.6	---	3.6
15	I10	P	C1	TC	6	50	44	7.9	4.9	7.6
16	I10	P	C3	L	45	35	20	8.5	0.5	7.2
17	I10	P	C1	TCL	19	42	39	8.0	1.6	4.3
18	I10	P	C7	L	35	39	26	8.5	0.5	4.7
19	I10	P	C7	L	33	41	26	7.8	5.7	1.7
20	I10	P	C1	TCL	14	48	38	8.4	1.0	2.7
21	I10	P	C7	L	39	36	25	8.8	0.7	2.5
22	I10	P	C1	CL	31	42	27	8.5	1.3	2.2
23	I10	N	C7	CL	31	36	33	8.1	1.9	4.2
24	I10	N	C3	CL	39	34	27	7.9	1.9	10.0
25	I10	P	C1	L	46	33	21	8.3	1.0	5.2
26	I10	P	C7	L	44	32	24	7.9	1.3	11.1
27	I10	N	C7	CL	23	38	39	8.2	0.6	2.5
28	I10	P	C1	CL	42	23	35	8.1	0.9	3.5
29	I10	P	C1	L	42	42	16	8.3	1.6	3.3
30	I10	P	C1	L	44	37	19	8.1	2.0	4.3
31	I10	N	C1	L	39	44	17	8.3	1.1	1.1
32	I10	F	C7	L	50	32	18	8.1	1.5	3.2
33	I10	P	C7	SCL	52	23	25	8.4	0.7	2.8
34	I10	F	C7	SCL	51	27	22	8.0	2.8	3.1
35	I10	N	C7	SL	66	26	8	8.2	1.6	2.0
36	360	F	E3	L	45	29	26	8.0	2.7	1.9
37	360	P	E3	SCL	50	27	23	8.2	2.9	2.0
38	360	N	E3	CL	41	22	37	8.2	2.9	4.4
39	360	N	E5	SL	62	30	8	7.9	1.3	4.6
40	360	P	E5	L	48	40	12	7.4	0.6	17.6
41	360	F	E5	L	50	34	16	8.5	1.4	2.3
42	360	F	E4	SL	57	26	17	8.4	0.8	1.9

(a) # refers to the lab number assigned for analysis.
(b) Location refers to SR 360 or I-10.
FOOTNOTES CONTINUED ON FOLLOWING PAGE

Table 8. (continued - footnotes)

(c) Type is designated as P=plating, F=fill, and N=nonfill.
(d) Soil associations are described by the name and survey:
- E3 = Laveen association, Eastern Maricopa
- E4 = Mohall-Contine association, Eastern Maricopa
- E5 = Gilman-Estrella-Avondale association, Eastern Maricopa
- C1 = Gilman-Estrella-Avondale association, Central Maricopa
- C3 = Carrizo-Brios association, Central Maricopa
- C7 = Laveen-Collidge association, Central Maricopa

(e) Textural classes are abbreviated as:
- CL = clay loam
- L = loam
- SCL = sandy clay loam
- TC = silty clay
- TCL = silty clay loam
- SL = sandy loam

(f) %Sd = % sand; %St = % silt; %Cy = % clay.
(g) dS/m is deciseimens per meter and is equivalent mMho/cm.

Table 9. Analysis of variance table for percent sand.

DEPENDENT VARIABLE: SAND R-SQUARE = 0.303423

SOURCE	DF	SUM OF SQUARES	F VALUE	PR > F
MODEL	7	1781.70104746	2.12	0.0685
LOC	1	228.66666667	1.90	0.1770
TYPE	2	221.80556226	0.92	0.4075
ASSOC	4	1331.22881853	2.77	0.0430
ERROR	34	4090.29895254		
CORRECTED TOTAL	41	5872.00000000		

Table 10. Analysis of variance table for percent clay.

DEPENDENT VARIABLE: CLAY R-SQUARE = 0.272320

SOURCE	DF	SUM OF SQUARES	F VALUE	PR > F
MODEL	7	991.89784674	1.82	0.1158
LOC	1	82.88095238	1.06	0.3098
TYPE	2	85.94158301	0.55	0.5813
ASSOC	4	823.07531135	2.64	0.0507
ERROR	34	2650.50691517		
CORRECTED TOTAL	41	3642.40476190		

Table 11. Analysis of variance table for pH.

DEPENDENT VARIABLE: PH R-SQUARE = 0.146554

SOURCE	DF	SUM OF SQUARES	F VALUE	PR > F
MODEL	7	0.42863466	0.83	0.5667
LOC	1	0.11523810	1.57	0.2188
TYPE	2	0.06682639	0.46	0.6382
ASSOC	4	0.24657017	0.84	0.5097
ERROR	34	2.49612725		
CORRECTED TOTAL	41	2.92476190		

Table 12. Analysis of variance table for electrical conductivity (EC).

DEPENDENT VARIABLE: EC R-SQUARE = 0.037361

SOURCE	DF	SUM OF SQUARES	F VALUE	PR > F
MODEL	7	1.83971186	0.18	0.9871
LOC	1	0.29109408	0.20	0.6555
TYPE	2	0.39500784	0.14	0.8720
ASSOC	4	1.15360995	0.20	0.9361
ERROR	33	47.40223936		
CORRECTED TOTAL	40	49.24195122		

Table 13. Analysis of variance table for available phosphorus (P).

DEPENDENT VARIABLE: P R-SQUARE = 0.213830

SOURCE	DF	SUM OF SQUARES	F VALUE	PR > F
MODEL	7	88.59063019	1.32	0.2706
LOC	1	20.44023810	2.13	0.1533
TYPE	2	9.32558084	0.49	0.6188
ASSOC	4	58.82481126	1.54	0.2141
ERROR	34	325.71341743		
CORRECTED TOTAL	41	414.30404762		

which it was derived but not to the route location or the soil environmental type. When percent clay was used as the dependent variable in the ANOVA, the soil association was very close to being significant at the alpha level of 0.05 (Table 10). The relationship between soil association and soil physical properties such as particle sizes is to be expected. As mentioned earlier the soil associations represent broad differences across landforms. Some of these differences are due to type of parent material which in turn is related to soil texture.

The results are different when soil chemical properties are considered. None of the main effects of location, type, or association were significant when the dependent variable was pH (Table 11). Only 3% of the variability of the electrical conductivity can be explained by location, type, and association (Table 12). The same factors were also not significant when available phosphorus was the dependent variable (Table 13). Differences in soil chemical properties in the study area are not directly related to the route location, the soil association, or the environmental type.

Several conclusions can be drawn from the statistical analysis described above. If soil associations have been established by a soil survey completed by the Soil Conservation Service, the associations may become a useful planning tool in identifying areas that would be expected to show differences in soil physical properties. The amount of sand and clay greatly influences the infiltration and water holding capacity of the soil as well as its susceptibility to compaction. These properties are important to plant establishment and survival. The information from the soil associations could be supplemented with bore holes logs to provide a better evaluation of the expected properties of the plating soil and fill material.

Another conclusion that may be drawn is that plating soil may not have been necessary in this area since the soil environmental type did not relate to any of the properties measured. The researchers would caution against using this information to discontinue the use of plating soil. It would appear that the plating soil of the study area is similar to the sampled fill and nonfill. The results may not be applicable to other areas. For instance, observation of the construction area for the pump house at I-10 and 7th Street in May, 1987 indicated that plating soil would be absolutely necessary. The upper 10 feet (3.0 meters) of the cut consisted of light brown, fine grained, soil-like material. Beneath the upper layer was river gravel characterized by smooth stones whose longest dimension was roughly 10 inches (25.4 cm). The upper portion of the granite did not appear to be cemented but with depth the matrix appeared almost rocklike. In this section of the freeway, a finished slope face would extend into the gravel and possibly into the cemented zone. Plants placed directly in the gravel would experience water problems since not enough fines were present to insure good water supply to the plants. The cemented zone would not support plant life.

Suggested criteria for plating soil

Perhaps what is needed are criteria as to when a plating soil is required. These criteria should be based on the physical and chemical properties of the material that is expected to act as the root zone. Without plating soil, the growth medium becomes the fill material placed above the ground surface and the undisturbed material present along the cut faces of the slopes. For any location if either or both of these materials can be judged suitable as a plant growth medium, then they could be used in place of the plating soil.

Suggested criteria for suitability are based on texture, density, and chemical parameters. The texture of the material that is less than 2 mm (#10 screen) should be loam or an associated loamy texture such as clay loam, silt loam, silty clay loam, sandy loam or sandy clay loam. Less acceptable textures would be clay, sandy clay, silty clay, silt, loamy sand, or sand. The amount of coarse fragments (greater than 2 mm) should probably not exceed 35% by volume. These textural criteria insure good water holding capacity and provide a potentially high cation exchange capacity which is needed for plant nutrient supply. Only three samples in Table 8 have one of the less desirable textures; two are plating soils, and one is fill material.

In all situations, the plants should still be planted in a pit excavated in the surface material. If the rooting zone is comprised of fill or nonfill, then a larger pit might provide a better opportunity for the plant to become established. The pit should contain good quality topsoil amended with fertilizer and/or organic material. Analysis of the available phosphorus in the study area indicates that the levels are generally low. A rule of thumb used in for agronomic plants is that the sodium bicarbonate extractable phosphorus should be above 5 ppm. Levels between 5 and 10 ppm indicate sufficient phosphorus for moderate growth. Plants growing in soils with greater than 10 ppm P generally do not show a response to additions of phosphorus fertilizer. Twenty three soil samples in the study area had values less than 5 ppm while only four had more than 10 ppm (Table 8).

It should be noted that problems might arise if the texture of the material used in the plant pit differs strongly from the surrounding surface material. If the texture of the surface material is much coarser than the material in the pit, irrigation water will not move readily across the contact between the two materials. This will result in restriction of the roots to the pit which increases the chances of wind throw and reduced survival under stress. On the other hand, if the texture of the surface material is much finer than the pit material, then the water will be drawn away from the pit material. In the early stages of growth, the plants could be damaged by a lack of available water. The amount of irrigation water applied must be adjusted to compensate for the loss of water from the root growth area when the plants are first established. After establishment, water application should be readjusted to encourage the plants to explore the material outside the pit. High water rates will retard root exploration since sufficient water will be available.

The density of the root zone materials should be in the same range as the surface soils of the area. Many of the landscape plants currently in use are natives to arid areas and are generally adapted to the soil conditions of the region including the soil density. Examination of some of the borings made on SR 360 and I-10 indicates that the blows per foot with a 1.4" I.D. standard penetration spoon sampler might be used as the density criteria. In general non-cemented materials with suitable textures appeared to have SPT values from 10 to 75 blows/ft. This range included dry and moist samples. Most of the material in the portion of the core that would be exposed as the slope face or used for fill should show a density that requires less than 75 blows/ft.

Two important chemical parameters are pH and EC (electrical conductivity). The pH will provide an indication of the exchangeable bases (Ca, Mg, Na, and K) present on the soil cation exchange sites. These bases are essential for plant growth. It also provides information on nutrients that might be insoluble. For instance, at pH values greater than about 6.5, micronutrients such as Fe, Zn, Cu and Mn are very insoluble in solution. Plants that have evolved in areas where the soil pH is greater than 7 may have difficulty obtaining these micronutrients from the soils of the study area.

The pH can also indicate sodium problems in normal surface soils. A soil with a pH greater than 8.5 has a potential for moderate to high levels of sodium. The acceptable pH range is between 6 and 8.5. If the pH is greater than 8.5 then the sodium adsorption ration (SAR) should be evaluated. The SAR is a good indicator of sodium since it accounts for the mitigating effect of Ca and Mg. Only one sample in Table 8 had a pH value greater than 8.5. The lack of high pH values and the calcareous particles observed in the soils suggest that sodium is not a problem in the study area.

The EC provides an indication of the salt content of the soil. For most agronomic plants EC values greater than 4 dS/m (equivalent to 4 mMho/cm) will strongly affect plant growth and survivability. Since the salt tolerance of native landscape plants is not actually known, the 4 dS/m should be used as a conservative guideline.

The number of samples needed to establish whether the material on the cut face or the fill material is acceptable plant growth medium must be established. As expected, the more variable the material is, the more samples are needed to characterize it. Perhaps one or more samples within each half mile interval may be sufficient. If 90% of these samples meet the plant growth medium criteria, then the material could be deemed suitable for plant growth.

<u>Separation of environments</u>

A second issue in the use of plating soil should be addressed. This concerns changing the design concepts of the freeway in order to segregate the engineering environment from the plant growth environment. In this situation the environment refers to the parameters that must be present to fulfill the design standards. The two environments are usually inversely related. What is a good environment by engineering standards generally is a poor environment for plant growth. For instance, the slope materials must be compacted to insure the stability of the slope (engineering environment); however, compaction of plant growth medium (plant environment) increases resistance to root penetration and water infiltration at the surface resulting in poor plant growth and survivability.

An example of the segregation of two environments would be the restriction of deep-rooted shrubs and trees to the areas at or above the existing ground surface. The region above the existing ground level is composed of fill material and is dominated by the plant environment. The emplacement of the fill disrupts cemented zones in the original material which may allow better water infiltration and percolation.

In the above example, the undisturbed area below the existing ground level on the slope face is dominated by the engineering environment. If plants are not located on this portion of the slope, then plating this area may not be needed. Properties of the undisturbed material such as its density and its ability to armor could be utilized in the slope stabilization.

Erosion Index Testing of Slope Materials

The study team began the program of assessing slope erosion by reviewing available literature. In Appendix A summary of the literature reviewed and major topic grouping of each source is provided. A great deal of information on the Universal Soil Loss Equation and modifications to this predictive equation were found. There are two basic problems with using predictive techniques such as the Universal Soil Loss Equation and those of a similar genre to predict slope erosion. These are:

1. These predictors of erosion require parameters for soil and events that are difficult to predict or quantify. For example soil erodibility is a key parameter and extremely difficult to predict especially for highway slopes which experience both construction and maintenance activities. Unfortunately, the more parameters that must be input into the predictive equation, the greater the potential to err in determining a parameter. This potential is coupled with the fact that most applications in which the result is checked against the predicted erosion are in rather flat laying sites.
2. The effects of changing slope erosion resistance with time are also not considered in the predictive techniques reviewed. The research team has observed that most soils and rock masses develop increasing resistance to erosion with time. The predominant reason in soils for this increasing resistance is due to the armoring of the surface by the larger particles present in the soil. This protection tends to become more effective with time as the surface concentration of the larger particles increases. The reason for the increasing concentrations of larger particles is the removal of sand size and finer soil

particles. The larger particles are in effect left behind. As the coarse particle concentrations grow at the surface, the underlying soil becomes ever more protected. The underlying soil is protected until an erosion event severe enough to remove the coarse accumulations occurs. The research team concluded that any attempt to predict erosion must incorporate a simplified assessment of slope erosion resistance and must consider the change in erosion resistance with time.

In the previous discussion, the importance of the coarse size fraction in changing resistance with time was mentioned. However, the review of the literature failed to provide real guidance on how erosion resistance was related to size distribution and surface protection. The literature that was discovered applied to cultivated fields. Though numerous examples of slope armoring can be found, the authors were unable to find any quantification of the experience of others concerning armoring of slopes.

Development of the Research Program

The study team initially proposed to develop an index to erosion testing program which would reference slope material erosion to actual slope materials where a history of erosion was available. To accomplish this objective, it was decided to select several sites along SR 360 and I-10 in the greater Phoenix Metropolitan area as index sites. Samples of those site surface materials would be tested under a simulated rainfall that was the same as the predicted 50 year 30 minute event. The test duration, at this event's fall rate, would be determined as the testing began. The samples to be tested were to be placed into 2.0 by 2.0 ft panels. The testing would then proceed by placing the panels at predetermined slopes and then use spray heads to apply the precipitation.

Once the erosion performance of the materials was determined, that performance would be compared to observed slope erosion behavior. Additional materials not taken from existing slopes would also be tested and their performance indexed to the known slope performance.

Observations of Slope Damage

The planned program was modified, however, as a result of a storm that occurred during October 1986. This storm produced significant erosion damage on several sections of SR 360. The freeway was closed due to slope material that had been washed from the slopes. Slope damage west of Gilbert Road, can be seen on Plate 1.

The study team took the opportunity to examine the slope damage and noticed several phenomena that provided insight into the slope erosion processes. When Plate 1 is examined, the visible erosion pattern is striking. Not only is the density of the rills high but their spacing is remarkably uniform. The rills also start at the same location on the slope. Plate 2 presents a side view showing the rill start point relative to slope curvature.

Plate 1. Slope Damage SR 360 West of Gilbert Road.

Plate 2. Profile of Slope Erosion Damage, West of Gilbert

The slopes in this section were protected with approximately 0.5 to 1.0 inches of granite slope protection, which when sampled was designated as SRG8 for later reference. The profile of the slope shown in Plate 2 is provided on Figure 2.

The authors concluded from these observations, and others along the alignment that in terms of erosion what stressed the slopes the most was the overland flow contributed from the upper slope segments. When Plate 1 is reviewed, the relationship between the upper slope reach that contributes water to the steeper lower segment is apparent. It was the water delivered to the break in slope shown on Plate 2 that created the slope damage. It is the overland flow, which when combined with the precipitation falling on the lower slope segment, that cuts the rills. Though raindrop impact and lower slope precipitation contribute to slope destabilization and transport of particles, it is the overland flow that arrives in microdrainages that controls the slope erosion forces. The mean spacing of the rills on Plate 1 varies but is approximately 3 feet. The upper slope microdrainages which were observed to range from approximately 3 to 8 feet are suspected to be a function of upper slope segment slope, upper segment length, and quality of grading.

The implications of the upper slope overland flow observations are numerous. The first one that the research team addressed was the erosion index testing program. It was clear that any erosion testing program that was expected to predict slope material resistance to erosion must consider overland flow. Overland flow is hereafter defined as water delivered to a slope surface via a microdrainage system.

It was recognized that any slope protection scheme that was under consideration must also resist an overland flow contribution to erosion if it were to survive on the slope. The observation of slope damage also made it clear that slope design and maintenance procedures should minimize the amount of slope surfaces that received flow via these channels.

The granite thickness west of Gilbert Rd. was less then the original thickness which was supposed to be placed at a thickness of 2.0 inches. During the preparation of the research proposal the study team had noticed that the granite surface protection on most slopes was much thinner than expected. When the eroded slopes were examined, it was discovered that previous rills had been filled by blading the slope granite into them. Earlier storms had cut rills through the original two inch thick protection. These early rills when filled, contributed to the decreasing thickness of the surface protection.

West of Val Vista Rd. on SR 360 is another example of slope damage as shown in Plate 3. When the plate is examined, it is apparent that the rills exist essentially only in the planted areas. Rills were not found on sections of the slopes where plants had not been placed. The surface protection on these sections as well as where Plate 3 was taken is a granite designated SRG1. This granite was placed in the spring and summer of 1986 and was not only approximately 2 inches thick but also contained larger particle sizes than did the SRG8 mate-

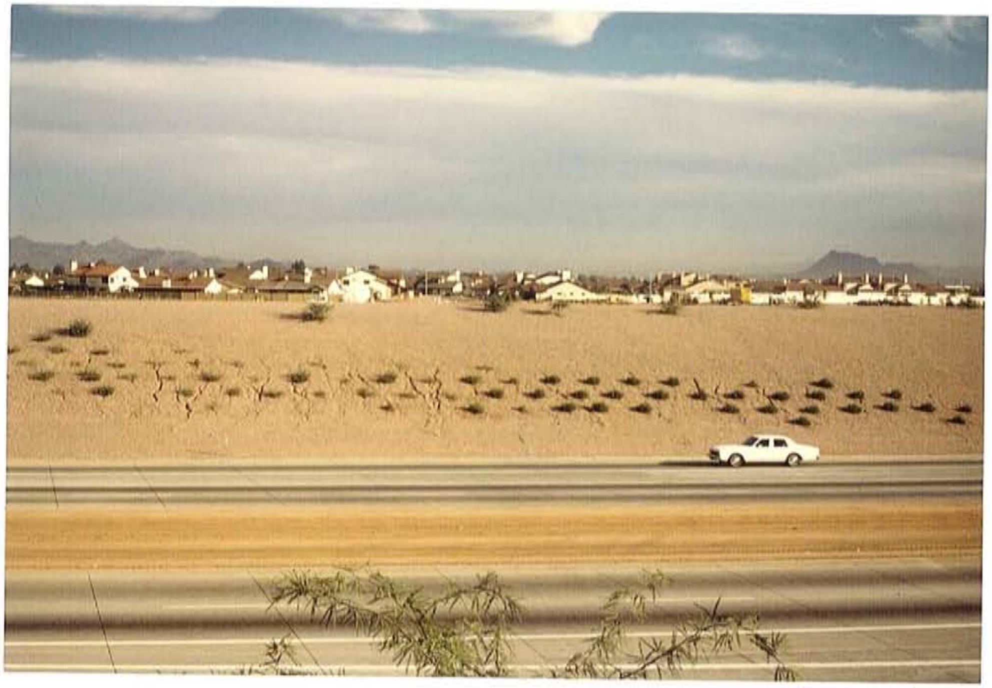

Plate 3. Dlope Damage SR 360 West of Val Vista Road.

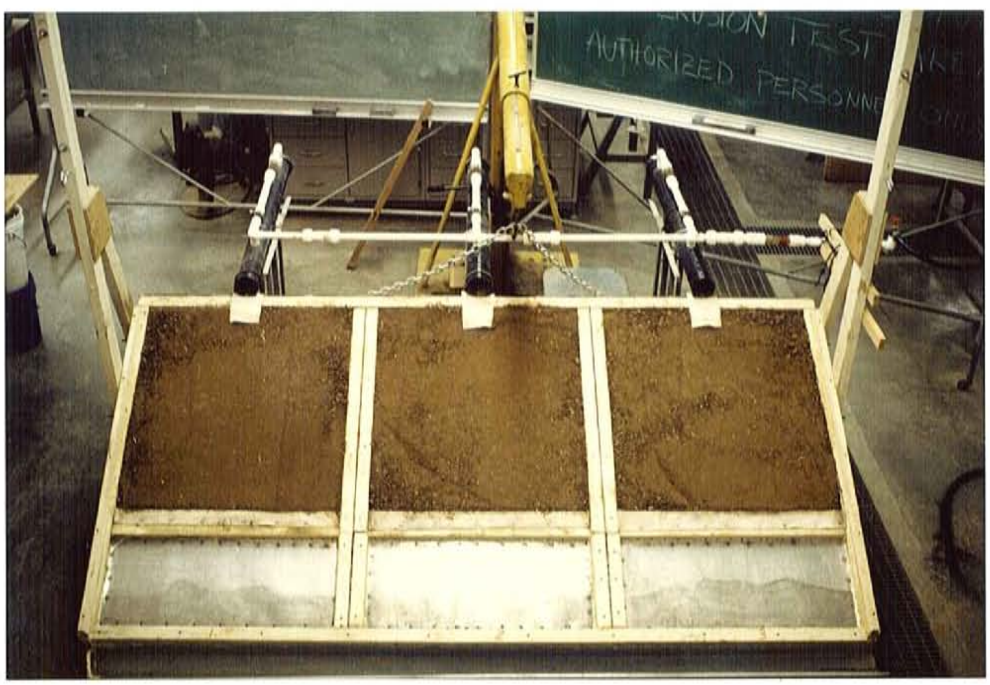

Plate 4. Front View of Erosion Test Cell

rial. The observations at this location led the study team to suspect that the low density soil beneath the SRG1 material had allowed undermining of that material to occur. In other locations, where a higher density subgrade existed, such rill development was resisted by the SRG1 material.

It appeared possible to simulate the erosive effects observed in the laboratory and then have two controlled field sections whereby the lab results could be verified.

However, to do this the planned testing program would have to be significantly modified. The study team contacted ADOT and received approval to modify the testing program to incorporate the influence of overland flow.

Erosion Test Apparatus

To simulate the combined effects of precipitation and overland flow, an erosion cell was constructed. The main elements of the cell were a three panel bank which contained three replicated specimens of the material to be tested, and a overland flow simulator component. Each panel was 2.67 ft long in the slope dimension by 2.5 ft wide and allowed placing the material to a thickness of 2.5 inches. The slope of the panels could be varied to simulate any range of field slopes. The overland flow was delivered by 3 inch diameter ABS pipes which had been lined with Mirafi 6000 plastic placed with the extrusions up into the flow. The 6000 material was used to simulate field channel roughness and to increase the depth of flow prior to discharge onto the panels.

The overland flow pipes were constructed so as to allow their slope to vary, which in turn enabled the water discharge velocity to vary. The ability to vary the discharge velocity is important since the upper slope segments of field slopes vary widely, thus providing a corresponding variation in water velocity delivered to the lower slope segments. There was no way to measure overland flow velocities. The Mirafi 6000 material was intended to provide an approximation of these field channels thus enabling an estimate of the actual range of field flow velocities to be used in the testing. The velocity of discharge water is provided in Table 14.

The precipitation component of the fluid application was achieved by utilizing full cone spray heads located 50 inches vertically above the panel. Each spray head and each overland flow pipe had a flow meter. The flow meters insured that equal amounts of water were being applied to each of the replicated panels. Plates 4, 5 and 6 show the assembled erosion test cell.

The cell contains a sediment trap which is designed to hold all eroded particles greater than number 40 sieve size. The trap utilizes filter fabric to allow the water to leave the trap while holding the sediment back. The particles finer than the number 40 sieve size are not retained. To build traps large enough to contain all size particles is unnecessary and would have made the testing schedule impossible. The minus 40 material lost is estimated from the initial or pretest grain size curve and the particles larger than the number 40 sieve that were collected.

Table 14. Overland flow discharge velocities with quantity of flow Q

DISCHARGE QUANTITY (gpm)	SLOPE ANGLE (degrees)	VELOCITY (ft/min)
1.2	2	78
1.2	9	127
1.2	16	141
2.4	2	104
2.4	9	132
2.4	16	167

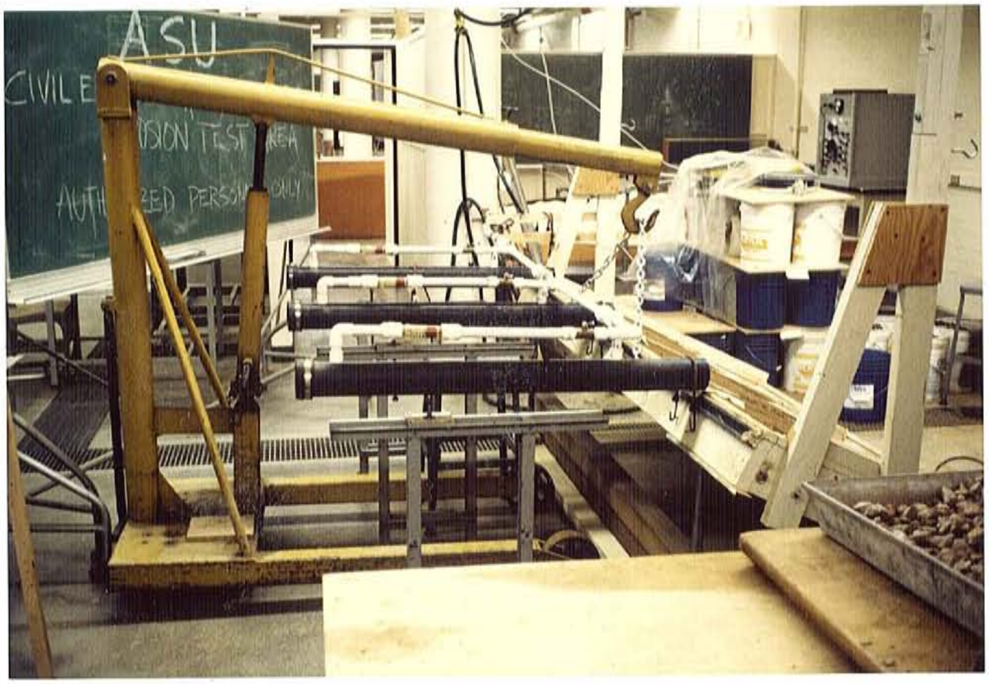

Plate 5. Side View of Erosion Test Cell

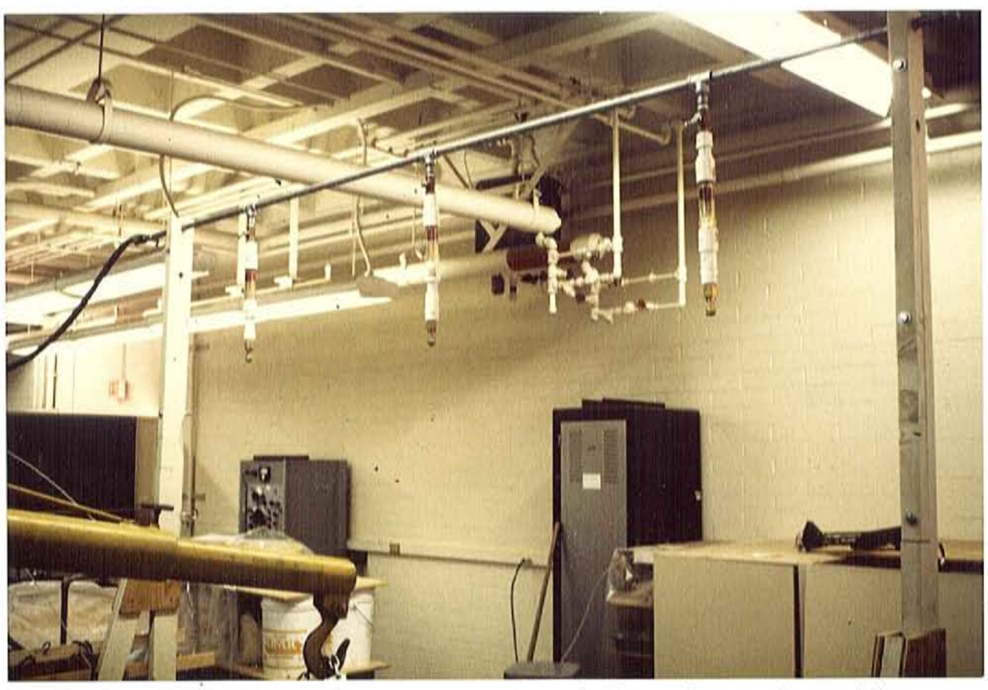

Plate 6. View of Spray Head and Flow Meter Assembly

To prevent sliding at the contact with the panel and the materials and to protect the test cell, Mirafi 6000 material was used to line the panel bottoms. At the lower end of the panel holding the material, holes covered with Mirafi 140N were used to allow subsurface flow similar to flow beneath the slope protection to occur without piping. This subsurface flow system also helped prevent artificially high pore pressures to develop.

The rate of water application to the panels to correspond to what will here after be referred to as "precipitation". It was determined by taking the predicted 50 year 30 minute intensity storm rainfall and dividing that amount of water by 30 minutes. This product was then multiplied by the spray area, which was approximately 22 inches in diameter, to determine the precipitation flux through the spray heads. The calculated amount of flow determined was 0.21 gpm. However, since the intensity varies widely during the design storm it was decided to increase the spray head flow rate to 0.5 gpm (1.9 L/min). At this higher flow rate a more severe erosion test resulted and the flow rate was more easily controlled thus insuring more reproducible test results.

The overland flow rates corresponded to the design storm precipitation falling on two microdrainages. The width of the drainages was established by reviewing the erosion channels produced along SR 360 by the storm of October, 1986. The spacing of rills was obtained from photographs taken after the storm and containing objects which enabled photo scale factors to be established. The examination of the slope rill spacing indicated that a microdrainage width of 3 feet should be used to calculate appropriate overland flow rates. The length of these drainages was established from reviewing the profiles of the slopes at the eroded sections. An example of a profile is given in Figure 2. Based on observed upper slope lengths, two lengths were used to determine the overland flows. Lengths of 15 feet and 30 feet were used in the calculations that produced 1.2 gpm (4.5 L/min) and 2.4 gpm (9.1 L/min). The graphs and discussions in the following section will refer to these flow rates.

In addition to the two standard flow rates, additional flows were used when the design flows did not produce slope distress. Flows as high as 8 gpm (30.3 L/min) were utilized for appropriate tests when additional information could be obtained.

<u>Typical Testing Operation</u>

A typical specimen testing operation would proceed as follows:

1. The sample location is selected.
2. The field sampling is done by removing 1200 to 2000 lb samples and transporting to the laboratory.
3. The sample is mixed to insure uniformity and then placed in the test cell.
4. When the material is being placed, the cell is at approximately 5 degrees slope. More material than is necessary is being placed on the three panels to allow for an as-placed

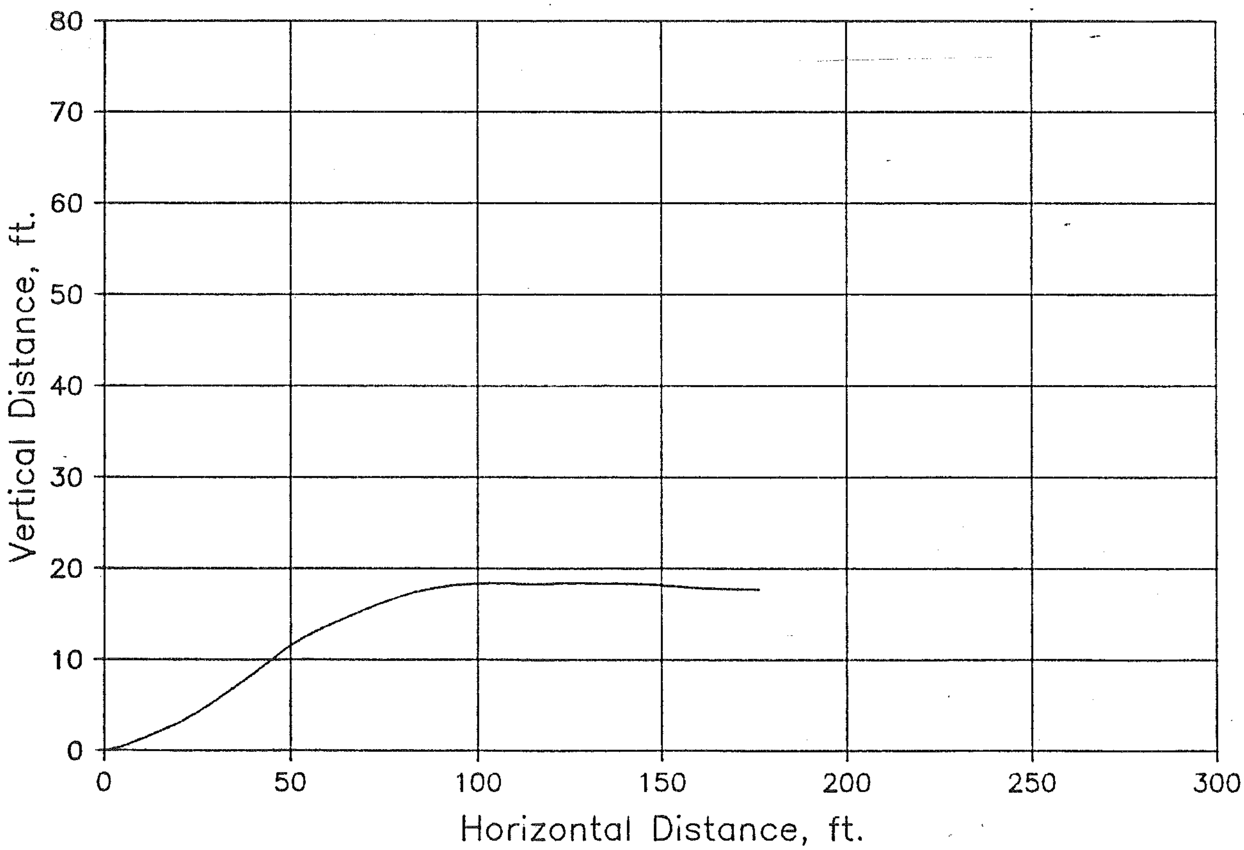

Figure 2. Profile of Slope West of Gilbert Rd. at Plate No. 2 Location

sample to be taken for grain size analysis. That sample is taken and the panel surfaces are leveled.

5. The panels are rolled with a custom built steel roller producing a line load of 110 lbs/ft of roller. This roller was selected as the best available simulator of construction and maintenance induced compaction on ADOT's slopes.
6. The cell is then brought to the proper test angle, generally at a 2:1 slope and locked into place.
7. The precipitation and overland flows have been preset and checked and test begins. Precipitation alone and then precipitation plus overland flow (combined flow) erosion test increments are run with care taken to insure that each panel functioned separately.
8. As the erosion test is running notes on the slope performance are kept. At the completion of a test interval the flows are stopped and the material eroded from each slope panel removed, panel by panel.
9. To facilitate the testing vacuum cleaners are used to remove the collected sample. Once collected, the sample from each panel is washed on the number 40 sieve and placed in the oven for drying and later grain size analysis.
10. Photos are taken to document the surface condition at the completion of the test and at other times when warranted.
11. The remaining material is then removed from the panels and the panels cleaned in preparation for the following test.

12. The material removed from the cell is transported from the laboratory.

13. The analysis of data begins.

<u>Grain Size Analysis of Materials Tested</u>

The materials selected for use in the erosion testing, either as is or as the basic material whose properties were modified, are shown in Table 15. The grain size curves for these materials are provided in Figures 3 through 14.

The initial testing operations, after the construction and calibration of the test cell were completed, involved examining several materials to establish their general response to the erosional environment. Approximately 10 tests or portions of tests were conducted during this early phase. As a result of the initial work it was apparent that several materials that were originally to be part of the testing program should be excluded. The most important exclusion from the testing program were slope protection materials from the Salt River channel. The initial testing comprised of three panels, showed these materials to be very well suited for slope protection against stresses caused by raindrop impact and overland flows greater than 8 gpm.

The Salt River materials were excluded from the production testing because they performed so well during the initial testing. The omission of these materials from the test program allowed the affect of particle shape on erosion to be made. The purpose of this phase of the testing was to establish basic erosional aspects of slopes and develop protective systems. As

Table 15. Summary of erosion test material properties.

SAMPLE ID	PERCENT PLUS #4	PERCENT MINUS #200	PI (a)
SRS1 (W/+ 1")	22	40	20
SRS1 (W/- 1")	13	32	20
SRG1	49	9	NP
SRP5	3	55	17
SRP5 W/ 10% SRG1	8	52	17
SRP5 W/ 30% SRG1	31	30	17
SRP5 W/10% IG1+20% SRG1	29	36	17
SRP5 W/20% IG1+20% SRG1	43	8	17
SRP5 W/ 30% Slate Creek	23	12	17
SRG8	72	0	NP
IP9	6	46	--
IG1	97	0	NP

(a) PI = plasticity index

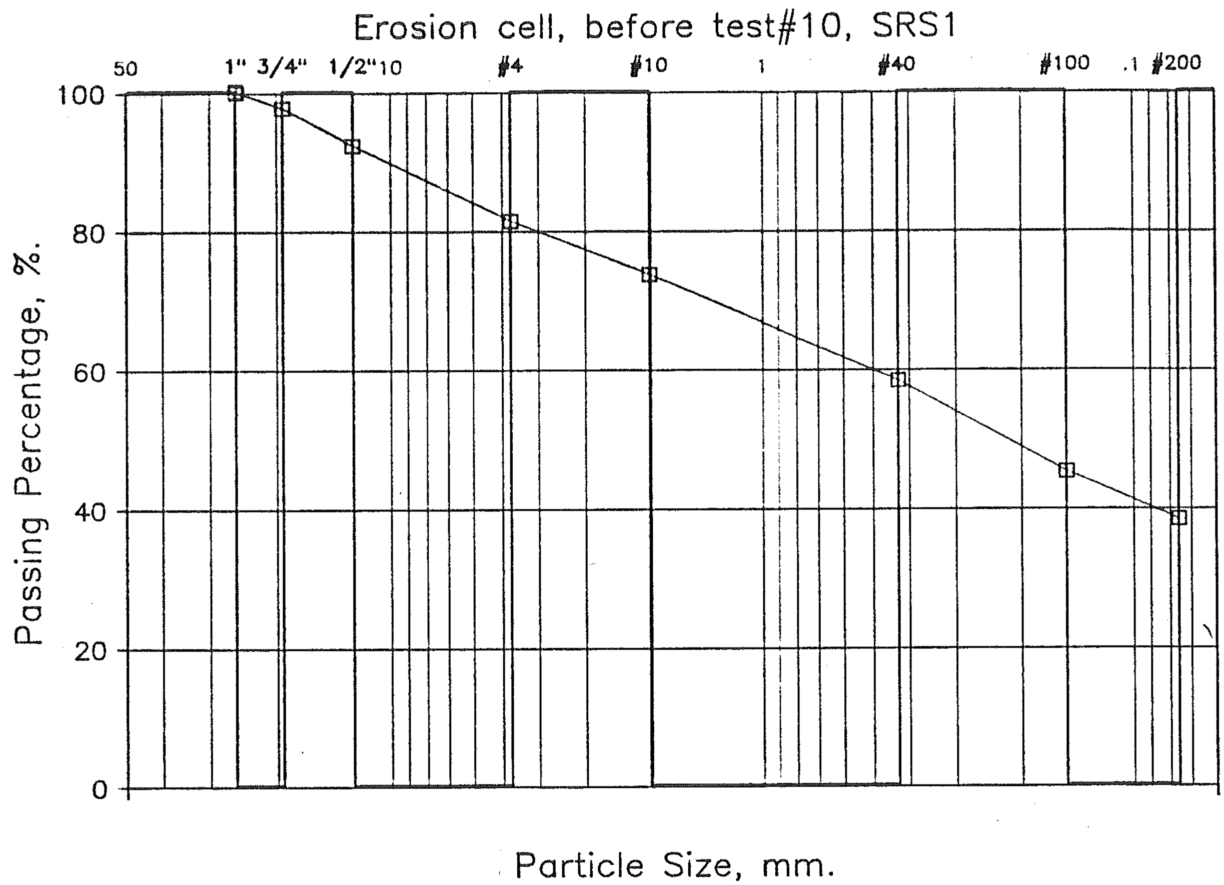

Figure 3. SRS1 Grain Size Analysis

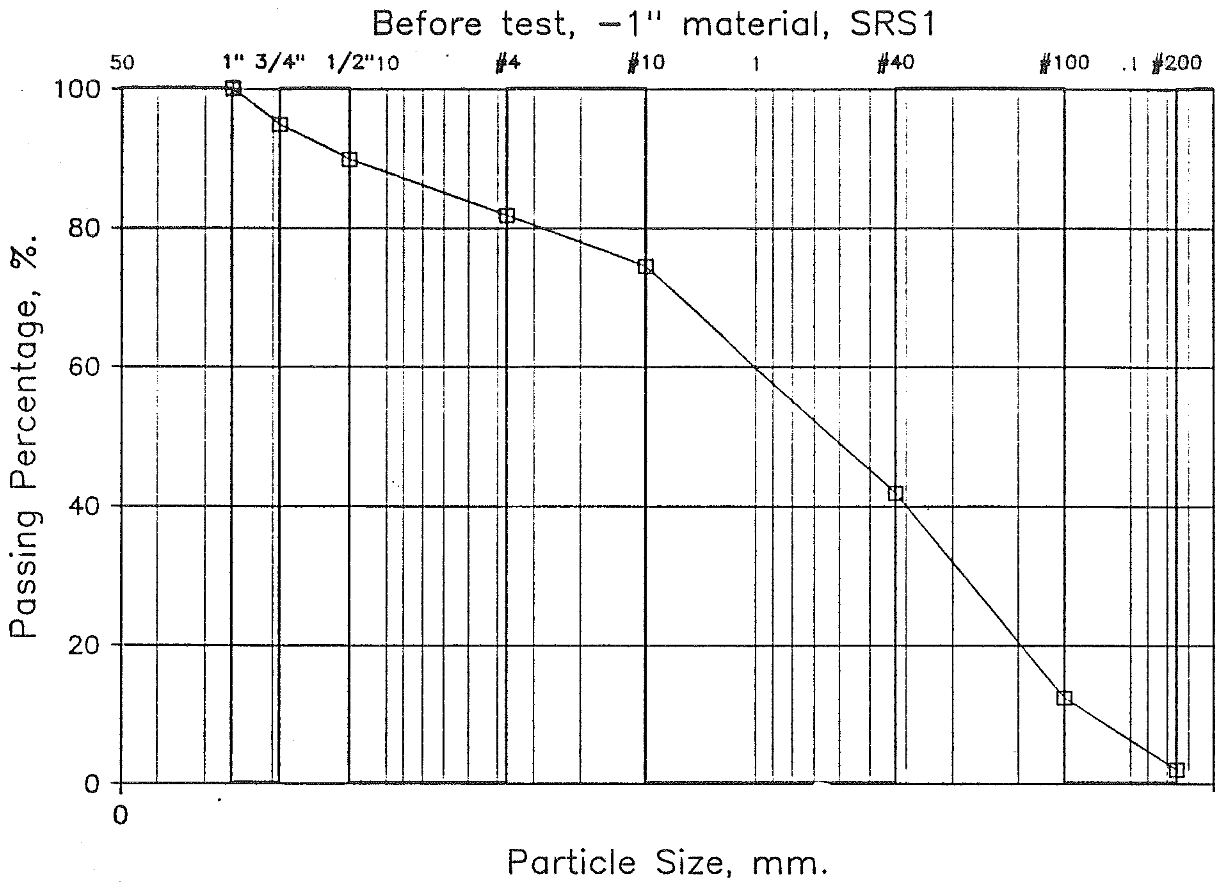

Figure 4. SRS1 - 1" Grain Size Analysis

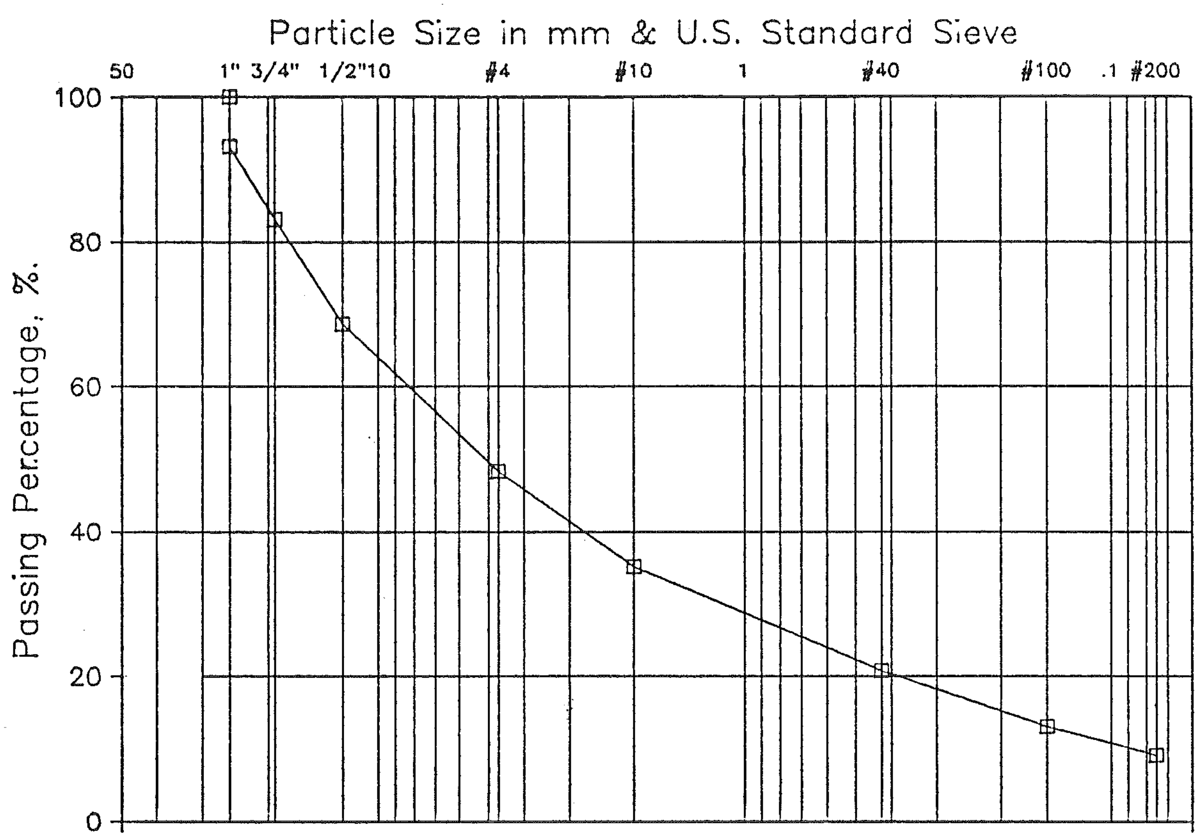

Figure 5. SRG1 Grain Size Analysis

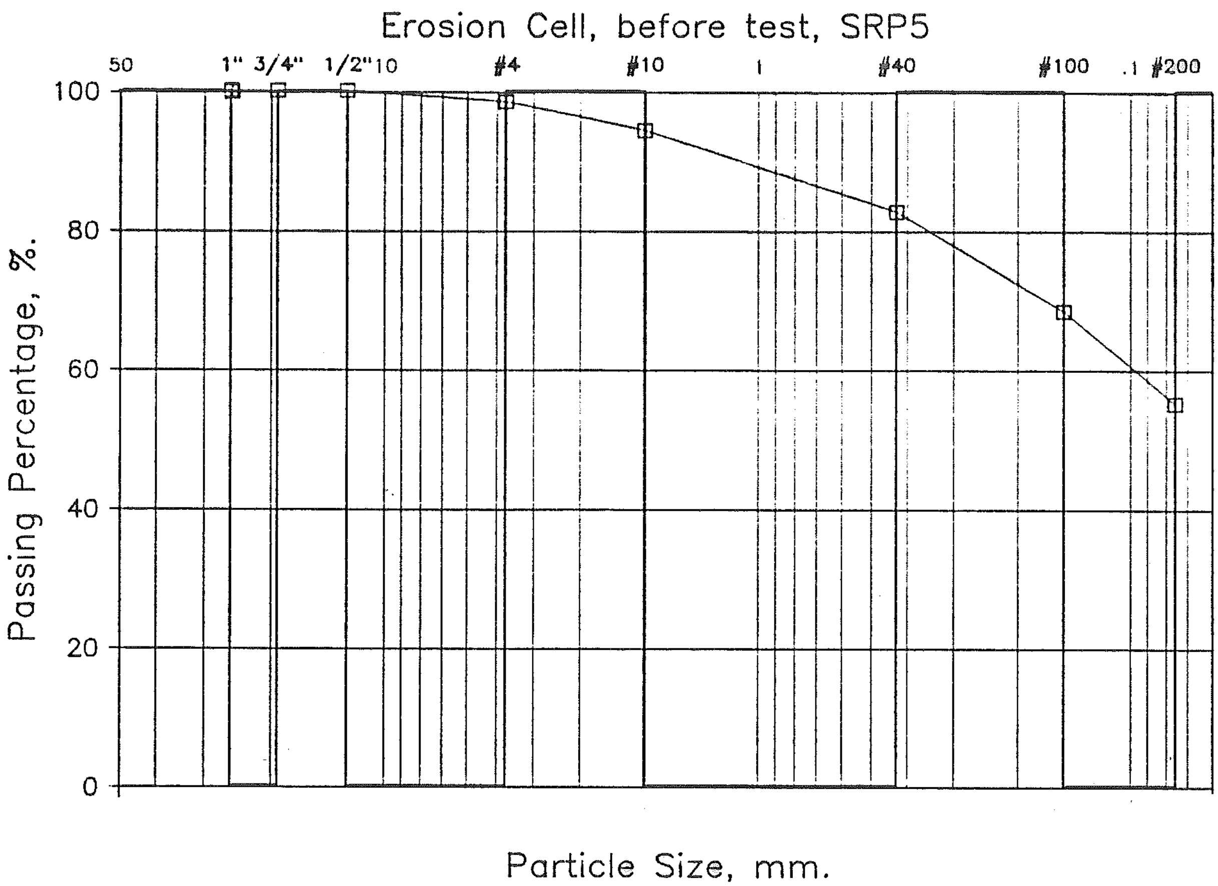

Figure 6. SRP5 Grain Size Analysis

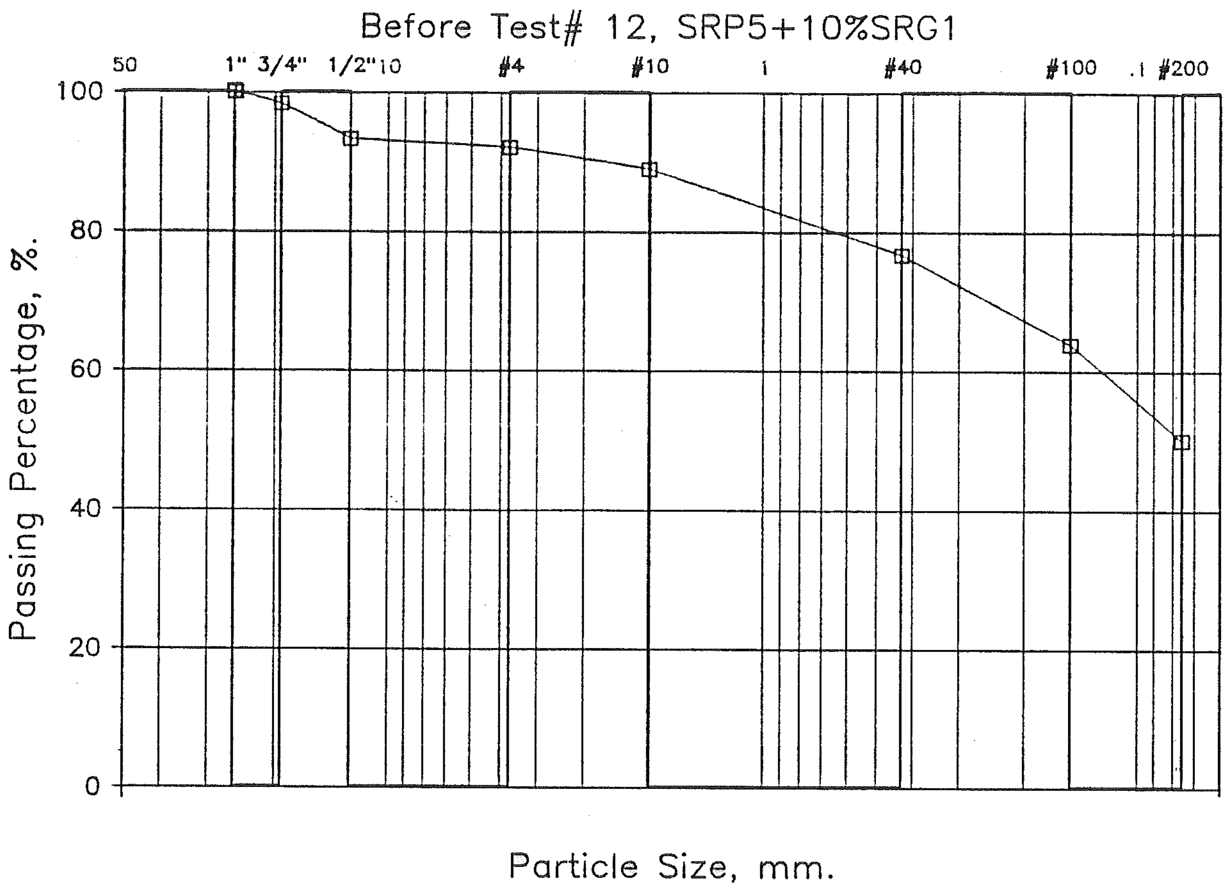

Figure 7. SRP5 Plus 10 % SRG1, Grain Size Analysis

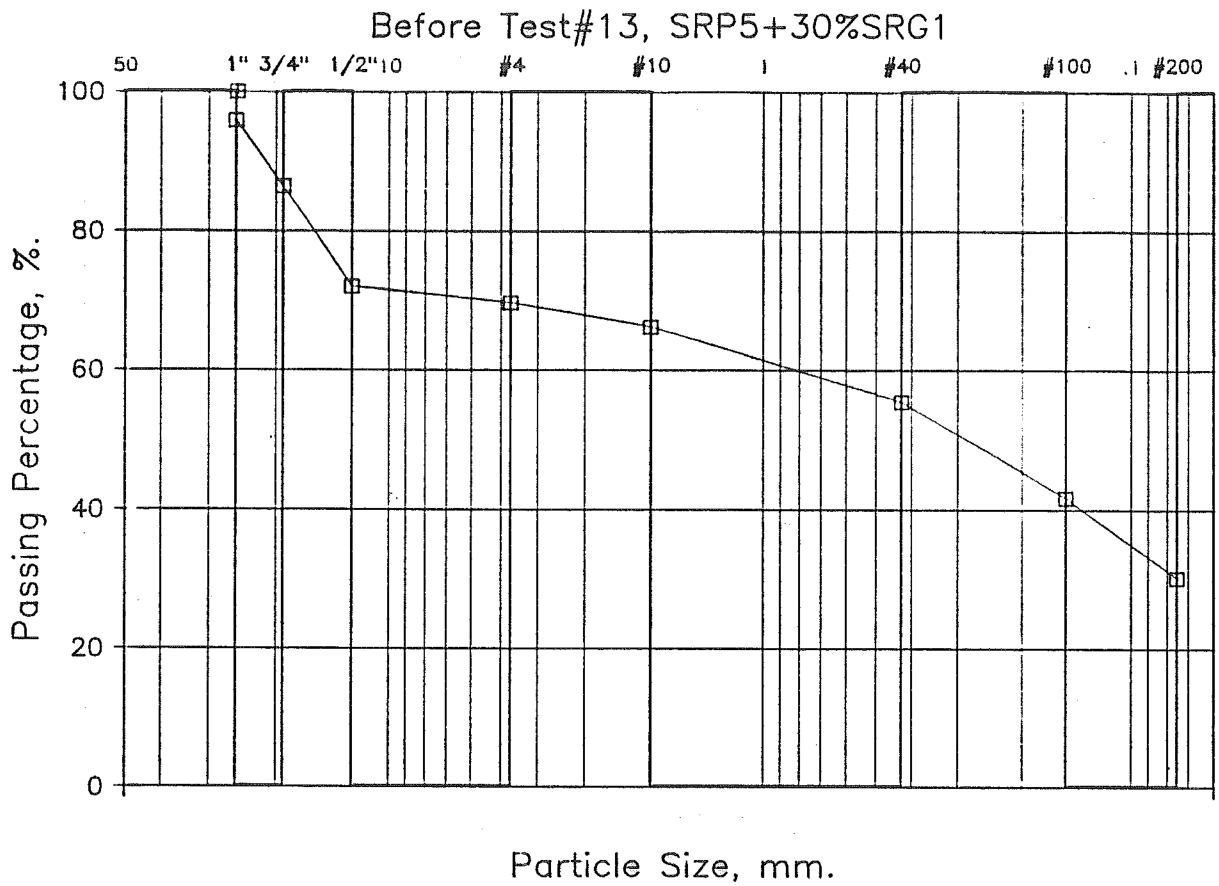

Figure 8. SRP5 Plus 30 % SRG1, Grain Size Analysis

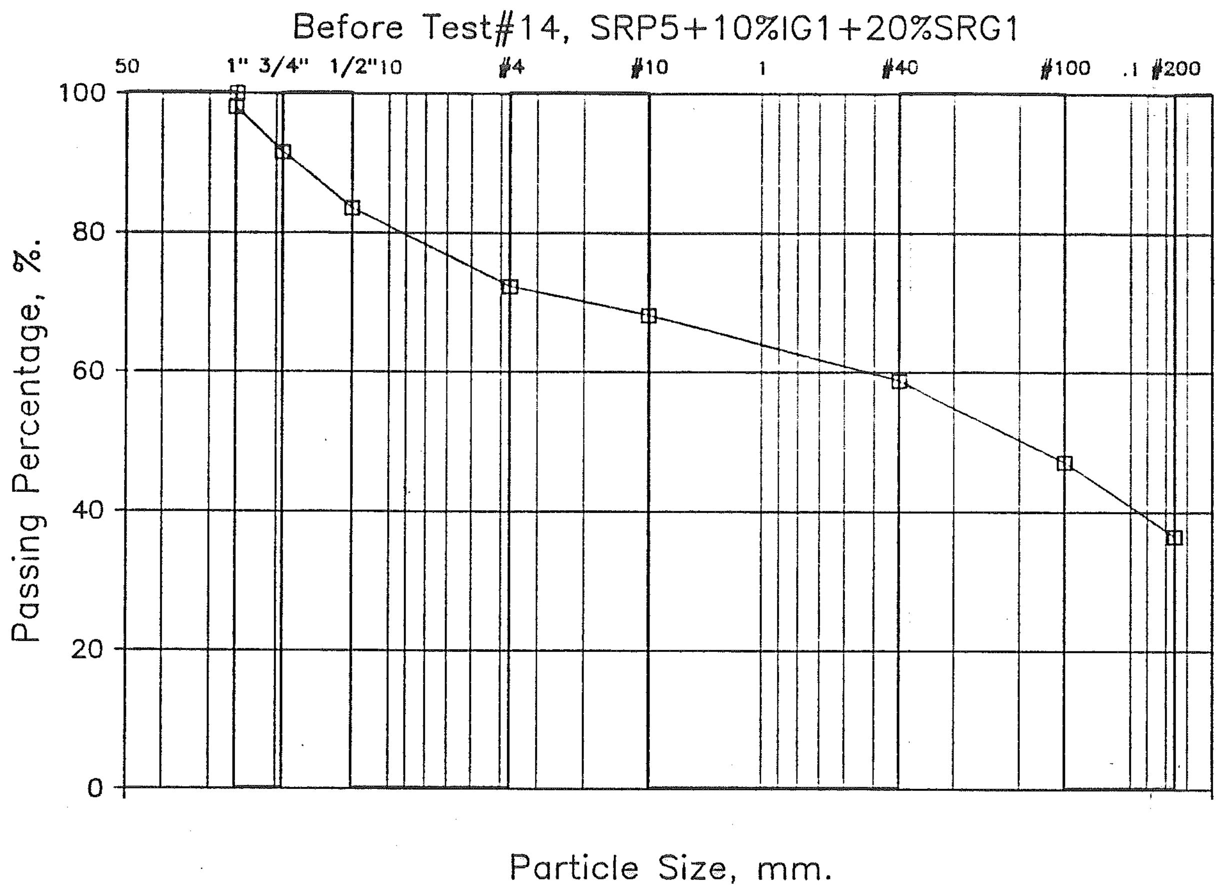

Figure 9. SRP5 Plus 10 % IG1 & 20 % SRG1, Grain Size Analysis

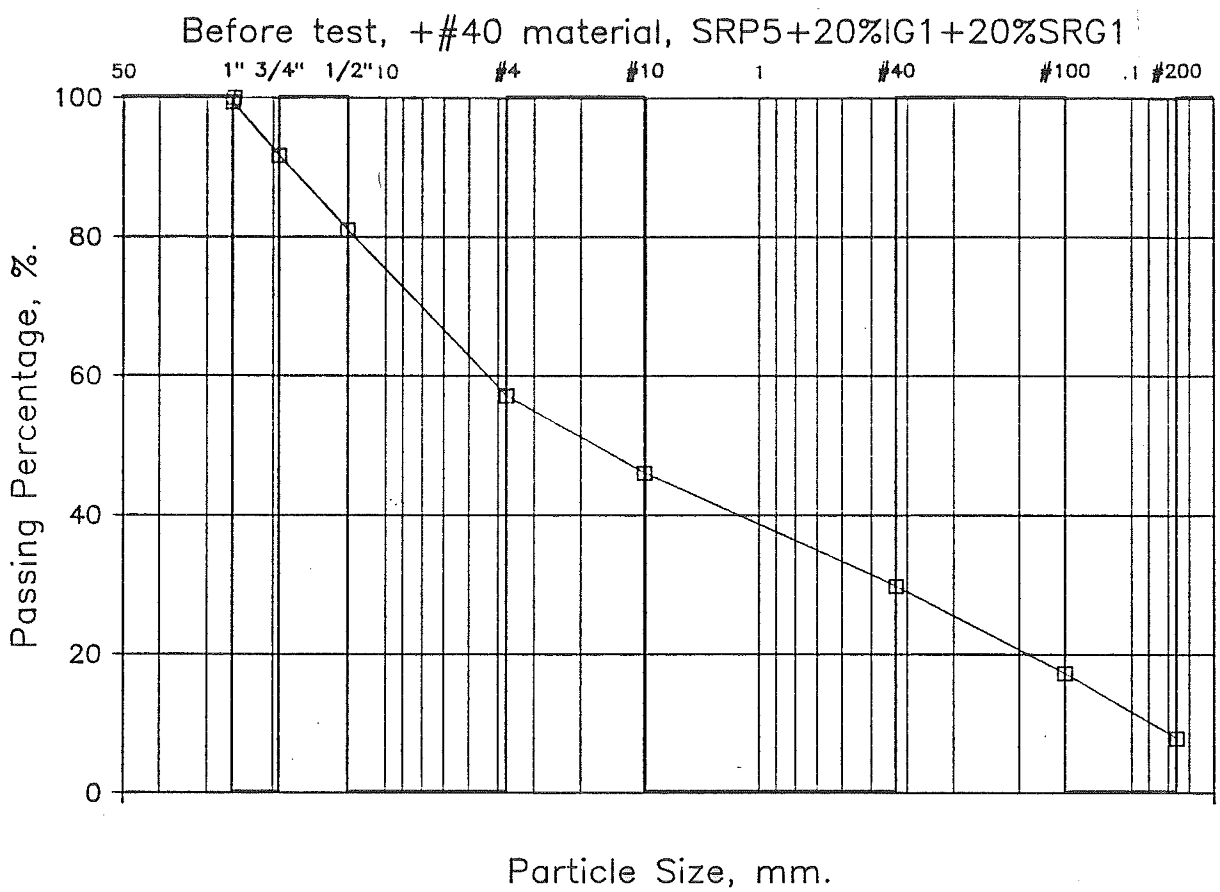

Figure 10. SRP5 Plus 20 % IG1 & 20 % SRG1, Grain Size Analysis

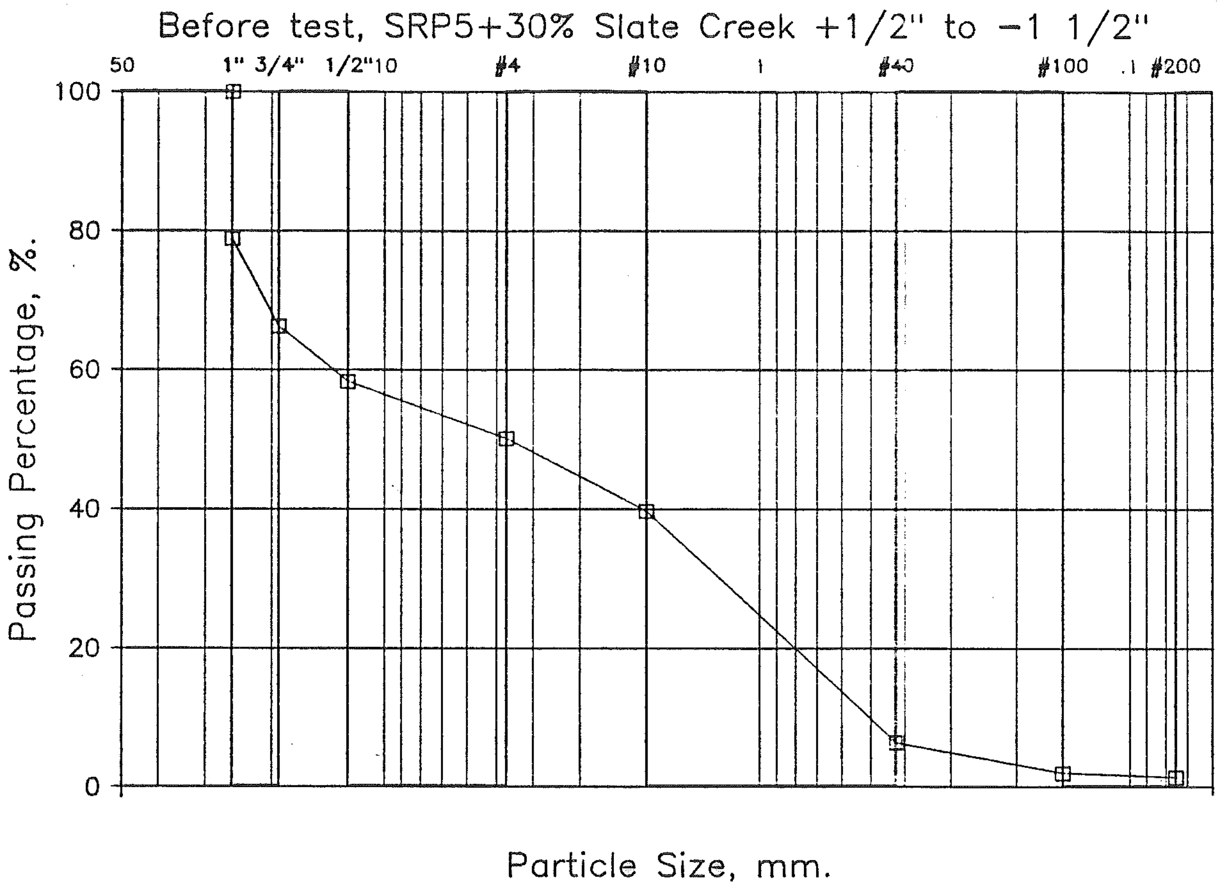

Figure 11. SRP5 Plus 30 % Slate Creek, Grain Size Analysis

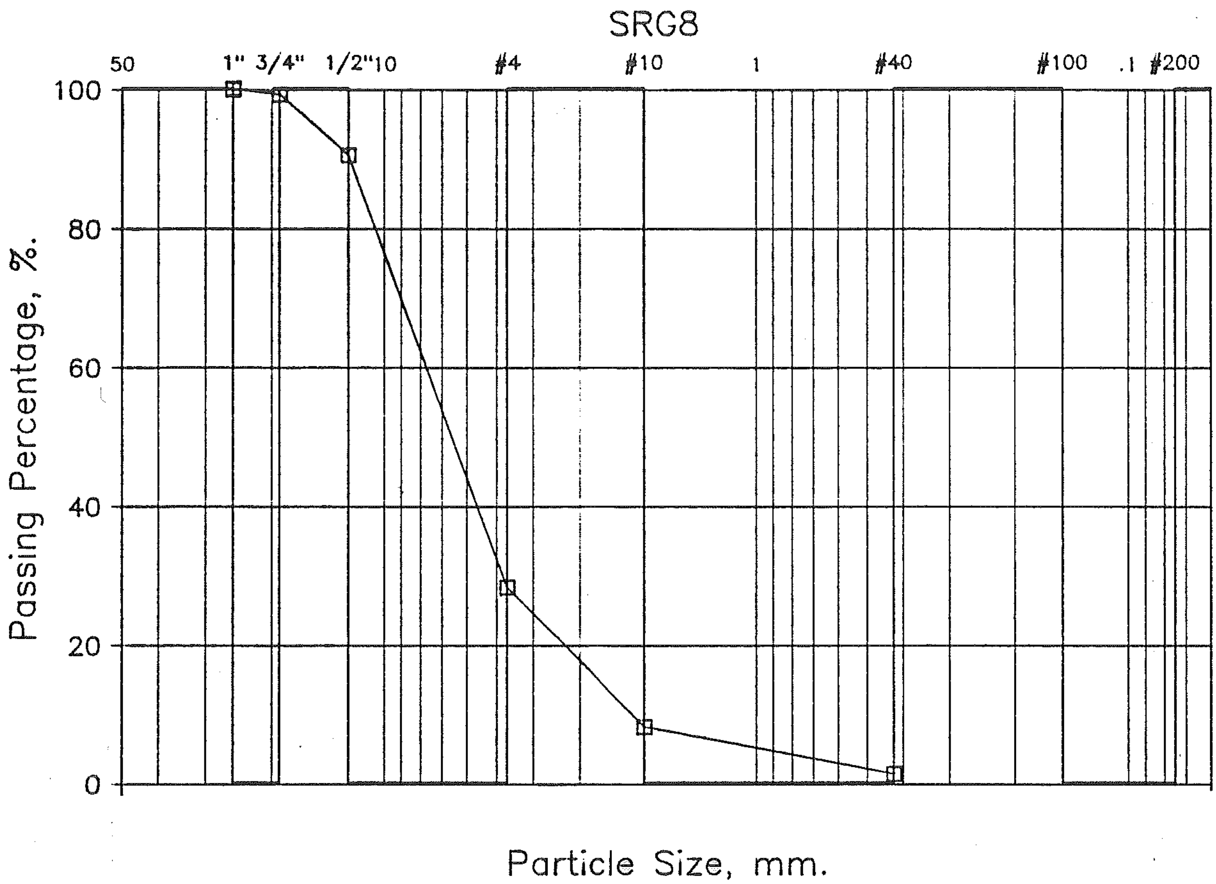

Figure 12. SRG8 Grain Size Analysis

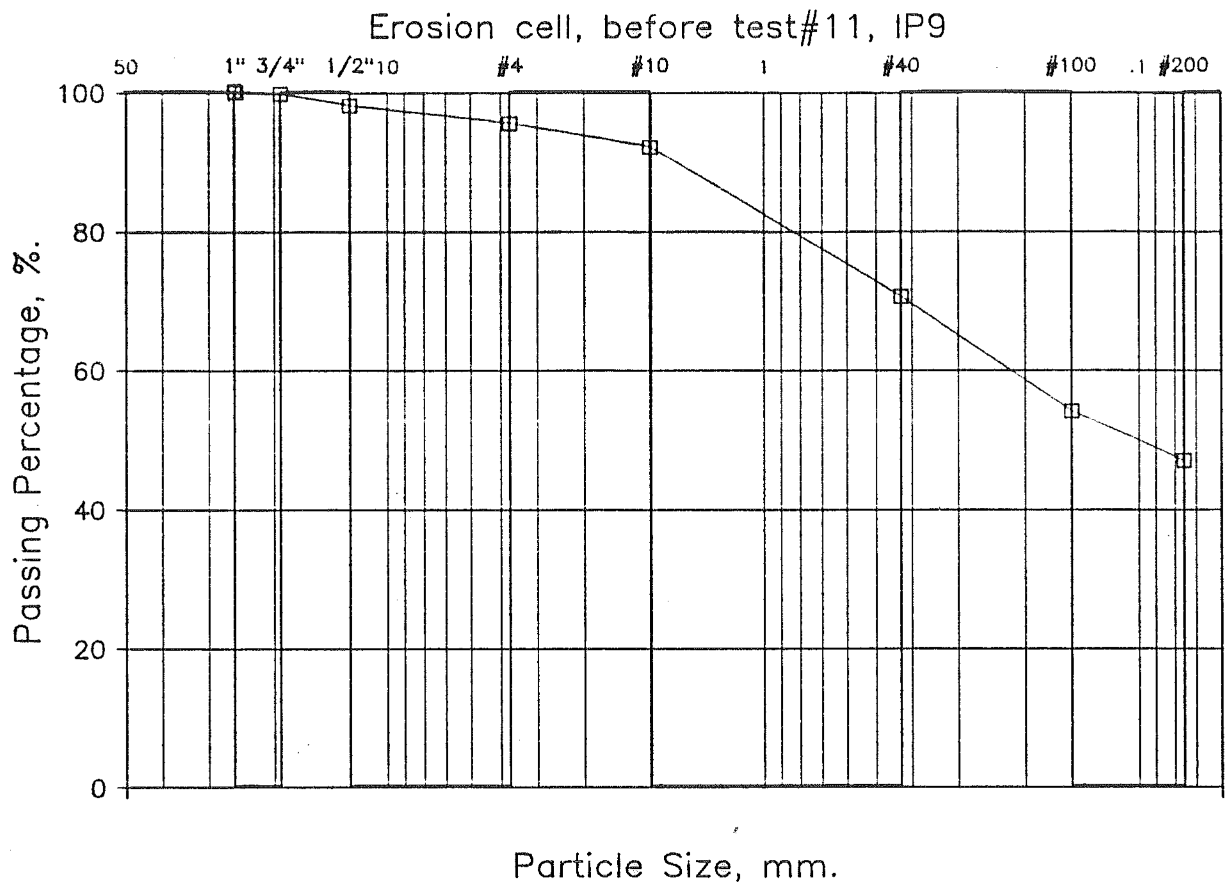

Figure 13. IP9 Grain Size Analysis

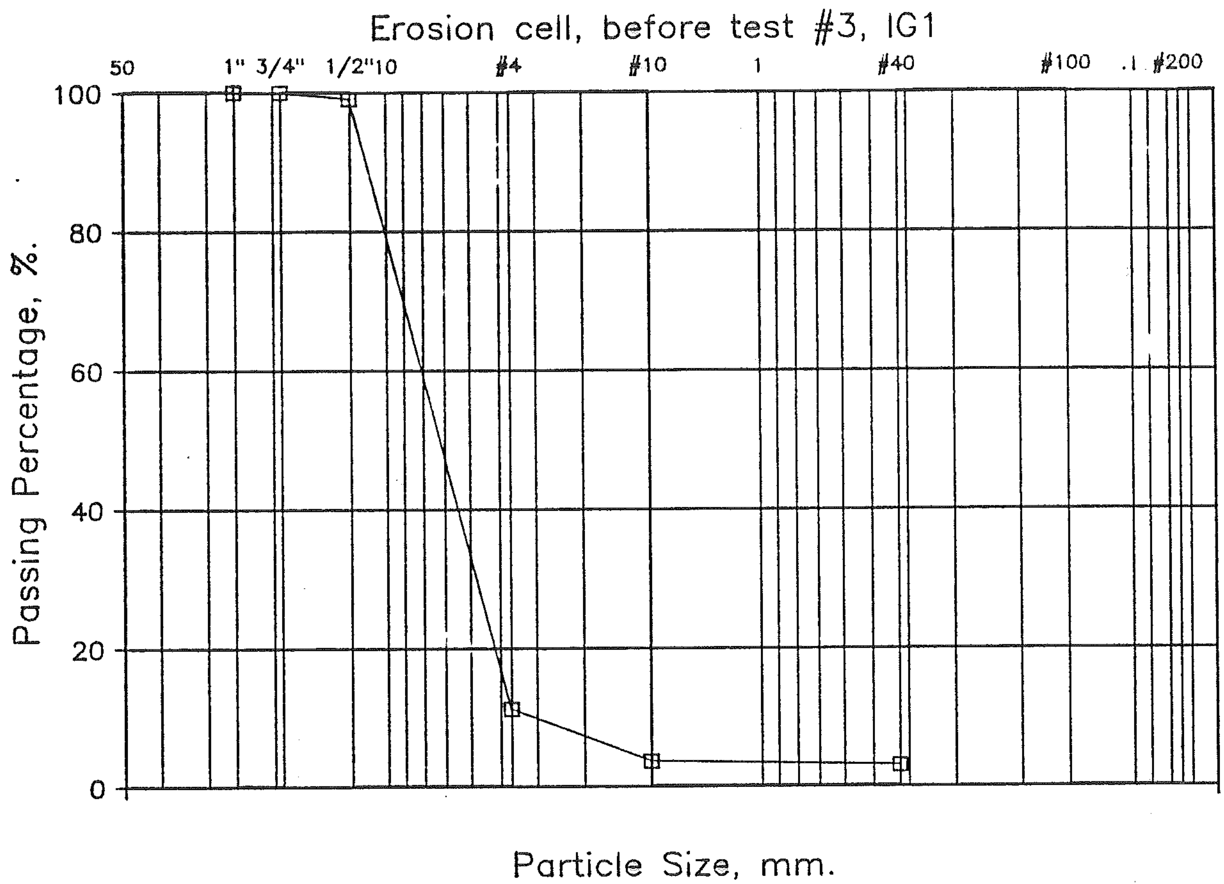

Figure 14. IG1 Grain Size Analysis

a result, a number of promising slope protection materials were not examined during this phase. It is hoped that in the future additional research can be directed to optimizing these materials for use as slope protection systems.

The initial testing also provided direction in refining the testing program by establishing the importance of surface permeability to slope protection. The early results demonstrated that materials with a very poor actual slope performance fared extremely well during testing, the SRG8 and IG1 granites in particular. These materials had very high permeabilities, so high in fact that they did not support surface flow even during the maximum flow test. The observation of this phenomenon alerted the research team to the need to consider the long term permeability of protection systems. In addition to incorporating long term permeability testing into the research program, the interaction between thin surface protection systems and the underlying soils was also explored.

Another observation that assisted in focusing the testing program was the role surface density played in erosion resistance. The initial testing made it clear, that (for soils similar to the plating soils used on SR 360 and I-10, some densification is essential). After soils from these highways were spread on the panels and leveled they eroded so badly at the initiation of the testing that further testing was pointless. As a result of these observations, the research team used a uniform placement density that simulated actual field placement conditions. Later research can explore the density versus resistance relationships for a wide suite of materials. However, it is clear at present that smooth and dense surfaces are necessary to mobilize erosion resistance when soils with fines are present.

The initial testing also indicated that the testing program should concentrate on testing at the steeper slope range. The erosion relationships are so complex, that the researcher needs to know what works at the upper limit of design slopes, the early observations showed that the severity of erosion increased from 22 degree slopes to 27 degree slopes and that some materials were stable at the lower slope but suffered channel erosion at the higher angle. The testing operations focused on the 2:1 slopes (approximately 27 degrees) because it was apparent that what would benefit the steeper slopes would benefit the lower ones. Erosion would occur at the lower slopes but at a less rapid rate. Further research should be directed at exploring the slope-erosion resistance relationship for a variety of materials and slope protection systems.

The initial erosion testing also made it clear that small amounts of coarse particles (the plus no. 4 size fractions) could produce big returns in reduced erosion. The study team expanded this aspect of the testing because of the potential advantages possible in minimizing slope protection costs.

The early testing also provided an indication that the design overland flows would not be high enough to produce channel or rill failures with some materials. The program was expanded to incorporate flows larger than designed to assess the upper limit of material resistance. Though the test times were increased by this step, the information gained was valuable.

A point of concern to the study team was the dimensions of the panels and the manner in which the overland flow was simulated. There was a concern that the panels were not long enough and that the overland pipes may create too much local damage and invalidate the results. The early tests were examined closely with respect to these concerns. Both concerns were dispelled after the first four test panels were tested. Erosion channels similar to those found in the field were developed in the laboratory. During the erosion testing results were reviewed to insure that good correlation with field observations were realized. This included the observation of rills starting at mid panel. The occurrence of rills starting at mid slope, slope break point, were documented at SR 360 west of Gilbert Rd. following the storms of February 1987 plates 1 and 2 in volume II. The study team was satisfied that an adequate representation of field induced erosion was possible and obtained in the erosion test cell.

Discussion of Test Results

The production testing began once the initial examination of material response to erosion was completed. the SRG1 material from west of Val Vista Rd. on SR 360 provided some useful information concerning how soil with a coarse fraction can develop increased erosion resistance through armoring. This material had 51 percent plus number 4 size material prior to erosion testing. The results of the initial testing of SRG1 are shown on Figure 15. The precipitation only erosion increased to a maximum value 10 minutes into the test and then continually decreased to a minimum value at 40 minutes.

The reason for the initial increase in the rate of erosion is believed to be caused by surface irregularities left after panel preparation and "poorly" placed coarser particles which are in rather unstable positions at the start of precipitation.

The erosion rates are the averages of the three test panels. Three panels were utilized since it was recognized that although great effort was taken to make the three panels identical, variations would occur. The researchers felt that three replicates were the minimum number necessary to comply with project scope. The erosion rate was determined by dividing the total weight of the plus number 40 material collected by the duration in minutes. To determine the total amount of material eroded the rates for each time increment must be multiplied by the time and summed. At the completion of the 40 minute test increment the SRG1 soil had developed an effective surface armor comprised of primarily plus number 4 particles. In fact what was observed in the laboratory was a high initial loss of fines followed by steadily decreasing sediment transport from the panel. The sample of the plus number 40 material from panels 1 and 2 after 10 minutes of testing was combined and the grain size established, (Figure 16). The sample collected was 99 percent finer than the number 4 sieve and 57 percent finer than the number 10 sieve size. The grain size analysis for the similar samples collected at 30 and 40 minutes into the test;

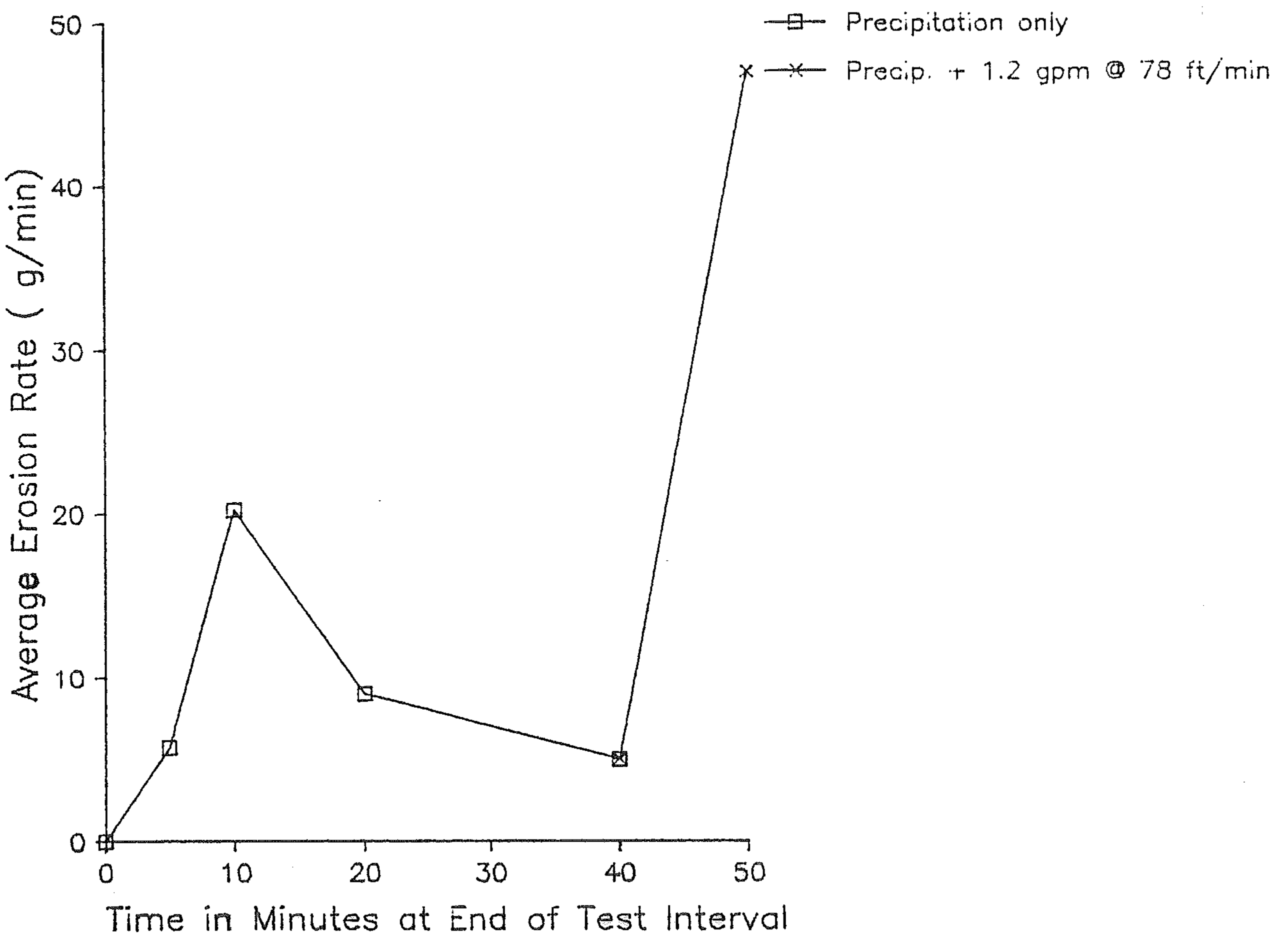

Figure 15. SRG1 Erosion Vs. Time, Combined Flow Conditions, for 2:1 Slope

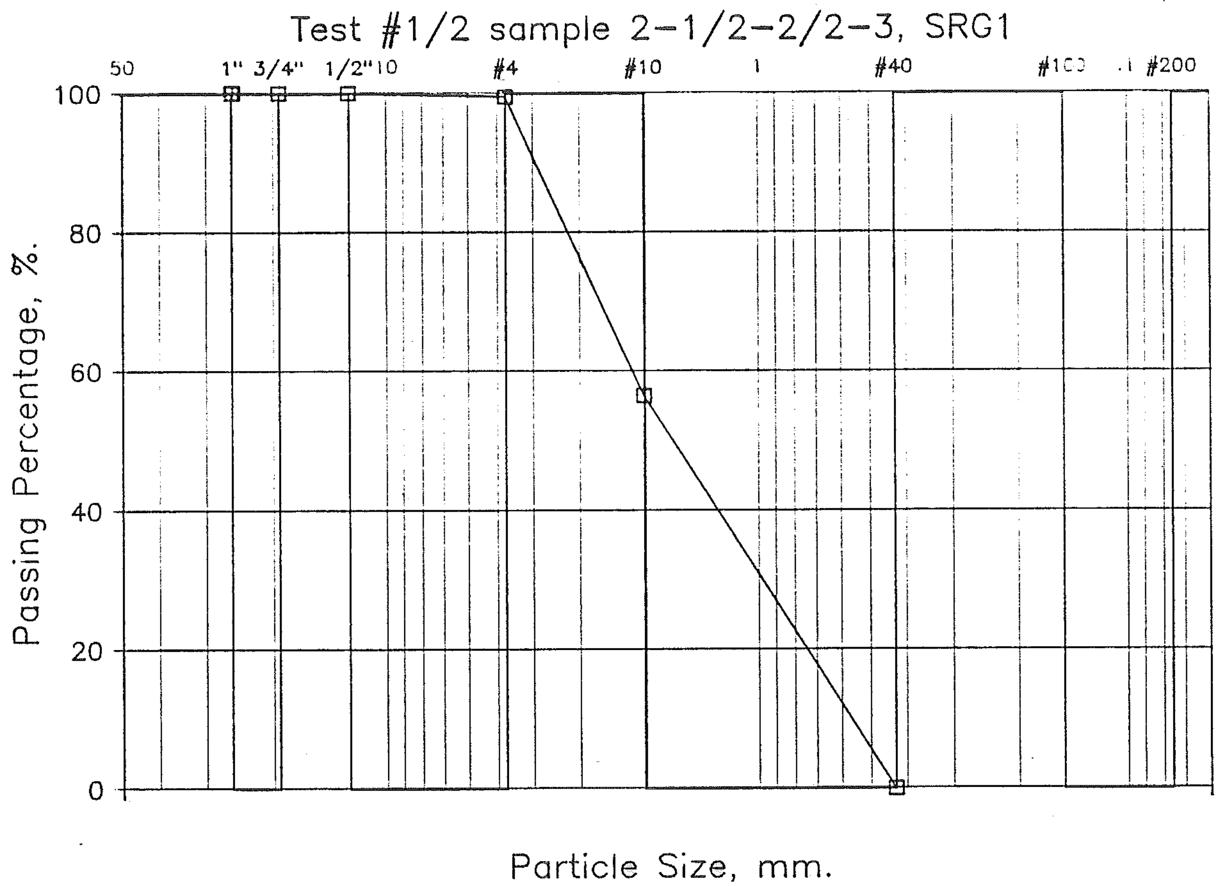

Figure 16. SRG1 Grain Size Analysis after 10 Minutes of Precipitation Induced Erosion

Figures 17 and 18 show similar results. These data show that it is the minus number 4 sieve size particles that are transported by precipitation alone.

Another interesting observation apparent when Figure 18 is examined concerns the relatively steady state processes at work on the soil face. The percentage of plus number 4 size particles collected increased from 0 at 30 minutes to approximately 5 percent at the end of 40 minutes. While very small, this increase in the plus number 4 size particles is to be expected as the slope continues to be stressed by the precipitation. As long as fines continue to be removed the coarse particles will be shifting into more stable positions. The fact that these coarse particles are in motion provides some particles sufficient movement to be transported from the panel. This soil is so efficient at developing protection by the armoring process plus number 4 size particles involved in large movements are few.

The fact that the precipitation portion of the SRG1 test eroded essentially fine particles is interesting because the storm of October, 1986 produced the closure of SR 360 in the vicinity of the sample source for SRG1. The freeway was closed due to water and "mud" on the road. The transport of fines from the first rain after placement of the SRG1 material was predicted by the laboratory test.

Overland flow was started at the completion of 40 minutes of precipitation for the SRG1 material. There was a dramatic increase in the rate of erosion as the combined effect of pre-

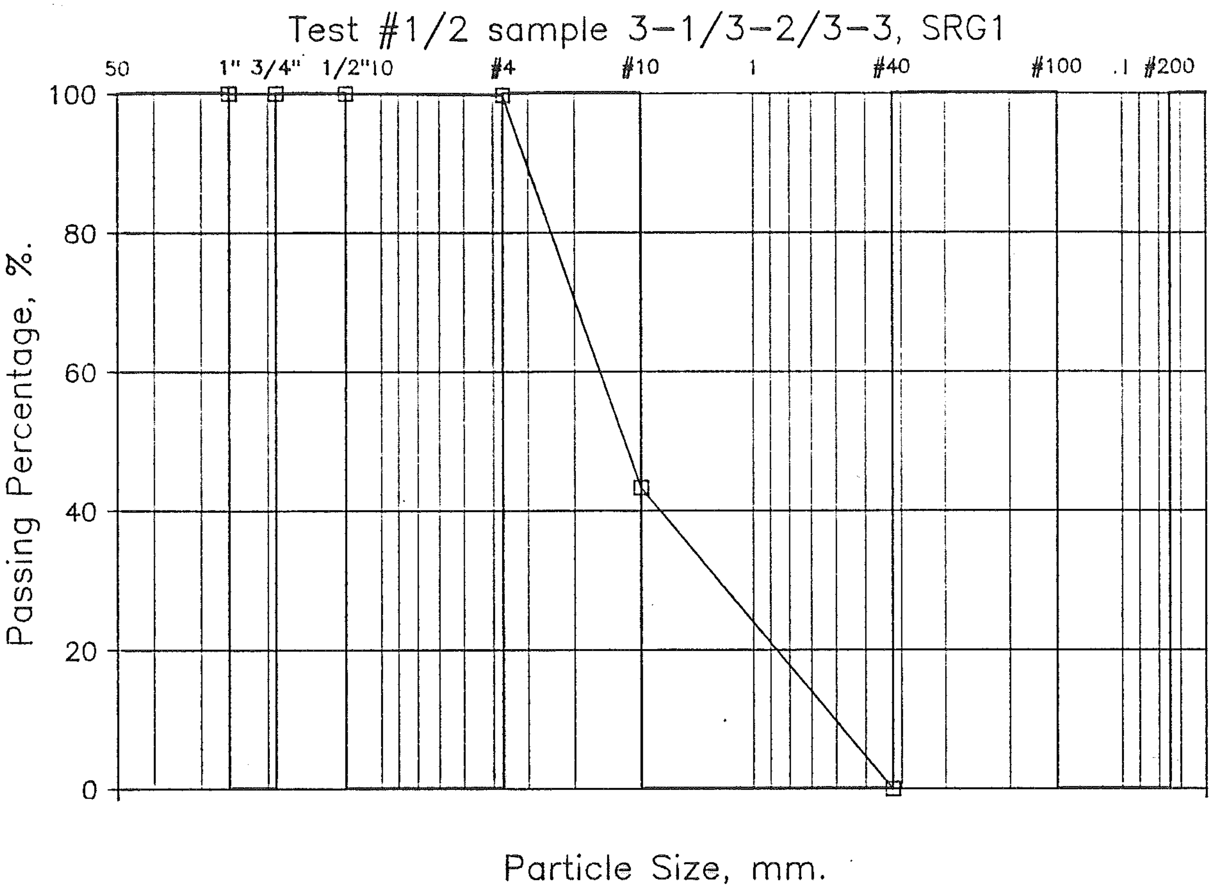

Figure 17. SRG1 Grain Size Analysis after 20 Minutes of Precipitation Induced Erosion

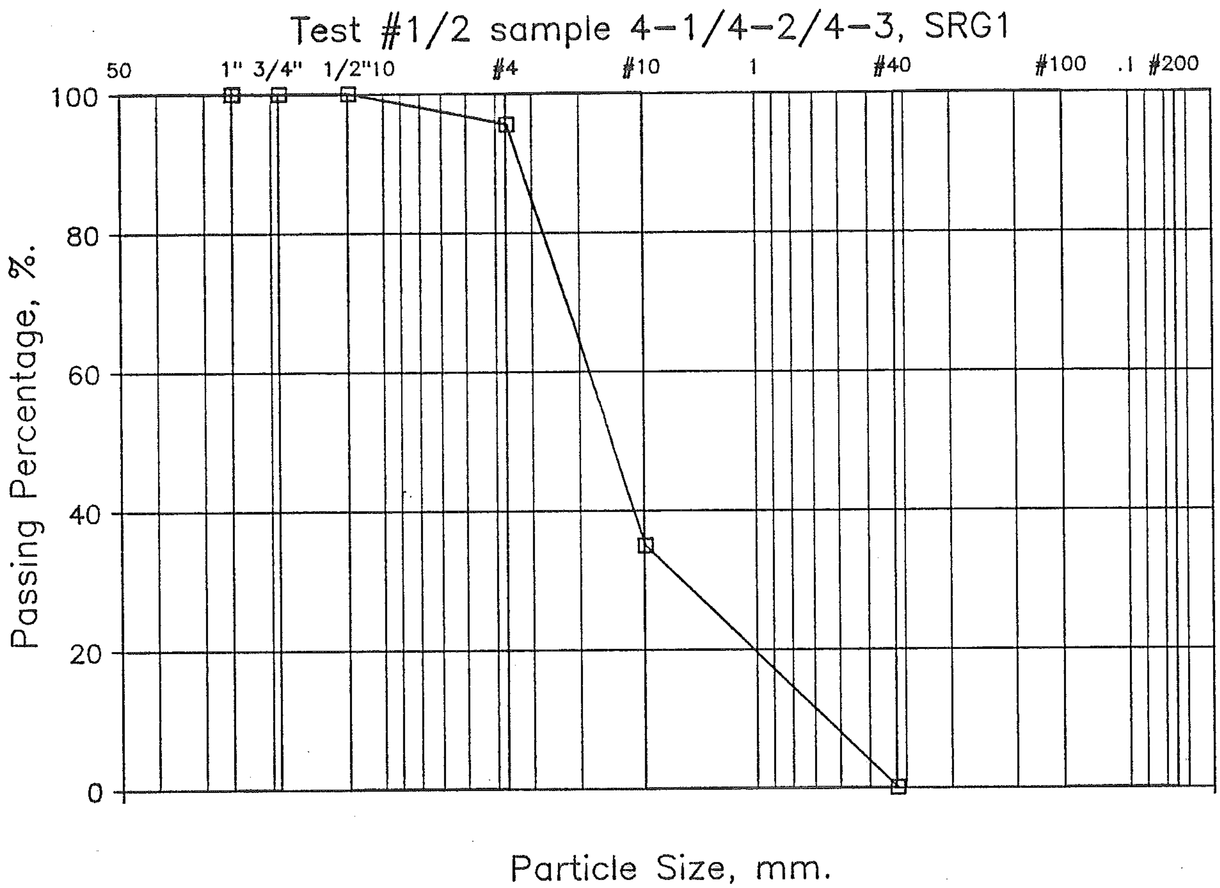

Figure 18. SRG1 Grain Size Analysis after 40 Minutes of Precipitation Induced Erosion

cipitation and overland flow was felt, (Figure 15). Even after 40 minutes of previous testing the erosion rate more than doubled. This increase in erosion occurred as particles which had been stable under the previous flow regime proved unstable under the new one. Figure 15 makes it clear that any erosion prediction must consider the overland contribution if the true material erosion resistance is to be predicted.

The cumulated samples of the panels after 10 minutes of the combined flows still had 88 percent of the plus number 40 material finer than the number 4 sieve size (Figure 19). It is apparent that under the added stress of the 1.2 gpm flow the plus number 4 particles are relatively stable. These coarse particles are able to develop new armor at the slope surface.

At the completion of the initial 10 minutes of flow with both precipitation and overland flow applied, the combined flow testing was continued for SRG1. The flow volume of 1.2 gpm was continued but the overland flow velocity was increased to 141 ft/min (43.0 m/min). The rate of erosion versus time for this additional testing is provided on Figure 20.

When Figures 20 and 15 are compared it is apparent that when testing started with the same flow but at a higher velocity, the erosion rate increased. However, the armoring associated with the overland flow of 1.2 gpm and 78 ft/min was considerable. The rate of erosion of approximately 47 g/min associated with the first overland flow after 10 minutes is approximately 5 times greater than the rate of erosion for the second interval, with a velocity of 141 ft/min, after the same time

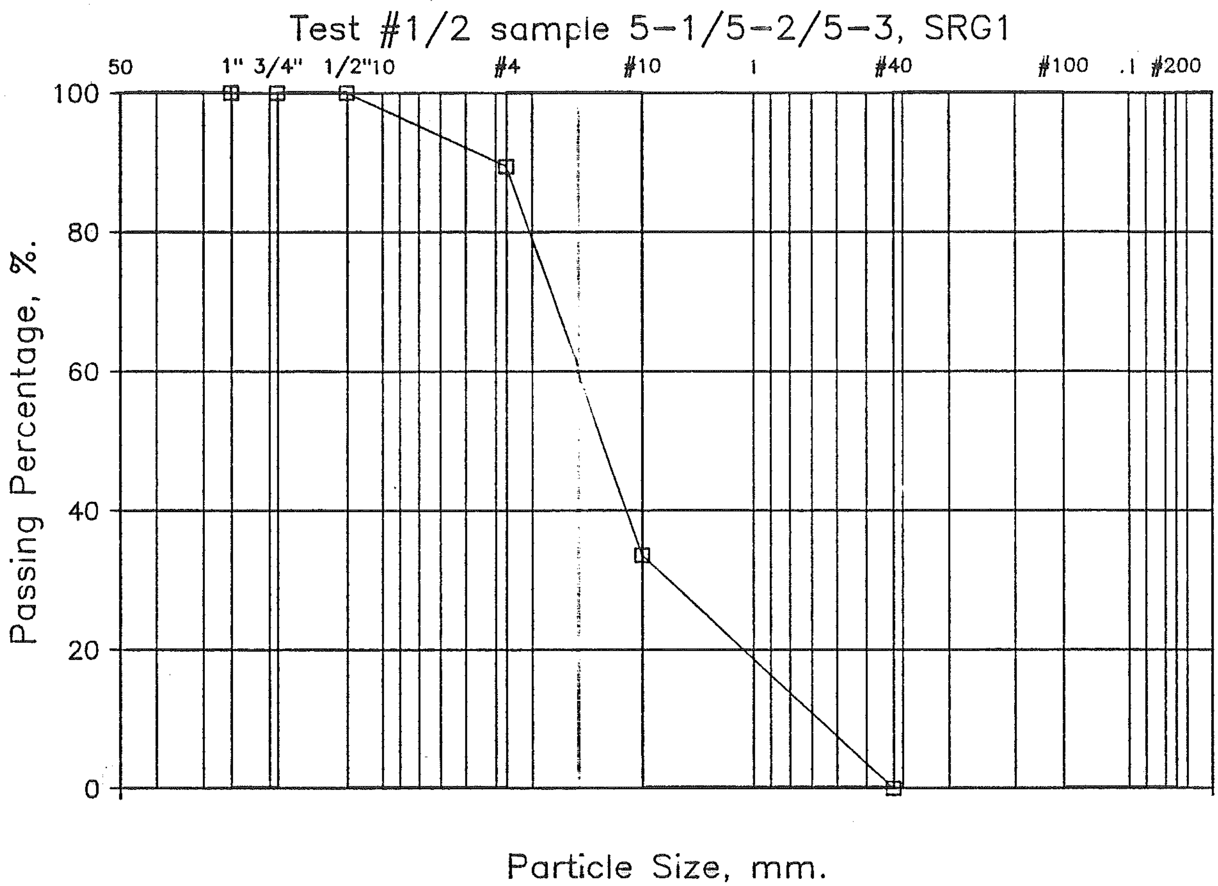

Figure 19. SRG1 Grain Size Analysis after 50 Minutes of Precipitation and 10 Minutes of Overland Flow

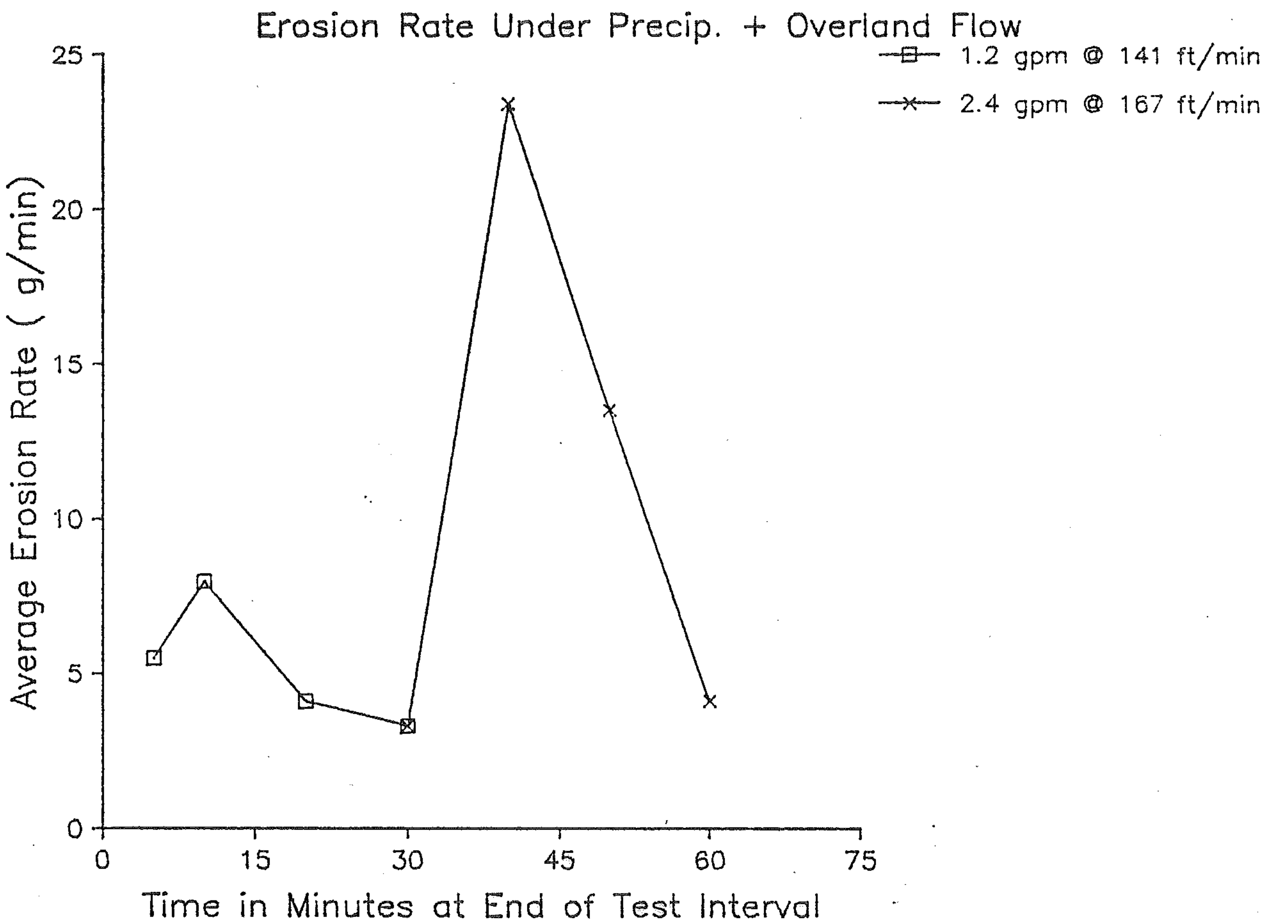

Figure 20. SRG1 Erosion Vs. Time for 2:1 slope and Q = 1.2 & 2.4 gpm (4.5 & 9.1 L/min)

had passed. The erosion process continued, but the rate of erosion decreased rapidly.

The reason for the increase in the rate of erosion shown on Figure 20 between 5 and 10 minutes is believed to again be the initial relocation of some coarse particles. When the velocity of flow increased by over 80 percent, some particles were unable to resist the new flow environment without an adjustment in position. The combined samples of the plus number 40 material eroded after 10 minutes at the higher velocity flow were 95 percent finer than the number 4 sieve size. (Figure 21). Not only does the slope continue to armor, as demonstrated by the reduction in the rate of erosion, but primarily the transport of particles smaller than the number 4 sieve size continues.

As flow at the velocity of 141 ft/min continued the rate of erosion continued to decrease for the following two 10 minute test intervals, (Figure 20). The rate of erosion decreases from 8.0 to 3.3 g/min over the 10 minute to 30 minute test periods.

After 30 minutes of testing at the 1.2 gpm and 141 ft/min flow rates was completed the flow was increased. The volume was increased to 2.4 gpm and the flow velocity increased to 167 ft/min (50.9 m/min). The rate of erosion for the next 10 minute test interval increased to 23.4 g/min, (Figure 20). At this more severe erosion condition the percentage of plus number 4 size particles that were eroded increased to 27 percent of the collected combined sample (Figure 22).

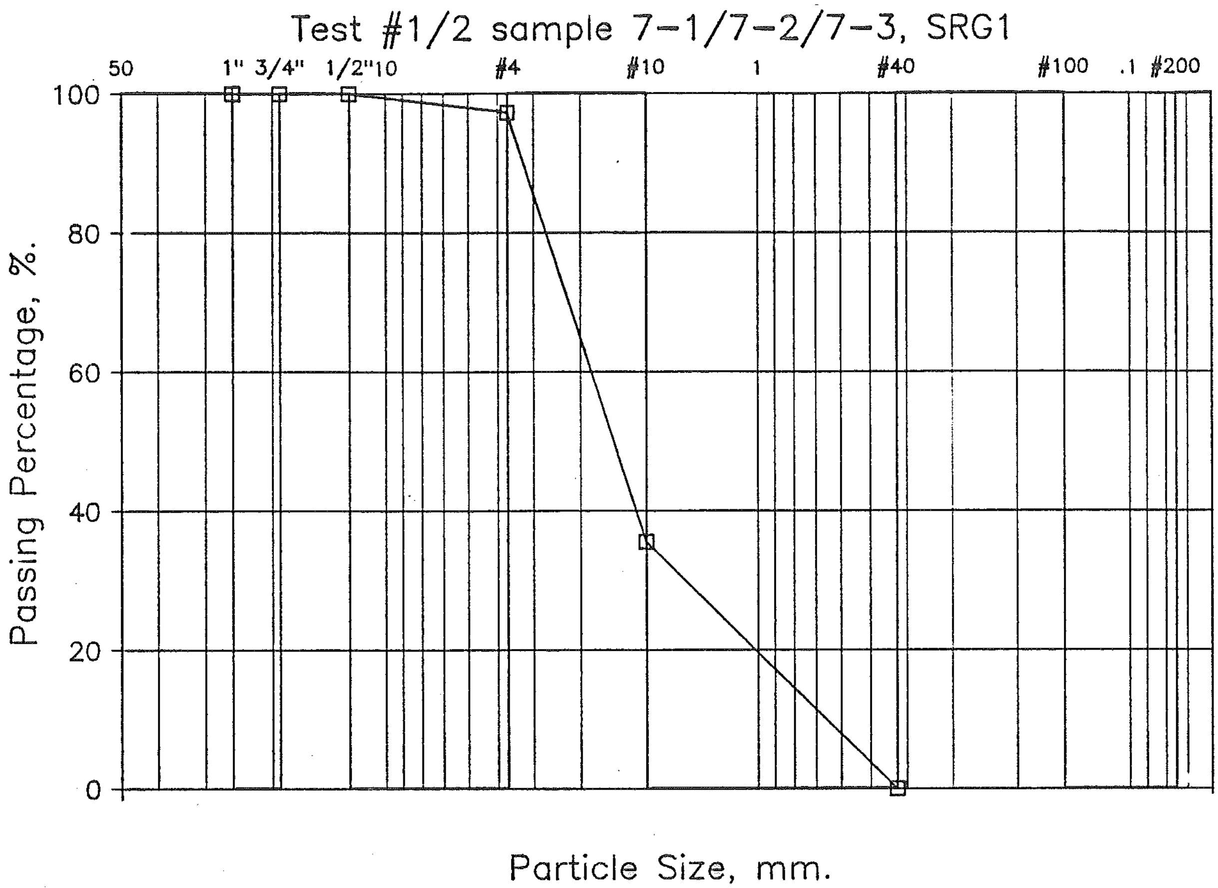

Figure 21. SRG1 Grain Size Analysis after 10 Minutes of Combined Flows of 1.2 and 2.4 gpm (4.5 & 9.1 L/min)

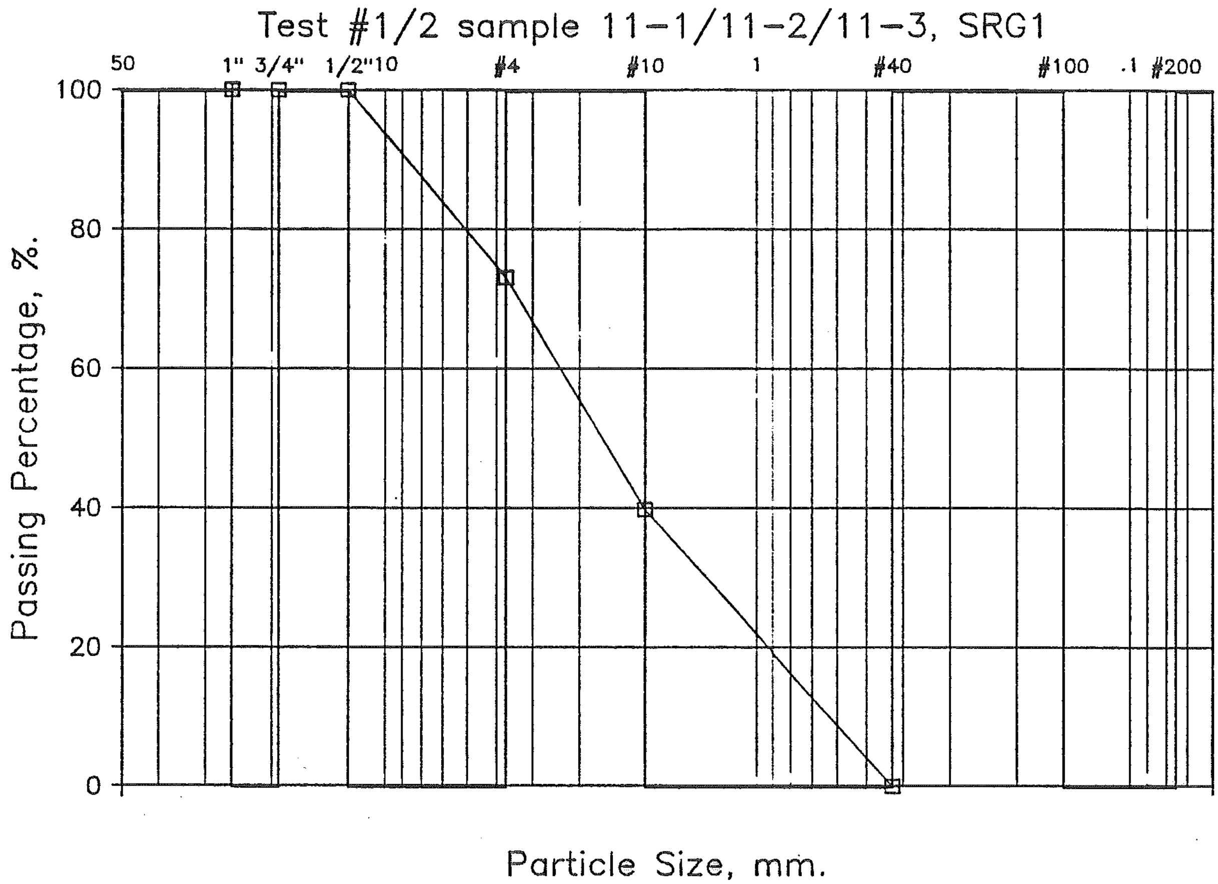

Figure 22. SRG1 Grain Size Analysis, 10 minutes at 2.4 gpm (9.1 L/min) With a Velocity of 167 ft/min (50.9 m/min)

After the initial period at high flow, the erosion rate once again dropped rapidly as surface protection developed until at 60 minutes into the test. The erosion rate was once again below the 5 g/min level (Figure 20). At the 60 minute point in the test there were no plus number 4 size particles collected (Figure 23). Once again the coarse particles were able to adjust to the flow and were effectively protecting the slope.

In another test, the overland flow component was increased to establish the upper resistance of the SRG1 material, (Figure 24). The flow rate was increased to 6.0 gpm (22.7 L/min) with a corresponding velocity increase. The increased severity of the overland flow portion of the event produced a rapid removal of material, creating two deep rill through the full panel height, which included 18 percent plus number 4 size particles collected in from Panel 1 (Figure 25).

Panel 3 of SRG1 was selected for additional testing above the 2.4 gpm overland flow rate. The flow rate with precipitation was increased to 6.0 gpm. The rate of erosion increased 10 fold as the flow rate increased from 5.0 to 6.0 gpm (Figure 26).

The removal of the armoring that had been formed during the prior testing began when the flow reached 6.0 gpm. As can be seen on Figure 27, the surface protection was being destroyed. Slope surface particles as large as 0.75 inches were being transported. In fact a straight channel had been cut in the SRG1, though the channel had not cut through to the Mirafi 6000 material.

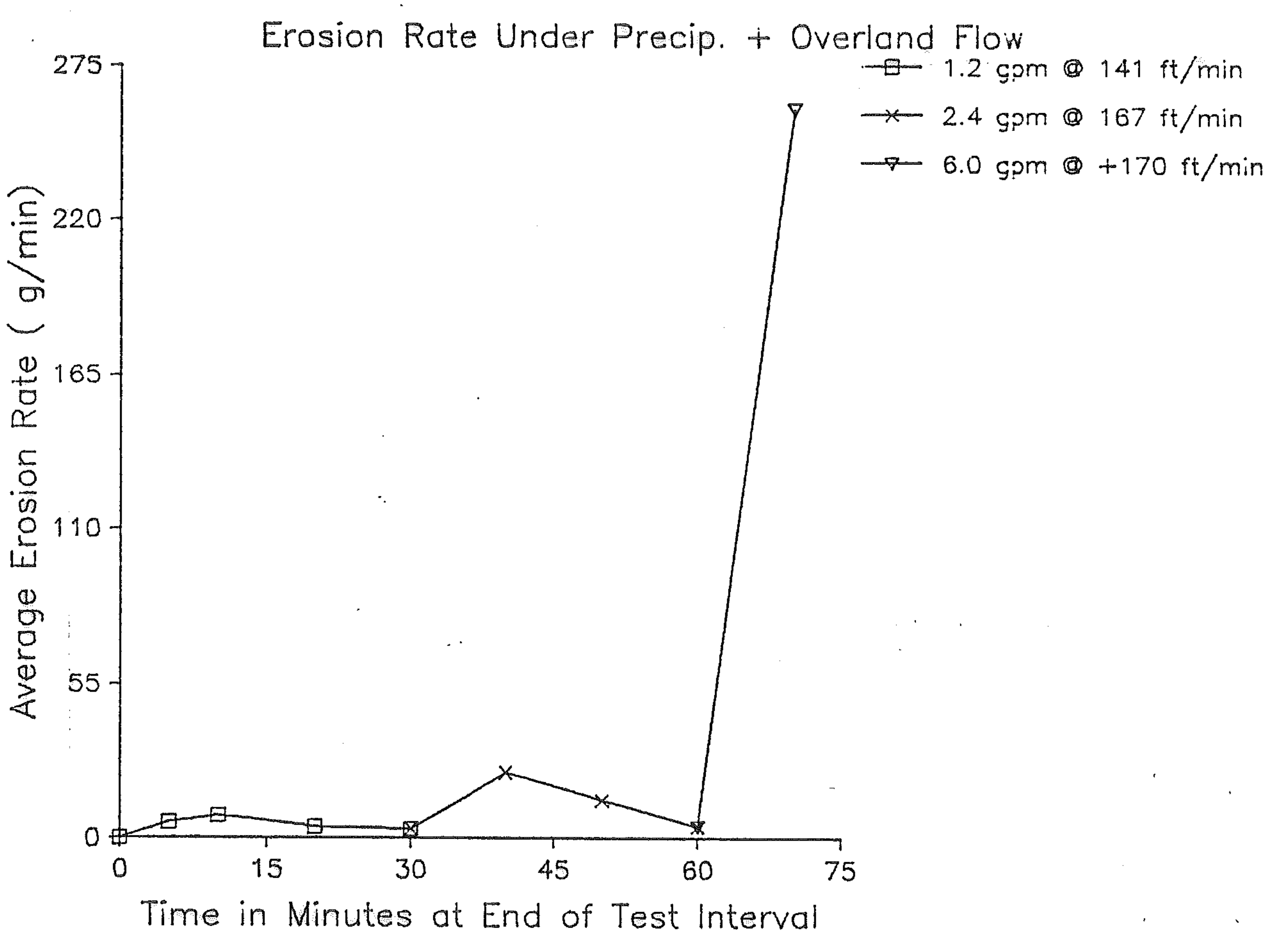

Figure 23. SRG1 Erosion Vs. Time With Flow Quantity and Velocity Varying

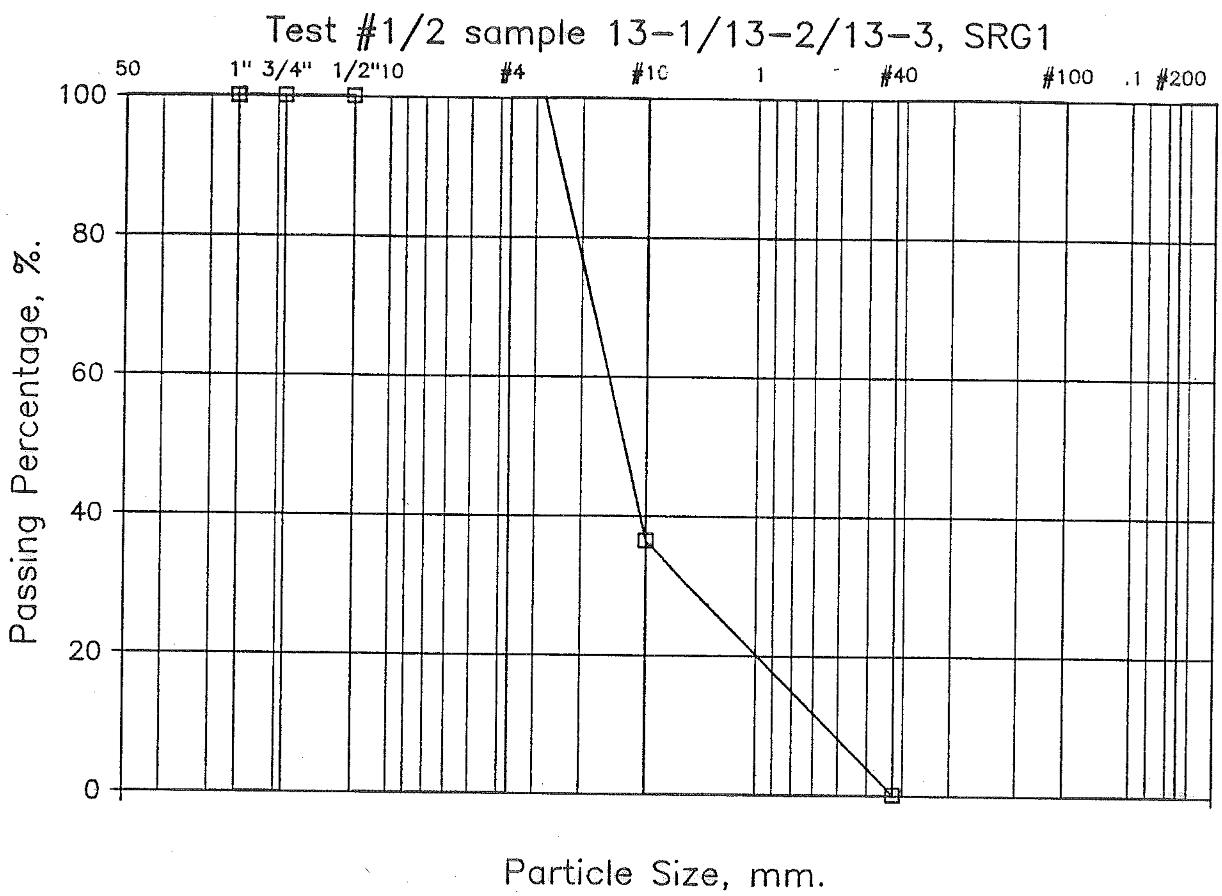

Figure 24. SRG1 Grain Size Analysis, 30 Minutes at 2.4 gpm (9.1 L/min) With a Velocity of 167 ft/min (50.9 m/min)

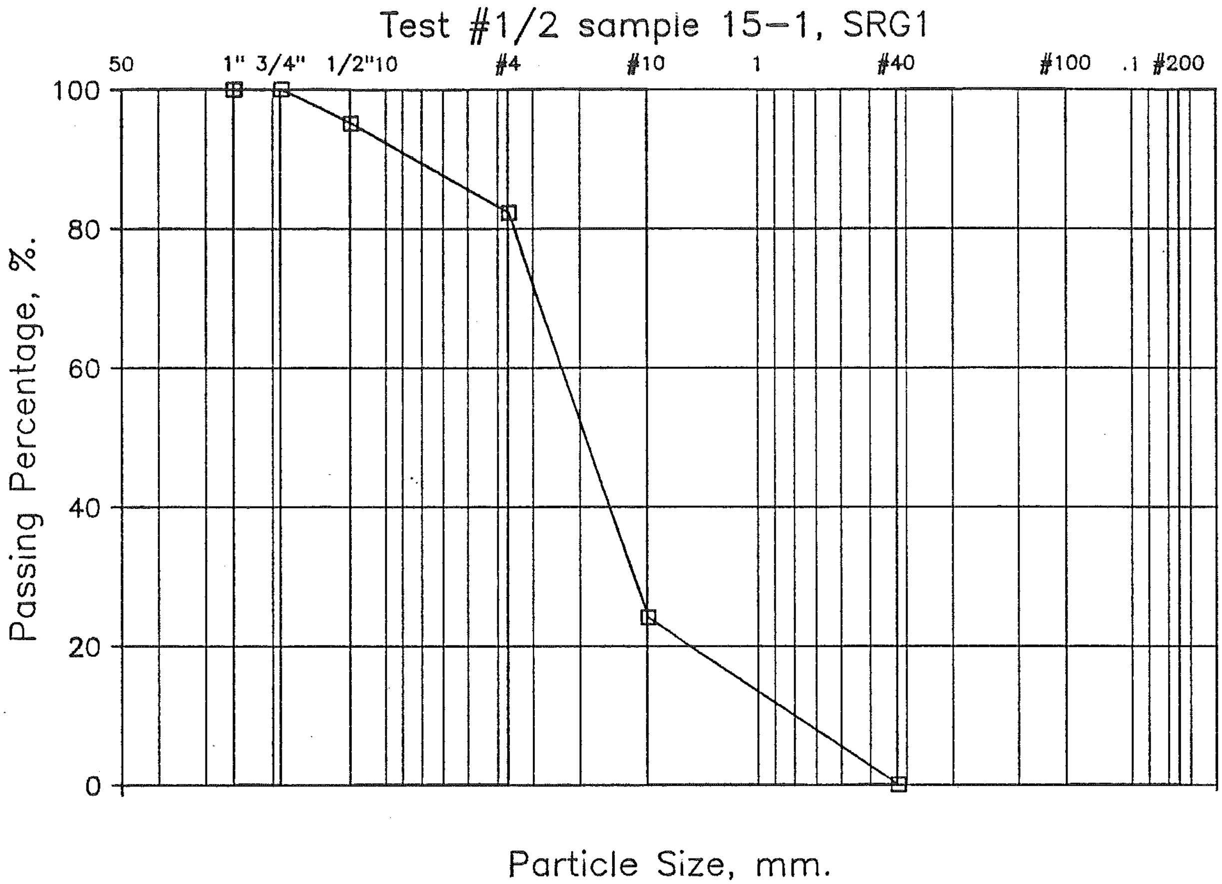

Figure 25. SRG1 Grain Size Analysis, 10 minutes at 6.0 gpm (22.7 L/min) With a Velocity of + 170 ft/min (+51.8 m/min)

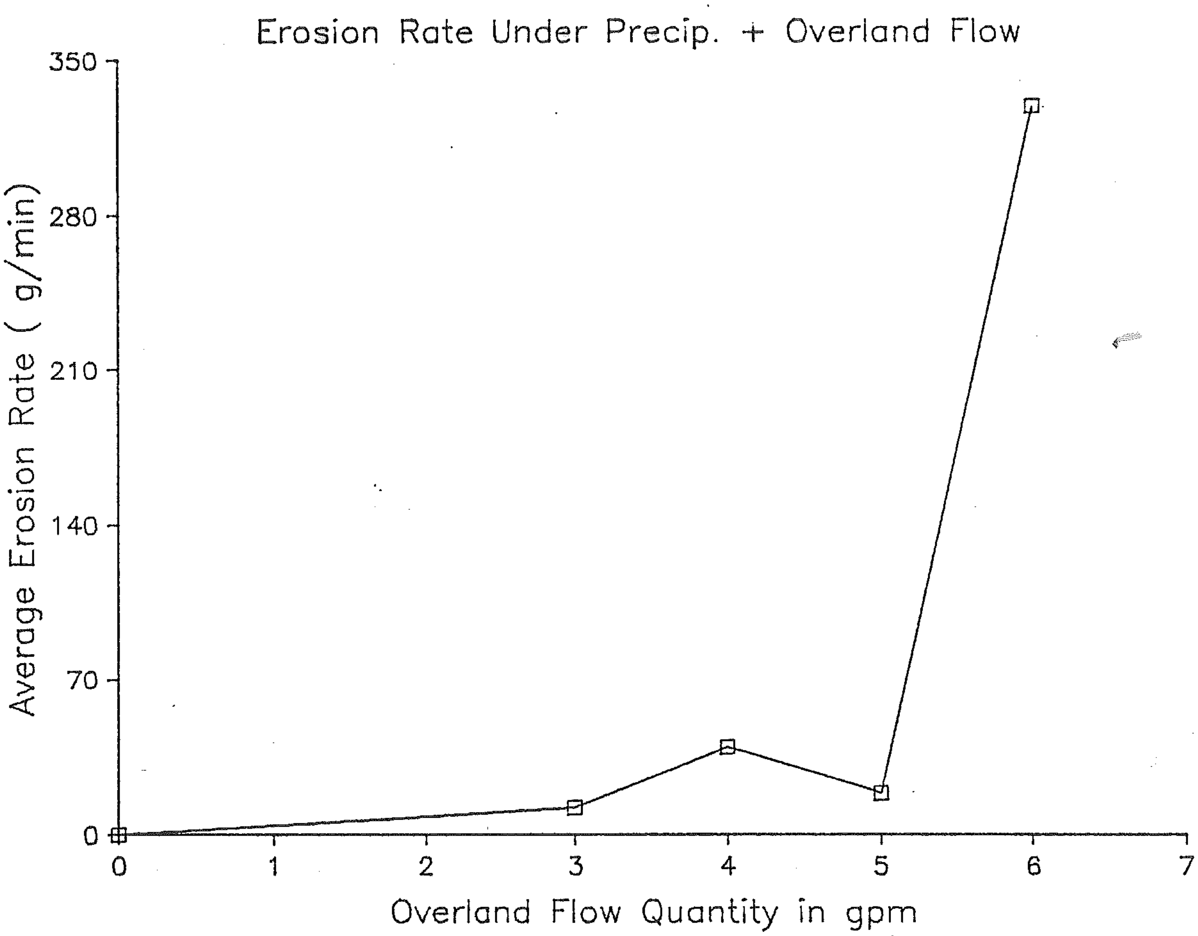

Figure 26. SRG1 Erosion Vs. Overland Flow Quantity,
2:1 Slope With a Flow Velocity of +170 ft/min (+51.8 m/min)

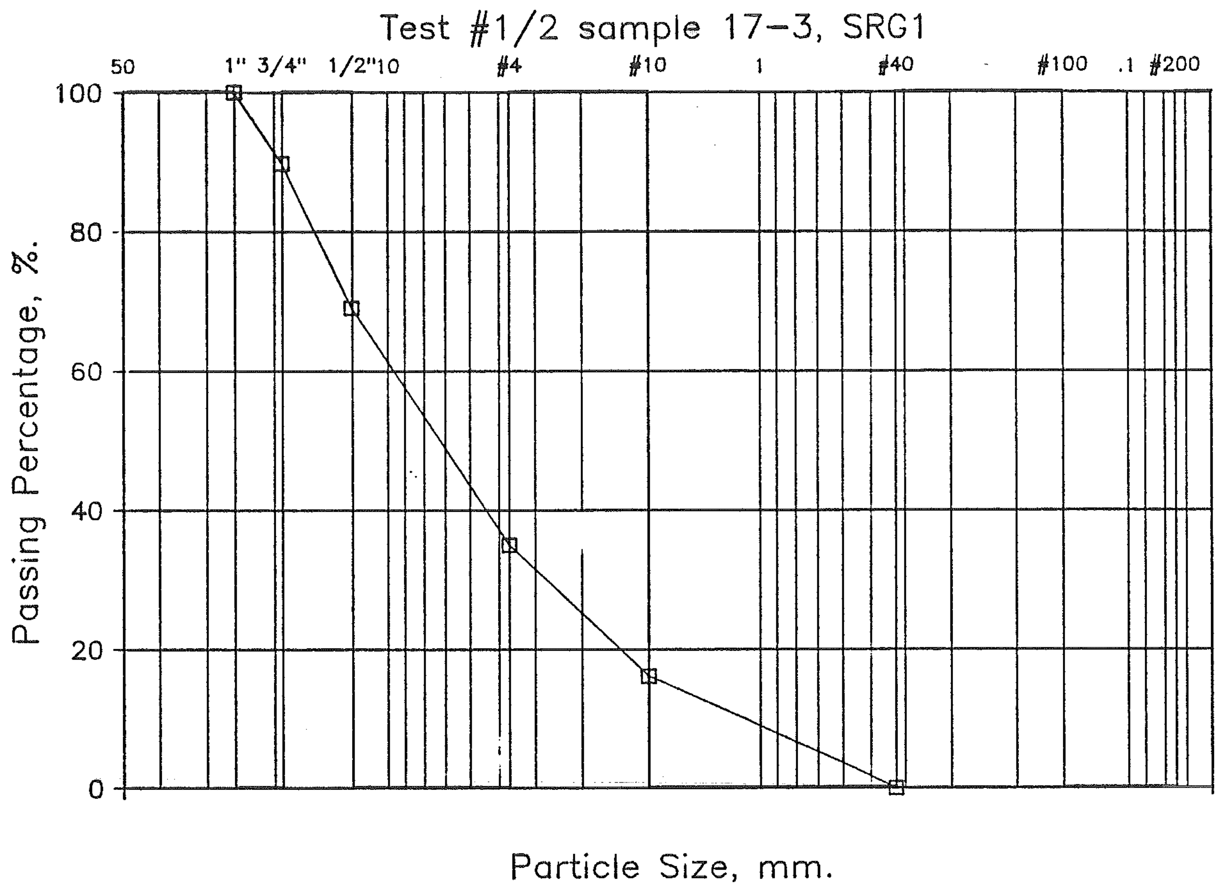

Figure 27. SRG1 Grain Size Analysis, Panel 1, 10 Minutes of Combined Flow at 6.0 gpm (22.7 L/min)

To depict the relationship between erosion rate and overland flow velocity when a 2:1 slope of SRG1 material is stressed by precipitation and overland flow, Figure 28 was prepared. When the flow rate is 1.2 gpm and the velocity is less than 141 ft/min the slope of SRG1 material will armor itself. As can be seen in Figure 28, the erodibility of the SRG1 material was not increasing even when the erosion stress was increasing due to the development of a resistive surface.

All of the data examined so far has indicated that when a soil with the properties of SRG1 is subjected to precipitation and overland flow erosion stresses the soil has a tendency to protect itself. If the material can resist the flow, surface armor will develop. Relationships depicted on Figures 15 and 20 show clearly that with time the rate of erosion will decrease. If the slope is not disturbed then surface protection is available to resist erosion during subsequent flows. Should the surface protection that has developed be damaged then the rate of erosion would increase with the next flow until the armor could be reformed.

Data on Figures 15 and 20 also show that with successively higher flow events the rate of erosion first increases and then rapidly decreases as a more efficient form of surface protection is formed. However, at some point the erosion stresses will become large enough to transport the largest soil particles. When this severe erosion environment is brought to bear on the slope, the slope will fail.

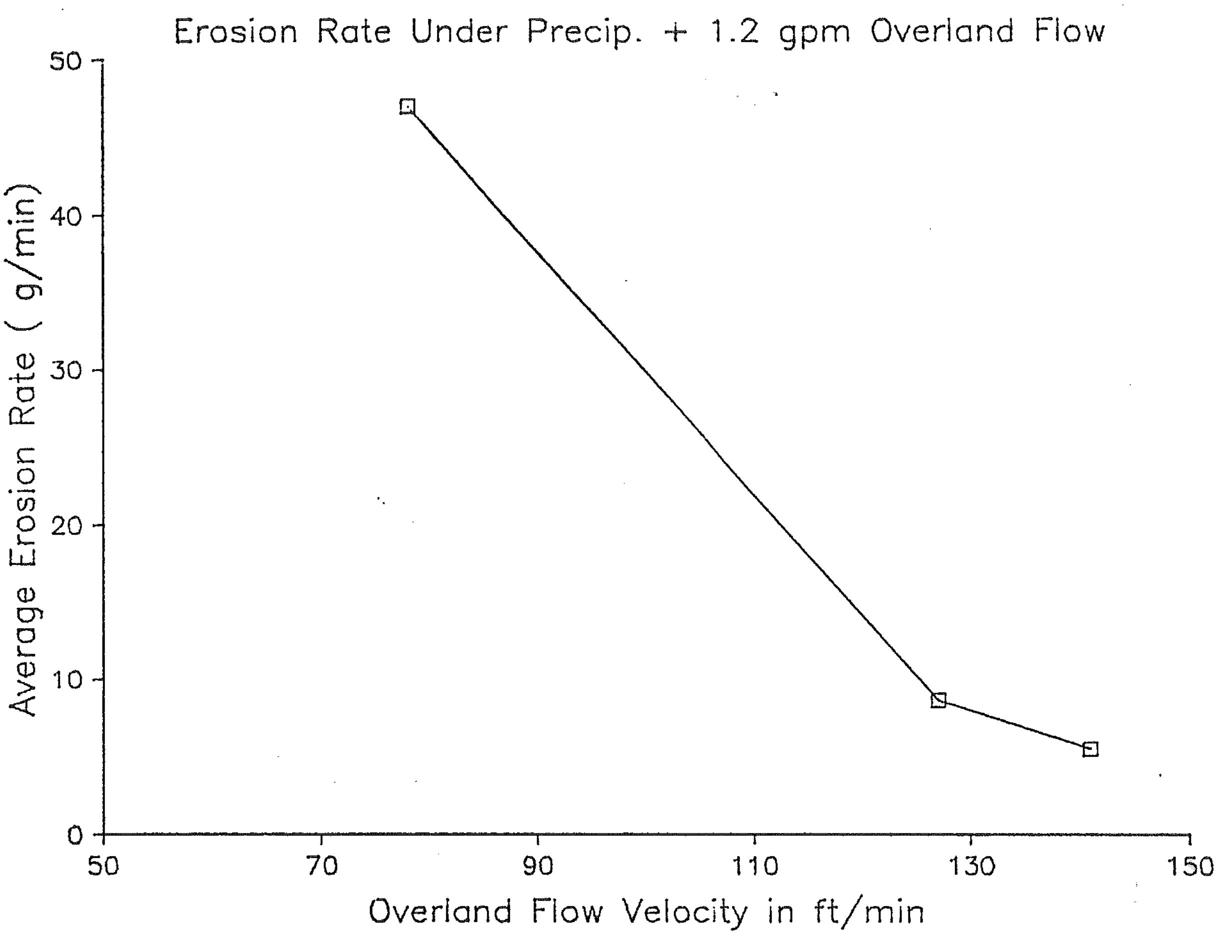

Figure 28. SRG1 Erosion Rate Vs. Overland Flow Velocity, 2:1 Slope and 1.2 gpm (4.5 L/min)

Another test was performed using the SRG1 material. This test examined the resistance to erosion at high overland flow rates while the slope was kept at 2:1. The overland flow was increased to 8.0 gpm (30.3 L/min) which resulted in panel failure for two of the panels, (Figure 29). This data and the data from the first series of SRG1 tests show similar behavior. The precise flow at which the slope fails appears to lie between 6.0 and 8.0 gpm flow rates. The differences between panels is sufficient to produce this range in maximum erosion stress resistance. It is adequate to know the conditions at which stress will have a high probability of producing an erosion channel when SRG1 material is placed on a 2:1 slope. These conditions are met when the precipitation and overland flows are combined and the overland flow component is greater than 4.0 gpm.

An example of the variability to be found on "identical" panel surfaces is depicted on Figure 30. The results of panel 3 present proof that for an advantageous arrangement of surface particles even SRG1 material is resistant to combined flows with an overland component of 8.0 gpm. It should be noted that considerable movement and surface erosion occurred prior to the development of this rather stable surface. The sample at the end of the 8.0 gpm 10 minute event contained no particles larger than the number 4 size. This indicates that the preceding flow events were responsible for the slope resistance (Figure 31).

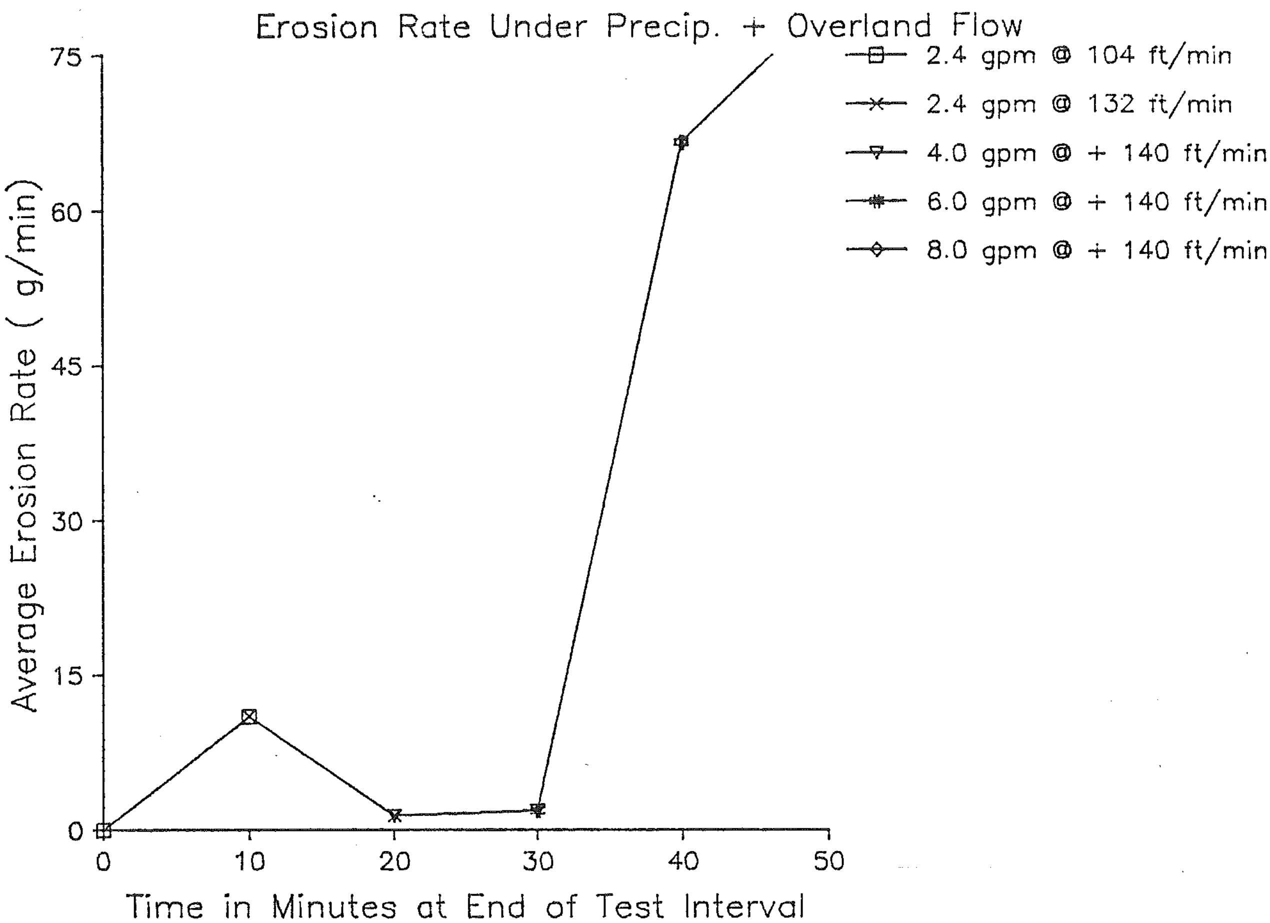

Figure 29. SRG1 Test 2, Erosion Rate Vs. Time, 2:1 Slope and Varying Overland Flow Conditions

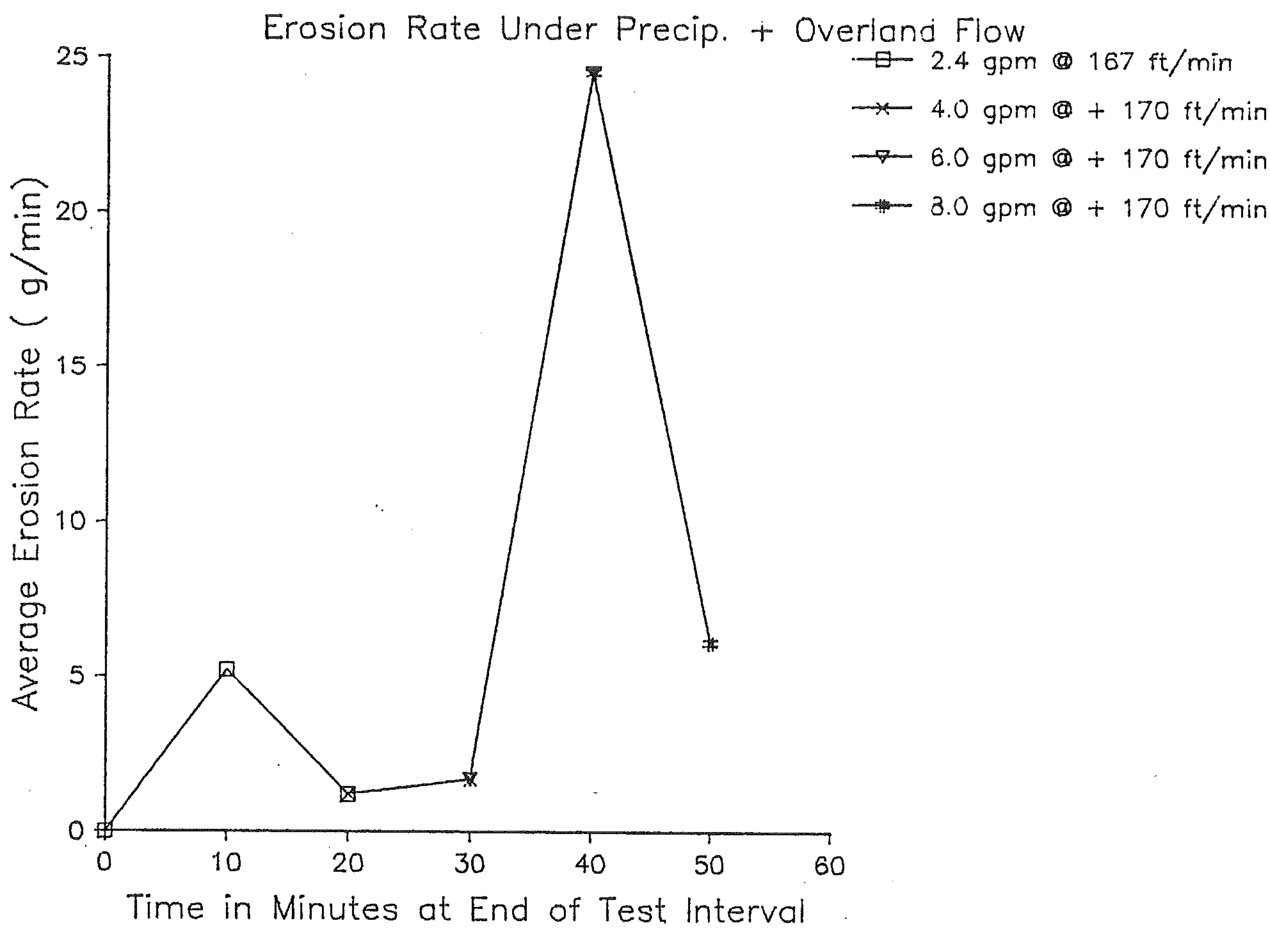

Figure 30. SRG1 Test 2, Panel 3, Erosion Rate Vs. Time, 2:1 Slope

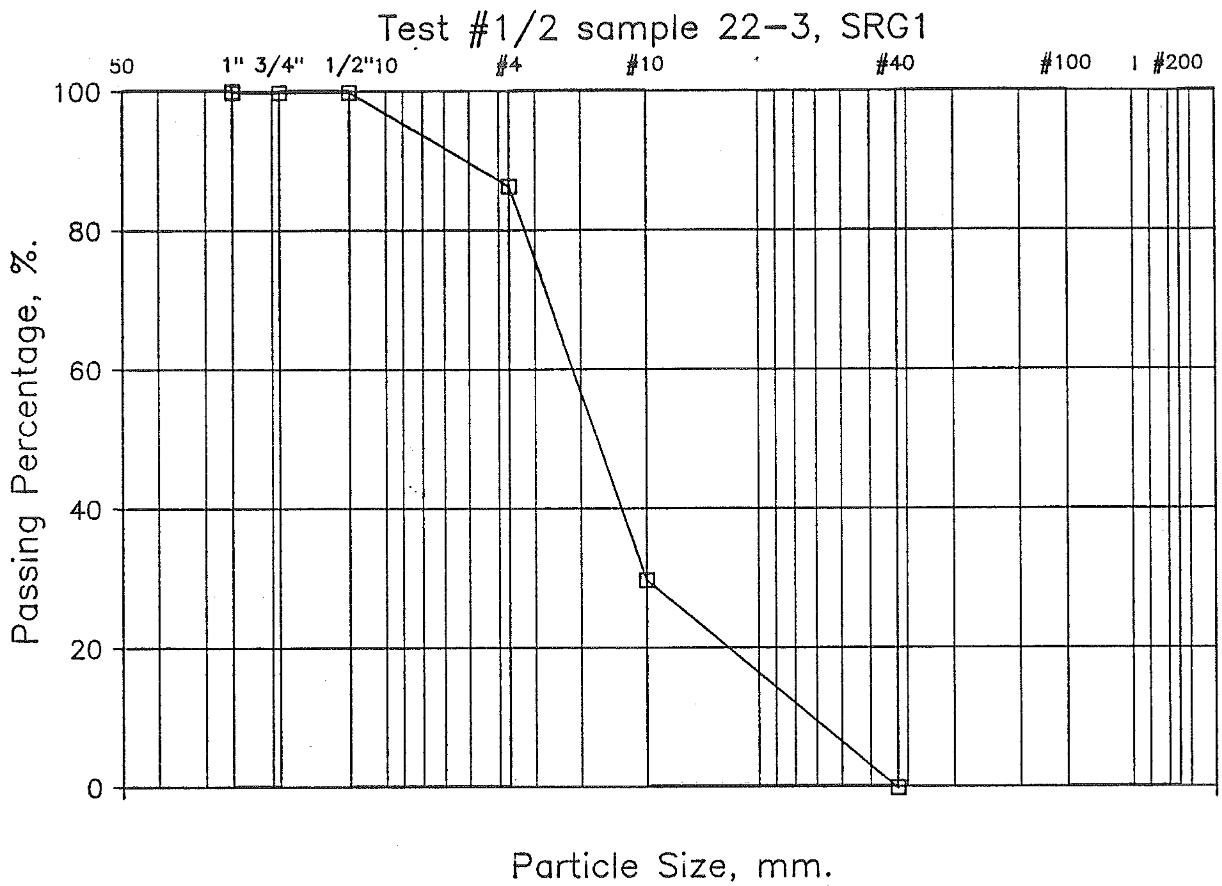

Figure 31. SRG1 Grain Size Analysis, Panel 3, Collected after 10 Minutes of Combined Flow With 8.0 gpm (30.3 L/min)

A sample of the granite surface protection that was placed west of Gilbert Rd. on SR 360, was also tested at 2:1 slopes (SRG8). Panel 1 of SRG8 was very resistant to the combined erosion flow testing until 8.0 gpm was applied (Figure 32). In fact until the failure occurred there was no material removed from the slope. Panels 2 and 3 failed at a combined flow with the overland component at 6.0 gpm although the failure showed more sluffing than the previous channel forming failures (Figure 33). As with panel 1 no material was transported until the failure erosion stresses were applied.

The SRG8 material has a very high permeability. The permeable nature of this material prevented the precipitation and overland flow from causing failure with an overland component up to 6.0 gpm when the slope was at 80 percent of the 2:1 slope (Figure 34). All three panels were able to resist eroding to failure. When the slope was increased to 2:1, one panel was able to resist the 6.0 gpm condition though the other two panels did not exhibit formation of channels. The material was so permeable that no surface flow could be sustained below 6.0 gpm. Without surface flow erosion would not occur under test conditions.

To assess the effect of dust and maintenance activities in adding material that would eventually reduce the permeability on slopes, the test was modified. The SRG8 was placed as for the first two test series then 1300 g of minus number 40 soil derived from SRP5 and IP9 was sprinkled on each test panel. Each panel was wetted from the spray heads alone until the soil

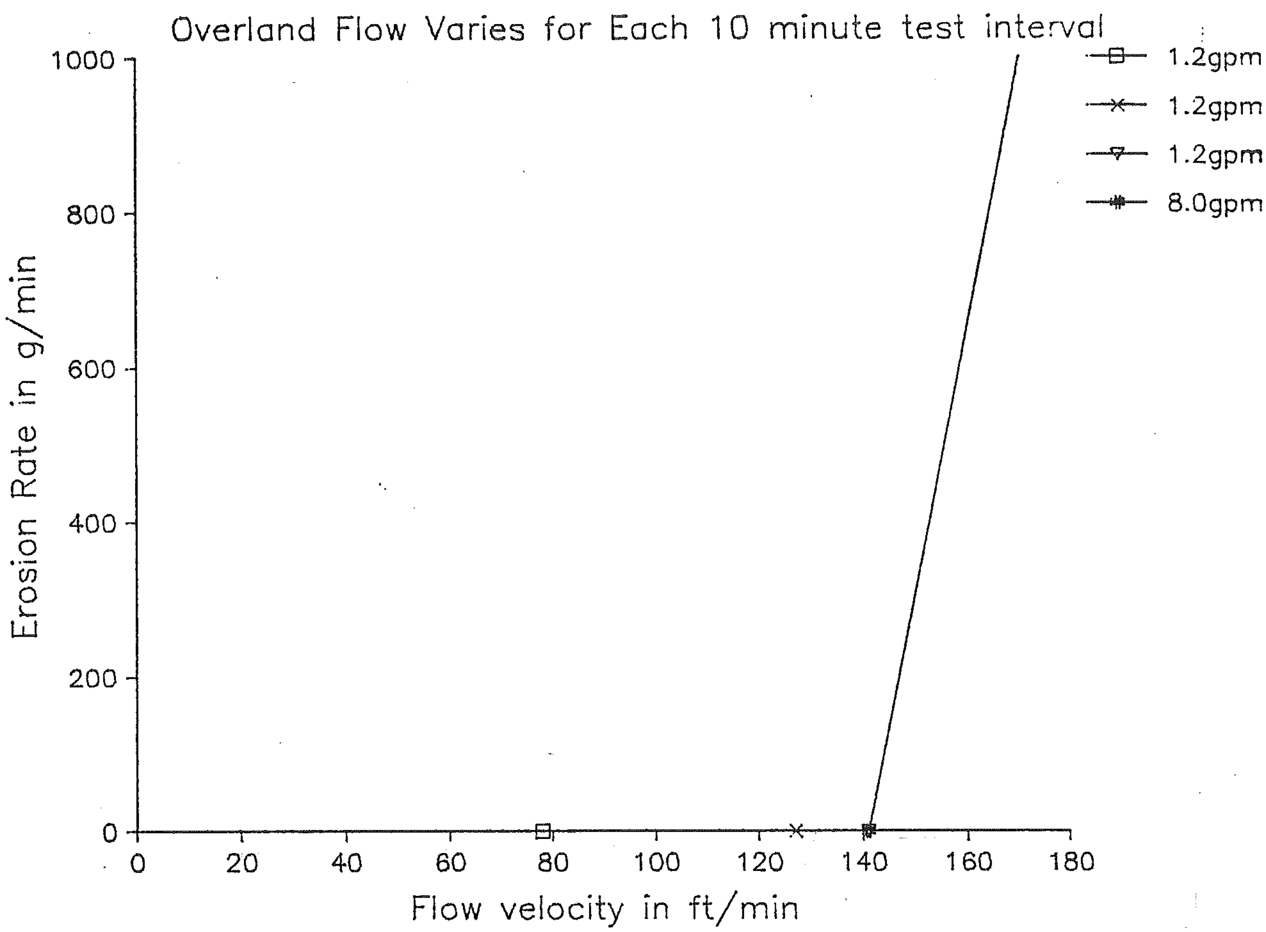

Figure 32. SRG8 Panel 1, Erosion Rate Vs. Flow Velocity, 2:1 Slope

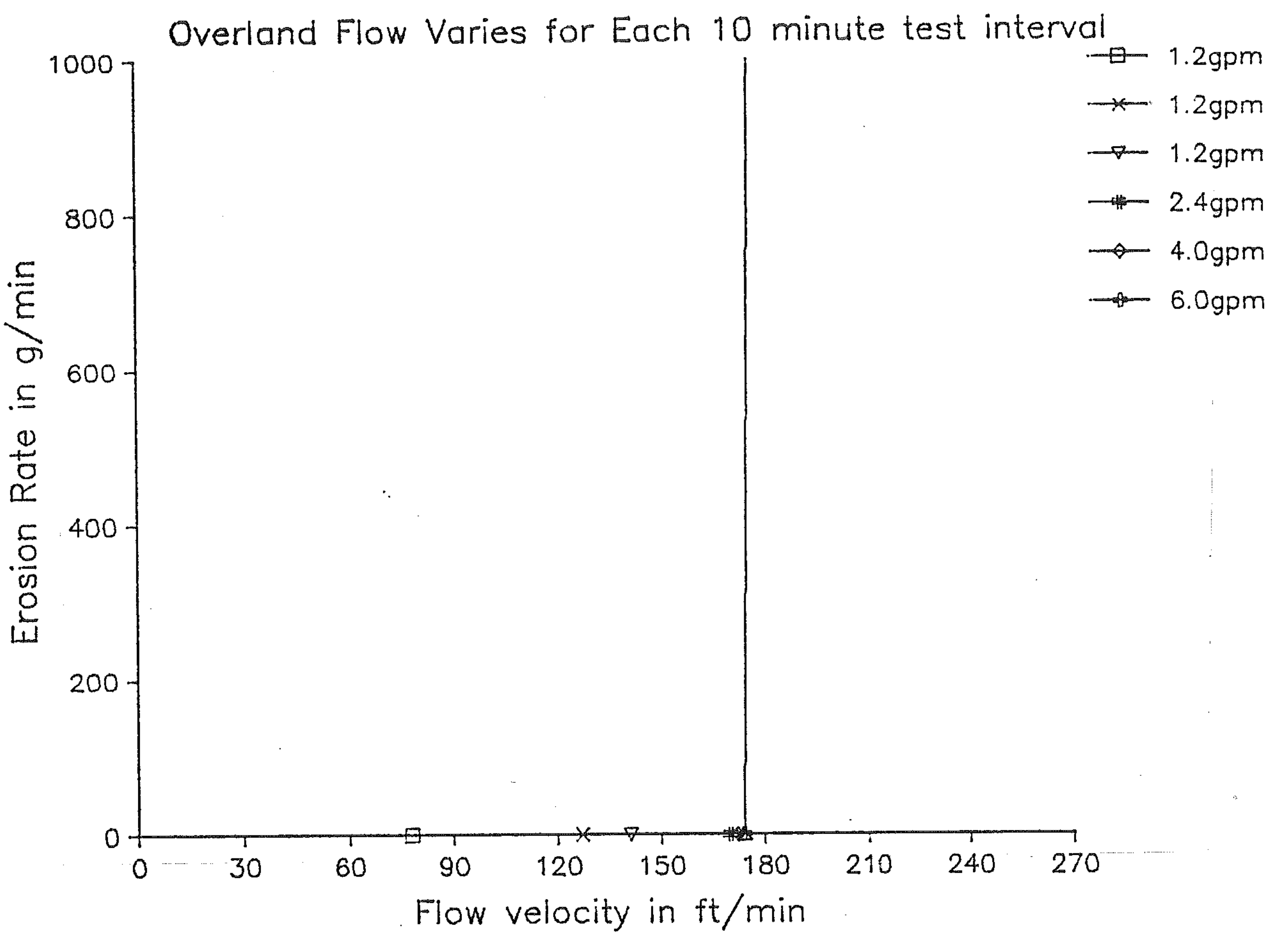

Figure 33. SRG8 Panels 2 & 3, Erosion Rate Vs. Flow Velocity, 2:1 Slope

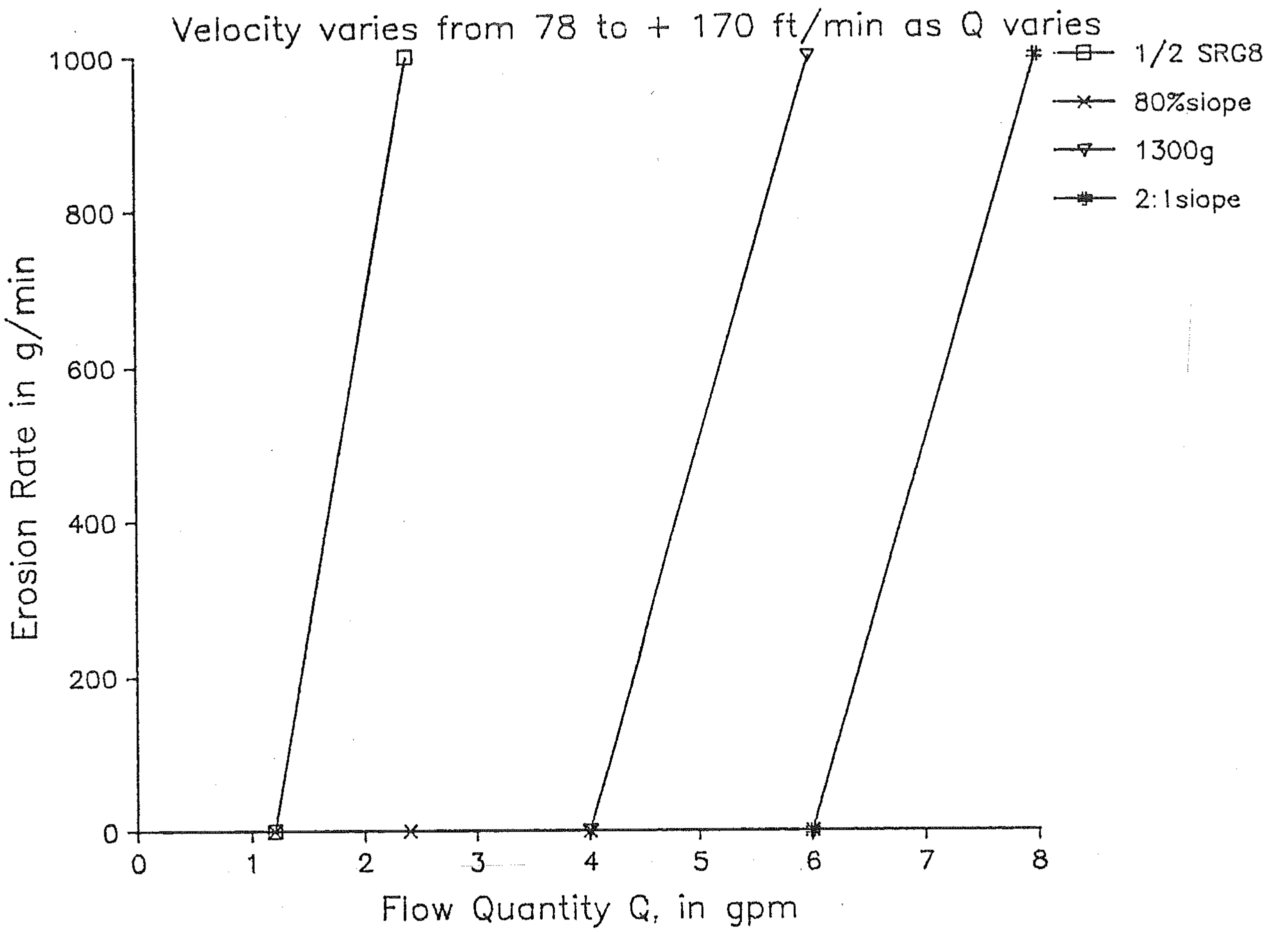

Figure 34. SRG8 Erosion Rate Vs. Flow Quantity for 26.6 and 21 Degree Slopes

had been transported into the pore spaces of the SRG8. The erosion testing then proceeded with the combined effects of precipitation and overland flow. With the 2:1 slope all panels failed within seconds of applying the combined flow with an overland component of 6.0 gpm (Figure 34). The failure was rapid and took the form of a clear channel until the 6000 material was exposed. There was no question that an erosion failure had occurred (Figure 34).

One additional test series was performed using the SRG8 material. That test modeled the field condition in which a thin 0.5 inch thick layer of SRG8 was placed over a thick layer of low permeable soil. SRP5 was used for the underlaying material and 0.5 inches of SRG8 were placed over it. This test condition examined the erosion resistance when the permeability remained high but due to the thin section water would be forced to move across the surface. When tested under the combined flow conditions with an overland component of 2.4 gpm failure occurred for all panels (Figure 34).

It is of interest to note that the rills produced in the test panels under the last two series of tests looked remarkably similar to the rills observed west of Gilbert Rd. following the referenced storms. Shape and dimensions of both field and laboratory channels were approximately the same.

This series of tests using the SRG8 material was enlightening because it demonstrates the complexity of the slope erosion environment both as placed and as it may potentially change with time. It is not enough to perform a slope erosion test and then proclaim the success when little or no erosion occurs. Instead, the slope designer must understand why the erosion resistance is high and thus why the test is successful. If the results are due to high permeability then the role of thickness and long term permeability in future erosion resistance must be developed. Insufficient knowledge now exists to enable the time plugging relationship to exist for any slope protecting material. However, the designer does not need that specific information, it is sufficient to recognize that time effects will reduce the protection. When that knowledge exists, the designer can at least build redundancy into the protection system or avoid using the materials unstable with time.

The interest in the role of thickness led to another series of tests using material that came from Dysart Rd. and I-10 and designated as IG1. The IG1 material was also used for slope protection on the overpass at Dysart Rd. It possessed a high surface permeability similar to the SRG8 samples. A series of tests terminating with a combined flow environment containing an overland component of 2.4 gpm with a velocity of 167 ft/min produced neither sediment nor failure (Figure 35).

The IG1 material prevented surface flow from developing and thus resisted erosion. A new series of panels were prepared with a 0.5 inch thick layer of IG1 over SRP5 material. The testing was repeated but this time the panels failed when the minimum combined flow with an overland component of 1.2 gpm was applied, Figure 35. The reduced thickness could not support the flow within the section. As soon as flow occurred on the sur-

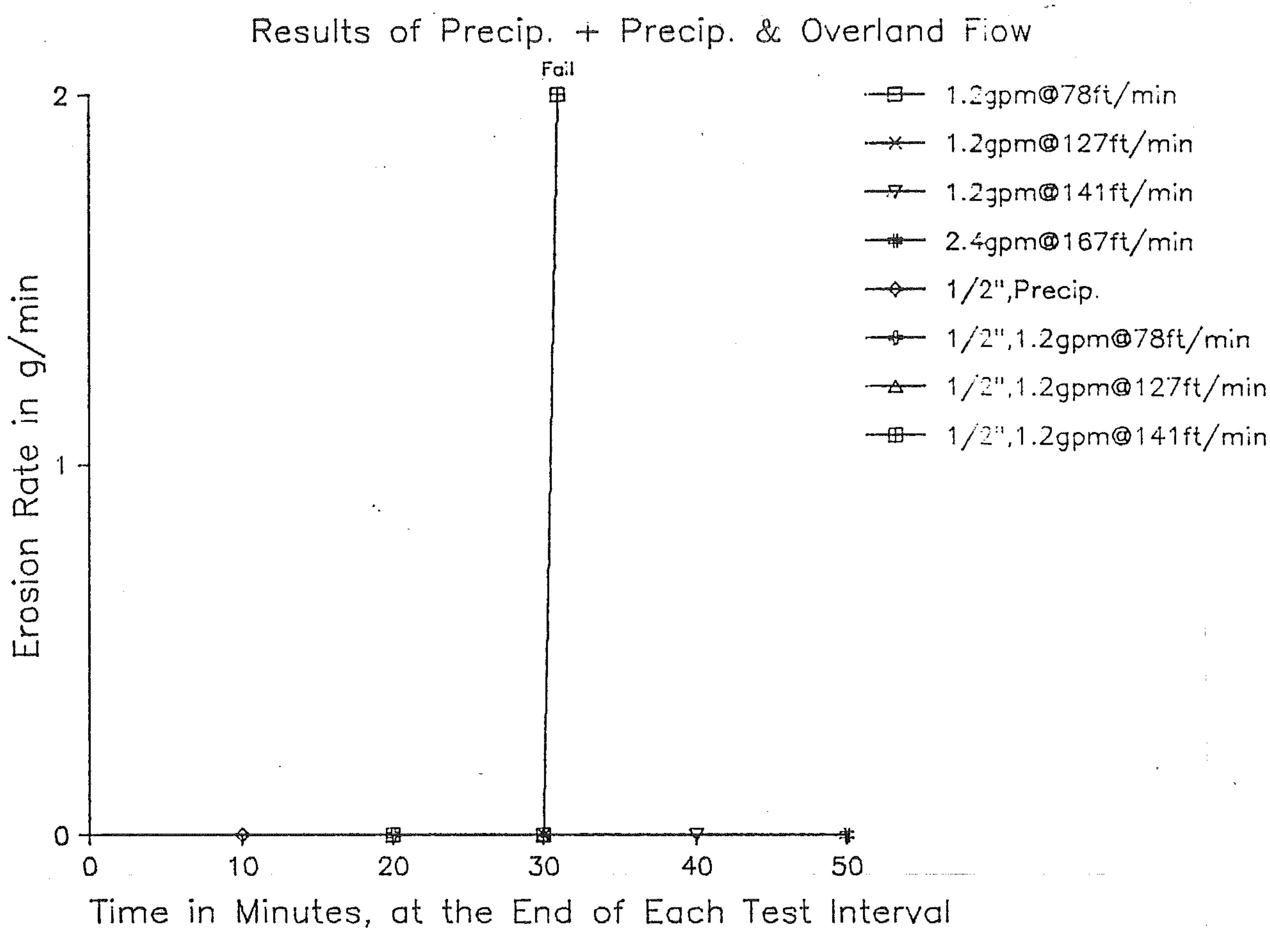

Figure 35. IG1 & 1/2 " IG1, Erosion Rate Vs. Time, 2:1 Slope

face the rather small particles could not resist transport. Because the particles were all approximately the same size no larger particles were available to protect the smaller ones. Therefore when the erosion started it proceeded rapidly to failure. With respect to the speed of failure the development of channels, resembled a piping failure in fine grained soil.

The erosion channels that formed in the laboratory were similar in geometry to those observed at the Dysart Exchange that were produced from the rumble strip discharge over the slopes. Like the SRG8 materials the correlation between field and laboratory for the IG1 panels was remarkably good.

The reported testing to this point has dealt with materials that have been used on the slopes as protection. A soil, IP9, was selected for testing because unlike the IG1, SRG1, and SRG8 materials it had only six percent of particles larger than the number 4 size (Table 14). Unlike the other materials it had failed during precipitation testing while at the 2:1 slope (Figure 36). This soil could not develop an effective armoring system because of the paucity of plus number 4 size particles. Without these particles and with the low permeability that produced efficient runoff, the slopes were doomed to fail. In fact an interesting phenomena is expressed in the data (Figure 36). It should be noted that in all prior tests that produced sediment, the initial increase in rate of erosion was followed by a drastically reduced rate. This was hypothesized as the result of initially unstable coarse particles moving to achieve

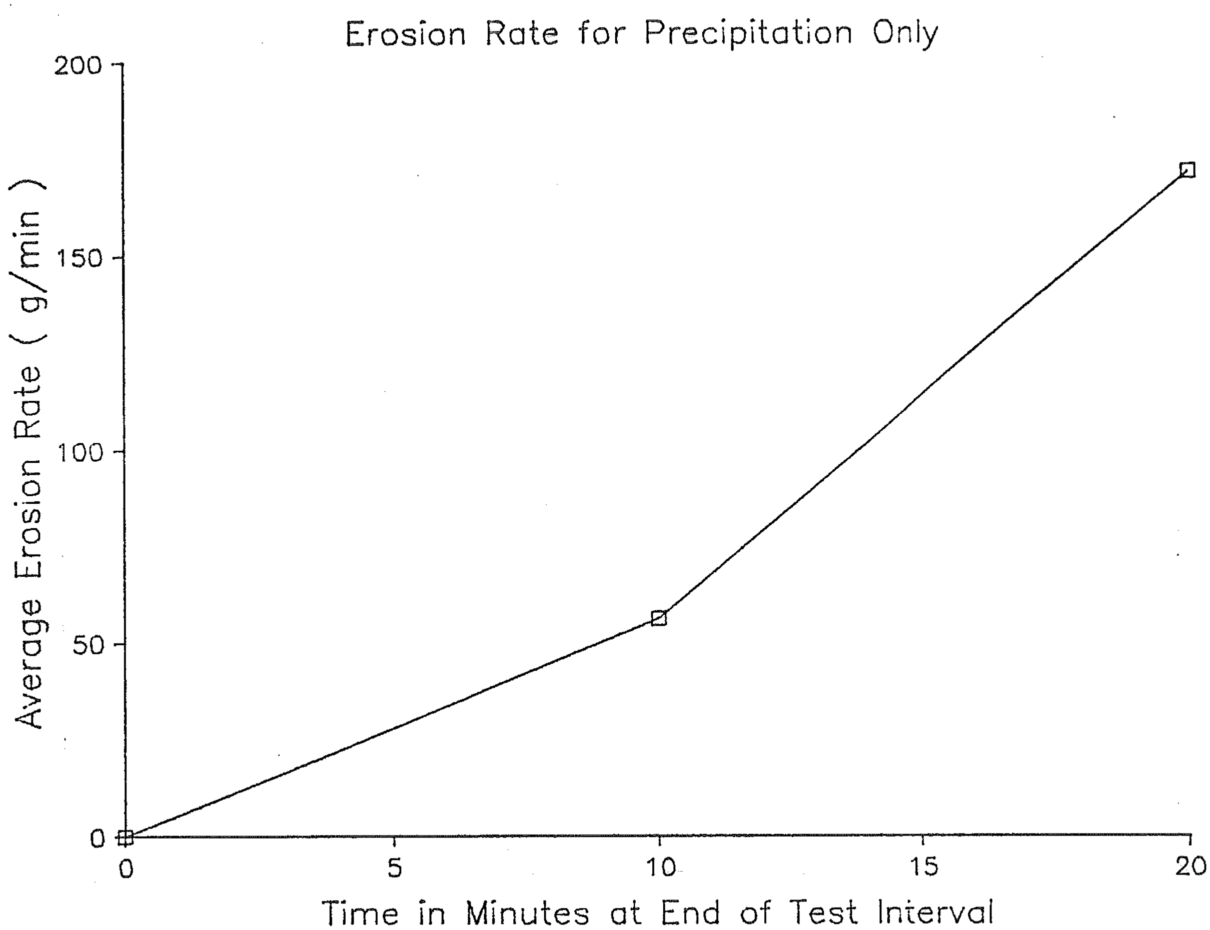

Figure 36. IP9 Erosion Rate Vs. Time, 2:1 Slope

a more stable orientation. For the IP9 soil, there were not enough coarse particles to have any affect.

The IP9 panels appeared to express the development of microchannels on the surfaces. Without the development of incise resisting surface armoring, rills were incised in the surface. As the duration of flow persists these rills drained larger and larger portions of the surface. Each rill was in effect developing an overland flow component that increased minute by minute. The net effect of this increasing flow is the acceleration of the erosion rate to failure. The test results from IP9 are graphic indicators of erosion when the development of armoring is lacking.

One final observation on the IP9 test results also deals with the small amount of coarse particles in the soil. During the initial three minutes of the test a marked change in the appearance of the panel surfaces. occurred. Each panel's color lightened as the lighter colored larger soil particles were exposed. The finer particles were washed away leaving the sand and what few gravel particles behind. In effect, armoring was occurring, however, there was an insufficient amount of these particles left behind to link together. Without the linking or buttressing of each other these particles could not prevent the incisement of small channels. Once the incisement process started, the flow regime was able to transport larger and larger particles from the surface. The analogy of a piping failure is applicable since with piping each particle removed increases the gradient; thus the rate of removal increases.

The testing program was beginning to provide a window that enabled a look into the world of particle interaction as surfaces were exposed to erosive environments. To remove some of the mud from this window another fine grained soil was selected for testing. The SRP5 soil was taken from Greenfield Rd. and SR 360. SRP5 has only 8 percent of the particles larger than the number 4 sieve size (Table 15).

When SRP5 was tested under the stress of precipitation alone on a 2:1 slope, the 10 minute erosion rate was 125 g/m when corrected for the total amount eroded (Figure 37). This erosion rate compared to the IP9 initial 10 minute rate of 185 g/min. The SRP5 slopes did not fail. When the combined flow was applied with a overland component of 1.2 gpm, a corrected rate of erosion of 1549 g/min was produced (Figure 38). The corrected rates are developed by relating the amount of plus number 4 material eroded to the starting percentage of the same size fraction. The rate of erosion is adjusted to reflect this estimate of the total amount eroded. It is recognized that this estimate of the total amount eroded will be conservative since the armoring process prevents the removal of proportional amounts of plus number 4 size particles. However, the difference for the soils tested is believed to be small.

To evaluate how erosion resistance of this soil is affected by coarse particles, varying amounts of large particles were mixed with the SRP5 soil. Once mixed, erosion tests examined the effect of precipitation (Figure 37). The results of six soil erosion tests are provided on Figure 37. The numer-

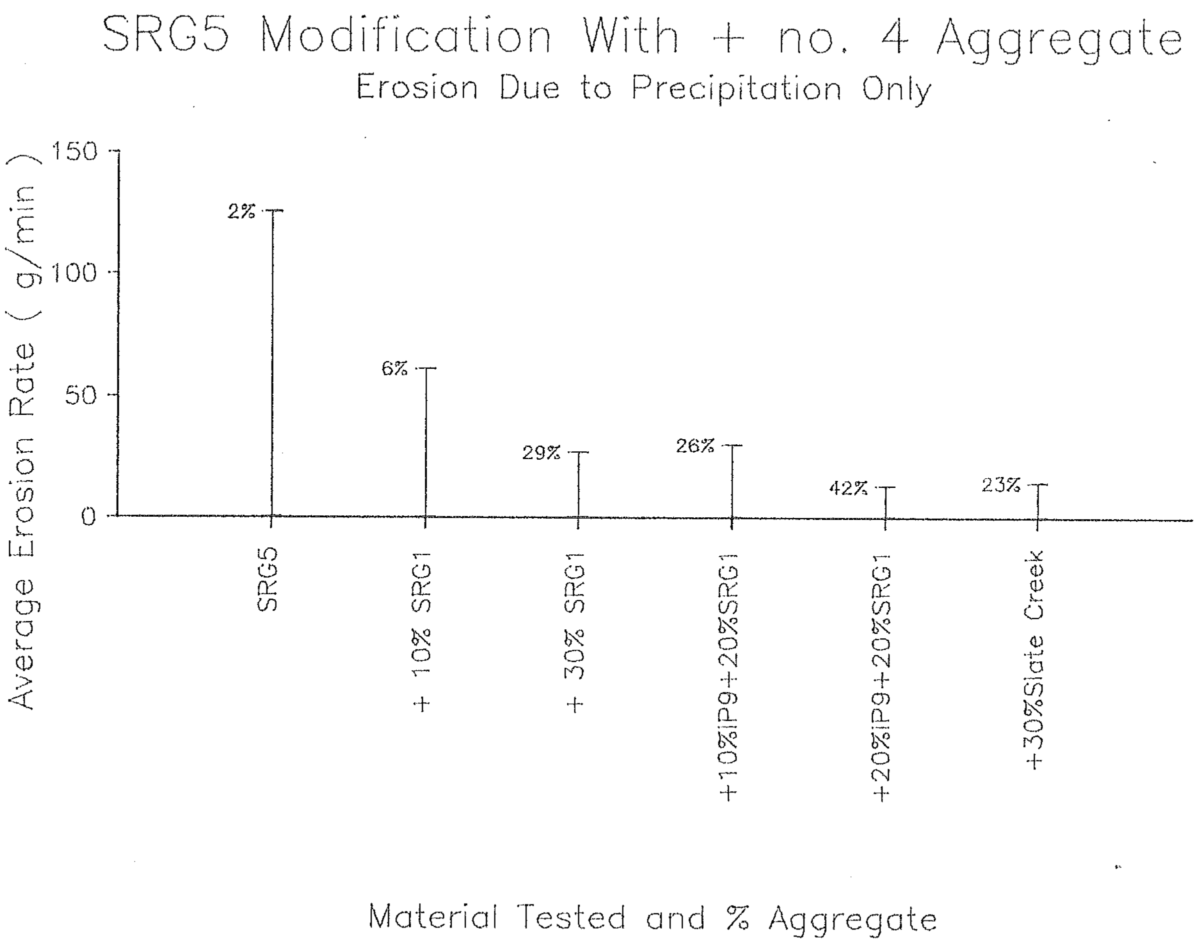

Figure 37. SRP5 Erosion Rate Vs. Material Tested & Percent Aggregate Larger than the No. 4 Sieve, 2:1 Slope, Precipitation Only

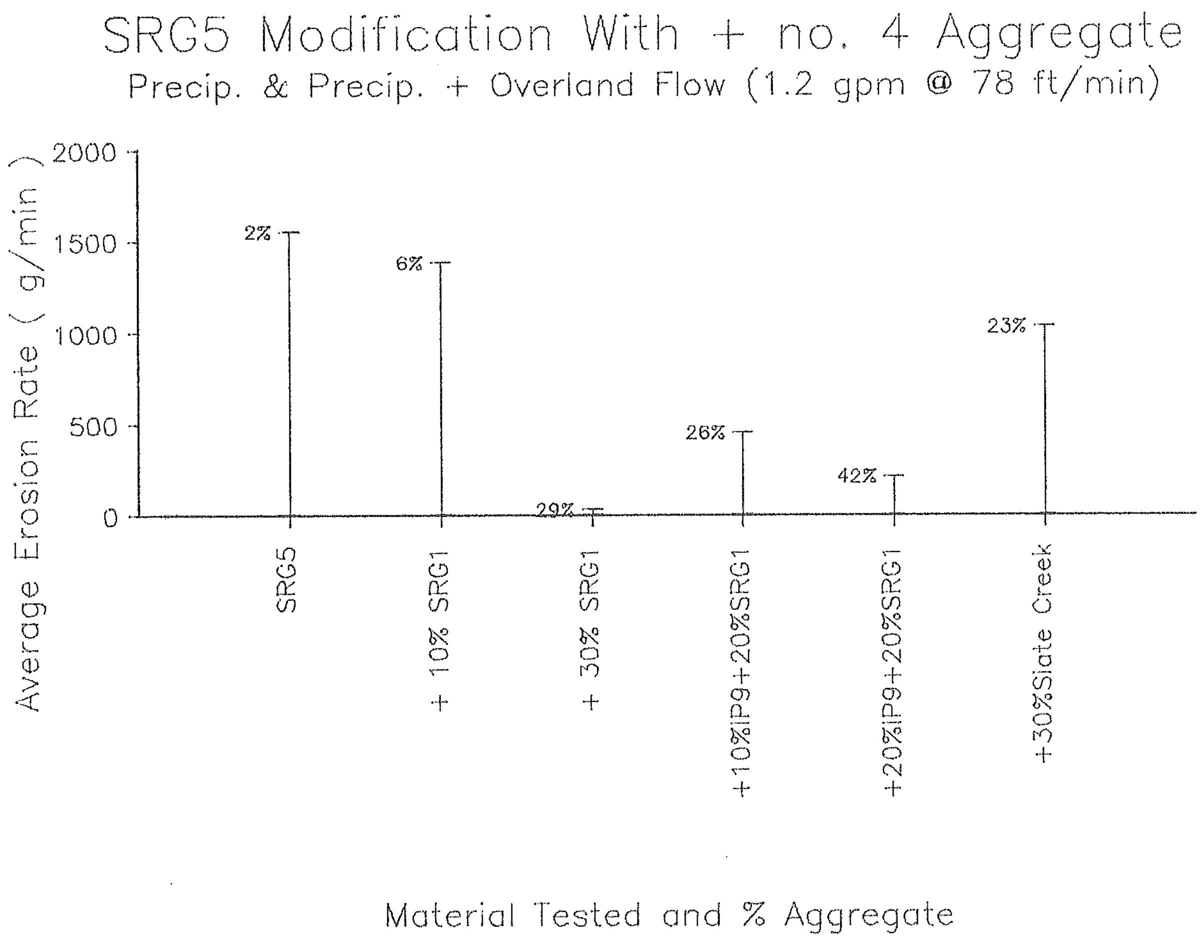

Figure 38. SRP5 Erosion Rate Vs. Material Tested & Amount of Aggregate Larger than the No. 4 Sieve, 2:1 Slope, Combined Flow

ical values shown for the percent aggregate were determined by sieve analysis after the soils were mixed, and prior to erosion testing. The percentages shown with the material added to the SRP5 soil were the measured amounts of materials by weight. The added SRG1 particles were all retained on the 0.5 inch screen. The IG1 material was obtained from the field. The Slate Creek material was obtained from SR 87 at Slate Creek and was sieved to pass the 1.5 inch mesh and be retained on the 0.5 inch sieve. The Slate Creek particles were used because of their flat shape.

The ratio of the longest particle dimension to the smallest dimension was established for these additives. This dimension ratio is defined as the shape factor (SF). The SF values were 2.0 for SRG1, 2.1 for IG1, and 8.4 for Slate Creek aggregate.

The relative erosion rates for the combined erosion stress with an overland flow component for the SRP5 modified soils can be found on Figure 38. A considerable reduction in rates of erosion was observed particularly when the amount of aggregate added was greater than 29 percent. When Figures 37 and 38 are compared, it becomes apparent that the modified soil has the same relative beneficial reduction in rate of erosion for both test conditions.

When rate of erosion caused by precipitation is plotted against the percentage of plus number 4 material in the soil for the SRP5 base soil, Figure 39 results. When the percentage of particles larger than the number 4 sieve is greater than 10

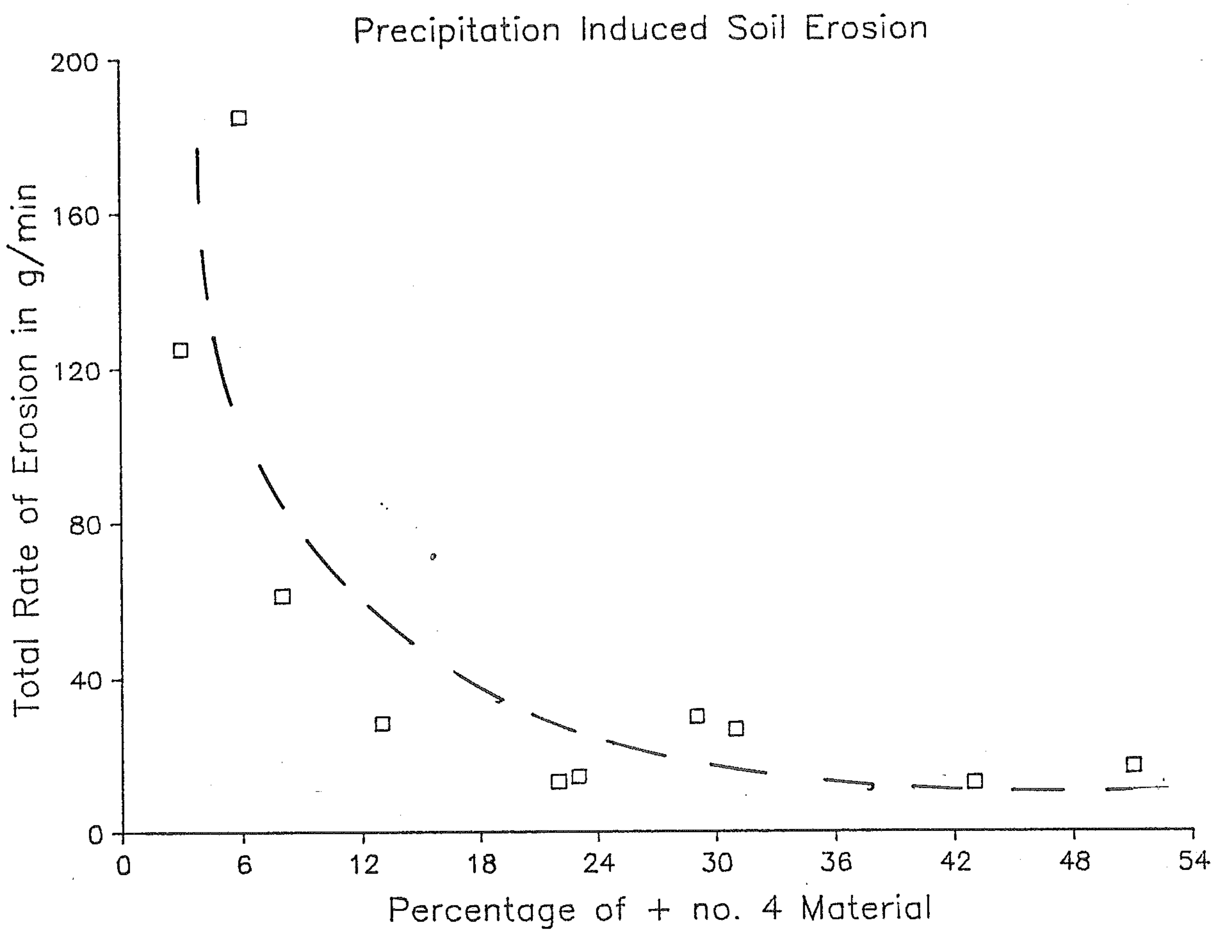

Figure 39. SRP5 Base Soil, Rate of Erosion Vs. Amount of Aggregate Larger than the No. 4 Sieve, 2:1 Slope, Precipitation Only

percent, a significant reduction in erosion potential occurs. Essentially only a very small change occurs beyond 20 percent.

The addition of an overland flow component at 1.2 gpm with a velocity of 78 ft/min also reduces the erosion rate very effectively (Figure 40). For this more severe erosional stress condition at least 20 percent added coarse particles are necessary to significantly reduce erosion. The results of both test conditions are provided in Figure 41.

The testing with the SRP5 soil provides a clear example of the potential benefits to be derived when armoring is enhanced for a slope. The reduction in erosion to less than 15 percent of the unmodified soil potential while adding approximately 20 percent of plus number 4 material would appear to have considerable economic appeal.

The other aspect of aggregate additives to soil is the shape factor influence. The SRP5 erosion rate versus aggregate shape factor for the 30 percent aggregate additive soils is shown on Figure 42. The Slate Creek aggregate is the most efficiently shaped to reduce erosion. However, the data indicates that shape factor is not nearly as important as the total percentage of plus number 4 size particles available. Whenever a choice in particle shape factors is available, the higher SF value material should warrant special consideration.

The results of the aggregate addition experiments were very productive but the study team turned to other methods of reducing erosion by modifying the original site soil. Chemical

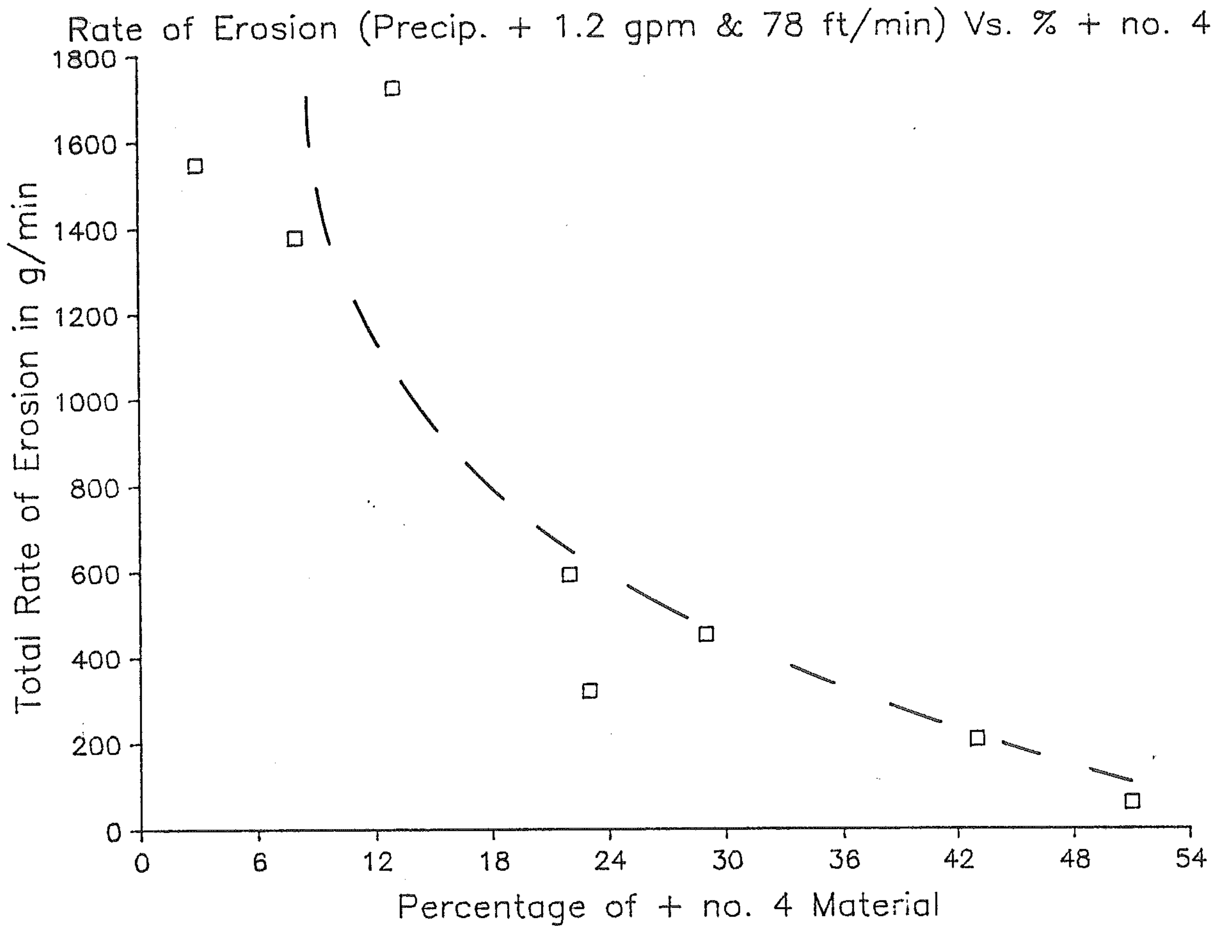

Figure 40. SRP5 Based Soil, Rate of Erosion Vs. Amount of Aggregate Larger than the No. 4 Sieve, 2:1 Slope, Combined Flow

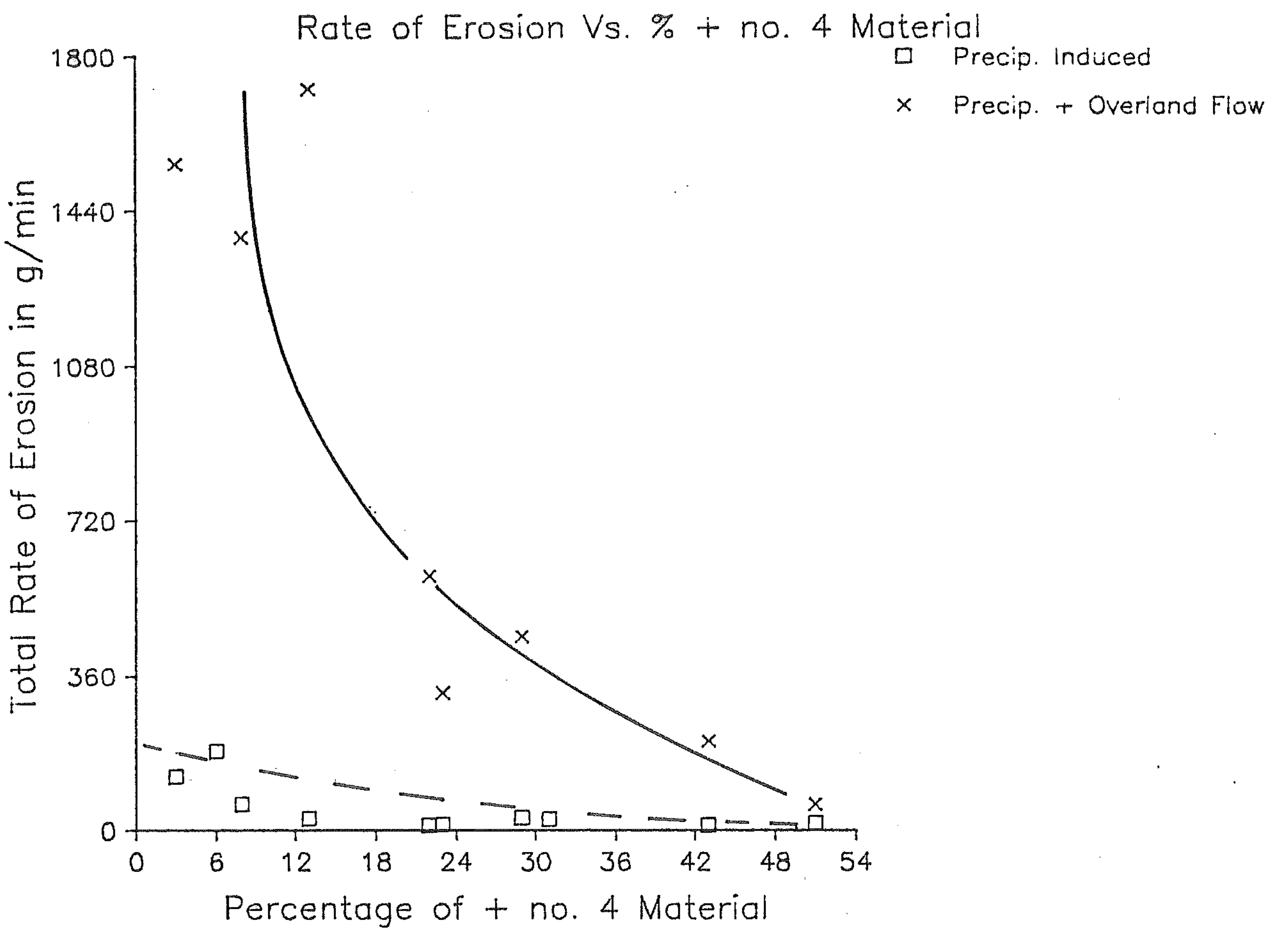

Figure 41. SRP4 Based Soil, Summary of Erosion Rate Vs. Amount of Aggregate Larger than the No. 4 Sieve, 2:1 Slope

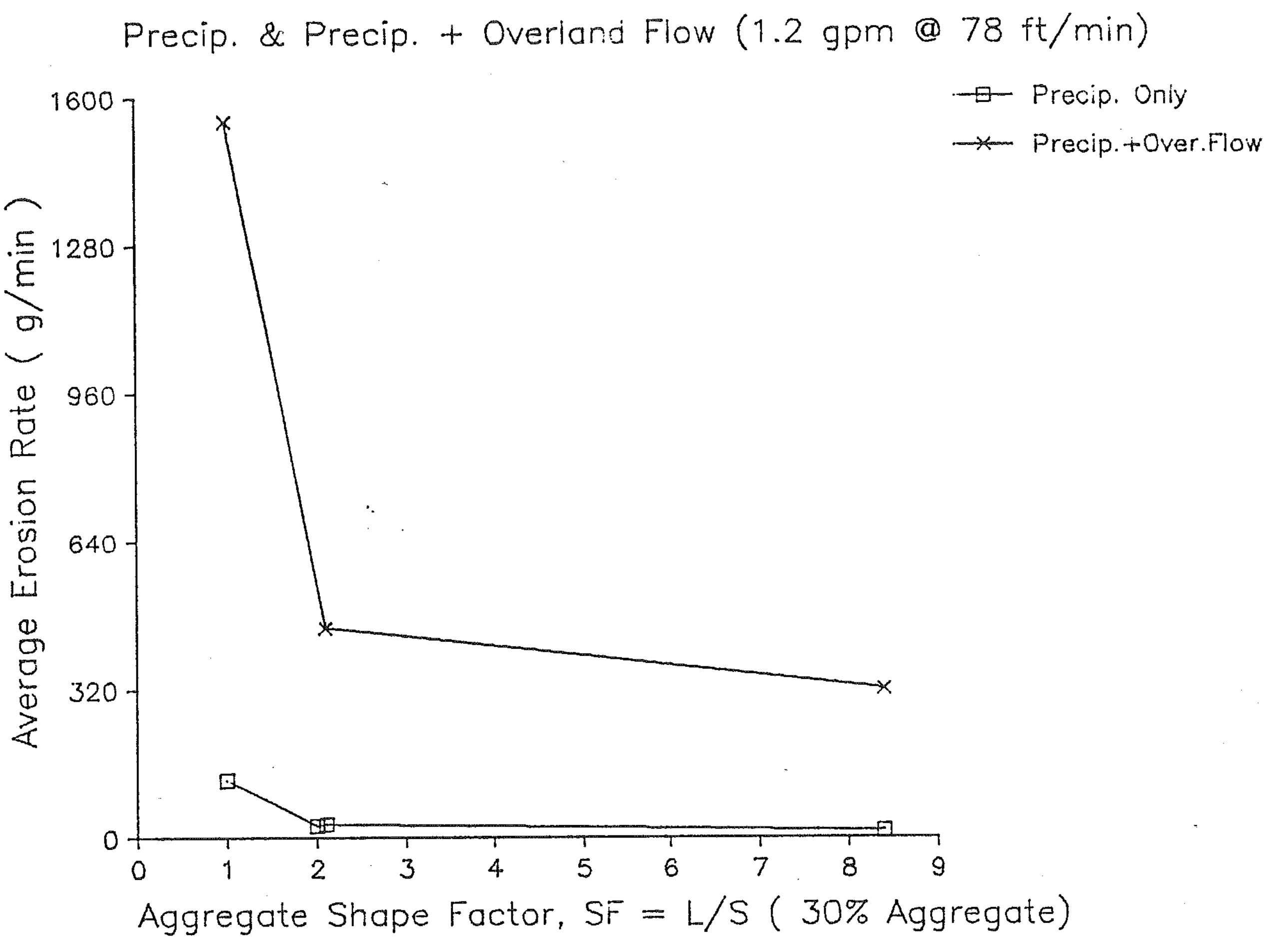

Figure 42. SRP5 Based Soil, Erosion Rate Vs. Aggregate Shape Factor, 2:1 Slope

additives were the next logical choice. Project constraints allowed three types of chemical additives to be tested.

The additives to be evaluated were selected after consultation with Kent Cairns of ADOT. One was a polyacrylamide supplied by the Complete Green Co. and marketed under the name Soil Drain. The second material was a latex copolymer supplied by the Soil Seal Co. and marketed under the name Soil Seal. The third material supplied by the Stabilizer Co. is believed to be an enzyme and is marketed under the name Stabilizer.

These three products were selected on the basis of differing product base and their present product involvement in arid regions. The philosophy of the chemical additive testing program was to evaluate products for short term applications. These chemical additives are viewed as having the potential, if effective, of providing short term erosion protection. They would be an interim solution to erosion control to bridge the gap between the completion of the grading operation and the final landscaping. Ultraviolet radiation and soil biological activity present serious potential problems to these materials.

Each of the manufactures supplied literature on their products. The Stabilizer Co. refused to provide a chemical description of their product because of patent problems. The research team decided to test the Stabilizer product in spite of the manufacture's refusal to provide the requested product information. The team had prior experience with enzyme based materials in the past which suggested that a trial use was justified. The other organizations provided reasonably complete descriptions of their products. The chemical additive tests were all conducted with the same test constraints as was the SRP5 test. Each test used a 6 minute interval with precipitation only followed by 6 minutes of combined flow. The overland flow segment was conducted with a 1.2 gpm flow rate and a velocity of 78 ft/min.

The products were applied to the test cell materials in accordance with the supplier's recommendations. The Soil Drain was therefore applied to an unrolled SRP5 soil by spraying a water based solution at a rate of 1.5 lbs/100 square feet. The panels were allowed to dry and then tested without compaction. The material formed the soil into a crust 0.25 to 0.5 inches thick. When the overland flow component was applied to the surface the initial resistance was very good. 1.5 minutes into the overland flow portion of the test small surface defects in the crust formed by the Soil Drain allowed holes to erode. Once the crust was eroded, the uncompacted SRP5 soil eroded rapidly during the remainder of the test.

The Soil Drain test data is compared to the SRP5 data on Figure 43. The range of values shown for each material on Figure 43 is the difference in resistance for precipitation alone (the lower value) and for the combined flow case. The reduction in erosion potential was dramatic. During the test duration the Soil Drain reduced the erosion rate to approximately 1/6 the untreated SRP5 erosion rate. Although the reduction in erosion potential was impressive, the "crust" was penetrated. Had a longer test pro-

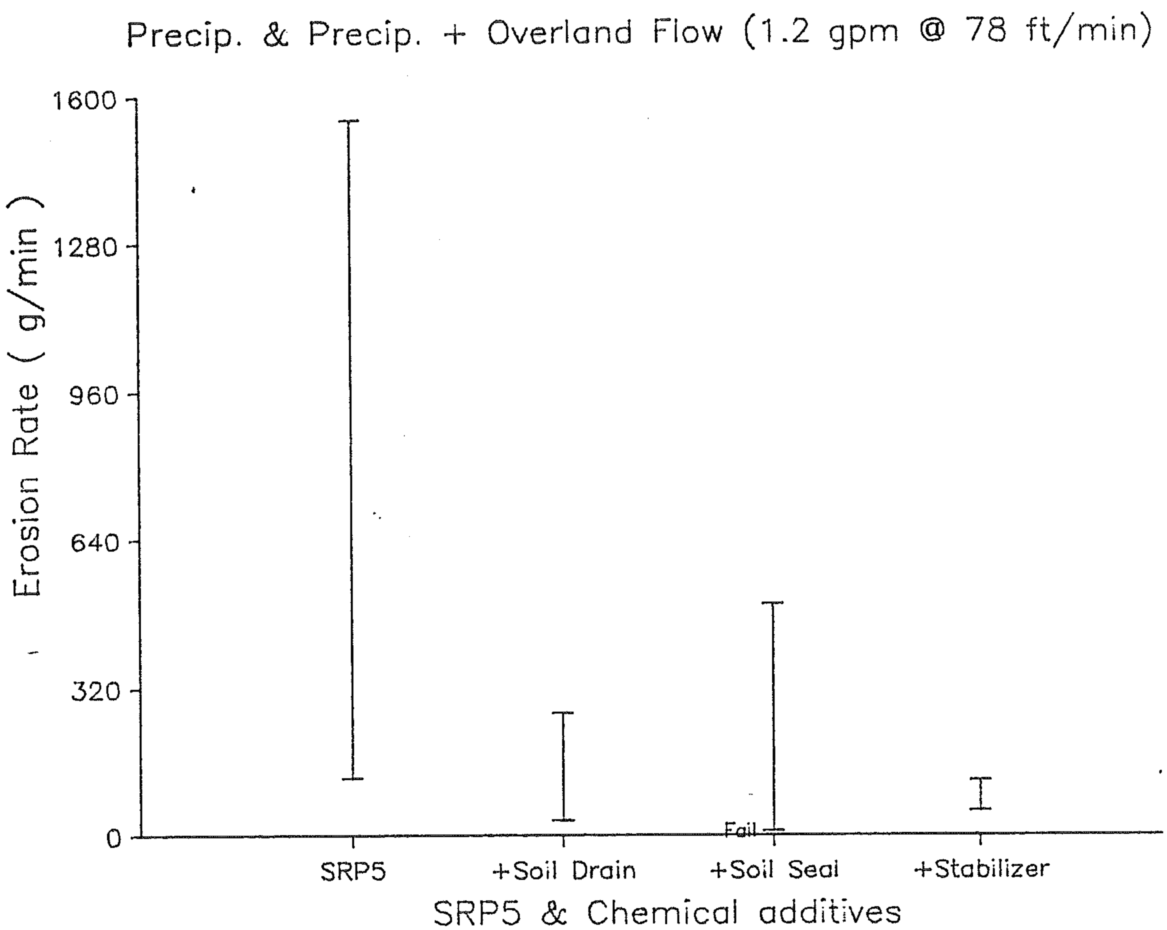

Figure 43. SRP5 Chemical Additive Performance, 2:1 Slope

gram been possible, the treated erosion rate would be expected to approach the untreated soil rate.

The Soil Seal was applied to compacted SRP5 material by spraying at a rate of 55 gal/acre. A soil crust 1/16 to 1/8 inch was formed after the treatment was allowed to dry. At 1.1 minutes into the precipitation-only portion of the test, holes began to appear in the surface. The size of the holes continued to grow during the remainder of the precipitation portion of the testing. The combined flow testing produced widening holes in the surface until 2.8 minutes into the test when the 6000 material was exposed. When the 6000 material was exposed the test was stopped.

The erosion rate of the Soil Drain modified SRP5 soil is substantially less than the untreated SRP5 soil (Figure 43). It is apparent that as long as the surface "crust" functions, the erosion resistance of the SRP5 soil is enhanced. However, once the crust is broken the uncompacted and untreated soil begins to deliver sediment at close to the rate for the unprotected soil. As long as some crust is present on the surface a residual resistance remains.

The Stabilizer was applied in powder form to the SRP5 soil on the cell and mixed dry. The mixture was then soaked and then allowed to dry. At the completion of the drying phase the panels were rolled but the rolling did not appear to have an effect on the panels. The modified material modulus was large relative to the applied load and as a result no densification was observed. The Stabilizer did not develop holes during the precipitation phase. There was no apparent crust. The mixing of material throughout the full depth of the material provided continuous modification with depth. The panels also effectively resisted the combined flow which lasted for 6 minutes. (Figure 43). At the completion of the first 6 minutes of combined flow, only small rills were present at the toe of the panels. An additional 6 minutes of combined flow testing was started. The test was terminated at 5.75 minutes into the final period when the 6000 material was exposed. Even after almost 18 minutes of testing, the panels did not contain channels. The only damage occurred from several holes distributed along the panel.

The comparison of all modifications of the SRP5 soil relative to the SRP5 original erosion potential is provided on Figure 44. The lower limit of the data represents the precipitation alone rates of erosion. The upper limits are the combined flow rates of erosion.

It is apparent that considerable reduction in erosion potential can be achieved by modifying a soil such as SRP5. The greatest erosion rate reduction occurred when the Stabilizer was used. A close second was the mixture of 20 percent IG1 and 20 percent SRG1. The promise of erosion reduction has been made. The relationship of time to resistance and cost to resistance gain must now be established.

The study team obtained cost data from each of the chemical additive vendors supplying products for testing. A cost analysis is not available because an equal basis for comparison does not exist between chemical products tested. As mentioned

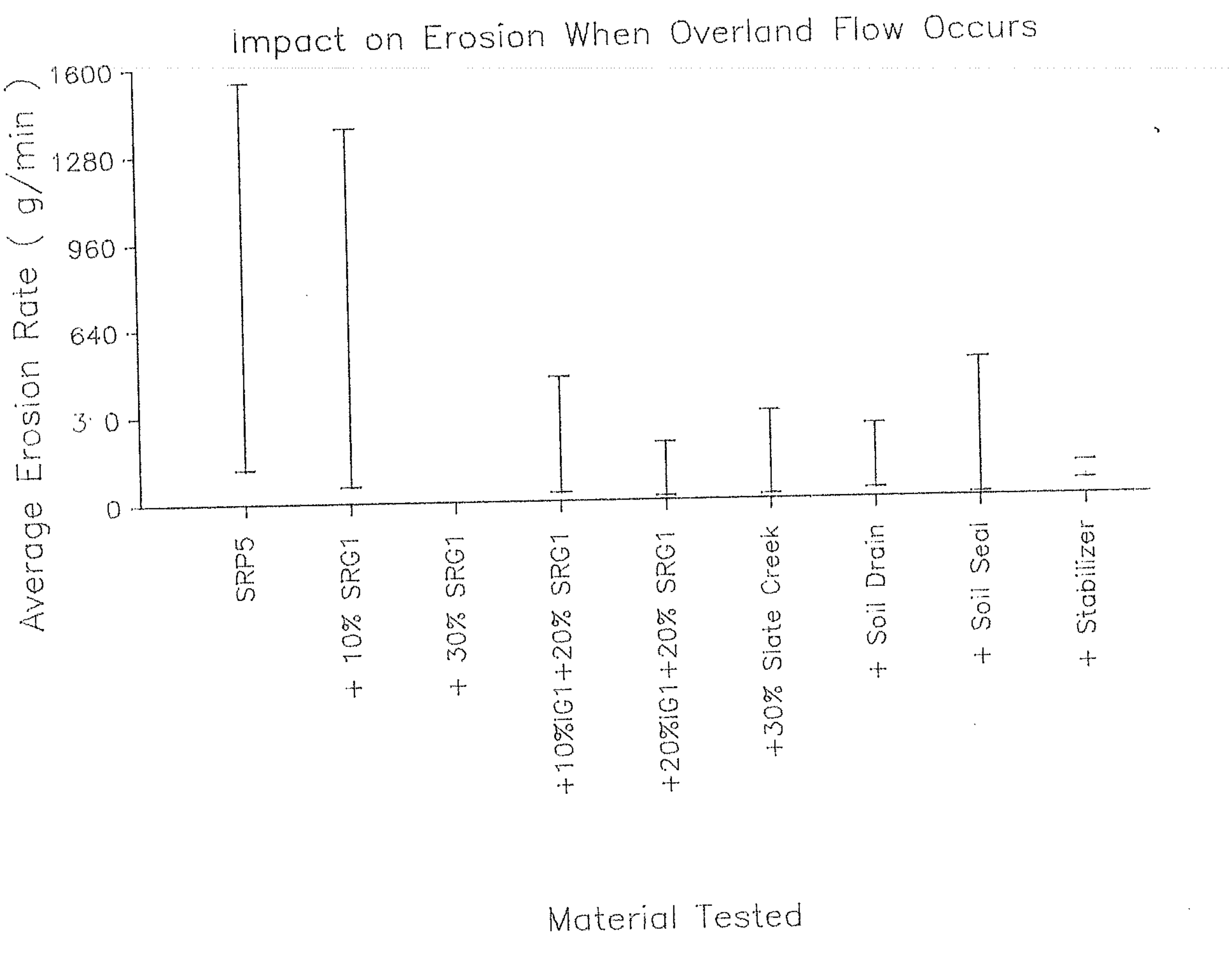

Figure 44. SRP5 Summary of Soil Modification Impact on Rate of Erosion, 2:1 Slope

previously, the materials were supplied with recommended application rates and with suggested means of application. There were several different ways in which each of the three materials could have been applied. The research team believes that the different methods of application would result in a beneficial change in the improvement to cost ratios. The purpose of the chemical additive testing was not to select the best product. The purpose was to establish a potential to modify soil erosion potential. Now that the large potential benefit of reducing short term erosion is apparent, additional work is necessary to:

1. Optimize the application of the chemical agents,
2. Evaluate the time affect of chemical improvement duration,
3. Determine the cost benefit relationship for chemical agents per unit of time, and
4. Explore the integration of chemical modifiers with mechanical systems such as coarse aggregates to provide the most efficient protection system.

Leaving the area of chemical stabilization, the research team turned to the utilization of the natural erosion resistance possessed by soils. To examine the resistance, SRS1, a subgrade sample from Kyrene Rd on SR 360 SRS1 was selected for testing. This material contained 22 percent plus number 4 size material as shown in Figure 45 and Table 15. The maximum particle size the soil contained was 2 inches. To examine the change in erosion resistance when the material larger than 1

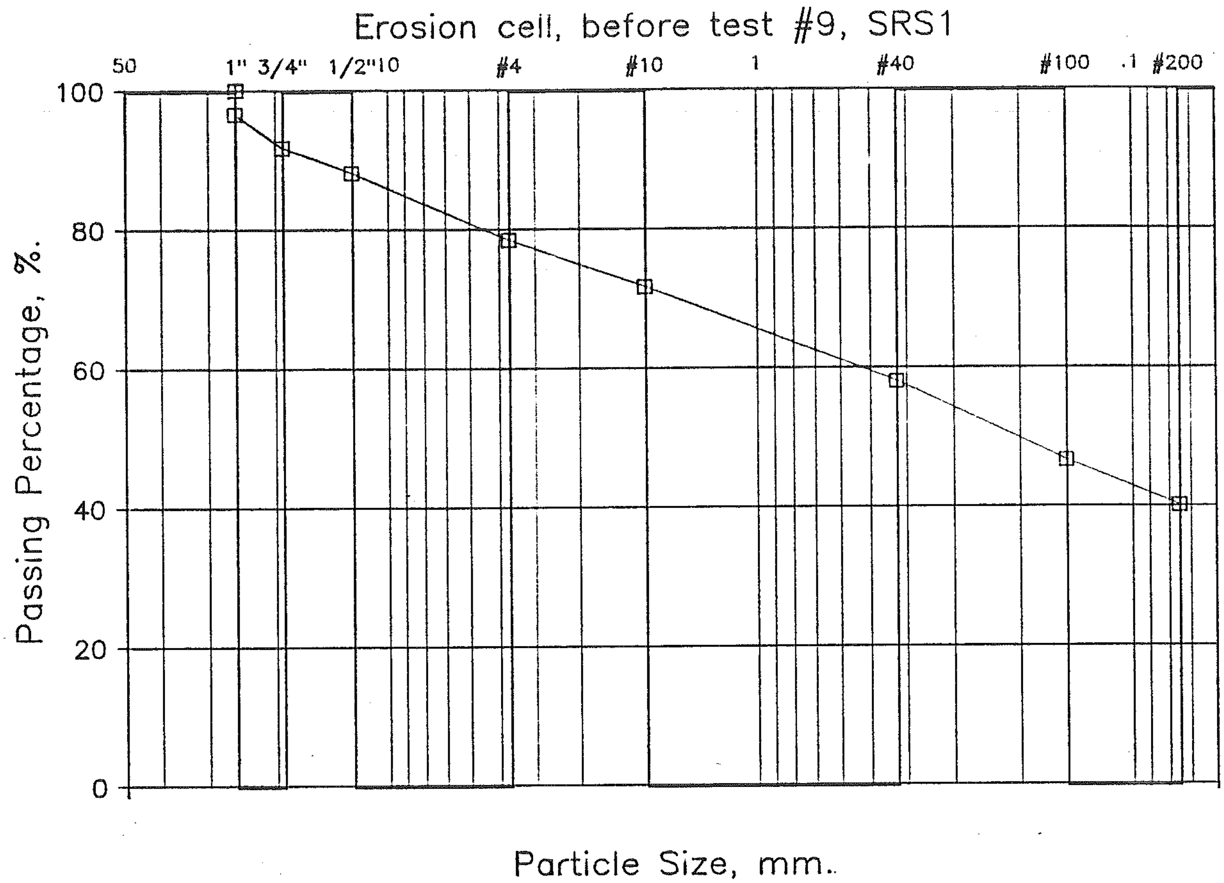

Figure 45. SRS1 Grain Size Analysis

inch was removed (Figure 49) an identical test series was performed. The material with 100 percent passing the 1 inch sieve size was designated SRS1 - 1". The results of the precipitation testing for these two materials can be seen on Figure 47. Both samples behaved the same until after 20 minutes of testing. At 30 minutes the difference in coarse size fraction which was 22 versus 13 percent plus number 4 size particles began to be felt. The difference in erosion resistance continued to grow as the test continued.

The difference in erosion potential is apparent when the combined flow testing is conducted (Figure 48). There is a three fold difference in erosion resistance when the combined flow starts. However, as Figure 48 indicates, both materials failed in less than 3 minutes into the combined flow testing period. The reason for the failure appeared to be related to the round shape of the coarse particles. SRS1 contains a large number of rounded $CaCO_3$ particles. These rounded particles tend to roll on the 2:1 slope. Once the rounded particles begin moving they do not stop as easily as the angular particles. The more spherical a particle becomes, the less efficiently the particle interlocks with others to form the surface armor. During the erosion tests particles were observed rolling down the slopes. As Figure 46 shows even for the SRS1 -1" slopes, particles 0.5 inches and larger were being collected at the low flow rates applied. Most of these particles once set in motion did not stop until the collection chamber was reached.

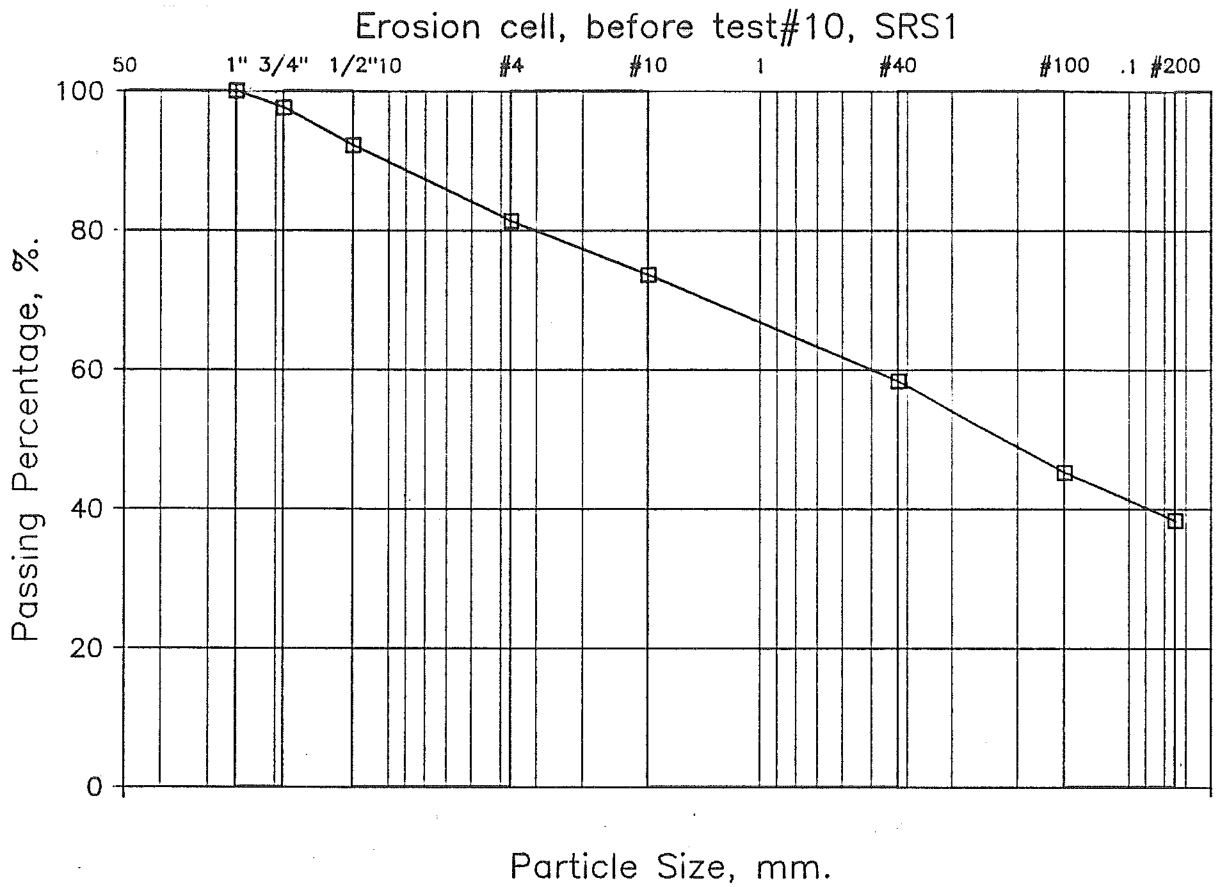

Figure 46. SRS1 - 1", Grain Size Analysis

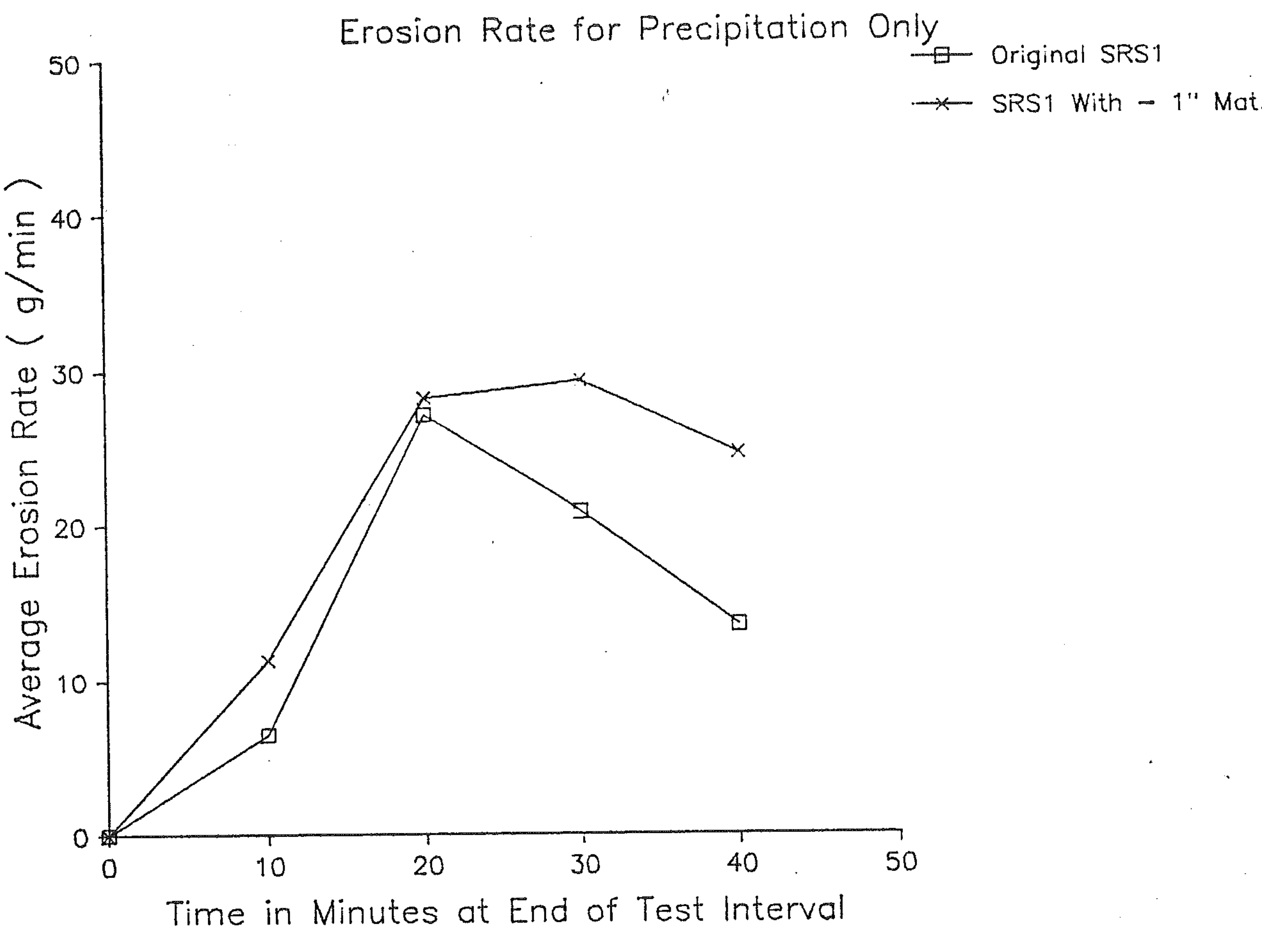

Figure 47. SRS1 & SRS1 -1", Erosion Rate Vs. Time, 2:1 Slope, Precipitation Only

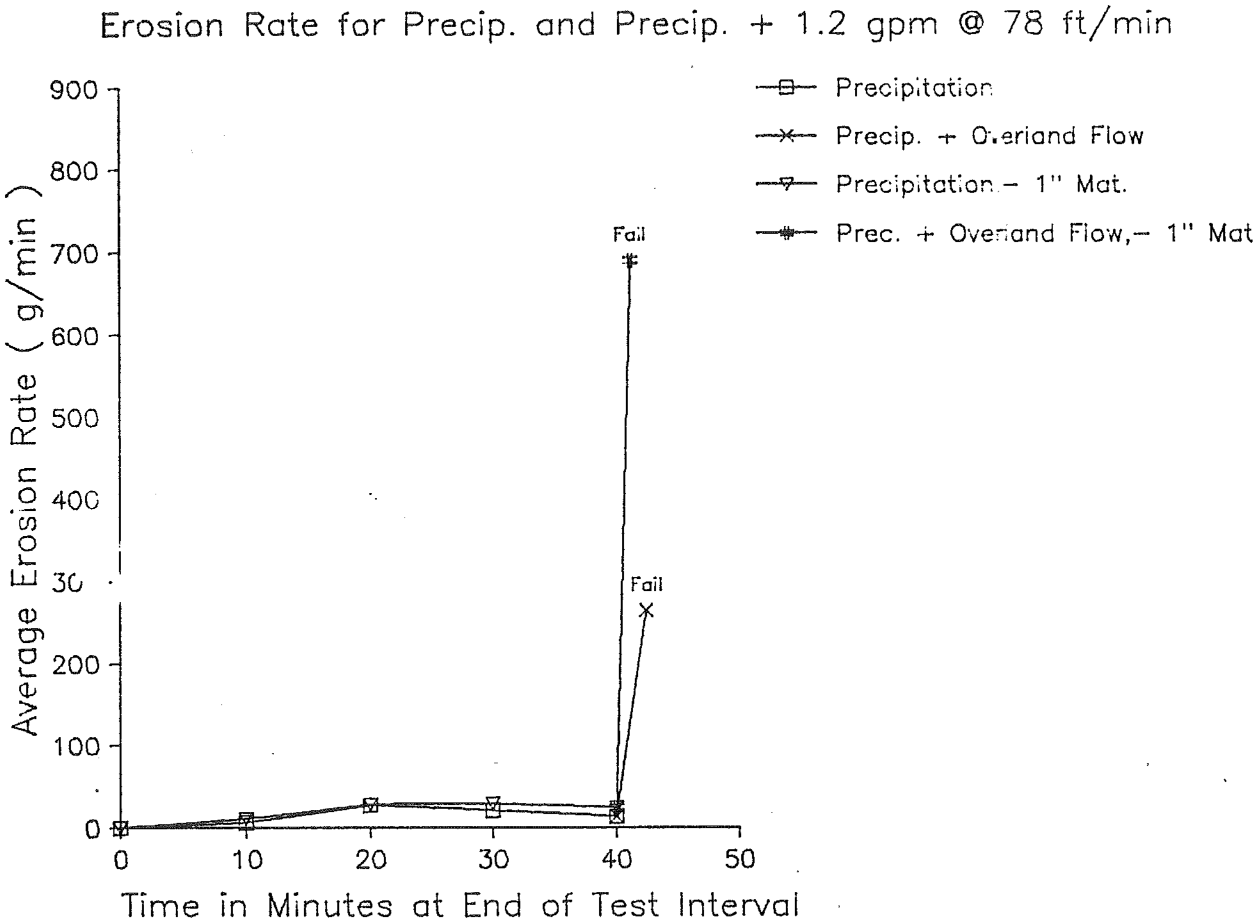

Figure 48. SRS1 & SRS1 -1", Erosion Rate Vs. Time, 2:1 Slope, Summary of Flow Conditions

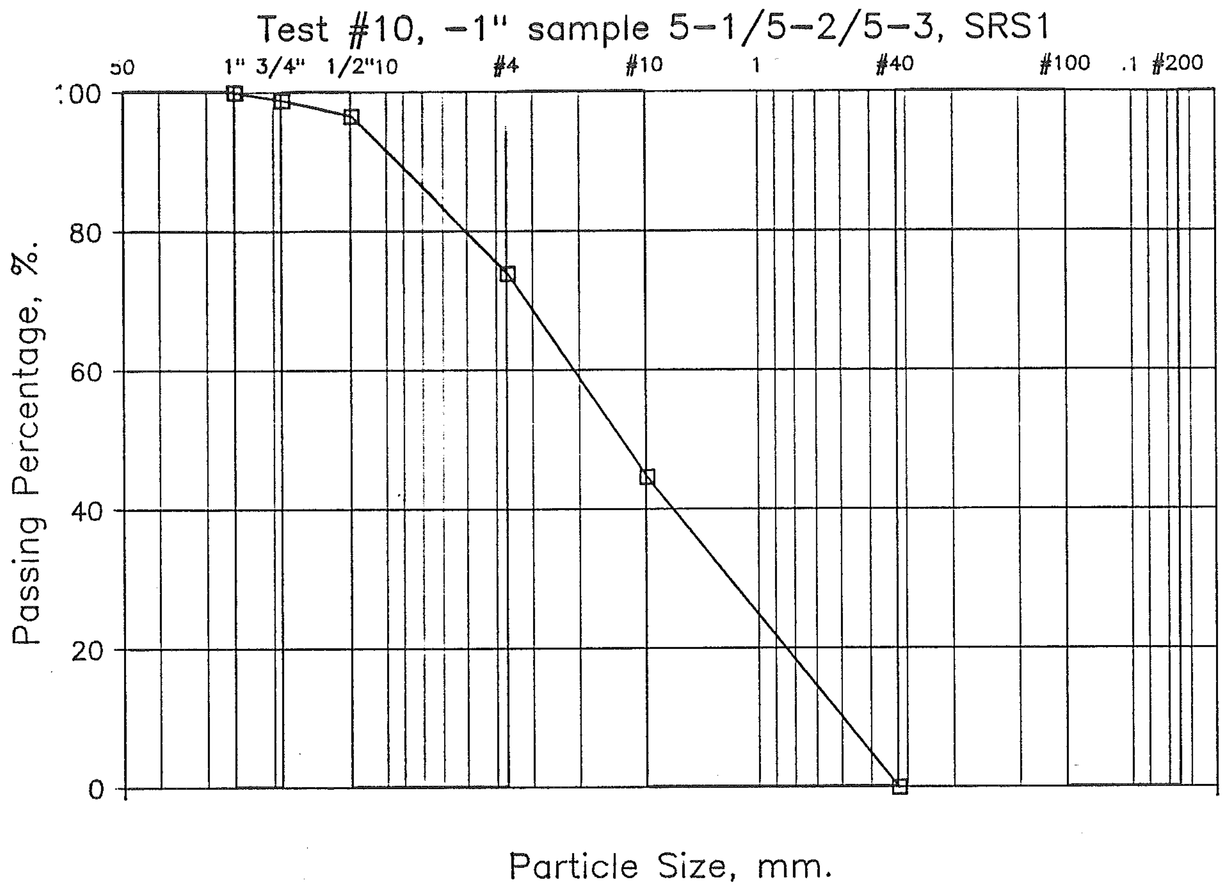

Figure 49. SRS1 -1", Grain Size Analysis,
After 2.2 Minutes of Overland Flow

The SRS1 soil testing shows the importance of the larger size particles in developing erosion resistance. The influence of particle shape is also indicated. When the same flow was applied to the other materials with particles larger than 0.5 inches the particles were retained on the panel. In addition to the shape factor, particle angularity plays a role in mitigating slope erosion.

The SRS1 testing shows the importance of the larger size particles in developing erosion resistance and the influence of particle shape. When the same flow was applied to the other materials with particles larger than 0.5 inches the particles were retained on the panel. Therefore, in addition to the shape factor, particle angularity is an important aspect of mitigating slope erosion.

Drainage Density

The original research plan involved determining existing slope drainage patterns and then correlating those patterns with the soil properties. The research found two factors that presented serious obstacles to this program. The first, was the high level of activity on the project area slopes. Between areas receiving final landscaping and regular slope maintenance, the disturbing forces on the slopes are considerable. With disturbance it becomes almost impossible to see the natural erosion characteristics of the slopes which only evolves when the armoring process can develop.

The second factor, was the presence of plating soils on the slopes. The placement of plating materials has tended to produce a rather similar surface material on both the I-10 and SR 360 slopes that have not been protected.

A summary of rill density versus the rate of erosion data for two typical soils exposed to rainfall is provided in Table 17. Though there are 17 rill density observations, the effects of the surface activities override the natural soil response. The erosion test data predicts a higher drainage density for the 115th Ave area than the Greenfield location. The opposite is observed in the data.

When the rill density data is examined for plating soils that were exposed through the study area an appreciation for the effects of disturbance and overland flow is developed (Table 16). The effect of particle size on erosion has been demonstrated in the erosion testing. The data in Table 16 show that with the exception of the Mill Rd. sample, all samples have essentially the same amount of coarse size particles. There is some variation in the minus number 200 sieve size data but only three of the samples have more than 69 percent passing the number 200 sieve, and the remaining samples are reasonably closely grouped. When the rill density data is examined no trends are apparent. Even when plotted as shown in Figure 50, there is too much scatter to reach any conclusion except that the influence of slope disturbance must be prevented if the true relationship between these variables is to be apparent. Influence of disturbance is short lived, in terms of the number of storms necessary to produce the characteristic surface. Once

Table 16. Summary of rill density and surface soil particle size.

SAMPLE LOCATION	PERCENT MINUS #4	PERCENT MINUS #200	RILL DENSITY (rills/ft)	# FIELD TEST SITES
91st Ave. & I 10	99.7	89.5	0.45	7 ea
115th Ave. & I 10	98.7	54.4	0.15	(a) 7 ea
75-67th Ave & I 10	100.0	97.1	0.28	5 ea
107th Ave & I 10	97.3	62.0	0.07	5 ea
Dysart Rd & I 10	99.0	59.8	0.28	3 ea
83rd Ave & I 10	98.7	85.3	0.38	4 ea
99th Ave & I 10	98.1	51.5	0.19	3 ea
75th Ave & I 10	98.1	63.2	0.12	2 ea
115th Ave & I 10	95.6	49.2	0.15	(a) 7 ea
Kyrene Rd & SR 360	96.5	55.5	Granite,	no Rills
Mill Rd & SR 360	65.1	37.8	"	" "
Mesa Dr & SR 360	95.8	53.0	"	" "
Lindsey & SR 360	99.8	69.0	"	" "
Greenfield Rd & SR 360	98.7	59.9	"	" "

(a) Same rill density data base used.

Table 17. Summary of rill density and rate of erosion data.

SAMPLE LOCATION	RILL DENSITY (rills/m)	EROSION RATE (g/min) (a)
115th Ave & I-10	0.49 (b)	185.1
Greenfield Rd. & SR 360	0.92 (c)	125.1

(a) Erosion rate due to design precipitation
(b) Average based on 7 observations
(c) Average based on 10 observations

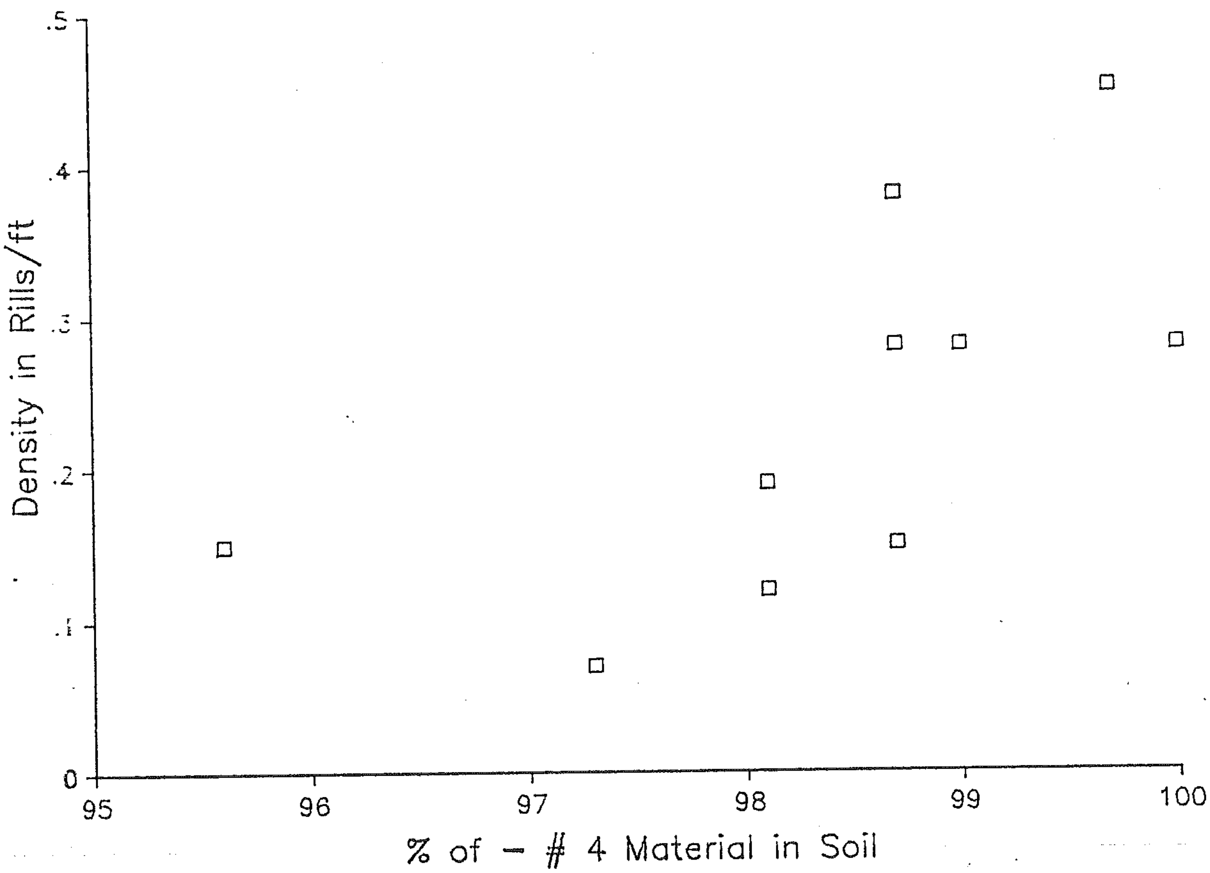

Figure 50. Summary of Minus No. 4% Material for Exposed Plating Soils

slope disturbance ceases, less than a year should typically be sufficient to remove the effects of disturbance.

The research team recognizes the theoretical relationship that exists between rill density and erosion test resistance. It is hoped that additional research will be directed to this topic in a slope controlled environment that will allow a natural slope surface to evolve.

Landscaping Vegetation

Vegetation survey

To gain a better understanding of the landscaping vegetation, a survey was conducted during July and August of 1986. The purpose of the survey was to acquire information that could identify plants that could be successfully used in the test sections. Ms. Stephanie Calderone, a recent graduate from the horticultural program at Arizona State University, was employed to conduct the survey under the guidance of the research team. Ms. Calderone visited several arboretums and nurseries to observe the various landscape plants that appeared in the landscaping contracts for the study area. She developed proficiency in identifying the species and recognizing their general growth characteristics.

Information was collected by using a rating scheme which had been developed from initial field observations. Plants that generally appeared isolated from others of the same species would be evaluated as individuals while plants that normally appeared as clusters of the same species would be evaluated as groups. It was deemed impractical to describe plants such as

Acacia redolens as individuals because of the time involved and the initial purpose of the survey.

The evaluator walked the survey area and assigned ratings to individuals or groups. Because of the hot weather conditions at the time of the survey, it was decided that the number of ratings would be kept to a minimum to allow reasonable accuracy. A detailed description of the ratings is provided in Table 18. The ratings were recorded on the as-built landscape contract plans. Since the ratings were of a descriptive nature, it was decided that either individual plants or a group of plants would receive as many ratings as needed to describe the existing conditions. After the survey was completed the ratings marked on the as-built drawings were tallied and recorded on working data sheets.

The contracts that were surveyed are listed in Table 19. At the time of the survey, the only landscaping contract that had been completed on I-10 was IR-10-2(69). The section of SR 360 between the I-10 intersection and Dobson Road was not surveyed for several reasons. The original intent of the survey was to observe the interactions of the landscaping plants in the freeway environment rather than collect specific data related to the problems in landscaping. The area omitted is characterized by grass expanses interspaced with dense plantings of Acacia redolens. This format was not used on the later contracts. The steep slopes, poor access, and closeness of the A. redolens to the roadway provided unsafe working conditions for the surveyor.

Table 18. Descriptions of ratings used in vegetation survey.

R1 = HEALTHY: (a)

This rating was given to a plant that exhibited healthy growth patterns for that particular genus and species. These patterns were established through observations of each species in nurseries and arboretums and from the landscaping experience of the surveyor. When a plant or tree was assigned this rating, it was well established in the landscape and appeared to have adapted ot the environment of the freeway. The growth pattern for the individual specimen appeared normal for age and type regardless of conditions of its environment.

R2 = SUNBURN:

This rating was assigned to plants that exhibited signs of sunburned bark. Trees with thin bark will become sunburned when unprotected from the harsh southwest sun. This damage will affect plant growth and influence its effectiveness as a landscape feature. The symptoms for this rating were cracked bark and in extreme cases bark which had peeled away from the trunk.

R3 = CHLOROTIC:

A pant with this rating exhibited classic symptoms of leaf chlorosis. The term chlorosis describes a physiological condition of a plant that is nutrient-starved. The term does not imply what nutrient is lacking since chlorosis represents the end result of the deficiency. Older or younger leaves can appear affected and in some cases the physiology of the leaves appears altered. Ultimately, the plant should die if this condition is not altered. The symptoms for this rating were pale green leaves that were not usual when compared to normal leaves.

R4 = TRAUMA:

This rating was applied to plants that had been physically damaged by any number of methods. Improperly staking of trees resulted in trunk and branch splits. Some plants had suffered trauma after being run over by vehicles; these plants were still alive but the quality of the plant in the landscape had been diminished. Plants which had been exposed to herbicides were also assigned this rating. It was not observed that this particular physical trauma had affected the plant growth, but since the growth habit was altered unnaturally, this form of trauma was noteworthy. Another form of physical damage that was given this rating was the apparent damage done to the bark of plants from rodents or rabbits. Gnawing marks were observed on small landscape specimens located on newly landscaped portions of SR 360.

R5 = NONCOALESCED:

This rating was applied to a group of the same species that was intended to form coalescing ground cover but had yet covered the entire ground surface. This rating was assigned when bare ground could be clearly observed between plants that were planted as low growing ground cover.

Table 18 (continued)

R6 = DEAD:
This rating was applied only when physical evidence was present that indicated that tree or shrub was in place at some previous time. Usually the crown or some portion of the trunk was still visible. In instances where the individual plant could not be located, it was assumed that the plant was either not originally planted or that it had died sometime prior to the survey and the physical evidence was no longer present.

R7 = OUT-COMPETED:
This rating refers to species that were out-competed by a neighboring species. This rating was assigned to a specimens that were dominated by noncompatible species. The dominated species appeared dwarfed and in some cases the entire tree or shrub had a chlorotic, unhealthy appearance.

R8 = WATER STRESS:
When a specimen showed physical evidence that it was under water-related stress, it was assigned this rating. Care was taken when this rating was applied since water-related stress can produce signs easily attributed to other causes. In cases where it was known that the irrigation water had been turned off for a period of time and the morphology of the plant had changed as a result of the lack of water, then this designation was use.

R9 = OTHER:
In instances when no causal agent could be identified, this rating was applied to plants that exhibited poor growth and/or appearance. Symptoms included excess dead wood and stunting. The plant was growing but represented a poor example of an attractive landscape specimen.

R0 = INSECT:
When evidence of insect infestation appeared on a plant, this rating was used. Since only a small number of trees appeared to be infested during the survey, the rating R0 was added to R9 and was not used in any of the descriptions or statical analyses. The particular infestation noted was one of white fly (Trialeurodes vaporariorum) on Cercidium floridum.

RX:
This rating was added after the survey was completed. It was used to describe plants which appeared on the landscape plans but which were not present in the actual landscape. If physical evidence of the plant remained, then the plant had received an R5 rating. This rating was needed in the statistical analysis.

(a) The descriptive words appearing in capital letters with each rating are the headings used in the statistical analyses.

Table 19. A list of the contracts that were evaluated for the vegetation survey.

CONTRACT NUMBER	LOCATION	ABBREVI-ATION	CONTRACT AGE (a)
F-028-1(26)	Gilbert Rd.- Val Vista Dr.	26	1 month
F-028-1(18)	State Route 87- Gilbert Rd. Unit II	18	17 months
IR-10-2(69)	Bullard Ave.- Dysart Rd.	69	25 months
F-028-1(17)	State Route 87- Gilbert Rd. Unit I	17	44 months
F-028-1(16)	Dobson Rd.- State Route 87	16	69 months

(a) Contract "age" refers to the number of months that had elapsed between the beginning of phase 2 (establishment period) and the time of the survey. Dates for the beginning of phase 2 were supplied by Mr. Harry Woelzlein in Roadside Development Services.

The data from the survey has been analyzed according to whether the plants were treated as groups or as individuals. This difference reflects the change in contract commitment concerning the vegetation data. A greater emphasis on the data has required a more thorough handling than the original intent. The use of the group concept for evaluation has precluded group plants from being statistically analyzed because the groups contained variable numbers of plants and covered variable areas. This variability is difficult to analyze without developing some type of weighting factor to reduce the uneven variability associated with different numbers of plants in each group.

An additional problem arises in that some of the ratings were not actually intended as group ratings but were merely indicators of individual plants within the group. As an example, a group receiving a rating of R6 (DEAD) did not mean that all plants in the group were dead but rather some dead plants were evident within the group. The same statement can be made for groups that received R2 (SUNBURN), R3 (CHLOROTIC), and R4 (TRAUMA) ratings. The rating that most reflected the group concept was R5 (NONCOALESCED). It was noted in the early field observations that many of the ground cover plants did not appear to have coalesced and it was considered worth noting in the survey.

<u>Evaluation of species planted as groups</u>

The tallies for plants that were evaluated as groups are listed in Table 20. Several species appeared on only one con-

Table 20. The totals of tallies by rating for plants that were evaluated as groups.

PLANT ID	CONTRACT ID	RATING DESIGNATION R1	R2	R3	R4	R5	R6	R7	R8	R9	RX
Acacia redolens	16	45	0	0	0	27	1	0	0	0	0
	17	30	0	0	0	6	0	0	0	0	0
	18	15	0	0	0	15	3	0	0	0	0
	26	9	0	17	1	20	5	0	0	0	0
	69	5	0	10	0	9	3	0	6	0	0
Caesalpinia pulcherrima	16	17	0	0	0	0	0	8	0	2	0
	17	8	0	0	0	0	2	2	1	1	0
	18	3	0	0	0	0	0	0	0	0	0
	26	3	0	0	0	0	1	0	0	0	0
	69	4	0	0	0	0	0	0	0	0	0
Cassia nemophila	17	10	0	0	0	0	3	0	0	0	0
Dalea greggii	16	1	0	0	0	1	1	0	0	0	0
	18	9	0	0	0	10	1	0	0	0	0
	26	18	0	0	0	13	5	0	0	0	0
Justicia californica	26	4	0	3	0	0	1	0	0	0	0
Beloperone californica (a)	69	1	0	0	0	0	1	1	0	0	0
Myoporum parvifolium	26	11	0	0	0	11	2	0	0	0	0
	69	1	0	0	0	0	1	0	0	0	0
Nerium oleander	16	4	0	0	0	0	0	0	0	0	0
	17	9	0	0	0	0	0	0	0	0	0
	18	3	0	0	0	0	0	0	0	0	0
	26	3	0	0	0	0	0	0	0	0	0
	69	3	0	0	0	0	0	0	0	0	0
Ruellia peninsularis	26	15	0	1	0	0	1	0	0	0	0
Vauquelinia californica	69	1	0	0	0	0	1	0	0	0	0

(a) The genus of Beloperone has been reclassified as Justica.

tract. Three out of thirteen groups of Cassia nemophila contained dead plants on contract 17. (See Table 18 for clarification of contract abbreviations.) Ruellia peninsularis appeared to have only one group with chlorosis and one group with dead plants while 15 groups were rated healthy. Of two groups of Vauquelinia californica on contract 69, one was rated healthy and one contained dead plants.

Species that appear on more than one contract provide additional information since comparisons can be made. Justicia californica did not appear to be successfully establishing on contract 26 as three groups appeared chlorotic and one group contained dead plants. Nor does Beloperone californica appear to be successful on contract 69. Dead plants were noted in one group and another group appeared to be out-competed while only one group was rated healthy. On the other hand, one of the most successful species in the freeway environment is Nerium oleander. Of the groups observed on five contracts, none appeared to have any discernible problems. Caesalpinia pulcherrima has few problems on contracts 69, 26, and 18 but appeared to have competition problems on contracts 17 and 18 as well as some dead plants and water stress on contract 18. A large portion of the Acacia redolens groups have shown chlorosis on contracts 69 and 26.

The Acacia redolens have also received a high number of R5 ratings which indicates that the plantings have not coalesced. The issue of whether some species have grown together to form ground cover is an interesting one. One of the concepts of using ground cover is the stabilization of the ground surface. The intergrown canopies provide protection from raindrop impact on the soil while the plant roots offer resistance to erosion. Canopies that have not intertwined leave the soil exposed. Field observations of the study area suggest that the ground covers are not generally successful in preventing erosion. Results from the erosion testing apparatus indicate the lack of successful stabilization may be due to the influence of overland flow on the slopes. While the plants may provide some slope protection against water falling directly on the planted area, the erosive forces added by overland flow will overcome the protection. The type of vegetation which may successfully retard the effects of overland flow is one in which the plants form a mat of interlacing roots at the ground surface. The classic example of this is grass species which have runners. Plants whose lower branches naturally layer may also provide some resistance to overland flow. In a telephone conversation of July 31 of 1987, Mr. Steve Priebe who is the chief horticulturist of the Desert Botanical Garden in Phoenix mentioned that he had observed natural layering in Dalea greggii.

Although the contribution of ground cover plants to slope erosion resistance may be minimal, ground cover is an important element in the landscape design. Three species in Table 20 can be considered as ground cover, Acacia redolens, Dalea greggii, and Myoporum parvifolium. If the ratio of the groups given an R5 to those given R1 is calculated, one would expect that the ratio should decrease with time as more groups coalesce. These ratios are given in Table 21. Ratios are used rather than percent of total to avoid problems with overlap in data that will be discussed later. In general the ratios for *Acacia redolens* do decrease; however, 69 months after the initiation date for the establishment period on contract 16, 27 groups had still not coalesced. Information from Mr. Priebe indicated that two varieties of *Acacia redolens* are grown in the Phoenix area, one with upright growth and one with a more prostrate growth pattern. Perhaps both varieties have been used in the study area. The *Dalea greggii* does not show a decreasing ratio with age and not enough information is available to evaluate the *Myoporum parvifolium*.

Further analysis of Table 20 indicates that the plants evaluated as groups on contract 26 seem to have more problems than the same species on other contracts. Contract 26 was the most recent contract evaluated on the survey. One major difference between 26 and the other contracts is the use of granite around the base of nearly all plants. Virtually no soil is left exposed on the slopes. Although this emplacement of granite may be useful in retarding erosion, one of the side effects appears to be an increase in undesirable symptoms exhibited by the plants, particularly those low growing species. This observation represents the opinion of the researchers since the trend can not be substantiated with statistics.

Evaluation of species planted as individuals

Table 22 provides the tallies used in the evaluation of individual plants in the study area. *Acacia farnesiana* appears

Table 21. The ratio of R5 to R1 ratings as an indicator of success in establishing a coalesced ground cover.

SPECIES	CONTRACT AGE	HEALTHY (R1)	NONCOALESCED (R5)	RATIO R5/R1
A. redolens	1 month	9	20	2.22
	17 months	15	15	1.00
	25 months	5	9	1.80
	44 months	30	6	0.20
	69 months	45	27	0.80
D. greggii	1 month	18	13	0.72
	17 months	9	10	1.11
	69 months	1	1	1.00
M. parvifolium	1 month	11	11	1.00
	25 months	1	0	---

Table 22. The totals of tallies by rating for plants that were evaluated as individual plants.

PLANT ID	CONTRACT ID	R1	R2	R3	R4	R5	R6	R7	R8	R9	RX
Acacia farnesiana	16	92	0	2	0	0	3	0	0	0	0
Acacia salicina	17	118	0	0	1	0	17	0	1	32	0
Acacia saligna	17	93	0	3	0	0	8	5	0	13	28
	18	55	0	16	0	0	0	0	0	0	0
	26	47	0	48	0	0	9	0	0	0	0
Acacia smallii	18	219	0	8	11	0	0	0	0	0	0
	26	53	0	5	0	0	0	0	0	0	0
	69	269	0	22	0	0	0	0	0	35	2
Acacia stenophylla	16	37	31	0	0	0	15	5	0	19	8
	18	20	6	6	0	0	0	0	0	0	0
	26	33	0	1	0	0	0	0	0	0	1
Cercidium floridum	17	261	0	1	0	0	47	45	0	33	53
	18	118	0	0	1	0	1	0	0	111	0
	69	159	0	0	1	0	4	0	0	10	5
Cercidium praecox	26	571	0	5	7	0	2	0	0	0	0
Chilopsis linearis	26	145	0	3	3	0	0	0	0	0	0
Eucalyptus microtheca	17	346	0	2	2	0	2	12	0	4	0
	26	101	0	11	0	0	1	0	0	0	0
	69	222	0	0	0	0	0	0	0	0	0
Melaeuca nesophylla	26	1	0	0	5	0	0	2	0	0	0
Pinus halepensis	16	2	0	285	0	0	6	225	0	1	0
Prosopis alba	18	341	0	0	69	0	3	0	0	0	0
	26	101	0	0	10	0	0	0	0	0	0

Table veg 22. (Continued)

PLANT ID	CONTRACT ID	R1	R2	R3	R4	R5	R6	R7	R8	R9	RX
Prosopis chilensis	16	317	0	15	1	0	13	24	0	20	11
	17	293	0	39	1	0	23	23	0	22	10
	26	325	2	7	33	0	1	0	0	12	0
	69	344	0	2	3	0	10	0	0	3	3
Rhus lancea	16	33	0	0	0	0	9	0	0	11	0
Washingtonia californica	69	24	0	9	0	0	1	0	0	7	0
Yucca aloifolia	16	29	0	0	0	0	8	0	0	0	0

to be successful in the environment of contract 16 with only two plants showing sunburn and three recorded as dead. On the other hand, Acacia salicina shows a large number of dead plants (R6) and plants that do not appear normal (R9). Cercidium praecox exhibits relatively few problems with only a few instances of sunburn and chlorosis. Chilopsis linearis also appears to be adapted to the environment of contract 26.

Eucalyptus microtheca shows evidence of being a successful plant in the freeway environment. A total of 669 plants of E. microtheca received a healthy score (R1) for three contracts. Eleven plants appeared chlorotic (R3) on contract 26 and 12 plants were judged as being out-competed (R7) on contract 17. Pinus halepensis can be classified as a failure in contract 16 since nearly all individuals evaluated received either R3 (chlorotic) or R7 (out-competed).

Although contracts 16 and 17 contained 99% of all observations of out-competed plants regardless of species, it should be noted that these contracts were the oldest and next oldest contracts evaluated in this survey. Field observations of the landscape styles in the study area suggest that designers have already responded to the incompatibility problems that appeared on these two contracts.

Prosopis alba appears to be susceptible to physical trauma as indicated by the number of R4 ratings for two contracts. Rhus lancea was not very successful on contract 16 with nine dead plants and 11 others not appearing normal (R9). Several of the Washingtonia californica specimens exhibited chlorosis on contract 69 while Yucca aloifolia showed eight dead plants versus 29 healthy ones on contract 16.

Statistical analysis of landscape plants

The information in Table 22 suggested that some form of statistical analysis of individual plants may be possible. To determine the relative accuracy of the survey, the total number of tallies for each plant was compared to the number of plants recorded on the as-built plans and the percent recovery was calculated as shown in Table 23. A discrepancy became apparent. Some species showed a low percent recovery such as Yucca aloifolia while some species such as Pinus halepensis displayed abnormally high values for percent recovery. The differences could be attributed to several factors. Some plants were located in right-of-way sections outside the slope environment of the freeway and were not evaluated. The crowns and stems of some plants that had died were removed or had simply decomposed leaving no record. A new rating, RX, was created to account for plants showing no record of death. High counts were the result of overlap in the data. Since the original survey had not been intended as a detailed analysis, when two or more ratings were assigned to the same plant no special note was made in tallying the results. In order to apply statistical analysis, the target species had to be recounted so that overlaps could be identified.

The data appeared to lend itself to analysis by contingency or frequency tables. Three criteria were established for selecting which species could be targeted for analysis. First,

Table 23. A comparison of the total number of tallies versus the number of plants recorded for each contract for plants evaluated as individuals.

PLANT ID	CONTRACT ID	TOTAL NO. TALLIED	CONTRACT COUNT	PERCENT RECOVERY
Acacia farnesiana	16	97	101	96
Acacia salicina	17	169	184	92
Acacia saligna	17	150	153	98
Acacia saligna	18	71	73	98
Acacia saligna	26	104	126	83
Acacia smallii	18	238	238	100
Acacia smallii	26	59	74	80
Acacia smallii	69	309	363	85
Acacia stenophylla	16	105	113	93
Acacia stenophylla	18	113	161	71
Acacia stenophylla	26	35	47	74
Cercidium floridum	17	440	446	99
Cercidium floridum	18	231	273	85
Cercidium floridum	69	179	203	88
Cercidium praecox	26	585	644	91
Chilopsis linearis	26	151	185	82
Eucalyptus microtheca	17	368	414	89
Eucalyptus microtheca	26	113	257	44
Eucalyptus microtheca	69	222	228	97
Melaleuca nesophylla	26	8	16	50
Pinus halepensis	16	519	314	165
Prosopis alba	18	410	391	105
Prosopis alba	26	111	113	98
Prosopis chilensis	16	401	407	99
Prosopis chilensis	17	411	411	100
Prosopis chilensis	26	381	383	99
Prosopis chilensis	69	371	407	91
Rhus lancea	16	53	89	60
Washingtonia robusta	69	41	48	85
Yucca aloifolia	16	37	76	49

the species must be one that was evaluated as an individual and not a group. Second, the species must appear on at least three contracts and third, sufficient problems must exist to warrant evaluation of the species. Six species were found on at least three contracts: *Acacia saligna*, *Acacia smallii*, *Acacia stenophylla*, *Cercidium floridum*, *Eucalyptus microtheca*, and *Prosopis chilensis*. *E. microtheca* was eliminated because it did not show sufficient problems. The remaining five were used in the statistical analysis. The percent recovery previously given in Table 23 for these five species provides the corrected count within 2%.

The objectives of the analysis were twofold: 1) to identify factors that had influenced the response of the target species to the freeway environment and 2) to evaluate plant problems or symptoms in relation to these factors.

The term contract age has been previously defined as the number of months that had elapsed between the beginning of phase 2 (establishment period) and the time of the survey. The time in months for each contract is listed in Table 19. This time period represents the length of time that a particular species has been exposed to the environment. A logical hypothesis to test is that the percent of healthy plants for a given species should decrease with age. The more rapid the decrease, the more likely that the plant is not suited to the freeway environment on a long term basis.

The above hypothesis was tested in the following manner. A category called STATUS was formed from two subgroups. HEALTHY was comprised of all plants receiving R1 for a particular species. The subgroup PROBLEM represented all other ratings for the same species. A two way frequency analysis was performed for each target species using SAS programing. Species were treated separately since no interaction between species was expected due to the plant spacing. The results for the five species are presented in Tables 24 through 28. Although several statistics have been calculated and presented with each table, the evaluations are based on the Chi-square test. An alpha value 0.05 is the generally accepted level for most plant related data.

The STATUS-CONTRACT AGE combinations are significantly different from one another for *Acacia saligna* at the 0.05 probability level since the probability of the Chi-square statistic is 0.00 which is less than the 0.05 probability level (Table 24). On the other hand, *Acacia smallii* does not show a significant difference in status when status is evaluated against the different contracts since the Chi-square probability is 0.176 which is greater than 0.05 (Table 25). Combinations of STATUS-CONTRACT AGE are significantly different for *Acacia stenophylla* (Table 26), *Cercidium floridum* (Table 27), and *Prosopis chilensis* (Table 28).

In four of the five species response of the plants (HEALTHY or PROBLEM) to the contract environment is evident. The hypothesis that the status of the plants on these contracts represents a response to length of time in the freeway environment can be evaluated with Figure 51 which is a plot of the

Table 24. Frequency table and statistics for *Acacia saligna* showing the relationship between status of plants and age of contract.

CONTRACT AGE		STATUS OF PLANTS: HEALTHY	PROBLEM	TOTAL
	1	47 14.46 45.19 24.10	57 17.54 54.81 43.85	104 32.00
	17	55 16.92 77.46 28.21	16 4.92 22.54 12.31	71 21.85
	44	93 28.62 62.00 47.69	57 17.54 38.00 43.85	150 46.15
	TOTAL	195 60.00	130 40.00	325 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	2	18.775	0.000
LIKELIHOOD RATIO CHI-SQUARE	2	19.256	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	3.759	0.053

Table 25. Frequency table and statistics for *Acacia smallii* showing the relationship between status of plants and age of contract.

STATUS OF PLANTS

CONTRACT AGE		HEALTHY	PROBLEM	TOTAL
	1	53 8.75 89.83 9.80	6 0.99 10.17 9.23	59 9.74
	17	219 36.14 92.02 40.48	19 3.14 7.98 29.23	238 39.27
	25	269 44.39 87.06 49.72	40 6.60 12.94 61.54	309 50.99
	TOTAL	541 89.27	65 10.73	606 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	2	3.478	0.176
LIKELIHOOD RATIO CHI-SQUARE	2	3.553	0.169
MANTEL-HAENSZEL CHI-SQUARE	1	1.214	0.271

Table 26. Frequency table and statistics for *Acacia stenophylla* showing the relationship between status of plants and age of contract.

STATUS OF PLANTS

CONTRACT AGE		HEALTHY	PROBLEM	TOTAL
	1	33 13.04 94.29 21.85	2 0.79 5.71 1.96	35 13.83
	17	81 32.02 71.68 53.64	32 12.65 28.32 31.37	113 44.66
	69	37 14.62 35.24 24.50	68 26.88 64.76 66.67	105 41.50
	TOTAL	151 59.68	102 40.32	253 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	2	50.252	0.000
LIKELIHOOD RATIO CHI-SQUARE	2	54.897	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	48.849	0.000

Table 27. Frequency of table and statistics for Cercidium floridum showing the relationship between status of plants and age of contract.

CONTRACT AGE	STATUS OF PLANTS: HEALTHY	PROBLEM	TOTAL
17	118 13.88 51.08 21.93	113 13.29 48.92 36.22	231 27.18
25	159 18.71 88.83 29.55	20 2.35 11.17 6.41	179 21.06
44	261 30.71 59.32 48.51	179 21.06 40.68 57.37	440 51.76
TOTAL	538 63.29	312 36.71	850 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	2	68.050	0.000
LIKELIHOOD RATIO CHI-SQUARE	2	77.465	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	0.396	0.529

Table 28. Frequency table and statistics for *Prosopis chilensis* showing the relationship between status of plants and age of contract.

STATUS OF PLANTS

CONTRACT AGE	HEALTHY	PROBLEM	TOTAL
1	325 20.91 85.30 25.41	56 3.60 14.70 20.36	381 24.52
25	344 22.14 92.72 26.90	27 1.74 7.28 9.82	371 23.87
44	293 18.85 71.29 22.91	118 7.59 28.71 42.91	411 26.45
69	317 20.40 81.07 24.78	74 4.76 18.93 26.91	391 25.16
TOTAL	1279 82.30	275 17.70	1554 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	3	64.640	0.000
LIKELIHOOD RATIO CHI-SQUARE	3	66.902	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	12.908	0.000

percent healthy plants versus contract age in months for the five species. It is evident from Figure 51 that the some unknown factor is influencing the status. The expected decrease in the percent healthy plants as age of contracts increases is present only for *Acacia stenophylla*. In contrast several species show a marked increase in percent healthy plants with time.

The results of Figure 51 may be explained in the following manner. The condition of the plants at the beginning of phase 2 was different for different contracts; thus, no baseline of healthy plants exists for the contracts. Some contracts were in better condition than others at the time of inception of the establishment period. Furthermore, different conditions have existed for each contract during the time span between phase 2 and the survey. Breakdowns in the irrigation system and different maintenance crews are two examples of those different conditions.

Although the differences are not age related, the recognition that the contracts do represent different environments is an important one. For whatever reasons, the contracts do represent a recognizable source of variation in the response of the plants to the freeway environment. Any future evaluations or sampling schemes should take these differences in contracts into consideration. In addition, if age of the plants is to be considered a parameter in any monitoring scheme then a baseline must be established.

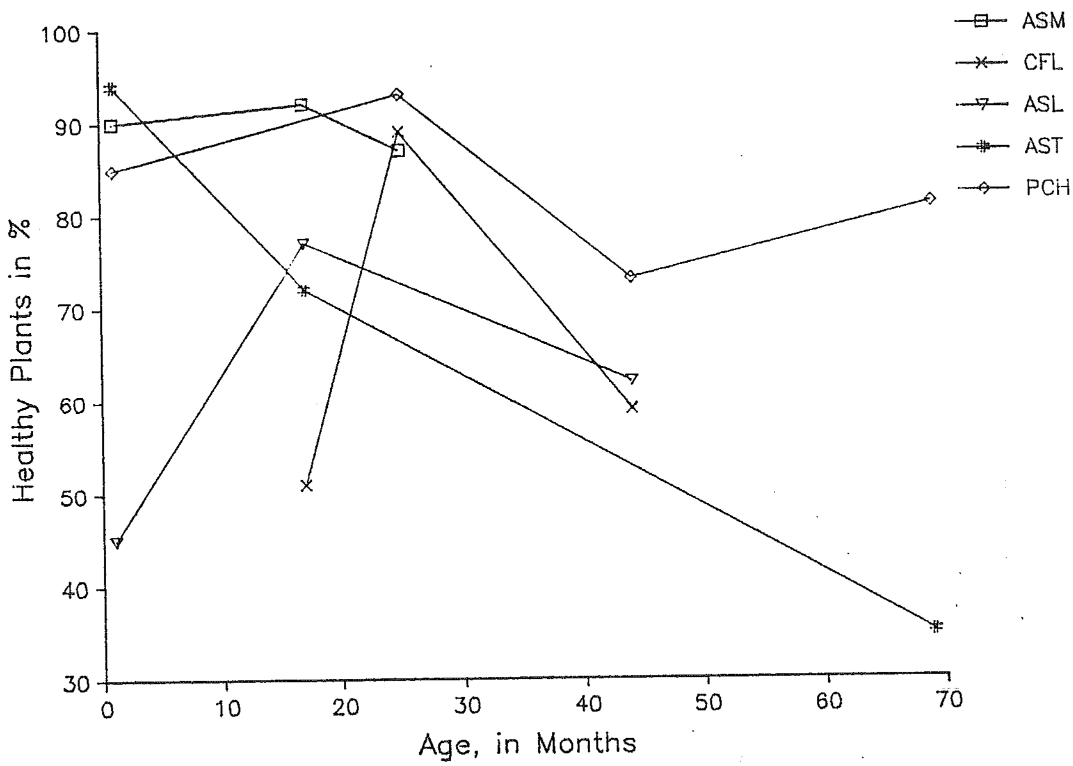

Figure 51. Relation Between Contract Age and Health of Landscaping Plants

Another factor which may have an influence on the response of the target species to the freeway environment is the location. In general the landscape design in the study area appears to be one of a mirror image about the median. What is visible to the westbound traffic is essentially the same as that which is visible to the eastbound traffic. Both I-10 and SR 360 follow an east-west alignment which allows the division into a north side viewed by westbound traffic and a south side viewed by eastbound traffic. The north side of the study area contains more south facing slope aspects while the south side contains more north facing slope aspects because of the cut and fill style of construction. A hypothesis related to locations is to consider whether plants have responded differently on the north side as compared to the south side.

The hypothesis was tested by comparing STATUS as defined earlier by two subgroups, HEALTHY and PROBLEM, against LOCATION. Location is divided into NORTH SIDE and SOUTH SIDE each of which is summed over all contracts for a given species. The results are variable and are presented in Tables 29 through 33. The status of Acacia saligna is definitely not related to location as indicated by the probability of 0.33 which is greater than an alpha level of 0.05 (Table 29). Very little of the response of Acacia saligna is related to its relative location. There is a strong relationship between status and location for Acacia smallii (Table 30). In general, 89% of all the ratings recorded were healthy (R1). Of the 11% registered as problems, 85% of these occurred on the south side.

Table 29. Frequency table and statistics for *Acacia saligna* showing the relationship between status of plants and location of plants on contracts.

STATUS OF PLANTS

LOCATION		HEALTHY	PROBLEM	TOTAL
	NORTH SIDE	120 36.92 62.18 61.54	73 22.46 37.82 56.15	193 59.38
	SOUTH SIDE	75 23.08 56.82 38.46	57 17.54 43.18 43.85	132 40.62
	TOTAL	195 60.00	130 40.00	325 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	0.938	0.333
LIKELIHOOD RATIO CHI-SQUARE	1	0.936	0.333
CONTINUITY ADJ. CHI-SQUARE	1	0.728	0.394
MANTEL-HAENSZEL CHI-SQUARE	1	0.935	0.334

Table 30. Frequency table and statistics for *Acacia smallii* showing the relationship between status of plants and location of plants on contracts.

STATUS OF PLANTS

LOCATION		HEALTHY	PROBLEM	TOTAL
	NORTH SIDE	289 47.69 96.66 53.42	10 1.65 3.34 15.38	299 49.34
	SOUTH SIDE	252 41.58 82.08 46.58	55 9.08 17.92 84.62	307 50.66
	TOTAL	541 89.27	65 10.73	606 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	33.585	0.000
LIKELIHOOD RATIO CHI-SQUARE	1	36.724	0.000
CONTINUITY ADJ. CHI-SQUARE	1	32.080	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	33.529	0.000

Table 31. Frequency table and statistics for *Acacia stenophylla* showing the relationship between status of plants and location of plants on contracts.

STATUS OF PLANTS

LOCATION		HEALTHY	PROBLEM	TOTAL
	NORTH SIDE	98 38.74 64.47 64.90	54 21.34 35.53 52.94	152 60.08
	SOUTH SIDE	53 20.95 52.48 35.10	48 18.97 47.52 47.06	101 39.92
	TOTAL	151 59.68	102 40.32	253 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	3.630	0.057
LIKELIHOOD RATIO CHI-SQUARE	1	3.618	0.057
CONTINUITY ADJ. CHI-SQUARE	1	3.149	0.076
MANTEL-HAENSZEL CHI-SQUARE	1	3.616	0.057

Table 32. Frequency table and statistics for *Cercidium floridum* showing the relationship between status of plants and location of plants on contracts.

STATUS OF PLANTS

LOCATION		HEALTHY	PROBLEM	TOTAL
	NORTH SIDE	310 36.47 64.99 57.62	167 19.65 35.01 53.53	477 56.12
	SOUTH SIDE	228 26.82 61.13 42.38	145 17.06 38.87 46.47	373 43.88
	TOTAL	538 63.29	312 36.71	850 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	1.345	0.246
LIKELIHOOD RATIO CHI-SQUARE	1	1.343	0.247
CONTINUITY ADJ. CHI-SQUARE	1	1.184	0.277
MANTEL-HAENSZEL CHI-SQUARE	1	1.343	0.246

Table 33. Frequency table and statistics for *Prosopis chilensis* showing the relationship between status of plants and location of plants on contracts.

STATUS OF PLANTS

LOCATION		HEALTHY	PROBLEM	TOTAL
	NORTH SIDE	721 46.40 86.14 56.37	116 7.46 13.86 42.18	837 53.86
	SOUTH SIDE	558 35.91 77.82 43.63	159 10.23 22.18 57.82	717 46.14
	TOTAL	1279 82.30	275 17.70	1554 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	1	18.340	0.000
LIKELIHOOD RATIO CHI-SQUARE	1	18.306	0.000
CONTINUITY ADJ. CHI-SQUARE	1	17.773	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	18.328	0.000

Acacia stenophylla displayed a relationship between status and location that was not statistically significant at the 0.05 level since the probability of the Chi-square test was 0.06 (Table 31). The *Cercidium floridum* did not show a relationship between status and location (Table 32). *Prosopis chilensis* followed the pattern of *Acacia saligna* in that a significant relationship exists between status and location (Table 33). Of the 1554 plants evaluated for *P. chilensis*, 46% were healthy and found on the north side, 36% were healthy and found on the south side, 8% showed problems and were on the north side, and 10% showed problems and were located on the south side.

The above results suggest that another variable to be considered in the response of plants to the freeway environment is location. The actual explanation of this effect would need further data collection. However, these results were discussed with Dr. Jean Stutz, a plant pathologist in the Division of Agriculture at Arizona State University. Dr. Stutz suggested that the effect may be related to slope exposure to cold weather since plants on the south side of the study area most frequently have a north facing aspect. All five of the species evaluated are plants adapted to a hot dry climate and may be susceptible to the colder conditions that would accompany a north facing aspect.

The second objective of the statistical analysis was to focus on specific plant problems or symptoms as related to the factors of contract number and location. To accomplish this the data was sorted to remove ratings of R1 (healthy). Large numbers of healthy plants would create large cell frequencies compared to the smaller cell frequencies associated with problem ratings. In turn this would influence sensitivity of the Chi-square test to the problem ratings. The data was also sorted to remove ratings of RX with had been included in the analyses previously described. The RX represented missing plants with no record of existence. This is considered to be a part of the overall analysis but was not considered a specific plant symptom.

The overall results of the above evaluation of the five species indicate that the data does not readily lend itself to analysis by contingency tables because of the lack of counts in some cells of the table. Under a rigorous handling of the Chi-square results, the test may not be valid when cell frequencies are equal to zero. This is especially true when the degrees of freedom (DF) are less than 30. Although more sophisticated analysis may be possible, the data does not warrant the treatment because of the design of the data collecting phase. The following discussion will center on examining the counts of various cells. The statistical tests are presented on the tables only as a point of reference.

Tables 34 and 35 provide the results for <u>Acacia saligna</u>. Of the 102 problems recorded in Table 34, 56% are logged in contract 26. This supports the earlier suggestion that conditions on 26 may not be conductive to a good environment for some species. However, since most of the tallies are listed under chlorotic, it may also indicate that the plants may not

Table 34. Frequency table and statistics for *Acacia saligna* showing the relationship between plant problems (ratings) and contract number.

DESCRIPTION OF PLANT PROBLEMS

CONTRACT #		DEAD	OTHER	OUT COMPETED	CHLOROTIC	TOTAL
	26	9 8.82 15.79 52.94	0 0.00 0.00 0.00	0 0.00 0.00 0.00	48 47.06 84.21 71.64	57 55.88
	18	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	16 15.69 100.00 23.88	16 15.69
	17	8 7.84 27.59 47.06	13 12.75 44.83 100.00	5 4.90 17.24 100.00	3 2.94 10.34 4.48	29 28.43
	TOTAL	17 16.67	13 12.75	5 4.90	67 65.69	102 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	6	69.445	0.000
LIKELIHOOD RATIO CHI-SQUARE	6	78.573	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	26.369	0.000

Table 35. Frequency table and statistics for *Acacia saligna* showing the relationship between plant problems (ratings) and location of plants on contract.

DESCRIPTION OF PLANT PROBLEMS

LOCATION		DEAD	OTHER	OUT COMPETED	CHLOROTIC	TOTAL
	NORTH SIDE	8 7.84 13.56 47.06	6 5.88 10.17 46.15	4 3.92 6.78 80.00	41 40.20 69.49 61.19	59 57.84
	SOUTH SIDE	9 8.82 20.93 52.94	7 6.86 16.28 53.85	1 0.98 2.33 20.00	26 25.49 60.47 38.81	43 42.16
	TOTAL	17 16.67	13 12.75	5 4.90	67 65.69	102 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	3	2.854	0.415
LIKELIHOOD RATIO CHI-SQUARE	3	2.930	0.403
MANTEL-HAENSZEL CHI-SQUARE	1	1.556	0.212

have been in prime condition when planted. The poor condition at planting may be related to a severe change in environment from the point of origin to the location on the freeway. Table 35 indicated that 60% of the plants receiving a chlorotic rating appeared on the north side.

For Acacia smallii, the biggest single problem appears to be a rating of other on contract 69 (Table 36). The cause of the problem is unknown since the category of "other" was a catchall one. A tally of 11 in the trauma category for contract 18 cell may indicate a sensitivity to physical damage. The interaction between status and location was significant for this species (Table 30) but it can not be attributed to a specific problem as indicated in Table 37.

Acacia stenophylla showed a concentration of problems in contract 16 (Table 38). The most noticeable were dead plants and sunburned ones. This species seems to be susceptible to sunburn. There are 46 counts of sunburn alone plus another five plants which displayed multiple symptoms (OVERLAP). The sunburn is associated with plants on the north side. As shown in Table 39, 34 plants (29 + 5) showed sunburn on the north side and 17 on the south. This trend might be expected since the north side generally has a south facing aspect which would expose the plants to more direct sunlight than a north aspect. Dead plants occur more frequently on the north side as well (Table 39).

The high count in OTHER for Cercidium floridum in Table 40 can be explained by the white fly infestation that was present

Table 36. Frequency table and statistics for *Acacia smallii* showing the relationship between plant problems (ratings) and contract number.

DESCRIPTION OF PLANT PROBLEMS

CONTRACT #		OTHER	TRAUMA	CHLOROTIC	TOTAL
	26	0 0.00 0.00 0.00	0 0.00 0.00 0.00	5 8.06 100.00 31.25	5 8.06
	18	0 0.00 0.00 0.00	11 17.74 57.89 100.00	8 12.90 42.11 50.00	19 30.65
	69	35 56.45 92.11 100.00	0 0.00 0.00 0.00	3 4.84 7.89 18.75	38 61.29
	TOTAL	35 56.45	11 17.74	16 25.81	62 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	4	64.345	0.000
LIKELIHOOD RATIO CHI-SQUARE	4	74.559	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	33.249	0.000

Table 37. Frequency table and statistics for *Acacia smallii* showing the relationship between plant problems (ratings) and location of plants on contract.

DESCRIPTION OF PLANT PROBLEMS

LOCATION		OTHER	TRAUMA	CHLOROTIC	TOTAL
	NORTH SIDE	6 9.68 66.67 17.14	2 3.23 22.22 18.18	1 1.61 11.11 6.25	9 14.52
	SOUTH SIDE	29 46.77 54.72 82.86	9 14.52 16.98 81.82	15 24.19 28.30 93.75	53 85.48
	TOTAL	35 56.45	11 17.74	16 25.81	62 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	2	1.195	0.550
LIKELIHOOD RATIO CHI-SQUARE	2	1.381	0.501
MANTEL-HAENSZEL CHI-SQUARE	1	0.882	0.348

Table 38. Frequency table and statistics for *Acacia stenophylla* showing the relationship between plant problems (ratings) and contract number.

DESCRIPTION OF PLANT PROBLEMS

CONTRACT #	DEAD	OTHER	OVERLAP	SUNBURN	TRAUMA	CHLOROTIC	TOTAL
26	0	0	0	0	0	1	1
	0.00	0.00	0.00	0.00	0.00	1.08	1.08
	0.00	0.00	0.00	0.00	0.00	100.00	
	0.00	0.00	0.00	0.00	0.00	14.29	
18	0	0	0	20	6	6	32
	0.00	0.00	0.00	21.51	6.45	6.45	34.41
	0.00	0.00	0.00	62.50	18.75	18.75	
	0.00	0.00	0.00	43.48	100.00	85.71	
16	15	14	5	26	0	0	60
	16.13	15.05	5.38	27.96	0.00	0.00	64.52
	25.00	23.33	8.33	43.33	0.00	0.00	
	100.00	100.00	100.00	56.52	0.00	0.00	
TOTAL	15	14	5	46	6	7	93
	16.13	15.05	5.38	49.46	6.45	7.53	100.00

OVERLAP = Plants that received a combined rating of SUNBURN, OUT-COMPETED, and OTHER.

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	10	53.420	0.000
LIKELIHOOD RATIO CHI-SQUARE	10	61.209	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	37.329	0.000

Table 39. Frequency table and statistics for Acacia stenophylla showing the relationship between plant problems (ratings) and location of plants on contract.

DESCRIPTION OF PLANT PROBLEMS

LOCATION		DEAD	OTHER	OVERLAP	SUNBURN	TRAUMA	CHLOROTIC	TOTAL
	NORTH SIDE	12	0	5	29	4	1	51
		12.90	0.00	5.38	31.18	4.30	1.08	54.84
		23.53	0.00	9.80	56.86	7.84	1.96	
		80.00	0.00	100.00	63.04	66.67	14.29	
	SOUTH SIDE	3	14	0	17	2	6	42
		3.23	15.05	0.00	18.28	2.15	6.45	45.16
		7.14	33.33	0.00	40.48	4.76	14.29	
		20.00	100.00	0.00	36.96	33.33	85.71	
	TOTAL	15	14	5	46	6	7	93
		16.13	15.05	5.38	49.46	6.45	7.53	100.00

OVERLAP = Plants that received a combined rating of SUNBURN, OUT-COMPETED, and OTHER.

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	5	31.190	0.000
LIKELIHOOD RATIO CHI-SQUARE	5	39.059	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	0.210	0.647

Table 40. Frequency table and statistics for Cercidium floridum showing the relationship between plant problems (ratings) and contract number.

DESCRIPTION OF PLANT PROBLEMS

CONTRACT #		DEAD	OTHER	OUT COMPETED	TRAUMA	CHLOROTIC	TOTAL
	18	1 0.39 0.88 1.92	111 43.70 98.23 72.08	0 0.00 0.00 0.00	1 0.39 0.88 50.00	0 0.00 0.00 0.00	113 44.49
	69	4 1.57 26.67 7.69	10 3.94 66.67 6.49	0 0.00 0.00 0.00	1 0.39 6.67 50.00	0 0.00 0.00 0.00	15 5.91
	17	47 18.50 37.30 90.38	33 12.99 26.19 21.43	45 17.72 35.71 100.00	0 0.00 0.00 0.00	1 0.39 0.79 100.00	126 49.61
TOTAL		52 20.47	154 60.63	45 17.72	2 0.79	1 0.39	254 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	8	144.298	0.000
LIKELIHOOD RATIO CHI-SQUARE	8	174.849	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	0.006	0.938

at the time of the survey. The trend in contract 17 for out-competed plants is also present with this plant species as contract 17 has a high count of dead C. floridum plants. An interesting association appears in Table 41 when location is examined. The ratio of dead plants on the north side to the south side is 2.06:1 while the ratio of out-competed plants on the north side versus south side is 0.5:1. The relationship is inverse since 0.5 is almost the exact inverse of 2.05. This suggests a possible association in which out-competed plants on the north side tended to die while those on the south side managed to survive the competition.

The same relationship between dead and out-competed plants appears in Prosopis chilensis (Tables 42 and 43). Seventy percent of the all of the problems logged for this species occur on contracts 16 and 17. High counts appear in dead and out-competed categories for these contracts on Table 42. The ratio of dead plants on the north side to dead ones on the south side is 1.47:1. The ratio of out-competed plants on the north side versus the south side is 0.62:1. The inverse of 1.47 is 0.68. Of other interest is the large number of plants which suffered trauma on contract 26. This is another indication of some contracts starting at different conditions than others. Contract 26 was one month into phase 2 at the time of evaluation. At that time there were 33 plants out of a total 381 plants that were showing physical trauma of some type.

The vegetation survey met the objectives of the researchers. It provided a wealth of information concerning

Table 41. Frequency table and statistics for Cercidium floridum showing the relationship between plant problems (ratings) and location of plants on contract.

DESCRIPTION OF PLANT PROBLEMS

LOCATION		DEAD	OTHER	OUT COMPETED	TRAUMA	CHLOROTIC	TOTAL
	NORTH SIDE	35	91	15	1	1	143
		13.78	35.83	5.91	0.39	0.39	56.30
		24.48	63.64	10.49	0.70	0.70	
		67.31	59.09	33.33	50.00	100.00	
	SOUTH SIDE	17	63	30	1	0	111
		6.69	24.80	11.81	0.39	0.00	43.70
		15.32	56.76	27.03	0.90	0.00	
		32.69	40.91	66.67	50.00	0.00	
	TOTAL	52	154	45	2	1	254
		20.47	60.63	17.72	0.79	0.39	100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	4	13.505	0.009
LIKELIHOOD RATIO CHI-SQUARE	4	13.922	0.008
MANTEL-HAENSZEL CHI-SQUARE	1	7.990	0.005

Table 42. Frequency table and statistics for Prosopis chilensis showing the relationship between plant problems (ratings) and contract number.

DESCRIPTION OF PLANT PROBLEMS

CONTRACT #	DEAD	OTHER	OUT COMPETED	SUNBURN	TRAUMA	CHLOROTIC	TOTAL
26	1 0.43 2.27 2.13	0 0.00 0.00 0.00	0 0.00 0.00 0.00	3 1.30 6.82 100.00	33 14.35 75.00 89.19	7 3.04 15.91 14.58	44 19.13
69	10 4.35 41.67 21.28	10 4.35 41.67 20.83	0 0.00 0.00 0.00	0 0.00 0.00 0.00	2 0.87 8.33 5.41	2 0.87 8.33 4.17	24 10.43
17	23 10.00 21.30 48.94	22 9.57 20.37 45.83	23 10.00 21.30 48.94	0 0.00 0.00 0.00	1 0.43 0.93 2.70	39 16.96 36.11 81.25	108 46.96
16	13 5.65 24.07 27.66	16 6.96 29.63 33.33	24 10.43 44.44 51.06	0 0.00 0.00 0.00	1 0.43 1.85 2.70	0 0.00 0.00 0.00	54 23.48
TOTAL	47 20.43	48 20.87	47 20.43	3 1.30	37 16.09	48 20.87	230 100.00

Key to numbers in frequency table:

Frequency count
% of total count
% of row count
% of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	15	214.469	0.000
LIKELIHOOD RATIO CHI-SQUARE	15	213.352	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	39.934	0.000

Table 43. Frequency table and statistics for Procopis chilensis showing the relationship between plant problems (ratings) and location of plants on contract.

DESCRIPTION OF PLANT PROBLEMS

LOCATION		DEAD	OTHER	OUT COMPETED	SUNBURN	TRAUMA	CHLOROTIC	TOTAL
	NORTH SIDE	28 12.17 25.69 59.57	11 4.78 10.09 22.92	18 7.83 16.51 38.30	0 0.00 0.00 0.00	22 9.57 20.18 59.46	30 13.04 27.52 62.50	109 47.39
	SOUTH SIDE	19 8.26 15.70 40.43	37 16.09 30.58 77.08	29 12.61 23.97 61.70	3 1.30 2.48 100.00	15 6.52 12.40 40.54	18 7.83 14.88 37.50	121 52.61
	TOTAL	47 20.43	48 20.87	47 20.43	3 1.30	37 16.09	48 20.87	230 100.00

Key to numbers in frequency table:

Frequency count % of total count % of row count % of column count

STATISTIC	DF	VALUE	PROB
CHI-SQUARE	5	25.148	0.000
LIKELIHOOD RATIO CHI-SQUARE	5	27.098	0.000
MANTEL-HAENSZEL CHI-SQUARE	1	4.407	0.036

the landscape plants used on a freeway in an arid environment. A search of the literature indicated that virtually nothing has been recorded about the properties and growth conditions of landscape plants in arid areas and in particular those used in urban freeways in arid climates. The only two real sources of information are the experience of the landscape designers and the responses of the plants themselves.

The survey identified two sources of variation associated with plant response. The first is the contracts which dissect the freeway into linear segments with different designs and different installations. The segments or contracts represent initial environments that are modified by events and conditions specific to each contract. For instance, the color of the granite on the newest sections of I-10 appears more gray than the pink granite which is used in the vicinity of Val Vista Drive on SR 360. This difference by contract has implications for future monitoring since the same species has responded differently on different contracts. The most common way of handling contracts for statistical purposes would be to use contracts as blocks since blocks are used to remove variability extraneous to the research objective. However, the more recent trends in statistics tend to utilize the information about spatial variability rather than remove it.

The second source of variability identified by the survey was the difference between plant response on the north and south sides of the freeway. Although the association between the side and aspect is not an exact one, it certainly warrants further investigation. Differences in plant response to slope aspect are widely accepted in plant ecology. The angle and alignment of a slope face controls the angle of incidence of sunlight which in turn controls the intensity of the light. Slope aspect gains particular importance because of the linear alignments created by the freeway. Future monitoring should explore this phenomena in relation to plant response.

The survey proved to be a good mechanism for collection of baseline data. It has helped to identify problems which are specific to some species such as sunburn as well as problems which are more general such as physical trauma. The categories included in the survey were derived from observations of the plants and the experience of the surveyor. The intent was to be qualitative rather than quantitative and thus allow for some judgement calls on the part of the observer. For instance, chlorosis is fairly easy to recognize in many plant species but the degree of chlorosis is considerably more difficult to document. The point at which a plant is deemed out-competed is a judgement but it is an important one in landscaping design. Because of these aspects the data was not well adapted to extended statistical analysis.

Future monitoring of a more detailed nature should be guided by the information provided by this survey. Perhaps new contracts should be surveyed in a more detailed manner in order to establish baseline information. The freeway environment presents a unique plant environment that needs to be further explored.

Summary of Vegetation Study

Evaluation of roadside landscaping in the past has frequently centered on the visual aspects associated with esthetic quality (Blair et al., 1979; Hampe and Noe, 1985; Lambe and Smardon, 1985). In recent years rising costs of labor and materials have resulted in reductions in maintenance activities and an increased interest in the performance of roadside plants. Species which deteriorate in the roadside environment represent a loss of both maintenance funds and visual quality. Research concerning the responses of various plant species to the roadside environment has generally concentrated on vegetation used in road cuts and highways in nonurban areas (Baker, 1983; Zak, 1983).

The lack of information concerning landscape plants along urban freeways in the Phoenix metropolitan area resulted in the implementation of a problem-based categorical survey. The objective of this survey was to rapidly acquire information that could provide a basis for future detailed monitoring and analysis. The information from the survey would inventory the general types of problems associated with plant species under the existing conditions and indicate sources of variability that could influence the location of future monitoring sites. Long-term detailed monitoring of existing species will be needed to determine the proper species selections for potential reduction in maintenance costs.

The types of surveys generally used in vegetation evaluations did not meet the objective of the present study. Rating schemes frequently used in environmental perception studies require procedures for evaluating individual rater reliability and unequally spaced rating scales (Schroeder, 1984). The problem-based categorical survey is an inventory and does not require a rating scheme. It does require visual identification of the presence or absence of the problem categories but does not rate the severity of the problem for a specific plant. The categories are based on recognizable problems such as chlorosis and should be defined before the initiation of the survey.

Surveys used in landscape ecology studies are generally concerned with spatial dispersion of vegetation and require detailed measurements of environmental parameters (Haase, 1984). This type of survey is useful in long-term detailed analysis since cause and effect can often be deducted from the results. However, it also requires large inputs of time and resources. The categorical survey provides information which can be used in the initial decisions needed for a detailed analysis.

This paper will provide the results of a problem-based categorical survey of the landscape plants along the Phoenix Metropolitan freeway system and will evaluate the strengths and weaknesses of this type of survey.

Materials and Methods

The area encompassed by the survey was located along SR 360 from Dobson Road to Val Vista Drive and along I-10 from Dysart Road to Bullard Avenue in the Phoenix Metropolitan area of Arizona. The survey area represented approximately 18 miles of landscaping which was evaluated by one person in about eighty manhours.

The study area contained several landscape installation contracts which had been completed at different times. Contract numbers and ages are given in Table 19. The age of the contract was defined as the number of months that had elapsed since the initiation of the one-year establishment period and the time of the survey. These contracts represented a convenient means of dividing the area into locations for comparison. The individual landscape contracts also contained a potential source of variability since each contract appeared to represent a distinct style of landscaping.

Categories of the survey were developed from initial field observations of the study area. Plants in each contract location were assigned to one or more of the following categories: healthy (HL), sunburned (SB), chlorotic (CH), trauma (TR), noncoalesced (NC), dead (DD), out-competed (OC), and other (OR). Healthy was used to describe plants that exhibited growth patterns normal for the species as determined by comparison with local arboretum and nursery specimens. Sunburned plants exhibited cracked or peeling bark. Chlorotic plants exhibited a pale green color or appeared more yellow than expected for a normal plant. Trauma referred to any discernible physical damage such as splitting from such as splitting from improper staking, gnawing from rodents, or destruction from vehicles. Noncoalesced was a category reserved for evaluation of groundcover category reserved for evaluation of groundcover plants whose canopies had not grown together. Dead was assigned only when the actual base of the missing plant could be identified. Out-competed referred to species that were dominated by a non-compatible species in the landscape, thus distorting the design and placing the plant under additional stress from competition. When a plant appeared to be an unhealthy or otherwise poor quality specimen but did not exhibit any of the above symptoms, it was assigned to other as a category. Initially, a water-stressed designation was suggested as a category but was eliminated as it proved to be too difficult to inventory with certainty.

Plants were evaluated in one of two modes which were determined before the initiation of the survey. Plants that generally appeared isolated from others of the same species were evaluated as individuals while plants that normally appeared as clusters of the same species were evaluated as groups. The group mode included plants used as groundcover but was not limited to that concept. The landscape contract as-built plans were used as base maps. Counts for contract location-species combinations did not always represent the total number of plants evaluated since each plant could be assigned to more than one category with the exception of HL. Plants placed in the HL category were not counted in any other category.

The chi-square test of independence was used to statistically evaluate the relationships between location and problem categories for each of the five plant species. Location was defined by two different variables, contract and side. Each contract as identified by its number represented a specific physical location for the plants. Since five contracts were used, five locations within the contract variable were available. As the study area encompassed only eastbound-westbound segments of the highways, plants were identified as being located in the landscaping corridor north of the median (adjacent to the westbound lane) or the landscaping corridor south of the median (adjacent to the eastbound lane). Thus, the side variable contained two locations, north and south.

The division of the problem categories is more complex than location since a plant could be assigned to more than one category. Because some categories contained too few observations to be valid, not all of the observations could be used for each comparison with the location variables. This entailed sorting the counts in categories into two populations. When all of the observations were to be used, then a category variable called status was specified. Status contained two levels, healthy and nonhealthy. The level designated healthy was comprised of counts in the healthy category for each species. The level designated nonhealthy represented the sum of all observations in categories other than healthy. In order to evaluate specific problems in relation to location, the population was restricted to observations pertaining to problem categories. Observations in the healthy category were excluded from this portion of the evaluation. Plants that were counted in more than one problem category were placed in combined categories to prevent overlap.

The relationship between each pair of variables was statistically evaluated with the probability of the calculated chi square statistic (Daniel, 1978). An alpha level of 0.05 was used as the acceptance level. If the probability of the chi square statistic was less than 0.05 then the hypothesis of independence between the two variables was rejected and an association between the variables was accepted. The chi square test was used to evaluate the following pairs: status versus location by contract, status versus location by side, and location by contract versus location by side.

The statistical procedure described in the preceding paragraphs was applied to the species that met the following criteria: evaluation in the survey as individual plants, location on at least three different contracts, and presence of sufficient problems to warrant further evaluation. The species used in the analysis were *Acacia saligna* (ASL), *Acacia smallii* (ASM), *Acacia stenophylla* (AST), *Cercidium floridum* (CFL), and *Prosopis chilensis* (PCH). Each species was evaluated independently of the others.

Results and Discussion

The results of the statistical analysis for status versus location are shown in Table 44. When plant status and location by contract were compared using all of the data for each species, the chi square probability was less than 0.05 for ASL, AST, CFL, and PCH. These results indicate that a significant

Table 44. Probabilities of the chi square test square test statistic computed for combinations of the category variable with location variables when all data for each species was used in the analysis.

PLANT SPECIES	CATEGORY VARIABLE	LOCATION VARIABLE	CHI SQUARE PROBABILITY
ASL (a)	status	contract	0.000
ASL	status	side	0.537
ASM (b)	status	contract	0.223
ASM	status	side	0.000
AST (c)	status	contract	0.000
AST	status	side	0.117
CFL (d)	status	contract	0.000
CFL	status	side	0.726
PCH (e)	status	contract	0.000
PCH	status	side	0.012

(a) *Acacia saligna*
(b) *Acacia smallii*
(c) *Acacia stenophylla*
(d) *Cercidium floridum*
(e) *Prosopis chilensis*

association exists at the 0.05 alpha level. The location of the plants as specified by contract has an influence on whether the four species are healthy or whether they exhibit the problems defined in the survey.

Although a category-based survey is an inventory of effects and does not provide a means of determining actual causes, a discussion of likely causes is warranted if the survey is to become the basis for further analysis. The relationship between location by contract and plant status may be related to conditions that would change from contract to contract. These conditions may include alterations in landscape design, differences in maintenance, initial differences in sources of plants, and the time of year of installation. Differences in soil properties are less likely to contribute to differences in plant status by location. Prior to installation of the landscaping, the area was plated with topsoil. The mixing caused by the topsoil placement should minimize the soil differences between contracts. However, location of future monitoring sites should account for differences in location associated with contract.

Differences in plant status with contract location did not appear to be related to time. If contracts represented different lengths of exposure time to the overall freeway environment, then a decrease in percent of healthy plants would be expected for those species that deteriorate with time of exposure to the freeway environment. This relationship was evaluated by plotting the age of the contract versus the percent of healthy plants for each species on each contract (Figure 51). Only AST displayed a decrease in percent healthy plants with time. When evaluated at one month after planting (contract number 26), 94% of all Acacia stenophylla plants were categorized as healthy. At 17 months after planting (contract 18), 72% of the AST plants were healthy and at 69 months (contract 16), 35% were healthy. The general trend of PCH was also downward. In contrast, the ASL, ASM, and CFL showed an increase in percent healthy with time followed by a decrease (Figure 51). These inconsistencies suggested that apriori factors controlled initial plant status. Factors such as time of year of landscape installations and initial condition of the plant material may have interacted with the factors identified by this survey. Nonhardened plant material and root-bound rootstocks will reduce the chances of survival in an arid freeway environment.

The location of plants with respect to the median appeared to influence the types and numbers of problems observed in the plant species. When plant status was compared to location by side for all observations in each species, ASM and PCH showed a significant association at the 0.05 alpha level (Table 44). The association between status and side may be related to slope aspect. The style of construction within the evaluation area is cut-and-fill with the final surface stabilized by a rock mulch composed of crushed granite. The east-west alignment of the highways in the study area has resulted in slopes with either north-facing or south-facing aspects.

The influence of slope aspect on plant growth was recognized in the early literature concerning range plants (Weaver and Clements, 1938). Differences in aspect in natural conditions are often related to differences in soil moisture. In the Phoenix Metropolitan system the landscape plants are irrigated with a drip system which should decrease differences in soil moisture between the two aspects. If the association between plant status and side with respect to medium is related to slope aspect, other factors such as exposure to desiccating winds, differential changes in temperature related to seasonal changes, angle of exposure to solar radiation, and the effect of the granite mulch should be considered in future analyses.

When observation counts in the healthy category were excluded, the comparison between contract location and side was significant for ASL, CFL, and PCH at the 0.05 acceptance level (Table 45). This relationship indicates a possible interaction between the location variables. For these three species, the effect of location with respect to median should be evaluated within the context of the location by contract. The relationship between contract location and side could not be evaluated for ASM and AST because low numbers of observations of problems in the contract-side combinations invalidated the chi square test of independence (Daniel, 1978).

The association between plant status and location with respect to the medium may have implications for future highway landscape designs. The use of a mirror image about the median with the arrangement of species on one side reflecting the

Table 45. Probabilities of the chi square test statistic computed for combinations of the location variables when data is restricted by excluding counts in the healthy category.

PLANT SPECIES	LOCATION VARIABLE	LOCATION VARIABLE	CHI SQUARE PROBABILITY
ASL	side	contract	0.001
ASM	side	contract	--
AST	side	contract	--
CFL	side	contract	0.038
PCH	side	contract	0.037

arrangement of plants on the opposite side of the median may not provide the best conditions for reducing maintenance costs for some species.

In addition to the statistical analysis which identified specific associations, the recorded counts for the various other species provided a basis for future analyses. The survey counts for species evaluated as individuals are given in Table 4. The ratio of the sum of counts in problem categories to counts in the healthy category appeared to be a useful indicator of success within a contract location. Successful species were defined as species that could grow in the freeway environment with minimal maintenance costs. Based on field observations, plants with a ratio of less than 0.10 were considered successful while those with ratios greater than 0.10 were considered unsuccessful in adjusting to the environment of the contract location. Plants with a large ratio for a particular contract environment would be less likely to succeed if placed in a similar environment on a new contract. The conditions of that environment would need to be evaluated with further analysis.

Evaluation of Table 22 provided information about specific species and contract locations. Acacia stenophylla was the only species exhibiting sunburn. Prosopis alba appeared to be susceptible to physical trauma. Yucca aloifolia did not exhibit any of the symptoms catalogued in the survey but it did have a tendency to die. Characteristics specific to certain contracts can also be found. Contracts 16 and 17 are the oldest and next oldest landscape installations (Table 19). All of the out-competed counts appeared on these contracts. The lack of out-competed plants on younger contracts may reflect successful design adjustments made by ADOT roadside personnel in order to reduce maintenance costs.

In general the survey was successful in identifying the range of problems exhibited by the species evaluated as individuals. This was indicated by the moderate counts in the category designated as OR (Table 22). The large count for Cercidium floridum on contract 18 is related to a white fly infestation which was classified as OR. The OR counts in Acacia farnesiana, Acacia smallii, Prosopis chilensis, and Washingtonia californica indicate that further observation of these species is needed to identify additional criteria for specific problems.

The results of the survey for the species evaluated as groups are provided in Table 46. The data illustrate a problem inherent in this type of survey. With the exception of non-coalesced (NC), the categories did not accurately describe all of the individuals within a group. However, the large numbers of plants in each group precluded the rapid evaluation of these plants as individuals. For example, the five contracts specified a combined total of 53,137 plants of Acacia redolens and 5,033 plants of Nerium oleander. The time required to evaluate each of these plants as individuals conflicted with the concept of a rapid inventory.

A modification of the category concept developed for indi-

Table 46. The counts for each category for some plant species evaluated as groups.

PLANT SPECIES	CONTRACT ID	CATEGORY (a)							
		HL	SB	CH	TR	NC	DD	OC	OR
Acacia redolens	16	45	0	0	0	27	1	0	0
	17	30	0	0	0	6	0	0	0
	18	15	0	0	0	15	3	0	0
	26	9	0	17	1	20	5	0	0
	69	5	0	10	0	9	3	0	0
Caesalpinia pulcherrima	16	17	0	0	0	0	0	8	2
	17	8	0	0	0	0	2	2	1
	18	3	0	0	0	0	0	0	0
	26	3	0	0	0	0	1	0	0
	69	4	0	0	0	0	0	0	0
Dalea greggii	16	1	0	0	0	1	1	0	0
	18	9	0	0	0	10	1	0	0
	26	18	0	0	0	13	5	0	0
Justicia californica	26	4	0	3	0	0	1	0	0
	69	1	0	0	0	0	1	1	0
Myoporum parvifolium	26	11	0	0	0	11	2	0	0
	69	1	0	0	0	0	1	0	0
Nerium oleander	16	4	0	0	0	0	0	0	0
	17	9	0	0	0	0	0	0	0
	18	3	0	0	0	0	0	0	0
	26	3	0	0	0	0	0	0	0
	69	3	0	0	0	0	0	0	0

(a) The abbreviations for categories are defined in the Materials and Methods vidual plants provided limited information concerning groups. Assignment of a group to a category such as dead was based on the concept that not all of the plants in the group were dead but rather dead plants could be found in the group. For example, in the evaluation of Dalea greggii, five groups contained dead plants on contract 26 while eighteen groups contained healthy plants with no noticeable problems. The conditions present in the location of contract 26 do not appear to be favorable for this species. In contrast, Nerium oleander appears to be one of the most successful plants used along the freeway regardless of the contract location.

The most useful category applied to group plants was NC (non-coalesced). Groundcover plants that coalesce are both a landscaping design element and a potential contributor to slope erosion resistance. The intergrown canopies provide soil protection from raindrop impact. Three of the species in Table 46 are considered groundcover, Acacia redolens, Dalea greggii, and Myoporum parvifolium (Arizona Dept. Water Resources, 1985). The counts in the NC category suggest that Acacia redolens and Dalea greggii are not successfully coalescing in the different contract environments. If coalescence is desired, then a closer plant spacing may be needed for these species. Insufficient information is available to evaluate the Myoporum parvifolium.

Conclusions

The problem-based categorical survey provided a useful means of rapidly providing initial information concerning the landscape plants along the Phoenix Metropolitan Freeway System. Statistical analysis of the survey data identified two relationships involving plant status and location. Location of plant species with respect to both landscaping contract and side of the median influenced the portions of healthy plants and plants exhibiting problems for a given species. Location provided sources of variability that should be considered in future analyses of the species ~~should be considered in future analyses of the species~~ response to the environment of the freeway. The differences in landscaping contracts need to be considered if detailed measurements and subsequent monitoring of the plants are to be undertaken. The side of the freeway on which the plants are located should be also considered. The use of a mirror image design may not provide the lowest maintenance costs when a cut-and-fill style construction is used.

The success of this type of survey in providing statistically valid information about potential sources of variability for future analyses will be defined by three conditions. First, the plant species must be repetitive and appear along diverse sections of the freeway. The relationship between plant status and location in this survey suggests that location is an important source of variability in species responses to a metropolitan freeway system. If information is known for only one contract or for only a very limited area, insufficient information is available to evaluate the response of that species in the larger freeway environment. Second, the evaluation categories must be selected with care. Categories should reflect the environmental conditions and plant species in the area to be evaluated. High counts in collective categories such as "other" indicate a lack of knowledge. Third, the plants should be evaluated as individuals rather than groups. If excessively large numbers of plants are to be evaluated, grouping may become necessary but detailed information will be lost.

When the above conditions are met, statistical analysis can be used to identify sources of variability. When the above conditions can not be satisfied, information such as the ratio of problem counts to healthy counts can be used in the evaluation. The problem-based categorical survey is a rapid and relatively inexpensive means of acquiring an initial data base for plant species used in the freeway landscape. The information provided by the survey can form the basis for future detailed monitoring and analysis.

Weathering effects on slope rock

The weathering of slope protection materials such as granite can influence the ability of those materials to provide long term protection. Granite is composed of quartz, feldspar, and small amounts of iron-rich minerals. When exposed to the forces of physical and chemical weathering, granite decomposes. The results of this decomposition are two fold. First, feldspars and some of the iron-rich minerals form clay minerals. Second, the overall size of the granite fragments is decreased by fracturing occurring during differential expansion of individual mineral grains. The resulting smaller particles can be more easily transported down slope.

To simulate the potential weathering occurring on an arid slope, the weathering scheme used a combination of heating and cooling with wetting and drying. The testing procedure involved several steps. Each designated sample was screened by hand. All material retained on a #4 Gilson screen was saved for testing while all material passing the #4 screen was discarded. The saved portion of each sample was split into six subsamples weighing approximately 1 to 2 kg. Three of the subsamples of each granite or rock were selected as controls and were stored at room temperature in an area protected from dust.

The remaining three subsamples of each granite or rock were subjected to the following weathering scheme. Each subsample was stored in the same container throughout the test. The subsamples were placed in an oven at 150 degrees F for 24 hours. At the end of the 24 hours, the subsamples were removed from the oven and allowed to cool for one hour at room temperature. The subsamples were then immersed in tap water and allowed to stand for 23 hours at room temperature. At the end of the 23 hour soaking period, the water was drained off and the subsample was placed back into the oven to begin the 24 hour heating period. The preceding process was defined as one cycle and required 48 hours for completion. Interruptions in the process were permitted at either the end or the beginning of the heating stage but not during the cycle. Samples were stored at room moisture content and temperature for the duration of the interruption.

After 50 cycles, each subsample was weighed and mechanically sieved for 10 minutes. The nest of screens used was: 2 inches, 1 inch, 0.75 inch, 0.50 inch, #4 US Standard screen, #10 screen, and #40 screen. The percent weight retained on each screen and the percent weight passing each was calculated. An Analysis of Variance (ANOVA) was performed on each sample-screen combination using the percent weight passing the designated screen as the response.

The selection of the materials to be tested was based on the location of the materials with respect to the study area, on the estimated size distribution of the material, and on the physical appearance, especially color and apparent degree of decomposition. Four of the materials selected, IG1, IG2, IG3, and SRG1 provided a good representation of the slope protection materials presently in use on freeway slopes. The IG1 granite was taken from I-10 near Dysart Road; the IG2 granite was sampled from I-10 at 67th Avenue; IG3 was granite taken from I-10 at 83rd Avenue; the SRG1 granite came from SR 360 near Val Vista Drive and RR 1 was river-run taken from a gravel pit in Tempe. The average percent weight retained on each sieve for the three subsamples in the control of each of the five samples is given in Table 47.

The results of the ANOVA for each sample-screen combination are provided in Tables 48 through 52. Each table contains the average percent passing the screen for the equivalent control and weathered subsamples. Listed also are the probabil-

Table 47. Average percent by weight retained on each screen for each rock sample. The averages were calculated from the three subsamples used for the control.

Screen Size	IG1	IG2	IG3	SRG1	SRG7
	-------Average percent retained--------				
2 inch	0.0	0.0	0.0	0.0	11.7
1 inch	0.0	3.0	9.6	5.2	48.5
0.75 inch	0.2	31.8	32.8	33.3	12.5
0.50 inch	0.6	60.9	30.4	59.3	20.7
#4 screen	95.6	3.9	26.5	2.0	6.5
#10 screen	3.2	0.1	0.4	0.1	0.1
#40 screen	0.1	0.1	0.1	0.1	0.0

Table 48. The probabilities associated with a difference in means of percent material by weight passing each screen size for weathering test of IG1.

Screen Size	Percent passing screen		Probability
	Control	Weathered	
2 inch	100.0	100.0	1.00
1 inch	100.0	100.0	1.00
0.75 inch	99.8	100.0	0.42
0.50 inch	99.1	98.1	0.56
#4 screen	3.5	4.0	0.02
#10 screen	0.3	0.7	0.13
#40 screen	0.2	0.4	0.18

Table 49. The probabilities associated with a difference in means of percent material by weight passing each screen size for weathering test of IG2.

Screen Size	Percent passing screen		Probability
	Control	Weathered	
2 inch	100.0	100.0	1.00
1 inch	97.0	98.1	0.60
0.75 inch	67.8	71.1	0.35
0.50 inch	4.6	6.8	0.05
#4 screen	0.7	1.2	0.19
#10 screen	0.6	0.7	0.92
#40 screen	0.6	0.5	0.88

Table 50. The probabilities associated with a difference in means of percent material by weight passing each screen size for weathering test of IG3.

Screen Size	Percent passing screen		Probability
	Control	Weathered	
2 inch	100.0	100.0	1.00
1 inch	90.4	87.5	0.37
0.75 inch	57.6	60.9	0.59
0.50 inch	27.2	29.8	0.43
#4 screen	0.7	1.7	0.05
#10 screen	0.3	0.8	0.11
#40 screen	0.2	0.4	0.26

Table 51. The probabilities associated with a difference in means of percent material by weight passing each screen size for weathering test of SRG1.

Screen Size	Percent passing screen: Control	Percent passing screen: Weathered	Probability
2 inch	100.0	100.0	1.00
1 inch	94.8	94.5	0.90
0.75 inch	61.5	58.1	0.60
0.50 inch	2.4	2.6	0.58
#4 screen	0.4	0.4	1.00
#10 screen	0.2	0.2	0.54
#40 screen	0.0	0.0	----

Table 52. The probabilities associated with a difference in means of percent material by weight passing each screen size for weathering test of RR 1.

Screen Size	Percent passing screen: Control	Weathered	Probability
2 inch	88.3	92.8	0.73
1 inch	39.8	39.1	0.94
0.75 inch	27.3	22.2	0.37
0.50 inch	6.6	7.5	0.71
#4 screen	0.1	1.4	0.15
#10 screen	0.1	1.0	0.16
#40 screen	0.1	0.8	0.33

ities associated with each combination. The probabilities may be interpreted in the following manner. The IG1 sample (Table 48), there is a 42% likelihood that the average of the control subsamples is the same as the average of the weathering subsamples for the 0.75 inch particle size. In contrast, there is only a 2% likelihood that the average percent passing the #4 screen for both the control and weathered subsamples of IG1 are the same. Thus the weathering scheme altered the particle size distribution of IG1 by creating a greater number of particles smaller than the #4 screen than in the control.

In addition to the change in particle size distribution of IG1, both IG2 and IG3 also showed changes in particle size after weathering. The change occurred at the 0.50 inch particle size for IG2 and at the #4 particle size for IG3 (Tables 49 and 50). However, neither SRG1 nor RR 1 showed a change in particle size distribution as a result of the weathering scheme (Tables 51 and 52).

Although the shifts in particle size with weathering are small, they do indicate a potential for decreases in the long term slope protection for three of the materials tested. When the crushing action from vehicular traffic on the slopes is added to the natural weathering of these slope materials, the potential for decreases in particle size becomes even greater. The sounder the initial rock was (ie. the greater the crushing required to make gradation) the more durable the rock proved to be during testing.

Field observations throughout the study area did not indicate that a strong chemical reaction was occurring between the emplaced granite and the underlying soil materials. Initial pre-study field observations did not reveal the magnitude of the traffic on the slopes; thus abrasion testing was not considered in the weathering scheme. In light of later discussions with ADOT personnel concerning the apparent shifts in particle size distribution occurring during transportation and emplacement of the granite protection material on the slopes as compared to pit distributions, the research team recommends:

1) That some form of abrasion testing be included in a future project. This abrasion testing should model the stress placed on the materials from the time they leave the pit until placed at density on the slopes, and
2) That as assessment of rock weatherability be made prior to acceptance for use as slope protection.

Phase 1 and Phase 2 Conditions

One of the fruitions of the research discussed in this report is the relationship of the results and observations of the research to the conditions existing in the study area. One aspect of this is the period of interim slope protection and a second is the existing granite protection. The interim slope protection period refers to the protection of slopes from the completion of the grading contract to the initiation of the landscaping contract. For brevity this period will be referred to as Phase 1. The granite protection scheme is part of the landscape period and will be called Phase 2.

Phase 1 - Interim slope protection

In the current Phase 1 status, the slopes are protected by the plating soil and by whatever vegetation is able to establish after seeding. The plating soil is selected for its properties as a plant growth medium rather than its ability to minimize erosion. This is another example of the opposing intentions of the engineering environment and the plant environment. Activities which may accomplish the engineering objective of stabilizing the slopes against erosion may not provide the best environment for the landscape plants which are eventually to be placed on the slopes. The best compromise between the two is to minimize the length of Phase I so that the initiation of the landscape immediately follows the slope grading and additional slope protection measures are not needed.

In cases where Phase 1 can not be minimized, other alternatives are needed. When the interim period is likely to be long enough to allow at least one precipitation event but landscaping will soon follow, a chemical alternative may be appropriate. The test results of the three chemical additives, suggest that a very effective short term protection may be available. The research program was not able to resolve all questions concerning satisfactory performance of chemical agents. The reduction in short term erosion and the possible compatibility with plants makes additional research very attractive. The research should address the optimum placement techniques that should be employed; the effective life of the material before degradation reduces effectiveness; the cost effectiveness of the most successful additives; and the development of understanding of how these chemicals affect plant growth.

A compromise between the engineering environment and the plant environment may be made in Phase 1 by utilizing soils that contain more than 20 percent plus number 4 sieve size material wherever possible. The reduction in erosion caused by coarse particles at these concentrations warrants using these soils whenever they are found, provided they meet the previously described criteria as the plant growth media. In addition to using the soils with the coarse particles, all traffic on the interim slopes should be held to a minimum to preserve what natural armoring that does develop.

Another potential compromise between the two environments might be to place the granite as soon after slope grading as possible even if the landscape plants are not immediately installed. The results of this research indicate that granite can be effective in slope stabilization provided certain criteria are met. The landscape design used on Contract F-028-1(26) utilizes granite as a complete cover with no exposed soil. Further research is needed to determine if the observed poor response of plants on this particular contract is related to the conditions created by the extensive granite cover or to some other factor such as too drastic a change in climate from their point of origin.

If the length of Phase 1 is expected to last for at least one growing season, then the use of stabilizing interim vegetation should be considered. The lack of establishment of the current seeding mix may be related to the time of planting and the style of seeding rather than to the actual components of the mix. The planting should be timed to allow the young plants to access the soil moisture accumulated from rainfall. Roughing the slopes to provide microcatchments would also enhance infiltration and subsequent water storage in the soil. The seeding mix could be hydro-mulched onto the slopes to preserve the roughed surface.

Phase 2 - Existing granite

The problems presented by the granite surfaces placed west of Gilbert Rd on SR 360 have warranted a solution for some time. The laboratory testing program of the granite materials produced some interesting information on the granites in use at the time of the study. This information indicated that the granite protection on most of the slopes should have resisted the 50 year storm if placed approximately 2 inches thick. The protection did not work as planned and therefore one or more reasons for the failure must exist.

Some of the possible reasons for the failure are as follows. 1) The material was not placed two inches thick or as a result of traffic on the slopes it was thinned after placement. Once thinned to the 0.5 inch thickness range, the rilling would proceed. 2) The slopes experienced a precipitation event that exceeded the resistance of the material. As can be seen from the laboratory data, very high overland flow rates would be required to fail the slope granite. Once a few rills were produced, the procedure of filling the rills with granite robbed from adjacent slope areas would facilitate the thinning of the material. 3) The slope granite is subjected to sufficiently severe rain drop impact to allow a continual migration of particles down slope. The laboratory testing did not document that movement even on 2:1 slopes. Since the research did not simulate the worse case raindrop impact, it is possible that slope migration did occur. However, the study team did not see a clear expression of surface particle migration associated with size. Such a surface expression would be necessary if the rain drop impact were producing a slope protection thinning. 4) It is possible that surface plugging occurred which in turn reduced permeability to the point that rills were cut in certain areas. Once the rills were filled by blading existing slope material into them, the overall protection was thinned.

Whether one or more of the above hypothesis or perhaps one not conceived is the cause, slope distress occurred. To fix the existing problem additional information would help with understanding the effectiveness of proposed fixes. Recommendations for additional research in the form of, among other things, a test section will be discussed in following sections.

If remedial decisions for the granite had to be made on the basis of the present knowledge than the following recommendations would be put forward for ADOT consideration:

1. Bring present slopes to a 2 inch thickness with additional granite.
2. The augmenting granite should have a minimum size of plus number 4 sieve size, and pass through the 1.5 inch sieve with at least 15 percent retained on the 1 inch sieve.
3. Where possible the upper slopes should be regraded to minimize the amount of overland flow passing over the slopes. Where possible the upper slope runoff should be directed to locations where drainage ditches could transmit the flow, or where it passes over the slope at controlled sections. These sections should contain surface particles with maximum sizes on the order of 6 inches to resist the high flow rates that would be experienced. Particular sizes of materials and widths of the overland flow sections would vary as the slope requirements would vary.
4. In areas where erosion is occurring around planted areas and the slope areas are faring well, geotextiles should be used. The purpose of the geotextiles would be to provide support to the surface protection that is lacking due to irrigation and plant construction activities that resulted in low density subgrade.
5. Slope maintenance activities should continue to minimize slope traffic. The slopes should experience as little disturbance as possible. If severe storms produce surface rills after remedial action is taken, the rills should be filled with material added to the slopes and not bladed into the rills from adjacent areas. This restriction is necessary to

maintain the long term surface protection.

In spite of the problems the slope sections have had, the granites exhibited considerable relative erosion resistance when compared to the soils examined. When erosion due only to precipitation is considered, the relative erodibility of the materials examined compared to the SRG1 granite can be found on Table 53. The SRG1 compares favorably with all of the materials except the SRS1 soil. The Soil Seal additive and the SRS -1" results are too close to differ and the other granites were too permeable to produce erosion. Too many variables enter into the overland flow component of testing to make so simple a comparison. However, it should be noted that with the exception of the other granites, no other material could exhibit the same resistance as did the SRG1 material under combined flow conditions.

Test Section

The research team is convinced that a test section would be in ADOT's best interest. This test section, which could actually be comprised of several discrete sections along SR 360 and I-10, would test the products of this research as well as provide a training tool for ADOT personnel.

The test section could have many forms and the study team feels that the specific details of the test would most effectively be developed from discussions with and among the Research Committee. However, we do offer the following comments

Table 53. Erosion index, relative to SRG1 under precipitation-induced erosion alone

MATERIAL	I (a)
SRG1	1.0
IG1	0
SRG8	0
SRP5	9.6
SRP5+105SRG1	4.7
SRP5+30%SRG1	2.0
SRP5+10%IG1+20%SRG1	2.3
SRP5+20%IG1+20%SRG1	1.0
SRP5+30% Slate Creek	1.1
SRP5+Soil Drain	2.5
SRP5+Soil Seal	0.8
SRP5+Stabilizer	4.2
IG9	4.3
SRS1	0.5
SRS1 - 1"	0.9

(a) I = material erosion rate/SRG1 erosion rate.

about aspects of the test section which are felt to warrant consideration.

The study team recommends that a slope test section encompass one of the areas that has experienced erosion damage and presently contains the granite. This test section would utilize the best techniques believed feasible. The study team recommends that one test segment have an additional 1 inch of granite added. This granite would contain particles of from 1.5 inches to those particles retained on the number 4 sieve. The material shall be well graded and contain particles with a Shape Factor of at least 2.0 and have primarily angular shape. The addition of the new material, when spread with slope dressing equipment already used by ADOT, would produce a section approximately 1.5 inches thick with angular shape that would resist overland flow. The thickness of 1.5 inches should be sufficient to allow the development of a very effective surface armor. Granite is recommended to better blend with the existing materials. The weathering data indicates that granite with similar weathering resistance to the granite from the 67th Ave pit would prove satisfactory for many years durability.

Coupled with the surface treatment should be a continuation of the concept of keeping slope traffic to a minimum. Slope access needs to be severely restricted. Slope traffic destroys a portion of the armoring that develops. If erosion is to be minimized, so must be traffic.

A second section of the test area would require regrading the upper slope segment to prevent surface runoff over the lower slope. If the proper section of freeway is selected, the regrading should be slight. In addition to the change in grading enough granite should be added to bring the slope to 2 inches of granite protection. The gradation and size of the added material should be as specified in the first trial section.

Several sections are needed in the test area to explore changes in landscape design. One section should evaluate the effects of placing plants in the best plant environment. In this section, the density of plants near intersections should be decreased while the intensity of plants in the expanses between the intersections should be increased. The granite should not be placed in the intraspacing areas of plants that are intended to be ground covers but the spacing should be decreased to allow for faster coalescing of the plants. Plants that layer naturally should be selected for these areas. Both the plants and the amount of erosion should be closely monitored.

A small area of the section described in the previous paragraph should evaluate the use of geotextiles under granite to compensate for low density subgrade adjacent to plant sites. The erosion in vegetated areas in the SRG1 material west of Val Vista presents a unique problem. To densify the planted areas and sprinkler line trenches among the plants is to make the growth medium less viable. However, the granite protection cannot be allowed to fail due to the low subsoil densities. A way to protect the granite and still foster the growth of vegetation would be to use a geotextile beneath the granite. If a geotextile such as the Mirafi 140N were placed over the low density areas adjacent to the plants but prior to the placement of granite and prior to the installation of the landscape plants, adequate support would be provided to prevent rilling. A geotextile will allow water to pass through the granite soil interface without particle transport. The granite would also protect the fabric from ultraviolet radiation.

If more intense regrading is deemed feasible, then a somewhat radical change in landscape design should be evaluated. Figure 52 depicts an example of the design changes that might facilitate the separation of the engineering environment from the plant environment. In this design, the upper portion of the slope is graded so that the final surface is a gentle trough which does contains plating soil but not granite. The trough acts as a water catchment. Water collected in the trough will infiltrate into the plating soil, thus making it plant available and removing it from participating in overland flow. At appropriate intervals the reverse face or the freeway side would contain armored mini-spillways that would channel flow in such a way as to minimize erosion damage. Vegetation would be restricted to the upper portion of the slope. Tall shrubs in the trough would be visible but the ground surface would not. Unless weeds became a severe problem, they would not need to be removed except for cosmetic purposes. The shrubs would also provide a visibility barrier. The edges of the trough should be planted with a ground cover that can

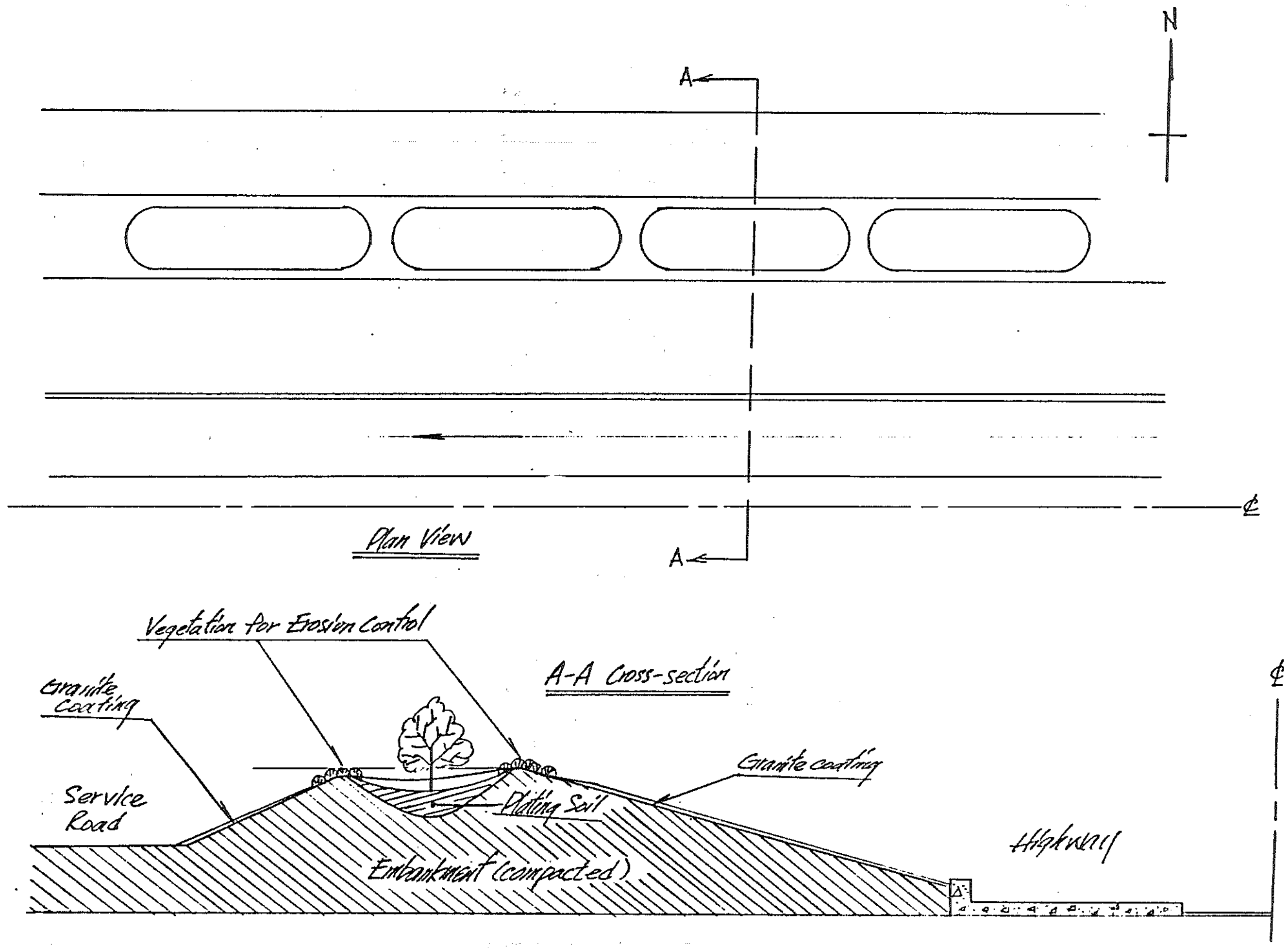

Figure 52. Design of a Test Section Which Combines Engineering Environment with Plant Environment

develop a mat or one that layers.

Another section of unprotected plating or subgrade material should be selected for chemical additive evaluation. At least three additives selected from additional testing, should be placed under optimal conditions for each one. An adjacent unprotected area should be roughed and seeded by hydromulching at the time when soil moisture is highest. This would allow comparison between the additives and successful stabilization vegetation.

The final trial section in the test area would function as control. This section will remain as it presently exists. This section will have maintenance conducted as has been applied in the past.

The proposed test section should demonstrate the following concepts:

1. Surface protection can be significantly increased by particles of size and shape that facilitate the development of natural armoring.
2. The control of overland flow will yield increased benefits over and above just providing surface armoring. The reduction in overland flow on the slope will reduce the amount of fines that are transported to the traveling surface environment.
3. The engineering design can be made more compatible with landscaping needs.
4. Geotextile applications to correct problem areas on the slopes without harming vegetation.

5. The relative importance of chemical additives in reducing short term erosion.

Conclusions

1. Any program that attempts to assess erosion resistance of slope materials must consider the combined influence of simulated precipitation and overland flow acting on the slope.

2. The overland flow component is generally orders of magnitude greater than the precipitation component alone.

3. The slope damage observed on freeway slopes within the study area was due primarily to overland flow delivered via small collection areas on upper slope segments.

4. Slope materials containing material finer than the number 40 sieve can expect a portion of that material to be eroded from the slope during events on the order of the 50 year 30 minute intensity storm. The bulk of the material will be removed at the initial period of surface flow. The recognition of the heavy sediment load with the first rainfall, may provide opportunities to minimize pump damage and other freeway damage. Precautions such as settling basins with baffels may be used to trap the initial sediment load. Subsequent rains should produce steadily reducing quantities of sediment if the slope is designed properly.

5. When compatible with the plant requirements, slope soil should contain as high a percentage of plus number 4 sieve size material as possible. The presence of this coarse fraction facilitates the armoring of the slope. By taking

advantage of the soil's natural ability to protect itself, slope protection requirements can be minimized.

6. The coarse slope particles should have a minimum Shape Factor of 2.0 and should have angular faces. As the Shape Factor increases the efficiency of the surface protection increases.

7. Rounded slope particles are less likely to form effective surface protection. These particles are more easily transported by rolling with the transporting flow.

8. When the percentage of plus number 4 size particles is greater than 20 percent the potential for the development of an effective armoring system is good. The better graded the coarse and fine fractions are, the more efficient will be the surface protection formed.

9. The three chemical additives applied to the study soils, a polyacrylamide, a latex copolymer, and an enzyme provided short term protection. All three demonstrated a potential to restrict fine particle transport that could most likely be enhanced following additional research.

10. On 26.6 and 21 degree slopes, with the combined flow conditions, most particles removed from the slope will be smaller than the number 4 sieve size.

11. When slopes are designed, minimizing the amount of overland flow delivered to the slope is critical if erosion is to be minimized. Water falling on the upper slope segments should be diverted to sections especially designed for high overland flow conditions. Where it is not possible to

prevent upper slope runoff from flowing over the lower slope segments, those segments receiving the flow should have surface protection designed to handle that flow.

12. Slope surfaces once constructed should not be disturbed. The disturbance of the armored surfaces exposes the underlaying soil to erosion. Maintenance, motorists, and pedestrian traffic should all be restricted.
13. Tree and shrubs in the landscaped areas do not appear to influence erosion in either a positive or negative matter. This may be related to the effects of overland flow.
14. The lack of variation in the soils of the study area appears to be related to the lack of major differences in the pre-construction land surface and to the amount of mixing that occurs in the construction process. The low variability in the study area may <u>not</u> be characteristic of the entire area encompassed by the freeway system.
15. The chemical and physical properties of the soil materials taken from the study area are generally within the range of those properties needed for good plant growth. There is no indication of serious salt or sodium problems. However, the levels of available phosphorus tend to be low.
16. Soil associations developed by the SCS may be an effective tool for characterizing expected differences in soil texture of the root zone when the upper four feet of natural soil material is used as plating material.
17. The freeway represents a drastically disturbed environment in respect to the ability of the materials to provide good

growth conditions for plants. The system is in a state of ecological disequilibrium which affects the normal adaptation and functioning of plants.

18. The freeway environment can be separated into an engineering environment and a plant environment. The requirements of both are inversely related and frequently incompatible.

19. The use of plating soil may not always be necessary provided that the material left as the root zone strictly meets certain chemical and physical criteria.

20. A vegetation survey using ratings based on the conditions along the freeway is a successful means of establishing guidelines to be used in collecting baseline data related to the landscape plants.

21. Landscaping contracts are a key factor in the differences in response of plants in the study area. The contracts do not appear to represent a continuum of time but they do represent environments that have allowed the plants to respond differently.

22. A second factor that influences the response of the plants in the freeway environment is location with respect to direction. Plants on the north side of SR 360 and I-10 responded differently than plants on the south side. These differences may be related to the different slope aspects such as sun exposure and prevailing wind directions.

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Appendix A Review of Literature

TABLE OF CONTENTS

INTRODUCTION

Erosion along highways is detrimental to the slopes, costly to repair, potentially dangerous to passing motorists and aesthetically displeasing. Erosion occurring in an urban freeway is complicated by the urban environment. Narrow right-of-ways can create steep slopes in the cut and fill style freeways used in the Phoenix area. The use of landscaping requires relatively expensive plants which must be maintained by irrigation. Pumps needed to divert water can be damaged by material eroded from nearby slopes.

Solutions to the problem of erosion on urban freeway systems require a combination of practical and theoretical considerations. Field experience and observations must be tempered with a good understanding of the available literature. This literature represents the collective experience of other researchers who have applied their interpretation of theory to various aspects of the erosional problem.

This document was prepared for the purpose of providing a summary of the literature which has the potential to impact the study of erosion on urban freeways. The search for pertinent information was initiated by computer searches completed through the Noble Science and Engineering Library at Arizona State University. Three data bases were searched: CAB (Commonwealth Agricultural Bureau), BIOSIS (Biology Abstracts) and NTIS (National Technical Information Service). Other references were added through the use of published indices such as the Biological and Agricultural Index and by cross referencing literature cited from key articles. This portion of the project was accomplished with the assistance of three graduate students employed on the project: Jiann Jong Liu, Stephanie Calderone, and Ali Banani.

For convenience of use the literature is divided into two parts. Part I represents a general list of articles that were reviewed. It is arranged alphabetically by the last name of the first author. Part II provides abstracts of selected articles.

The abstracts in Part II were chosen by two criteria: 1) the article was representative of the type of information available on the subject or, 2) the article provided information or data which directly supported the scope of this research project. The citations in Part II are grouped by topic and are arranged according to the outline provided in Table 1. Abstracts of articles pertinent to more than one topic are replicated in the respective topics.

As with any literature review, the process is always ongoing. The information provided often adds new dimensions to the research project. In turn, these new dimensions must be further explored. As data from the actual project begins to accumulate, it is compared and interpreted against previous information. This necessitates further exploration of new data and new information. The research team will continue this process throughout the project.

TABLE 1

OUTLINE OF LITERATURE TOPICS FOR PART II

1. <u>SLOPE GEOMETRICAL FACTORS</u>

   a. Slope Angle, Degree of Concavity
   b. Slope Length (Distance Water Travels without a Break)

2. <u>SLOPE SURFACE FACTORS</u>

   a. General Concepts
   b. Soil Properties that Restrict or Enhance Erosion
   c. Slope Moisture State
   d. Slope Surface Materials

3. <u>SLOPE ENVIRONMENTAL FACTORS</u>

   a. General Concepts
   b. Factors that Develop Erosion Stresses on the Slope
   c. Weathering Processes that Impact Slope Erosion Resistance

4. <u>SLOPE CONSTRUCTION FACTORS THAT AFFECT EROSION RESISTANCE</u>

   a. Factors that Affect Surface Conditions
   b. Effectiveness of Initial Slope Treatments

5. <u>STABILIZATION OF SLOPES</u>

   a. Chemical Stabilizers
   b. Mechanical Stabilizers

6. <u>SLOPE SURFACE TREATMENTS</u>

   a. Mechanical Techniques
   b. Chemical Techniques
   c. Vegetative Techniques

TABLE 1 (continued)

7. REVEGETATION OF DISTURBED AREAS

   a. Revegetation of Arid Areas
   b. Types of Plants
   c. Techniques of Revegetation

8. WATER INFILTRATION AND MOVEMENT IN SOILS

   a. General Concepts
   b. Interaction with Soil Properties
   c. Effect of Surface Aggregation and Crusting
   d. Influence of Vegetation

9. WATER HARVESTING

   a. Types of Materials used for Catchment Aprons
   b. Design of Aprons and Basins

10. VEGETATION IN THE ROADSIDE ENVIRONMENT

11. LOW WATER-USE VEGETATION IN ARID AREAS

   a. Landscape Plants
   b. Non-landscape Plants
   d. Environmental Factors Affecting Growth

12. DRIP (TRICKLE) IRRIGATION

   a. Emitters and Layout Design
   b. Use on Landscape Plants

PART I

ALPHABETICAL LISTING OF CITATIONS

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Wischmeier, W.H., and D.D. Smith. 1965. Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains. USDA Agric. Handbook No. 282.

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PART II

CITATIONS AND ABSTRACTS BY TOPIC

1. SLOPE GEOMETRICAL FACTORS

a. Slope Angle, Degree of Concavity

Hart, G. E. 1984. Erosion from Simulated Rainfall on Mountain Rangeland in Utah. J. of Soil and Water Conservation 39 (5).

Simulated rainfall was applied to large runoff plots that were bare or covered with sagebrush and grass. Soil erosion on the vegetated plots was negligible; on the bare plots soil loss averaged 1.9 t/ha from lower intensity rain on dry soil and 16.6 t/ha from higher intensity rain on prewet soil. Antecedent soil moisture condition had a pronounced effect on erosion. The universal soil loss equation greatly overestimated measured loss on dry soils, but was within 13 to 51 percent of measured losses on prewetted plots with a 10 percent slope. Comparison of predicted and measured soil losses on a 32 percent slope suggested that overestimation was due partly to the USLE's slope value.

Meyer, L. D., and E. J. Monke. 1964. Mechanics of Soil Erosion by Rainfall and Greenland Flow. ASAE Paper No. 64-215.

Data were obtained under controlled laboratory conditions using simulated soil, simulated rainfall, and simulated slope length. The particles used were large, spherical, and thus easily detached, so the resulting erosion represents primarily the transportation phase of erosion.

Runoff erosion increased rapidly with increasing slope steepness and length, except at small steepnesses and lengths where essentially no erosion occurred. Smaller particle sizes were more erosive at most slope steepnesses and lengths, but the larger sizes were more erosive at small steepnesses and lengths. Rainfall plus runoff, as compared with runoff alone, increased the erosion of the smaller particle sizes but decreased erosion of the larger sizes.

Modified power equations of the forms, $e_r = C_3 (S-S_c)^m$ and $e_r = C_L (L-L_c)^n$, where $e_r = 0$ when $L < L_c$ and $S < S_c$, better described these erosion phenomena. The critical values were large at small steepnesses and lengths, but decreased to nearly zero at large steepnesses and lengths. Particle diameter, D, was related to runoff erosion as $e_r = C_D^{-0.5}$ at all except the small slope lengths and steepnesses.

Increased sediment availability and runoff carrying capacity, due to raindrop-induced runoff turbulence and splash, were dominant for the more easily transported small particles, whereas decreased carrying capacity of the runoff due to decreased flow velocity from splash leveling of the soil bed and to raindrop-impact dissipation were dominant for the larger sizes.

Smith, D. D., and W. H. Wischmeier. 1957. Factors Affecting Sheet and Rill Erosion. Transactions AGU, Vol. 30.

This paper discusses the two principal processes by which sheet erosion occurs and the six factors which effect the magnitude of the losses. The processes are raindrop impact and transportation of soil particles by flowing water. The factors are length and percent slope, cropping, soil, management and rainfall. The relative effectiveness of each of the three main conservation practices in control of erosion, contour farming, strip cropping, and terracing is presented. The factors and practices are combined in a rational erosion equation for calculating field soil loss for use in application of conservation practices and in assessing land program benefits.

Zingg, A. W. 1940. Degree and Length of Land Slope as it Affects Soil Loss in Runoff. Ag. Eng. Vol. 21.

Available data on soil loss in runoff from degree and horizontal length of land slope experiments were studied by a system of coding. From an average of these coded data it was found that (1) doubling the degree of slope increased the total soil loss 2.80 times, and (2) doubling the horizontal length of slope increased the total soil loss 3.03 times.

An experiment, in which a simulated 20-year frequency rainfall was simultaneously applied to various degrees of slope and horizontal lengths of land slope, was conducted on small plots. For an average of the tests conducted on these plots, the following occurred:

1. Doubling the degree of slope increased the total soil loss in runoff 2.61 times.
2. Doubling the horizontal length of slope increased the total soil loss in runoff 3.03 times.
3. Increasing the degree of slope increased the total runoff.
4. Increasing the length of slope decreased the total runoff.
5. The moisture content of the soil at the completion of the tests showed an inverse relationship to total runoff.

For practical purposes, the rational equation $X = CS^{1.4}L^{1.6}$ will give a relation between total soil loss, degree of slope, and horizontal length of slope which, as a generalization, will be applicable to field conditions. The equation is based upon a limited amount of data which was not developed for the purpose of this study, and when more satisfactory data are available, refinements will undoubtedly be possible.

1. SLOPE GEOMETRICAL FACTORS

b. Slope Length (Distance Water Travels without a Break).

Smith, D. D., and W. H. Wischmeier. 1957. Factors Affecting Sheet and Rill Erosion. Transactions AGU, Vol. 30.

This paper discusses the two principal processes by which sheet erosion occurs and the six factors which effect the magnitude of the losses. The processes are raindrop impact and transportation of soil particles by flowing water. The factors are length and percent slope, cropping, soil, management and rainfall. The relative effectiveness of each of the three main conservation practices in control of erosion, contour farming, strip cropping, and terracing is presented. The factors and practices are combined in a rational erosion equation for calculating field soil loss for use in application of conservation practices and in assessing land program benefits.

Zingg, A. W. 1940. Degree and Length of Land Slope as it Affects Soil Loss in Runoff. Ag. Eng. Vol. 21.

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2. SLOPE SURFACE FACTORS

a. General Concepts

Rogowski, A. S., R. M. Khambiluardi, and D. L. Jones. 1984. Point of Estimates of Erosion. ASAE Paper No. 84-2035.

Abstract not provided. A comparison was made between erosion measured from erosion pins and erosion predicted from a numerical model. Discrepancies between observed and expected values are explained by increases in turbulence and the amount of rain near the pin. For both plots, the erosion measured by erosion pins was 90 to 93 percent higher than that measured by sampling runoff and 92 to 94 percent higher than predicted by the Erosion Deposition Model (EDM). The reasons for this difference were assumed to be the increase in runoff turbulence and wind velocity around the pins. The pins may increase runoff turbulence and therefore create local scour around the pins. The role of vegetation and its potential effects on water runoff were also considered.

Rojiani, K. B., K. A. Tarbell, V. O. Shanholtz, and F. W. Wheste. 1983. Probabilistic Modeling of Soil Loss from Surface Mined Areas. Office of Surface Mines, U.S. Dept. of Interior V[1983-103].

Abstract not provided. A probabilistic model was introduced. Authors believed that a probabilistic approach will give more realistic data from analysis. A regression equation has been derived which has been proved to be extremely close to actual data. In a three-year study, silt and silt loam types of soil were found to have a normal distribution pattern for sediment yield, but sandy loam had a log normal distribution. The limitation of this method is the completeness of the site records for the past events upon which this method relied. A modified USLE was utilized.

Spanner, M. A., A. H. Strahler, and J. E. Estes. 1982. Soil Loss Prediction in a Geographic Information System Format. Papers Selected for Presentation at the 16th International Symp. on Remote Sensing of the Environment. Vol. 1.

Soil loss due to erosion from rainfall was accurately predicted for the Santa Paula 7.5 minute quadrangle, Ventura County, California, utilizing the VICAR/IBIS image processing and geographic information system to simulate the Universal Soil Loss Equation (USLE). This work was part of a NASA funded research project investigation methods of incorporating collateral information in Landsat classification and modelling procedures (NSG-2377), performed at the University of California, Santa

Barbara. Representing the rainfall, soil erodability, length of slope, slope gradient, crop management and soil loss tolerance coefficients of the USLE were data planes generated from digital Landsat data, USGS Digital Elevation Model topographic data, a digitized NOAA isopluvial map and digitized USDA soil conservation service soil maps. The Pearson product moment correlation coefficient, R, of soil loss predicted from the developed geobased model to a sample of manually derived soil losses was .91 after a log transform, significant to the .0001 level. Estimates of accuracy for the intermediate data planes representing the rainfall, soil erodability, length of slope, slope gradient, crop management and soil loss tolerance ranged from a correlation coefficient, R, of .81 for the length of slope to 100 percent for the rainfall coefficient. The soil loss information system accurately targeted soil loss problem areas for subsequent analysis by Soil Conservation Service personnel.

Wischmeier, W. H., and J. V. Mannering. 1969. Relation of Soil Properties to its Erodibility. Soil Science Society of Am. Proc. 33.

A soil's inherent erodibility, which is a major factor in erosion prediction and land-use planning, is a complex property dependent both on its infiltration capacity and on its capacity to resist detachment and transport by rainfall and runoff. The relations of these capacities to soil physical and chemical properties were investigated in a five-year field, laboratory, and statistical study including 55 selected Corn Belt soils. Properties that contributed significantly to soil-loss variance included percentages of sand, silt, clay, and organic matter; pH, structure and bulk density of plow layer and subsoil; steepness and concavity or convexity of slope; pore space filled by air; residual effects of sod crops; aggregation; parent material; and various interactions of these variables. An empirical equation was derived for calculating the universal soil-loss equation's erodibility factor K for specific soils. Tests of the equation against soils of the older erosion-research stations, for which the erodibility factor is known, substantiated its general applicability over a broad range of medium-textured soils.

Wischmeier, W. H., and D. D. Smith. 1958. Rainfall Energy and its Relation to Soil Loss. Transactions, AGU, Vol. 39(2).

A relatively simple procedure is presented for computation of kinetic energy of a rainstorm from information on a recording-raingage chart. An equation is developed describing rainfall energy as a function of rainfall intensity. The effects of rainfall energy and its interaction with other variables are evaluated in multiple regression analyses based on data representing four soil types. Application of this information to separate the effects of rainfall from those of physical and management characteristics in plot data is discussed briefly.

2. SLOPE SURFACE FACTORS

b. Soil Properties that Restrict or Enhance Erosion.

Gillete, D. A. and J. Adams. 1983. Accelerated Wind Erosion and Prediction of Rates. Environmental Effects of Off-Road Vehicles. Springer-Verlag, New York.

Abstract not provided. This paper considers the relationship between threshold velocities while varying soil types and particle distribution. A set of predicting formulas has been suggested. The recommendation to change ORV's riding area from alluvial to bahada, and desert fans to dune areas and playas will greatly reduce the wind erosion which has been accelerated by ORVs.

Grant, W. J., and R. A. Struchtemeyer. 1959. The Influence of the Coarse Fraction of Two Maine Potato Soils on Infiltration, Runoff and Erosion. Soil Science Society Am. Proc. 23.

The influence of the coarse material in Caribou and Thorndike soils on infiltration, runoff and erosion was studied with the use of a laboratory infiltrometer which applied water at 2.5 inches per hour but with energy of impact appreciably less than that in natural rain of the same intensity. Various sized coarse particles were removed from both soils to determine the function of the coarse fraction. There was a significant decrease in the rate of infiltration and likewise an increase in runoff as the particles > 12.7 mm. were removed from both soils. A further decrease in infiltration resulted when all material > 4.76 mm. was removed; however, the fraction between 4.76 mm. and 2.38 mm. did not have a significant effect on infiltration and runoff.

The amount of soil in the runoff from the Caribou sample was found to be nearly proportional to the runoff. It also increased with runoff as the coarse fractions were removed from the Thorndike soil, but there was not a significant increase for the second and third trials.

Lamb, J. Jr., and Chapman, J. E. 1943. Effect of Surface Stones on Erosion, Evaporation, Soil Temperature, and Soil Moisture. Agronomy J. 35.

This study to determine the effect of surface stones on soil erosion and soil moisture was carried out to save many farmers the labor of unnecessary stone removal. Soil and water runoff from field plots was collected and weighed, and soil moisture and soil temperature conditions were noted. Soil in special boxes was weighed to determine the water loss by evaporation from the surface.

The removal of surface stones above two inches largest dimension on field plots approximately doubled the water runoff and increased soil loss as much as six fold.

A 65 percent stone cover compared to the normal 18 percent stone cover over the soil in weighed boxes slightly reduced the loss of soil water by evaporation, increased water absorption, decreased soil loss, and maintained a relatively high water-holding capacity.

A 6-ton per acre straw mulch cover over the soil in weighed boxes reduced the loss of water by evaporation, greatly increased water absorption, prevented soil loss, and maintained a high water-holding capacity.

A 65 percent stone cover on field plots increased soil temperatures and maintained a higher content of soil moisture than the 18 percent stone cover. A 4-inch layer of stones maintained a higher content of soil moisture than the 65 percent stone cover.

A straw mulch of 6 tons per acre gave soil temperatures at 1-inch depth as much as 24°F lower than at similar depths under the 18 percent stone cover.

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Modified power equations of the forms $e_r = C_3 (S-S_c)^m$ and $e_r = C_L (L-L_c)^n$, where $e_r = 0$ when $L < L_c$ and $S < S_c$, better described these erosion phenomena. The critical values were large at small steepnesses and lengths, but decreased to nearly zero at large steepnesses and lengths. Particle diameter, D, was related to runoff erosion as $e_r = C_D D^{-0.5}$ at all except the small slope lengths and steepnesses.

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Nearing, M. A. and J. M. Bradford. 1985. Single Waterdrop Splash Detachment and Mechanical Properties of Soils. Soil Sci. Soc. Am. J. 49.

This study was an assessment of the use of soil mechanical properties to predict soil detachment by single waterdrop impact. Soil mechanical properties were measured on four soils with a triaxial consolidated-undrained compression test and a Swedish fall-cone device. The weight of soil detached was measured for 5.7-mm diameter drops falling a distance of 13 m. The results indicated that strength and pre-failure deformational properties, as measured by the triaxial test alone, were not good predictors of soil resistance to splash. As previously reported, soil splash weight was a linear function of the ratio of waterdrop kinetic energy to fall-cone strength on a per soil basis, but the slope of the line differed among soils. The slopes were, however, greater for soils with greater consolidated, undrained friction angles as determined in the triaxial test and expressed in terms of total stresses. Therefore, the fall-cone strength term was reduced as a function of the triaxial friction angle, and detachment was plotted versus the ratio of raindrop kinetic energy to the corrected fall-cone strength term. The resultant relationship was linear with the same slope for all four soils. This result was explained in terms of our current understanding of the soil splash mechanism. The fall-cone alone predicts the initial splash phase of cavity formation upon impact, but overpredicts the resistance of the soil to subsequent lateral jetting of water.

Rubio-Montoya, D., and K. W. Brown. 1984. Erodibility of Strip-Mine Spoils. Soil Science. 138(5).

Erosion remains one of the greatest problems in reclaiming strip-mine areas. We evaluated the erodibility of spoil samples from lignite-bearing geological deposits along the Gulf Coast, using a rainfall simulator and predictive methods developed for agricultural soils. The materials studied represented a wide range of physical and chemical characteristics. They were subjected to two 100-year 30-min. rainfall events at inclinations of 2, 9, and 18 percent. The eroded and splashed materials were collected and quantified. The topographical factor LS in the universal soil loss equation (USLE) was adjusted to allow extrapolation from small plots to the standard unit plot. The erodibility factor K was thus determined, and the resultant values were compared with those calculated from the physical and chemical properties of the samples by the equation developed by Wischmeier. The comparison indicates that K values estimated from the physical properties of mine spoil are larger than those experimentally determined. The erodibility factor of mine spoil (K_m) may be calculated as

$$K_m = 0.339 K_w^{0.48}$$

where K_w is the erodibility factor estimated from the physical properties of the spoil using the Wischmeier equation.

Wischmeier, W. H., C. R. Johnson, and B. V. Cross. 1971. A Soil Erodibility Monograph for Farmland and Construction Sites. J. Soil and Water Conservation 26.

A new soil particle-size parameter was found and used to derive a convenient erodibility equation that is valid for exposed subsoils as well as farmland. A simple nomograph provides quick solutions to the equation. Only five soil parameters need to be known: percent silt, percent sand, organic matter content, structure, and permeability. The new working tool opens the door to several new considerations in sediment-control planning.

2. SLOPE SURFACE FACTORS

c. Slope Moisture State

Gillete, D. A. and J. Adams. 1983. Accelerated Wind Erosion and Prediction of Rates. Environmental Effects of Off-Road Vehicles. Springer-Verlag, New York.

Abstract not provided. This paper considers the relationship between threshold velocities while varying soil types and particle distribution. A set of predicting formulas has been suggested. The recommendation to change ORV's riding area from alluvial to bahada, and desert fans to dune areas and playas will greatly reduce the wind erosion which has been accelerated by ORVs.

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Simulated rainfall was applied to large runoff plots that were bare or covered with sagebrush and grass. Soil erosion on the vegetated plots was negligible; on the bare plots soil loss averaged 1.9 t/ha from lower intensity rain on dry soil and 16.6 t/ha from higher intensity rain on prewet soil. Antecedent soil moisture condition had a pronounced effect on erosion. The universal soil loss equation greatly overestimated measured loss on dry soils, but was within 13 to 51 percent of measured losses on prewetted plots with a 10 percent slope. Comparison of predicted and measured soil losses on a 32 percent slope suggested that overestimation was due partly to the USLE's slope value.

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This study to determine the effect of surface stones on soil erosion and soil moisture was carried out to save many farmers the labor of unnecessary stone removal. Soil and water runoff from field plots was collected and weighed, and soil moisture and soil temperature conditions were noted. Soil in special boxes was weighed to determine the water loss by evaporation from the surface.

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A straw mulch of 6 tons per acre gave soil temperatures at 1-inch depth as much as 24°F lower than at similar depths under the 18 percent stone cover.

Mutchler, C. K., C. E. Carter. 1983. Soil Erodibility Variation During the Year. Tran. ASAE. 26.

Six years of data from erosion plots at Holly Springs, MS, and 10 years of data from plots at Morris, MN, were used to study variation in soil erodibility through the year. Monthly values of soil erodibility were related to time with a cosine curve. Erodibility varied from a high of 169 percent of annual average K (K of the Universal Soil Loss Equation) on February 4 to a low of 31 percent of annual average on August 5 for the Mississippi data. Minnesota erodibility data were described similarly except the maximum and minimum of the erodibility function lagged the Mississippi curve by about 2 months. It was suggested that erodibility could be predicted using a variability function based on normal air temperature data described by a cosine function and average annual K factor values.

2. SLOPE SURFACE FACTORS

d. Slope Surface Materials

Tarchitzky, J., A. Banin, J. Morin, and Y. Chen. 1984. Nature, Formation and Effects of Soil Crusts Formed by Water Drop Impact. Geoderma 33.

Research was conducted to investigate: (1) the structure, formation and nature of soil crusts which develop as a result of raindrop impact under controlled conditions of simulated rain, and (2) the crust effect on infiltration rates. Scanning electron microscope (SEM) observations performed on sandy, sandy-loam and clayey soil samples show the crust to be composed of two layers: (1) a "skin," 0.1 mm thick, and (2) a layer, 2-3 mm thick, with a higher bulk density in which aggregates have been destroyed. A "washingin" zone described by earlier investigators could not be detected. The soil beneath the crust maintains its original structure and particle orientation. The chemical composition of the rainwater was found to have a significant but not very large effect on the infiltration rate vs. cumulative rain curve of the clayey soil material only; final infiltration rate was about 20 percent lower than distilled water was applied compared to tap water (electrical conductivity ~ 0.6 mmho cm^{-1}). An increase of the bulk density from 1.35-1.48g cm^{-3} in undisturbed soil to 1.74-1.88g cm^{-3} in crusts was found. The amount of eroded material increased gradually with increase of runoff and decrease of infiltration. At steady state the erosion rates were 0.45, 1.25, and 0.76g m^{-2} min^{-1} in the sandy, sandy-loam and clayey soil specimens, respectively. Percentages of clay and silt in the eroded material were higher than in the bulk samples. Three stages to describe the changes in nature and effects of crusts during their formation are suggested: (1) the rate of infiltration decreases to a point at which runoff begins, (2) the initiation of runoff until infiltration and runoff rates become stabilized, and (3) infiltration and runoff maintain steady rates.

3. SLOPE ENVIRONMENTAL FACTORS

a. General Concepts

Rogowski, A. S., R. M. Khambiluardi, and D. L. Jones. 1984. P Point Estimates of Erosion. ASAE Paper No. 84-2035.

Abstract not provided. A comparison was made between erosion measured from erosion pins and erosion predicted from a numerical model. Discrepancies between observed and expected values are explained by increases in turbulence and the amount of rain near the pin. For both plots, the erosion measured by erosion pins was 90 to 93 percent higher than that measured by sampling runoff and 92 to 94 percent higher than predicted by the Erosion Deposition Model (EDM). The reasons for this difference were assumed to be the increase in runoff turbulence and wind velocity around the pins. The pins may increase runoff turbulence and therefore create local scour around the pins. The role of vegetation and its potential effects on water runoff were also considered.

Rojiani, K. B., K. A. Tarbell, V. O. Shanholtz, and F. E. Wheste. 1983. Probabilistic Modeling of Soil Loss from Surface Mined Areas. Office of Surface Mines, U.S. Dept. of Interior V[1983-103].

Abstract not provided. A probabilistic model was introduced. Authors believed that a probabilistic approach will give more realistic data from analysis. A regression equation has been derived which has been proved to be extremely close to actual data. In a three-year study, silt and silt loam types of soil were found to have a normal distribution pattern for sediment yield, but sandy loam had a log normal distribution. The limitation of this method is the completeness of the site records for the past events upon which this method relied. A modified USLE was utilized.

Spanner, M. A., A. H. Strahler, and J. E. Estes. 1982. Soil Loss Prediction in a Geographic Information System Format. Papers Selected for Presentation at the 16th International Symp. on Remote Sensing of the Environment. Vol. 1.

Soil loss due to erosion from rainfall was accurately predicted for the Santa Paula 7.5 minute quadrangle, Ventura County, California, utilizing the VICAR/IBIS image processing and geographic information system to simulate the Universal Soil Loss Equation (USLE). This work was part of a NASA funded research project investigation methods of incorporating collateral information in Landsat classification and modelling procedures (NSG-2377), performed at the University of California, Santa Barbara. Representing the rainfall, soil erodability, length of slope, slope gradient, crop management and soil loss tolerance coefficients of the USLE were data planes generated from digital Landsat data, USGS Digital Elevation Model topographic data, a digitized NOAA isopluvial map and digitized USDA soil conservation service soil maps. The Pearson product moment correlation coefficient, R, of soil loss predicted from the developed geobased model to a sample of manually derived soil losses was .91 after a log transform, significant to the .0001 level. Estimates of accuracy for the intermediate data planes representing the rainfall, soil erodability, length of slope, slope gradient, crop management and soil loss tolerance ranged from a correlation coefficient, R, of .81 for the length of slope to 100 percent for the rainfall coefficient. The soil loss information system accurately targeted soil loss problem areas for subsequent analysis by Soil Conservation Service personnel.

3. SLOPE ENVIRONMENTAL FACTORS

b. Factors that Develop Erosion Stresses on the Slopes

Christensen, B. A. 1982. Prediction of the Risk of Soil Erosion by Flowing Water on Wind. Proc. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation.

The onset of soil erosion depends on the flow characteristics of the eroding medium, water or air, and on the composition of the soil surface being eroded. It must therefore be a stochastic process since both turbulent flow and the composition of natural soils, and man-made granular surfaces for that matter, are of a probabilistic nature.

Costs of construction and insurance are usually functions of the risk of failure. Decreasing risk corresponds to increasing construction cost and decreasing insurance cost. The risk that gives the minimum total cost is the one desired by the designer. To carry out such an optimization the designer must know how to evaluate the risk of erosion of a given soil surface exposed to a given flow. The present paper addresses this problem.

Another design need is a method for determination of the riprap size needed to protect a natural deposit against erosion when the flow condition and the acceptable risk of failure are known. The paper is also treating that problem.

Flow induced drag and lift forces acting on the particles of the topmost layer of the soil surface are evaluated. Based on the time mean values of these forces, the standard deviation of the corresponding turbulent fluctuations and the soil parameters (grain-size, angle of repose, etc.) a formula is developed for the critical shear stress of a horizontal soil surface. Correction factors taking longitudinal slope and bank slope into consideration are presented and incorporated in the development.

By setting this shear stress value, properly corrected for slopes, equal to the actual time-mean value of the bed shear stress at the considered site, an equation is established from which it is possible to calculate the risk of erosion. If, on the other hand, the risk is prescribed, this equation may be solved for the particle size and thus yield the riprap or gravel size that will stabilize the considered bed or embankment with the chosen risk of failure.

Cohesionless, uniform and nonuniform soils are considered.

Cole, G. W., L. Lyles, L. J. Hagen. 1984. A Simulation Model of Daily Wind Erosion Soil Loss. Trans. ASAE. 26(6).

EPIC's (Erosion Productivity Impact Calculator) wind erosion submodel is described in terms of the equations and concepts needed for interfacing the wind erosion equation with EPIC. The required equations are presented following an analysis of the wind erosion equation literature which shows how the wind erosion equation was developed from short-term data. This analysis is based on viewing the soil loss as a time and space integration of a surface soil flux. The wind erosion equation is then partitioned into those parts that represent the short-term effects and the integration process. From this it is seen how one might ideally modify the wind erosion equation. The analyses point the way for future improvements in soil loss prediction equations. The results of the five 50-year simulations are also presented.

Gillete, D. A. and J. Adams. 1983. Accelerated Wind Erosion and Prediction of Rates. Environmental Effects of Off-Road Vehicles. Springer-Verlag, New York.

Abstract not provided. This paper considers the relationship between threshold velocities while varying soil types and particle distribution. A set of predicting formulas has been suggested. The recommendation to change ORV's riding area from alluvial to bahada, and desert fans to dune areas and playas will greatly reduce the wind erosion which has been accelerated by ORVs.

Smith, D. D., and W. H. Wischmeier. 1957. Factors Affecting Sheet and Rill Erosion. Transactions AGU, Vol. 30.

This paper discusses the two principal processes by which sheet erosion occurs and the six factors which effect the magnitude of the losses. The processes are raindrop impact and transportation of soil particles by flowing water. The factors are length and percent slope, cropping, soil, management and rainfall. The relative effectiveness of each of the three main conservation practices in control of erosion, contour farming, strip cropping, and terracing is presented. The factors and practices are combined in a rational erosion equation for calculating field soil loss for use in application of conservation practices and in assessing land program benefits.

Tarchitzky, J., A. Banin, J. Morin, and Y. Chen. 1984. Nature, Formation and Effects of Soil Crusts Formed by Water Drop Impact. Geoderma 33.

Research was conducted to investigate: (1) the structure, formation and nature of soil crusts which develop as a result of raindrop impact under controlled conditions of simulated rain, and (2) the crust effect on infiltration rates. Scanning electron microscope (SEM) observations performed on sandy, sandy-loam and clayey soil samples show the crust to be composed of two layers: (1) a "skin," 0.1 mm thick, and (2) a layer, 2-3 mm thick, with a higher bulk density in which aggregates have been destroyed. A "washingin" zone described by earlier investigators could not be detected. The soil beneath the crust maintains its original structure and particle orientation. The chemical composition of the rainwater was found to have a significant but not very large effect on the infiltration rate vs. cumulative rain curve of the clayey soil material only; final infiltration rate was about 20 percent lower than distilled water was applied compared to tap water (electrical conductivity ~ 0.6 mmho cm^{-1}). An increase of the bulk density from 1.35-1.48g cm^{-3} in undisturbed soil to 1.74-1.88g cm^{-3} in crusts was found. The amount of eroded material increased gradually with increase of runoff and decrease of infiltration. At steady state the erosion rates were 0.45, 1.25, and 0.76g m^{-2} min^{-1} in the sandy, sandy-loam and clayey soil specimens, respectively. Percentages of clay and silt in the eroded material were higher than in the bulk samples. Three stages to describe the changes in nature and effects of crusts during their formation are suggested: (1) the rate of infiltration decreases to a point at which runoff begins, (2) the initiation of runoff until infiltration and runoff rates become stabilized, and (3) infiltration and runoff maintain steady rates.

Wischmeier, W. H., and D. D. Smith. 1958. Rainfall Energy and its Relation to Soil Loss. Transactions, AGU, Vol. 39(2).

A relatively simple procedure is presented for computation of kinetic energy of a rainstorm from information on a recording-raingage chart. An equation is developed describing rainfall energy as a function of rainfall intensity. The effects of rainfall energy and its interaction with other variables are evaluated in multiple regression analyses based on data representing four soil types. Application of this information to separate the effects of rainfall from those of physical and management characteristics in plot data is discussed briefly.

3. SLOPE ENVIRONMENTAL FACTORS

c. Weathering Processes that Impact Slope Erosion Resistance

Reeve, I. J., and N. S. W. Armidale. 1982. A Splash Transport Model and its Application to Geomorphic Measurement. Zeitschrift Geomorphologie. Vol. 26(1).

A model of the process of transport of soil particles by rainsplash is developed from a consideration of basic drop impact mechanisms. The model enables the rate of splash transport on a slope to be expressed in terms of the initial angle of elevation and velocity of splashed particles, and the surface slope. The empirical relationship, determined by various workers in the past, that the percentage of particles transported downslope is 50 + % slope, is verified by the model and shown to be a function of the initial angle of elevation of splashed particles. The model is also used to assess field and laboratory methods of splash transport measurement by comparing the predicted rate of splash transport with that determined by measurement. It is found that total splash loss from laboratory samples, and the catch in field splash funnels, are unrelated to the splash transport rate according to the model; and that relationships between total splash loss (or funnel catch) and surface slope are affected by sample (or funnel) size and geometry. Modifications to measurement methods have overcome these problems are proposed.

4. SLOPE CONSTRUCTION FACTORS THAT AFFECT EROSION RESISTANCE

a. Factors that Affect Surface Conditions

Free, G. P. 1953. Compaction as a Factor in Soil Conservation. Soil Science Society. Am. Proc. 17.

The results of recent studies in New York of soil compaction as related to infiltration and percolation of water are presented and discussed.

By using treatments affecting the amount of surface compaction occurring under natural rainfall, the ratio of infiltration to runoff for one soil was varied over a range of 300 to 600 percent. Compaction and permeability of another soil within and below plow depth was shown to be related to traffic and other factors of soil and crop management. Some of the broad aspects of the soil compaction problem are discussed.

Liu, Hon-ho. 1972. Rain Erosion Control of Compacted Soils. Unpublished Master's Thesis. Department of Civil Engineering. The University of Arizona, Tucson.

The effects of concentration of nine stabilizers and curing time on the rainwater erodibility of three compacted clay-sand mixtures using simulated rainfall through a laboratory study were investigated. Temperature effects on curing were also considered with one of the soil mixtures. An extensive literature survey on the mechanisms and factors involved in rainfall soil erosion is presented. Details of laboratory procedure and testing using the "Rotadisk Rainulator" are also given. Data relating cost and effectiveness are compiled for comparison purposes. It was found that Cement, Petroset-SB and Formula 125 are the most promising stabilizers in rainfall soil erosion control from the study.

4. SLOPE CONSTRUCTION FACTORS THAT AFFECT EROSION RESISTANCE

b. Effectiveness of Official Slope Treatments

Liu, Hon-ho. 1972. Rain Erosion Control of Compacted Soils. Unpublished Master's Thesis. Department of Civil Engineering. The University of Arizona, Tucson.

The effects of concentration of nine stabilizers and curing time on the rainwater erodibility of three compacted clay-sand mixtures using simulated rainfall through a laboratory study were investigated. Temperature effects on curing were also considered with one of the soil mixtures. An extensive literature survey on the mechanisms and factors involved in rainfall soil erosion is presented. Details of laboratory procedure and testing using the

"Rotadisk Rainulator" are also given. Data relating cost and effectiveness are compiled for comparison purposes. It was found that Cement, Petroset-SB and Formula 125 are the most promising stabilizers in rainfall soil erosion control from the study.

5. STABILIZATION OF SLOPES

a. Chemical Stabilizers

Kinter, E. B. 1975. Development and Evaluation of Chemical Soil Stabilizers. Federal Highway Administration, Offices of Research and Development, Report No. FHWA-RD-75-17.

A study of chemical stabilization of soils began in 1954 with a program enlisting the aid of chemical industry in the search for effective chemicals. Nineteen firms signed a letter of agreement, and others cooperated on an informal basis. Federal participation consisted mainly of consultation, instruction, development of suitable laboratory evaluation test procedures, and review of test results furnished by cooperators. A number of chemicals, notably phosphoric acid, PDC, Terbec, lignins and quaternary amines, were proposed and evaluated in laboratory and field tests. Many others were given limited examination and laboratory testing.

At about 1965, industry's interest shifted largely toward chemicals affecting compaction and moisture-density relationships of soils. Several proprietary compaction aids were evaluated by laboratory tests and one was the subject of field testing. A report on laboratory evaluation of two compaction aids has been prepared.

No single chemical or combination of chemicals has been found acceptably effective or economical as a major soil stabilizer. However, further work with phosphoric acid and phosphates may make use of some of these substances possible. Prospects are promising for chemicals to improve moisture-density relationships and to supplement or enhance the effects of the major stabilizers, lime and portland cement.

Morrison, W. R. 1985. U.S./U.S.S.R. Joint Studies on Soil Stabilizers for Erosion Control. Proc. of Conference XVI. International Erosion Control Assoc. San Francisco, CA.

The U.S./U.S.S.R. Joint Studies on Soil Stabilizers for Erosion Control was made possible by the Soviet-American Joint Commission on Scientific and Technical Cooperation Program, signed at Moscow, May 1972. Under the joint study, soil stabilizers produced in both countries were exchanged for evaluation. The evaluation included both laboratory and field studies. The laboratory portion was conducted to document the physical characteristics of soils treated with stabilizing polymers. Also, greenhouse testing was performed to evaluate the effect of soil stabilizers on vegetation establishment and growth. The field studies were conducted at several sites in both countries to determine the performance of the stabilizers under different soil and climatic conditions. This paper summarizes the joint study conducted from 1975 through 1982.

5. STABILIZATION OF SLOPES

b. Mechanical Stabilizers

Carroll, R. G., Jr. 1985. ECRM - The Natural Alternative for Erosion Control. Proc. of Conf. XVI. International Erosion Control Assoc. San Francisco, CA.

ECRM is the acronym for erosion control and revegetation mat(s) . . . a new concept in erosion control product and technology that offers a cost-effective alternative to rip-rap and paved linings. ECRM is especially designed for erosion control and revegetation in those areas where simple mulching techniques do not work because of severe erosive forces, e.g., steep slopes, ditches, and banks.

The primary functions of ECRM are temporary erosion control, mulching, and permanent erosion control. The optimum ECRM product to serve these functions is a three-dimensional web of bonded monofilaments, that provides a flexible ground armor to resist erosion while allowing natural vegetation to establish.

This paper discusses product and application technology for ECRM including functions, important properties, applications, benefits over conventional erosion control alternatives, generic specifications, and installation guidelines.

Martin, J. S. 1985. Use of Silt Fences for Control of Sediment Run-off. Proc. of Conference XVI. International Erosion Control Assoc. San Francisco, CA.

Construction activity can generate significant quantities of sediment even when the best erosion control practices are utilized. Traditional forms of sediment control such as hay and straw bale barriers often do not adequately control sediment produced under low flow conditions. Silt fence sediment control systems, however, have been field proven to provide a low cost, high efficiency means of retaining sediment from sheet flow construction site run-off.

Silt fences are manmade vertical barriers composed of synthetic fabric and posts (see Figure 1). A wire or synthetic backing is sometimes used to provide extra support. The fabric is designed to trap a large portion of sediment run-off by functioning as a filter and a velocity check. Because silt fence fabrics are permeable, storm water run-off will pass through the material at a controlled rate. This fabric feature allows the effects of downstream storm water damage to be minimized.

The silt fence concept represents the state-of-the-art in construction site sediment control. This paper highlights the performance advantages of silt fences and provides easy guidelines for their installation and use.

6. SLOPE SURFACE TREATMENTS

a. Mechanical Techniques

Beedlow, P. A., L. L. Cadwell, and M. C. McShane. 1983. Design Surface Covers: An Approach to Long-Term Waste Site Stabilization. Department of Energy NTIS Report: PNL-SA-11174.

The wide range of existing environmental conditions, potential contaminants and available cover materials at waste disposal sites necessitates site-specific designing of surface covers for effective long-term erosion resistance. This paper presents a systematic approach to designing surface covers for hazardous waste repositories that can be tailored to conditions at any site. The approach consists of three phases: 1) an assessment, during which the degree of required surface protection (erosion potential) is determined; 2) a preliminary design that integrates surface cover design with the need to minimize transport of contaminants; 3) a final design, where the cost and effectiveness of the surface cover are determined.

6. SLOPE SURFACE TREATMENTS

b. Chemical Techniques

Forsyth, R. A. 1973. Erosion Control of Uncemented Sands. Transportation Laboratory Technical Report TL-1139A-142-73-34. Sacramento, CA.

This study was made to determine the effectiveness of several temporary erosion control materials and to evaluate their effect on the development of the permanent vegetative cover.

The treatments tested include elastomeric polymers, copolymers, and two types of excelsior blankets. The best results were obtained with an excelsior blanket. It appears that chemicals, if applied at the proper rate, will perform as well as the excelsior, will be less expensive without posing the initial fire hazard of the excelsior. No treatment appeared to significantly affect the development of vegetation.

6. SLOPE SURFACE TREATMENTS

c. Vegetative Techniques

Barnett, A. P., E. G. Diseker, and E. C. Richardson. 1967. Evaluation of Mulching Methods for Erosion Control on Newly Prepared and Seeded Highway Backslopes. J. Agronomy 59.

Evaluation of several mulching methods used by different highway departments showed that 2 tons of grain straw per acre provided adequate protection to newly prepared and seeded 2 1/2:1 backslopes when subjected to 1-year frequency storms, 1.3 inches of rain in 30 minutes. However, when subjected to a 10-year frequency storm, 2.7 inches in 60 minutes, two treatments stood out as superior. These were "whisker dams," called the Florida method, which permitted 41 percent runoff and 10 tons per acre soil loss; and surface mulch, called the Cartersville method, which permitted 40 percent runoff and 11 tons per acre soil loss.

In all cases where asphalt spray was a part of the treatment, the effectiveness of mulch was decreased when tested by the 10-year frequency storm. Runoff and soil loss from mulch and mulch plus asphalt were 1.1 inches and 11 tons per acre and 1.3 inches and 3.2 tons per acre, respectively. Mulch mixed and mulch mixed plus asphalt were the same--1.3 inches and 27 tons per acre--indicating that the asphalt had no beneficial effect.

The California method was a checkerboard arrangement of straw pressed into the surface. This treatment was inferior to the "whisker dams" because the staggered arrangement permitted more soil transport by overland flow. Runoff and soil loss for these two treatments were 1.2 inches and 44 tons per acre and 1.1 inches and 10 tons per acre, respectively.

Bare, unprotected backslopes eroded at the rate of 97 tons per acre and permitted 62 percent runoff. Six months or more after planting, satisfactory stands had been established with all mulch treatments.

Beedlow, P. A., L. L. Cadwell, and M. C. McShane. 1983. Design Surface Covers: An Approach to Long-Term Waste Site Stabilization. Department of Energy NTIS Report: PNL-SA-11174.

The wide range of existing environmental conditions, potential contaminants and available cover materials at waste disposal sites necessitates site-specific designing of surface covers for effective long-term erosion resistance. This paper presents a systematic approach to designing surface covers for hazardous waste repositories that can be tailored to conditions at any site. The approach consists of three phases: 1) an assessment, during which the degree of required surface protection (erosion potential) is determined; 2) a preliminary design that integrates surface cover design with the need to minimize transport of contaminants; 3) a final design, where the cost and effectiveness of the surface cover are determined.

Bengson, S. A. 1985. ASARCO's Revegetation of Mill Tailings and Overburden Wastes from Open-Pit Copper Mining Operations in Arizona. Proceedings of Second Annual Meeting of American Society for Surface Mining and Reclamation. Denver, CO. Oct. 1985.

Revegetation of mining wastes, especially in an arid environment is a difficult task. This paper describes the problems encountered and techniques developed by Asarco to solve those problems. By using the proper revegetation techniques, Asarco has successfully revegetated over 160 acres of mill tailings and overburden waste slopes in southern Arizona.

Carroll, R. G., Jr. 1985. ECRM - The Natural Alternative for Erosion Control. Proc. of Conf. XVI. International Erosion Control Assoc. San Francisco, CA.

ECRM is the acronym for erosion control and revegetation mat(s). . . a new concept in erosion control product and technology that offers a cost-effective alternative to rip-rap and paved linings. ECRM is especially designed for erosion control and revegetation in those areas where simple mulching techniques do not work because of severe erosive forces, e.g., steep slopes, ditches, and banks.

The primary functions of ECRM are temporary erosion control, mulching, and permanent erosion control. The optimum ECRM product to serve these functions is a three-dimensional web of bonded monofilaments, that provides a flexible ground armor to resist erosion while allowing natural vegetation to establish.

This paper discusses product and application technology for ECRM including functions, important properties, applications, benefits over conventional erosion control alternatives, generic specifications, and installation guidelines.

Koon, D. L. and D. H. Graves. 1981. Cost Analysis for Several Mulching Systems Used in Surface-Mine Reclamation in Eastern Kentucky. Transportation Res. Record 805. Nat. Academy of Sciences.

Several mulching agents were evaluated for their economic feasibility and revegetative responses on surface mines in eastern Kentucky. The most widely used soil amendments are wood fiber mulches. Wood fiber mulch, along with a seed and fertilizer mixture, is suspended in water for a one-step revegetative effort. Alternative mulches, such as processed municipal waste, bark, general sawmill residues, and straw and hay with asphalt binders, were evaluated for their economic feasibility. Each mulching system's equipment, labor, and daily area of application were evaluated. Costs per acre indicated that processed bark was the least expensive to apply on outslopes and hollow fills. The machinery for applying mill residue was more complex and required that the mulch be processed before its application with a truck-mounted thrower unit. In the two most heavily mined regions of eastern Kentucky, bark resources were available in sufficient quantity to revegetate 2956 acres annually at the recommended rate of 45 yd^3/acre. Almost all these mill residues required processing to improve quality, reduce equipment breakage, and increase ease of handling.

7. REVEGETATION OF DISTURBED AREAS

a. Revegetation of Arid Areas

Bengson, S. A. 1985. ASARCO's Revegetation of Mill Tailings and Overburden Wastes from Open-Pit Copper Mining Operations in Arizona. Proceedings of Second Annual Meeting of American Society for Surface Mining and Reclamation. Denver, CO. Oct. 1985.

Revegetation of mining wastes, especially in an arid environment is a difficult task. This paper describes the problems encountered and techniques developed by Asarco to solve those problems. By using the proper revegetation techniques, Asarco has successfully revegetated over 160 acres of mill tailings and overburden waste slopes in southern Arizona.

Clairy, R. F. Jr. 1983. Planting Techniques and Materials for Revegetation of California Roadsides. Report No. FHWA/USDA-LMPC-2. USDA-Soil Conservation Service, Davis, CA.

Plots of herbaceous and woody plant materials were established at six locations in the Mojave Desert. Grasses, legumes and shrubs were evaluated for survival, erosion control and esthetics. Woody plants were mainly native species. Plantings were also made on problem soils (serpentine soils, high boron soils, high and low pH soils) to determine suitable plants for use under adverse growing conditions. The rate of natural woody plant invasion onto cut and fill slopes was studied at over 100 sites in the Sierra Nevada Mountains, Sierra Nevada Foothills and Mojave Desert. Slopes of different ages were inventories to determine the type of slope most receptive to plant invasion as well as the rate at which woody plants revegetate naturally. Plots established during the 1970-75 cooperative CALTRANS-SCS study were evaluated to note changes in plant performance that could influence current seeding and planting recommendations. A revised seeding guide is included.

Ludeke, K. L. 1970. Vegetative Stabilization of Tailings Disposal Berms. Unpublished Report.

Pima Mining Co. has voluntarily attempted to stabilize copper tailing berms in Arizona. The program involved evaluating plant types suited to harsh environments and steep slopes of berms. Plants included shrubs, cacti and other desert plants, and grasses, forbes and legumes. Mesquite, palo verde, ironwood, desert broom, creosote bush, hopseed bush, lovegrass, bermudagrass and saltbush have been successfully grown. Utilization of hydroseeding with mulch and chemicals (Soil Seal) was effective but costly.

Yamamoto, T. 1982. A Review of Uranium Spoil and Mill Tailings Revegetation in the Western United States. General Technical Report RM-92. USDA-Forest Service.

The following aspects of uranium mine and mill tailing management are reviewed and discussed: (1) the history of the uranium remedial action program, (2) magnitude of the uranium spoils problem, (3) uranium deposits, mining, and milling, (4) status of reclamation, (5) problems in revegetation of uranium spoils and tailings, and (6) health and safety considerations.

7. <u>REVEGETATION OF DISTURBED AREAS</u>

b. Types of Plants

Kay, B. L. 1985. Plant Choice Determines Soil Loss. Proceedings of Conference SVI. International Erosion Control Association. San Francisco, CA.

Commonly used erosion control plants were compared for effectiveness in retaining soil on inclined surfaces under artificial rainfall. Annual grasses consistently gave the best protection. Introduced perennial grass, flowers, and annual legumes were not as effective as annual grass. Native perennial grass or shrubs did not retain a significant amount of soil until the end of the growing season.

Soil retention is highly correlated with the amount of ground cover presented by the plants. Annual grasses were the fastest growing and thus retained the most soil. Straw mulch was shown to give excellent protection until the annual grasses became effective. The measurement of ground cover in the early growing season is suggested as the best criterion for selecting effective erosion control plants.

Morrison, D. G. 1981. Use of Prairie Vegetation on Disturbed Sites. Transportation Res. Record 822. Nat. Academy of Sciences.

Interest and activity in the use of native prairie vegetation on disturbed sites have increases in the past decade. The primary objective in this paper is to summarize and document the observations and experiences of researchers who have studied prairies, prairie vegetation, and prairie-restoration techniques. Particular emphasis is placed on design and implementation techniques that might be applied in the design and establishment of prairie vegetation on relatively large land areas, such as those associated with transportation rights-of-way. Quantitative and qualitative analyses of natural prairie stands as models for prairie plantings on disturbed sites are presented (e.g., species density, plant distribution patterns, and resulting aesthetic effects). Design implications for prairie restorations are drawn from these observations. An example of a sizable prairie-restoration project on a construction site is presented. Its success after six growing seasons is evaluated relative to the original design objectives of developing a prairielike vegetational cover on a corporation headquarters site with a low maintenance requirement. It is assessed in terms of prairie species presence and distribution, presence of exotic species, and visual similarity to natural prairie stands.

Thornburg, A. A. 1982. Plant Materials for Use on Surface-Mined Lands in Arid and Semiarid Regions. EPA 600/7-79-134. Soil Conservation Service.

This publication describes the characteristics, areas of adaptation, and performance of plant materials for mine spoils. General guidance is given for species selection, use, establishment, availability, and management techniques. Many of the plants described as named cultivars have been released by SCS cooperatively with state agricultural experiment stations or other agencies. Many varieties are in commercial production and are available for use. Other plants are named that have shown promise or are believed to have potential for use on surface-mined lands in arid and semiarid areas.

USDA-Forest Service. 1979. User Guide to Vegetation, Mining and Reclamation in the West. Intermountain Forest and Range Exp. Stn. General Tech. Report INT-64.

The vegetation specialist working on mined land must be aware of potential impacts of mining, as well as reclamation techniques available to him. This guide covers major points of concern to the vegetation specialist involved in planning for reclamation of mined land, including: exploration and baseline data; species selection, plant materials; site preparation;

planting methods; cultural treatments; and post-mining management plan and monitoring.

Information is presented in a question/rule/discussion format, and includes supporting graphic material, notes on additional sources of information, a glossary, and an index.

7. REVEGETATION OF DISTURBED AREAS

c. Techniques of Revegetation

Beedlow, P. A., L. L. Cadwell, and M. C. McShane. 1983. Design Surface Covers: An Approach to Long-Term Waste Site Stabilization. Department of Energy NTIS Report: PNL-SA-11174.

The wide range of existing environmental conditions, potential contaminants and available cover materials at waste disposal sites necessitates site-specific designing of surface covers for effective long-term erosion resistance. This paper presents a systematic approach to designing surface covers for hazardous waste repositories that can be tailored to conditions at any site. The approach consists of three phases: 1) an assessment, during which the degree of required surface protection (erosion potential) is determined; 2) a preliminary design that integrates surface cover design with the need to minimize transport of contaminants; 3) a final design, where the cost and effectiveness of the surface cover are determined.

Bennett, F. W. and R. L. Donahue. Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities. EPA-44019-75-006.

The Environmental Protection Agency is issuing this manual on "Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities," to assist the user in establishing protective stands of perennial vegetation on soils disturbed by all types of construction activities. The vegetative cover will prevent sediment runoff and thus minimize water pollution.

To quickly establish good vegetative cover on any soil of low productivity, one must know the climate; geological identification of parent material and the characteristics of the overlying soil; the biological factors of seed and plant selection, fertilizing, seedbed preparation, timely seeding, mulching, and perhaps irrigating. Establishment of vegetation can be most successful when conditions for plant growth are considered during the planning, designing, and construction stages of all soil-disturbing activities.

Chan, F. J. 1985. Vegetation Establishment. Proceedings of Conference XVI International Erosion Control Association. San Francisco, CA.

Fundamental concepts of a revegetation program will be examined in relation to achieving results and fulfilling regulatory requirements. The engineering/technical horticultural requirements will be discussed identifying goals and objectives of a revegetation project as well as the role of applied research at difficult sites. The discussion will include the nature of revegetation projects, special requirements, site problems, plant materials, planting methods, project time frame, recordkeeping, and reasonable costs. The effectiveness of nonirrigated plantings will be discussed in relation to the desired level of results to be achieved.

The concept and philosophy of revegetation is extended to conventional landscape applications in the hope of conserving water and to enhance the capabilities of the landscape industry to meet the future challenges in vegetation establishment and management.

Packer, P. E., and E. F. Aldon. 1978. Revegetation Techniques for Dry Regions. Chap. 24. Reclamation of Drastically Disturbed Lands. Am. Society Agronomy.

Abstract not provided. This article provides a general overview of revegetation with particular reference to the arid southwest. Much of the discussion centers on coal mining problems but in Section III, Part B discusses plant establishment in the southwest deserts. Topics include amendments for revegetation, mulches, fertilizers, seeding methods, planting methods, and supplement irrigation needs.

8. <u>WATER INFILTRATION AND MOVEMENT IN SOILS</u>.

a. General Concepts

Baver, L. D., W. H. Gardner, and W. R. Gardner. 1972. Soil Water - The Field Moisture Regime. Chap. 10. Soil Physics. Wiley and Sons.

Abstract not provided. This chapter provides a general discussion of the principles and equations involved in soil water relations. It contains an excellent section on the theory of water infiltration into soils, including infiltration when rainfall is limiting and in two and three dimensions.

Hillel, D. 1982. Infiltration and Surface Runoff. Chapt. 12. Introduction to Soil Physics. Academic Press.

Abstract not provided. This general textbook of soil physics provides a good discussion of the most current theory of water infiltration into soils and surface runoff. Topics covered include infiltrability, profile moisture distribution during infiltration, infiltrability equations, basic infiltration theory, infiltration into layered profiles, infiltration into crust-topped soils, rain infiltration, and surface runoff.

Klute, A. 1973. Soil Water Flow Theory and its Application in Field Situations. SSSA Special Publication #5. Soil Science Society Am.

The soil water flow theory based on the Darcy equation provides a first approximation to the description and prediction of soil water behavior. Solute-water and heat-water interactions may in some situations produce significant deviations from the Darcy-based flow theory. Methods of application of flow concepts range from their use as general, qualitative background, through various approximate uses of flow equations, to full-scale detailed prediction of the behavior of a given field flow situation. The latter is not generally feasible because of the cost and lack of the detailed knowledge of the pertinent hydraulic properties of the soil. The lack of rapid, reliable, routine methods of assessing the water flow properties of soils, and the difficulties of coping with the spatial and temporal variability of these properties are important barriers to the quantitative application of the flow theory.

8. WATER INFILTRATION AND MOVEMENT IN SOILS.

b. Interaction with Soil Properties

Akram, Mohd and W. D. Kemper. 1979. Infiltration of Soils as Affected by the Pressure and Water Content at the Time of Compaction. Soil Science Society Am. J. 43.

Infiltration rates, volume reduction, and bulk densities of soils were determined on soils as a function of compacting pressures and water content at the time of compaction.

Maximum compaction generally occurred when the soils were packed at water contents near field capacity.

When compacting loads were < 1 kg/cm^2 the minimum bulk densities occurred when soils had water contents of about one half field capacity, indicating that surface tension of water films in the soils plays a major role in cohesiveness and stabilization against compaction under these conditions.

Compacting loads of 3.46 kg/cm^2, at field capacity on sandy loams and finer textured soils, reduced infiltration rates to < 0.1 percent of values obtained after these soils had been compacted when they were air dry. In a loamy sand soil this reduction was to about 1 percent.

The low infiltration rates following compaction were increased by wetting and drying, although several cycles of wetting and drying did not raise the infiltration rate to the level observed before packing.

The large changes in infiltration rates using achievable levels of compaction at the "optimum" water contents indicate that compaction can play a major role in the management of water in ditches, reservoirs, furrows, and watersheds.

Miller, D. E. 1973. Water Retention and Flow in Layered Soil Profiles. SSSA Special Publication #5: Field Soil Water WaterRegime. Soil Science Society Am.

In general, any profile discontinuity that affects pore size distribution will decrease water movement across the discontinuity boundary compared with a uniform profile. If the profile contains a layer less permeable to water than the soil above, water can be transmitted through the soil more rapidly than through the layer and may accumulate above the layer. A coarse layer has a high saturated conductivity, but it ceases to transmit significant amounts of water at relatively low suctions. Thus, the suction in soil above a coarse layer will be lower and the water content higher than in a nonlayered soil. The water retained in soil above a coarse layer is determined by the coarseness of the layer, depth to the layer, and desorption characteristics of the soil. The effects of coarse and slowly permeable layers are similar in that suction distributions are dominated by the nature and position of the layer, and water contents above the layer are related to soil desorption characteristics.

Nutter, W. D. 1973. The Role of Soil Water in the Hydrologic Behavior of Upland Basins. SSSA Special Publication #5: Field Soil Water Regime. Soil Science Society Am.

The distribution of soil water in upland basins greatly affects the extent of source areas and the response patterns of both storm and between-storm streamflow. Except during the most extreme storms, all the precipitation falling on well-vegetated slopes infiltrates and while some reappears in the channel as stormflow, a major portion of the rain remains in the basin as dynamic storage. During a storm, the stormflow source area expands out from the stream channel as slopes contribute primarily unsaturated subsurface flow and the channel system lengthens. After the storm ceases, source areas may continue to expand as subsurface flow feeds the lower slopes near the channel, often leading to a second hydrograph peak several hours or days after the rain ceases. As the channel system and source areas recede, unsaturated subsurface flow continues to sustain baseflow. Basin parameters that affect the soil water regime and associated soil water energy conditions, and therefore the distribution of source areas, are slope length from channel to ridge, angle of slope, regolith depth, and regolith physical properties. Physical models of hillslope segments have provided some insight into the interrelations among the basin parameters as well as the flow pathways and source areas of subsurface flow.

8. WATER INFILTRATION AND MOVEMENT INTO SOILS.

c. Effect of Surface Aggregation and Crusting

Epstein, E. and W. J. Grant. 1967. Soil Losses and Crust Formation as Related Some Soil Physical Properties. Soil Science Society Am. Proc. 31.

Soil loss curves of six soil types were obtained using a laboratory rainfall simulator. During the first ten minutes of rainfall, soil losses increased to a maximum and then decreased sharply for the Marshall silty clay loam. Dunkirk silt loam, Caribou loam, and Nicholville silt loam soils. There was no peaking effect with the Hartland sandy loam and Winooski silt loam soils and the rate of soil loss was constant after ten minutes. A linear relationship was obtained between clay content and soil loss during the 5- to 10-min. period. Detailed studies on the Dunkirk and Winooski soils suggest that the peaking effect may be due to the rate and extent of crust formation in the early stages of rainfall wetting. Bulk density of the 0- to 5-mm layer increased from 1.15 to 1.65 g/cc for the Dunkirk soil and from 0.83 to 1.14 g/cc for the Winooski. The amount and distance of splash from a Caribou soil was measured using two drop sizes, 5.1 mm and 3.2 mm. Splash soil losses from the soil pans for the six soils was as much as three to four times those found in the runoff water.

Hardy, N., I. Shainberg, M. Gal, and R. Kern. 1983. The Effect of Water Quality and Storm Sequence Upon Infiltration Rate and Crust Formation. J. Soil Science 34.

The effect of applications of distilled water (DW) and saline water (SW) (EC: $5.0 dSm^{-1}$) upon the infiltration rates (IR) of crusted soil surfaces was studied using a rain simulator. A sandy loam and silt loam were placed in trays at a slope of 5 percent. The soils were pre-wet before each storm and a water table maintained at a depth of 5 cm. IR losses due to crust formation during storms of DW could be reversed by the use of SW in subsequent storms. A minor increase in IR was obtained in the silty loam soil, the crust of which stayed entire during successive rainstorms. Complete reversibility of IR was possible in the sandy loam, the crust of which was destroyed and reformed due to rainfall impact during each successive storm.

The cohesion of the particles in the crusted silty loam soil was sufficient to render it resistant to raindrop impact, but cohesion between the particles of the sandy loam was insufficient to prevent reworking by rainfall impact during each storm. Crust formation therefore occurs in each storm in the sandy loam and the IR obtained is a consequence of the EC of the applied water of that storm only.

Hartmann, R. and M. deBoodt. 1984. Infiltration and Subsequent Evaporation from Surface-Aggregated Layered Soil Profiles Under Simulated Laboratory Conditions. Soil Science 137.

Improving the aggregate stability of a 2-cm deep surface layer, effected by treatment with a polyurea soil conditioner, significantly increased the water infiltration during simulated rainfall and substantially reduced the evaporation.

For the same potential evaporation rate of 5 mm day^{-1}, differences in total mean water loss occurred due to different climatic conditions. For a wind speed of 5 km h^{-1} and relative humidity of 40 percent, water losses under untreated and treated surfaces were 50 and 38 percent, respectively, of the total amount of infiltrated water. With a wind speed of 15 km h^{-1} and relative humidity of 80 percent, water losses were 30 and 11 percent, respectively.

8. WATER INFILTRATION AND MOVEMENT IN SOIL

d. Influence of Vegetation

de Jong, E. 1981. Soil Aeration as Affected by Slope Position and Vegetative Cover. Soil Sci. 131.

We monitored the composition of the soil air in native grassland and cultivated fields over several years on upper, middle, and lower slope sits on an Orthic Dark Brown Chernozemic soil. Soil carbon dioxide concentrations approximated 0.1 percent, volume per volume, in late April, started to increase in early May, reached maximum values of 1 to 2 percent, volume per volume, in June and July, and by late September had decreased to the same levels as in late April. The CO_2 concentrations varied considerably from year to year and were affected more by slope position than by vegetative cover. Comparison between CO_2 and O_2 gradients indicated that anaerobic respiration rarely occurred.

Gaither, R. E. and J. C. Buckhouse. 1981. Infiltration Rates of Various Vegetative Communities within the Blue Mountains of Oregon. J. of Range Management 36(1).

Mean infiltration rates differed among several natural vegetation communities with ponderosa pine (Pinus ponderosa) exhibiting the lowest mean infiltration rate of 6.0 cm/hr and larch (Larix occidentalis) demonstrating the highest at 8.8 cm/hr. A trend toward increasing infiltration rates corresponded to increasingly mesic sites. Alpine, Douglas fir (Psuedotsuga menziesii), mountain meadow, and larch types demonstrated the greatest vegetative cover, occupied the most mesic sites, and exhibited the highest infiltration rates. Infiltration differences within vegetative communities based upon changes in condition and productivity were also noted. The forested sites were more dependent upon condition class than productivity class, with higher infiltration rates being exhibited on pole sites than on timbered sites, apparently in response to higher plant densities associated with the pole thickets. Nonforested sites were responsive to both productivity and condition class with higher infiltration rates being exhibited on these sites with the more productive or better condition classifications.

Kent, E. J., S. L. Yu, and D. C. Wyant. 1982. Drainage Control Through Vegetation and Soil Management. Transportation Research Record 896. Nat. Academy of Sciences.

A procedure is developed that promotes the use of soil infiltration capacity and available soil profile storage in the design of highway drainage systems. By considering a design volume represented by the soil profile storage, the dependence on constructed runoff detention basins or other drainage structures can be reduced. This design volume is selected as the antecedent available storage in the soil that produces the T-year runoff from the T-year design rainfall. Data requirements of the overall methodology are commonly available soils, vegetation, and climatic parameters. The influence of antecedent moisture on the relation between rainfall and runoff frequency was tested by using five years of daily soil moisture and hourly rainfall and ten years of hourly runoff data from the Calhoun Experimental Forest near Union, South Carolina. Equations that estimate the design antecedent moisture and its associated storage for ungaged sites are developed. Vegetation and soil management techniques that increase the volume of soil profile storage and soil infiltration capacity are reviewed. In addition, the Calhoun soil moisture data are fitted to frequency distributions to assess the risk involved in using soils-based drainage designs.

9. WATER HARVESTING

a. Types of Materials for Catchment Aprons

Fink, D. H. 1984. Paraffin-Wax Water-Harvesting Soil Treatment Improved with Antistripping Agents. Soil Science 138.

The paraffin-wax water-harvesting soil-treatment is being used in arid areas to supply precipitation-runoff water for a variety of agricultural uses. However, because paraffin has only weak van der Waals-type binding forces, it may, under adverse weathering conditions, be easily stripped off the soil by the wedging action of water acting at the wax-soil interface. Addition of 2 to 4 percent antistripping agent (compounds added to asphalt during highway construction to strengthen the asphalt-aggregate interfacial bond) to the paraffin-wax water-harvesting soil treatment markedly improved the treated soil's resistance to the weathering effects of freeze-thaw cycling and water erosion. Addition of the better of the nine antistrip compounds tested permitted a reduction of the wax application rate to 0.5 kg/m^2. Prior stabilization of the soil with cellulose xanthate reduced the required wax/antistrip rate to only 0.25 kg/m^2. This is 1/8 the currently recommended application rate of wax for soils exposed to freeze-thaw weathering.

Fraiser, C. W., K. R. Cooley and J. R. Griggs. 1979. Performance Evaluation of Water Harvesting Catchments. J. of Range Management. 32(6).

The runoff efficiencies of 14 operational water harvesting catchments were estimated using a small portable sprinkler. The sprinkler method was verified using actual rainfall-runoff data from test plots of various water harvesting treatments at the Granite Reef Test Site. Sprinkler results showed that membrane-type treatments yielded 90 to 100 percent runoff. The runoff from properly installed wax-type treatments averaged over 80 percent. The sprinkler method permitted evaluation of catchment runoff efficiencies without resorting to the time and effort required for large field-instrumentation projects.

b. Design of Aprons

Ehrler, W. L., D. H. Fink and S. T. Mitchell. 1978. Growth and Yield of Jojoba Plants in Native Stands Using Runoff-Collecting Microcatchments. Agronomy J. 70.

Water-harvesting techniques were applied to a water-stressed native stand of jojoba (Simmondsia chinensis (Link) Schneider) near Phoenix, Arizona, to evaluate this method of supplementing the normally scant rainfall for increasing seed yield and to gain insight into the consumptive water requirements of the plant. Thirty small, indigenous, female bushes were selected and randomly divided into three treatments: T_{09}, no water-harvesting catchments; T_{19} cleared, smoothed, and rolled 20-m^2 catchments; and T_{29} like T_{19}, but with the catchment treated with a water-repellant coating. Data collected were: rainfall, runoff, soil moisture, relative leaf water content, plant volume, and seed yield. The 4-year average of precipitation plus runoff to plants during the critical growth-yield period of October through June was: T_{09}, 154 mm; T_{19} 435 mm; and T_{29} 876 mm. These preliminary results on this slow-growing shrub suggest that its consumptive water requirement exceeds 450 mm, and may be as great as 900 mm. Water harvesting is one way of supplying this required water,

Evett, S. R. and C. R. Dutt. 1985. Effect of Slope and Rainfall Intensity on Erosion from Sodium Dispersed, Compacted Earth Microcathcments. Soil Science Soc. Am. J. 49.

Knowledge of erosion in microcatchment systems is needed for the design of water harvesting systems. This study was therefore conducted on the effects of microcatchment slope as length on runoff and erosion rates under natural rainfall. Two replicates of a two factor experimental plot design, including 1, 5, 10 and 15 percent slopes and 3 and 6 m lengths, were built on a gravelly sandy clay loam using 11.2 Mg/ha of NaCl mixed into the surface 2 to 5 cm of soil followed by compaction with a 6-Mg roller after a heavy rain. Most of the erosion was from interrill erosion. Length (m) and storm energy, E, (MJ/ha) had no significant effects on erosion. The effects of slope, s, (m/m) and maximum 30 min rainfall intensity, I_{30}, (mm/h) were significant at the 0.1 percent level for the 11 storms studied. These effects were significantly different from those in the USLE (Universal Soil Loss Equation), which underpredicted erosion at low slopes. The sodium treated surface layer is estimated to last up to 20 years under our conditions if slopes are kept to 5 percent or lower on these microcatchments of less than 6 m length.

10. VEGETATION IN THE ROADSIDE ENVIRONMENT

Cook, D. I. 1981. Role of Plant Materials in Traffic Noise Control. Transportation Res. Record 789. Nat. Academy of Sciences.

The primary objective of this series of studies was to determine the extent to which plant materials are capable of reducing intrusive noise, mainly that from traffic. Tape-recorded sound and live sound were used for noise sources. Measurements were made by direct instrument reading and by magnetic-tape recording. Distances in the range of 5 to 122 m (16 to 400 ft) were used. Several kinds of trees and shrubs along and combined with solid barriers were studied. More than 20,000 individual readings were taken in the three series of experiments; the minimum was 4 and the maximum was 12 readings at each position. Each experimental point shown on the graphs represents averages of eight or more readings. Although varying atmospheric conditions pose difficulties in the measurement of outdoor sound, the reduction of sound is less affected by the insertion of barriers than the individual day-to-day measurements are; under similar atmospheric conditions, measurements were repeatable within 1 or 2 dB. Readings much beyond 91 m (300 ft) from the noise source were subject to large atmospheric-induced fluctuations of sound level and are considered less reliable than are closer readings. Results indicate that plant materials can be used effectively to reduce intrusive noise under certain conditions. They are not a panacea, however, and considerable knowledge based on experience is needed for proper application. Perhaps the best use, in the majority of cases, is a combination of trees and some form of solid barrier. Three series of experiments, which span an eight-year period, serve as the basis for this paper.

Kent, E. J., S. L. Yu, and D. C. Wyant. 1982. Drainage Control through Vegetation and Soil Management. Transportation Research Record 896. Nat. Academy of Sciences.

A procedure is developed that promotes the use of soil infiltration capacity and available soil profile storage in the design of highway drainage systems. By considering a design volume represented by the soil profile storage, the dependence on constructed runoff detention basins or other drainage structures can be reduced. This design volume is selected as the antecedent available storage in the soil that produces the T-year runoff from the T-year design rainfall. Data requirements of the overall methodology are commonly available soils, vegetation, and climatic parameters. The influence of antecedent moisture on the relation between rainfall and runoff frequency was tested by using five years of daily soil moisture and hourly rainfall and ten years of hourly runoff data from the Calhoun Experimental Forest near Union, South Carolina. Equations that estimate the design antecedent moisture and its associated storage for ungaged sites are developed. Vegetation and soil management techniques that increase the volume of soil profile storage and soil infiltration capacity are reviewed. In addition, the Calhoun soil moisture data are fitted to frequency distributions to assess the risk involved in using soils-based drainage designs.

Orans, M. 1984. Trees that Tolerate Smog. American Nurseryman 195(9).

Abstract not provided. Certain landscape plants can tolerate a diversity of growing conditions. The author offers suggestions on three varieties of trees that appear to tolerate smog. One of the plants mentioned is Pyrus calleryana (Evergreen pear) which grows in the Phoenix area.

Wu, T. H. 1984. Effect of Vegetation on Slope Stability. Transportation Res. Record 965. Nat. Academy of Sciences.

Two ways are considered in which vegetation can affect slope stability: changes in the soil moisture regime and contribution to soil strength by the roots. Simple analytical models that may be used to calculate water infiltration into soil and soil reinforcement by roots are reviewed and their applications to stability problems are illustrated by examples. The need for reliable field data to support the analytical models is emphasized.

11. LOW WATER-USE VEGETATION IN ARID AREAS.

a. Landscape Plants

Arizona Dept. Water Resources. 1985. Proposed List of Low and Moderate Water Use Plants. AMA Management Plant. Appendix V-B.

No abstract provided. This list of trees, shrubs, or groundcovers, cacti, annuals/perennials, grasses, vines, and miscellaneous plants contains a brief description of each plant.

College of Agriculture. Date Unknown. Plant List of Drought Resistant Varieties Compiled for the Cooperative Extension Work in Agriculture and Home Economics. Univ. of Arizona, unpub.

No abstract provided. This list of drought resistant trees, shrubs, ground covers and vines for Maricopa County was apparently compiled for a 4-H Club activity. It contains height, blooming time, flower color and general remarks about each plant.

Cox, R. A. and J. E. Klett. 1984. Evaluation of Some Indigenous Western Plants for Xeric Landscapes. HortScience 19(6).

Forty-five indigenous Western plants, mostly herbaceous perennials, were transplanted into a field plot and evaluated for water requirements and landscape value. The majority of species showed no significant differences in growth between irrigated and nonirrigated treatments. Several species are suggested for use as ornamentals in dryland or low-maintenance situations.

Sacamano, C. 1982. Irrigation Water Requirement for Some Representative Landscape Plants in Central and Southern Arizona. Fact Sheet # MC-53. Cooperative Extension Service, Univ. of Arizona.

No abstract provided. This list is divided into space defining, groundcover, shade and shelter, foundation, and bedding plants. The range of gallons of water per plant per day for Tucson and Phoenix are provided for each plant.

11. <u>LOW WATER-USE VEGETATION IN ARID AREAS</u>

b. Non-landscape Plants

Clairy, R. F. Jr. 1983. Planting Techniques and Materials for Revegetation of California Roadsides. Report No. FHWA/USDA-LMPC-2. USDA-Soil Conservation Service, Davis, CA.

Plots of herbaceous and woody plant materials were established at six locations in the Mojave Desert. Grasses, legumes and shrubs were evaluated for survival, erosion control and esthetics. Woody plants were mainly native species. Plantings were also made on problem soils (serpentine soils, high boron soils, high and low pH soils) to determine suitable plants for use under adverse growing conditions. The rate of natural woody plant invasion onto cut and fill slopes was studied at over 100 sites in the Sierra Nevada Mountains, Sierra Nevada Foothills and Mojave Desert. Slopes of different ages were inventoried to determine the type of slope most receptive to plant invasion as well as the rate at which woody plants revegetate naturally. Plots established during the 1970-75 cooperative CALTRANS-SCS study were evaluated to note changes in plant performance that could influence current seeding and planting recommendations. A revised seeding guide is included.

Amme, D. 1985. Nursery Production of Western Native Perennial Grasses for Site Stabilization. Procedures of Conference XVI. International Erosion Association. San Francisco, CA.

A variety of western native perennial grasses are being grown and tested in forestry liner containers at a land restoration nursery facility in Berkeley, California. The containers are 1 to 2 inches in diameter and 3 to 6 inches deep with a 2 percent taper. Soil volume varies from 4 to 9 cubic inches per liner and between 100 and 200 liners can be grown on 2 square feet of nursery space. A uniform soil mix of peat and vermiculite is used. The grasses responded well to linear production with insignificant seedling loss and plant dieback. Plantable liners were produced within 12 weeks. Production costs are competitive with the lowest costs of linear produced material.

11. LOW WATER-USE VEGETATION IN ARID AREAS

c. Environmental Factors Affecting Growth

Colvin, T. S. and J. M. Laflen. 1981. Effects of Corn and Soybean Row Spacing on Plant Canopy, Erosion, and Runoff. Trans. ASAE. 28.

Little effect of kind of crop or row width on soil erosion was observed at any crop stage. This apparently was caused by two factors: (1) very little difference was expected between the treatments, based on soil loss predictions using the USLE and (b) the precision in this study was not sufficient to detect the small difference expected. Narrow row cropping should have only a minor effect on soil losses, if surface conditions are not different for narrow row crops than those of wide row crops.

Kacker, N. L., H. S. Daulay, and R. P. Singh. 1984. Effect of Inter and Intra-row Spacings on Grain Yield of Rainfed Clusterbean. Annals of Arid Zone 23(1).

A field experiment on the effect of inter and intra-row spacings on branched and single stemmed clusterbean varieties was carried out on light texture loamy sand soils of CAZRI, Regional Research Station, Bikaner Farm during monsoon seasons of 1977, 1978 and 1980. During 1978 and 1980 seasons, branched variety Durgajay gave significantly higher yield than single stemmed FS 277. There were no significant differences in grain yield due to intra-row spacings during 1977 and 1978 seasons. However in 1980, an acute drought year, narrow row spacing (30 cm) gave significantly higher yield than the 45 and 60 cm row spacings. In 1978 and 1980 seasons intra-row spacing of 15 cm resulted in significantly increased yield over 22.5 cm spacing. Interaction effects of varieties x inter and intra-row spacings did not influence the grain yield of clusterbean significantly.

Singh, M. 1984. Effect of Planting Geometry on the Yield of Cenchrus Ciliaris (Linn.) in Arid Regions. Annals of Arid Zone 23(4).

No abstract provided. The author concluded that crop yields were dependent on the number of plants per unit area and the spatial arrangement of the plants. The standard row spacing was 60 cm. When this spacing was reduced to 30 cm, yields were not significantly different from the 60 cm treatment. When plants were spaced at distances greater than 60 cm, yields were reduced.

Witcomb, C. E. 1984. Reducing Stress and Accelerating Growth of Landscape Plants. J. of Arboriculture 10(1).

No abstract provided. A brief summary of new technology in landscape plant establishment is provided along with a few research references illustrating the findings. Recommendations include considering the condition of the plant at the time of planting, removal of burlap after placement in the hole to avoid exposure of root tips to air, and staking only when necessary.

12. DRIP (TRICKLE) IRRIGATION

a. Emitters and Layout Design

Bralts, V. F., I. P. Wu, and H. M. Gitlin. 1981. Drip Irrigation Uniformity Considering Emitter Plugging. Trans. ASAE. 25.

The coefficient of variation was used to measure the effects of emitter plugging on the uniformity of emitter flow along single and dual chamber drip irrigation lateral lines. The number of emitters per plant was shown to be important when calculating uniformity including emitter plugging. As a result, the statistical uniformity coefficient was recommended for use in determining the design uniformity of emitter flow along a drip irrigation lateral line when emitter plugging is considered.

Braud, H. J. and A. M. Soom. 1981. Trickle Irrigation Lateral Design on Sloping Fields Trans. ASAE 24.

The paper presents new analytical expressions for the variables in lateral line hydraulics. Design equations are given in implicit form that include all lateral variables. The equations are in a form that can be inserted into many programmable digital calculators and are very convenient for direct application to field problems. The analysis uses dimensionless ratios for the pressure terms with lateral supply end pressure as the reference pressure rather than the average operating pressure. Both the Hazen-Williams and the Blasius friction equations are used and compared through graphic solutions for limiting lateral length.

Bucks, D. A., F. S. Nakayama, and A. W. Warrick. 1982. Principles, Practices, and Potentials of Trickle (Drip) Irrigation. Advances in Irrigation. Vol. 1.

Abstract not provided. This article is an excellent review of the general concepts of drip irrigation. The authors are associated with the USDA-ARS Water Conservation Laboratory and the University of Arizona so that the examples used are pertinent to the arid southwest. General topics covered include: potential advantages of trickle irrigation, potential disadvantages of trickle irrigation, advances in system components and innovations, advances in soil water modeling, advances in system design and evaluation, advances in system maintenance practices, and advances in systems management.

12. <u>DRIP (TRICKLE) IRRIGATION</u>

b. Use on Landscape Plants

Bengson, S. A. 1985. ASARCO's Revegetation of Mill Tailings and Overburden Wastes from Open-Pit Copper Mining Operations in Arizona. Proceedings of Second Annual Meeting of American Society for Surface Mining and Reclamation. Denver, CO. Oct. 1985.

Revegetation of mining wastes, especially in an arid environment is a difficult task. This paper describes the problems encountered and techniques developed by Asarco to solve those problems. By using the proper revegetation techniques, Asarco has successfully revegetated over 160 acres of mill tailings and overburden waste slopes in southern Arizona.

Ponder, H. G., C. H. Gilliam, and C. E. Evans. 1984. Trickle Irrigation of Field-grown Nursery Stock Based on Net Evaporation. HortScience 19(2).

Gardenia jasminmoides Ellis and Ilex crenata Thunb. 'Compacta' were field-grown with 4 irrigation rates based on 0 percent, 25 percent, 50 percent, and 100 percent replacement of net evaporation from a class A pan. Irrigated gardenia were larger than nonirrigated gardenia, and those grown with 50 percent and 100 percent replacement of net evaporation had greater total root growth than nonirrigated plants. Root number, root dry weight, and fibrous root number in a 20-cm rootball were generally greater with irrigated plants than nonirrigated plants. Ilex crenata shoot growth was greater also with irrigation versus nonirrigation. Based on this data, 25 percent replacement of net evaporation resulted in plants of both species being similar to higher irrigation rates.

Ponder, H. G., and A. L. Kenworthy. 1976. Trickle Irrigation of Shade Trees Growing in the Nursery. I. Influence on Growth. J. Am. Society Horticultural Science 101(2).

The effect of trickle irrigation on trunk diameter increase was studied with four shade tree species in 1973 and 1974. Irrigation treatments consisted of 5.7 liters per hour (2 gal/hr) and no supplemental water on sugar maple (Acer saccharum Marsh.) and honey locust (Gleditsia triacanthos L.). White ash (Fraxinus americana L. cv. Autumn Purple) treatments were no water, 1.4 liters per hour, and 2.u8 liters per hour. Irrigated pin oak (Quercus palustris Muench.) trees received 5.7 liters per day at application rates of 5.7, 2.8, and 1.4 liters per hour and application time per day was 1, 2, and 4 hours respectively. Leaf analysis was performed each year.

In 1973 there was a doubling in increase in diameter of irrigated pin oak, white ash, and sugar maple with the higher flow rate per hour over that of checks. Irrigated honey locust trunk diameter increase was greater than checks. In 1974, 1 hr and 2 hr irrigated pin oak and irrigated white ash again outgrew checks but irrigated honey locust and sugar maple did not.

Leaf N and K were the only elements to show consistent changes with all species. Leaf N was lower in 1974 compared to 1973 while K was higher. Trickle irrigation did not promote any consistent significant change in nutrient composition of leaves.

12. <u>DRIP (TRICKLE) IRRIGATION</u>

c. Effect of Drip Irrigation on Plant Response

Bacon, P. E., and B. C. Davey. 1982. Nutrient Availability Under Trickle Irrigation: I. Distribution of Water and Bran No. 1 Phosphate. Soil Science Society Am. J. 46.

The distribution of water and Bray no. 1 phosphate was measured in the surface soil of a Chromic Luvisol that had been under trickle irrigation for five years. The region of the soil reaching field capacity after 8 to 12 h of irrigation extended horizontally to at least 65 and up to 90 cm from the outlet and was no deeper than 12 cm from the surface. After irrigation had ceased soil water decreased with time but usually did not become significantly different from field capacity until after about 24 h.

Where the soil had not been fertilized, Bray no. 1 phosphate decreased from 42 to 19 ppm over a 25-cm depth immediately below the trickle outlet, while 65 cm away it decreased from 78 to 16 ppm. Banding fertilizer 50 to 80 cm from the outlet increased phosphate at the surface to 113 ppm but did not increase phosphate at depth. These results imply that trickle irrigation caused both horizontal and vertical movement of native soil phosphate near the outlet, and that phosphate fertilizer applied 50 to 80 cm away from the outlet remained near the soil surface and above the root zone.

Irrigation of an 8- to 12-h duration usually increased the concentration of Bray no. 1 phosphate by an average of 63 percent in a region of radius 30 cm from the outlet and about 12 cm in depth. The phosphate concentration remained above pre-irrigation levels for between 6 to 23 h after the end of irrigation but fell to pre-irrigation levels as the soil dried out.

Bacon, P. E., and B. G. Davey. 1982. Nutrient Availability Under Trickle Irrigation: II. Mineral Nitrogen. Soil Science Society Am. J. 46.

The effects of irrigation and fertilizer application on nitrate, nitrite, and ammonium concentration in a Chromic Luvisol were studied in an orchard that had been trickle irrigated for five years. Immediately before the first irrigation of the season, mean plot nitrate-N was 5 ppm; 8 h of irrigation reduced this to 0.5 ppm. Nitrite concentration fell from 0.8 to 0.4 ppm in the same period. During irrigation ammonium concentration rose from 7.1 to 13.5 ppm (the average rate of increase being 0.8 ppm/h) in the surface 6-cm depth of soil extending up to a distance varying from 30 to 65 cm from the outlet. There was no evidence that nitrate or nitrite accumulated at the A/B horizon boundary and it is likely that the loss was due to denitrification.

The results obtained for five 3-d irrigation cycles in early summer again demonstrated that the decrease in nitrate during the irrigation cycle was accompanied by an increase in ammonium. The phenomena was part of a continuous cycle which increased the mineral nitrogen availability during the wet portion of every 3-d cycle.

Koehler, H. P., P. H. Moor, P. A. Jones, A. Dela Cruz, and A. Marlzki. 1982. Response of Drip-irrigated Sugarcane to Drought Stress. Agronomy J. 74.

Though drip irrigation is used on more than half of the irrigated sugarcane (Saccharum spp. hybrid) in Hawaii, the effects of drought stress on the growth and yield of drip-irrigated sugarcane has not been investigated extensively.

Water depletion from the soil profile, leaf water potential (ψ_l), leaf solute potential (ψ_π), leaf pressure potential (ψ_p), stalk elongation, plant sugar, K, and amino acid concentrations were monitored at 1200 to 1400 hour during a five- or six-week period of drought stress. In three of four fields, soil water extraction was limited by low soil water content after cumulative profile water depletion of approximately 120 mm.

Stalk elongation was strongly correlated to ψ_l and cumulative soil water depletion. Stalk elongation of plants in drought-stressed plots was less than 80 percent that of plants in well-watered plots after only 50 mm of cumulative soil water depletion. During drought the concentrations of potassium and reducing sugars in the leaf blade increased, but the concentrations of sucrose and free amino acids changed little. None of these metabolites changed in the stem apex.

Shalhevet, J., D. Shimshi, and T. Meier. 1983. Potato Irrigation in a Hot Climate Using Sprinkler and Drip Methods. Agronomy J. 75(1).

Potato (Solanum tuberosum L.) is a heat- and drought-sensitive crop, which in hot climates usually requires large water applications for optimum production. Irrigation water in Israel is both limiting in quantity and high in price; thus it is critical to know the water requirement of the crop, as well as how to improve irrigation efficiency. Field experiments were conducted in the Negev (arid) region of Israel on a Typic Camborthid soil to determine the water production functions of potatoes ('Desiree') under drip and sprinkler irrigation. Irrigation treatments were based on Class A pan evaporation. Yield was reduced by 12 percent as soil water potential in the 0 to 0.6 m depth increment changed from -20 to -29 J kg^{-1} for sprinkler irrigation. Under drip irrigation the soil could dry to -40 J kg^{-1} without yield reduction, as long as the water supply was adequate. This was explained by the higher root concentration under drip than under sprinkler irrigation.

APPENDIX B

RECOMMENDATIONS FOR AN EROSION COST PROGRAM UTILIZING THE PECOS SYSTEM

Introduction:

The need for an erosion cost computing program has been recognized by the project committee and the research team. Discussions between the research team and the committee have led to the agreement that the most useful information on erosion costs is contained in the maintenance activities recorded in the PECOS system. The research team understands that the costs logged into the system are based on estimated costs calculated from work units distributed over an known inventory. Nonetheless, the PECOS system represents a tremendous data base which can be utilized. The following description of an erosion cost program is the result of the experiences of the research team and discussions with ADOT personnel.

The erosion cost data provided as a supplement to the slope erosion damage maps were based on costs associated with four maintenance activities (169Q, 169Z, 319F, and 319H) for the period of March 13, 1985 through June 21, 1986. These costs were calculated from information provided by Ms. Natalie Rohrig (Maintenance Analyst, District 1).

Several problems became evident during the analysis of the data. Entries were frequently too broad in terms of location since single activity entries were often logged for several miles at a time and for both directions. The most useful information will be that which provides erosion cost information about specific areas. Areas associated with higher costs should be related to continuing and/or severe erosion problems. More detailed entries for the milepost to milepost locations of the activities would allow problem areas to be identified through cost records. The research team recommends that detailed activity location entries be made for those activities identified as erosion related.

Discussions with Mr. Charles Kinsey, Jr. (Maintenance EDP Supervisor, Maintenance Planning Services) led to the identification of another problem in using the PECOS System. Mr. Kinsey reported that no documented means of retrieving data by activity number was currently available. Furthermore, he felt that activity numbers that contained a letter designation such as 169Q may require additional programming in order to be retrieved. He expressed an interest in devising a Mark IV program that could retrieve data pertaining to an activity as specified by route number, time period, direction, and milepost location.

Continuing evaluation of the project has led the research team to conclude that an effective erosion cost program should provide more output than a simple data retrieval system. The most useful erosion cost program will entail both identification of the data base and calculation of erosion costs.

Data base:

The data base is comprised of pre-selected maintenance activities. The selection of these activities was based on interviews with Mr. William Brisco (Area Engineer, District 1), Mr. Martin Mortensen (Vegetation Management Br. Supervisor, Roadside Development Services), Natalie Rohrig and field personnel from the Orgs that are included in the study area. For an activity to be selected, all or part of the work and associated costs are related to erosion damage. The following activities were selected:

Activity Number	Activity Title
131	Blade Unpaved Shoulders
132	Repair Unpaved Shoulders
157	Mechanical Sweeping
162	Emergency Drainage Maintenance
168	Roadway Pump Maintenance
169J	Clean and Reshape Grader Ditches
169Q	Cleaning of Erosion, Etc. on Freeway Pumps, Drains
169Z	Cleaning of Drainage Channels
309	Irrigation System Maintenance
313	Repair Berms and Basins
319F	Granite Replacement and Repair
319H	Replacement of Soil Lost from Erosion

The working data set will be identified by the user selection of the following parameters:

1. Route number,
2. Time period as designated by beginning date and ending date,
3. Direction as designated by northbound, eastbound, southbound, or westbound, and
4. Location as designated by beginning milepost and ending milepost.

The above information will be used to identify the PECOS cost records of the pre-selected maintenance activities. The route selection and time period should pose no problems. Of the records examined, all of the time periods logged for the four activities mentioned earlier are listed as single day entries. The direction and location will require additional manipulation. Direction entries for the study area were recorded as eastbound, westbound and both. The cost attributed to activity entries designated as both should be halved to divide the cost evenly between the two directions since actual distribution of the cost is not known.

The most difficult parameter will be location. In the records examined by the study team, location designations were recorded for a variety of lengths. For instance, on October 29, 1985 an entry for 319F eastbound on SR 360 was recorded between mileposts 0.1 and 2.4, while on May 7, 1985 the same activity was recorded between mileposts 1.3 and milepost 1.7. Similarly , on March 17, 1986 an entry for 169Q on I-10 was recorded between milepost 134.7 and 142.7 with the direction designated as both.

Data of the type described above requires a means of averaging costs over the user-selected areas. The total cost for each activity entry should be calculated as cost per one tenth of a mile for a single direction. Use of tenths of a mile is a reasonable base since activity entries are recorded to the nearest tenth. The unit cost is then multiplied by the portion of the recorded location that falls into the user specified location.

Erosion factor:

The erosion cost for a given route-time-direction-location combination are provided by summing the costs for the individual activities. Since not 100% of every activity represents an erosion cost, a factor representing the percent of the activity associated with erosion should be introduced. For instance, activity 319H represents replacement of soil lost from erosion. Whenever this activity is logged into PECOS, all of the costs for it are directly associated with damage from slope erosion. The erosion factor for this activity would be 1.00. On the other hand, activity 157 is listed as mechanical sweeping. Not all of the materials on the roadway are materials eroded from the slopes. Only a percentage of the cost of this activity can be attributed to erosion; thus, the erosion factor would be less than 1.00.

The numerical value of the erosion factor has been determined by drawing on the experience of ADOT personnel, particularly the Org foremen whose sections cover the study area. Because the erosion factor for each activity is based on opinion, the study team strongly suggests that the factor be given a default value that can be easily altered by the program user. This option allows flexibility in two ways. First, the experience of the program user can be utilized by allowing him to modify the factor based on his understanding of the area he has designated by the data base. Second, if the description of an activity is altered in such a way that a different portion of its cost can be associated with erosion, the default value can be reset. The suggested default erosion factor for each activity is as follows: (see next page)

Activity Number	Default erosion factor
131	0.05
132	0.25
157	0.20
161	0.15
162	0.15
168	0.10
169J	0.50
169Q	1.00
169Z	1.00
309	0.10
313	0.30
319F	1.00
319H	1.00

Program output format:

The study team recommends the following general format for the output of the erosion cost program:

ROUTE NUMBER________ TIME PERIOD______________

DIRECTION__________ LOCATION________________

ACTIVITY NUMBER	EROSION FACTOR	EROSION COST	% OF TOTAL
		TOTAL COST__________	100%

The EROSION COST column represents the sum of all cost associated with the activity. The erosion cost is calculated from the data set specified by the user.

Conclusions:

The erosion cost program described in this document will be effective because it provides specific erosion cost information and is adapted to the needs of the potential users. Features of the program include combination of pre-selected activities with user selection of route number, time period, direction, and location. The erosion factor assigned to each activity represents the percent of the activity associated with erosion costs. The erosion factor can be used as a default or set to a new value by the user. The sum of costs for each activity is provided in the output.

If any questions or problems concerning the program arise, the research team is willing to seek answers. Furthermore, the research team stands ready as needed to assist in the implementation of the program.

TABLE OF CONTENTS

INTRODUCTION

The Pecos Roadside Activity Costing System Report/File Search Procedure allows ADOT personnel to access records stored in the Pecos System. The available records pertain to the costs logged into the system from the Crew Day Cards. The records are categorized by activity numbers which are described by the Maintenance Management System Data provided by the Highway Maintenance Planning Services.

The program developed as a result of a research project entitled "Slope Erosion Control for Freeways in Arid Environments" which was awarded to the College of Engineering at Arizona State University. The initial program was designed by the principle investigators, Dr. Dennis Duffy, Department of Civil Engineering and Dr. Hilda Hatzell, Division of Agriculture. The purpose was to provide a means of tracking erosion problems and costs on the freeways in the Phoenix metropolitan area. It was limited to those maintenance activities that contributed to erosion costs.

Interaction between the research team and ADOT personnel resulted in the increased scope of the program. Provisions were made to allow modification of the factor associated with each activity, addition of activities other than those initially specified, and deletion of unwanted activity numbers. Older information on the Pecos System would be accessed by downloading from tapes while more recent information would be retrieved from disk files.

This user manual was prepared by Dr. Hatzell in compliance with ADOT Contract No. 85-43. Problems encountered with the operating system should be referred to Mr. Kurt Denham at 255-8714 or Mr. Joe Gregg at 255-8711 in Engineering Systems.

DESCRIPTION OF TERMS

TAPE...Retrieval of information in the Pecos System before July 1, 1981 is possible through the TAPE option associated with SUBMIT FILE SEARCH. Because tapes must be loaded from the library, a delay in retrieval will be likely. Activity numbers not given in the DISK option must be retrieved by TAPE regardless of the date.

DISK...Retrieval of information in the Pecos System dated July 1, 1981 through the current date is possible through the DISK option associated with SUBMIT FILE SEARCH. This retrieval is possible only for the following activity numbers: 131, 132, 157, 161, 162, 168, 169J, 169Q, 169Z, and any activity numbers in the 300 series.

ACTIVITY...The activity numbers used in the program refer to the numbers assigned to the various maintenance activities which are described in the Performance Standards/Definitions provided by Highway Maintenance Planning Services.

FACTOR...The factor is a percent value written as a decimal fraction. In some instances, not all of the costs accumulated in a given activity may relate to the interests of the user. A portion or percent of the total cost for an activity may be specified with the factor.

MAIN MENU

To initiate the Pecos Roadside Activity Costing System, type ROADSIDE. The screen will display the Main Menu as it appears in Figure 1.

```
            ARIZONA DEPARTMENT OF TRANSPORTATION

          PECOS ROADSIDE ACTIVITY COSTING SYSTEM
              REPORT/FILE SEARCH PROCEDURE



             A.  SUBMIT FILE SEARCH
             B.  DOWNLOAD SELECTED DATA
             C.  PRINT ROADSIDE ACTIVITY COST REPORT
             D.  EXIT TO DOS

                    OPTION:
```

Figure 1. Main Menu selection.

Option A is used to specify parameters such as route number, inclusive dates and mileposts, and activities. Option A is also the means of submitting a data request to the Pecos System. Option B is used to retrieve data requested in Option A. Option C provides the means of printing out the data. Option D ends the program by returning to the DOS of the personal computer (PC).

SUBMIT FILE SEARCH
(Option A of Main Menu)

Selection of Option A from the main menu will result in an additional specification of TAPE or DISK as shown in Figure 2. If the records to be retrieved occur on or after July 1, 1981 and are specified by activity numbers 131, 132, 157, 161, 162, 168, 169J, 169Q, 169Z or activity numbers between 300 and 399 then select DISK by typing D. Records stored on the disk are updated every two weeks. For records occurring before July 1, 1981 and for records relating to activities other than those described above, select TAPE by typing T.

ARIZONA DEPARTMENT OF TRANSPORTATION

PECOS ROADSIDE ACTIVITY COSTING SYSTEM
REPORT/FILE SEARCH PROCEDURE

A. SUBMIT FILE SEARCH
B. DOWNLOAD SELECTED DATA
C. PRINT ROADSIDE ACTIVITY COST REPORT
D. EXIT TO DOS

OPTION: A

TAPE DISK

Figure 2. Selection of Option A.

After typing either T or D, the FILE SEARCH PARAMETERS will appear as shown in Figure 3. The form in which each parameter is to be entered is shown in the parentheses to the right. To designate a value for a parameter, type the value and press the return key. A ROUTE LETTER does not need to be specified and may be skipped by pressing the return key. Note that the BEGINNING MILEPOST and ENDING MILEPOST values must be specified to the nearest tenth of a mile. The BEGINNING DATE and ENDING DATE must contain six digits. An example of the correct entries is given in Figure 4. If the parameter is not specified correctly, an error message will appear at the bottom of the screen. The message identifies the error and requests reentry.

```
ARIZONA DEPARTMENT OF TRANSPORTATION

PECOS ROADSIDE ACTIVITY COSTING SYSTEM
REPORT/FILE SEARCH PROCEDURE
FILE SEARCH PARAMETERS


ROUTE NUMBER            :             (XXX)
ROUTE LETTER (IF ANY)   :             (A,B,L,S,X,Y)
ROUTE DIRECTION         :             (N,S,E,W)
BEGINNING MILEPOST      :             (XXX.X)
ENDING    MILEPOST      :             (XXX.X)
BEGINNING DATE          :             (YYMMDD)
ENDING    DATE          :             (YYMMDD)
```

Figure 3. File Search Parameters

```
ARIZONA DEPARTMENT OF TRANSPORTATION

PECOS ROADSIDE ACTIVITY COSTING SYSTEM
REPORT/FILE SEARCH PROCEDURE
FILE SEARCH PARAMETERS


ROUTE NUMBER            : 360         (XXX)
ROUTE LETTER (IF ANY)   :             (A,B,L,S,X,Y)
ROUTE DIRECTION         : W           (N,S,E,W)
BEGINNING MILEPOST      : 5.4         (XXX.X)
ENDING    MILEPOST      : 10.2        (XXX.X)
BEGINNING DATE          : 860101      (YYMMDD)
ENDING    DATE          : 861231      (YYMMDD)
```

Figure 4. An example of file search parameters for 360 westbound from milepost 5.4 to 10.2 for the period of January 1 through December 31, 1986.

When entry of the parameters has been completed, the REPORT/FILE SEARCH PROCEDURE will automatically appear on the screen (Figure 5). This procedure has several options which allow changes in the activity - factor list. For convenience of explanation, the options will not be discussed in the order they appear in Figure 5.

```
                 ARIZONA DEPARTMENT OF TRANSPORTATION

                  PECOS ROADSIDE ACTIVITY COSTING SYSTEM
                      REPORT/FILE SEARCH PROCEDURE


        ACTIVITY     FACTOR
   1      131          0.05
   2      132          0.25
   3      157          0.20
   4      161          0.15
   5      162          0.15
   6      168          0.10
   7      169J         0.50
   8      169Q         1.00
   9      169Z         1.00
  10      309          0.10
  11      313          0.30
  12      319F         1.00
  13      319H         1.00


                  CONTINUE   ADD   MODIFY   DELETE   SAVE
```

Figure 5. The options available in the Report/File Search Procedure.

Typing M will select the MODIFY option. This selection will allow changes to be made in the FACTOR list. The lower portion of the screen will display the following request: ENTER LINE NUMBER OF ACTIVITY. Type the line number as it appears in the first column and press the return key. If the program does not respond with a request to ENTER FACTOR, check to be sure the line number of the activity was entered and not the actual number of the activity. Retype the line number if needed and press the return key. When the program responds with ENTER FACTOR, type the new value and press the return key.

The FACTOR is the decimal representation of a percent. In Figure 5 the preselected value of activity 131 is 0.05. A FACTOR value of 0.05 means that 5% of the total cost of activity 131 for the parameters selected in the FILE SEARCH PARAMETERS (Figure 4) will be reported in the printout. If the user desires to obtain 100% of the cost associated with that activity, then type 1.00 after the ENTER FACTOR request.

Typing A will select the ADD option and allow new activities to be added to the list. The lower portion of the screen will display the following request: ENTER ACTIVITY. Type the number of the activity from the list of Performance Standards/Definitions prepared by the Highway Maintenance Planning Services. Press the return key. The display will then respond: ENTER FACTOR. Type the percent of cost for this activity that should be included in the printout. Press the return key. The REPORT/FILE SEARCH PROCEDURE will now contain the additional activity and its factor.

Note that a discrepancy may arise if the ADD option is used to specify an activity is which is not included in the records that are accessed by the DISK request. The list of activities that are accessed by DISK is given in the Description of Terms on page 3 and again in the opening paragraph of the Submit File Search section on page 5. Inclusion of an activity not on the list will not result in an error message but will produce erroneous information. The print-out will show 0.00 in the Activity Cost column for that activity. To obtain the correct information, the activity would have to be accessed by selecting the TAPE option of the REPORT/FILE SEARCH PROCEDURE (Figure 2).

Typing D will select the DELETE option. The screen will display the following request: ENTER LINE NUMBER OF ACTIVITY. Type the line number of the activity as it appears in the left column. Press the return key. If the screen does not respond, check to be sure the line number was entered and not the activity number. If needed, type the corrected number and again press the return key. The REPORT/FILE SEARCH PROCEDURE will display the new activity-factor list. Note that the activities have changed line numbers.

Figure 6 is an example in which the MODIFY, ADD and DELETE options have been used. The MODIFY option was used to change the preselected FACTOR of activity 131 from 0.05 to 0.10. The ADD option entered activity 301 with a factor of 0.50 into the activity-factor list. The DELETE option removed activity 161 from the list.

Typing S will select the SAVE option. The SAVE option should be used with caution since it **permanently** saves any changes that have been made to the activity-factor list. The activities and factors which appear in Figure 5 were preselected to calculate the costs associated with slope erosion. They reflect the intent of the original program and may be of value to other users. If the SAVE option is selected, the screen will display the following request: ARE YOU SURE (Y OR N). Type the appropriate letter and press the return key. The REPORT/ FILE SEARCH PROCEDURE will reappear.

Typing C will select the CONTINUE option which produces the WYLBUR AND JCL SETUP shown in Figure 7. Enter the appropriate PHONE NO., USERID, and PASSWORD. To change any of the information type R for REENTER and retype the information. To exit from this portion of the program (Option A, SUBMIT FILE SEARCH) without submitting the request, type Q for QUIT and the Main Menu will appear (Figure 1). To submit the program, type C for CONTINUE. The program will be submitted and the screen will display the Main Menu.

ARIZONA DEPARTMENT OF TRANSPORTATION

PECOS ROADSIDE ACTIVITY COSTING SYSTEM
REPORT/FILE SEARCH PROCEDURE

	ACTIVITY	FACTOR
1	131	0.10
2	132	0.25
3	157	0.20
4	162	0.15
5	168	0.10
6	169J	0.50
7	169Q	1.00
8	169Z	1.00
9	309	0.10
10	313	0.30
11	319F	1.00
12	319H	1.00
13	301	0.50

CONTINUE ADD MODIFY DELETE SAVE

Figure 6. An example of changes made in the activity-factor list using the options ADD, MODIFY and DELETE.

ARIZONA DEPARTMENT OF TRANSPORTATION

PECOS ROADSIDE ACTIVITY COSTING SYSTEM
REPORT/FILE SEARCH PROCEDURE
WYLBUR AND JCL SETUP

OVERTYPE FIELDS AS NEEDED

WYLBUR PHONE NO. : 7502
WYLBUR USERID :
WYLBUR PASSWORD :

REENTER CONTINUE QUIT

Figure 7. The Wylbur and JCL Setup.

To exit the PECOS ROADSIDE ACTIVITY COSTING SYSTEM, select Option D from the Main Menu. The screen will then display the message shown in Figure 8.

```
                ARIZONA DEPARTMENT OF TRANSPORTATION

                 PECOS ROADSIDE ACTIVITY COSTING SYSTEM
                      REPORT/FILE SEARCH PROCEDURE



             END OF PECOS ROADSIDE ACTIVITY COST PROCEDURES
```

Figure 8. The results of selection Option D (EXIT TO DOS) from the Main Menu.

DOWNLOAD SELECTED DATA
(Option B of Main Menu)

After a request has been submitted through Option A (SUBMIT FILE SEARCH), the data must be downloaded into the PC memory before it can be printed. To download a file, select Option B (DOWNLOAD SELECTED DATA) from the main menu by typing B as shown in Figure 9.

```
            ARIZONA DEPARTMENT OF TRANSPORTATION

           PECOS ROADSIDE ACTIVITY COSTING SYSTEM
               REPORT/FILE SEARCH PROCEDURE



            A.  SUBMIT FILE SEARCH
            B.  DOWNLOAD SELECTED DATA
            C.  PRINT ROADSIDE ACTIVITY COST REPORT
            D.  EXIT TO DOS

                   OPTION:B
```

Figure 9. Selection of Option B from Main Menu.

The screen will display the WYLBUR AND JCL SETUP illustrated in Figure 7. After entering the correct information concerning userid and password, type C for CONTINUE. The program will automatically download the data requested and return to the Main Menu. To print out the data, select Option C.

Note that the data is always downloaded from the mainframe computer to the same file in the PC memory. Any data already in the file from a previous request will be lost.

If TAPE was selected in Option A (SUBMIT FILE SEARCH), a delay in assembling the data requested may be encountered since the tapes must be loaded into the mainframe before the information can be accessed. If DISK was selected in Option A, the turnaround time should be relatively fast depending on the workload of the system.

PRINT ROADSIDE ACTIVITY COST REPORT
(Option C of Main Menu)

After a data file has been requested (Option A) and downloaded (Option B), it may be printed by selecting Option C from the Main Menu. To select Option C, check to be sure the printer is turned on and type C. No other input will be needed to create the PECOS ROADSIDE ACTIVITY COST REPORT.

The format of the printout is illustrated in Figure 10. This printout was created from the example parameters described in Figures 4 and 6. The ROUTE NUMBER, DIRECTION, TIME PERIOD, and LOCATION were specified in the FILE SEARCH PARAMETERS. The ACTIVITY NUMBER and FACTOR lists were created by the REPORT/FILE SEARCH PROCEDURE.

The column labeled ACTIVITY COST represents the sum of LABOR COST, MATERIAL COST, and EQUIPMENT COST for each activity at the factor or percent specified. For example, the ACTIVITY COST OF Activity 131 is $78.29 which is the sum of $19.65 and $58.64. The $78.29 is 10% of the total amount of cost logged into Activity 131 from the period of 01/01/86 to 12/31/86 for westbound 360.

The column labeled % OF TOTAL represents the contribution of each activity to the total cost of all activities specified in the ACTIVITY NUMBER column. For example, $78.29 is 1.05% of the TOTAL COST of $7,467.01.

The last row in the printout is labeled TOTAL COSTS and designates the sum of each column. Note that in this example, the overall TOTAL COST for the requested parameters is $7,467.01 which is the sum of the ACTIVITY COSTS.

EXIT TO DOS
(Option D of Main Menu)

To exit from the PECOS ROADSIDE ACTIVITY COSTING SYSTEM REPORT/FILE SEARCH PROCEDURE, type D from the Main Menu (Figure 1). The screen will display the message shown in Figure 8.

The program is designed to automatically return to the Main Menu at the completion of the other options. Typing D from the Main Menu is necessary to disengage from the program.

APPENDIX D   Sampling Location

Samples from SR 360 & I 10 to be evaluated as plant growth medium.

I.D.	TYPE	LOCATION	COMMENTS
1	subgrade (fill)	SR 360 southside, eastbound W of Kyrene, 20'from top	2-6", no plating soil,
2	plating	SR 360 600'E of Hinkley, top of ridge, westbound	10" below surface darker than subgrade
3	subgrade (fill)	same as #2	28-30" below surface
4	plating	SR360 westbound, W of Recker, south facing slope	10" below surface, brk at 14", coarse up, fine below
5	subgrade (fill)	same as #4, 500'W of canal at base of slope	25"?? from top
6	plating	SR360, W of Kyrene, east bound, under grass	1-8", near #1*
7	plating	SR360, W of Lindsay, east bound, south face slope	20" from ground surface
8	subgrade (fill)	same as #7, at foot of slope	29-31" below surface, no visual dif from #7
9	plating	SR360 N of Exit 8 sign westbound, north facing slope, base of slope	4-10" with 0-4" granite on top
10	subgrade (fill)	same as #9, E of Country Club	28-30", less $CaCO_3$, no clr boundary
11	plating	SR360, 350'W of Val Vista, west bound, top of hill	10" from surface, no dif from subgrade
12	subgrade (fill)	same as #11	34" from surface
13	plating	same as #11	crust below granite, 1" thick, intact

I.D.	TYPE	LOCATION	COMMENTS
14	subgrade? (fill)	SR360, at canal edge, south side, between Stapley & Horn Dr., 1/3 from Stapley	35" below surface, no diff from top material
15	plating	I10, 100' E. of 91st Ave, south face,	10' ft from road
16	plating	I10, 20'E. of brass valve at 115th, southside, eastbound ramp, base of slope	0-16" depth, coarser and redder than #24
17	plating	I10, base of ltpost 6318A, southside, eastbound between 67th & 75th Ave.	0-9" depth,
18	plating(?)	W. of 107th Ave @ stn 6995, eastbound, south facing, 100 ft W. of fence.	<3' depth, no break between sub & plating
19	plating	I10, westbound on ramp @ Dysart, north side slope 20' W. of 2nd lt post	0-6", lot of patching on slope
20	plating	I10, 3000 ft E. of bridge @ 83rd, in diamond, east-bound, north facing	0-8", 20 ft from road,
21	plating	I10, 150' W. of 99th Ave, base of south facing slope off ramp, east bound	3-?",
22	plating	I10, W. of 75th, westbound northside, 20' from top	0-8", coarse frags
23	subgrade(?) (not fill-????)*	I10, milepost 130.9, east bound, south facing, 20' down slope	3-16", no plating evident, heterogeneous like river run
24	subgrade	I10, same as #16 but below it in same ditch	>16"(?),
25	plating	I10, 115th Ave., offramp in diamond, Eastbound	0-8"

* "non-fill" is used to designate those materials that are subgrade but have not been disturbed. They would exist on the slope face beneath the plating and below the existing ground level.

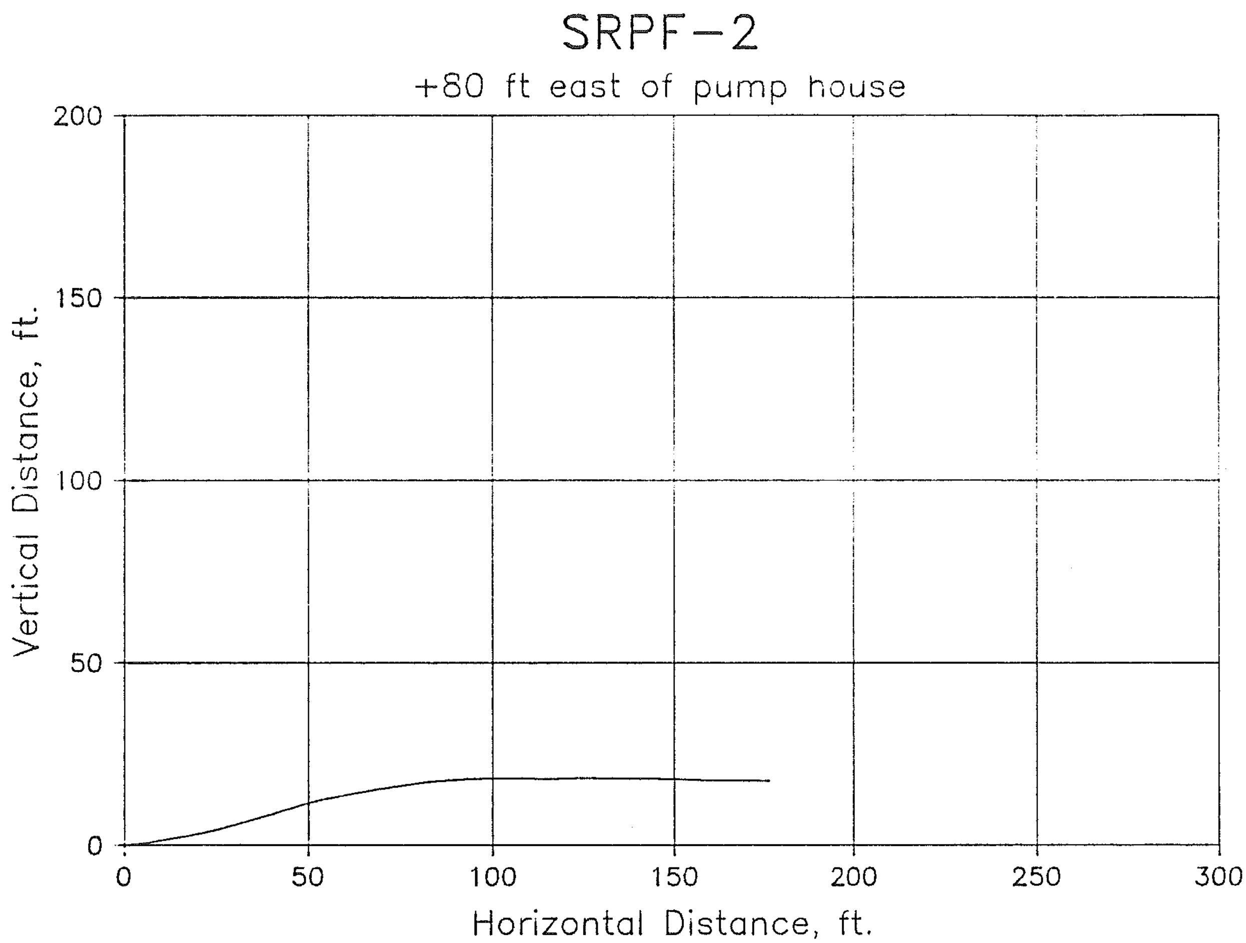
I.D.	TYPE	LOCATION	COMMENTS
26	plating	I10, 400' W of 99th, N facing diamond, S of westbd onramp at culvert pipe	6-8"(?), recent plt landscaping
27	subgrade (nonfill)	I10, at Litchfield Rd., 100 yds N in borrow pit at Wbd offramp, NW corner of pit	~5.5'below surface 2-6" deep sample
28	plating	I10, W of 115th, south facing, Ebound before offramp 20' from road edge	2-8" sample
29	plating	I10, 200' W of 115, 15' N of fence	2-8" sample
30	plating	I10, Wof 43rd Ave., top of slope at fence, Ebound	2-8" (?) sample
31	subgrade (nonfill)	same as #30	4'-5', core sample
32	subgrade (fill)	I10, 115th Ebound offramp 100' W of fence, ~25' from top of slope	2.5-3.5', core sample
33	plating	same as #27 but represents potential plating	~2' below surface 2-6" sample
34	subgrade (fill)	I10, 1/2 way Litchfield to RR crossing, N facing, 25' from slope top, N side, Wbound	2-3' core sample, material is from borrow pit to N
35	subgrade (nonfill)	I10, 20' SW of #35	3-3.5' core sample
36	subgrade (fill)	SR 360, 400' E of Alma School Rd., Ebound onramp, south facing slope, 5' from hill top.	30-33" depth
37	plating	same as #36	6-8", lenses of clay in sample
38	subgrade (nonfill)	SR 360, 25' E of Mesa Dr., 5' E of fence, south side 10' S of Stn 44+47.87	38-46" core sample
39	subgrade (nonfill)	SR 360, 600' E of Power in borrow pit	~4' below surface 2-6" surface sample

I.D.	TYPE	LOCATION	COMMENTS
40	plating	same as #39, represents potential plating	0-5" surface soil
41	subgrade (fill)	SR 360, Wbound between Recker & Higley, 20' W of milepost at begin of hill	30-34"
42	subgrade (fill)	SR 360, E of Val Vista, south facing back slope, 10' from hill top, Ebound near end of ramp.	32-36"

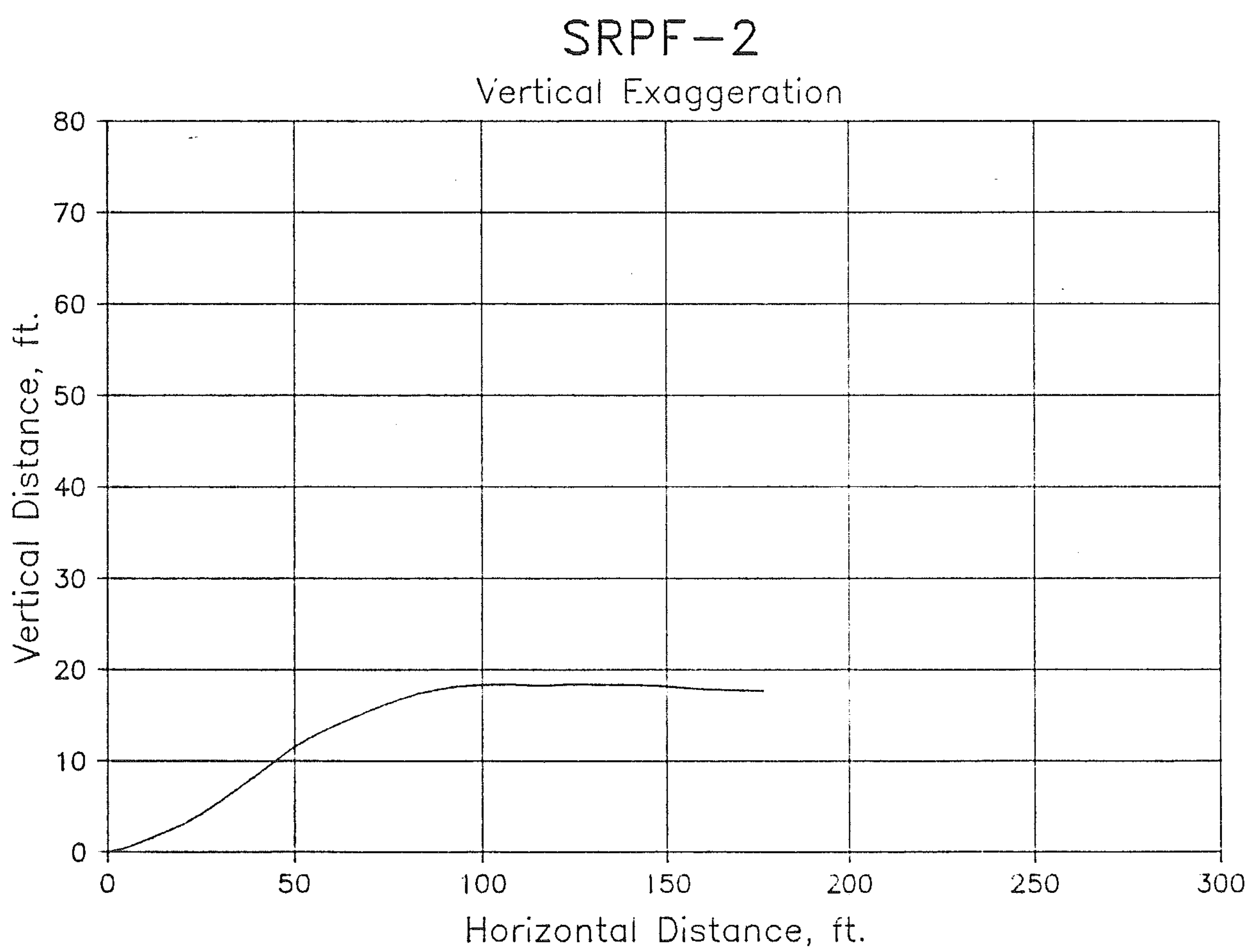
Appendix E

Summary of soil properties

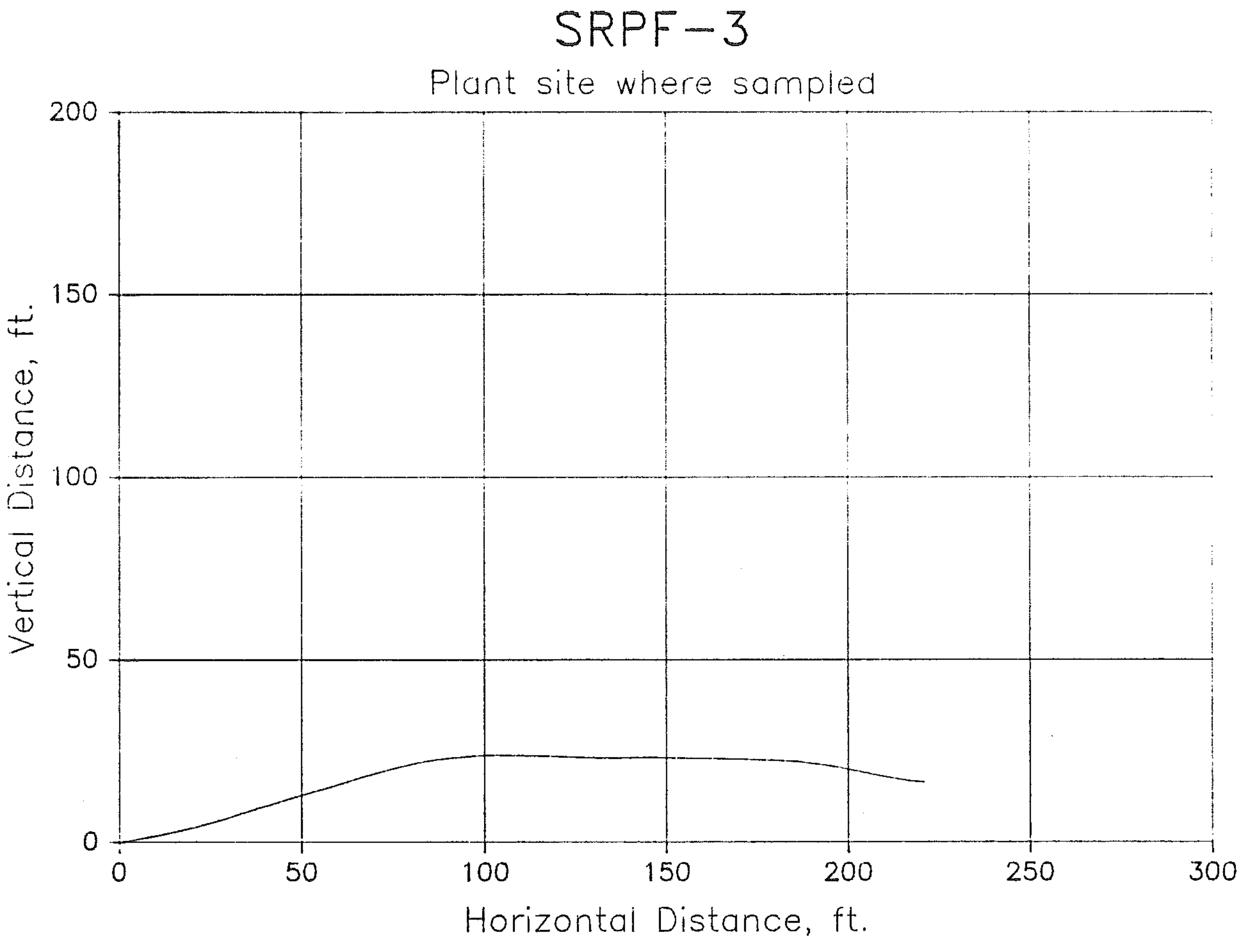
Soil	% + No.4	% - No. 200	PI
SRS1 w/+1"	22	40	20
SRS1 w/-1"	13	32	20
IP9	6	46	8
SRP5	3	55	17
SRP5 +10% SRG1	8	52	17
SRP5 +30% SRG1	31	30	17
SRP5 +10% IG1 +20% SRG1	29	36	17
SRP5 +20% IG1 +20% SRG1	43	8	17
SRP5 +30% Slate Creek	23	12	17
SRG1	51	9	NP
IG1	97	0	NP
SRG8	72	0	NP
SRDC	13	2	NP
SRDC +30% SRG1 (- 1.5")	39	1	NP
SRP5000	4	40	3
SRP5 +30% SRG1(1/2 -3/4")	45	37	17

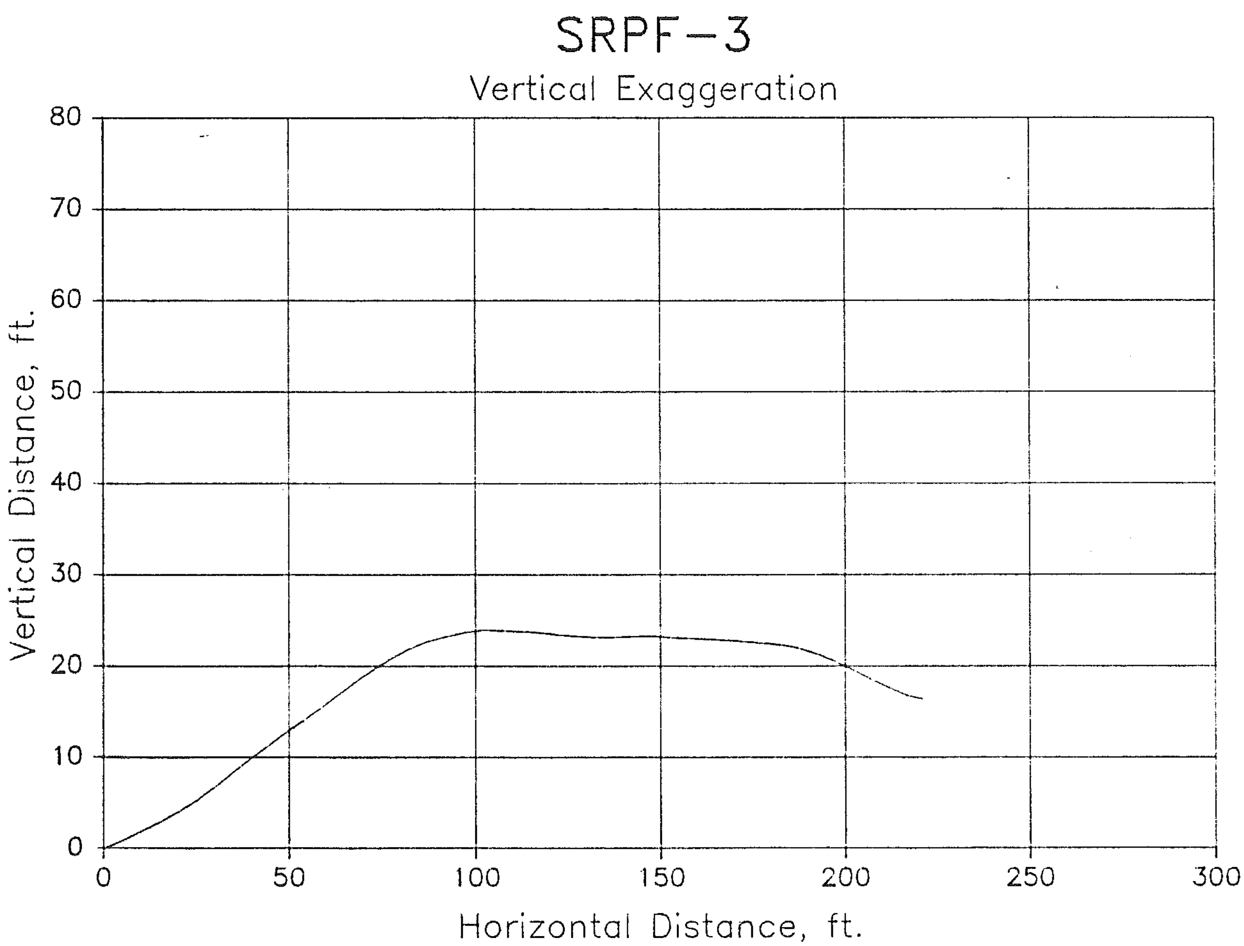


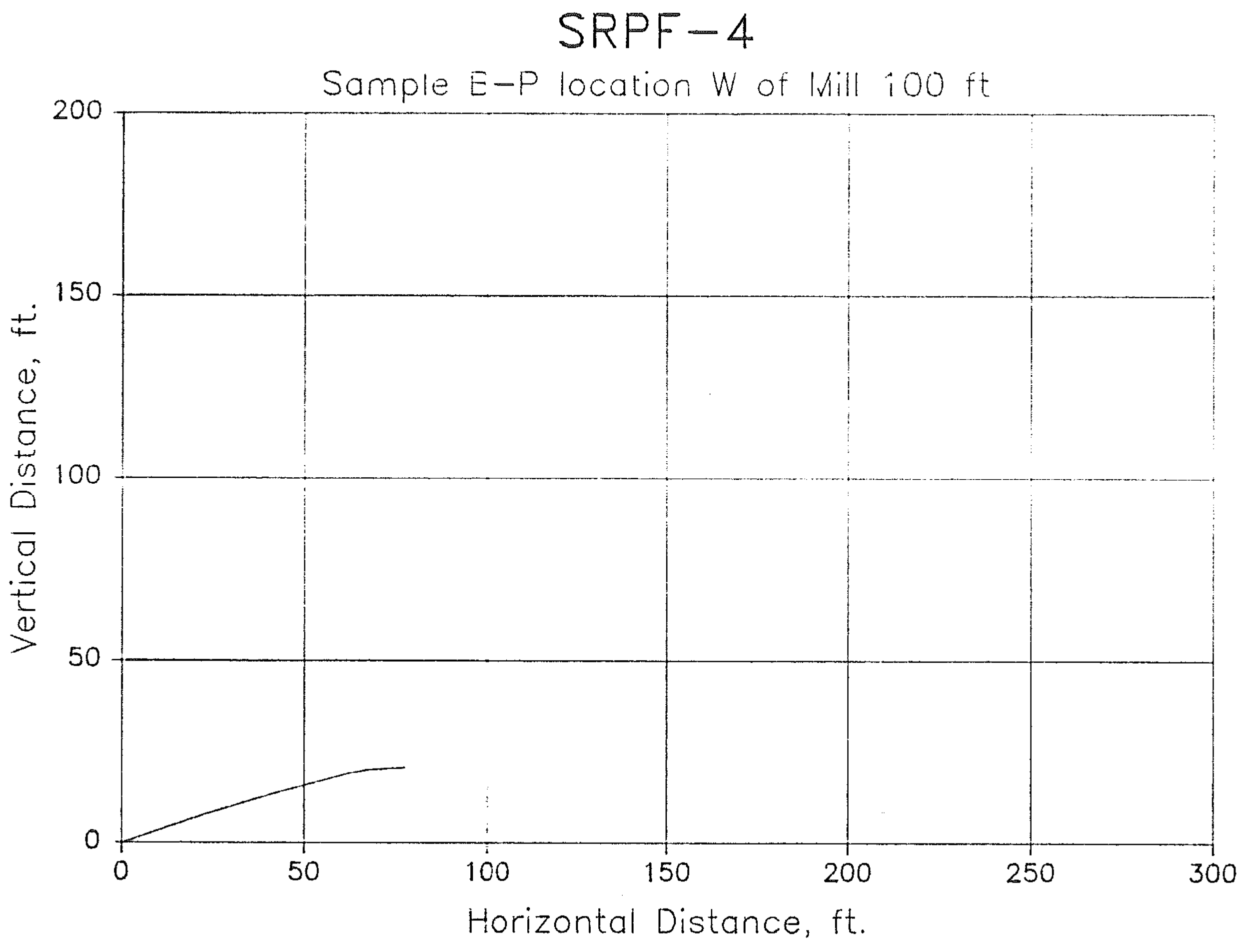
SRPF-2
+80 ft east of pump house
Vertical Distance, ft.
200
150
100
50
0
0
50
100
150
200
250
300
Horizontal Distance, ft.

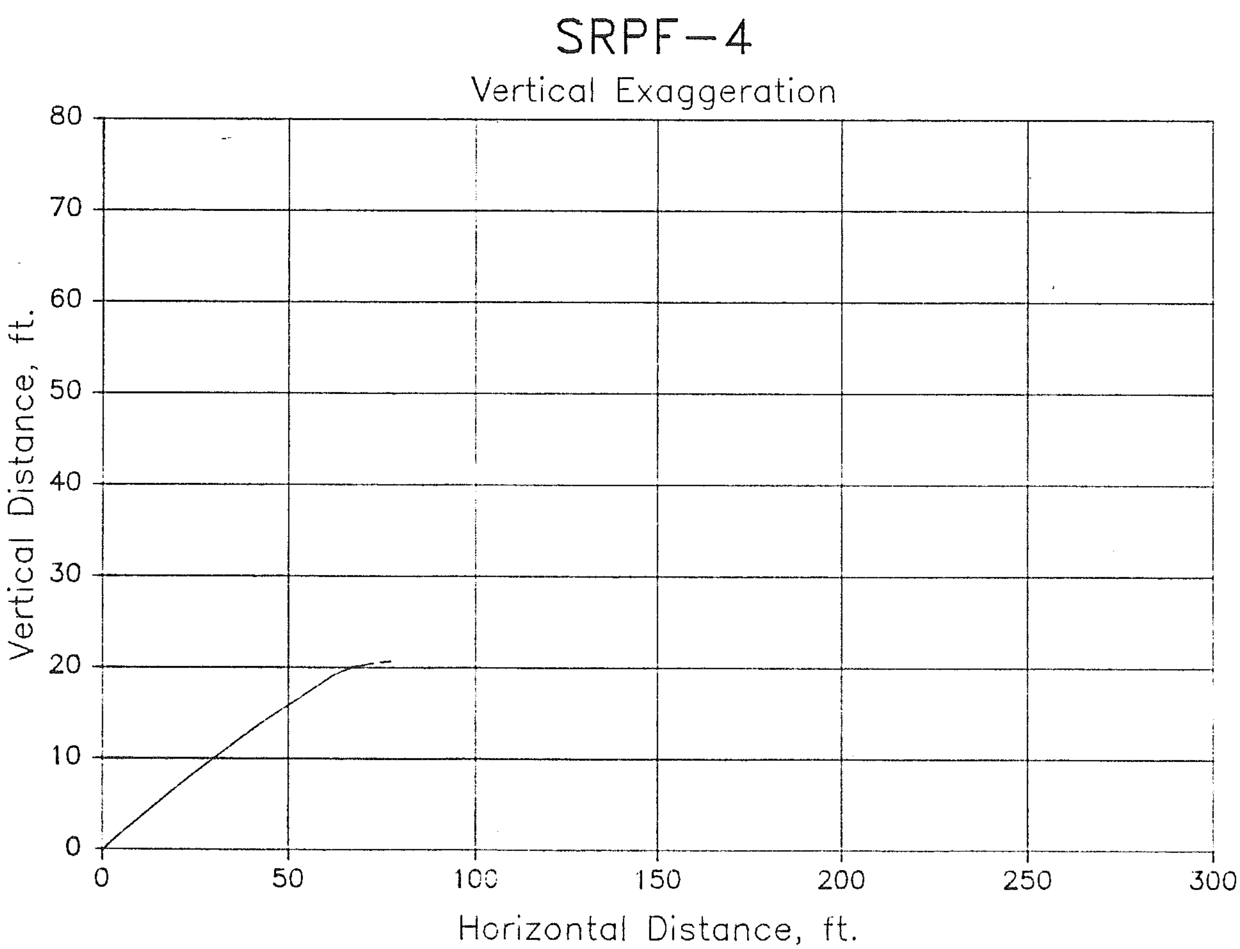


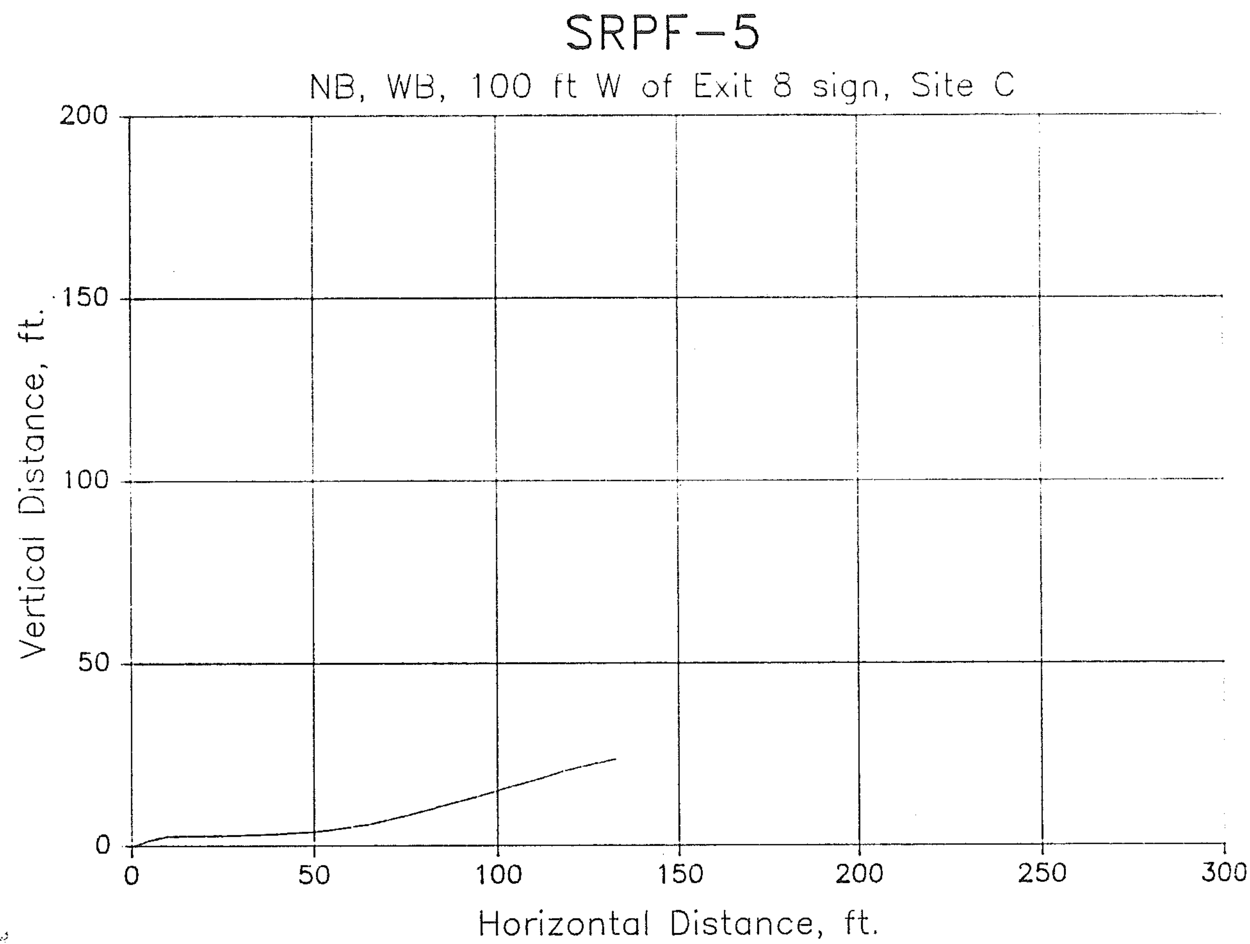
SRPF-2
Vertical Exaggeration
Vertical Distance, ft.
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Horizontal Distance, ft.

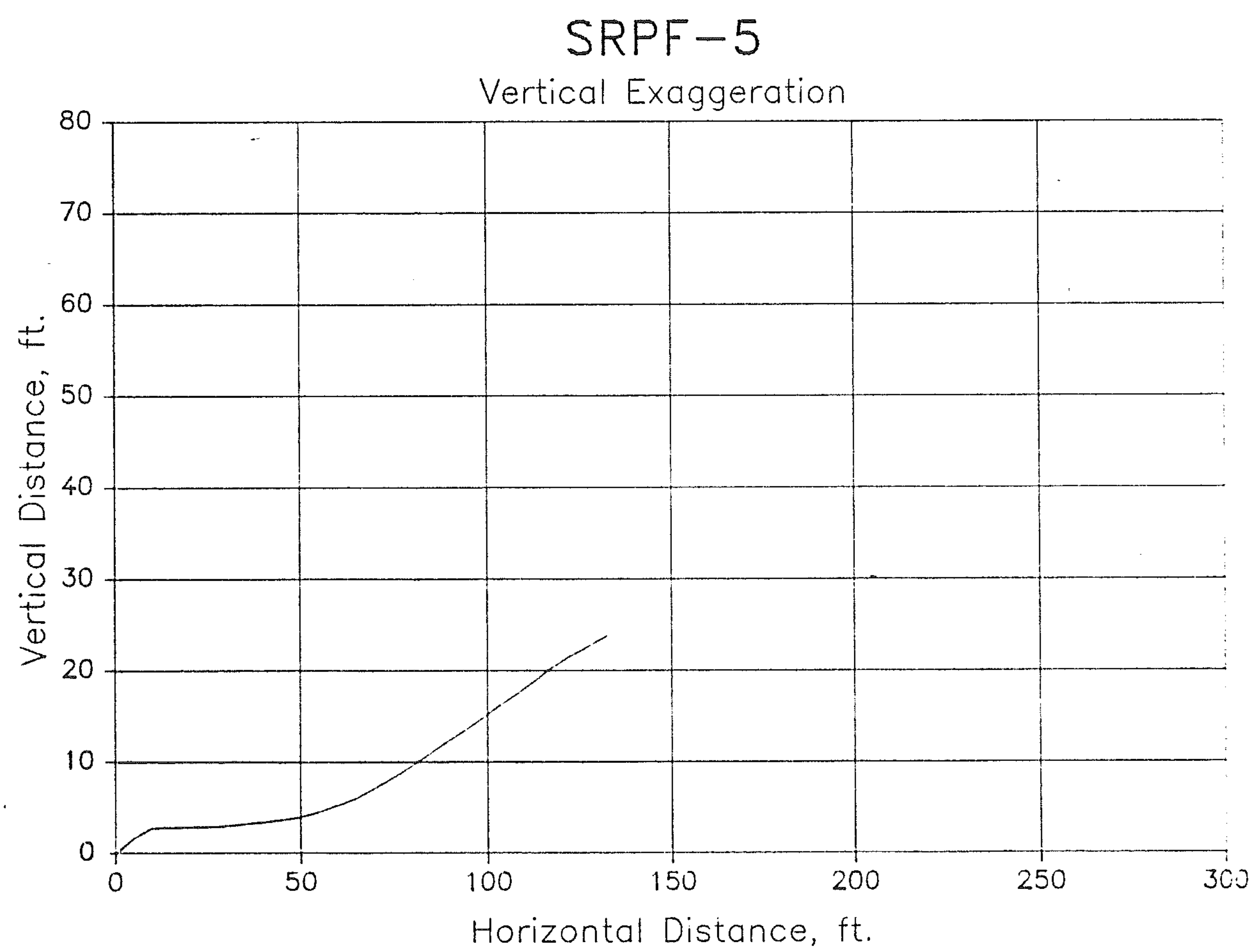

SRPF-3
Plant site where sampled
Vertical Distance, ft.
200
150
100
50
0
0
50
100
150
200
250
300
Horizontal Distance, ft.

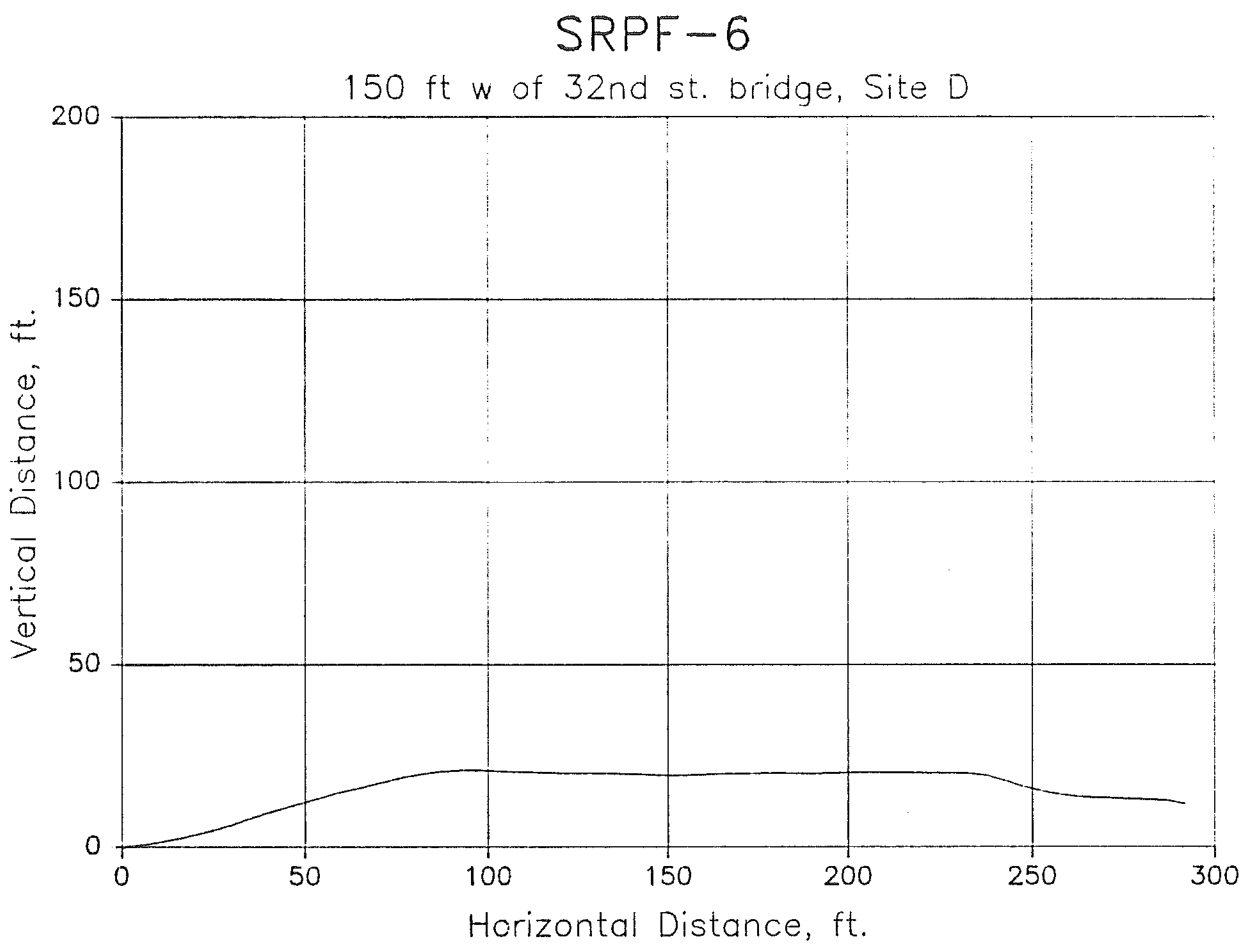

SRPF-3
Vertical Exaggeration
Vertical Distance, ft.
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Horizontal Distance, ft.

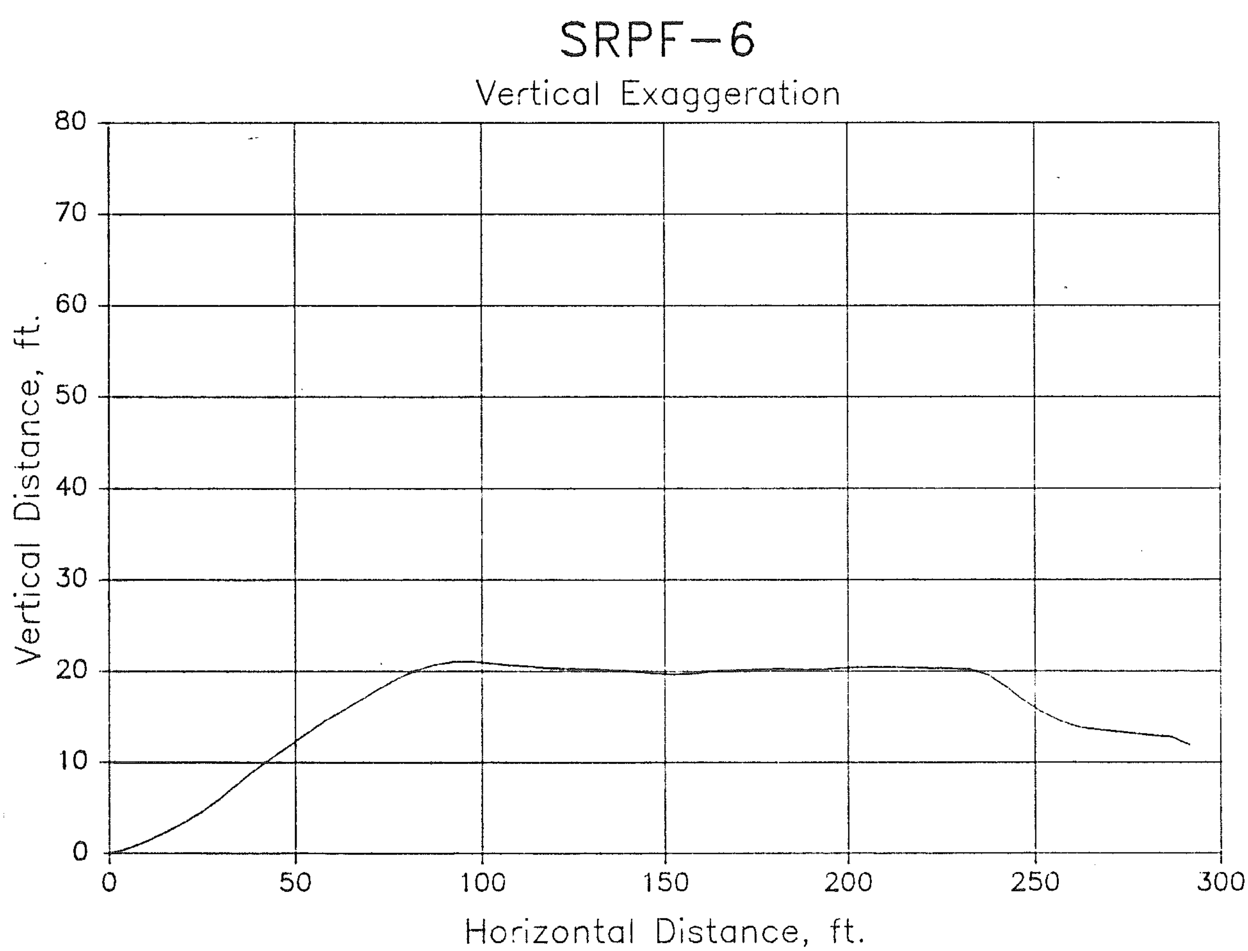

SRPF-4
Sample E-P location W of Mill 100 ft
Vertical Distance, ft.
200
150
100
50
0
0
50
100
150
200
250
300
Horizontal Distance, ft.


SRPF-4
Vertical Exaggeration
Vertical Distance, ft.
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Horizontal Distance, ft.


SRPF-5
NB, WB, 100 ft W of Exit 8 sign, Site C
Vertical Distance, ft.
Horizontal Distance, ft.
0
50
100
150
200
250
300

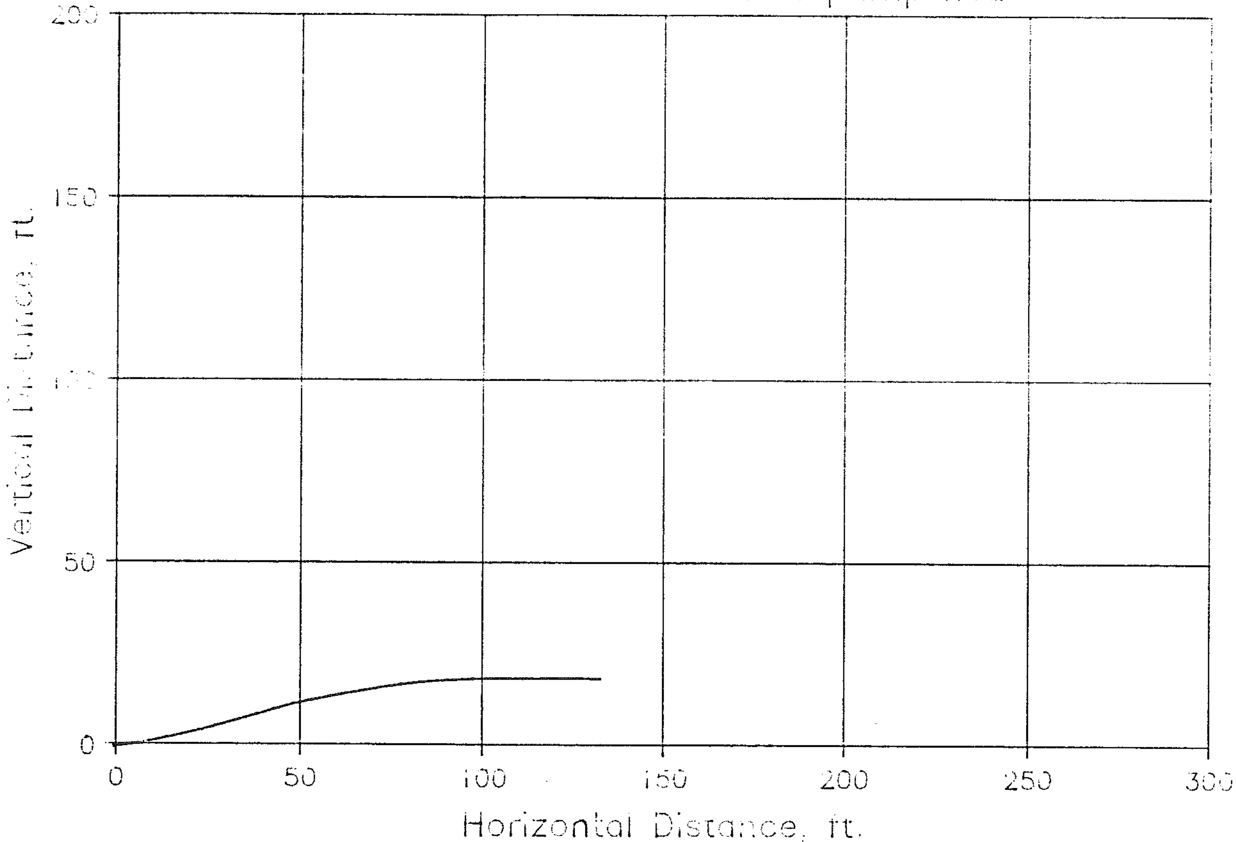

SRPF-5
Vertical Exaggeration
Vertical Distance, ft.
Horizontal Distance, ft.
0
10
20
30
40
50
60
70
80
100
150
200
250
300


SRPF-6
150 ft w of 32nd st. bridge, Site D
Vertical Distance, ft.
Horizontal Distance, ft.
0
50
100
150
200
250
300


SRPF-6
Vertical Exaggeration
Vertical Distance, ft.
Horizontal Distance, ft.
0
10
20
30
40
50
60
70
80
100
150
200
250
300

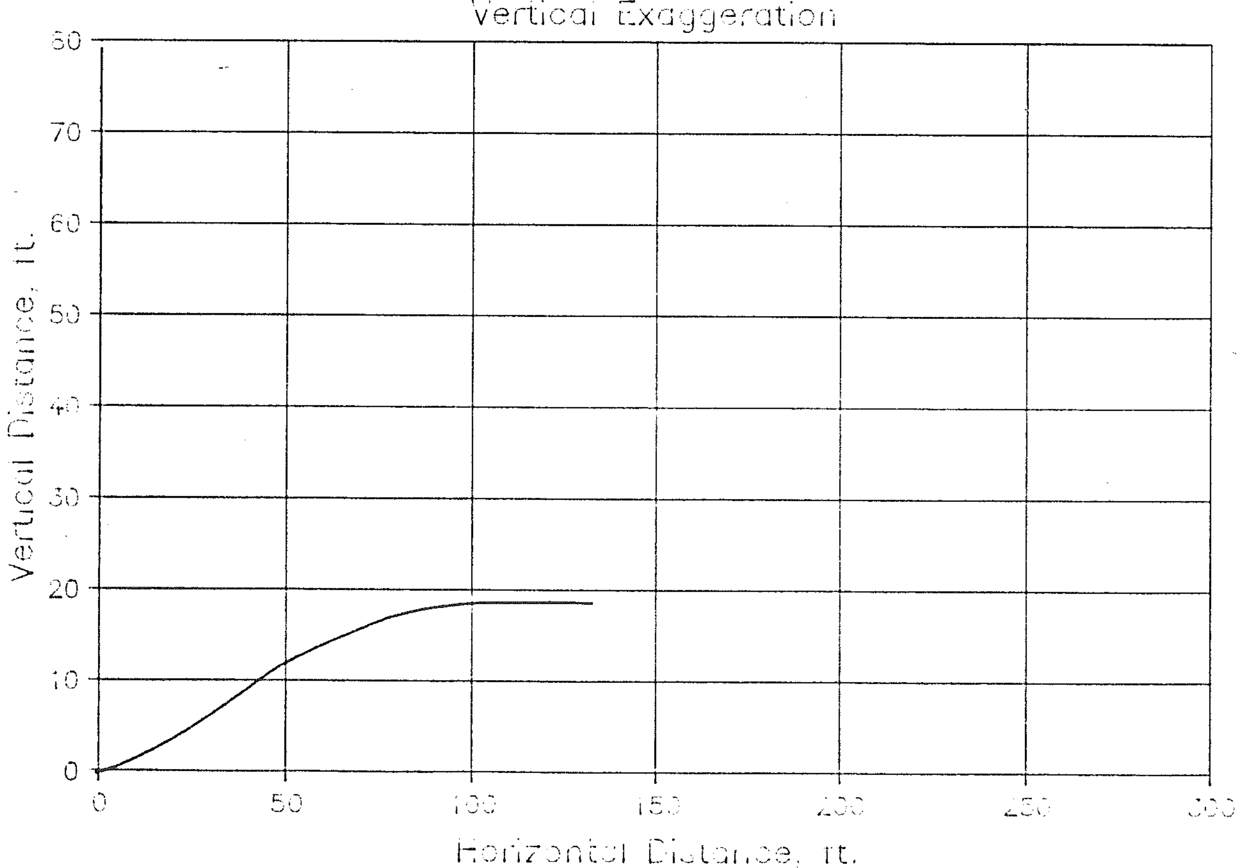
SRPF-7

W. of Gilbert [illegible] W of pump house



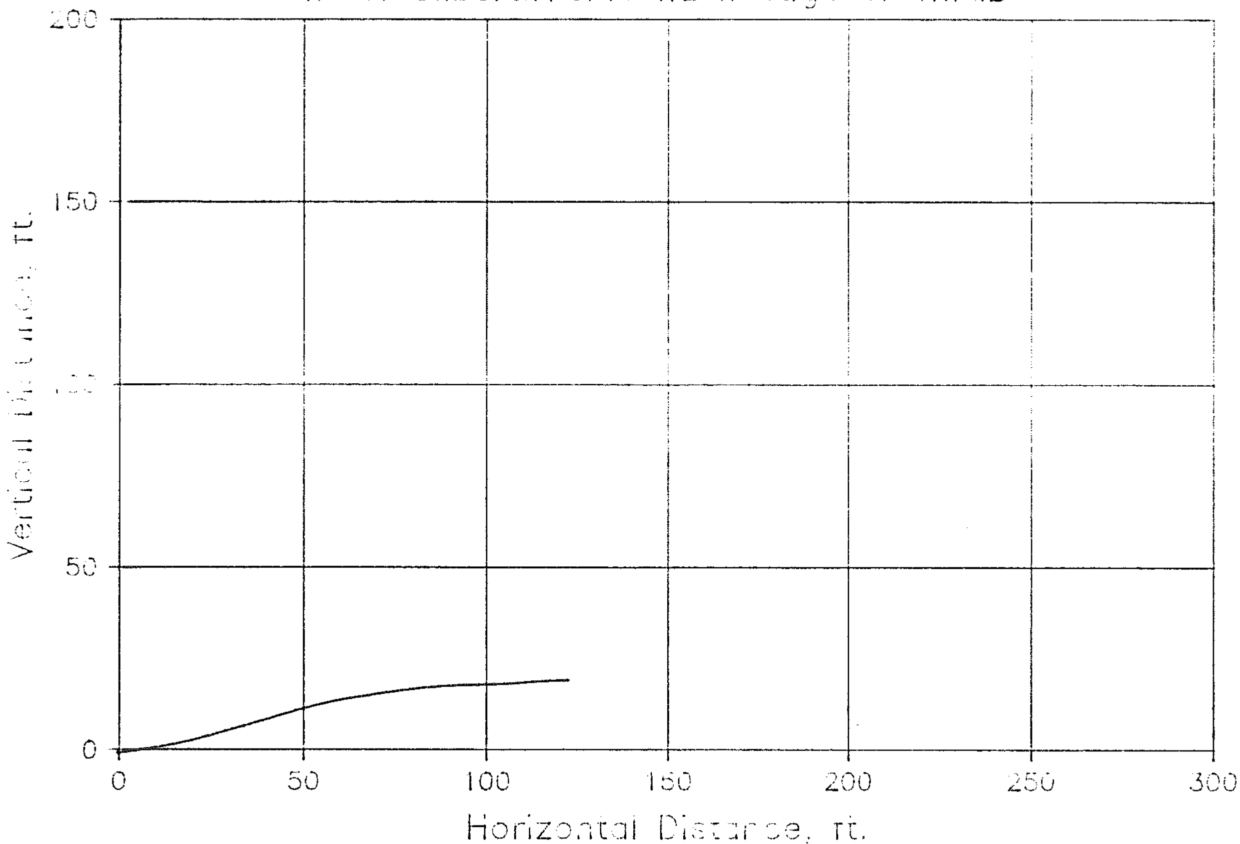
SRPF-7

Vertical Exaggeration



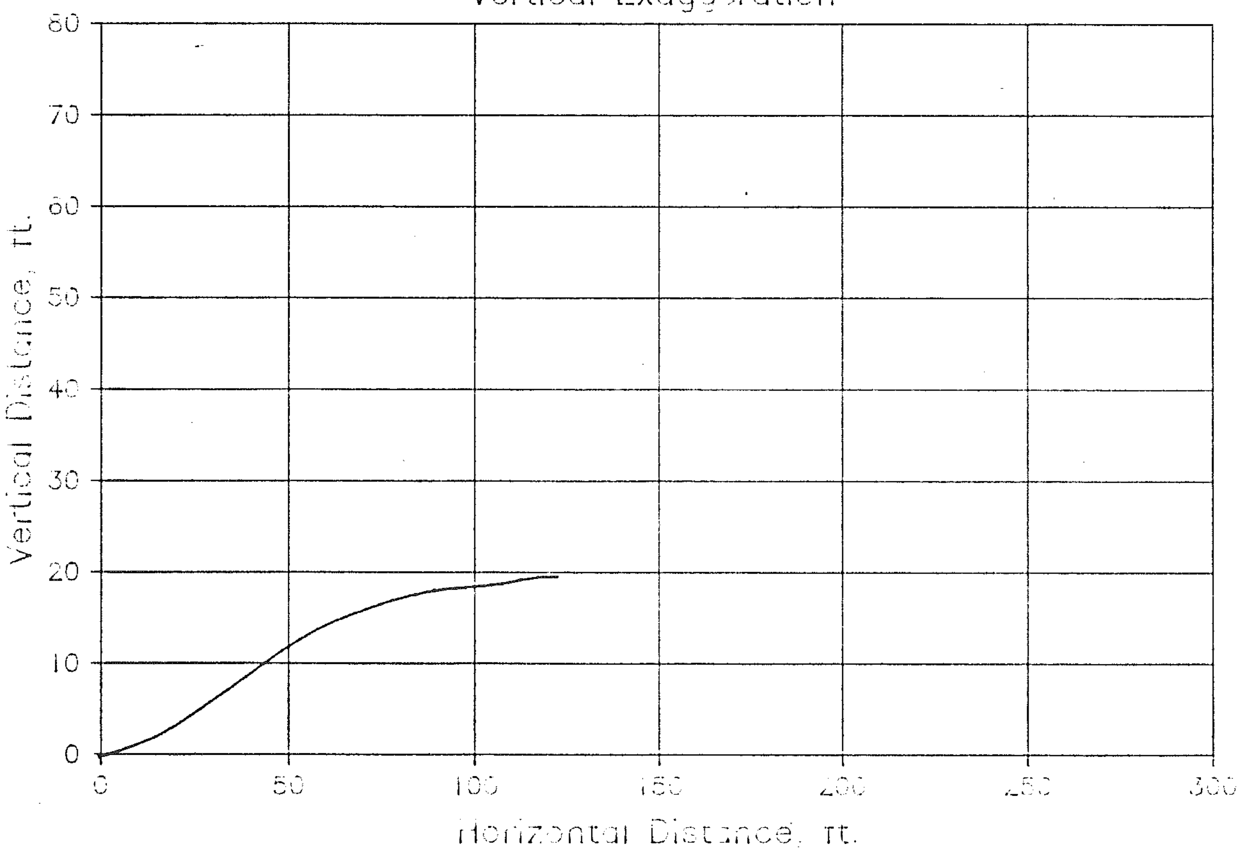
SRPF-8

W. [illegible]



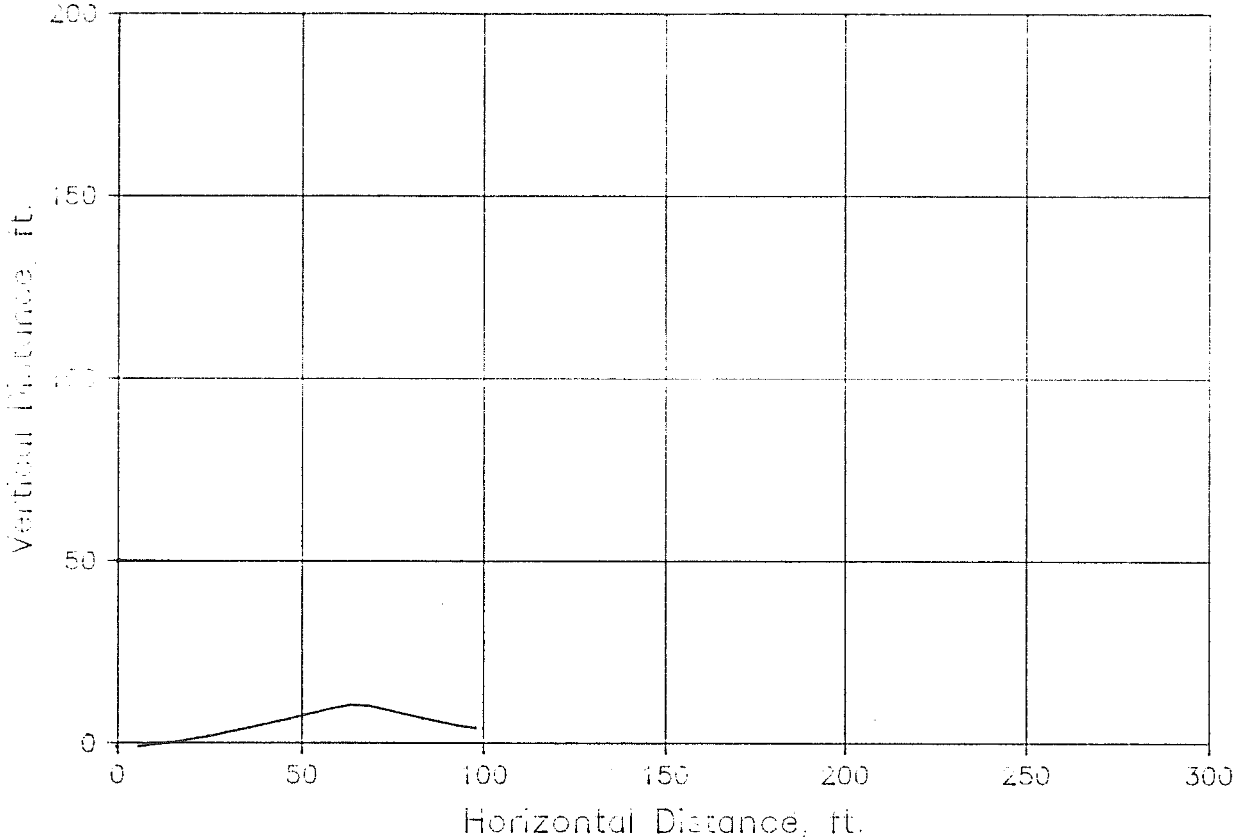
SRPF-8

Vertical Exaggeration



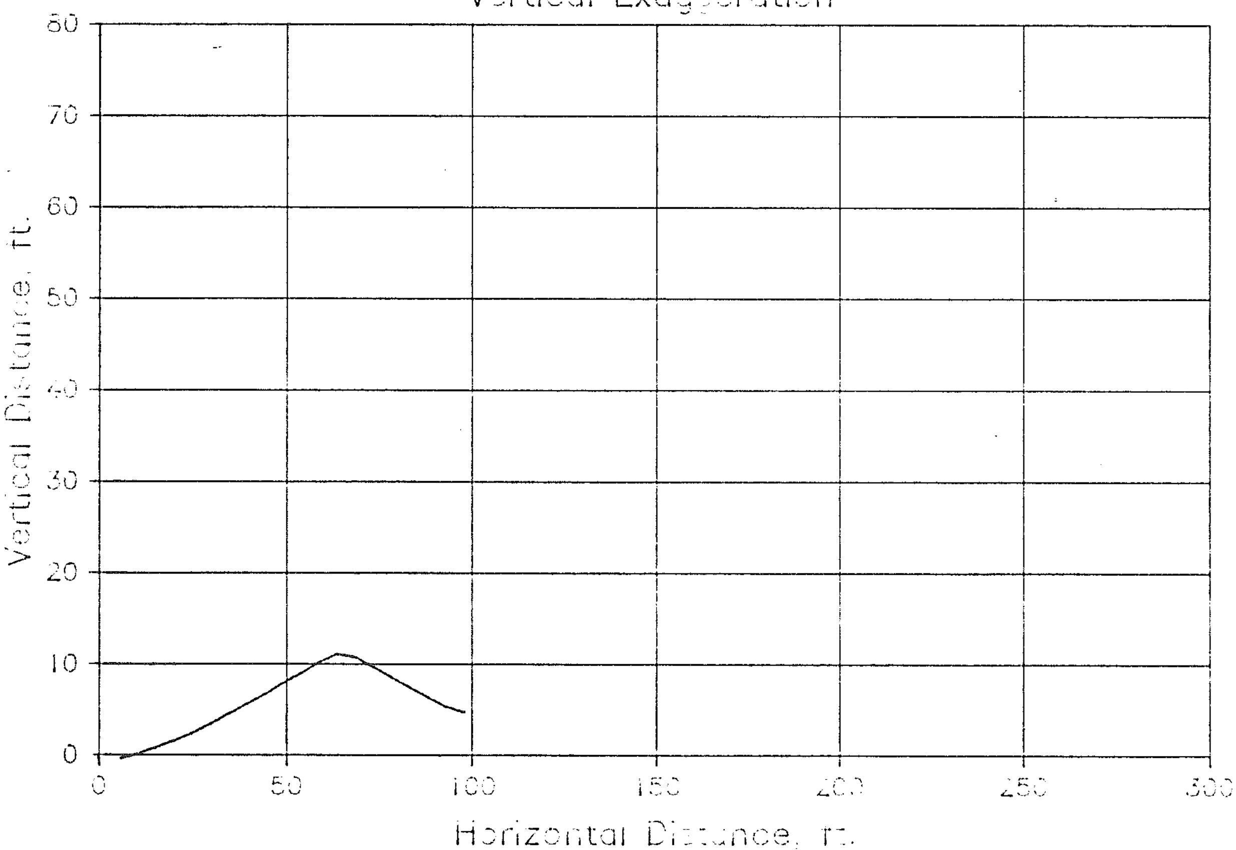
SRPF-9

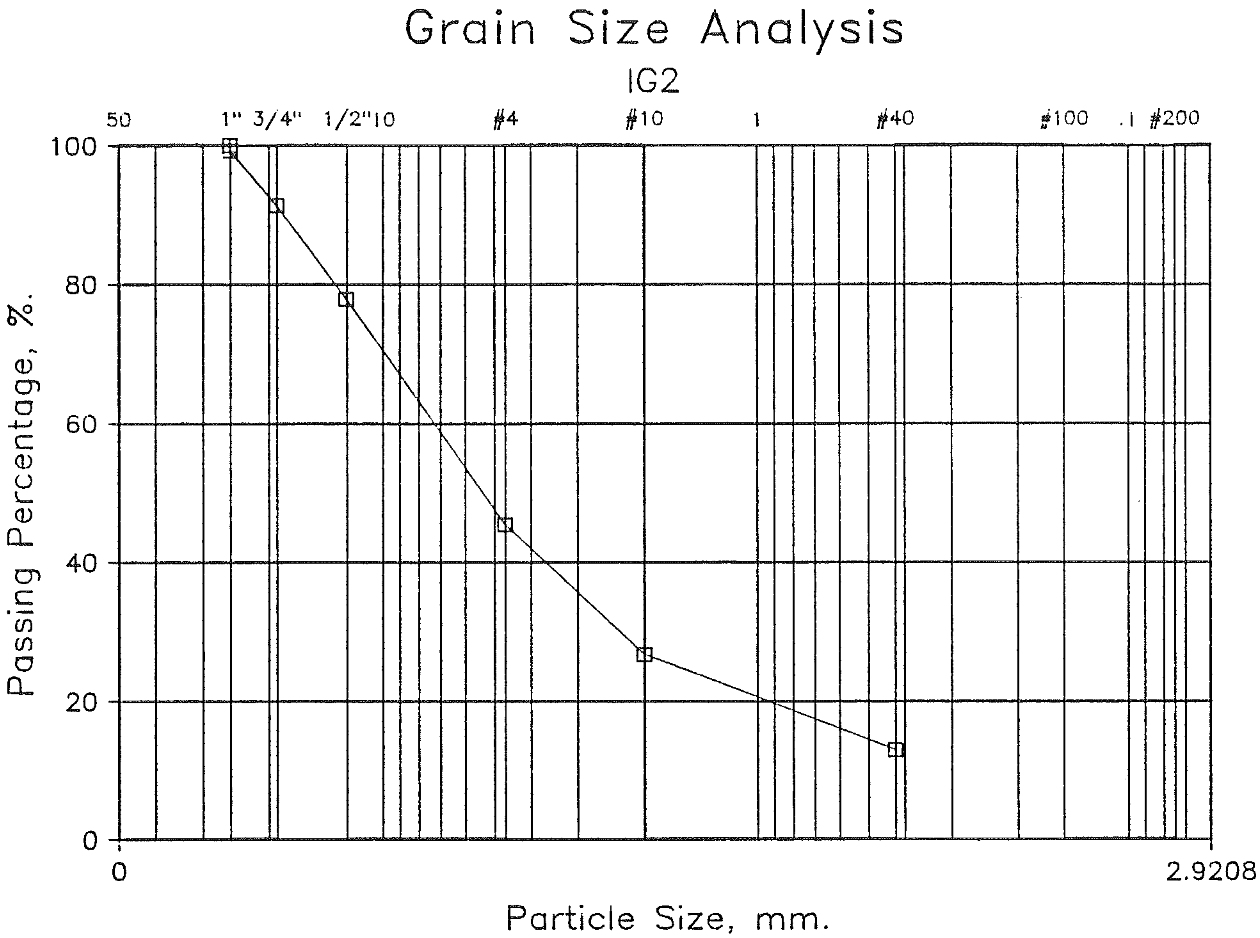
400 ft. W. of MP 13

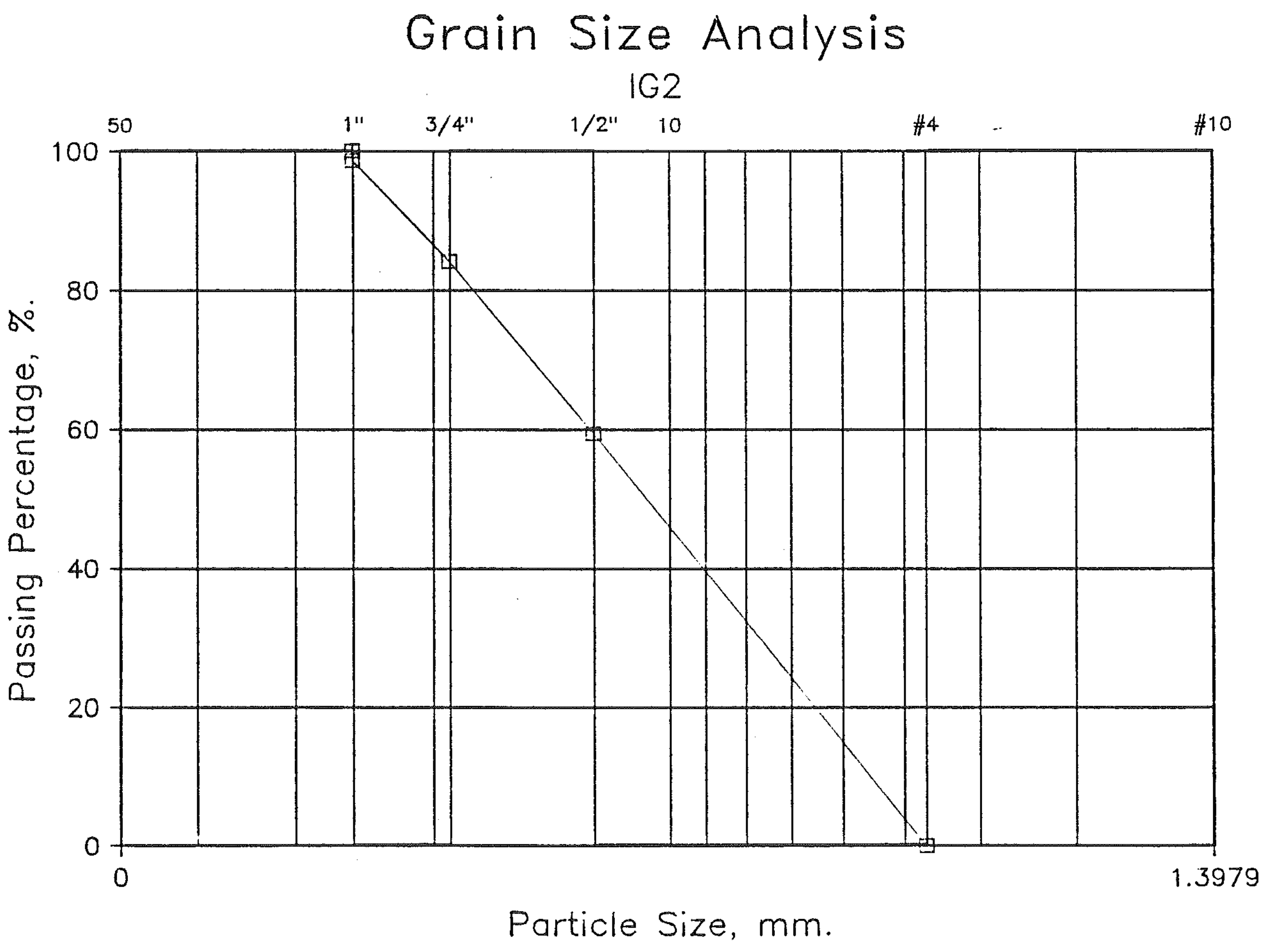


SRPF-9

Vertical Exaggeration

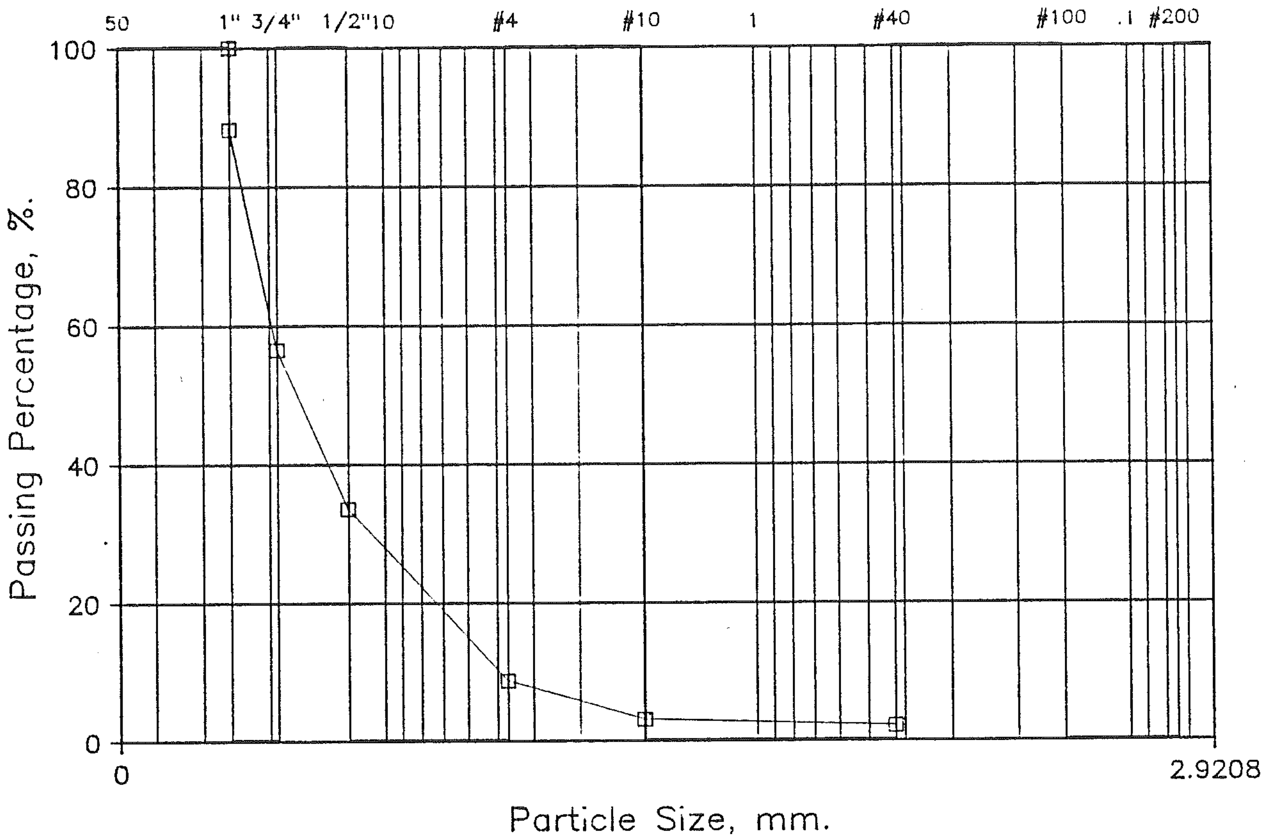



Grain Size Analysis
IG2
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
IG2
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

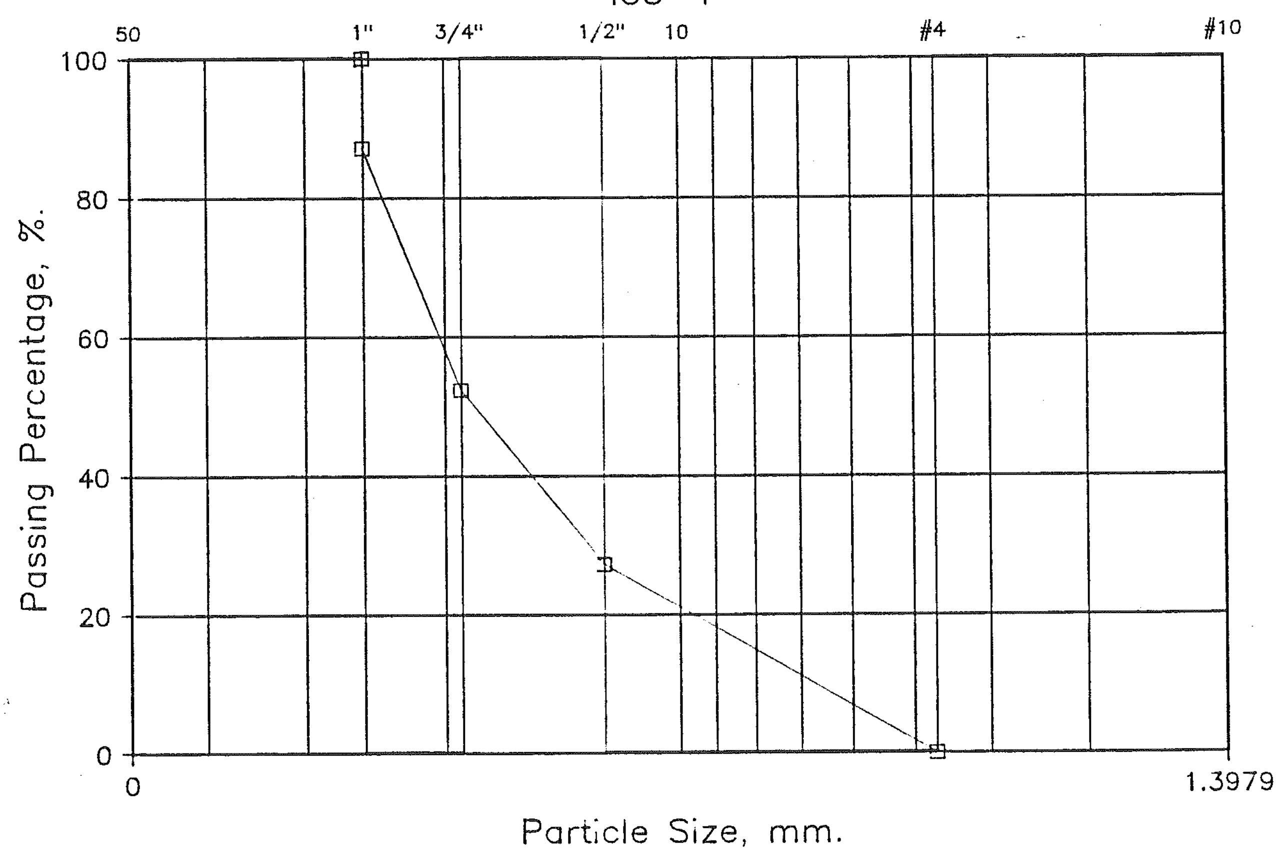
Grain Size Analysis

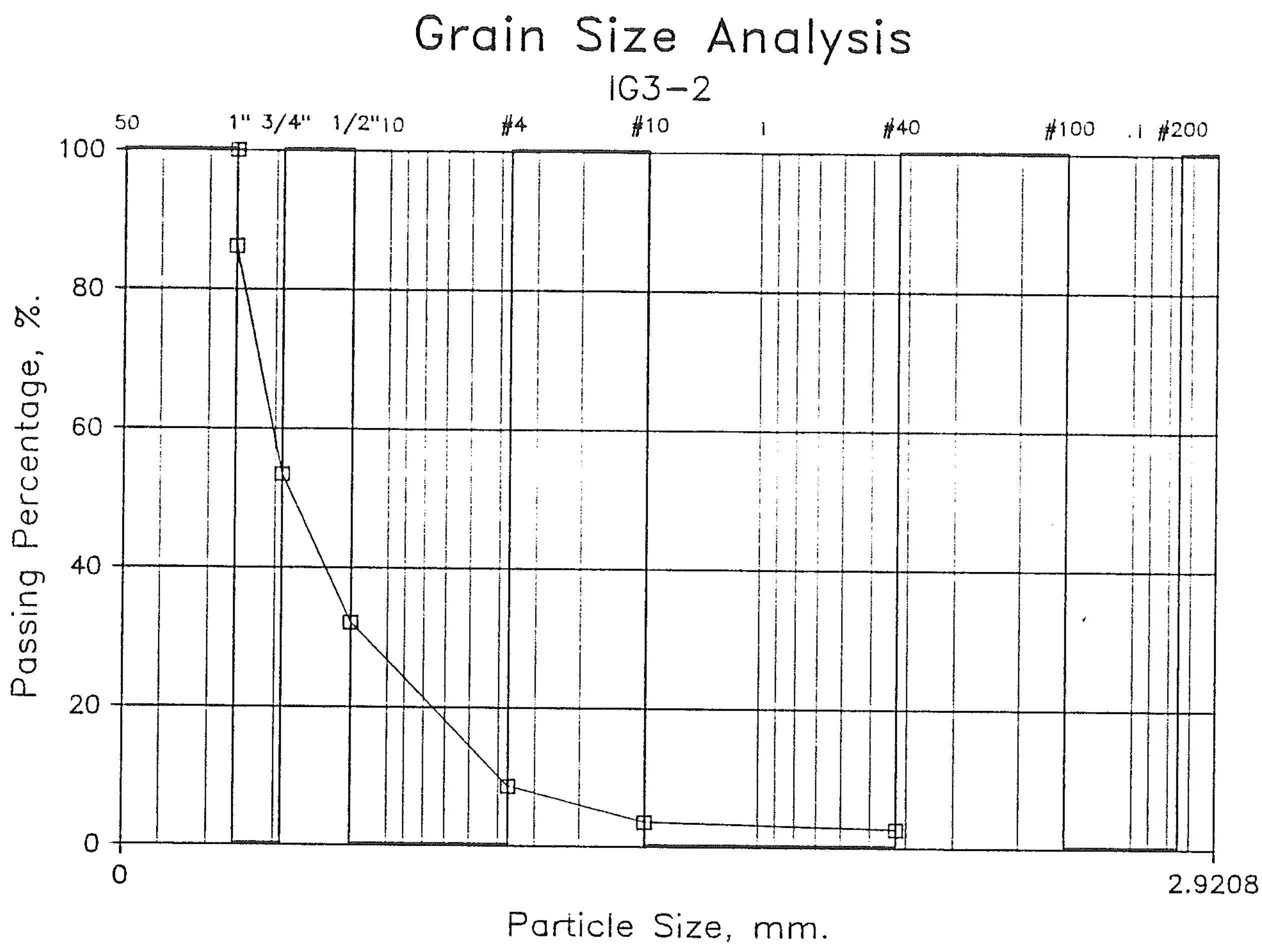
IG3-1

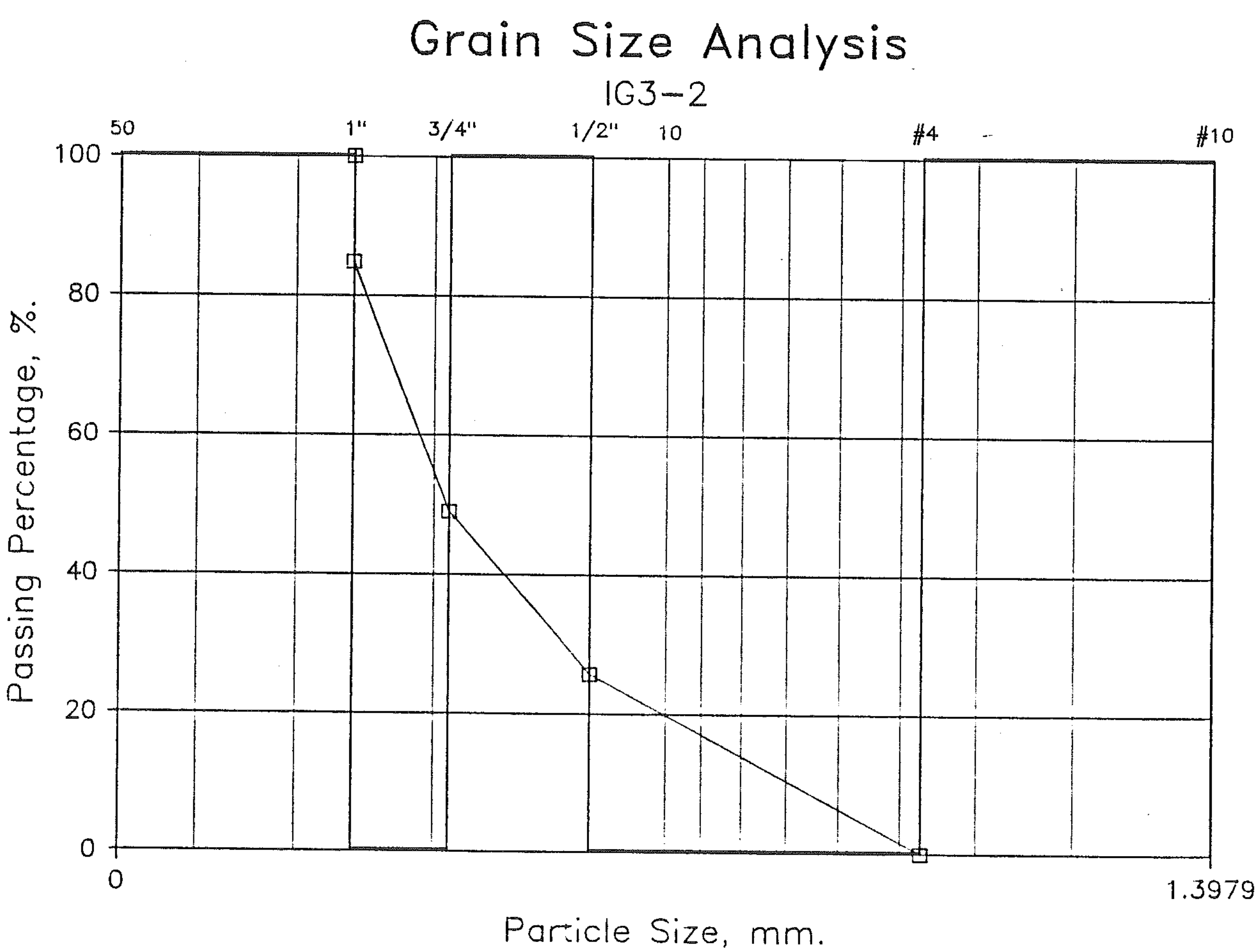


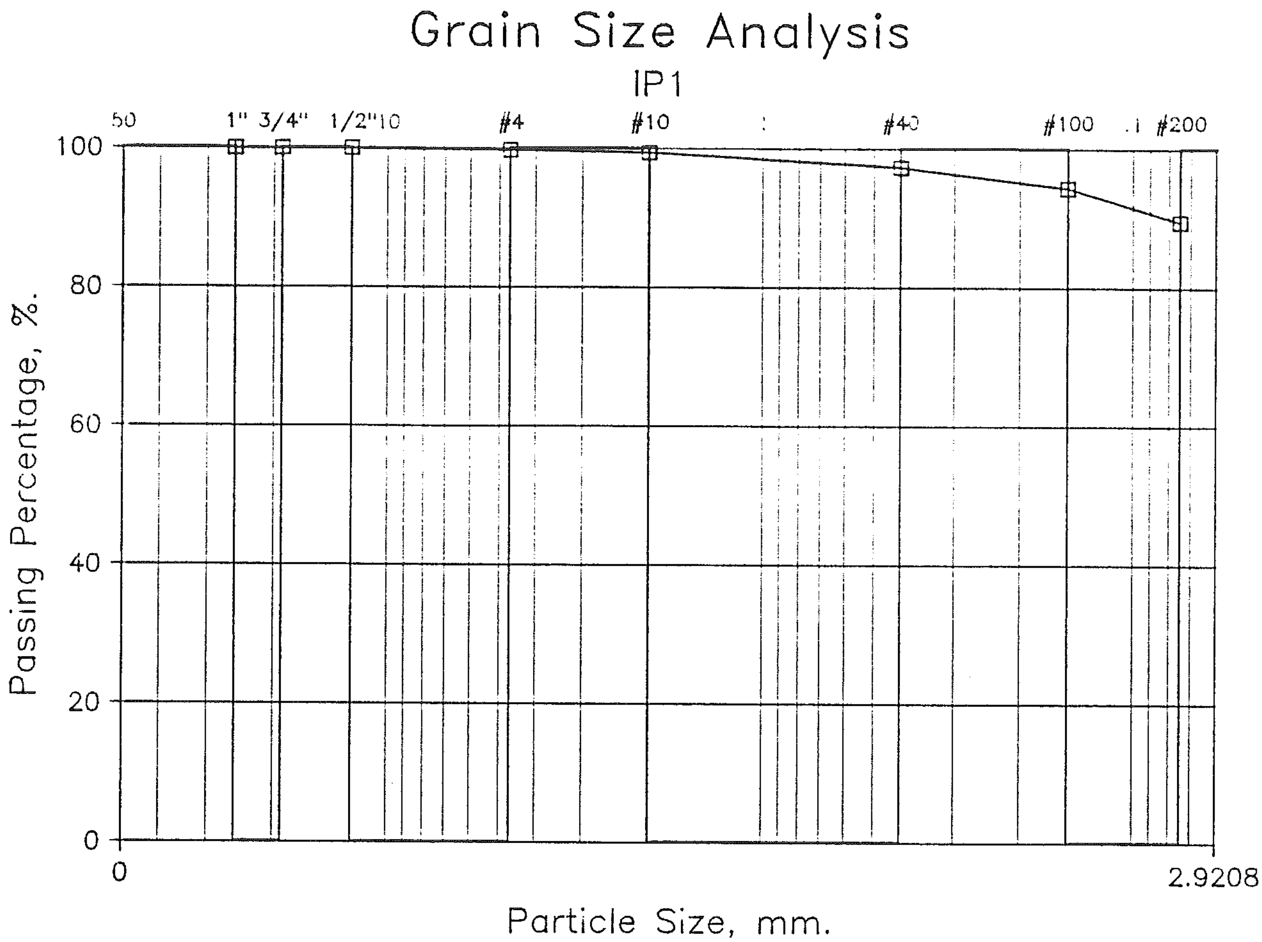
Grain Size Analysis

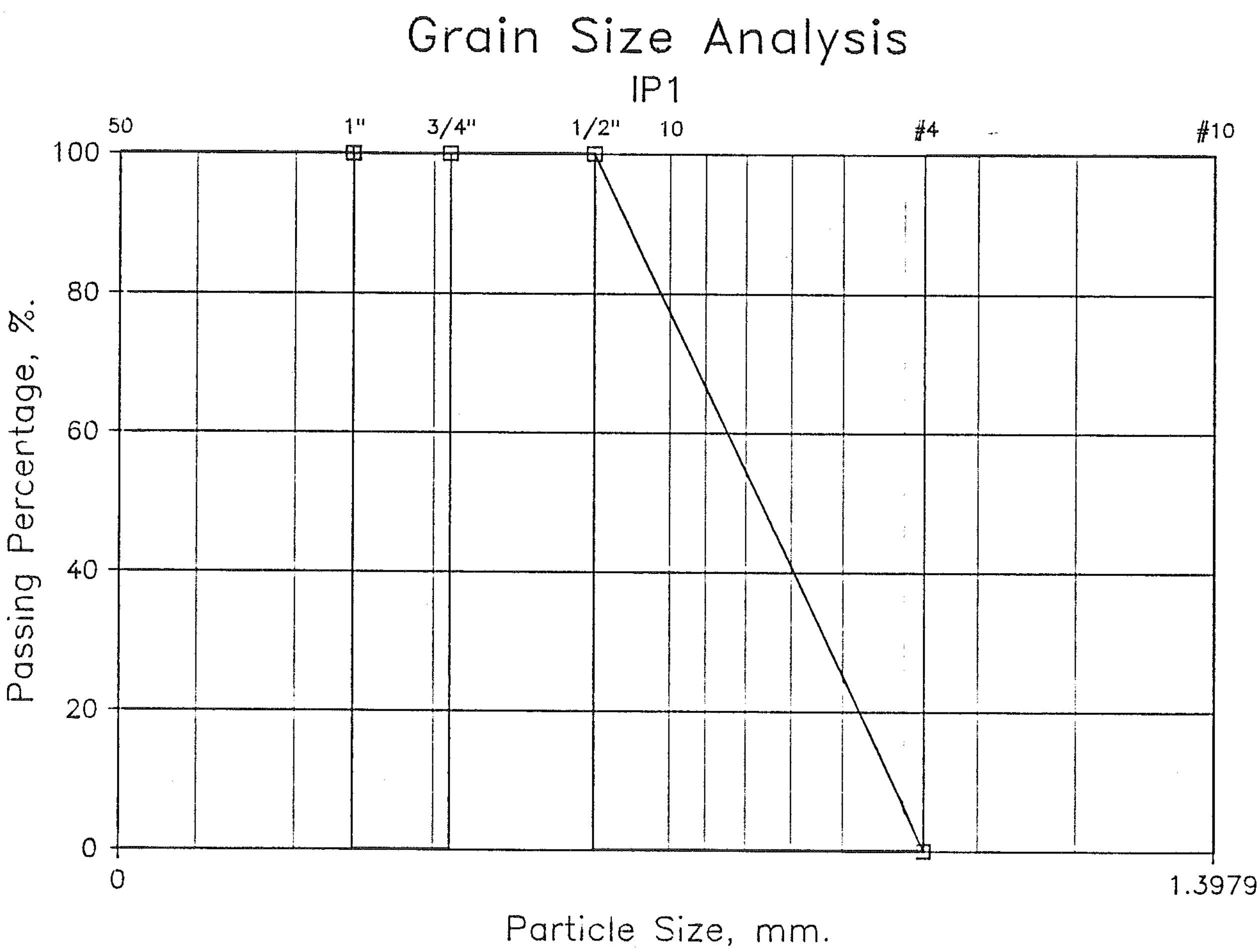
IG3-1

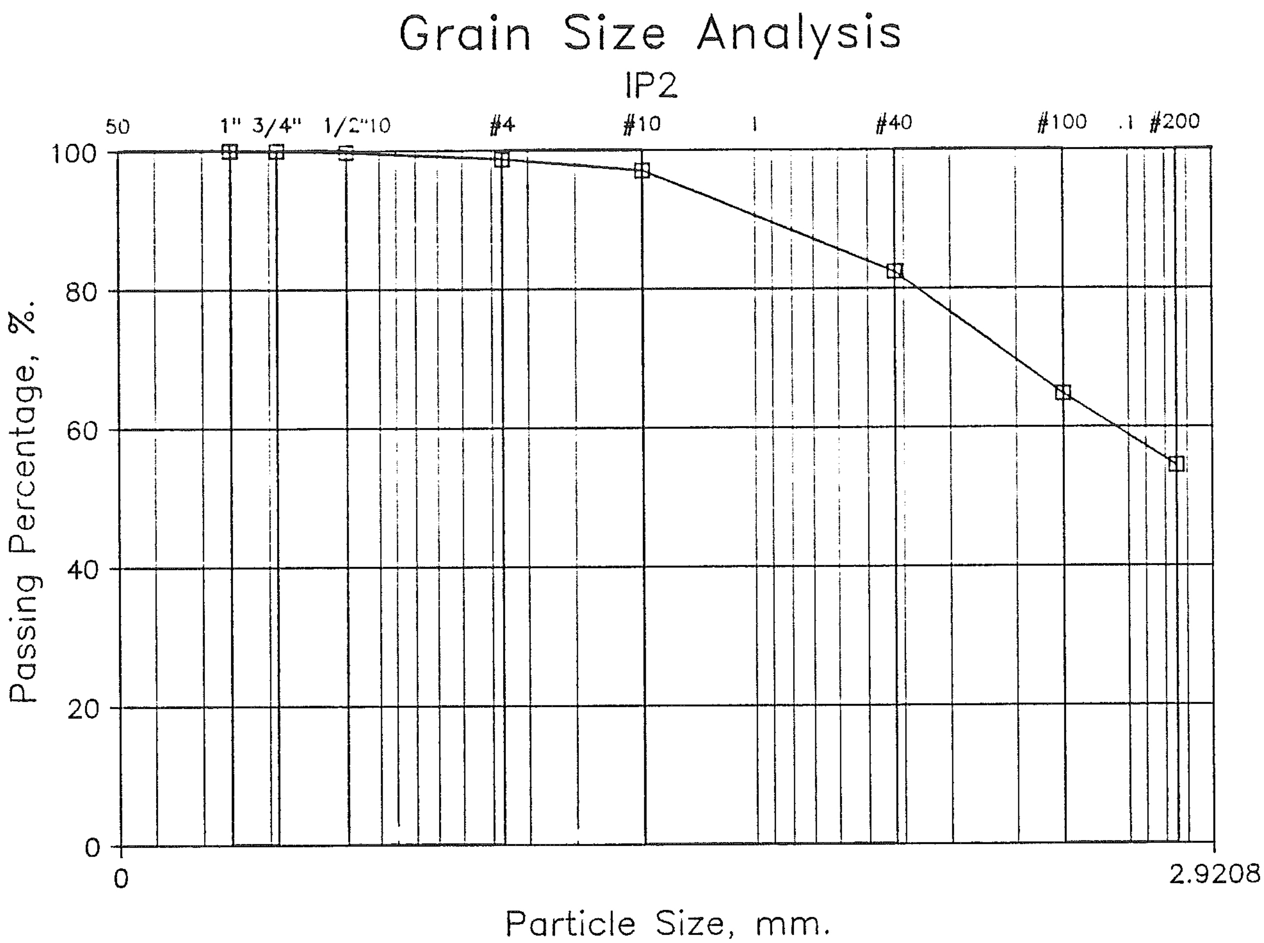


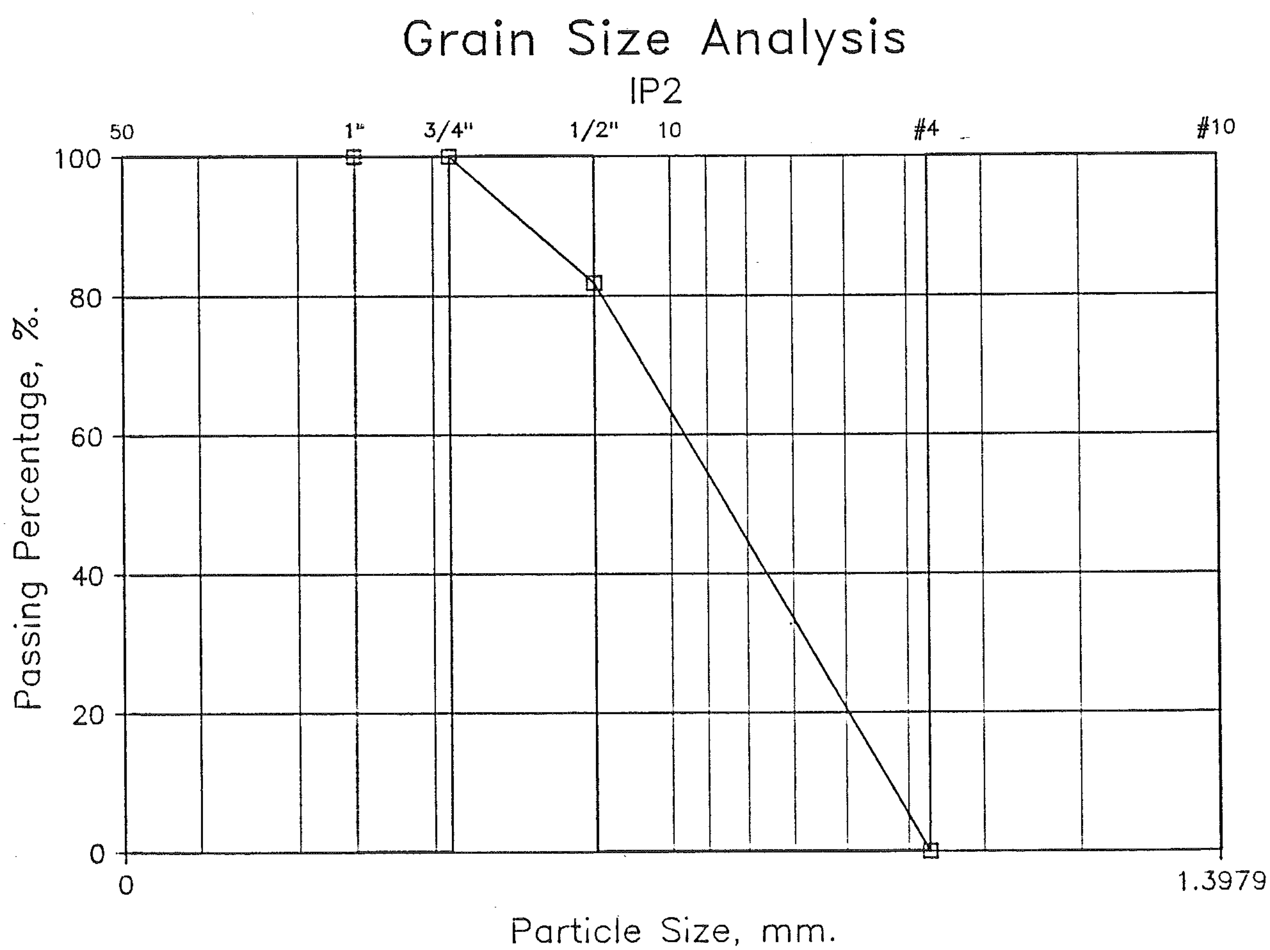

Grain Size Analysis
IG3-2
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
IG3-2
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
IP1
50
1"
3/4"
1/2"
10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

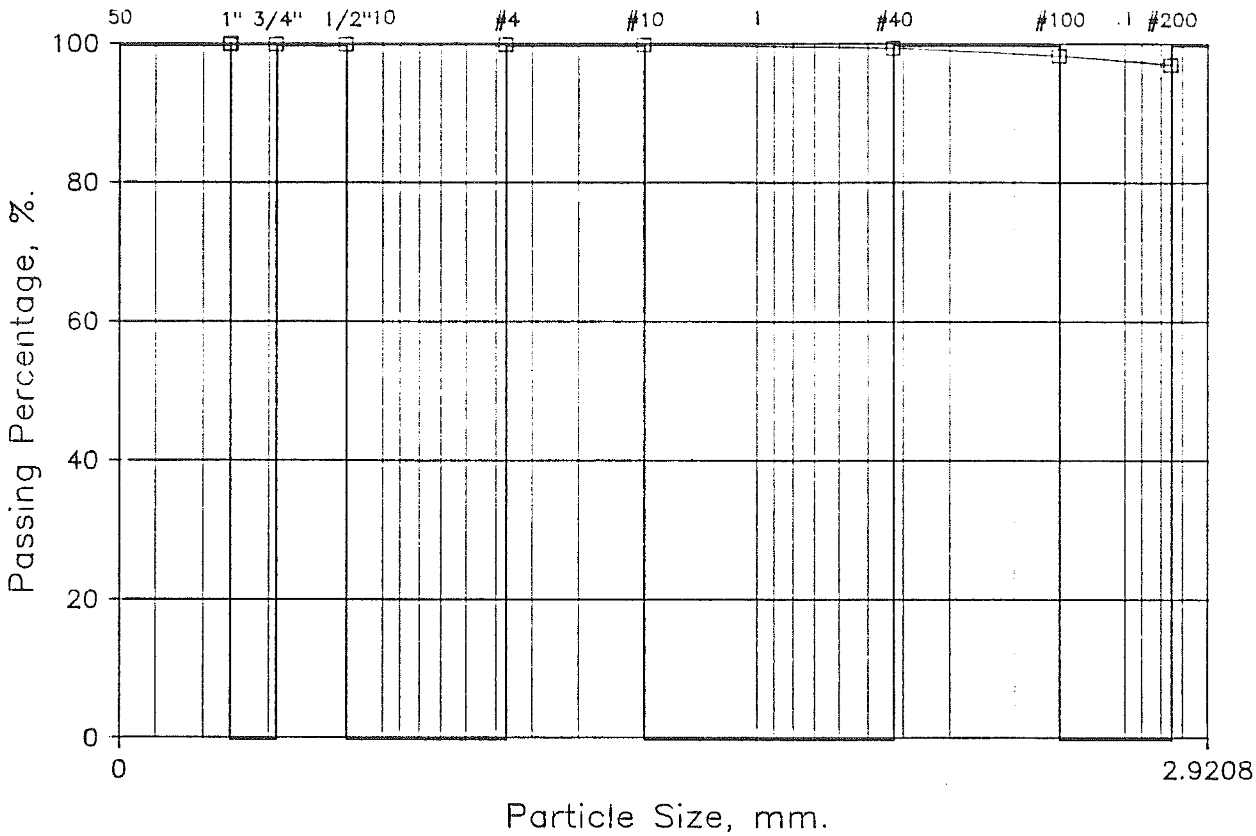

Grain Size Analysis
IP1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
IP2
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
0
2.9208
Passing Percentage, %.
Particle Size, mm.


Grain Size Analysis
IP2
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
0
1.3979
Passing Percentage, %.
Particle Size, mm.

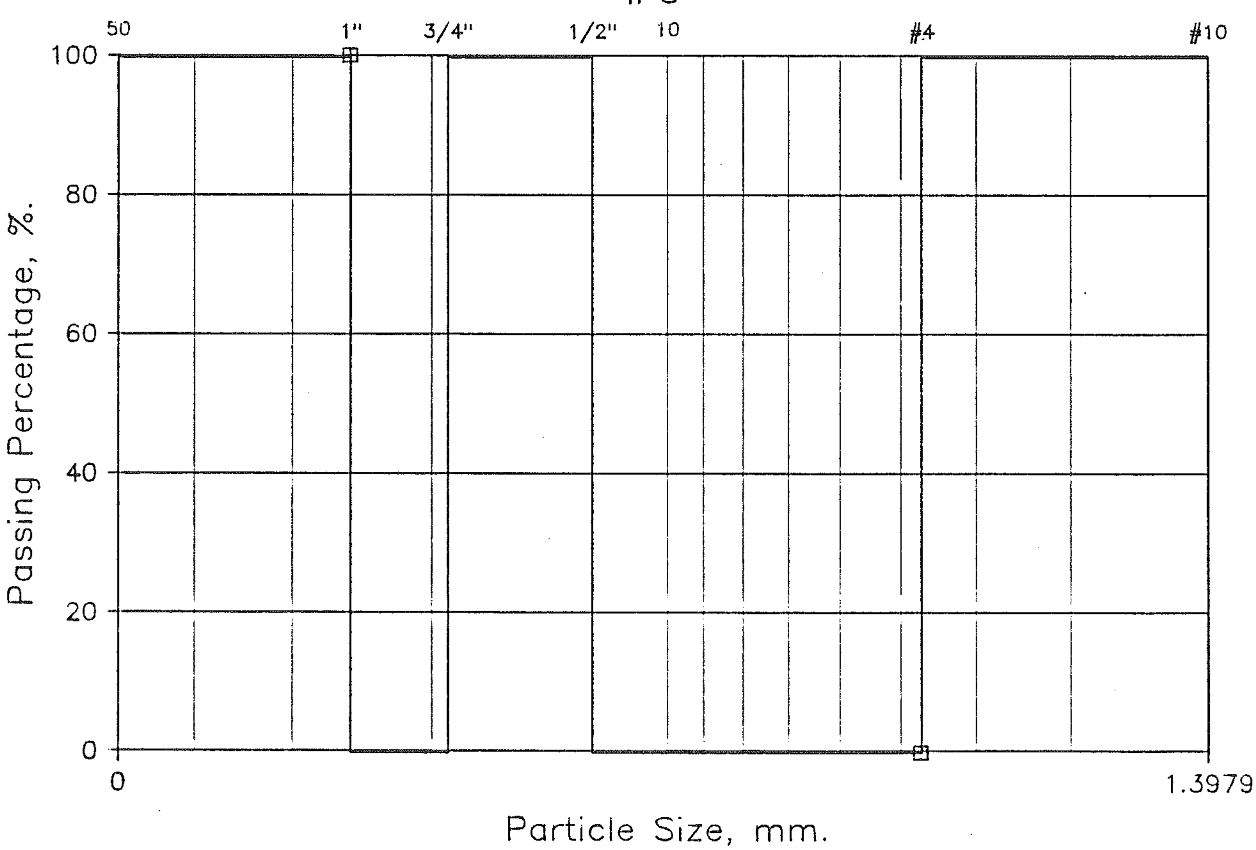
Grain Size Analysis

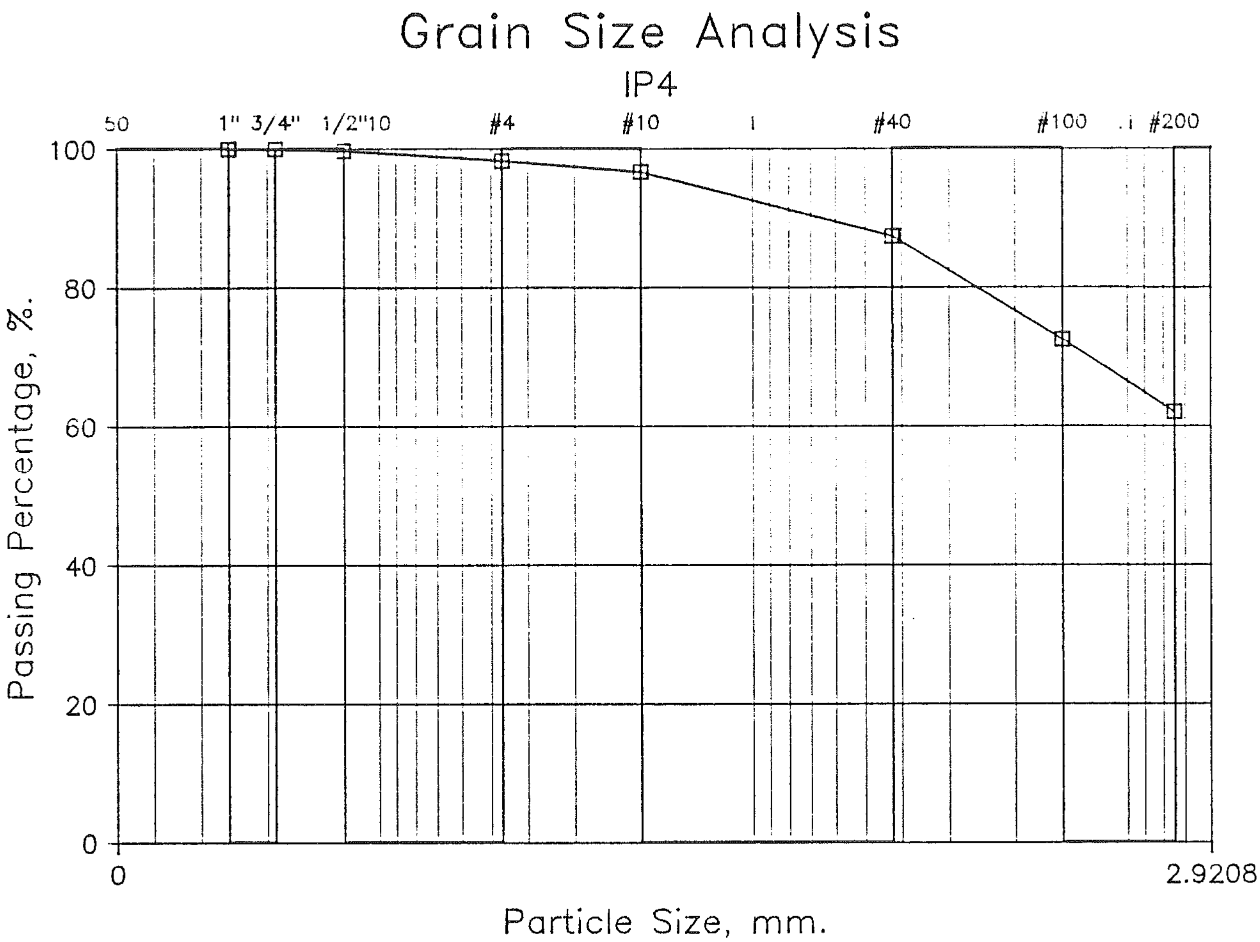
IP3

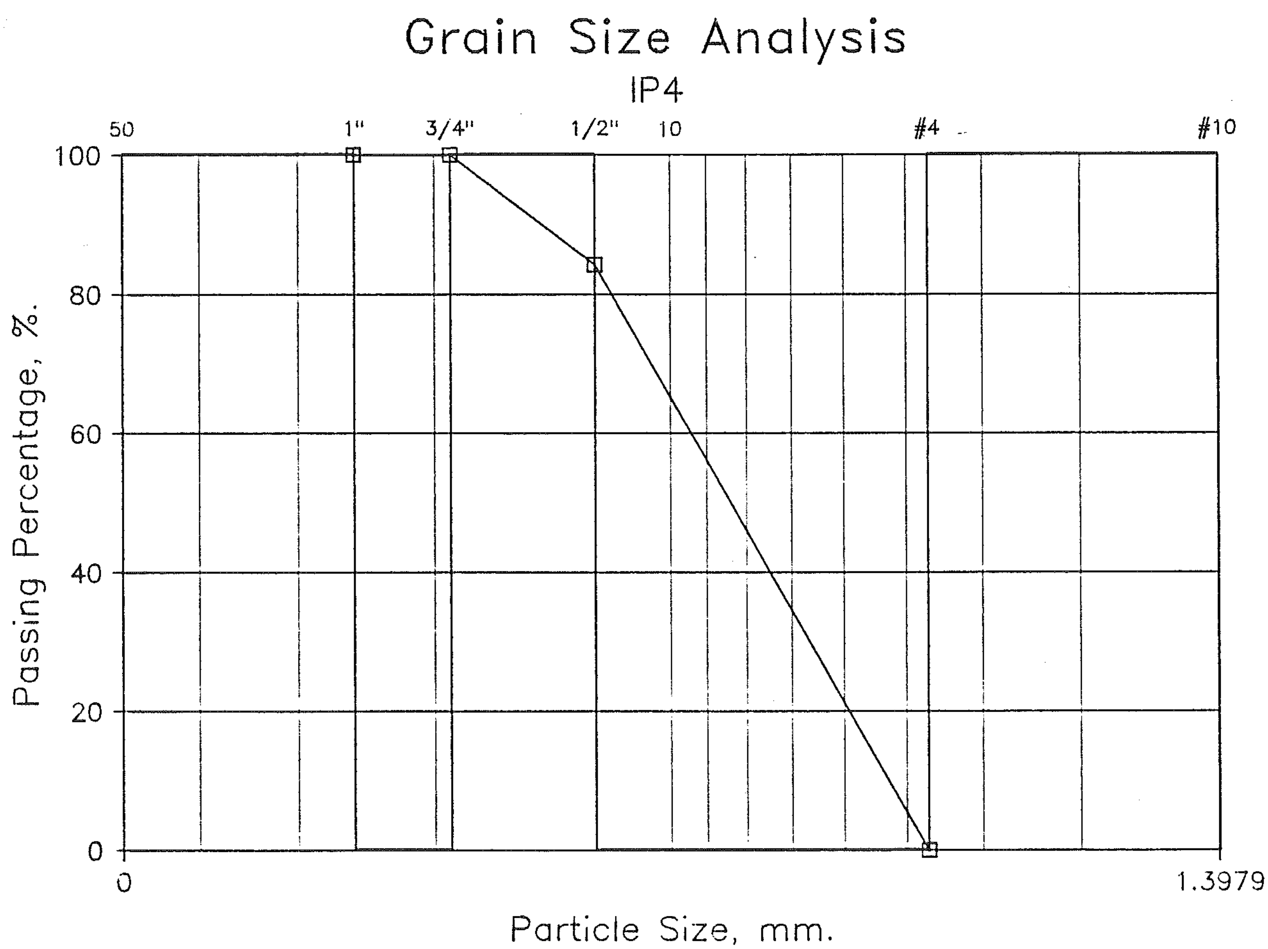


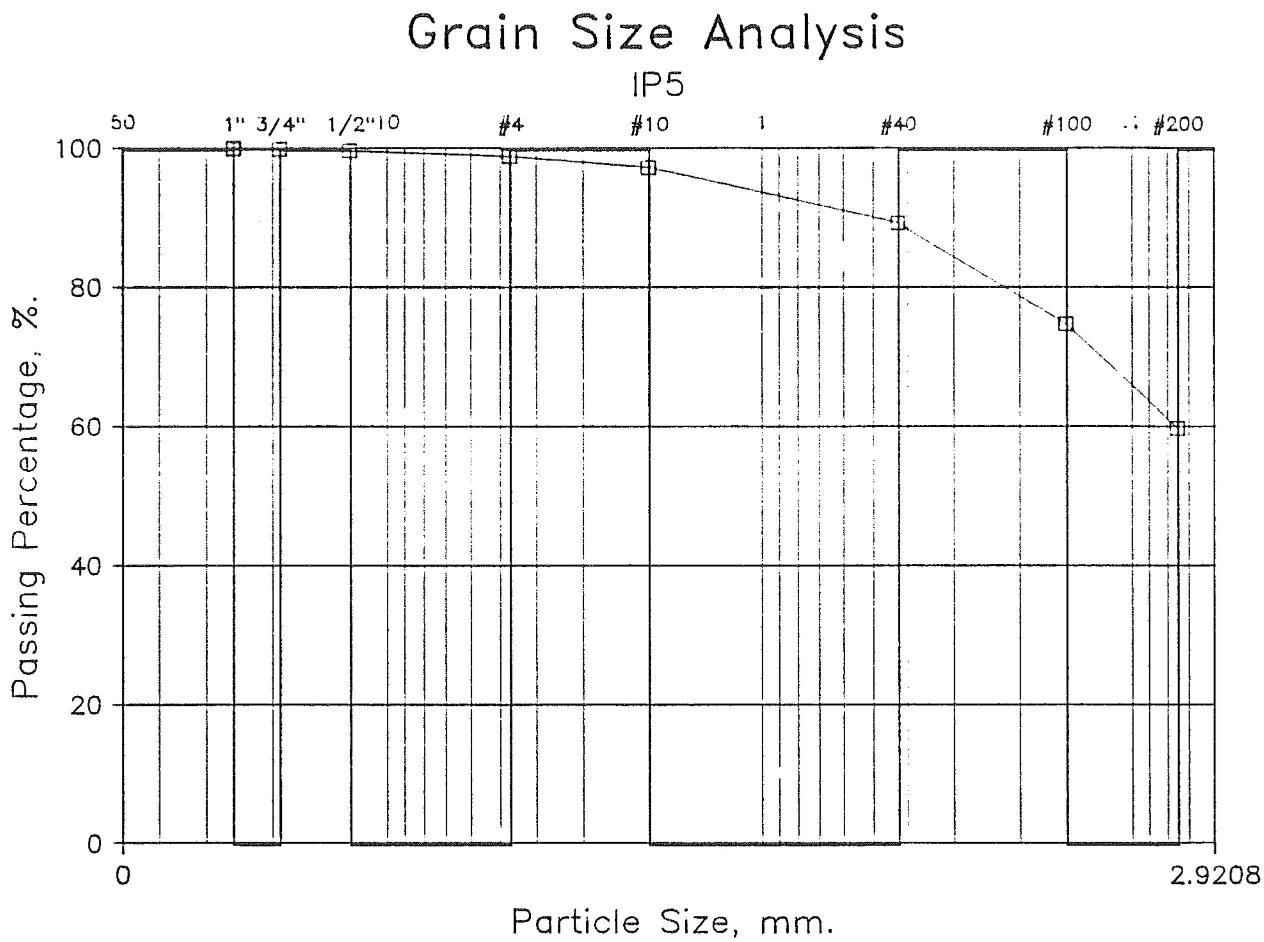
Grain Size Analysis

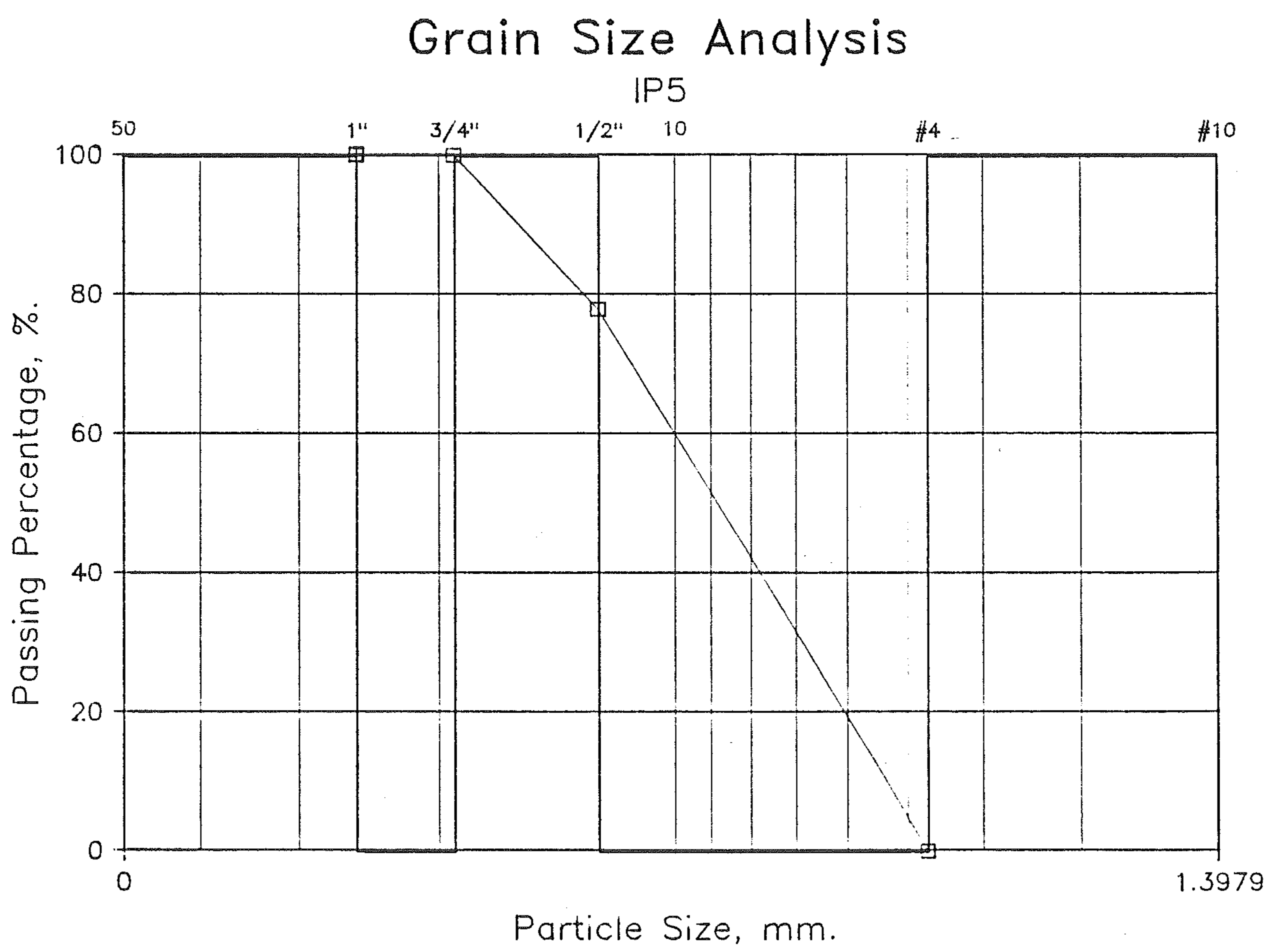
IP3




Grain Size Analysis
IP4
50
1"
3/4"
1/2"10
#4
#10
#40
#100
#200
Passing Percentage, %.
100
80
60
40
20
0
0
2.9208
Particle Size, mm.

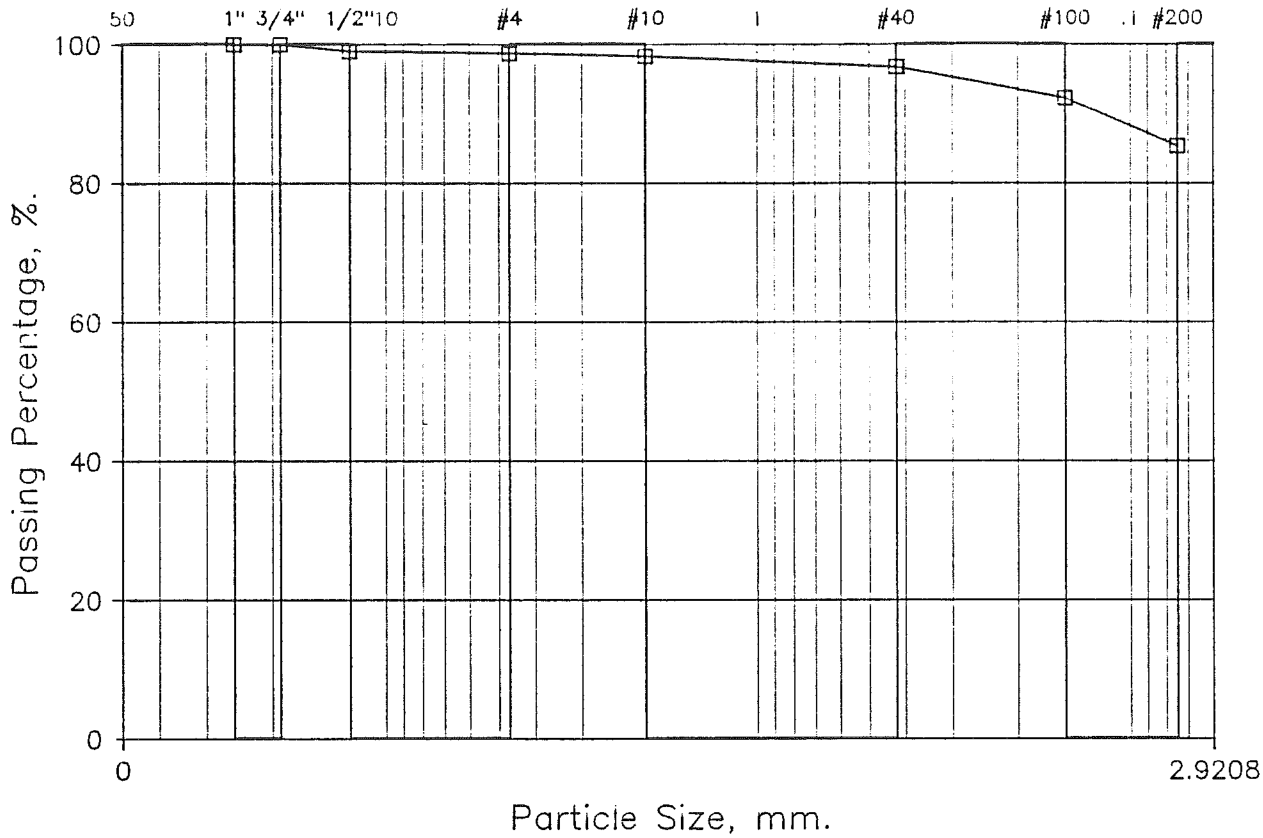

Grain Size Analysis
IP4
50
1"
3/4"
1/2"
10
#4
#10
Passing Percentage, %.
100
80
60
40
20
0
0
1.3979
Particle Size, mm.


Grain Size Analysis
IP5
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
IP5
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

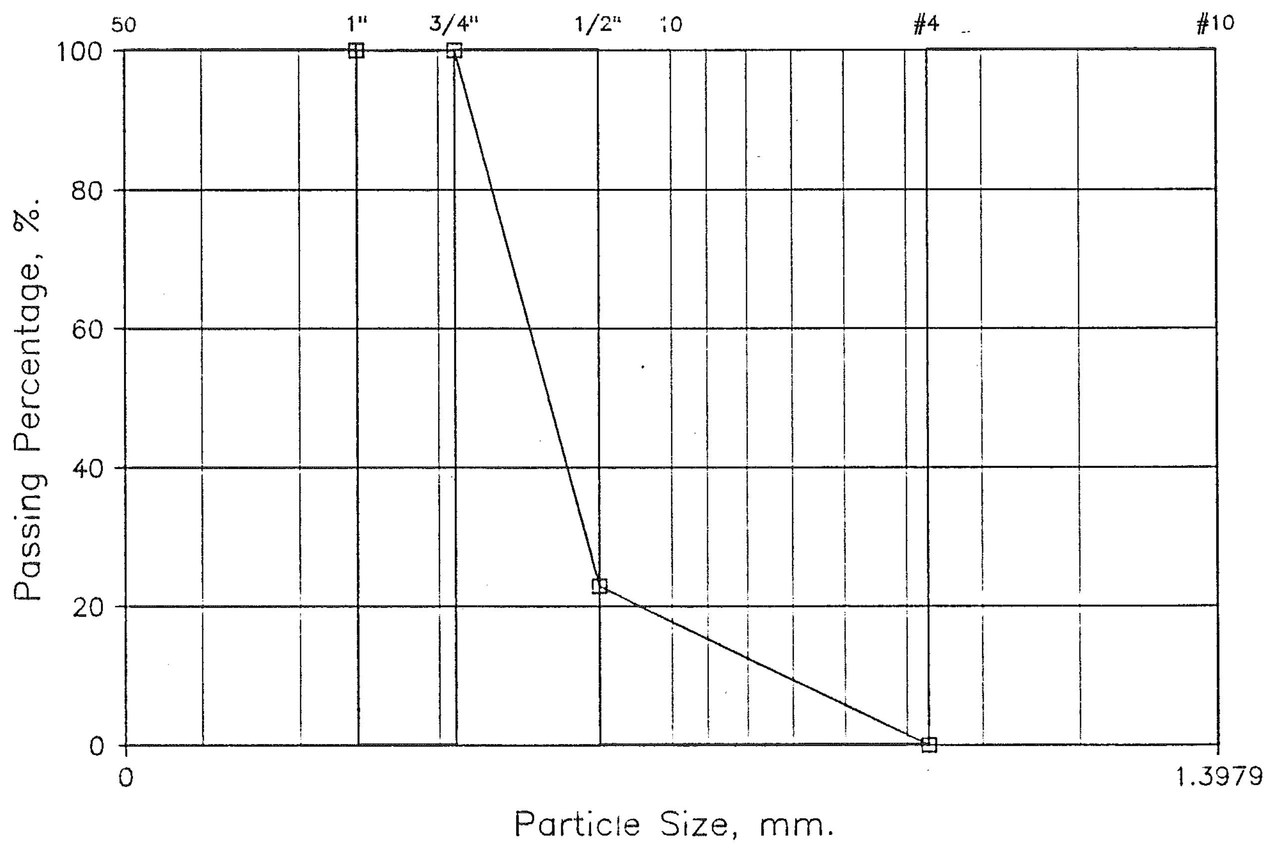
Grain Size Analysis

IP6



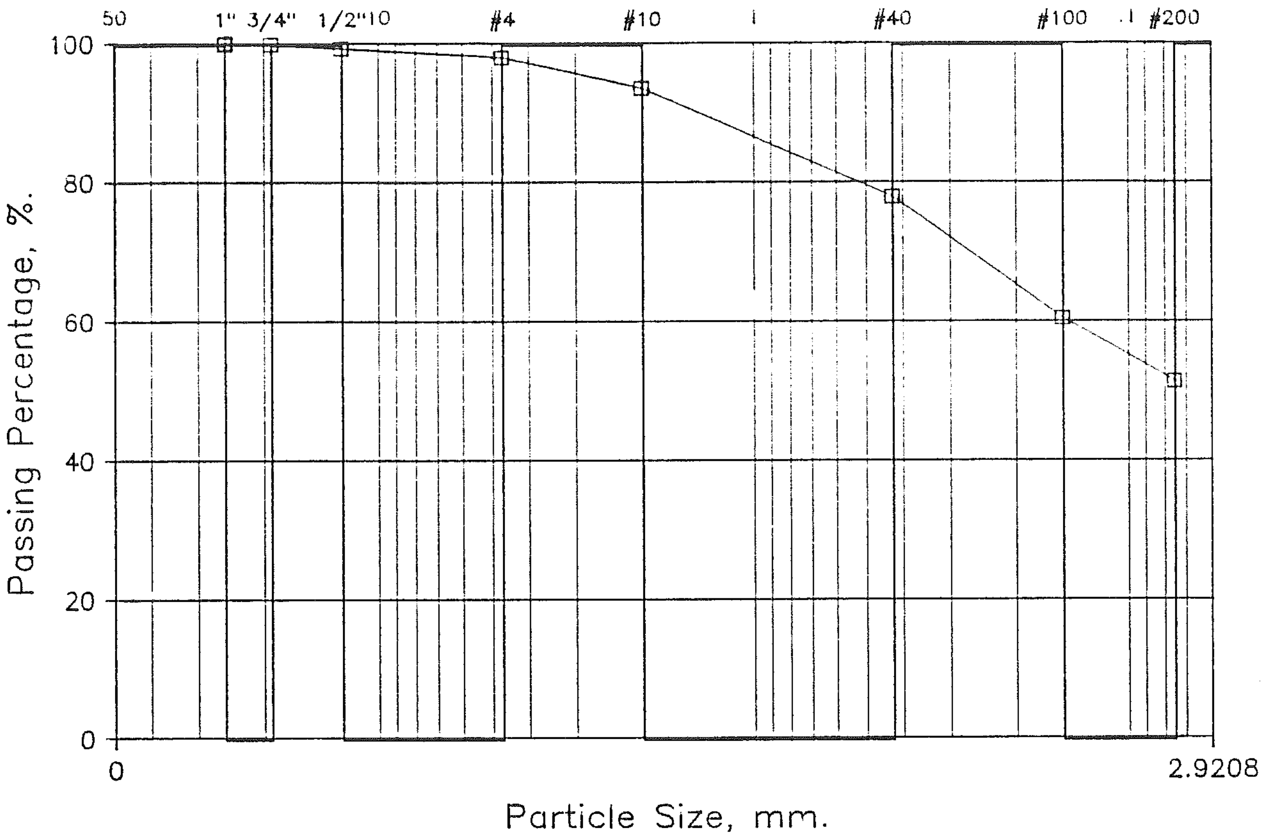
Grain Size Analysis

IP6



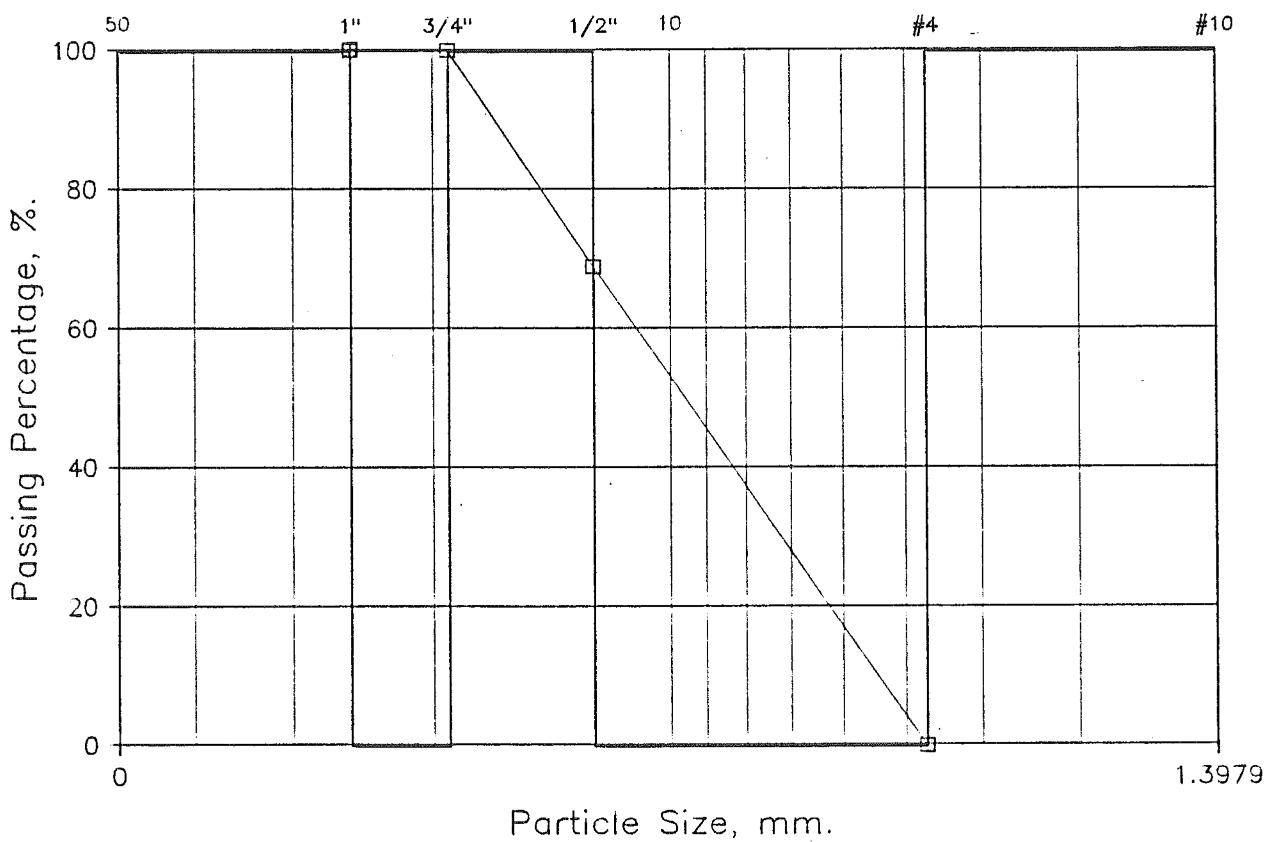
Grain Size Analysis

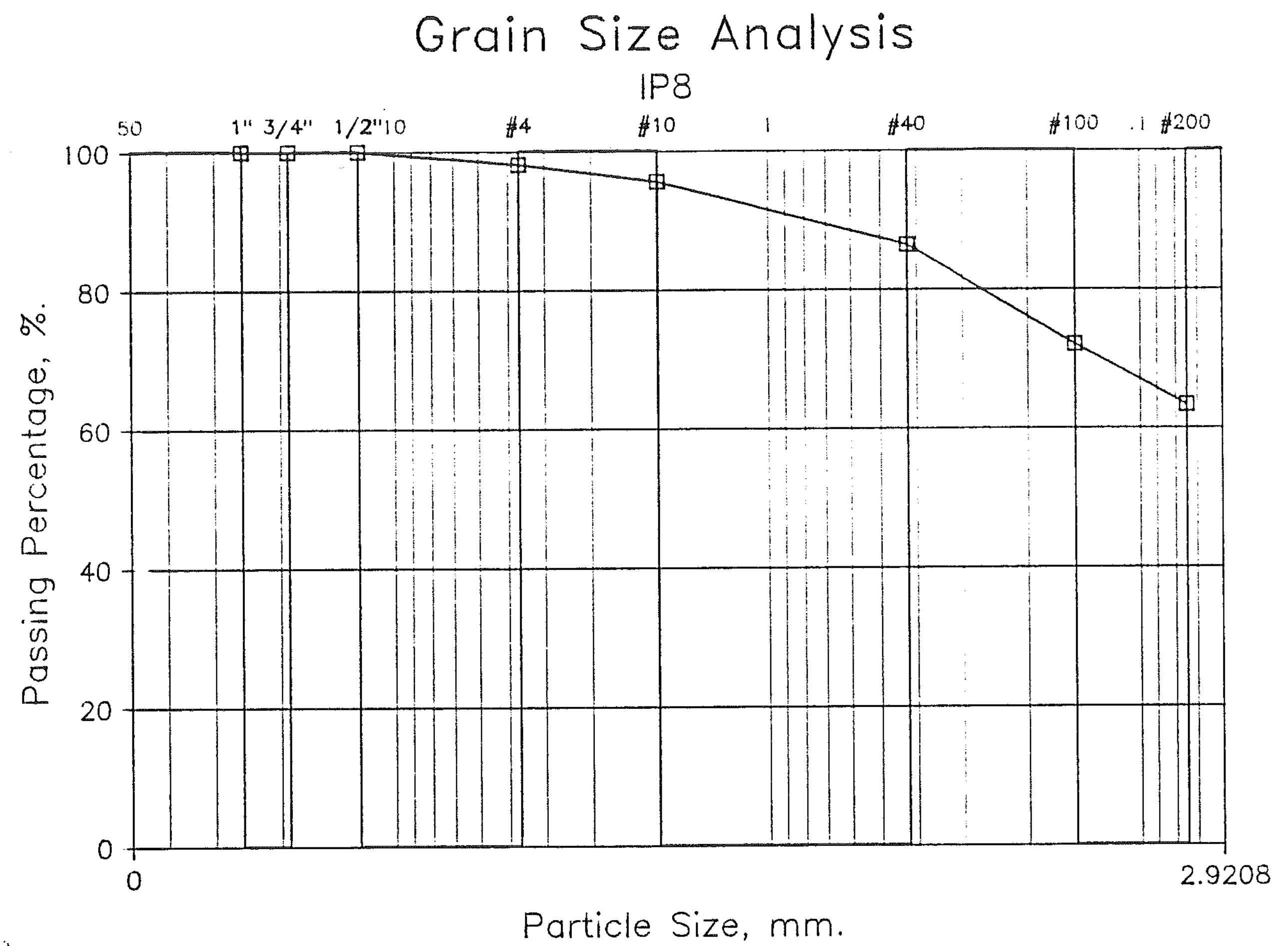
IP7

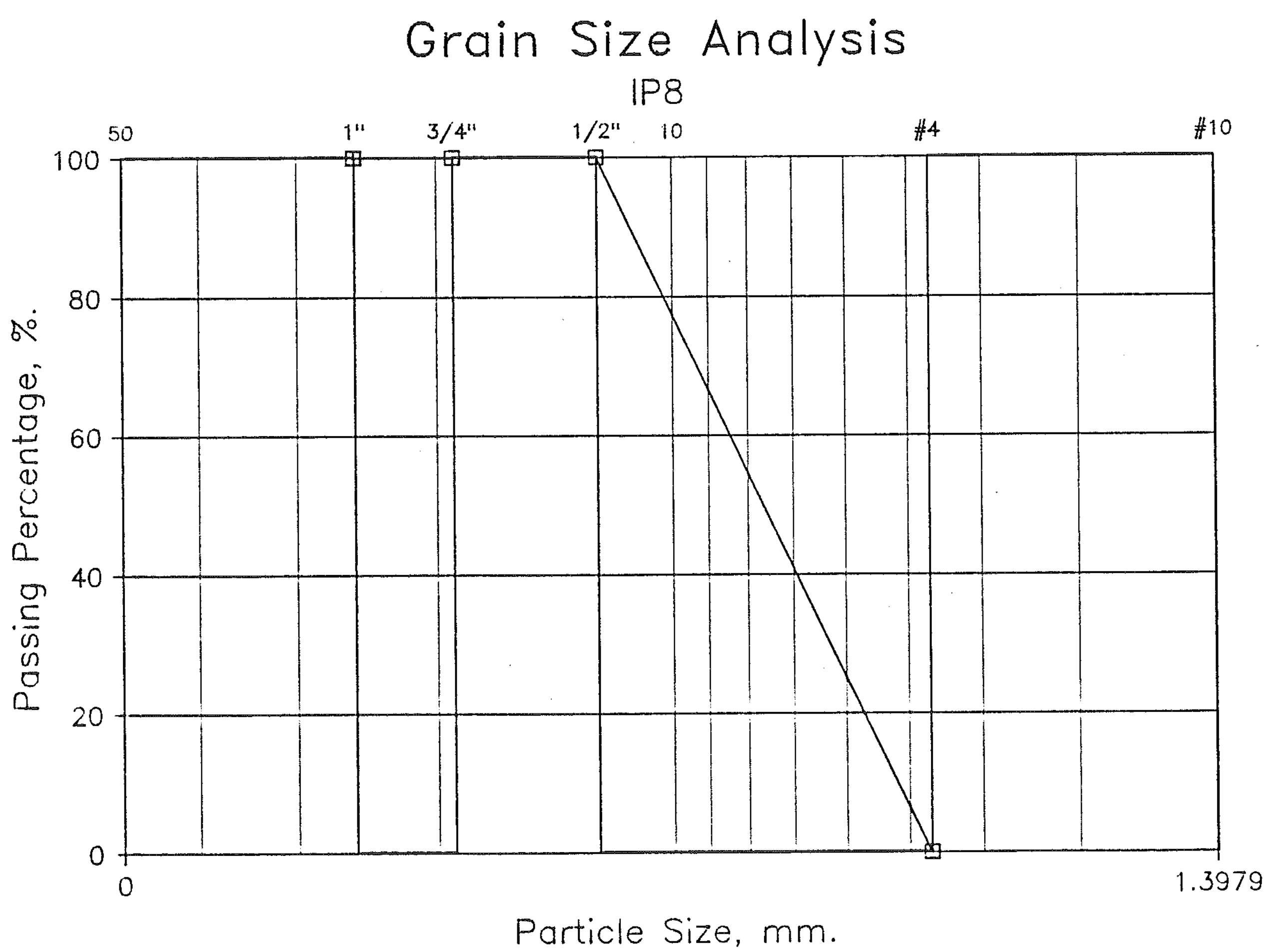


Grain Size Analysis

IP7

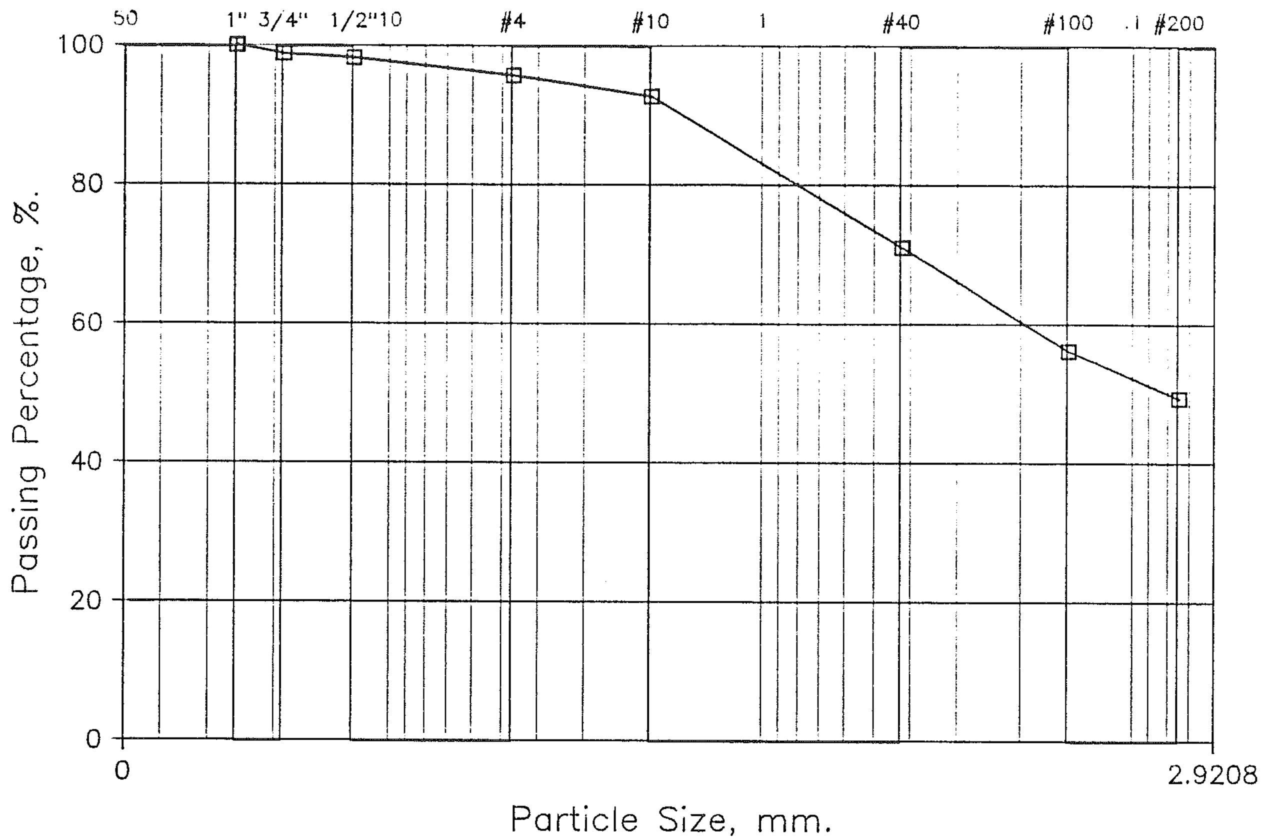



Grain Size Analysis
IP8
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
IP8
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

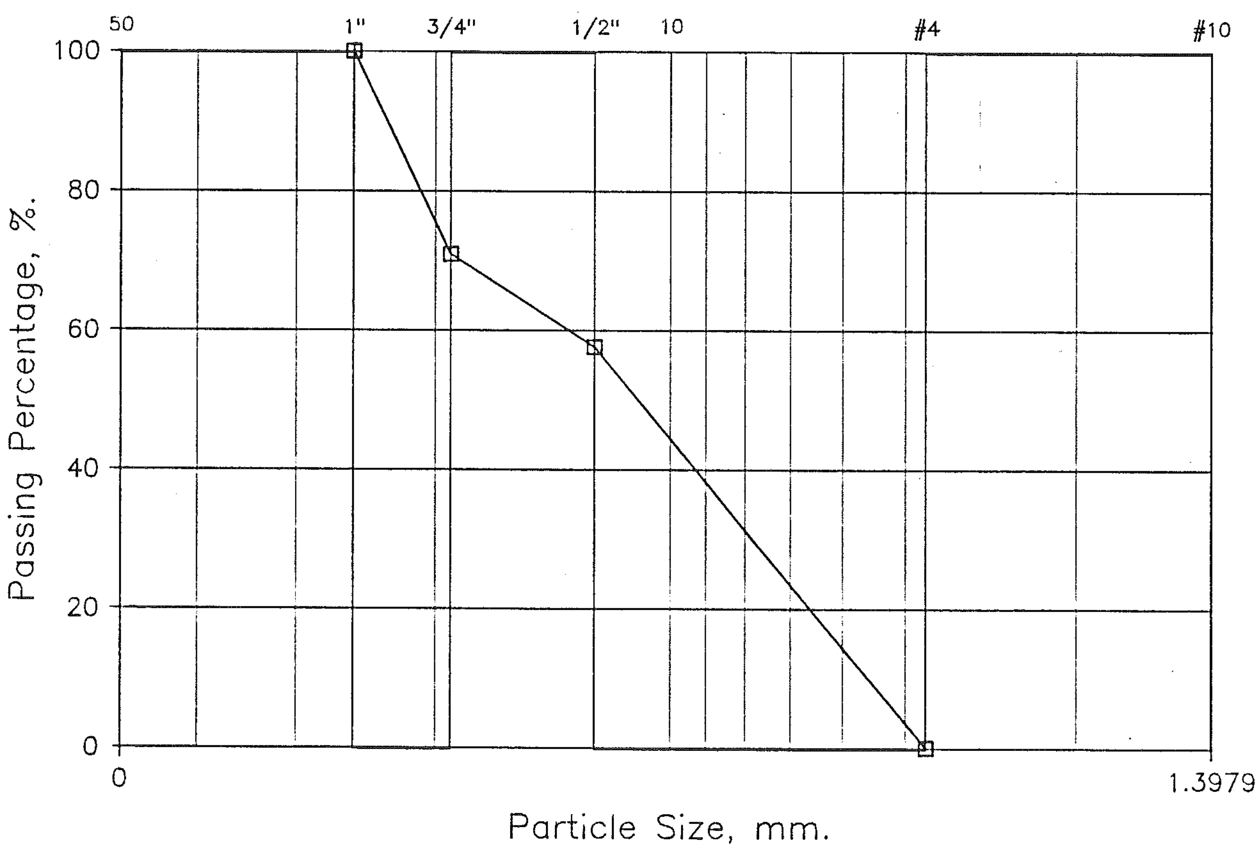
Grain Size Analysis

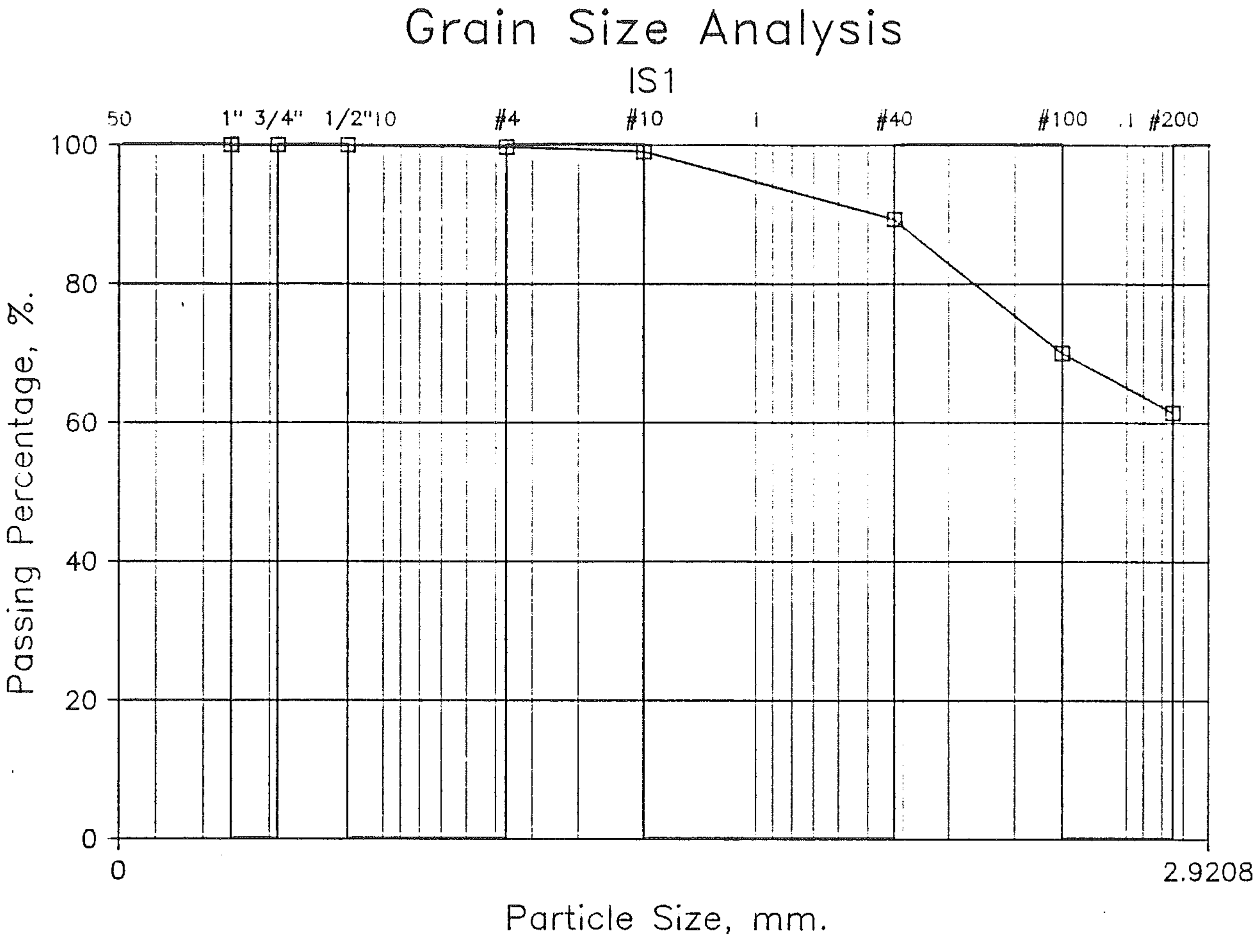
IP9

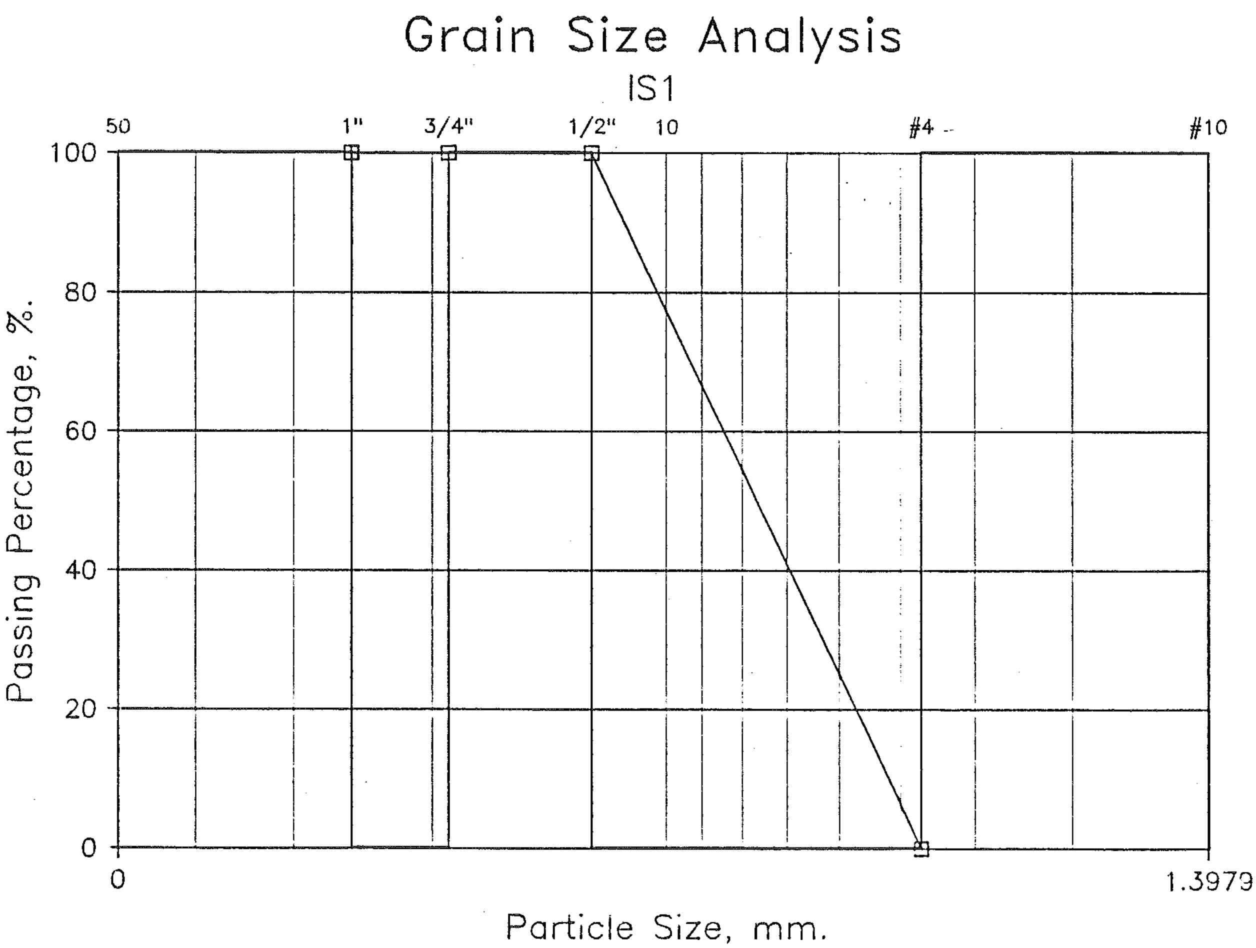


Grain Size Analysis

IP9

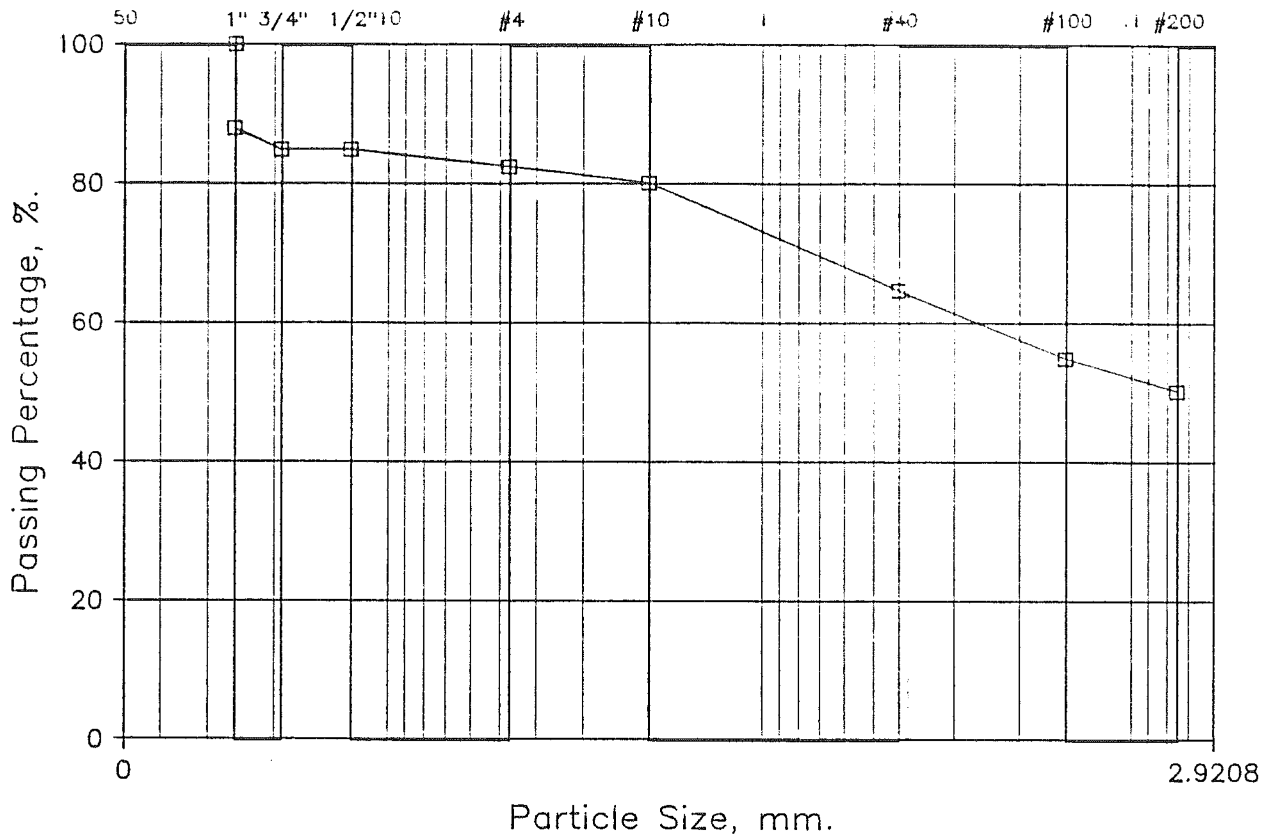



Grain Size Analysis
IS1
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
IS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

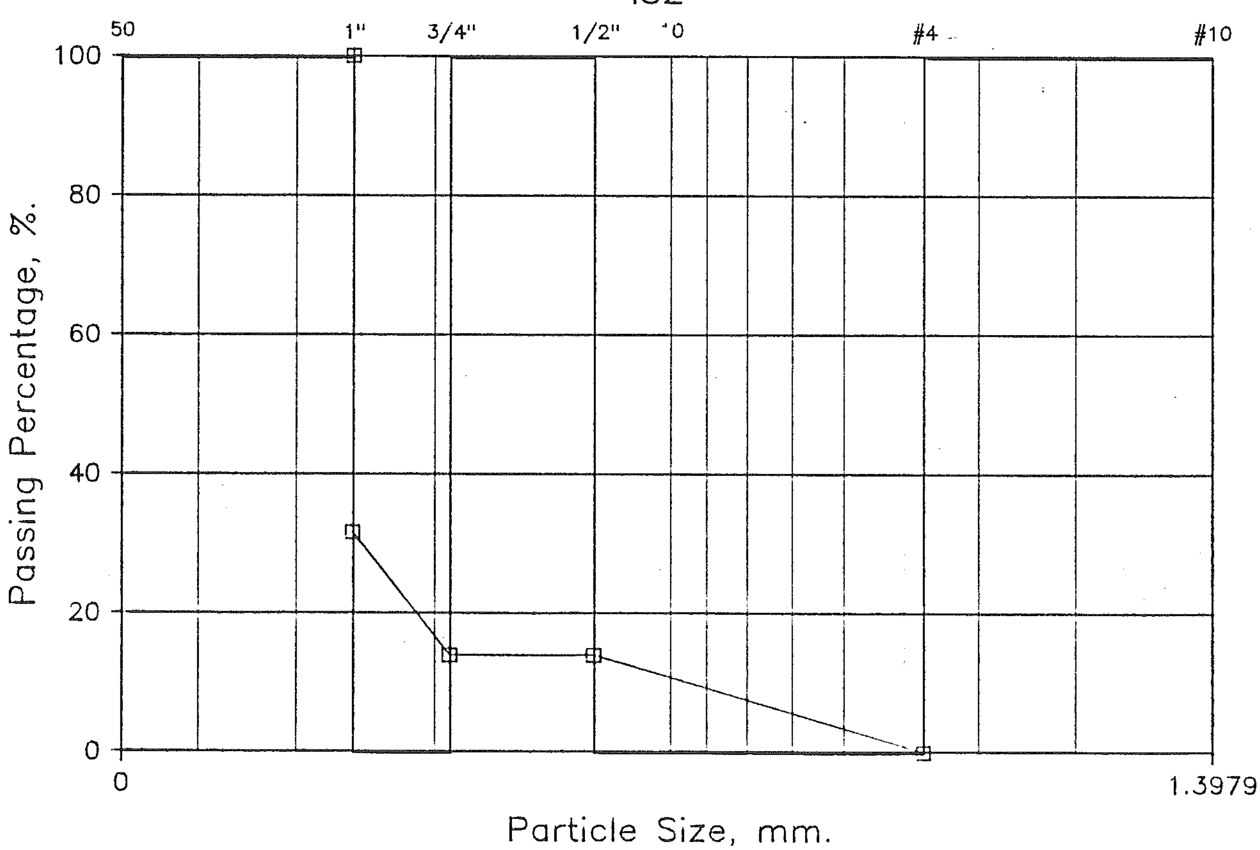
Grain Size Analysis

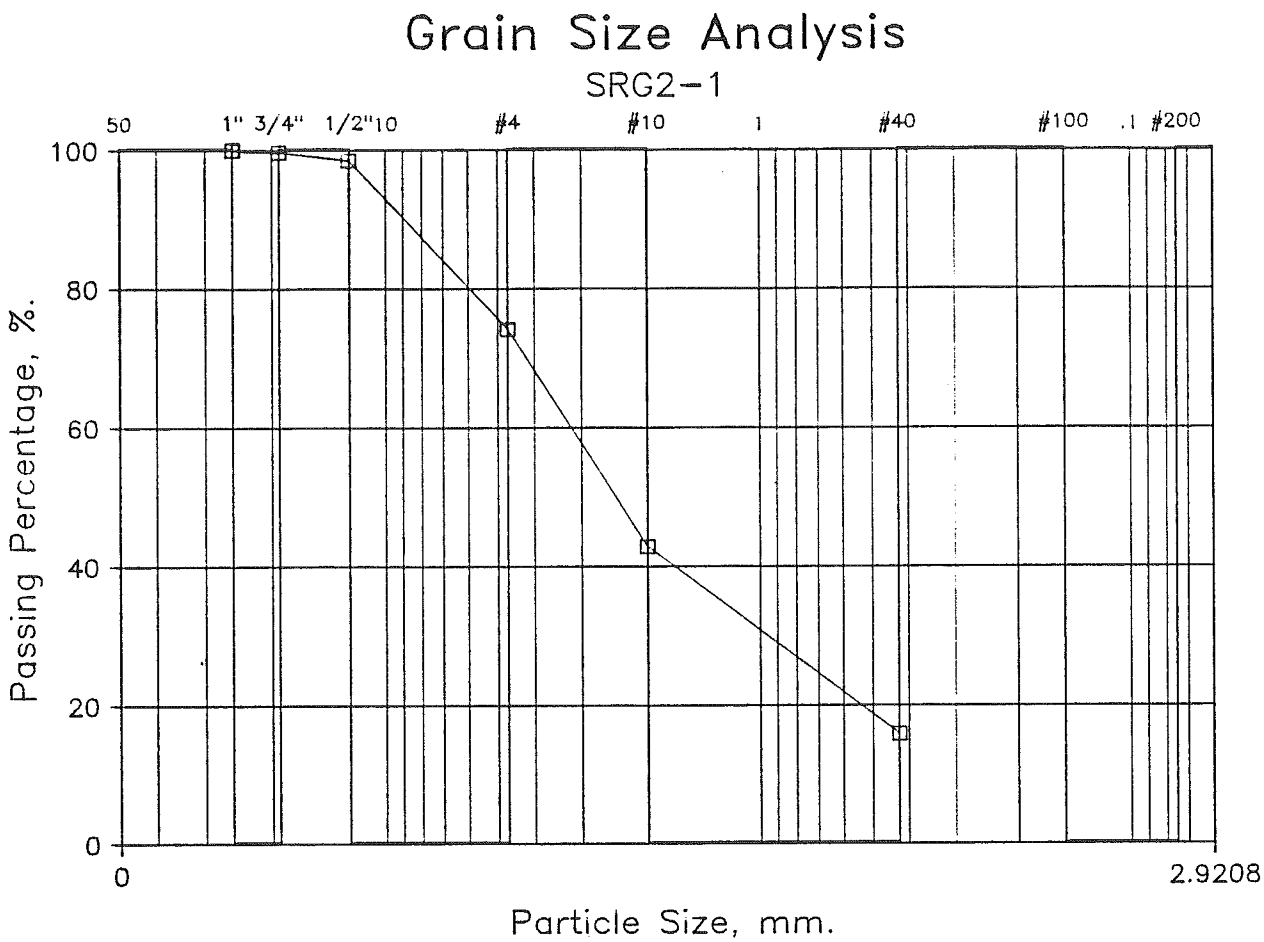
IS2

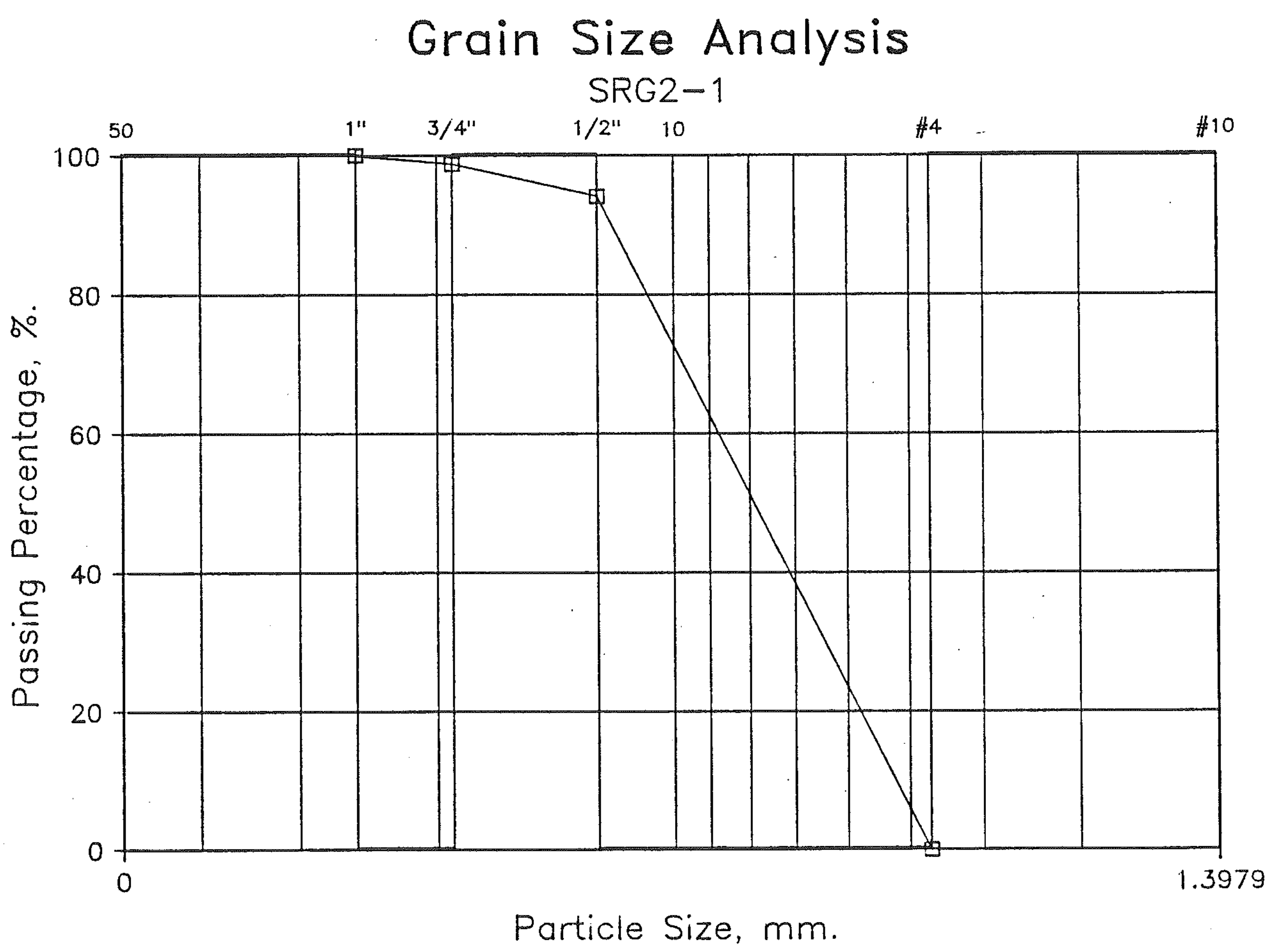


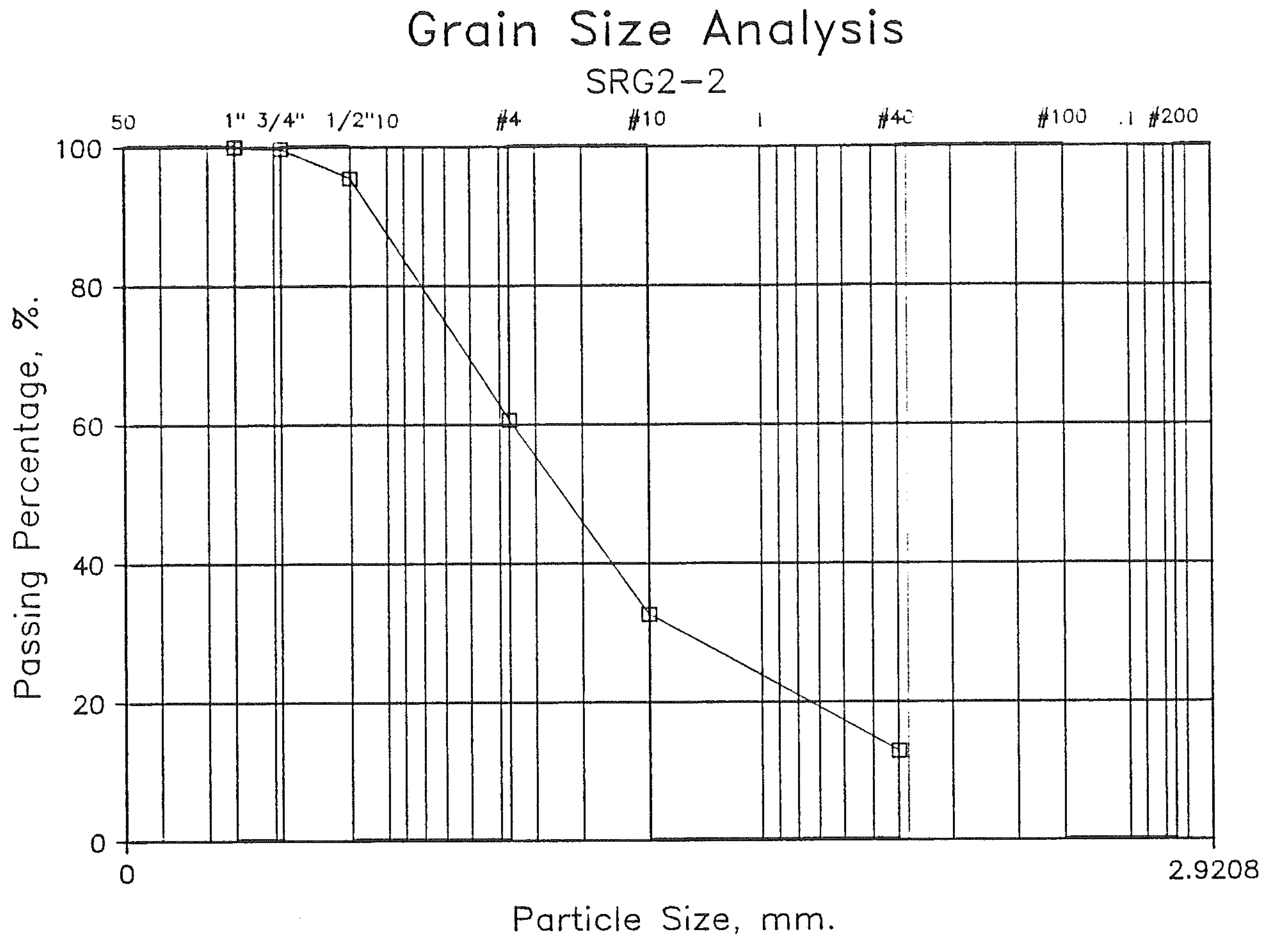
Grain Size Analysis

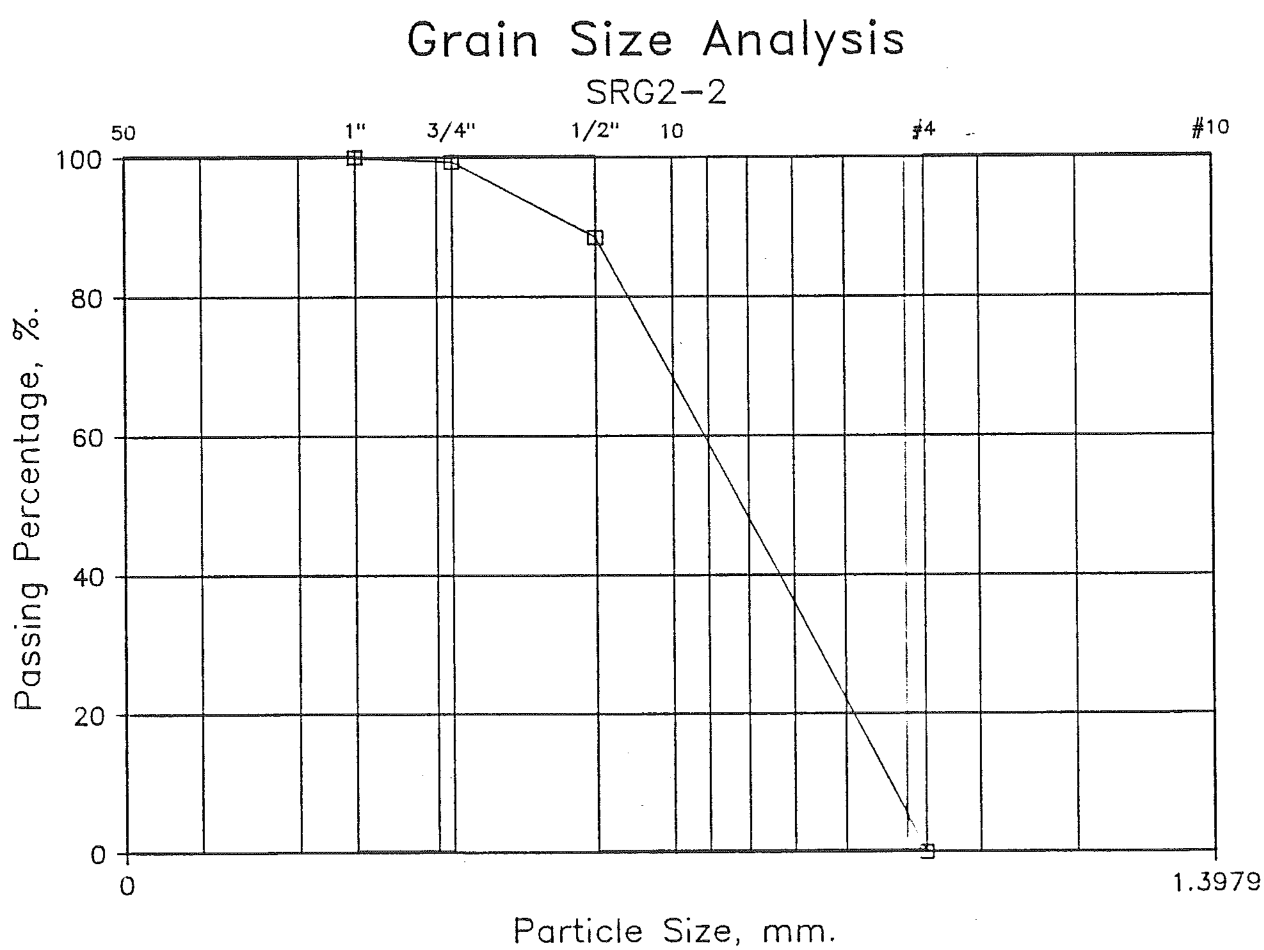
IS2

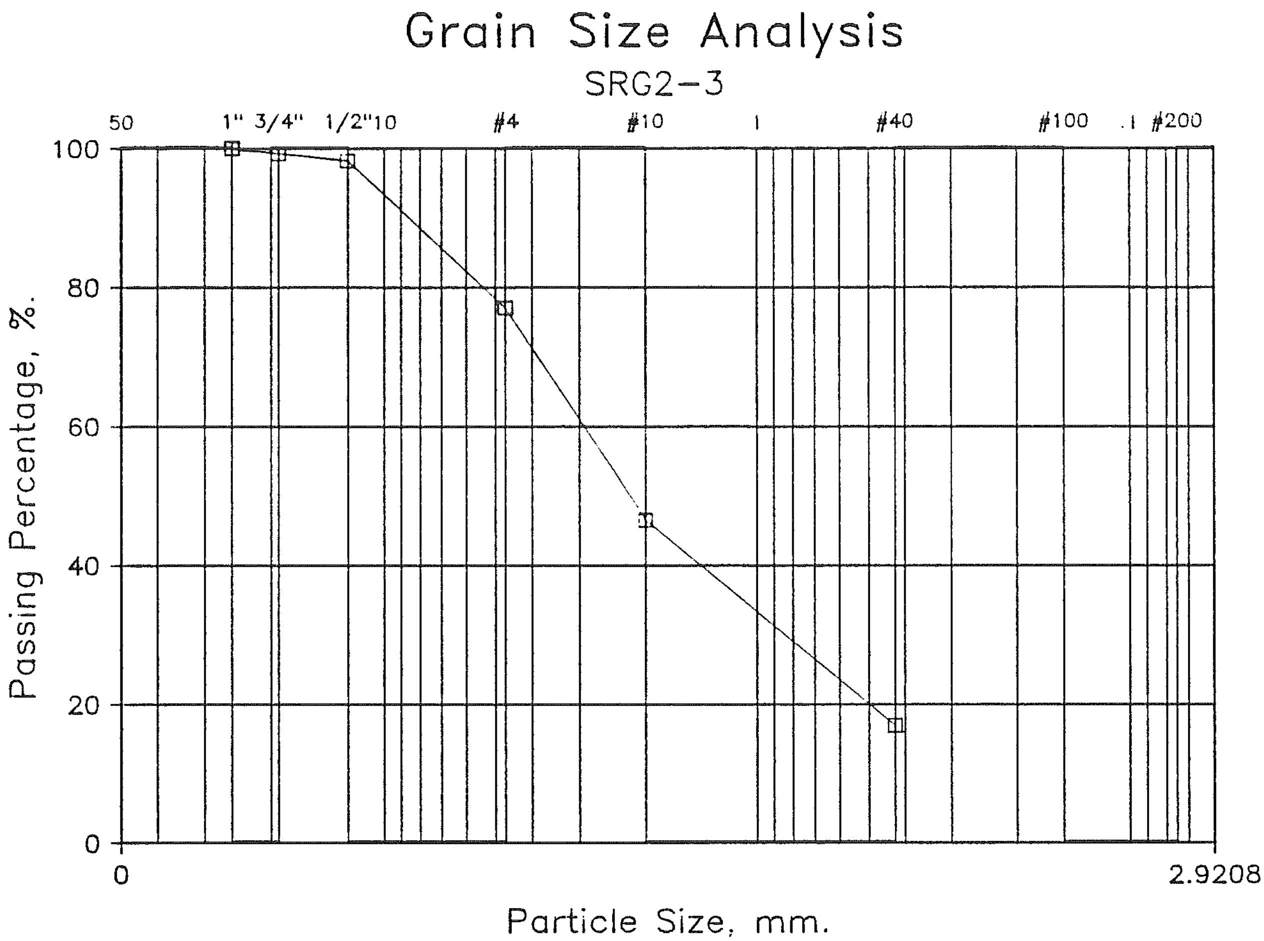



Grain Size Analysis
SRG2-1
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

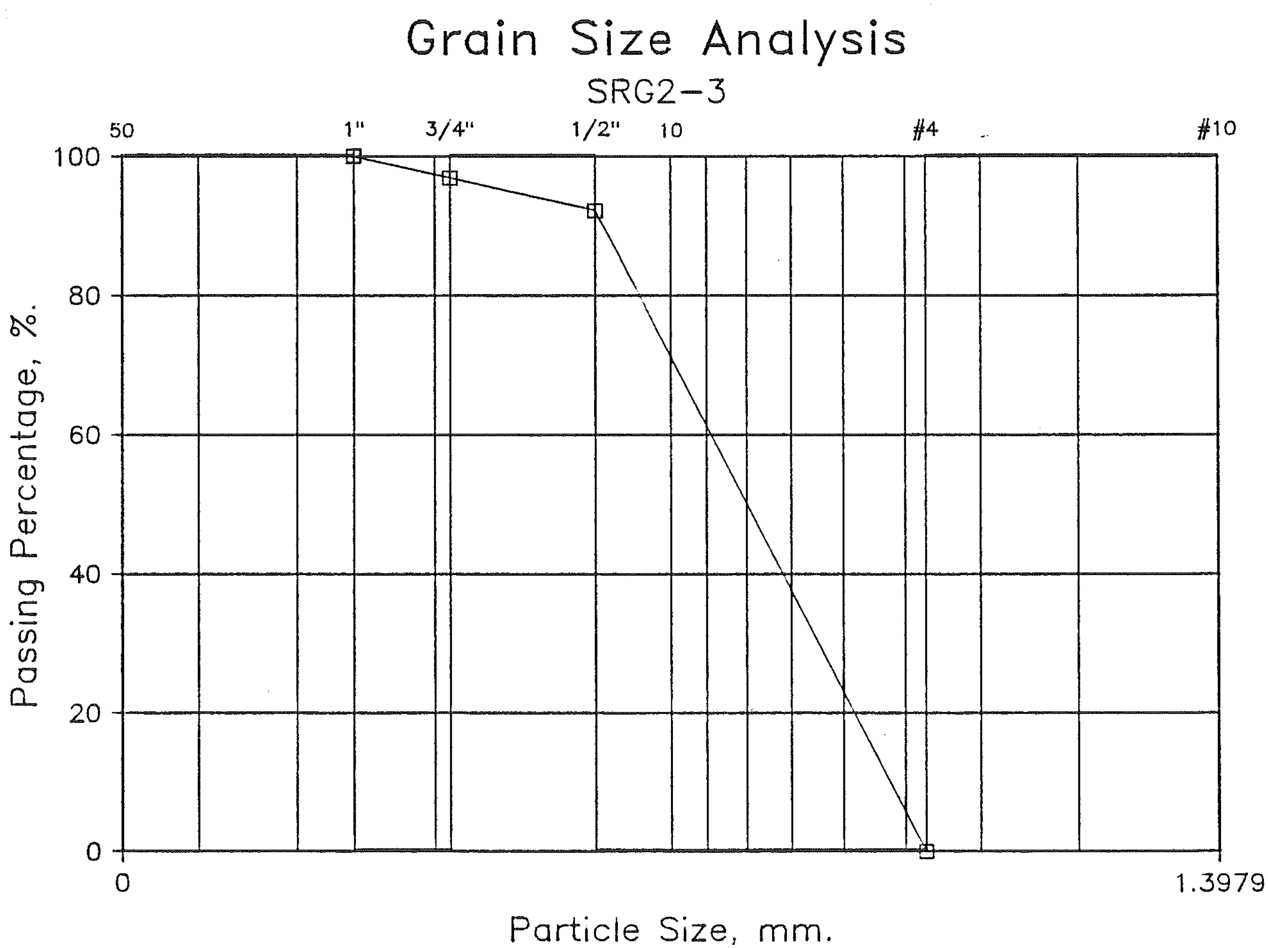

Grain Size Analysis
SRG2-1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
SRG2-2
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
SRG2-2
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.



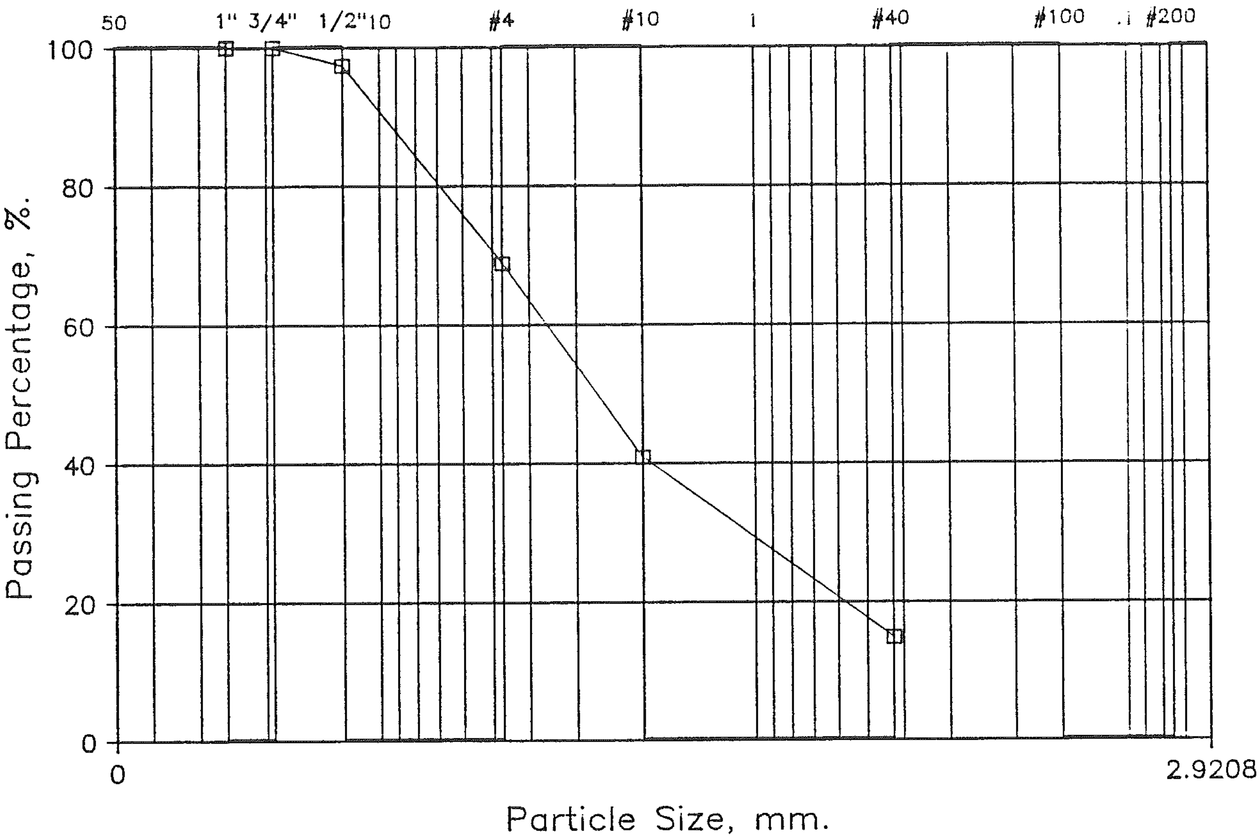
Grain Size Analysis
SRG2-3
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100 .1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.



Grain Size Analysis
SRG2-3
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

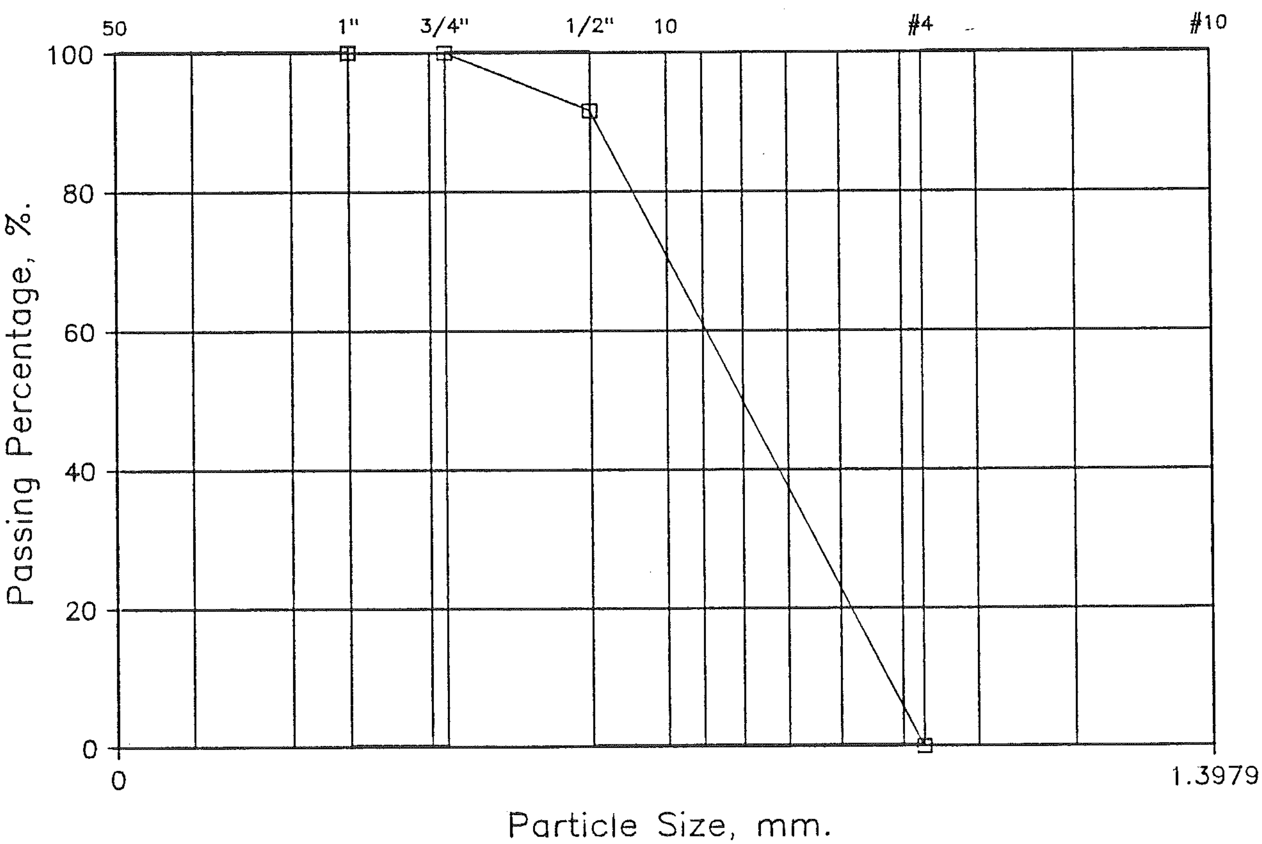
Grain Size Analysis

SRG3-1



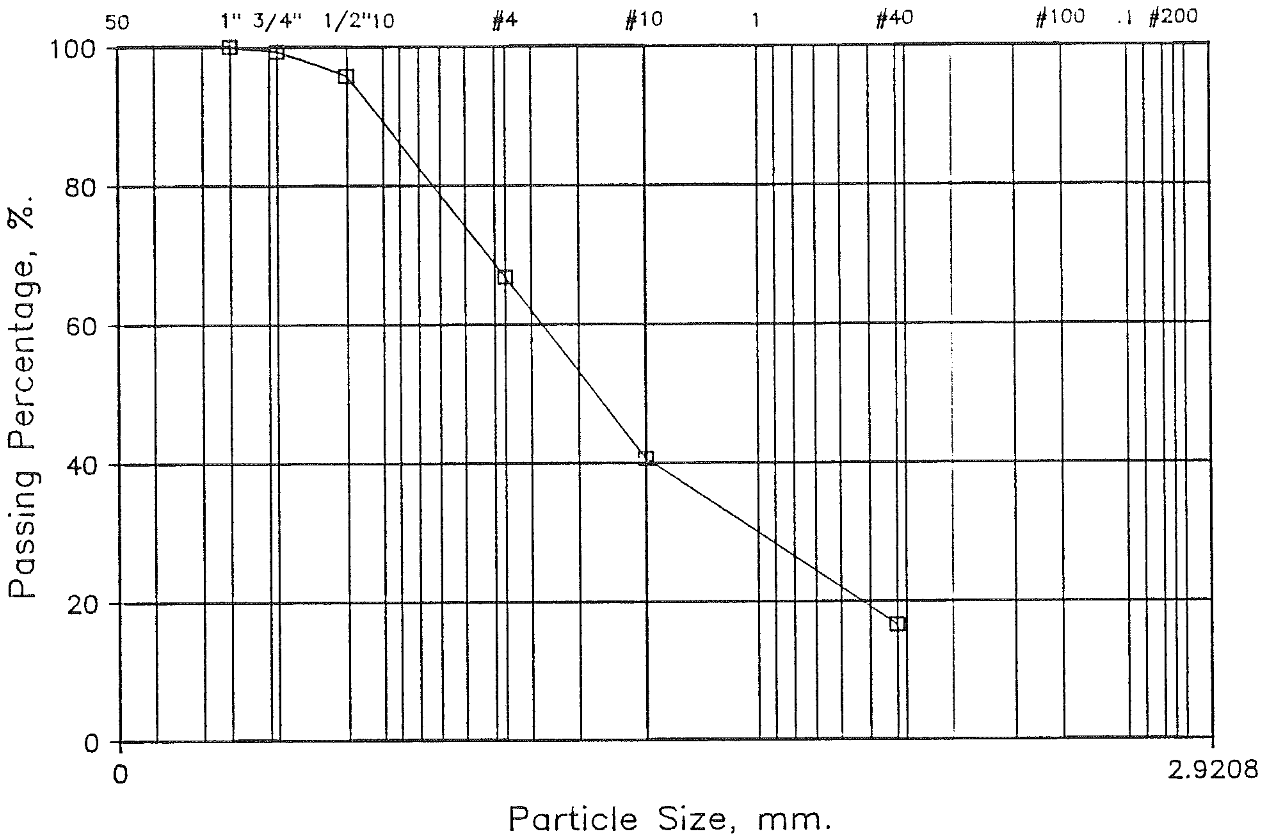
Grain Size Analysis

SRG3-1



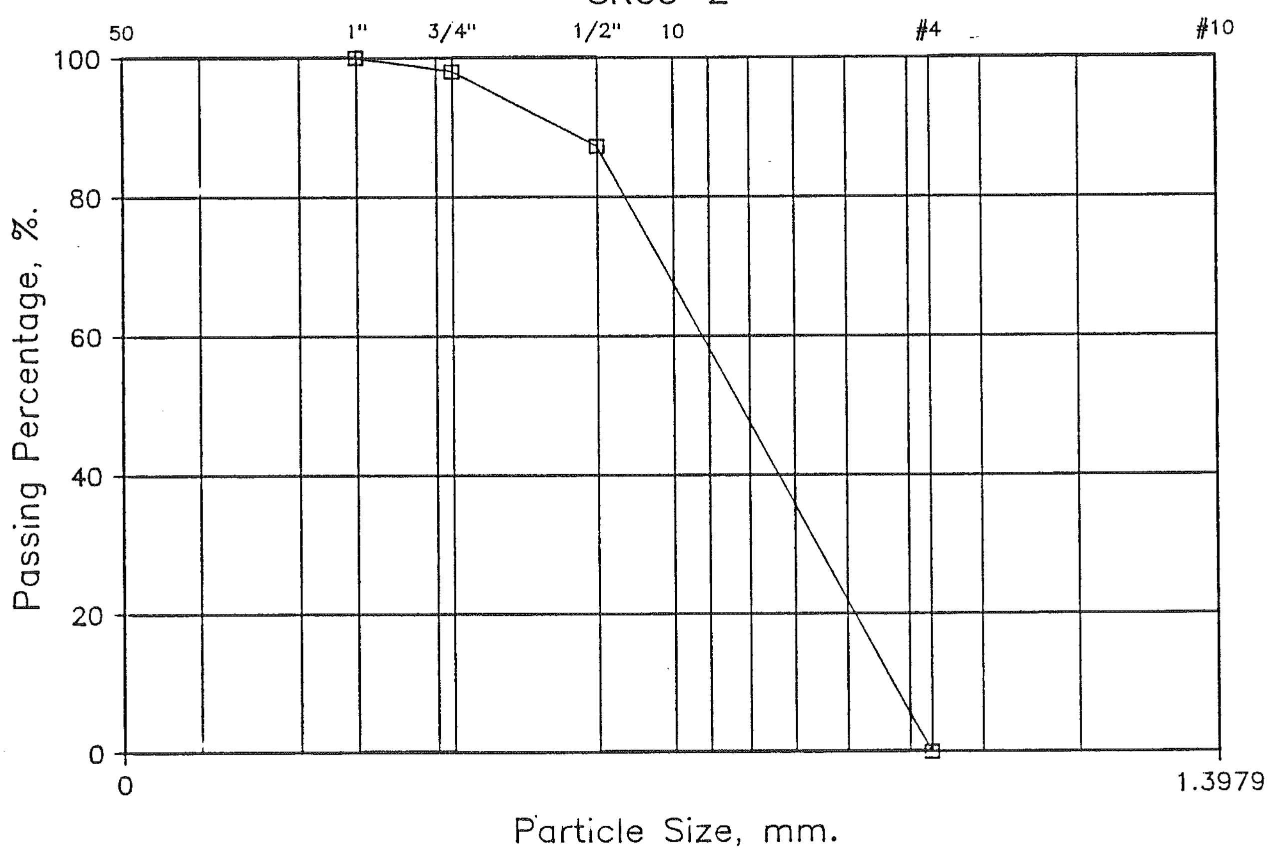
Grain Size Analysis

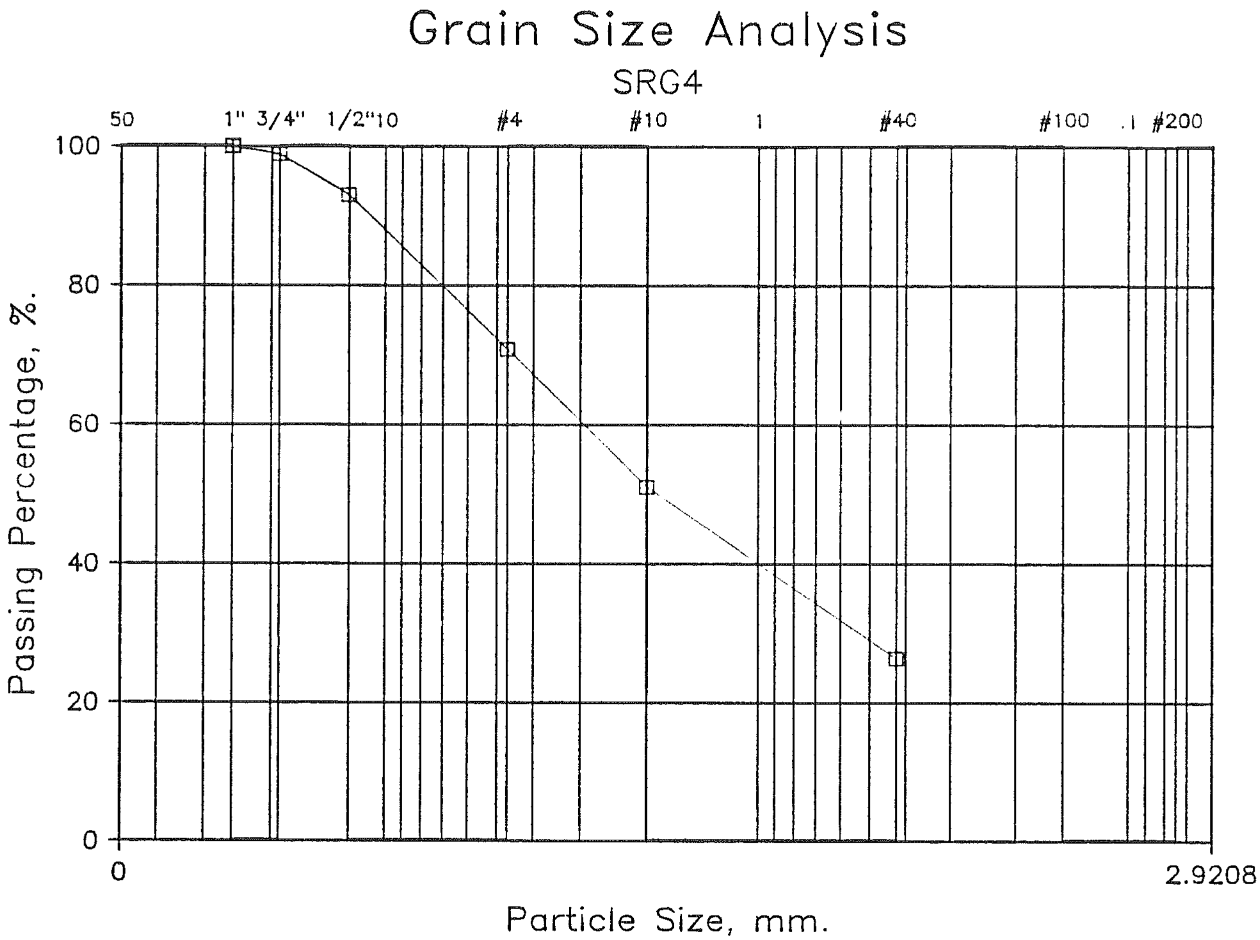
SRG3-2

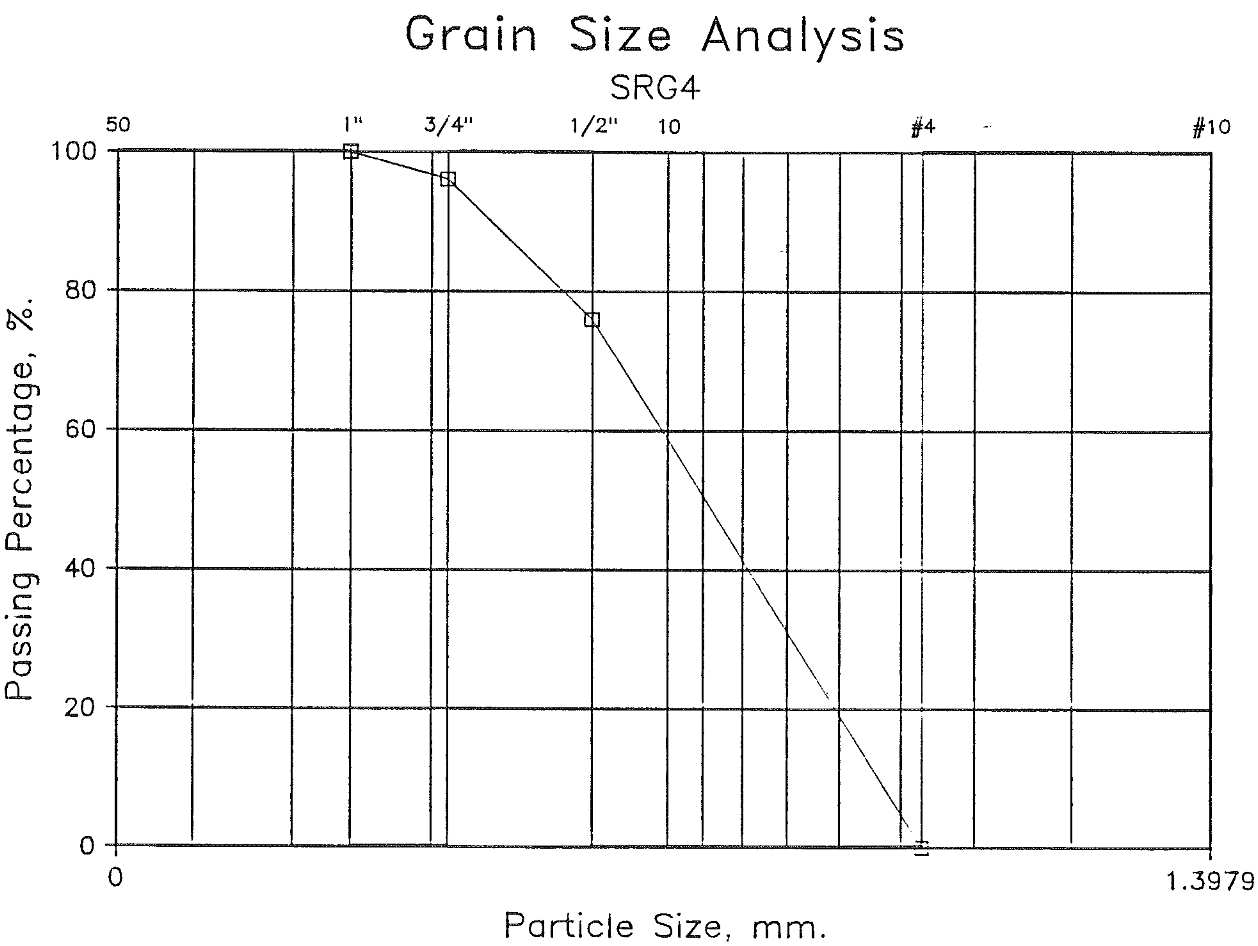


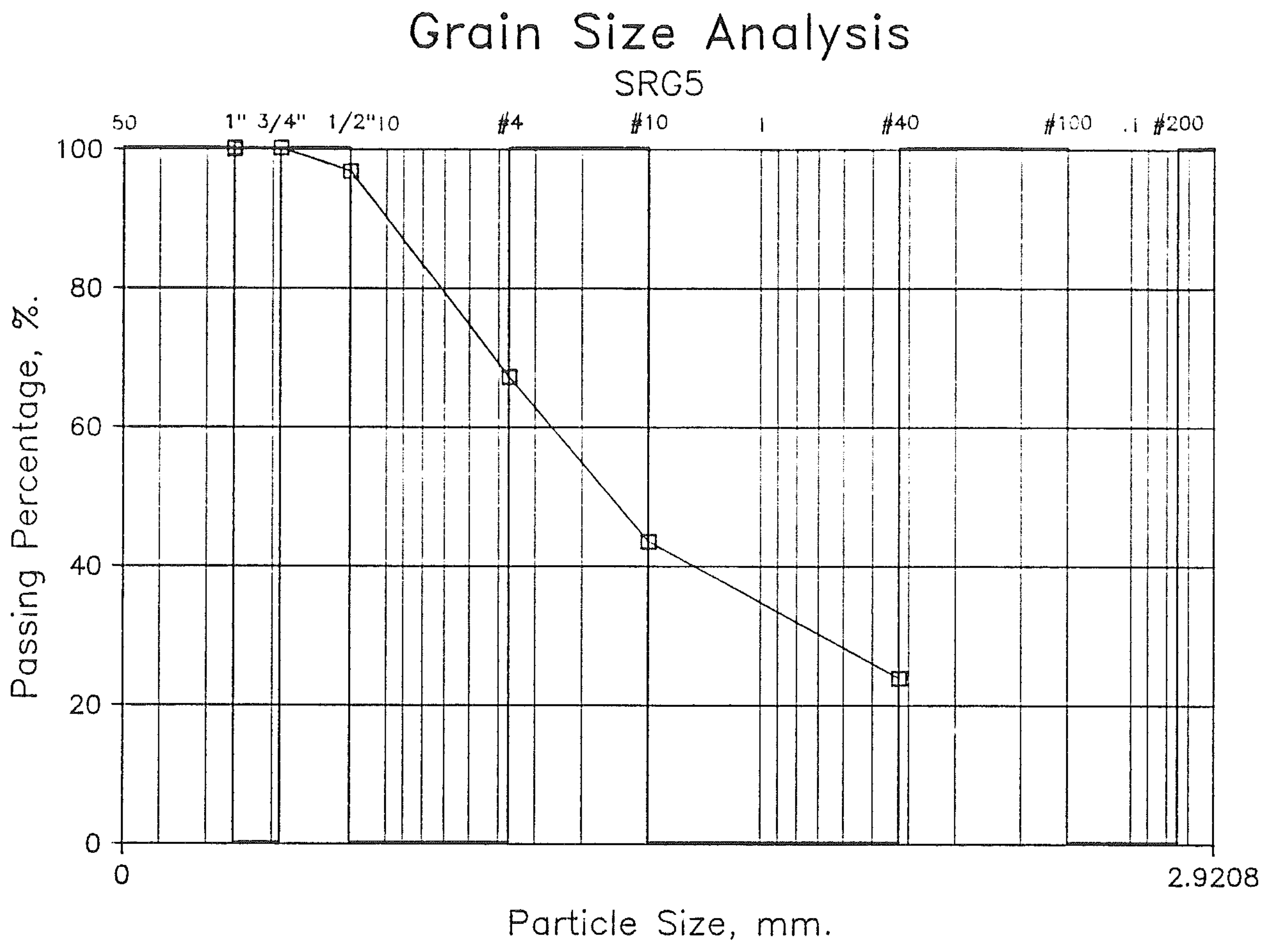
Grain Size Analysis

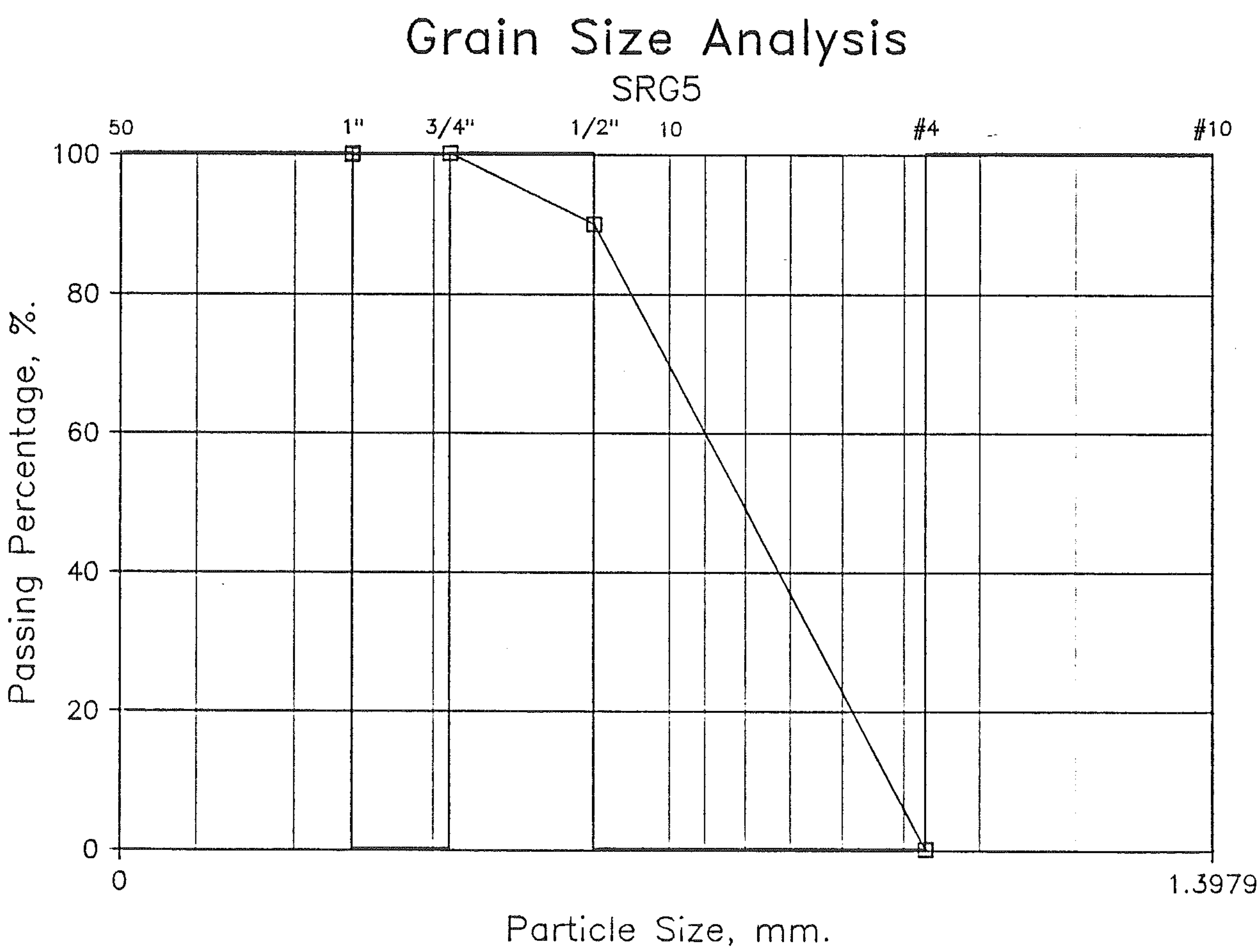
SRG3-2

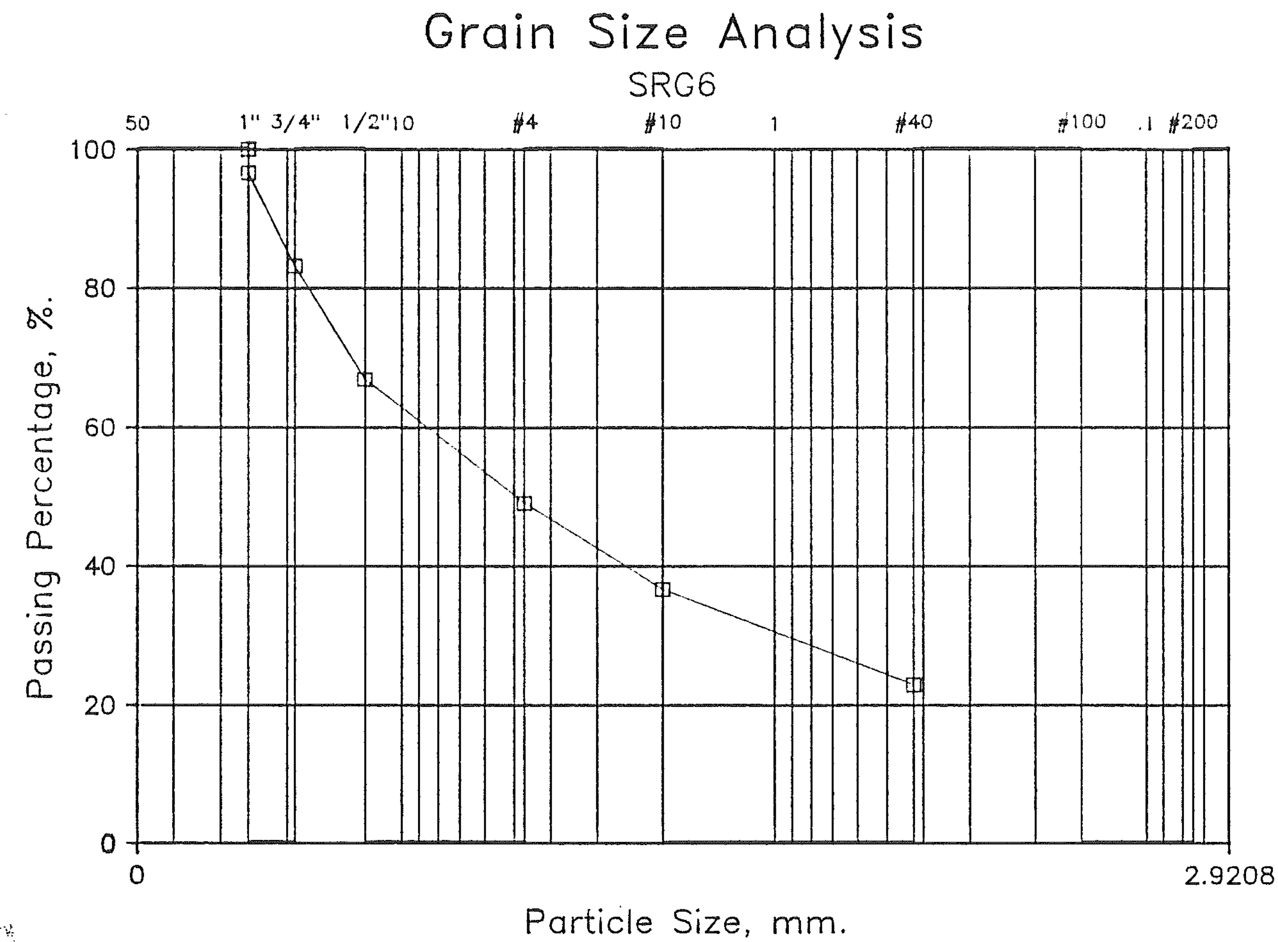


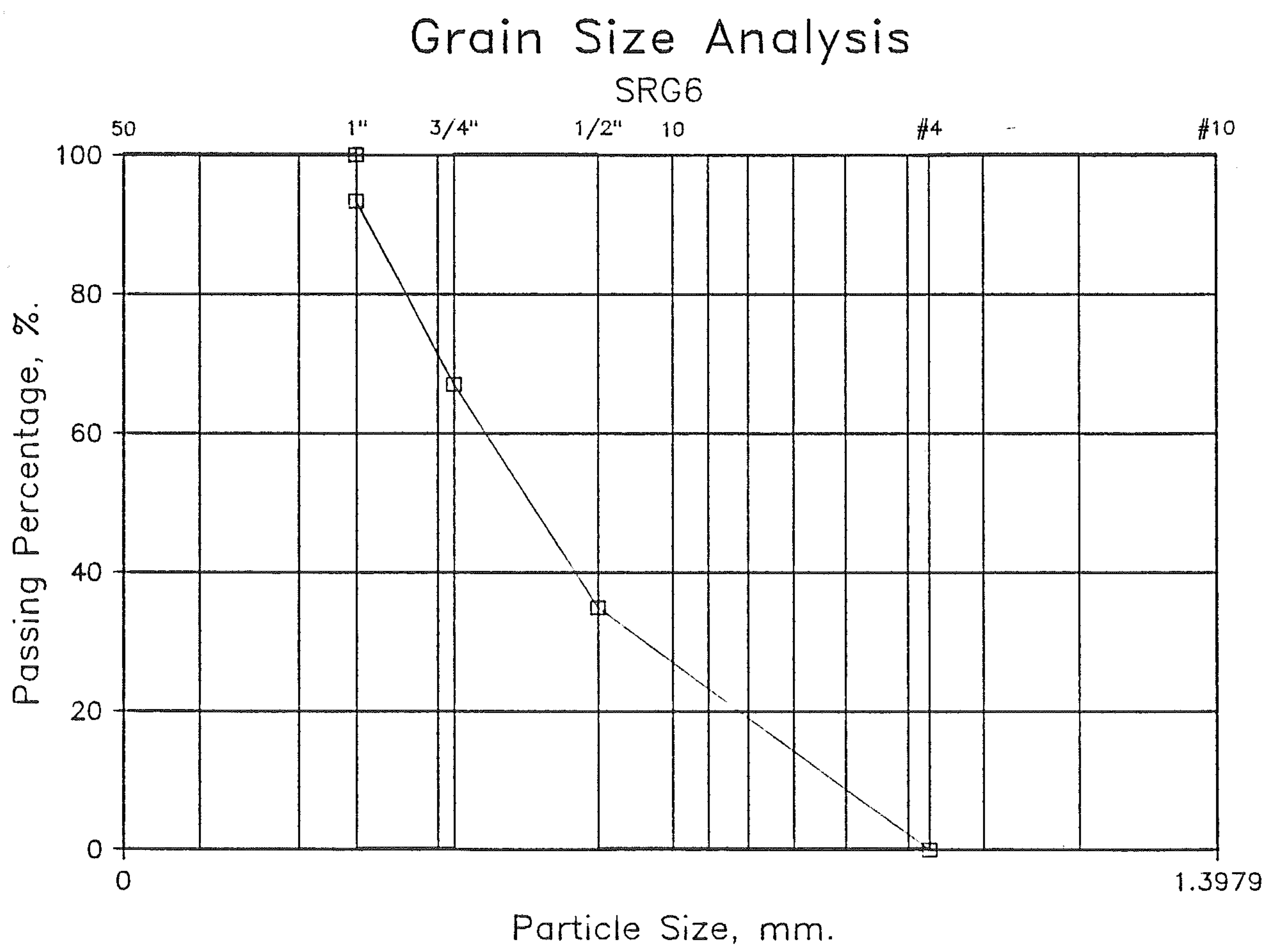

Grain Size Analysis
SRG4
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

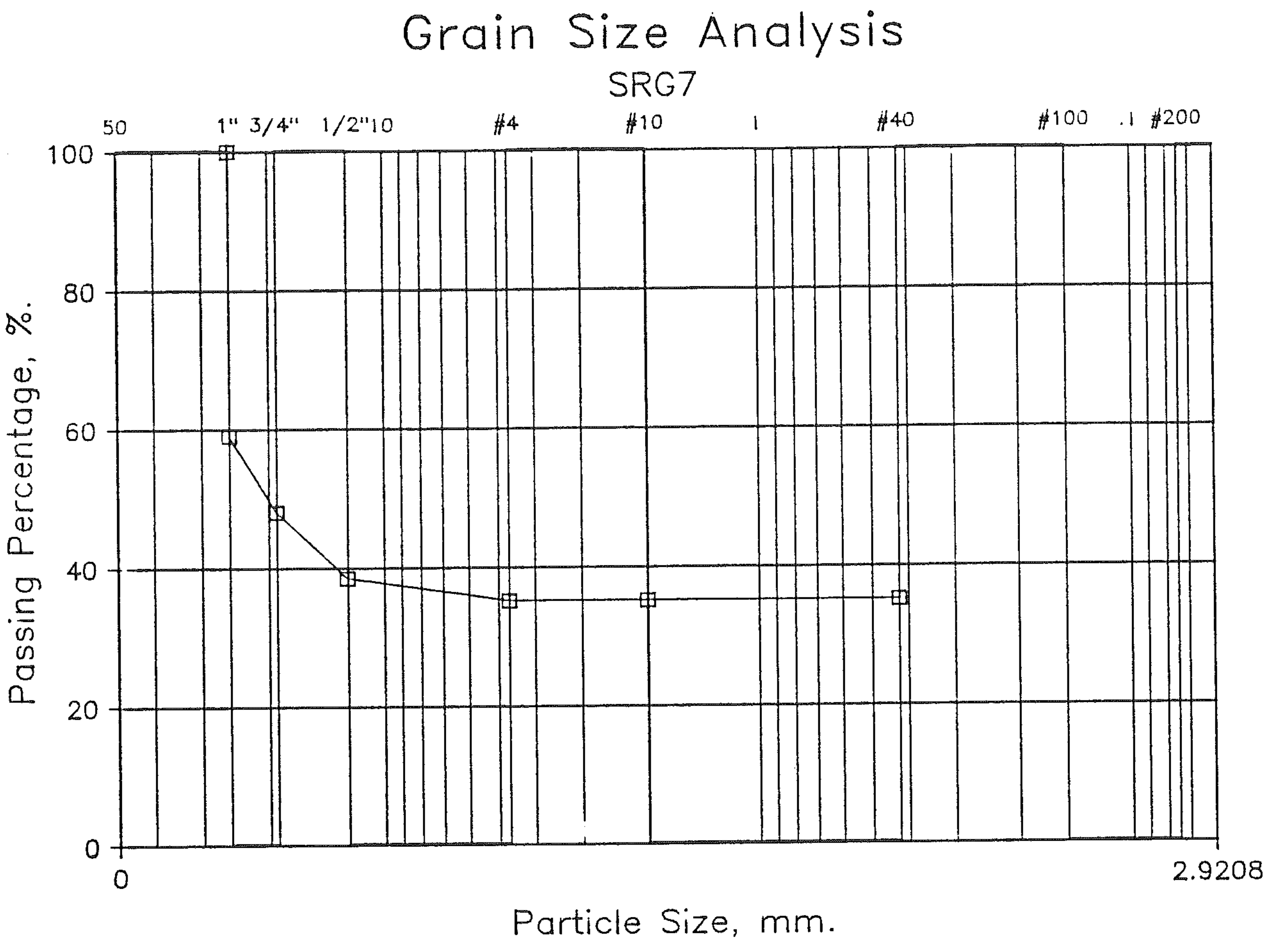

Grain Size Analysis
SRG4
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

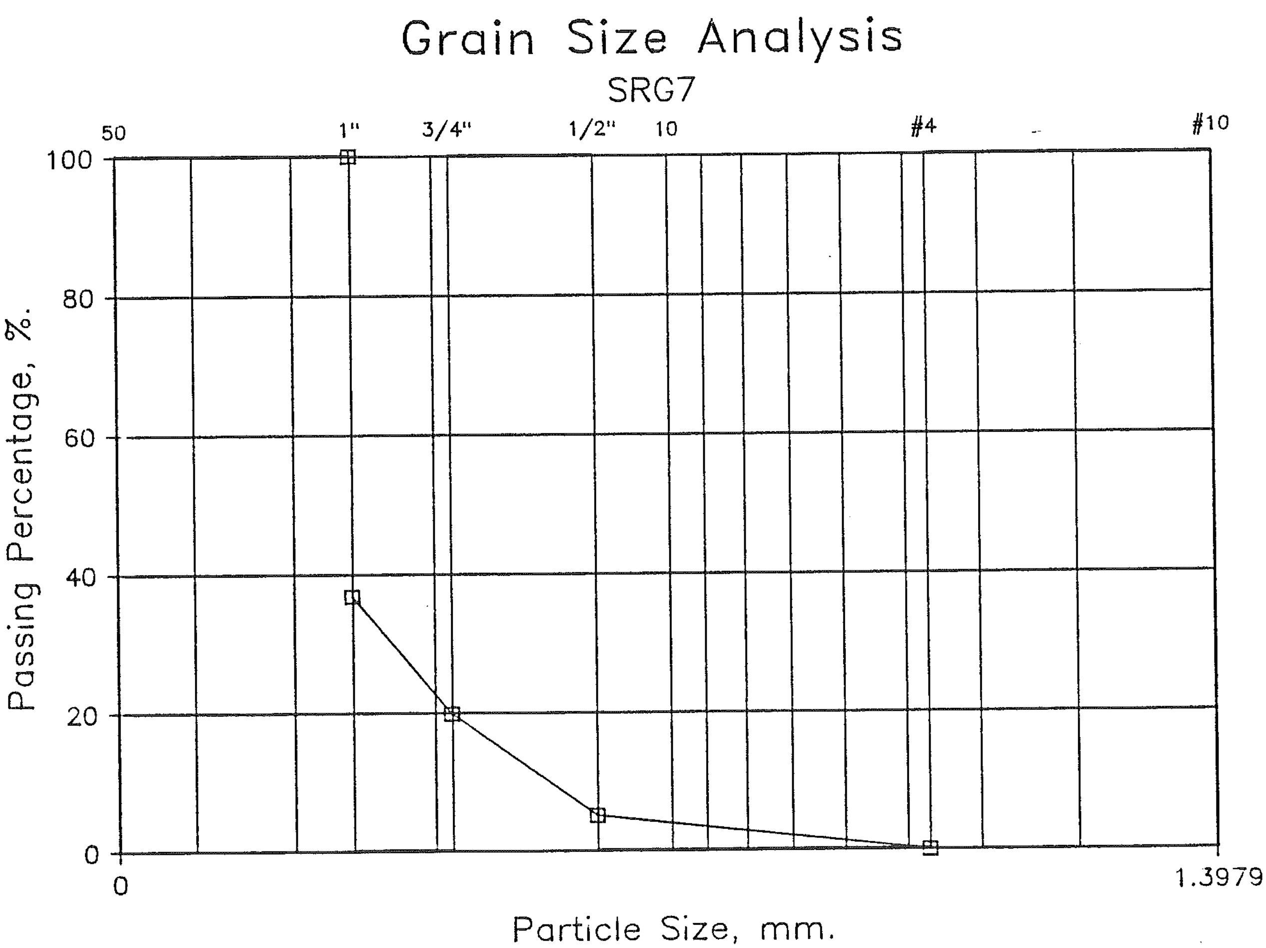

Grain Size Analysis
SRG5
50
1"
3/4"
1/2"
10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

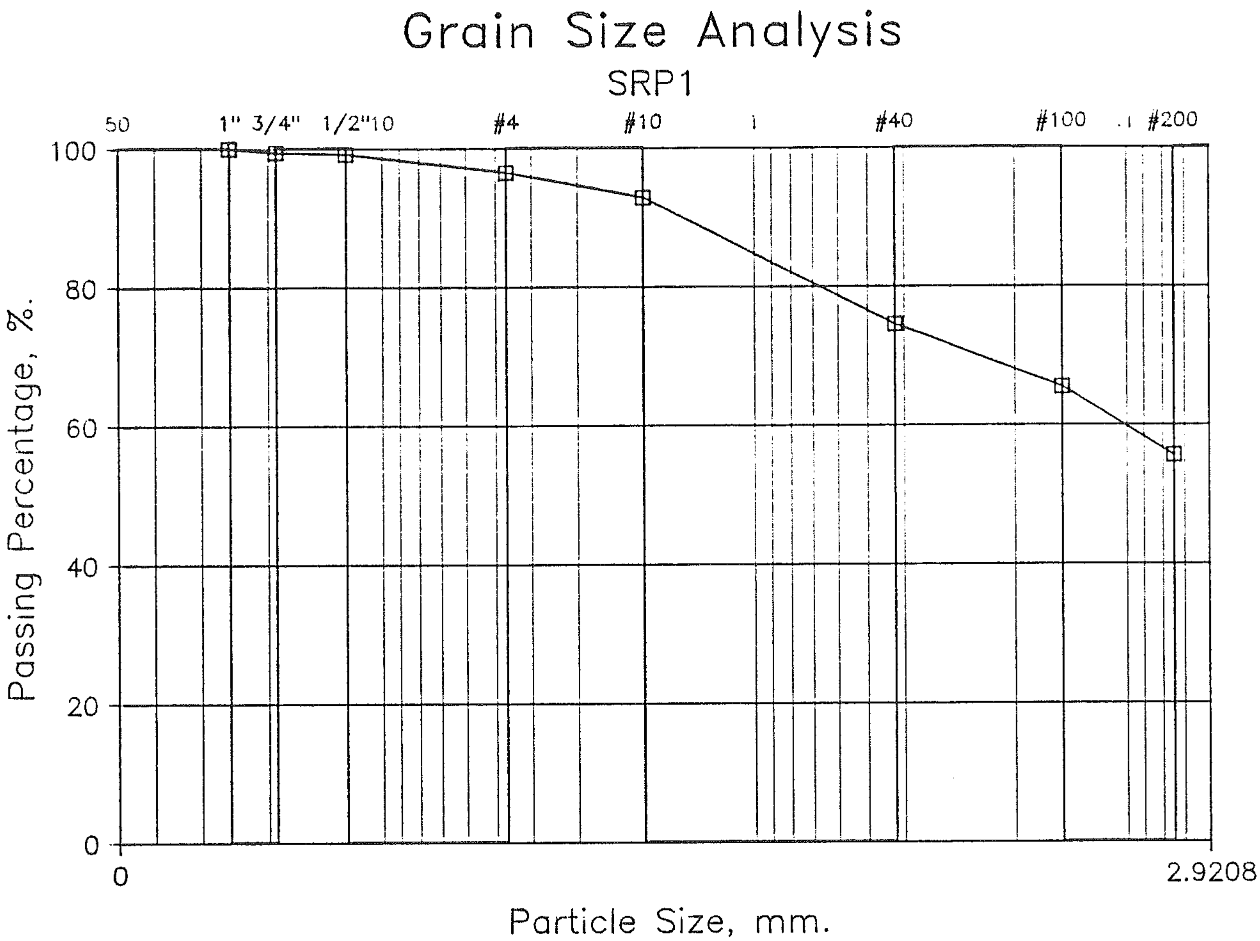

Grain Size Analysis
SRG5
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

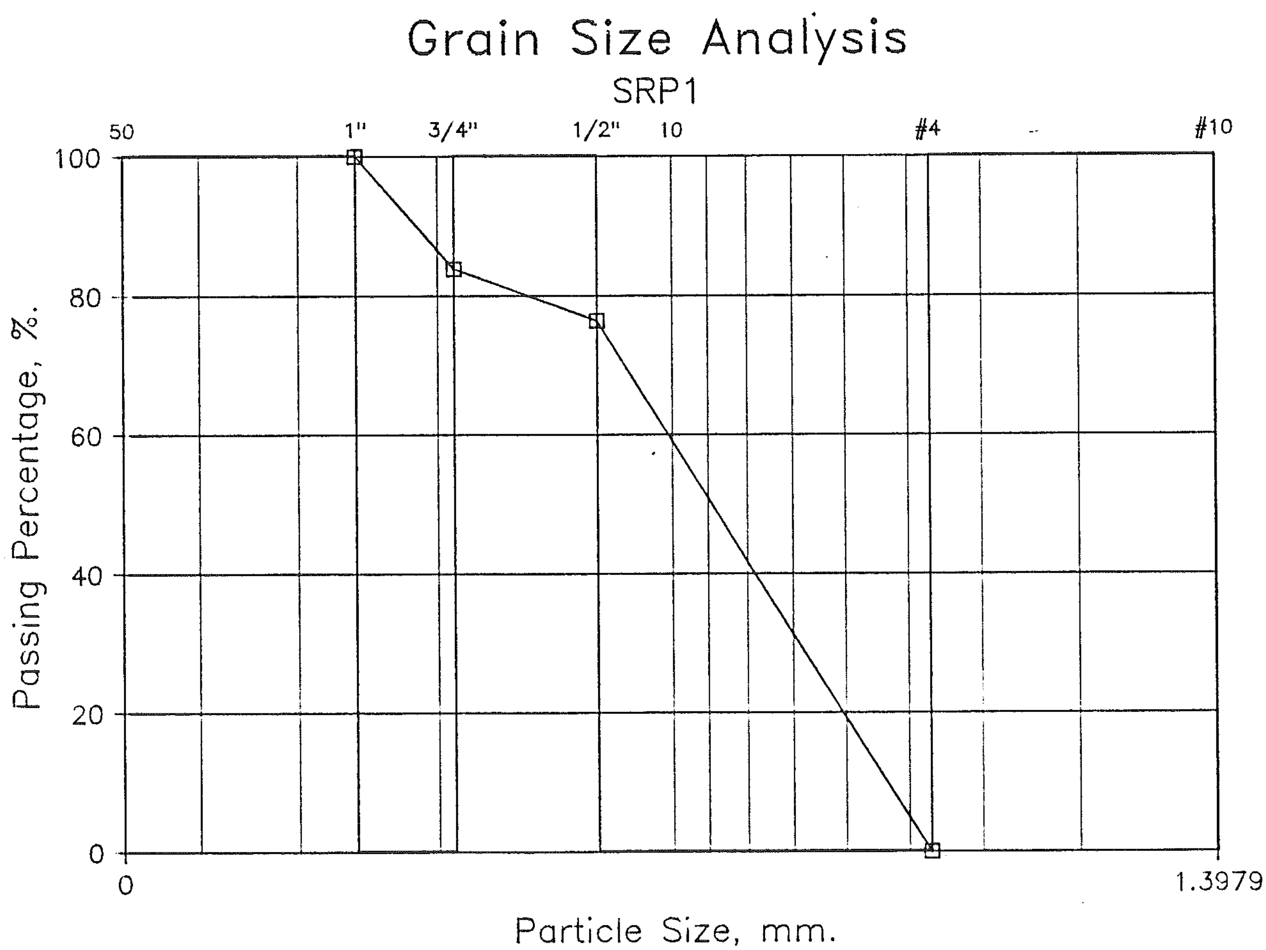

Grain Size Analysis
SRG6
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

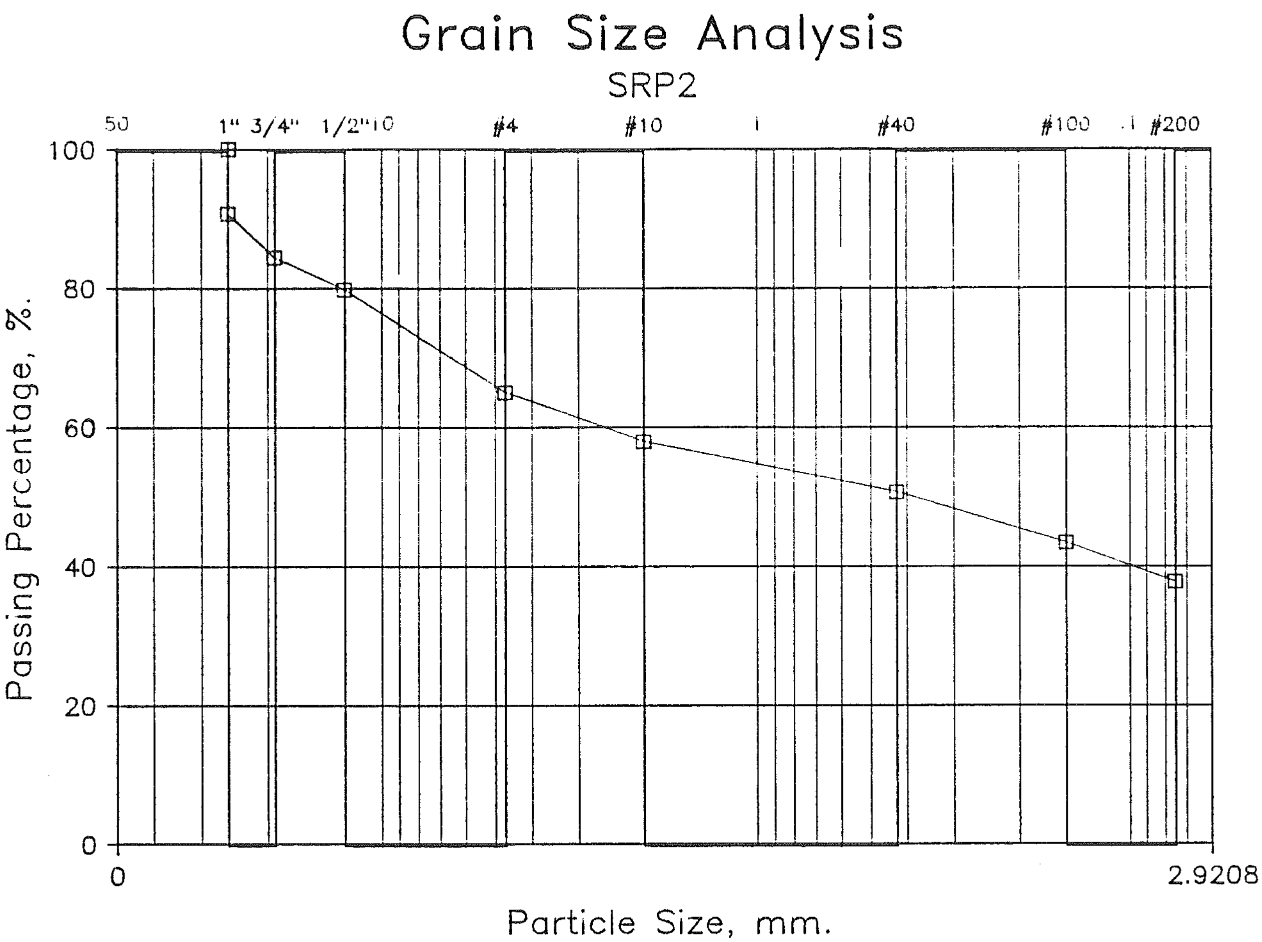

Grain Size Analysis
SRG6
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

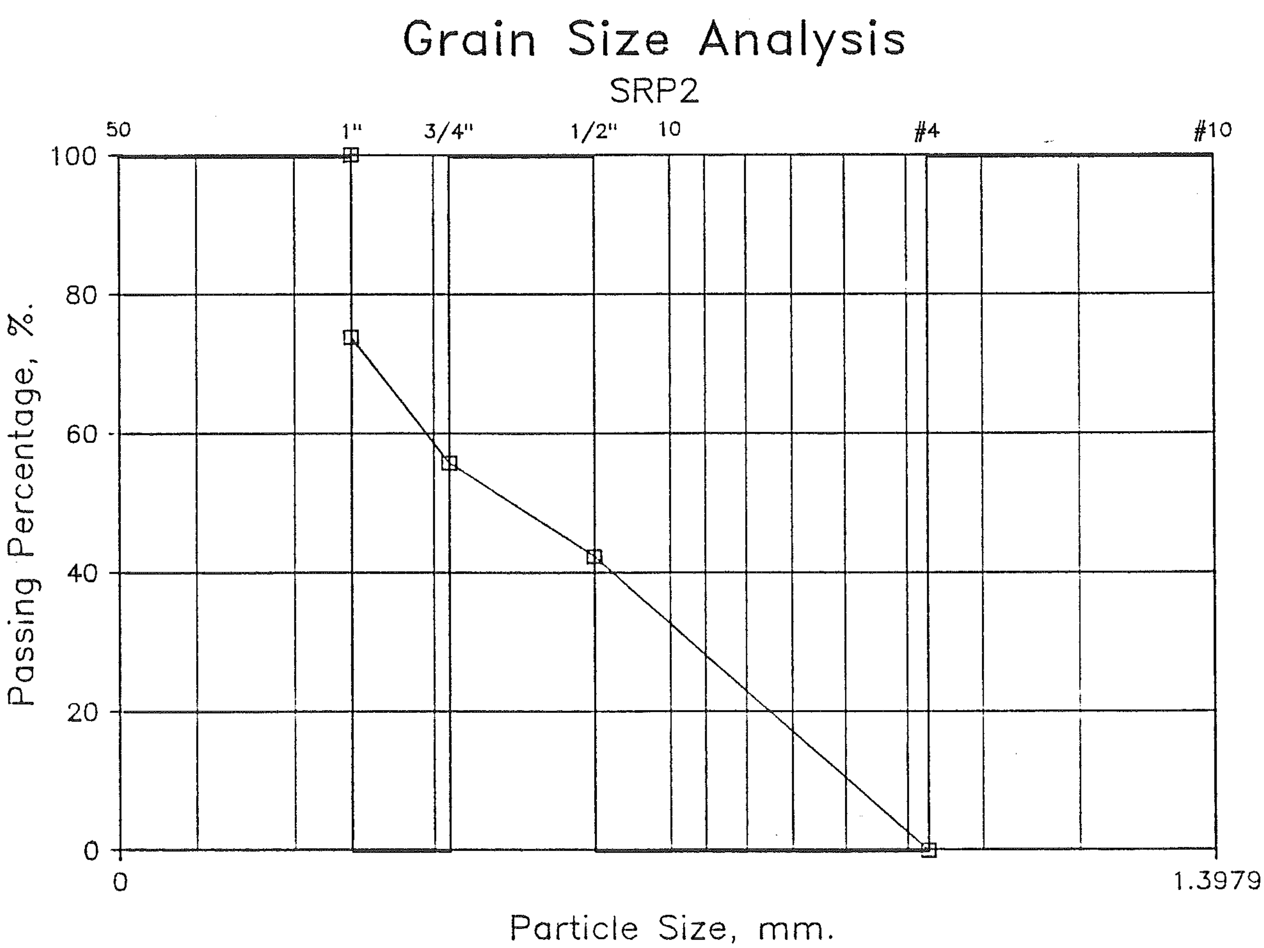

Grain Size Analysis
SRG7
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
0
2.9208
Passing Percentage, %.
Particle Size, mm.

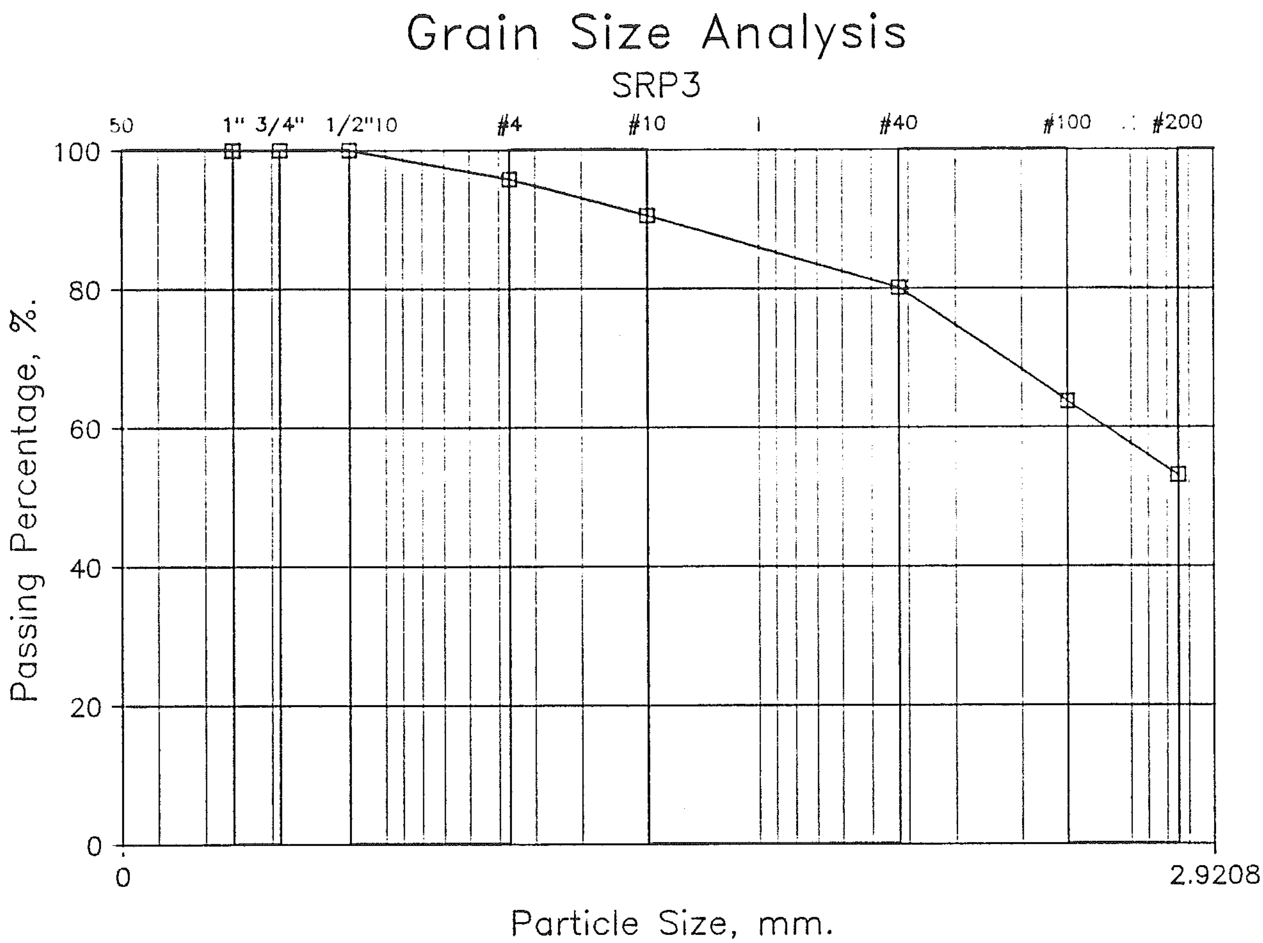

Grain Size Analysis
SRG7
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
0
1.3979
Passing Percentage, %.
Particle Size, mm.


Grain Size Analysis
SRP1
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

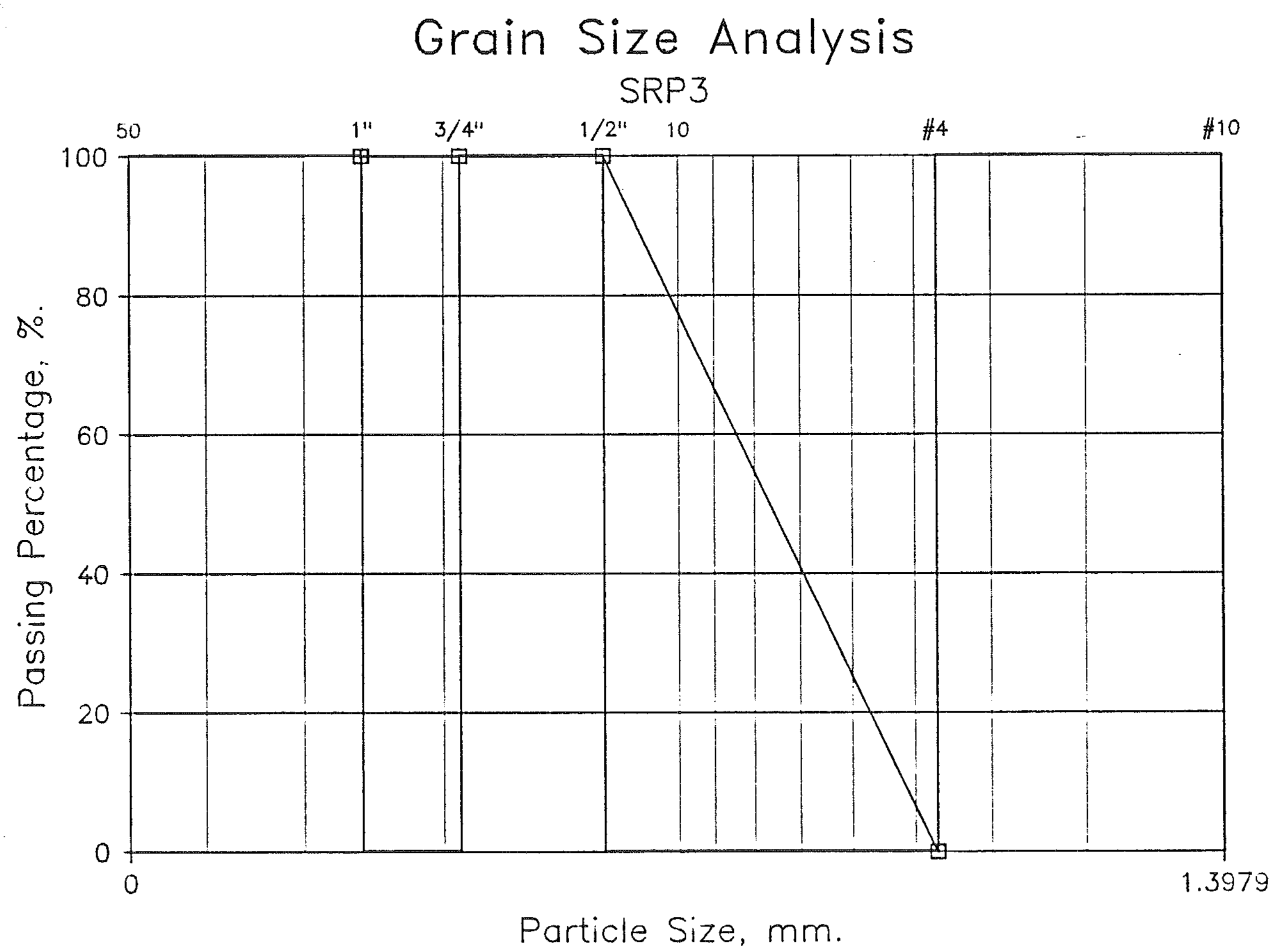

Grain Size Analysis
SRP1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
SRP2
50
1" 3/4" 1/2" 10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

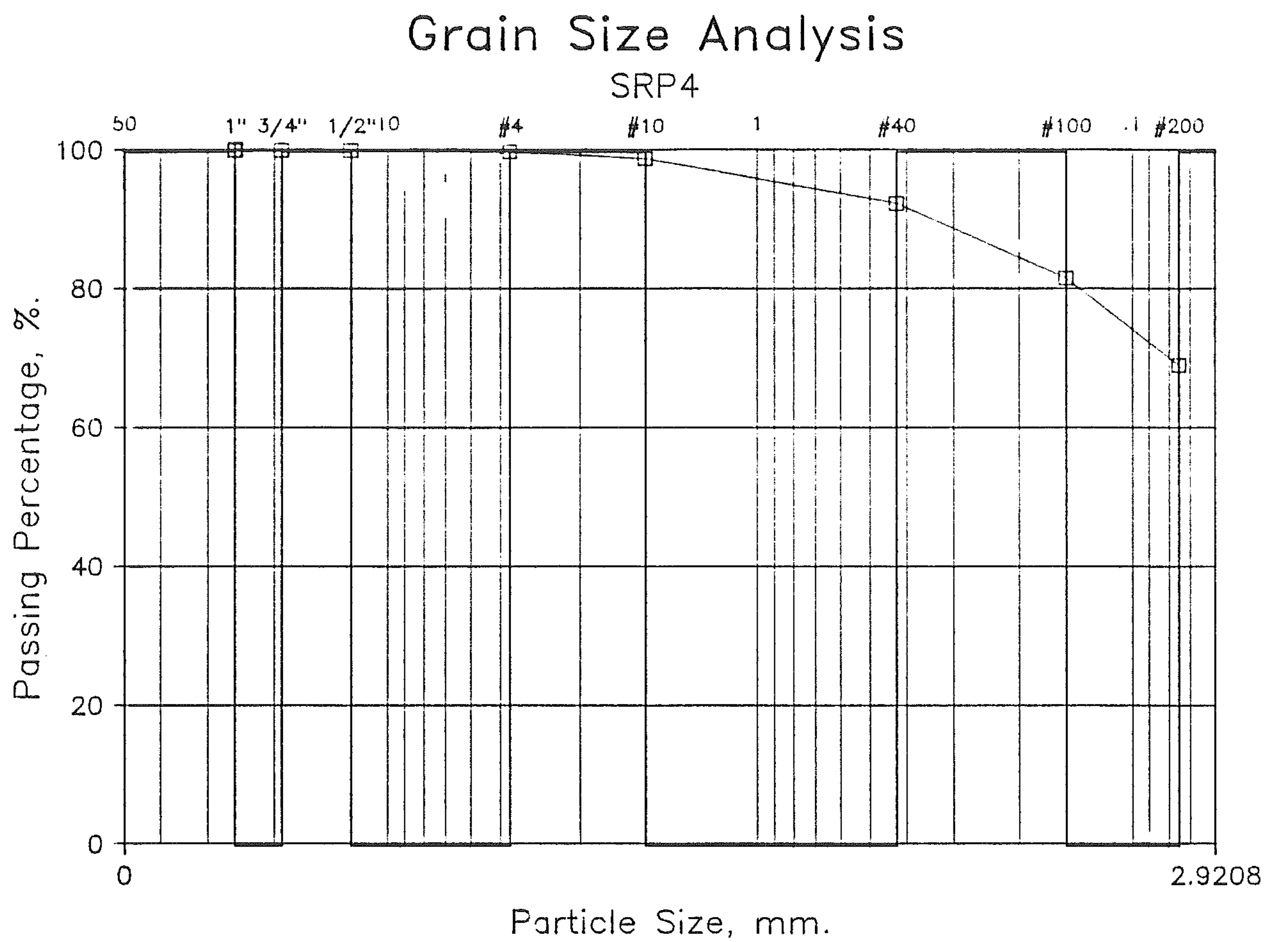

Grain Size Analysis
SRP2
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

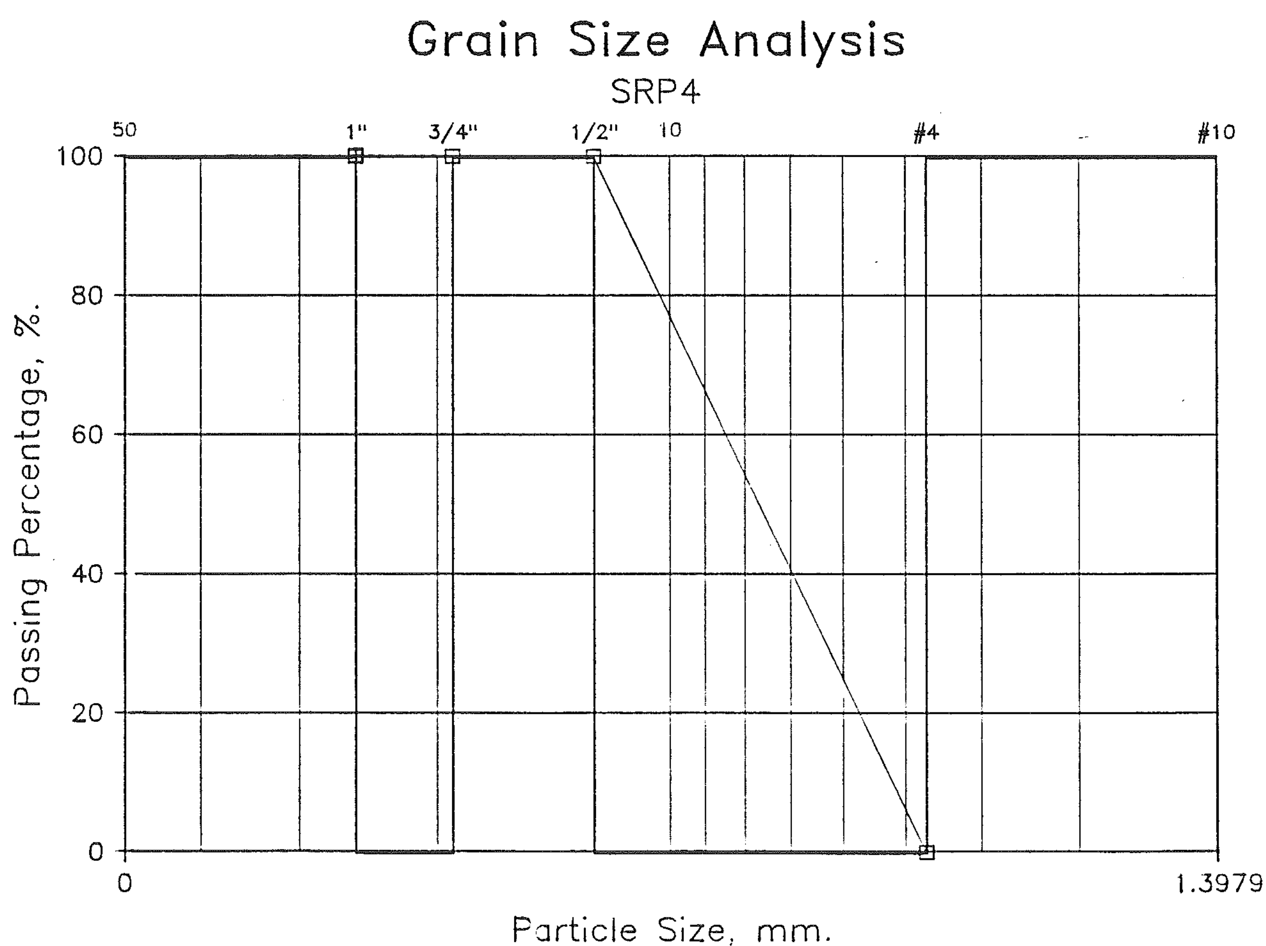


Grain Size Analysis
SRP3
50
1"
3/4"
1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.



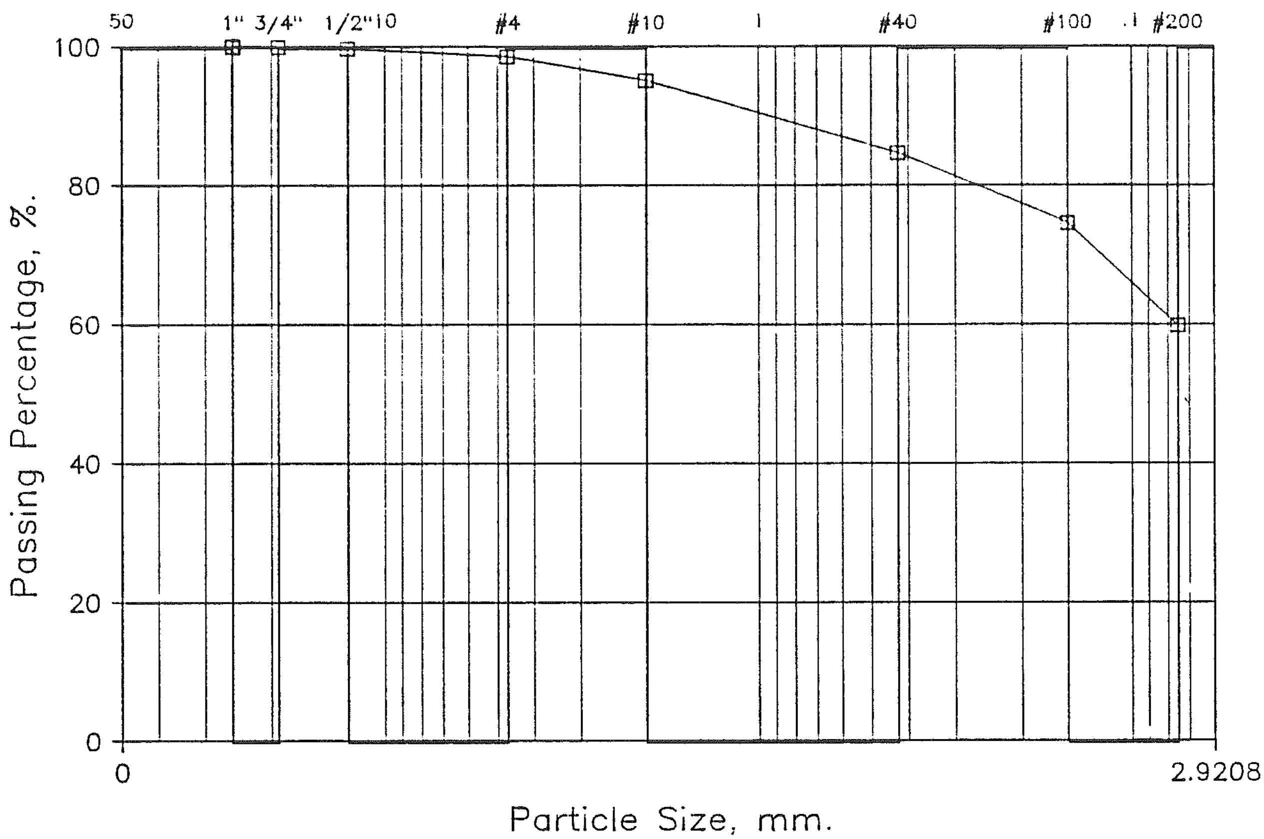
Grain Size Analysis
SRP3
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
SRP4
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
SRP4
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

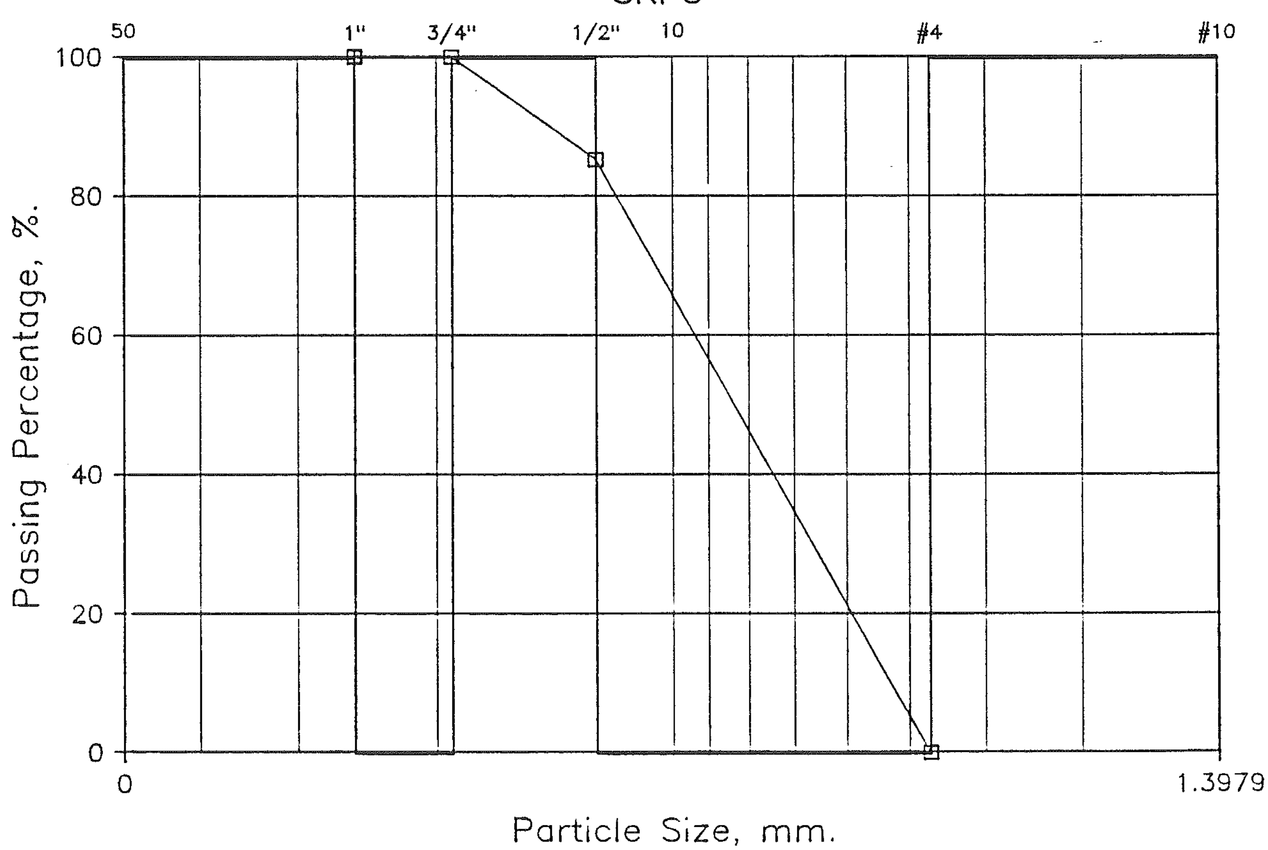
Grain Size Analysis

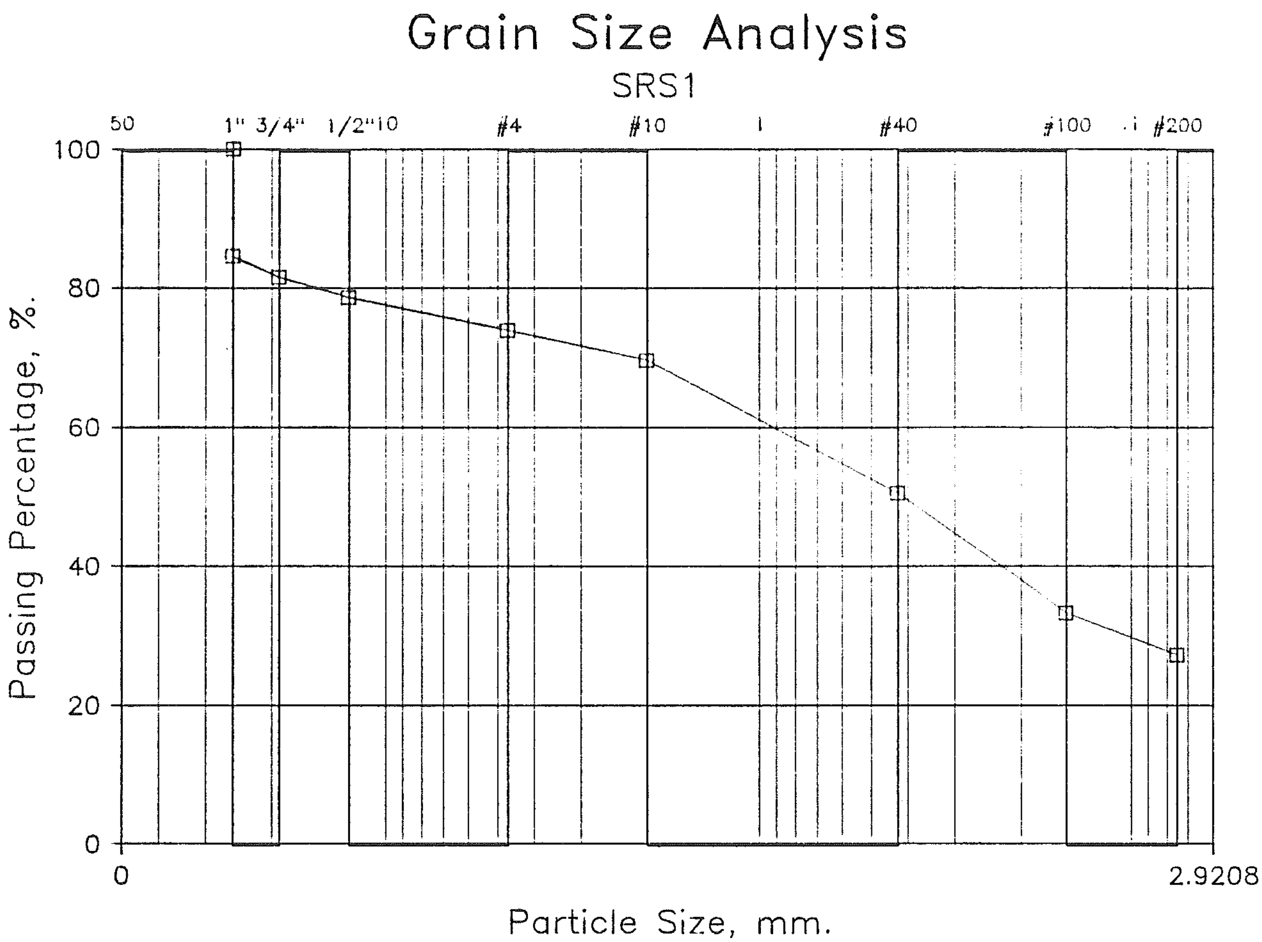
SRP5

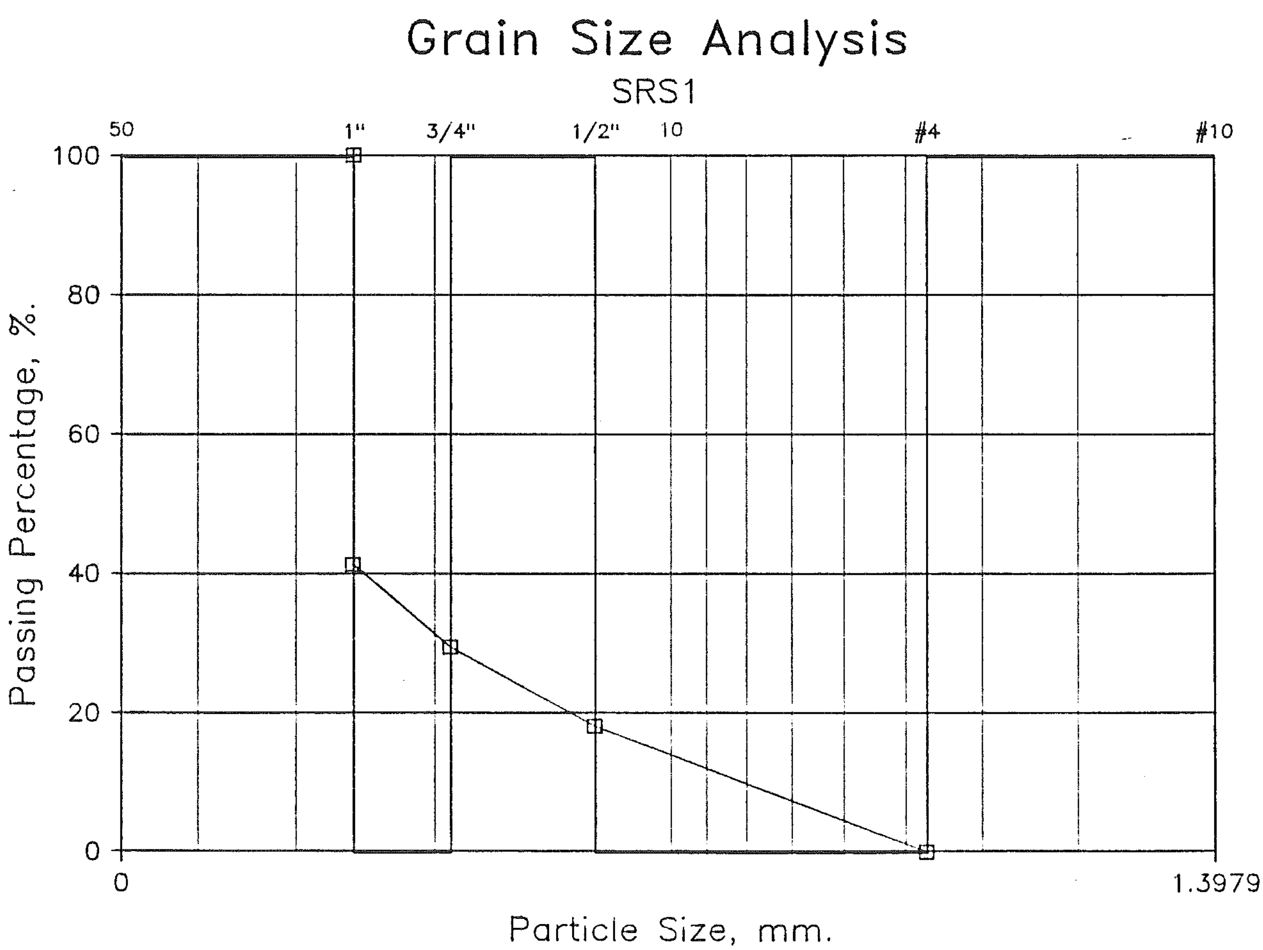


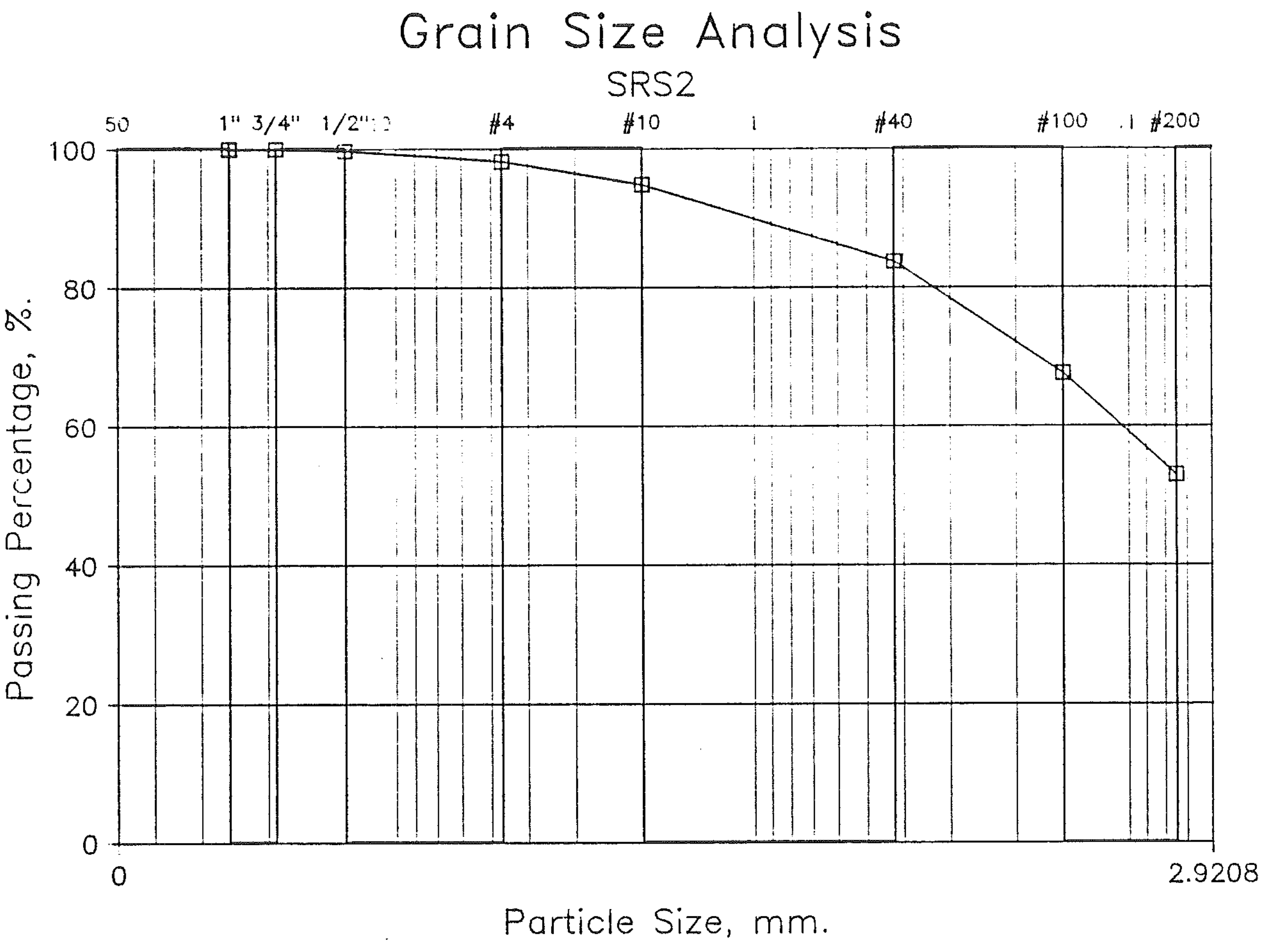
Grain Size Analysis

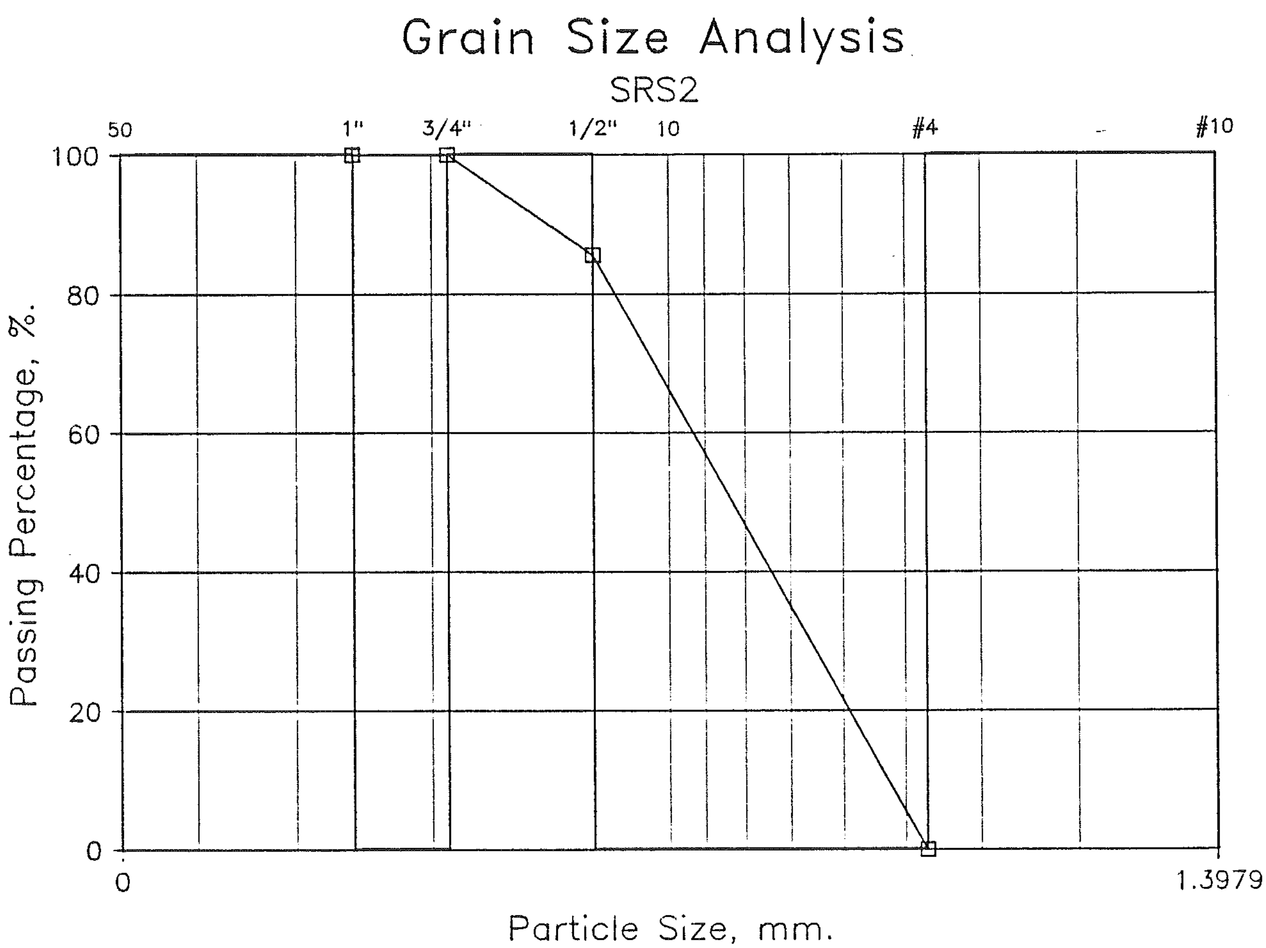
SRP5

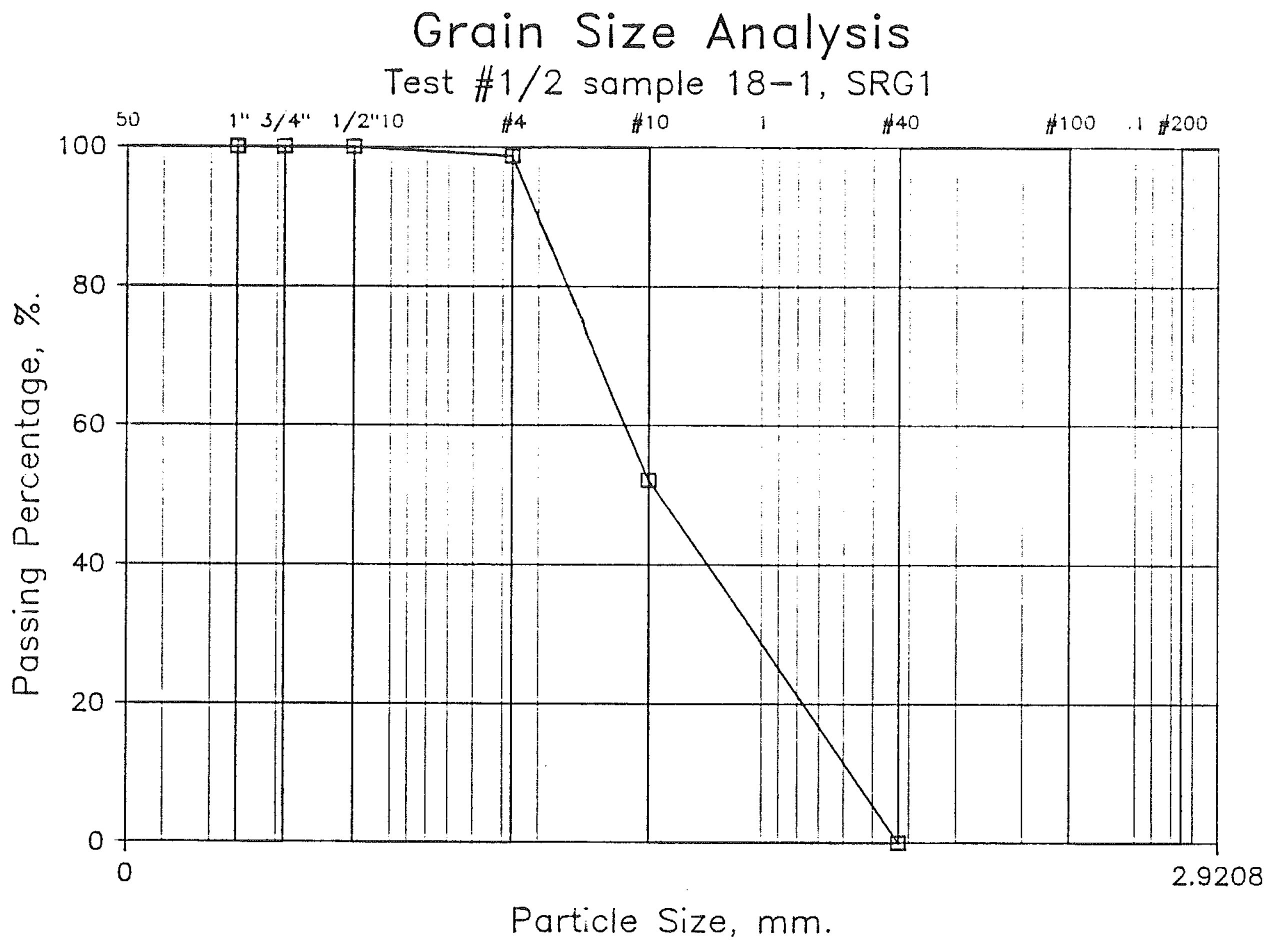



Grain Size Analysis
SRS1
50
1"
3/4"
1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

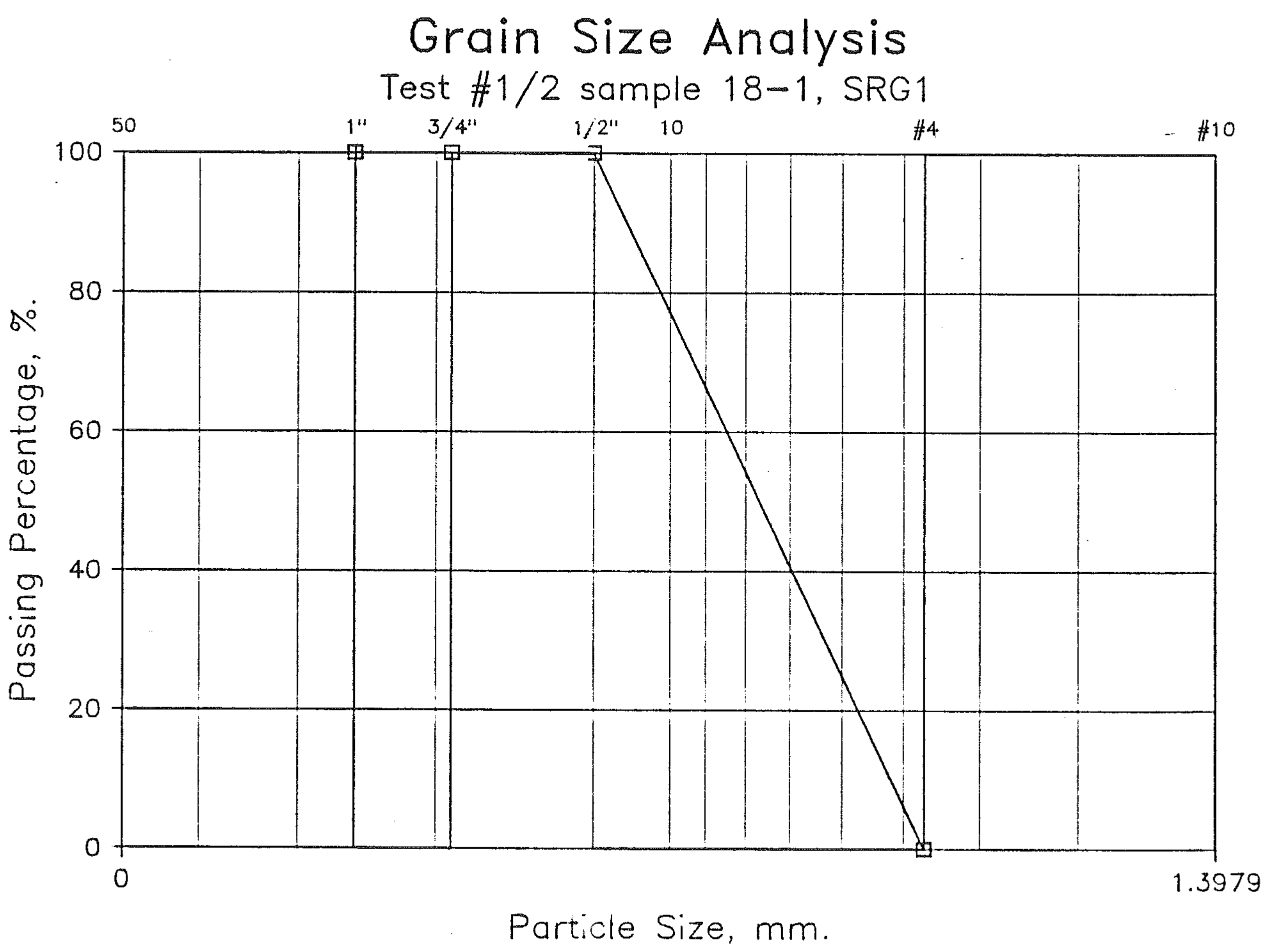

Grain Size Analysis
SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
SRS2
50
1"
3/4"
1/2"
#4
#10
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
SRS2
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.



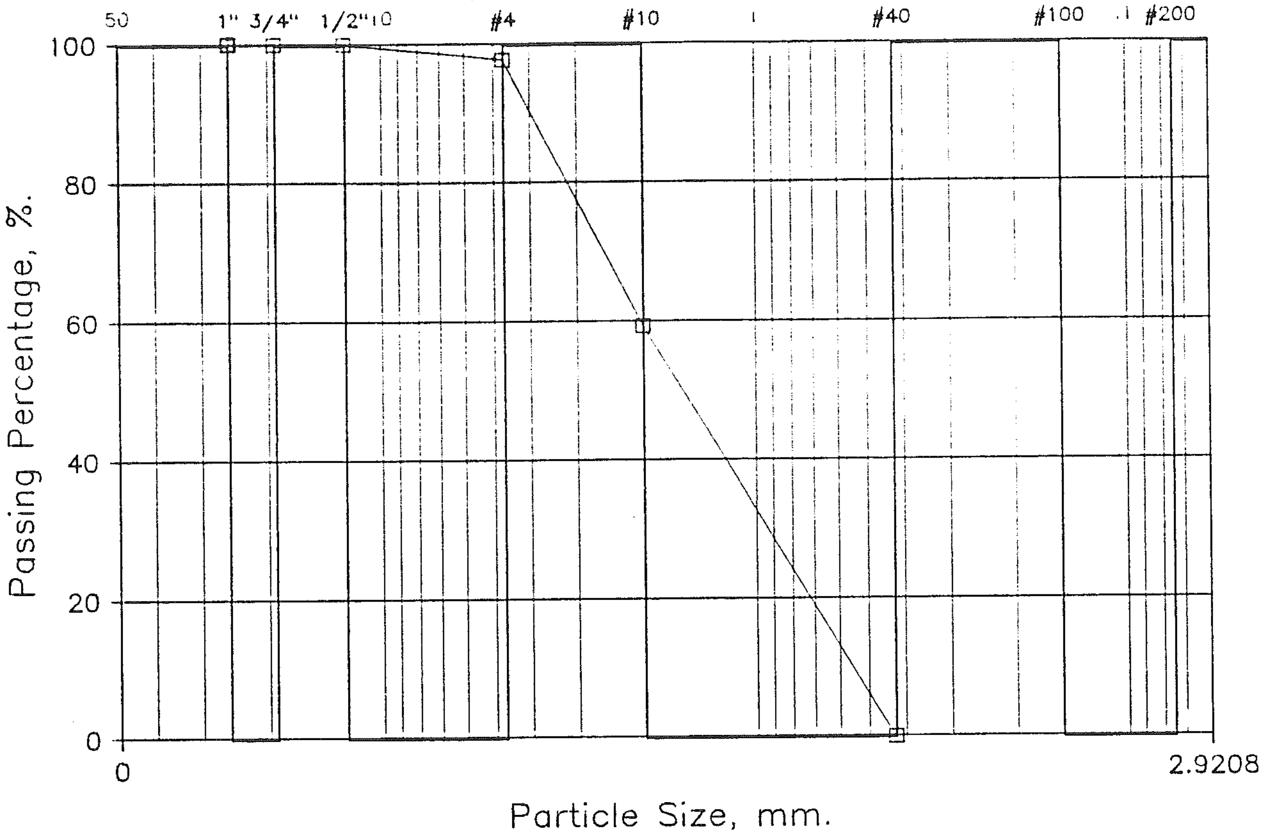
Grain Size Analysis
Test #1/2 sample 18-1, SRG1
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.



Grain Size Analysis
Test #1/2 sample 18-1, SRG1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

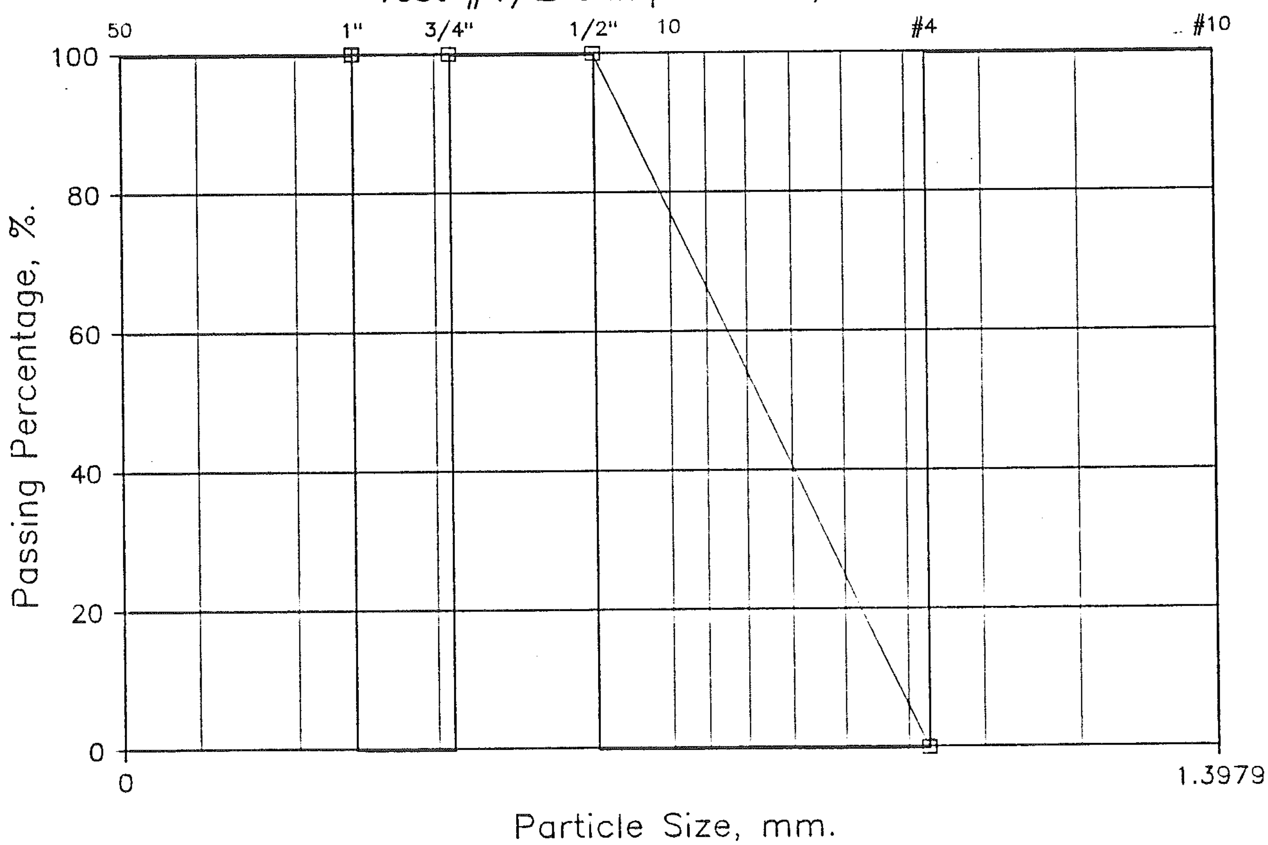
Grain Size Analysis

Test #1/2 sample 19-1, SRG1



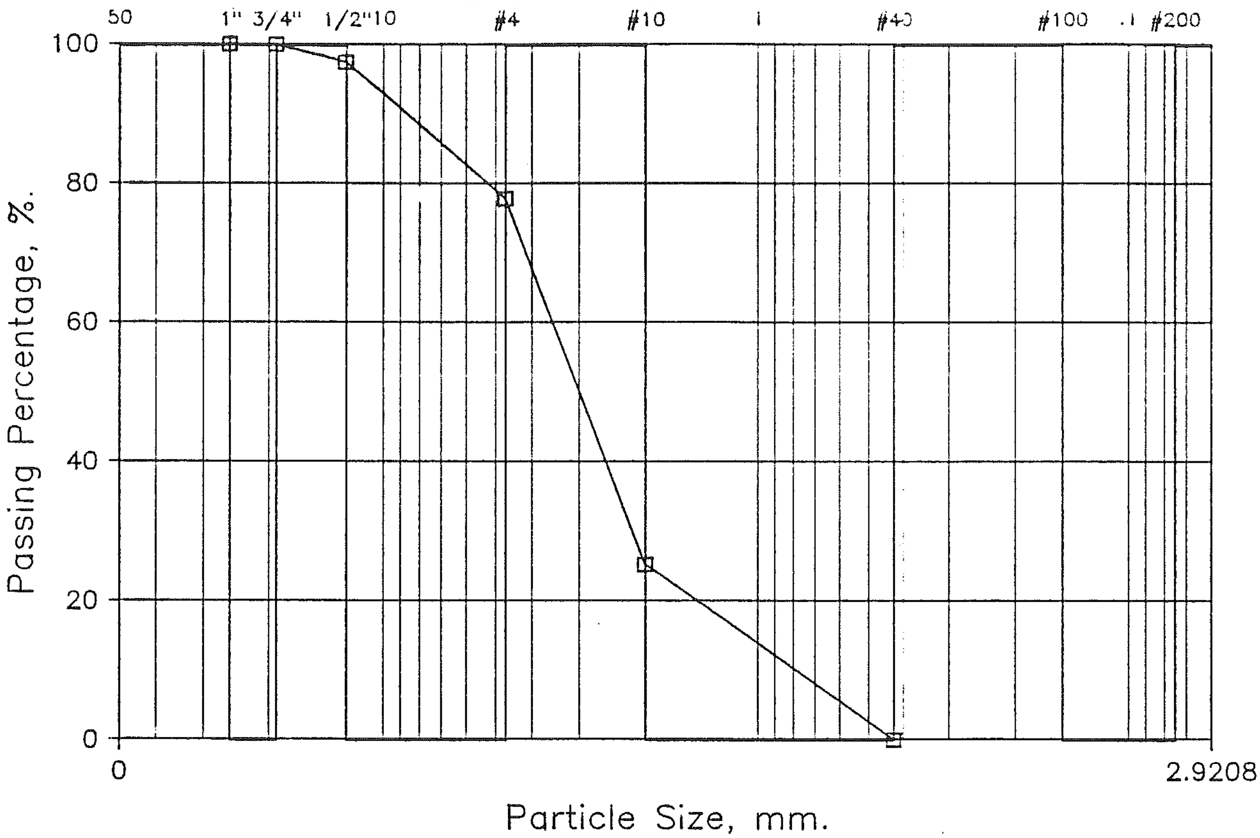
Grain Size Analysis

Test #1/2 sample 19-1, SRG1



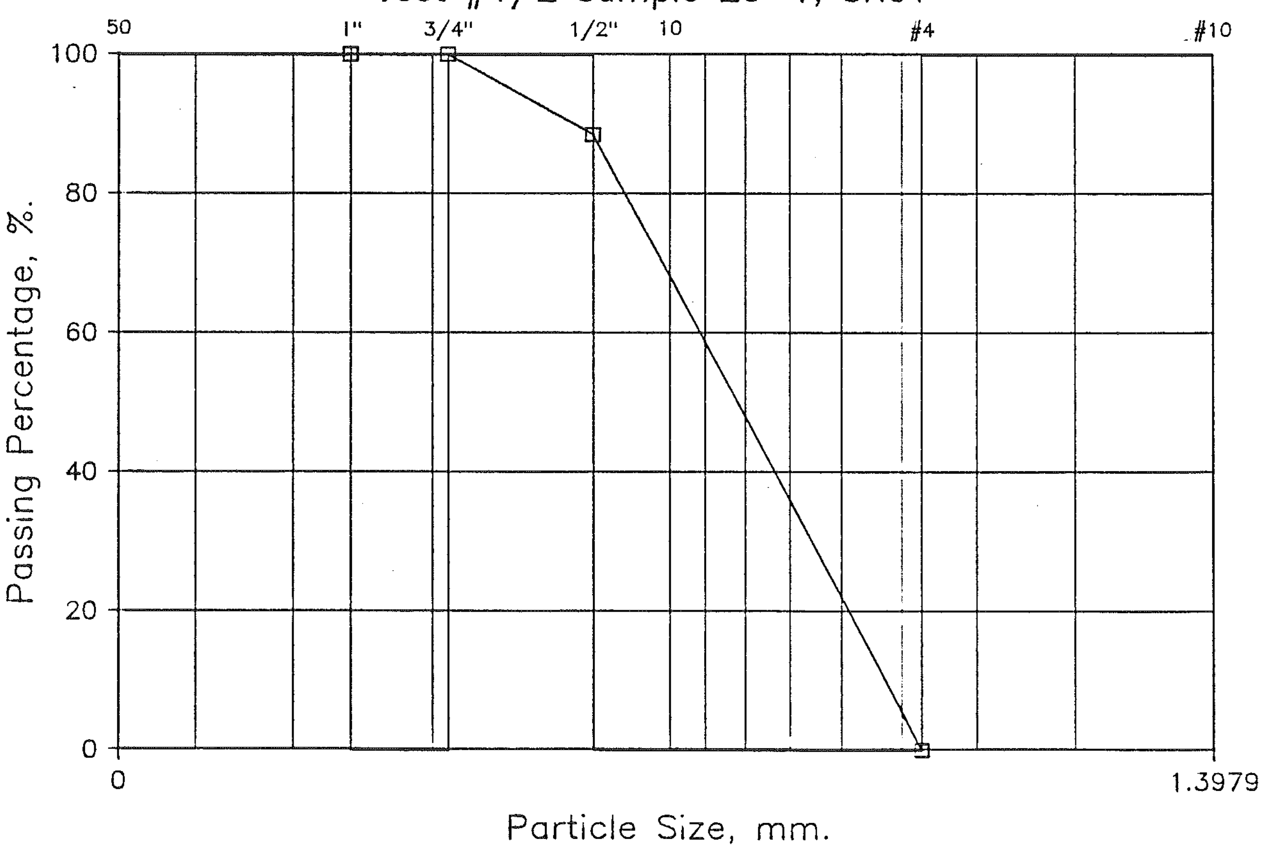
Grain Size Analysis

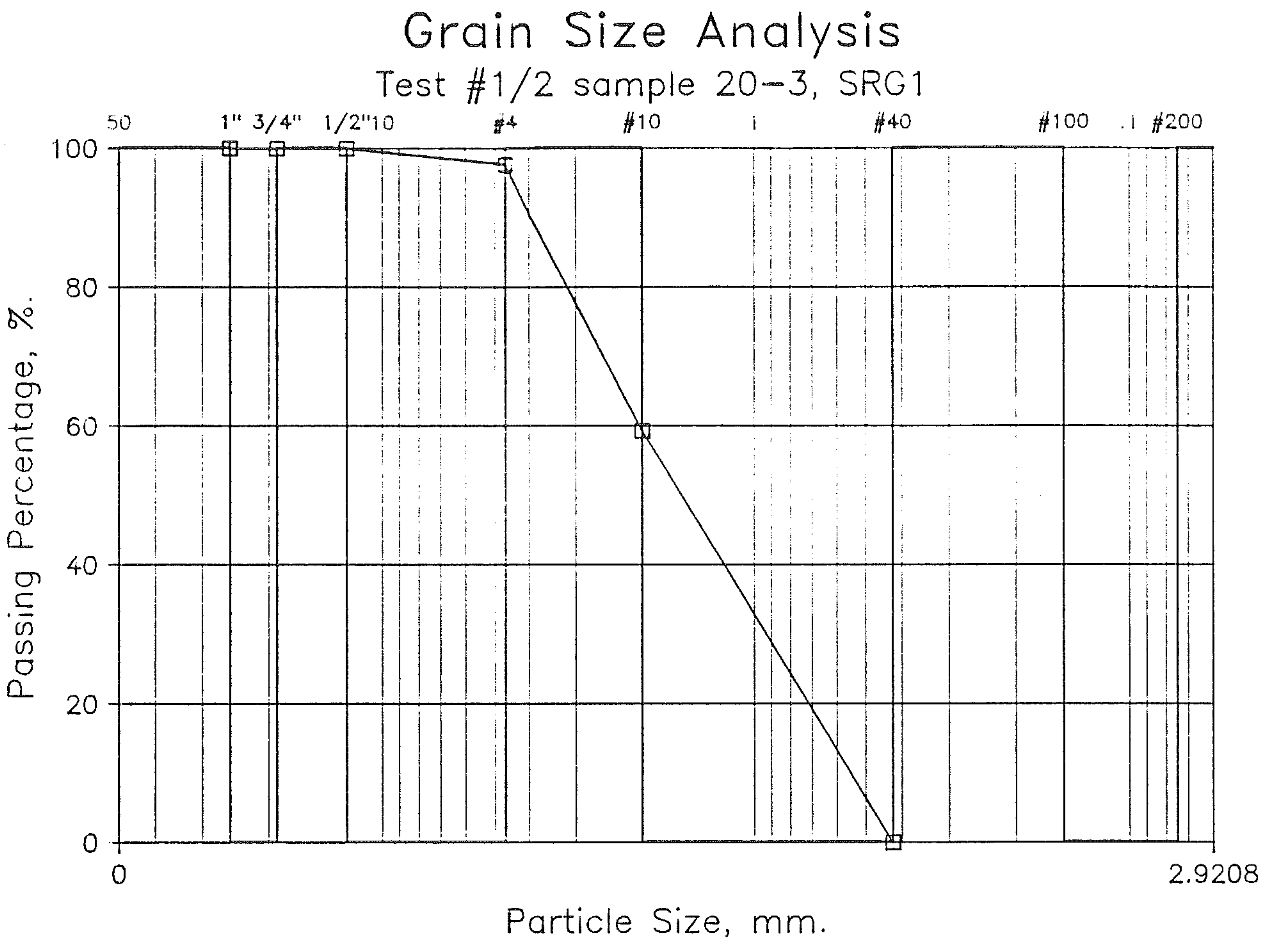
Test #1/2 sample 20-1, SRG1

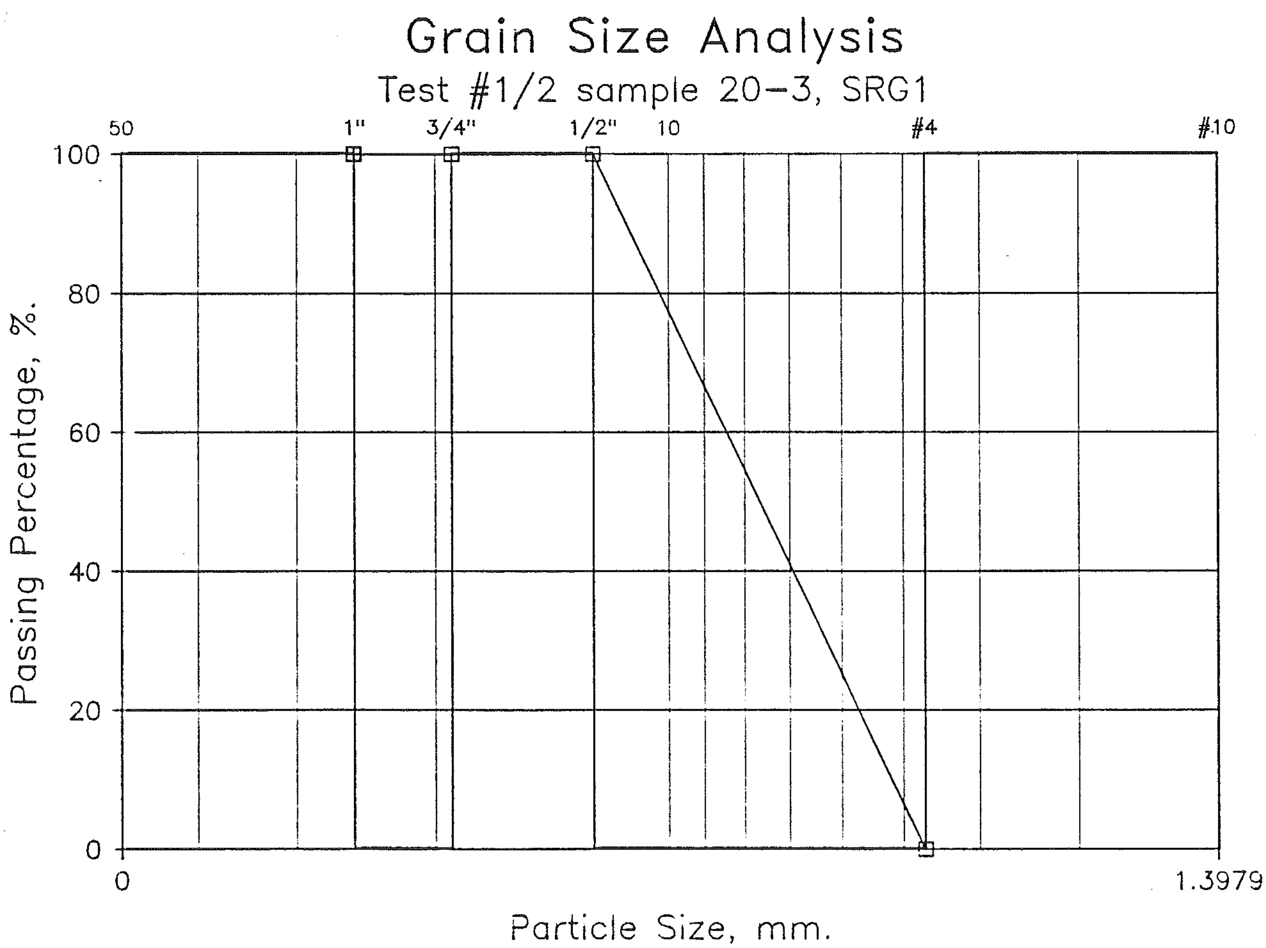


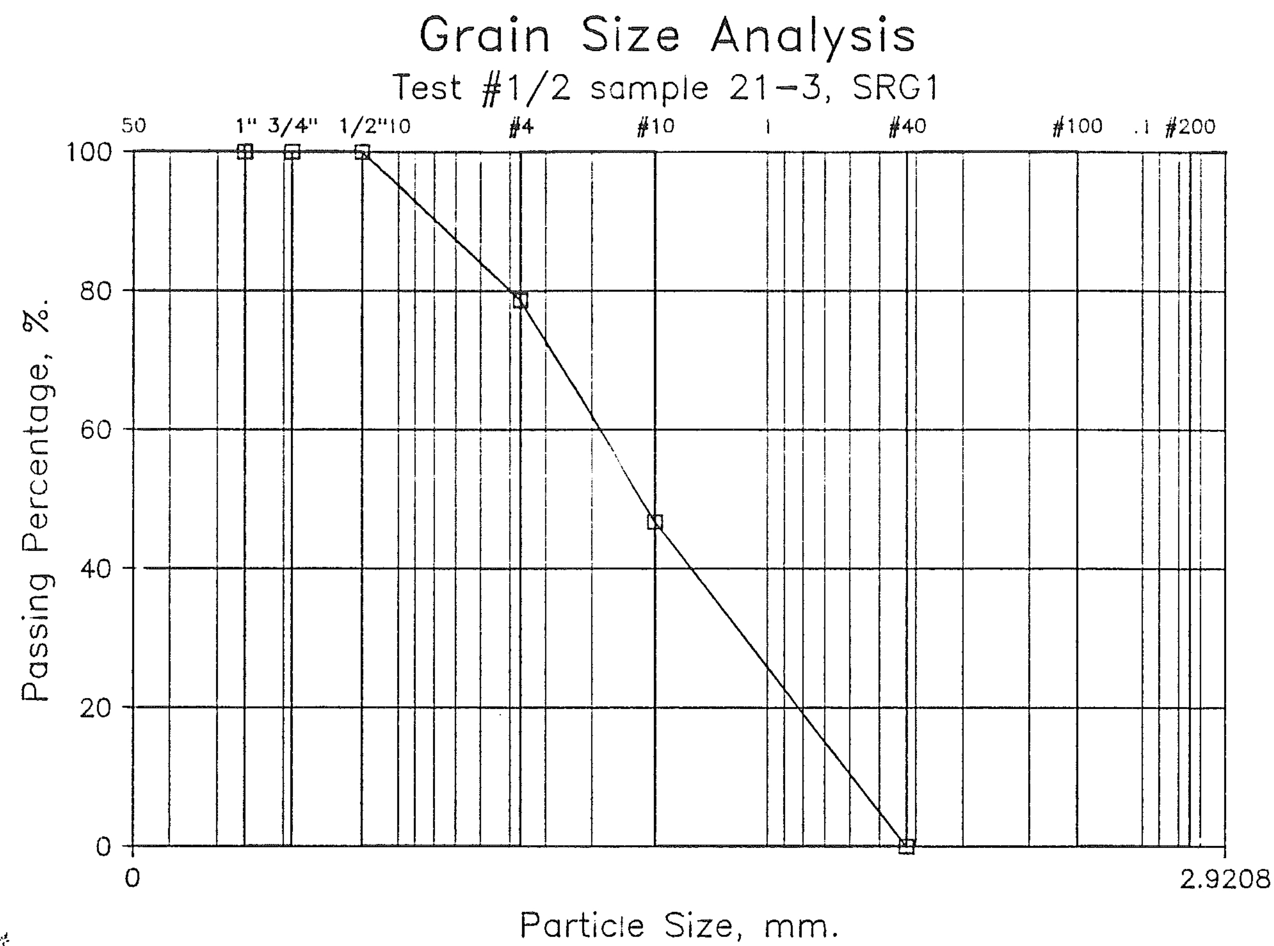
Grain Size Analysis

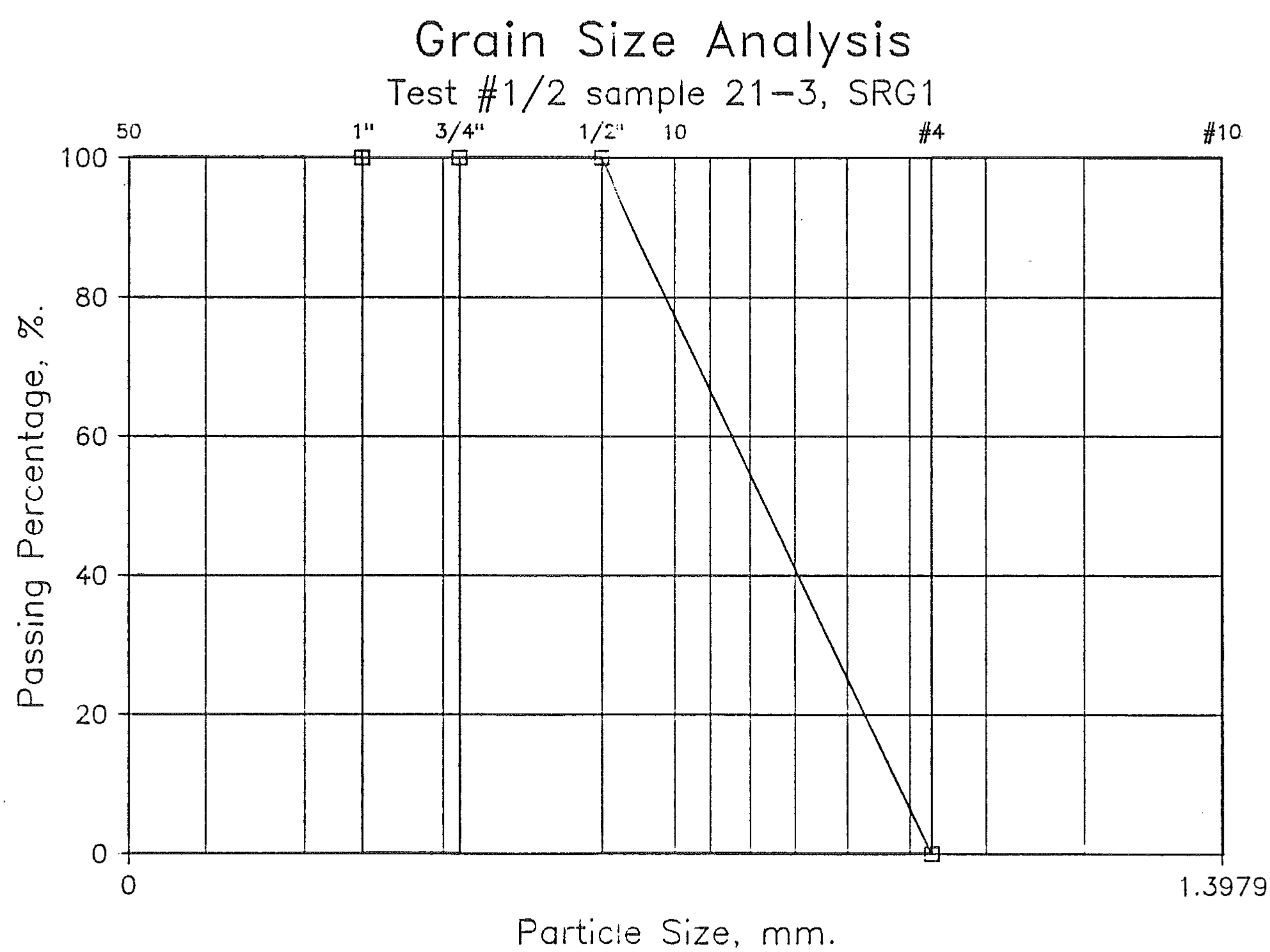
Test #1/2 sample 20-1, SRG1

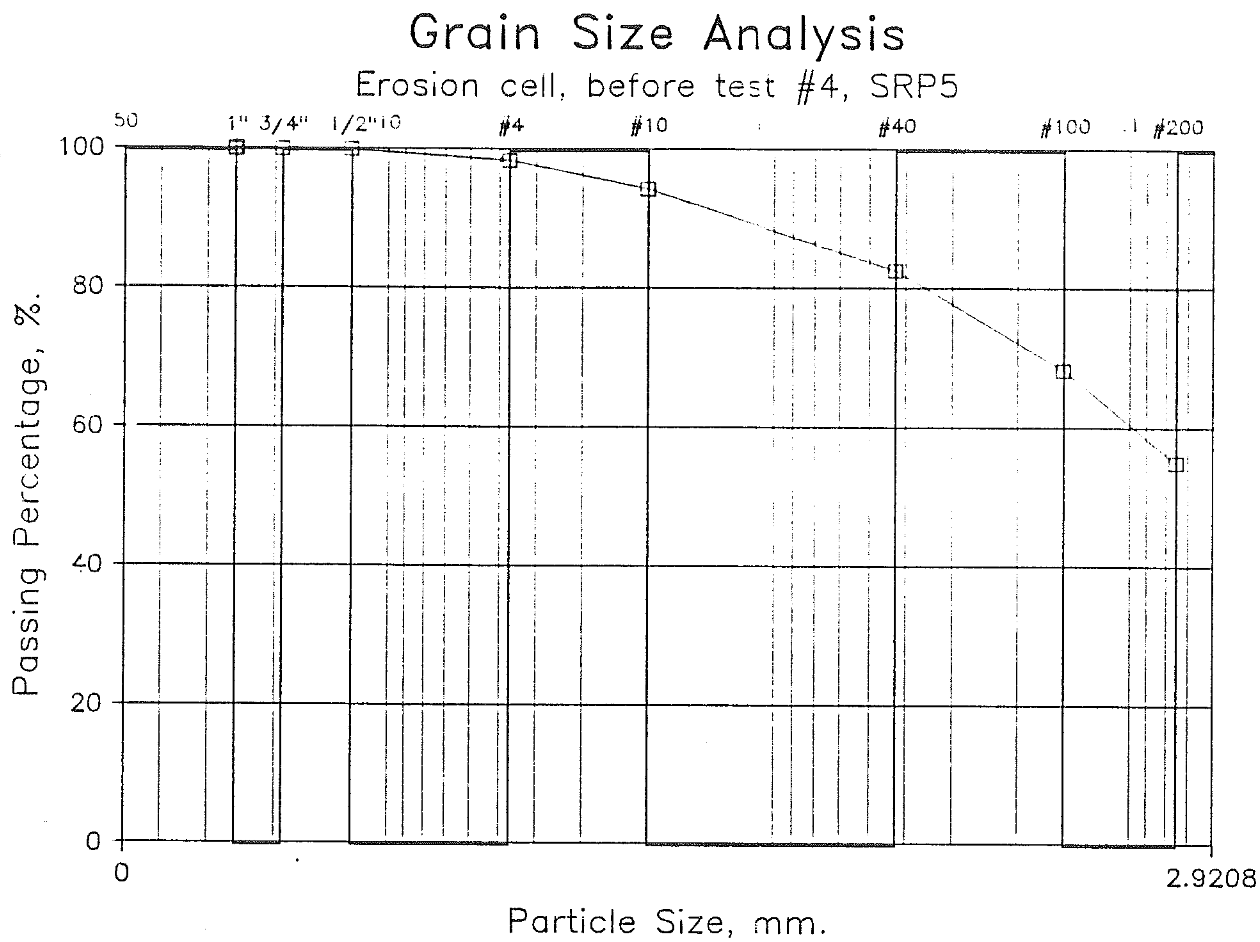


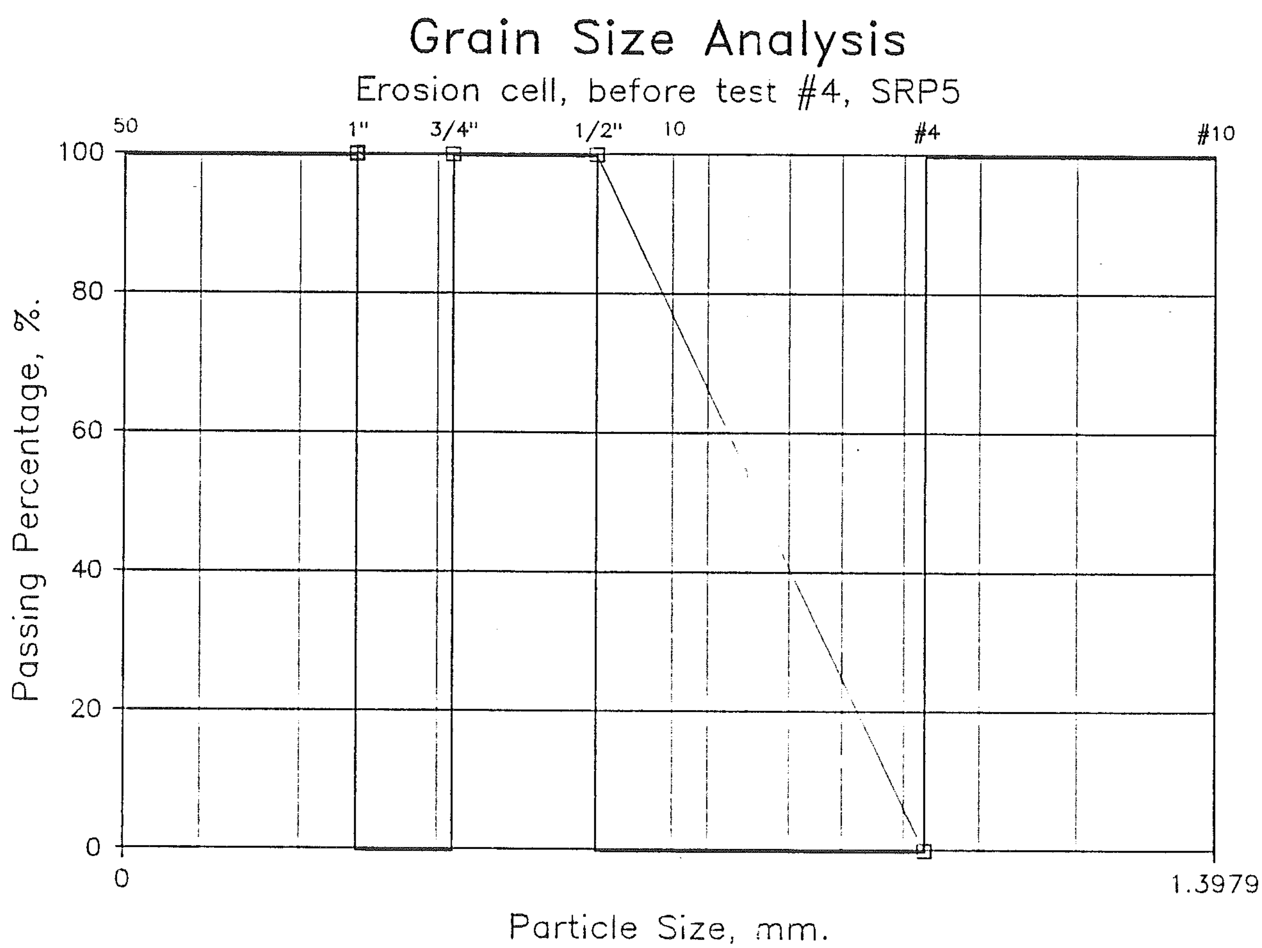

Grain Size Analysis
Test #1/2 sample 20-3, SRG1
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test #1/2 sample 20-3, SRG1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
Test #1/2 sample 21-3, SRG1
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

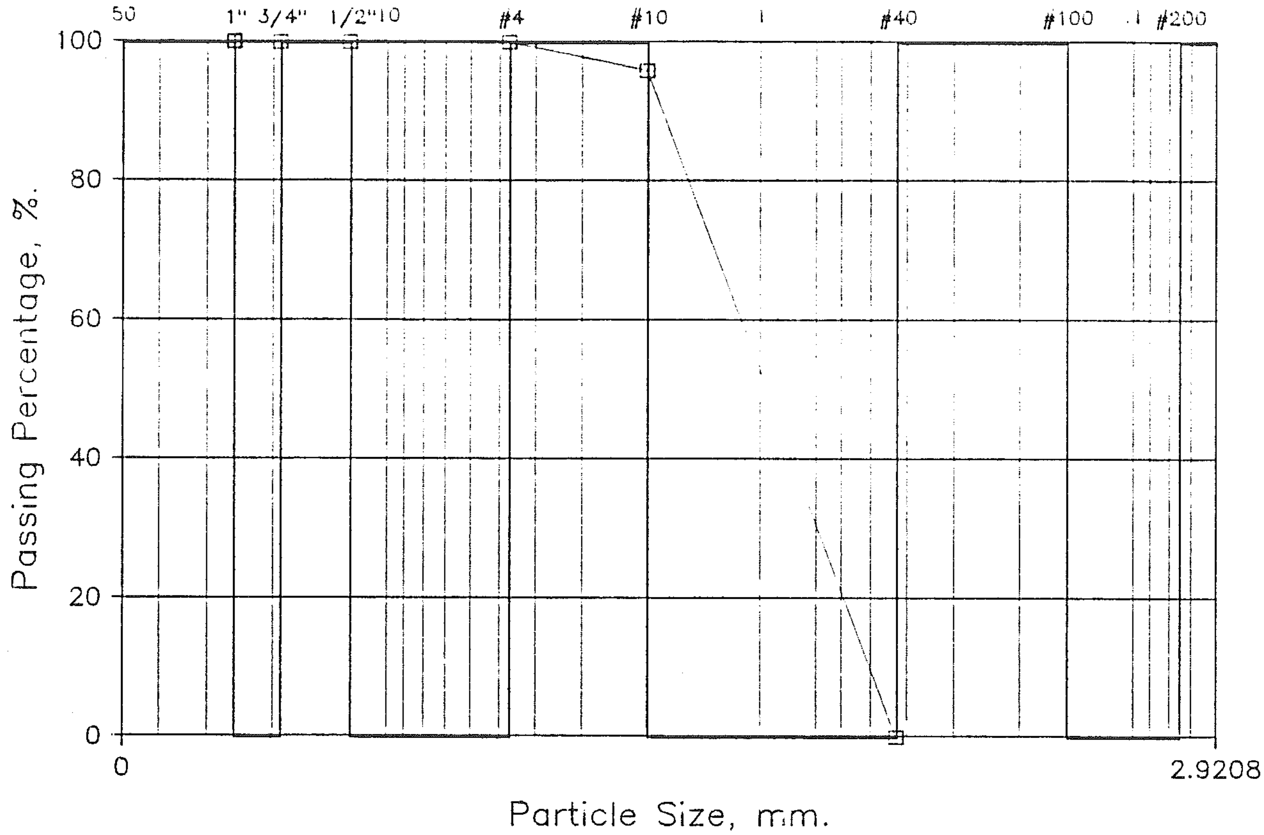

Grain Size Analysis
Test #1/2 sample 21-3, SRG1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
Erosion cell, before test #4, SRP5
50
1"
3/4"
1/2"
10
#4
#10
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Erosion cell, before test #4, SRP5
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

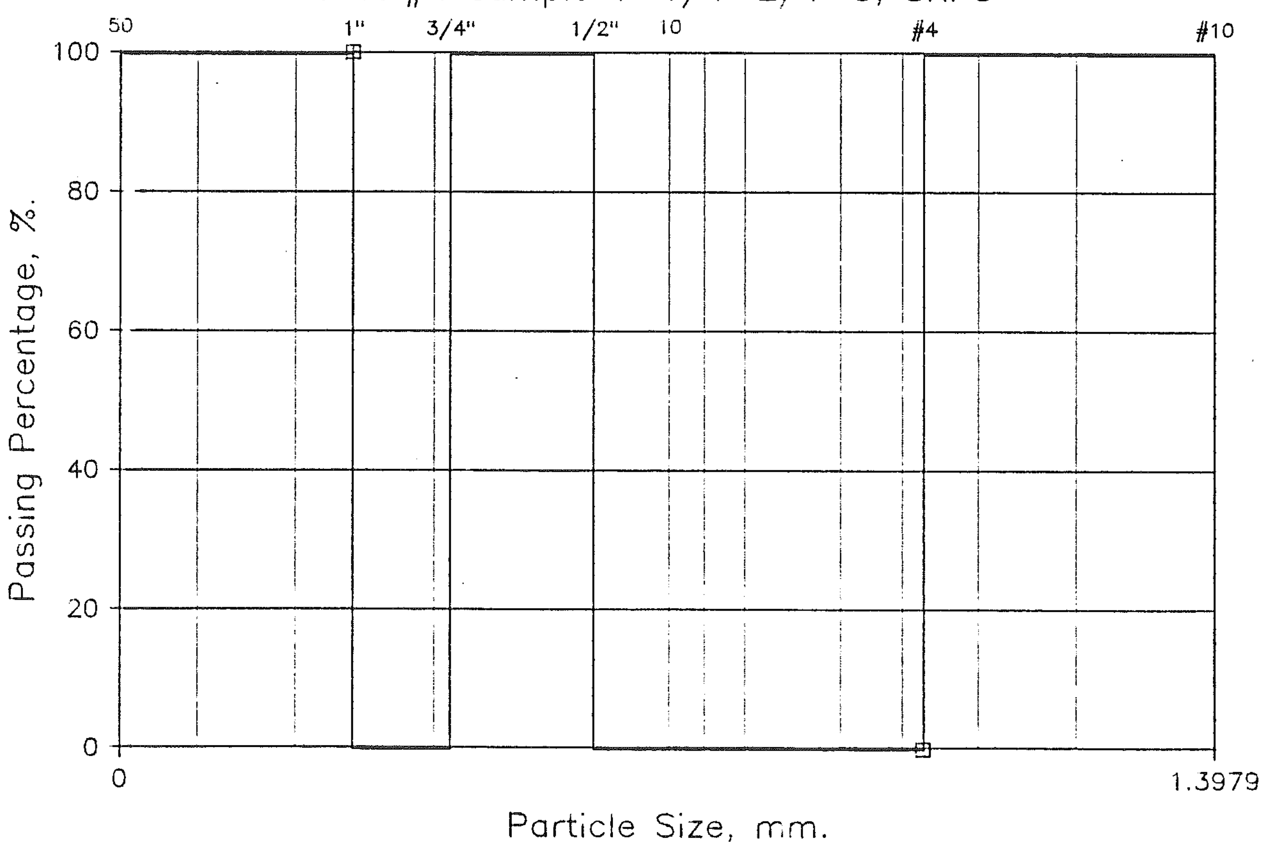
Grain Size Analysis

Test #4 sample 1-1/1-2/1-3, SRP5

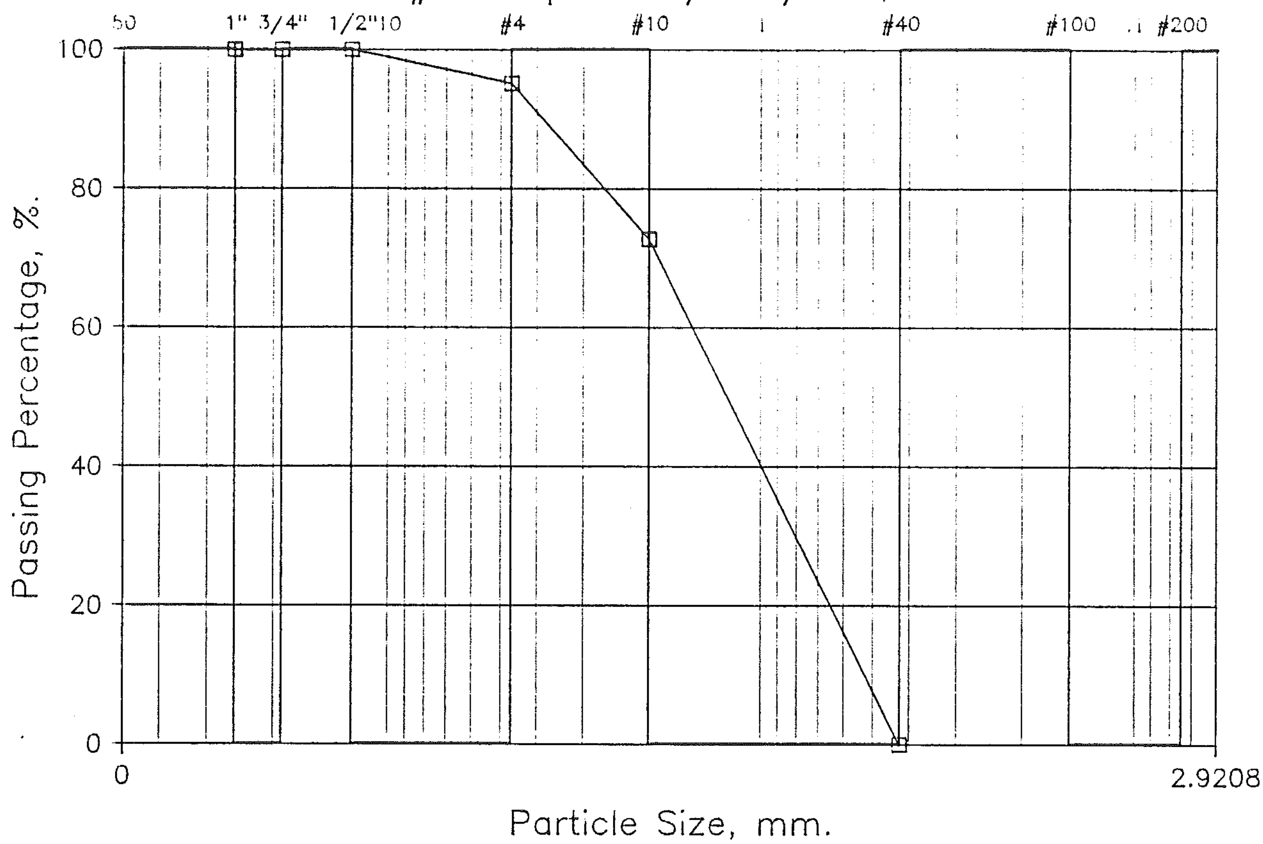


Grain Size Analysis

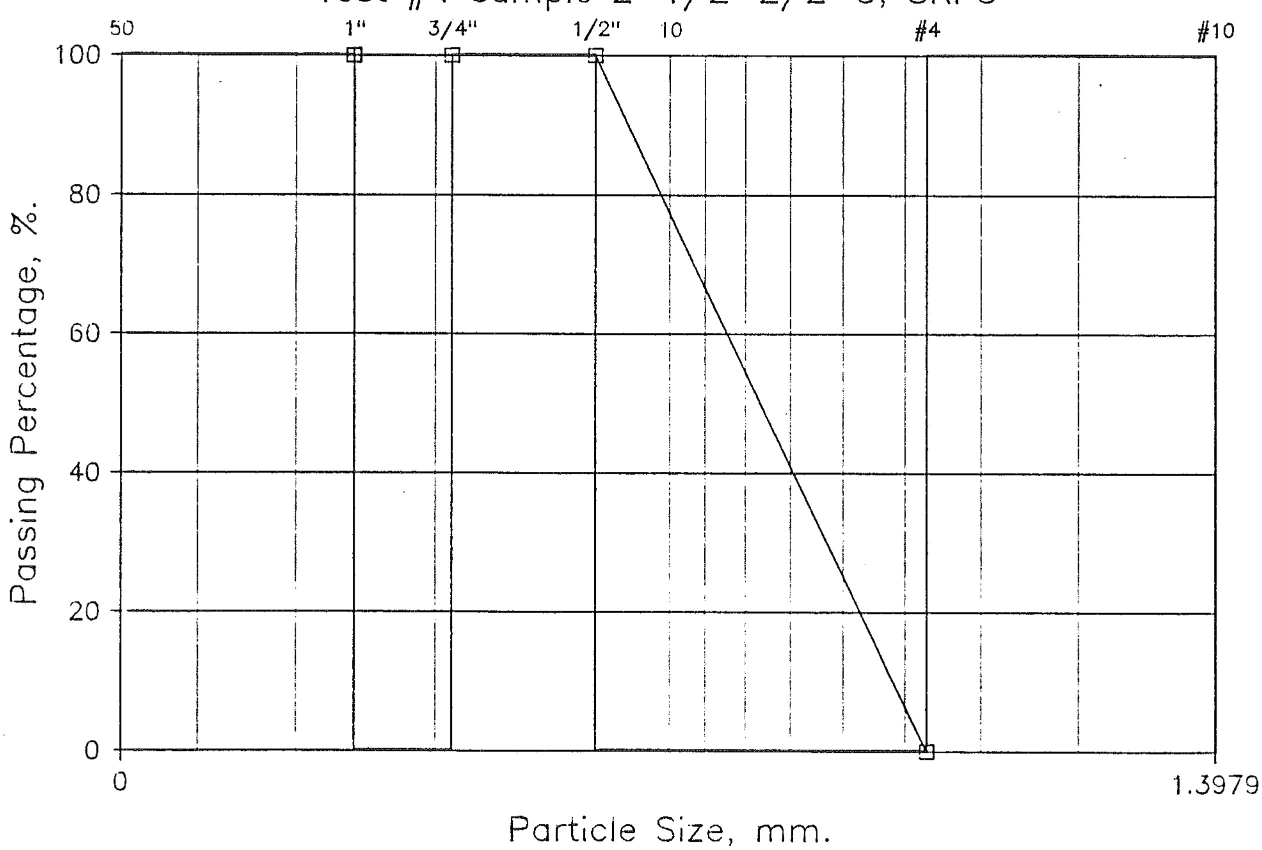
Test #4 sample 1-1/1-2/1-3, SRP5

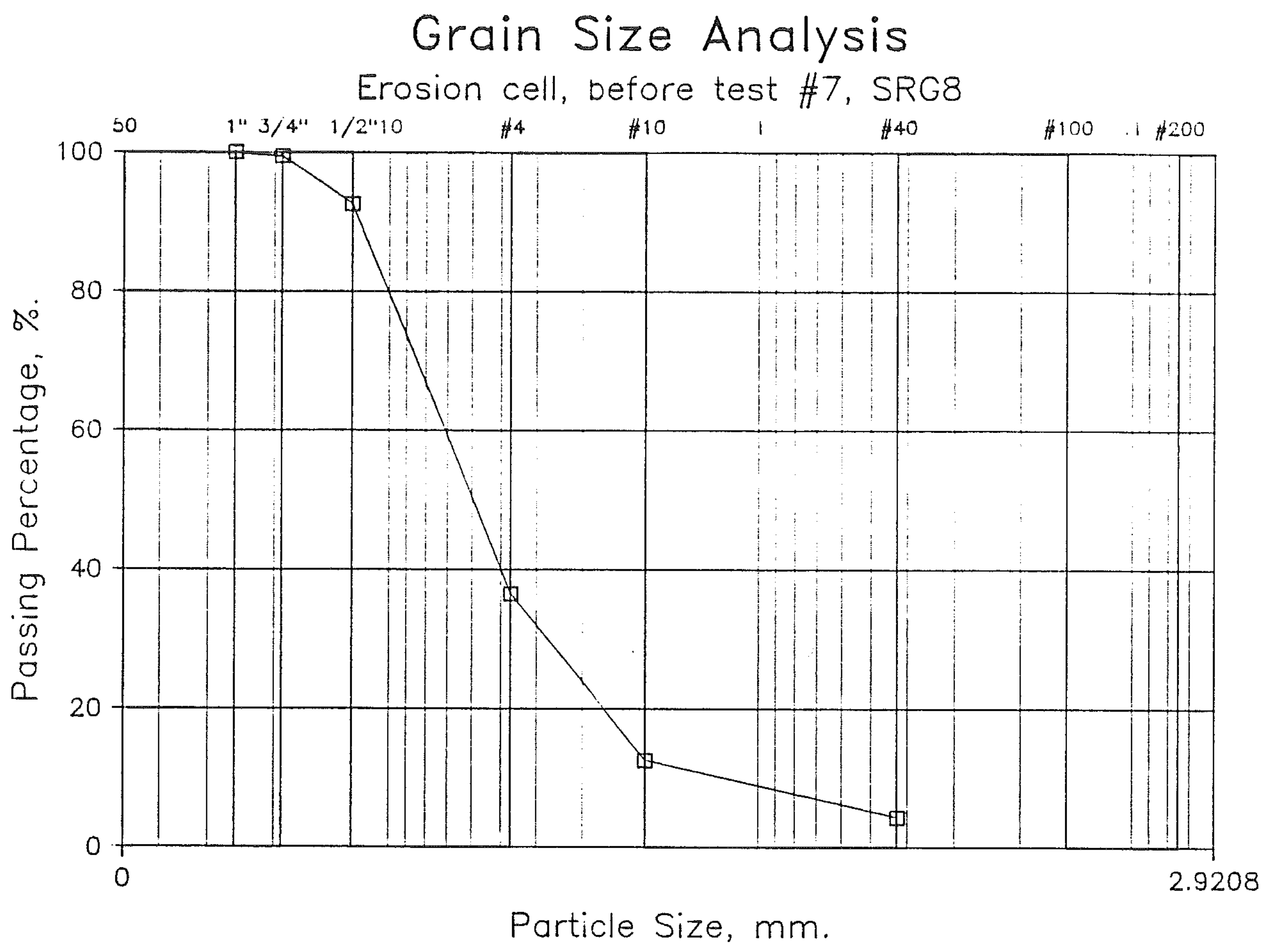


Grain Size Analysis
Test #4 sample 2-1/2-2/2-3, SRP5

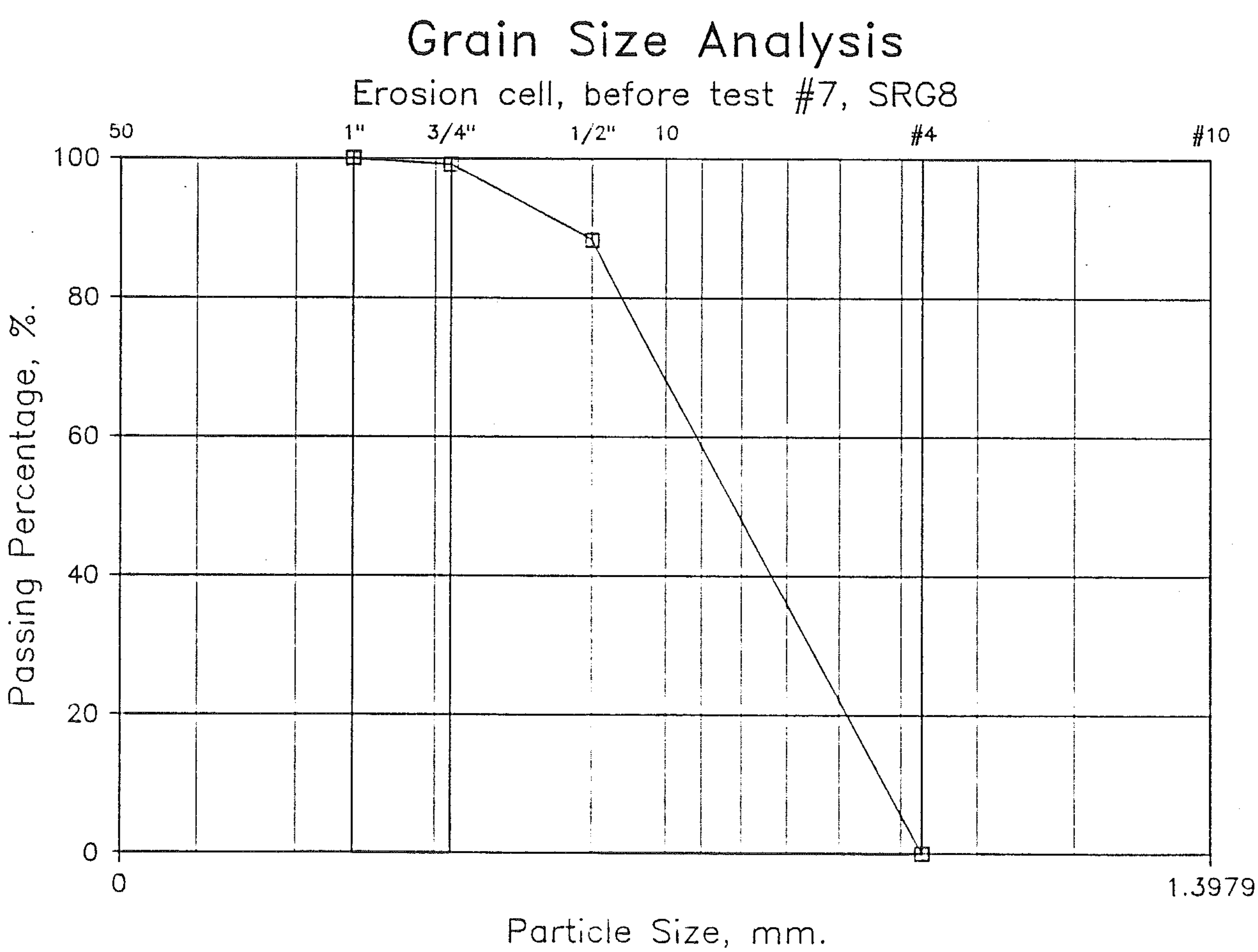


Grain Size Analysis
Test #4 sample 2-1/2-2/2-3, SRP5

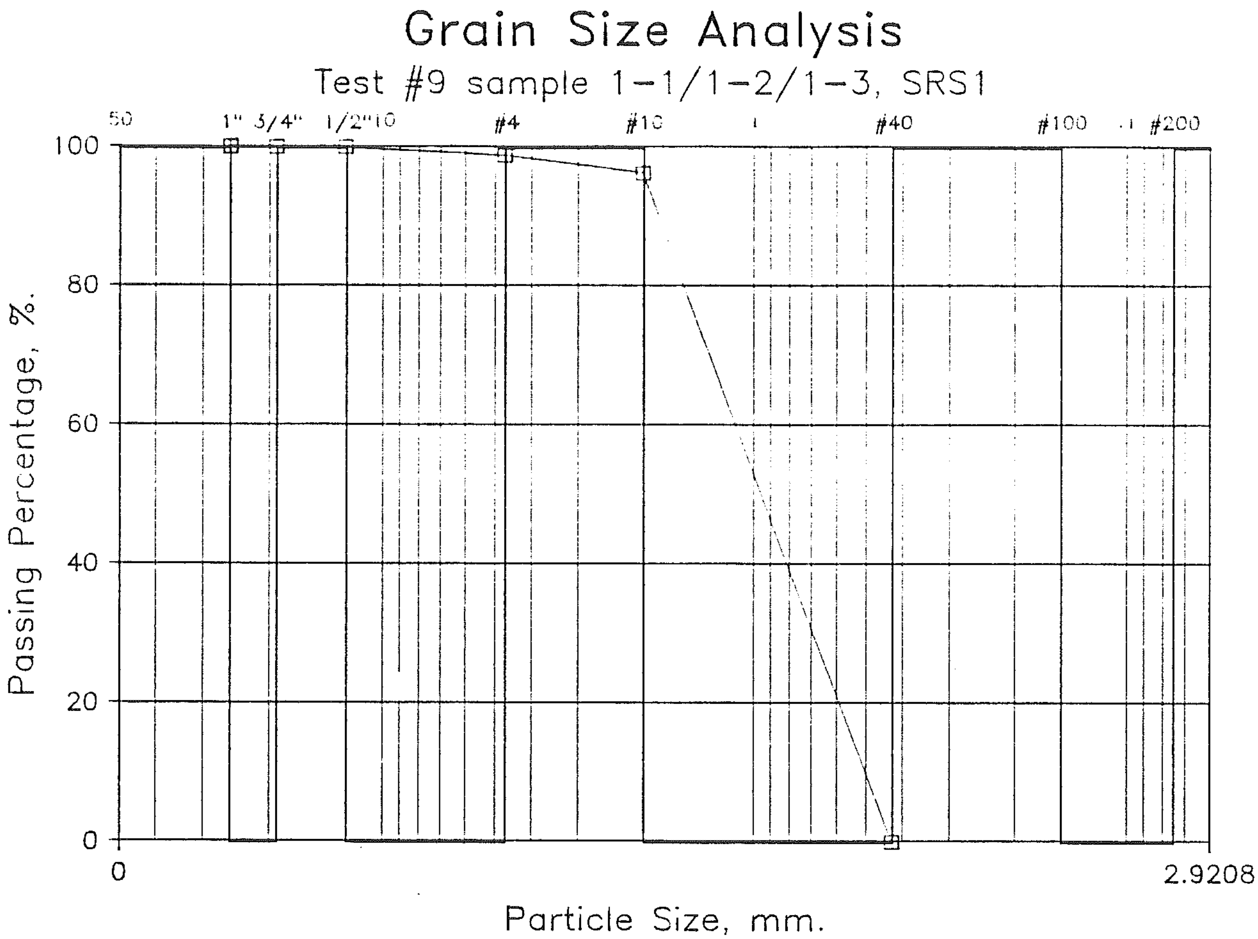


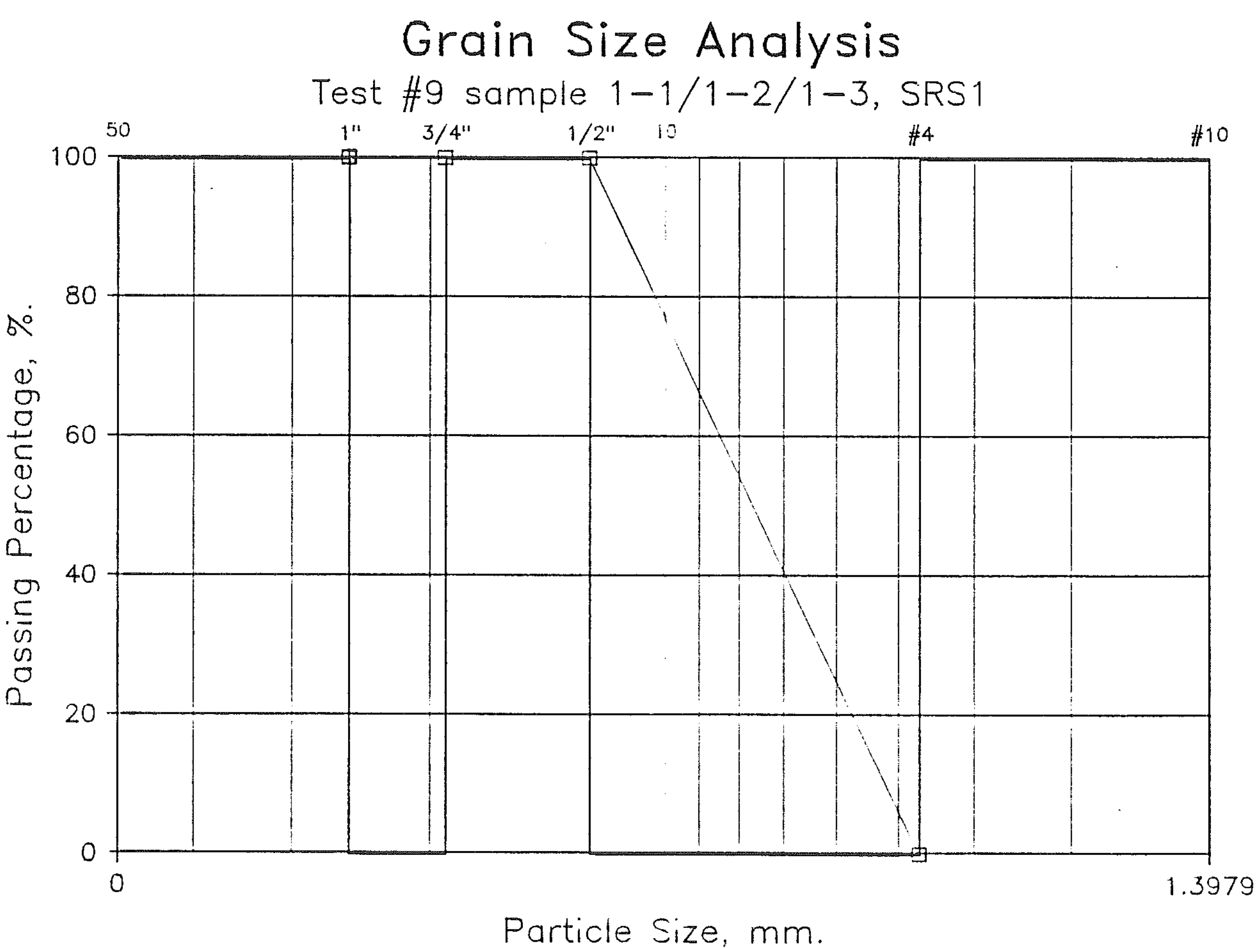


Grain Size Analysis
Erosion cell, before test #7, SRG8
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.



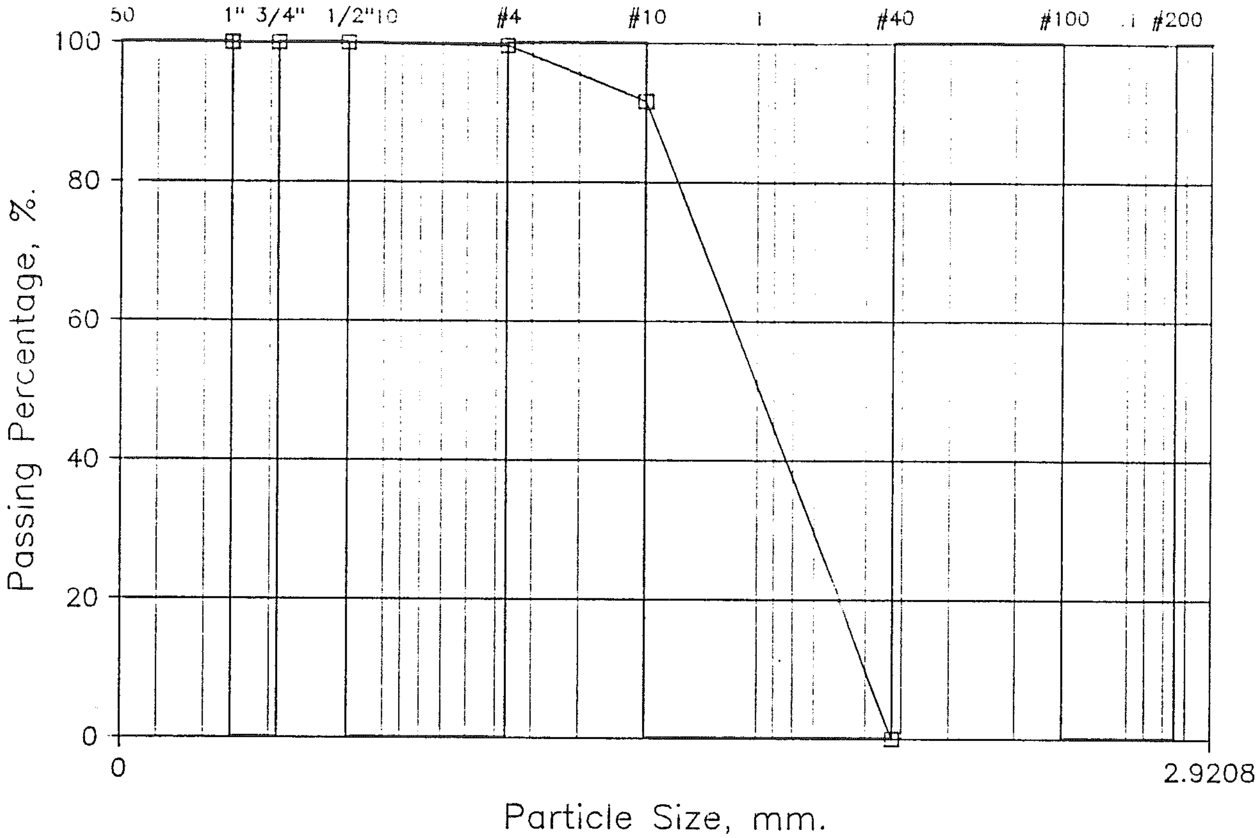
Grain Size Analysis
Erosion cell, before test #7, SRG8
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
Test #9 sample 1-1/1-2/1-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test #9 sample 1-1/1-2/1-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

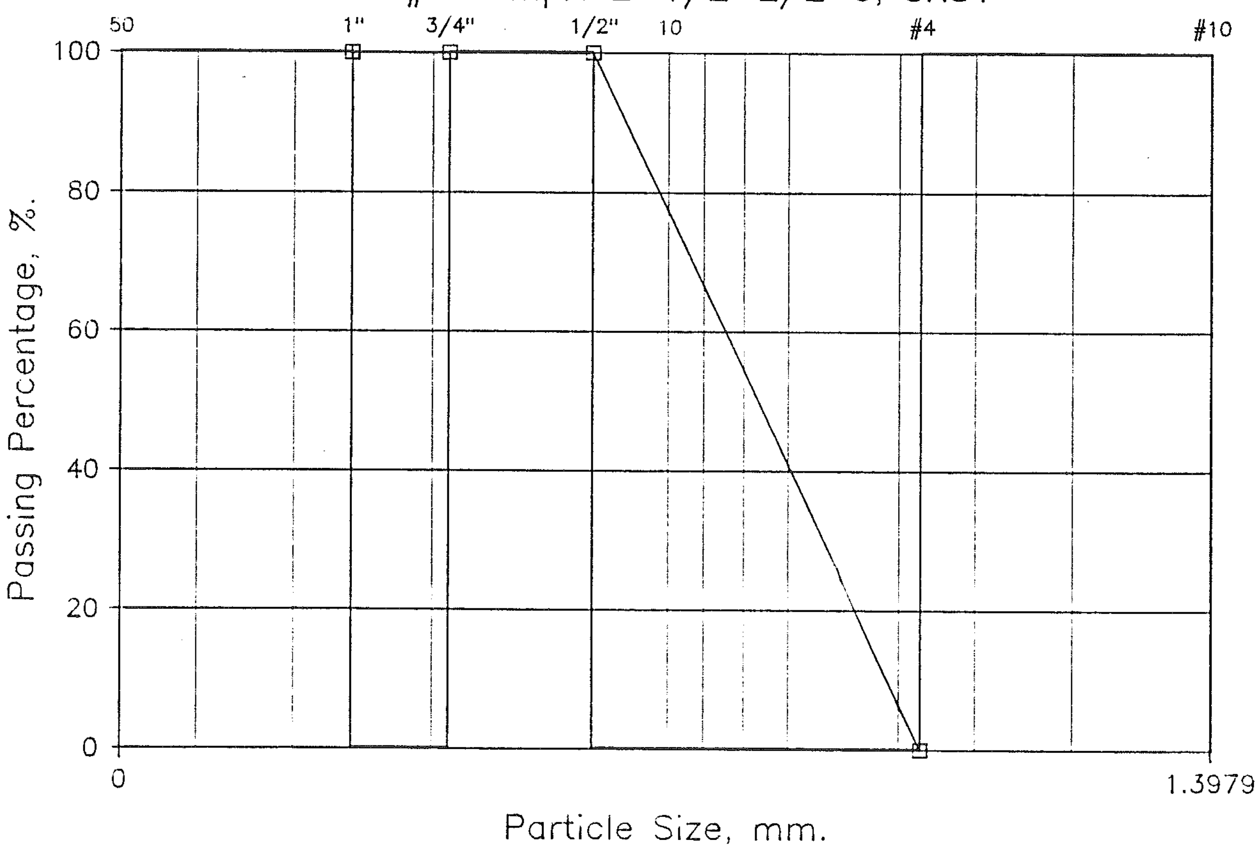
Grain Size Analysis

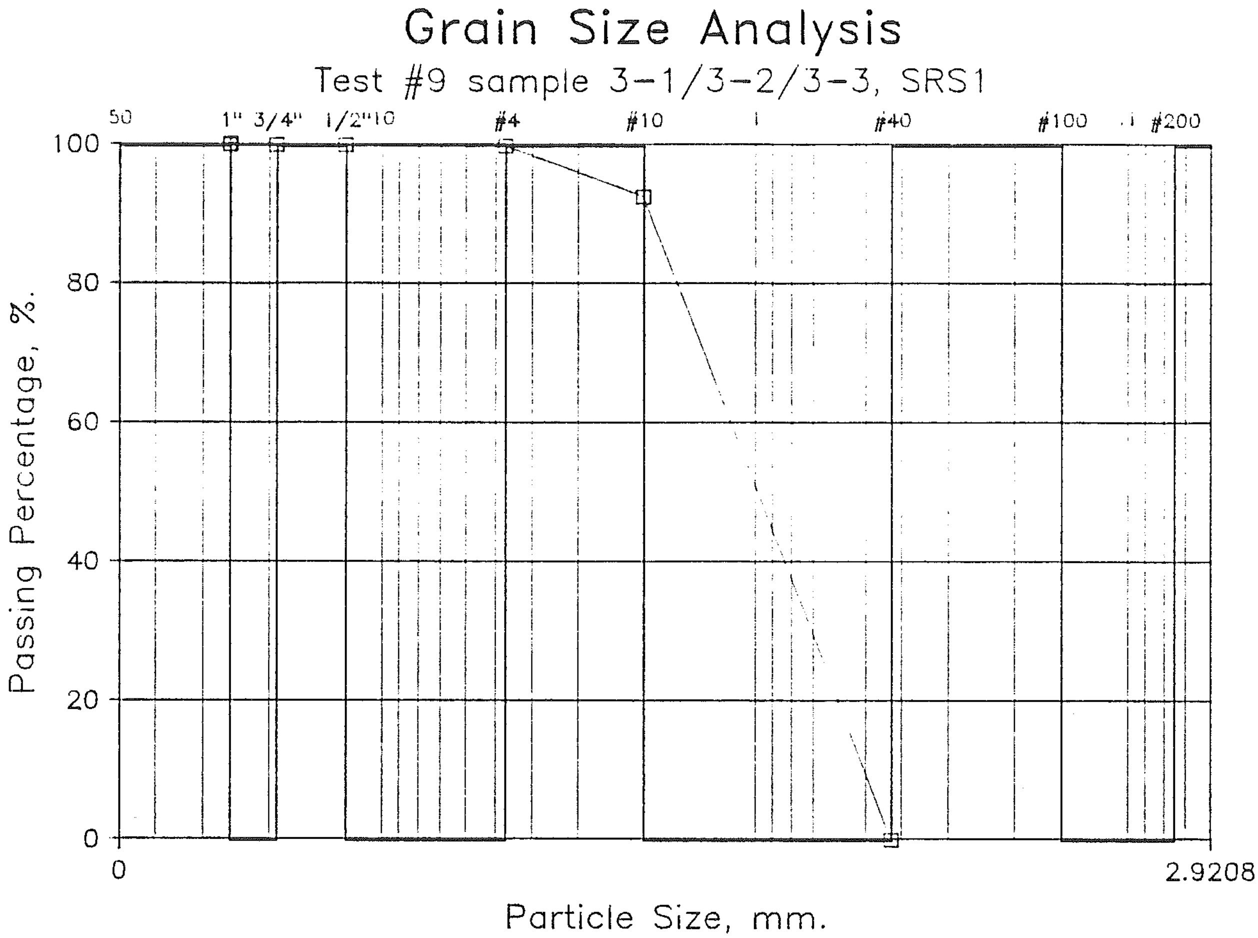
Test #9 sample 2-1/2-2/2-3, SRS1



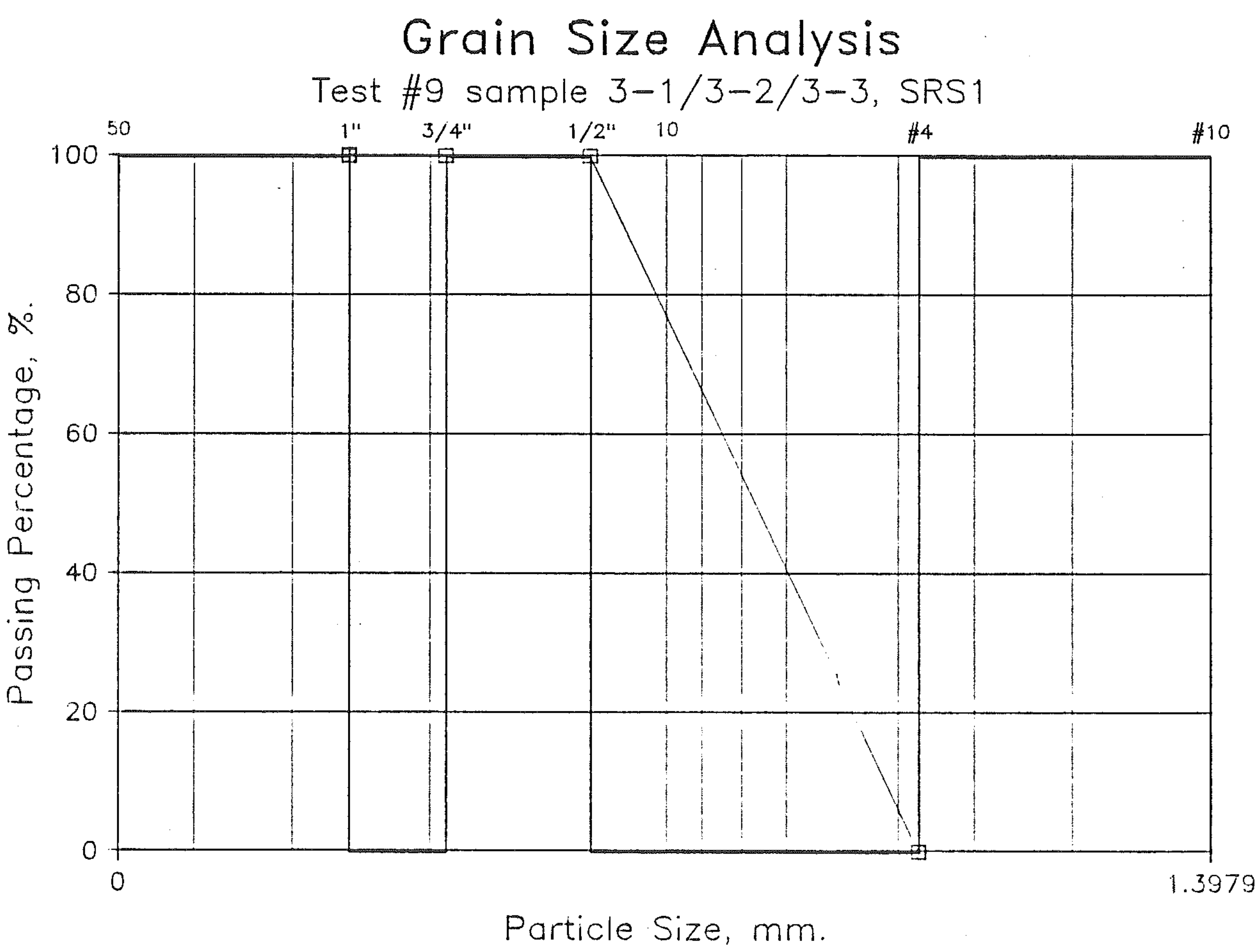
Grain Size Analysis

Test #9 sample 2-1/2-2/2-3, SRS1

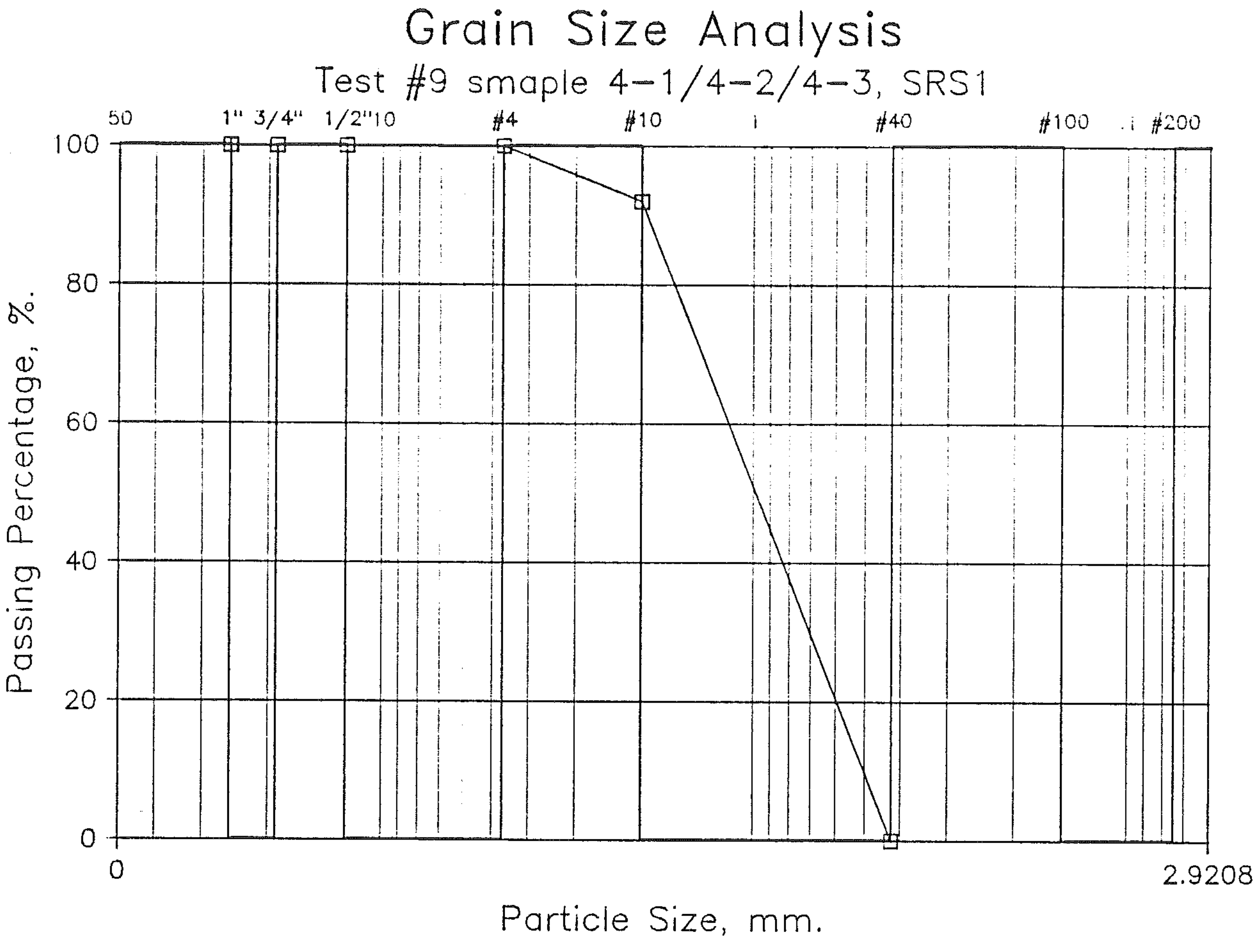


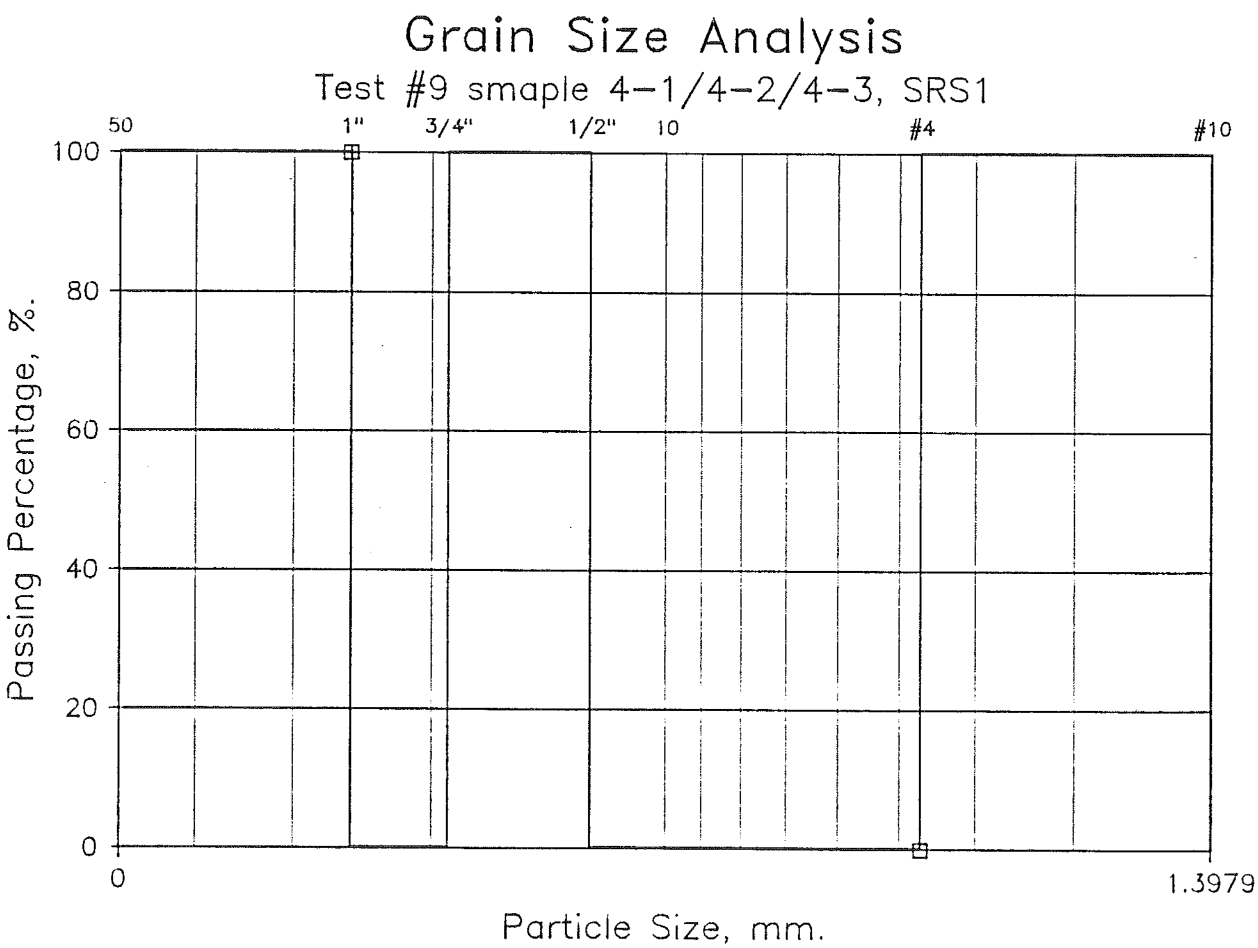


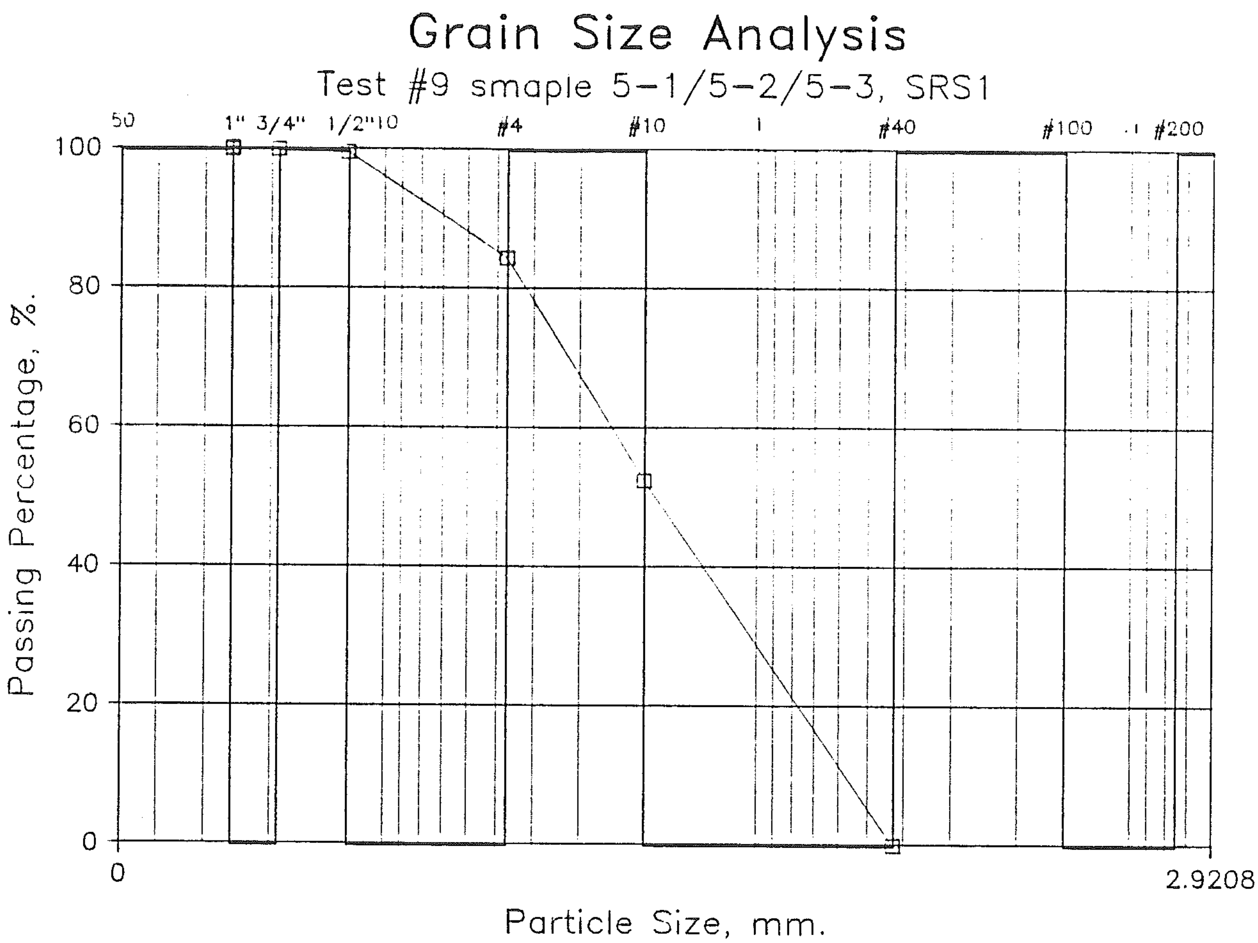
Grain Size Analysis
Test #9 sample 3-1/3-2/3-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
0
2.9208
Passing Percentage, %.
Particle Size, mm.

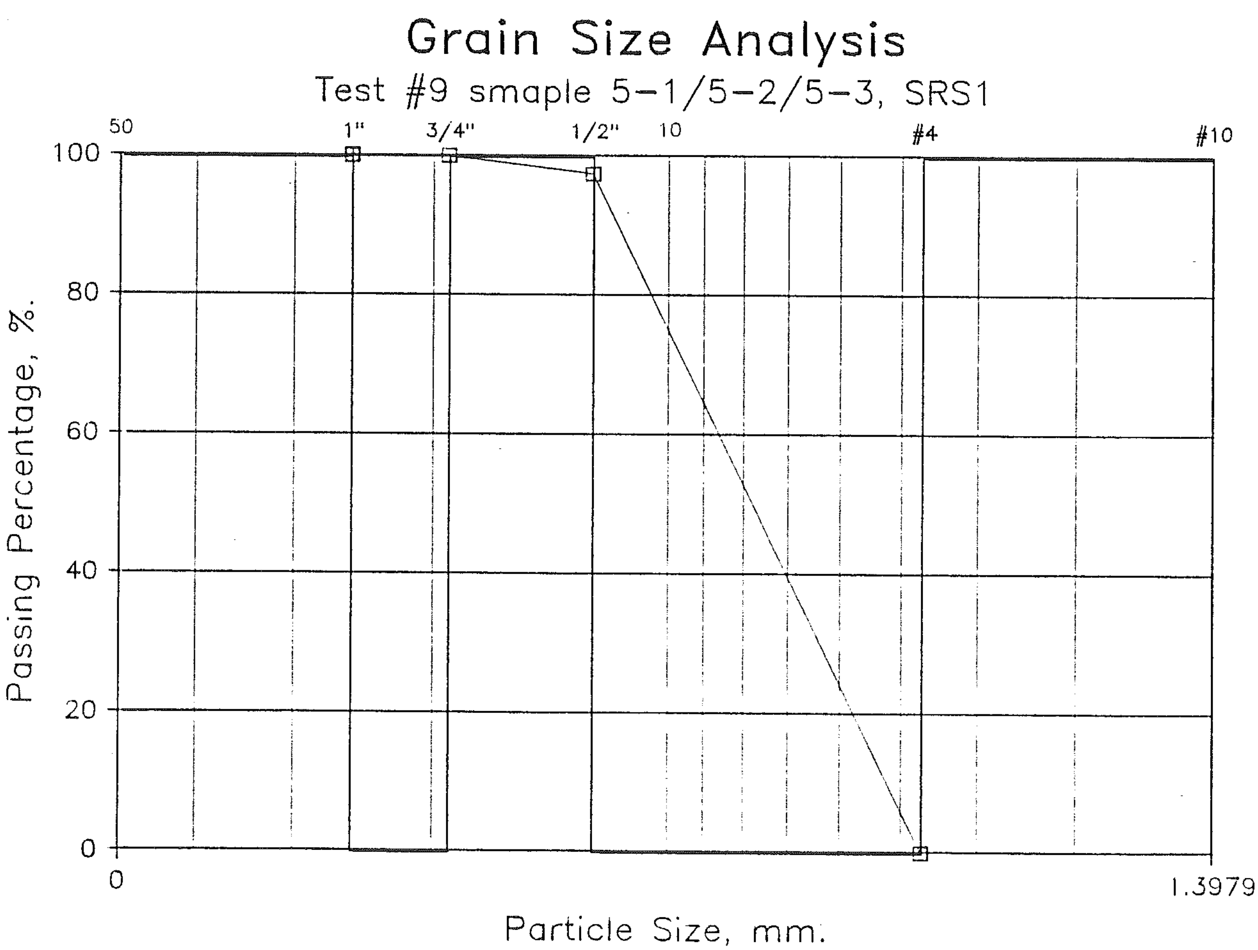


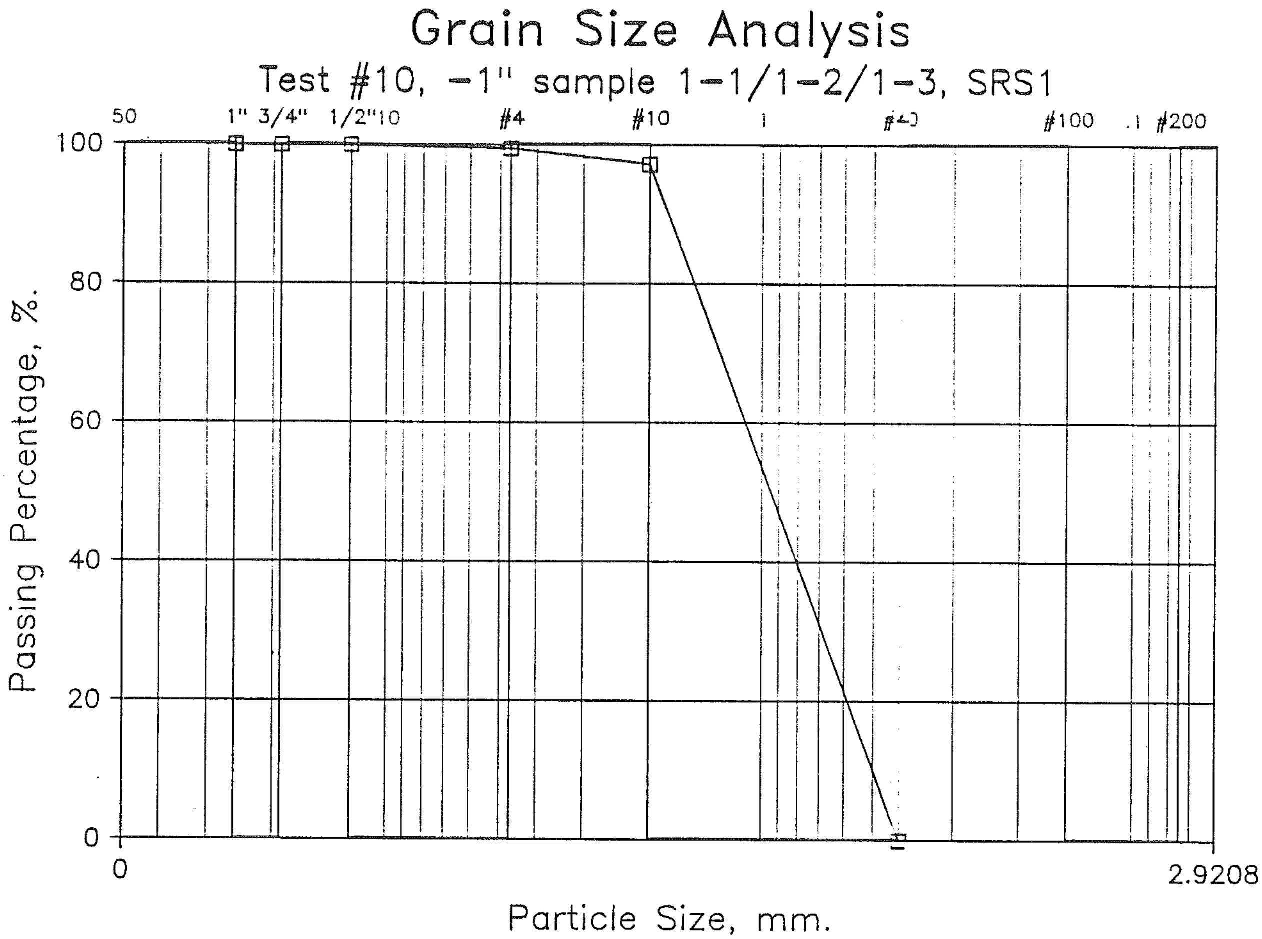
Grain Size Analysis
Test #9 sample 3-1/3-2/3-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
0
1.3979
Passing Percentage, %.
Particle Size, mm.

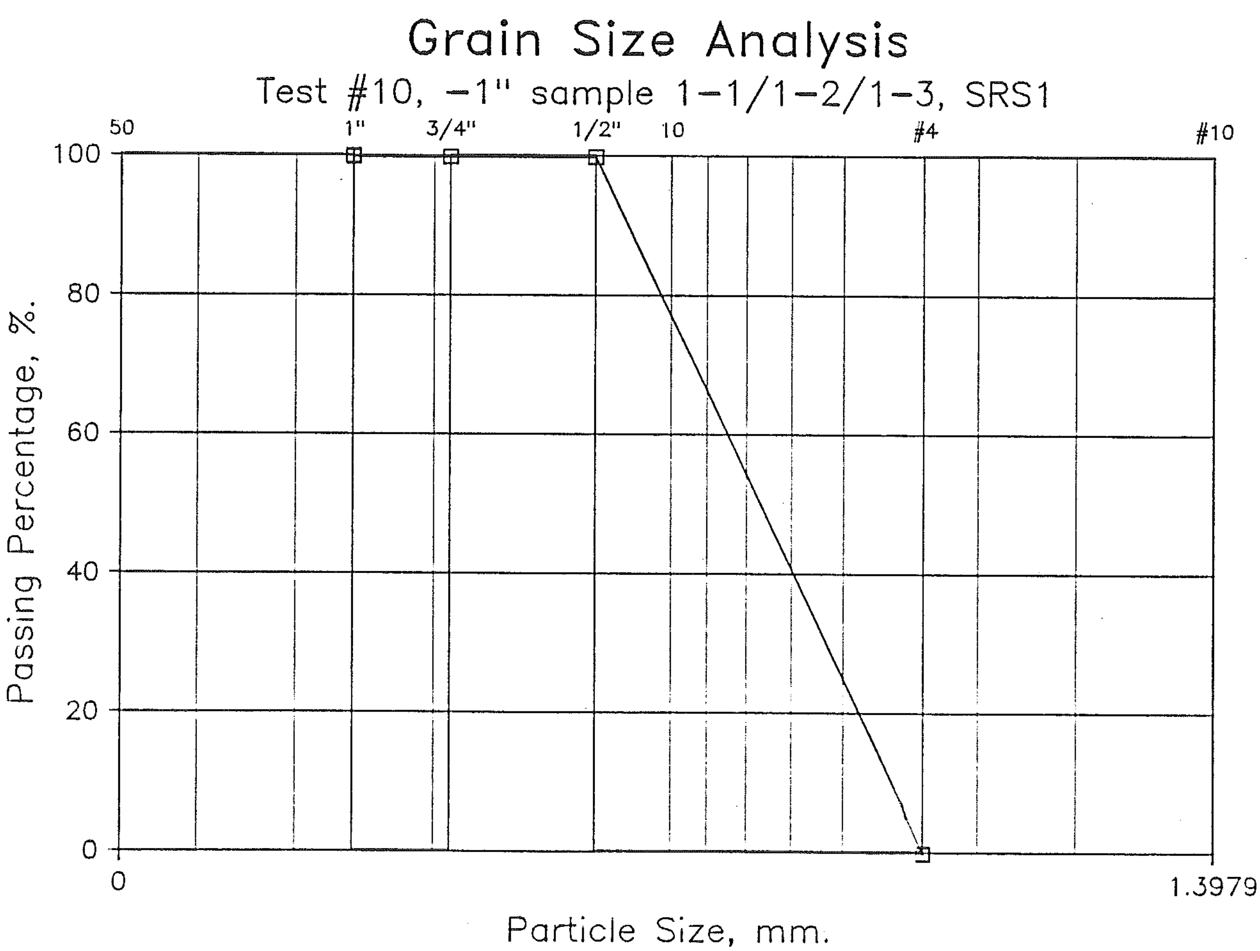

Grain Size Analysis
Test #9 smaple 4-1/4-2/4-3, SRS1
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

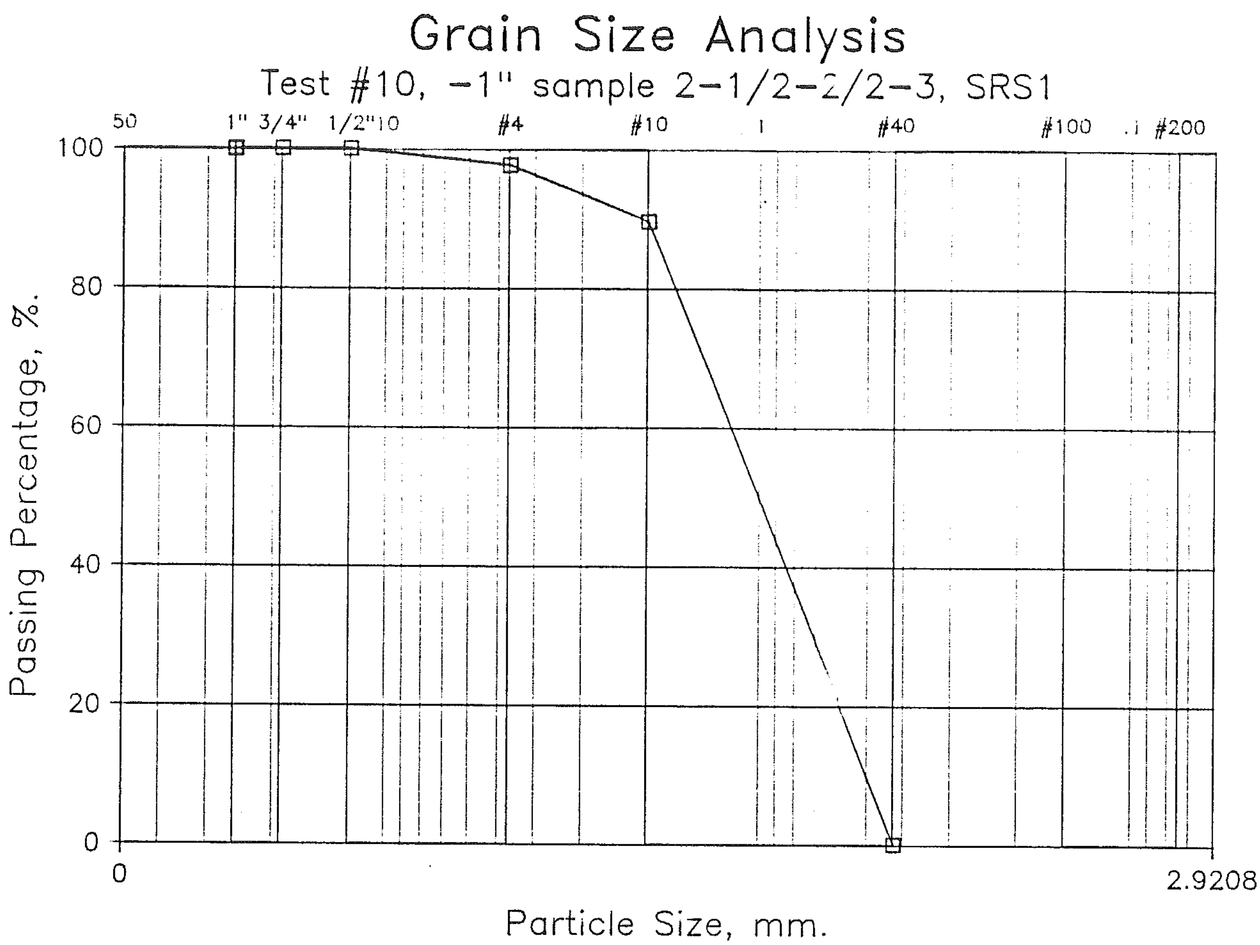

Grain Size Analysis
Test #9 smaple 4-1/4-2/4-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
Test #9 smaple 5-1/5-2/5-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
0
2.9208
Passing Percentage, %.
Particle Size, mm.

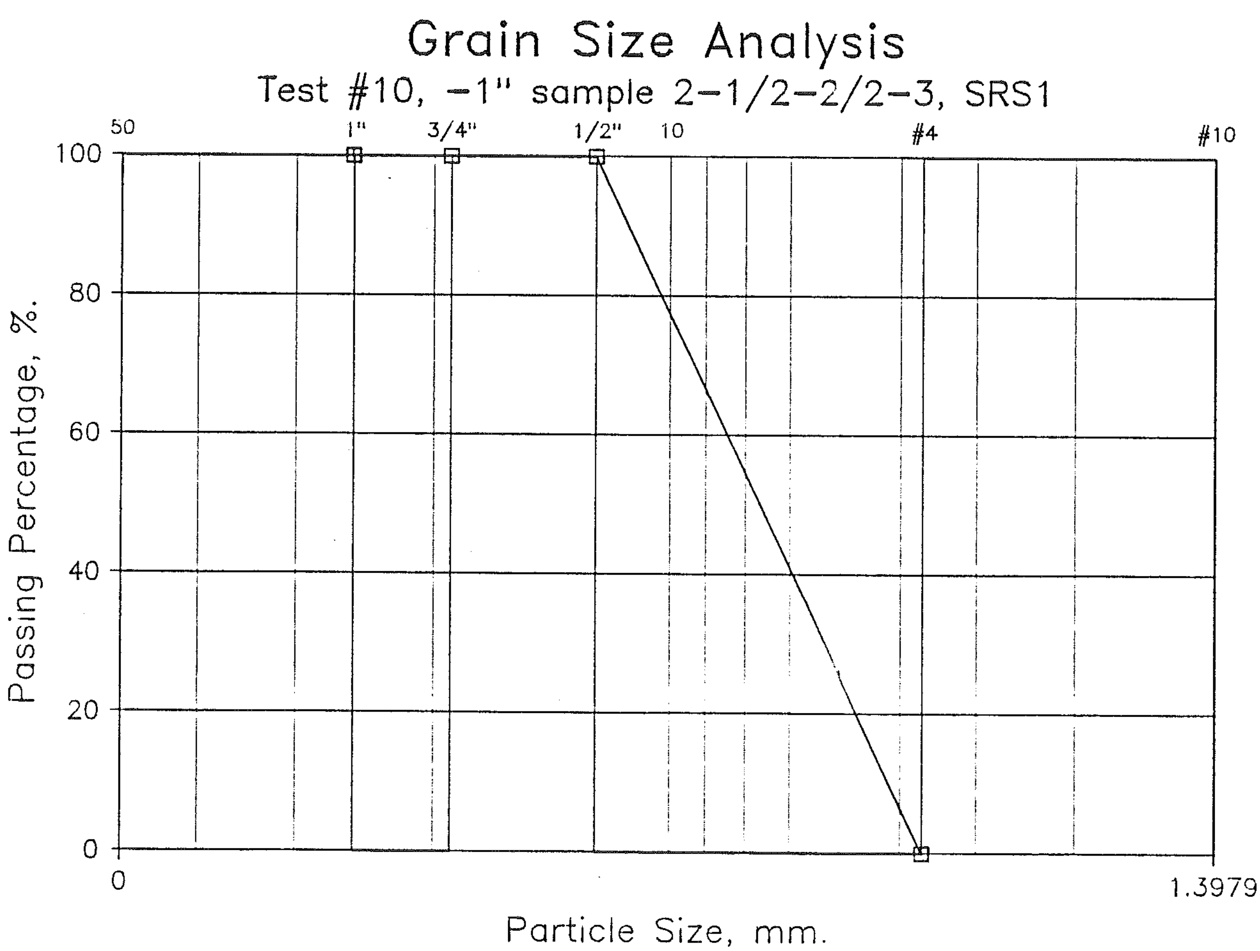

Grain Size Analysis
Test #9 smaple 5-1/5-2/5-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
0
1.3979
Passing Percentage, %.
Particle Size, mm.


Grain Size Analysis
Test #10, -1" sample 1-1/1-2/1-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
1
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

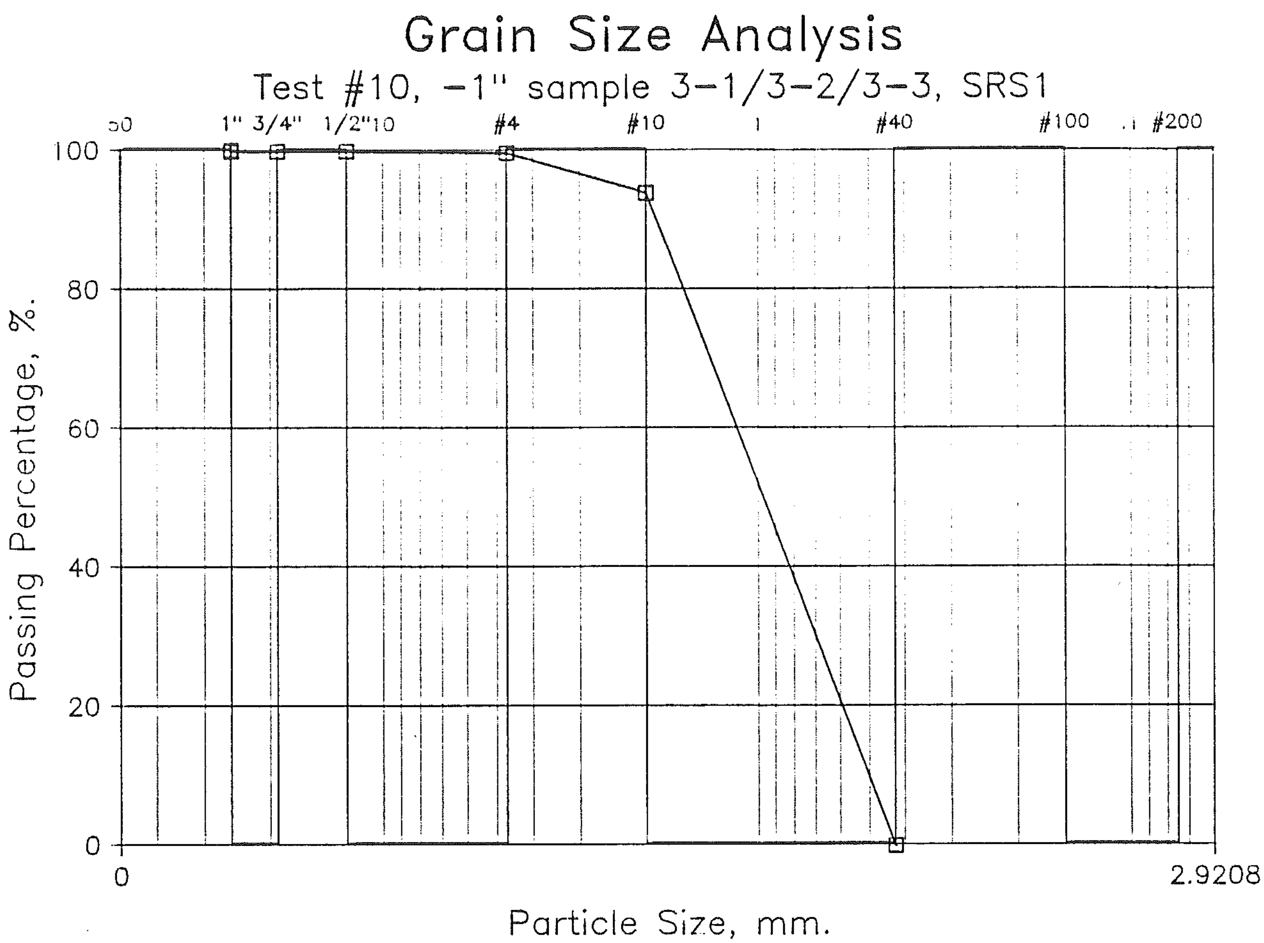

Grain Size Analysis
Test #10, -1" sample 1-1/1-2/1-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.



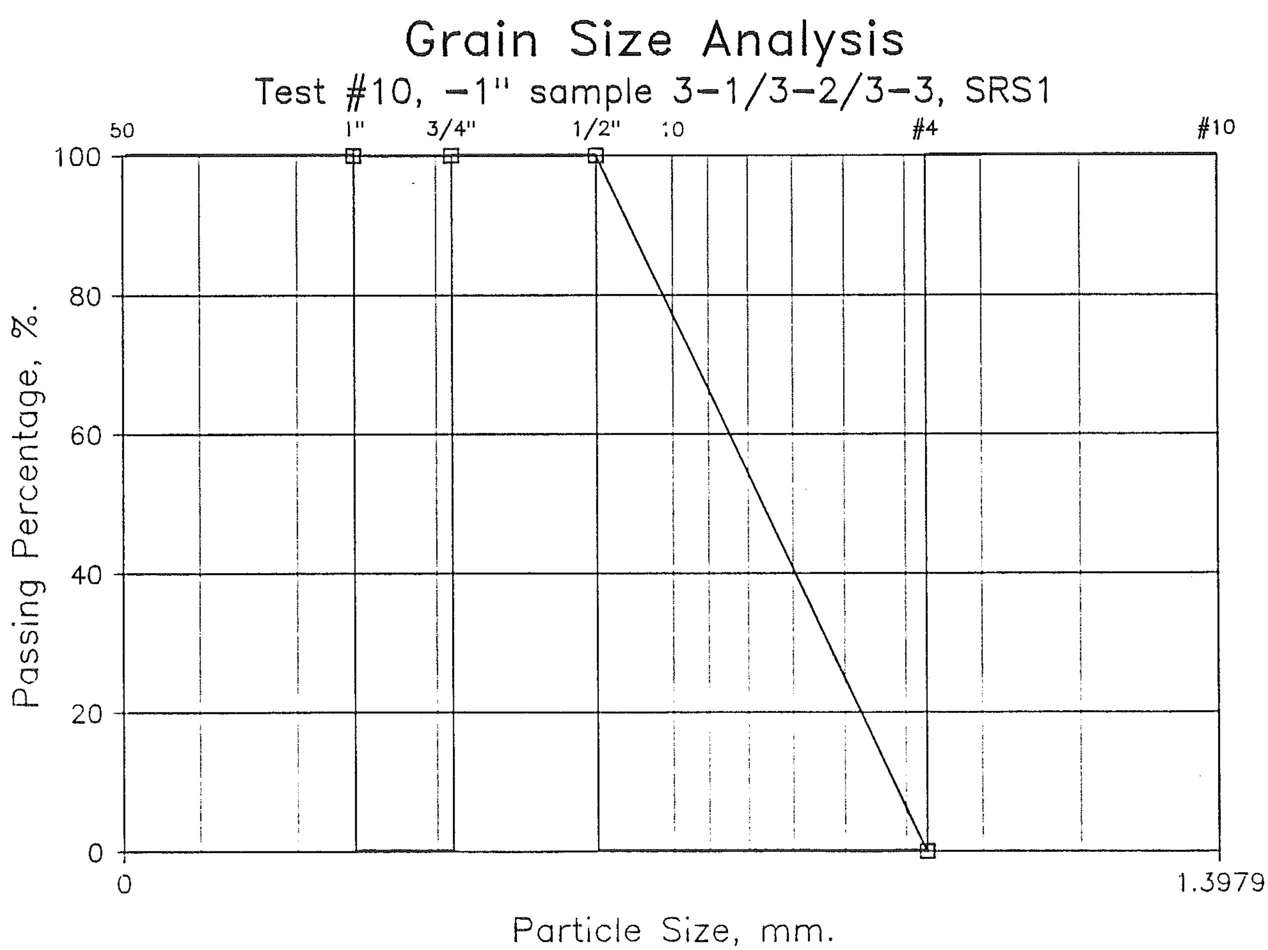
Grain Size Analysis
Test #10, -1" sample 2-1/2-2/2-3, SRS1
50
1" 3/4" 1/2" 10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.



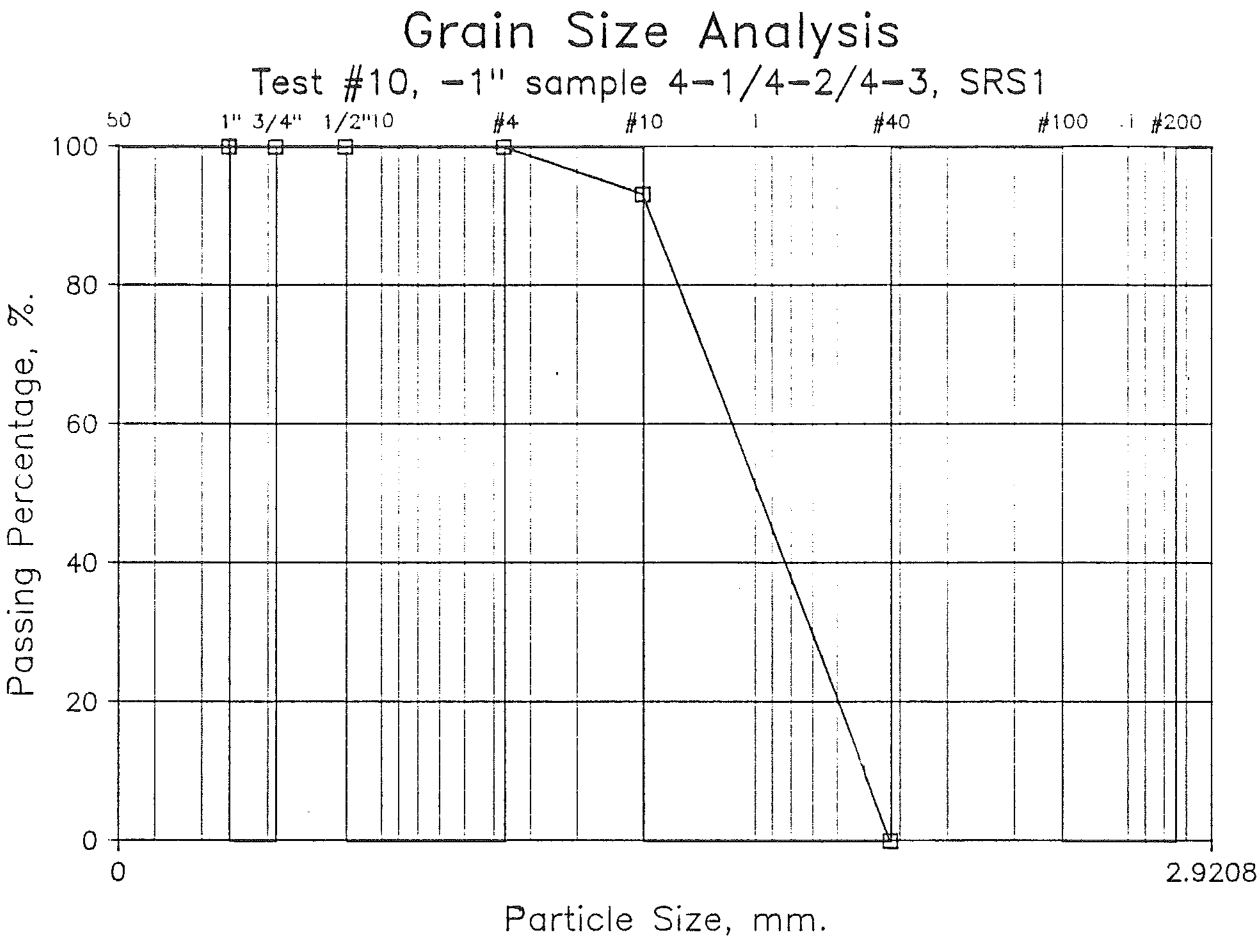
Grain Size Analysis
Test #10, -1" sample 2-1/2-2/2-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

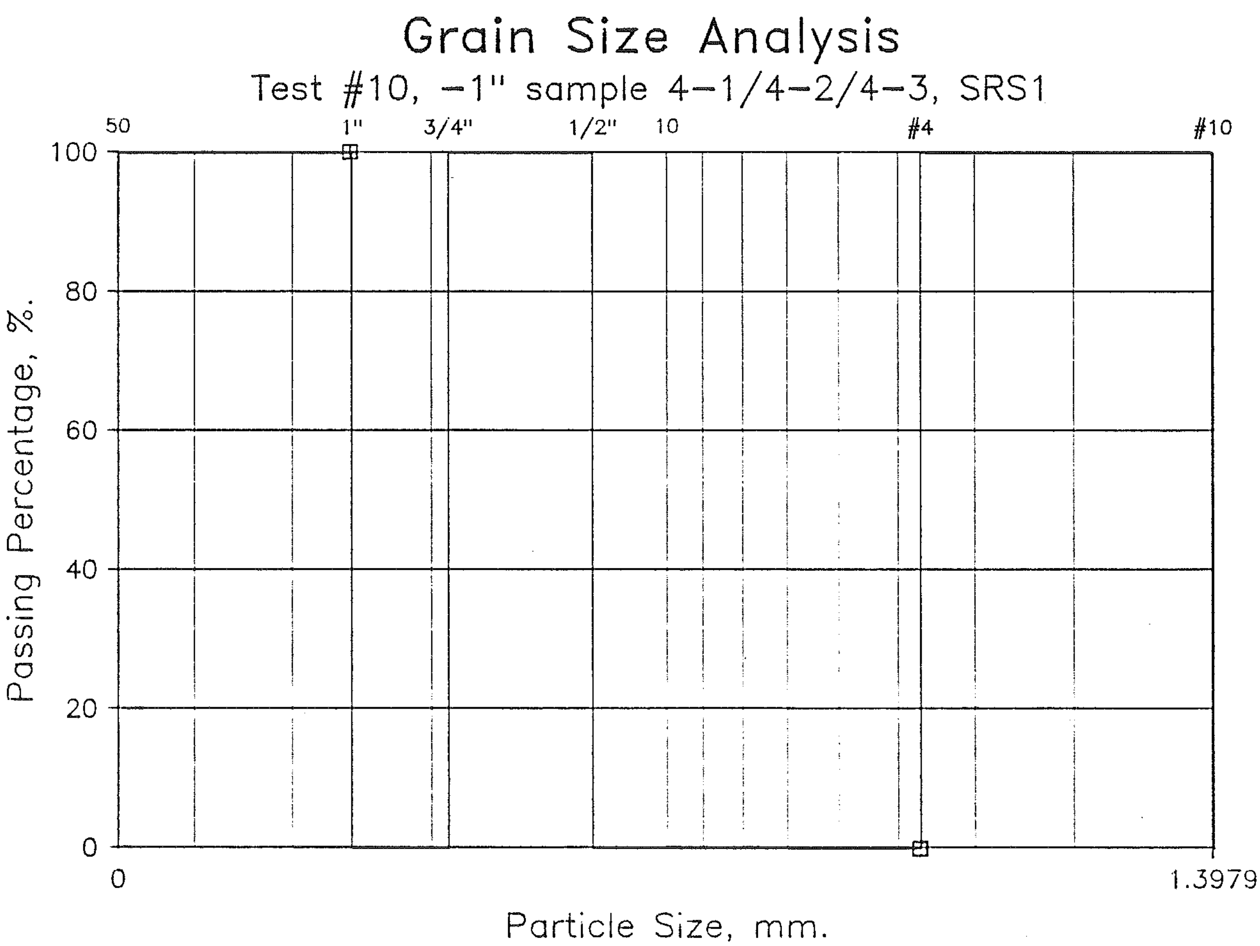


Grain Size Analysis
Test #10, -1" sample 3-1/3-2/3-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
Passing Percentage, %.
100
80
60
40
20
0
0
2.9208
Particle Size, mm.



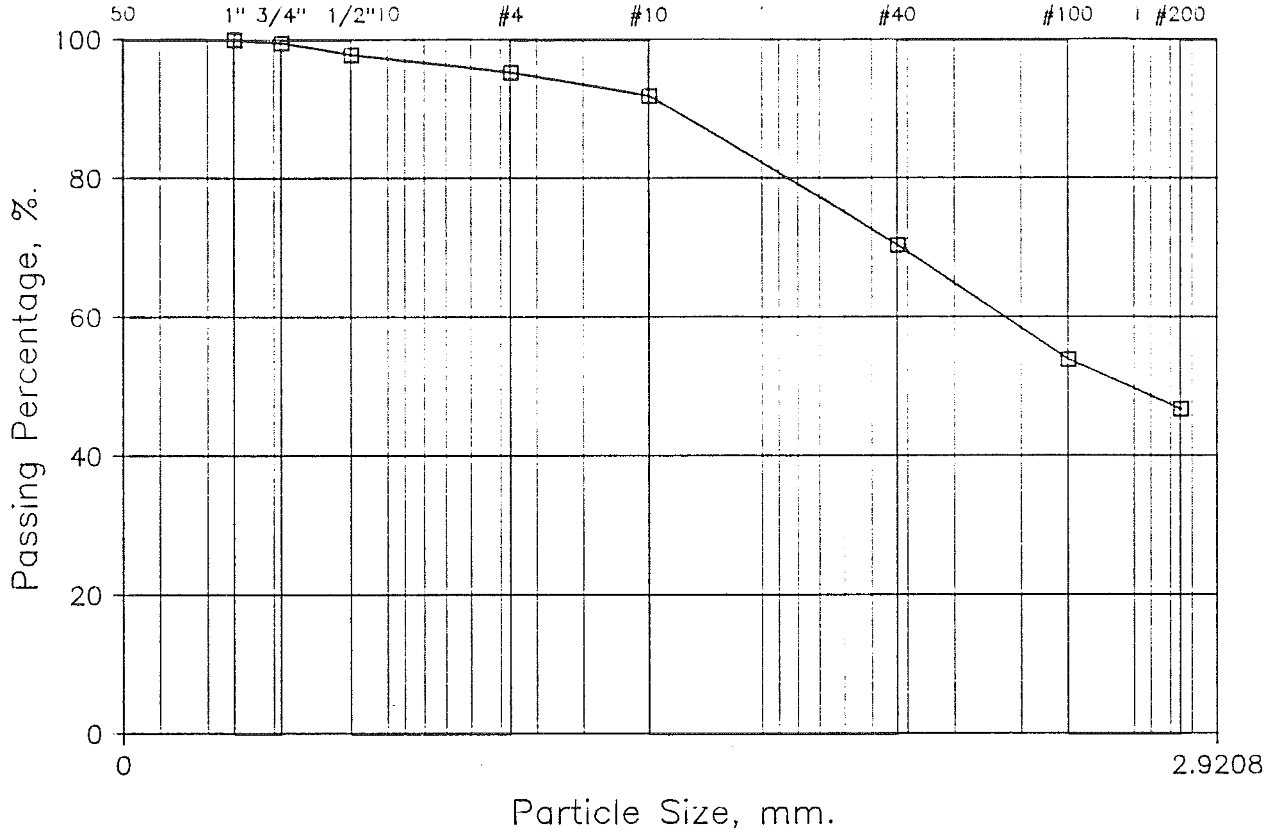
Grain Size Analysis
Test #10, -1" sample 3-1/3-2/3-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
Passing Percentage, %.
100
80
60
40
20
0
0
1.3979
Particle Size, mm.


Grain Size Analysis
Test #10, -1" sample 4-1/4-2/4-3, SRS1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test #10, -1" sample 4-1/4-2/4-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

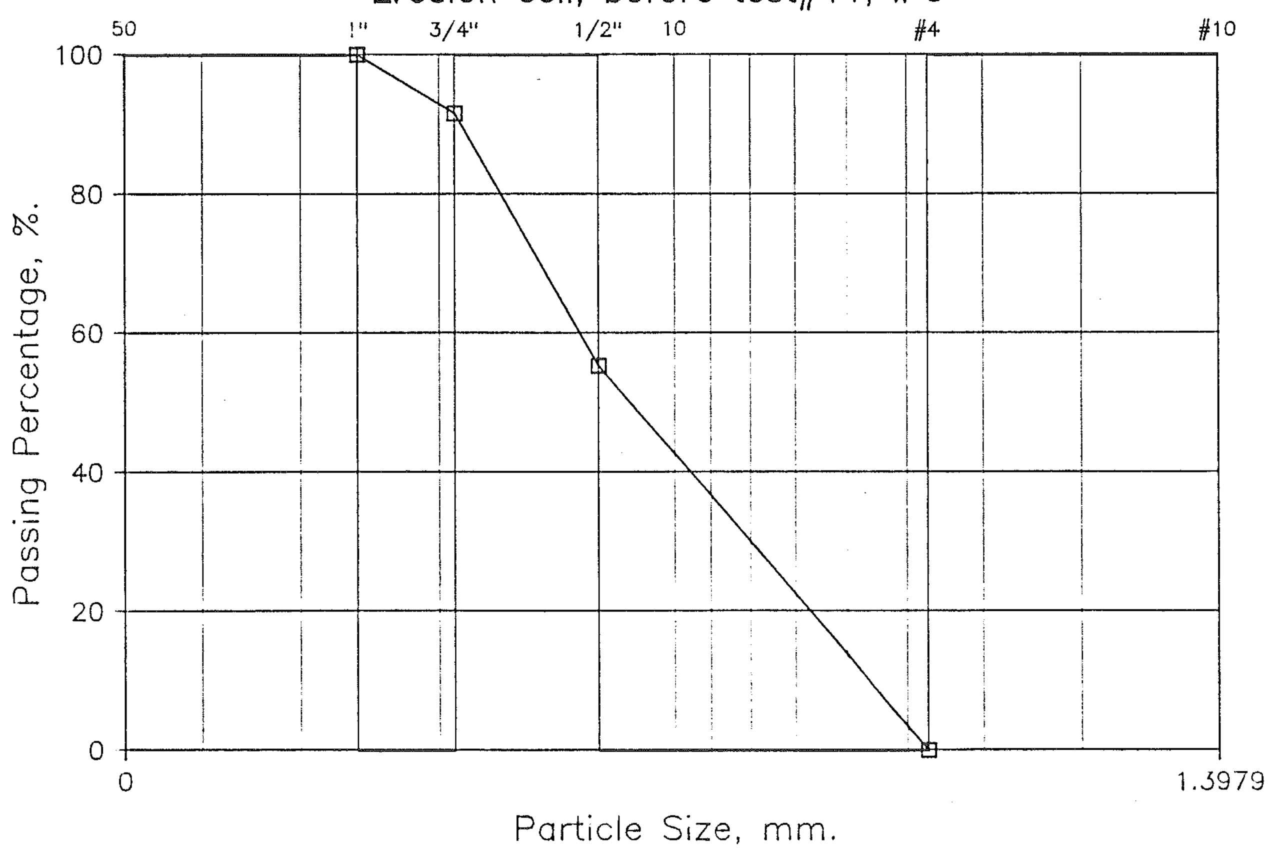
Grain Size Analysis

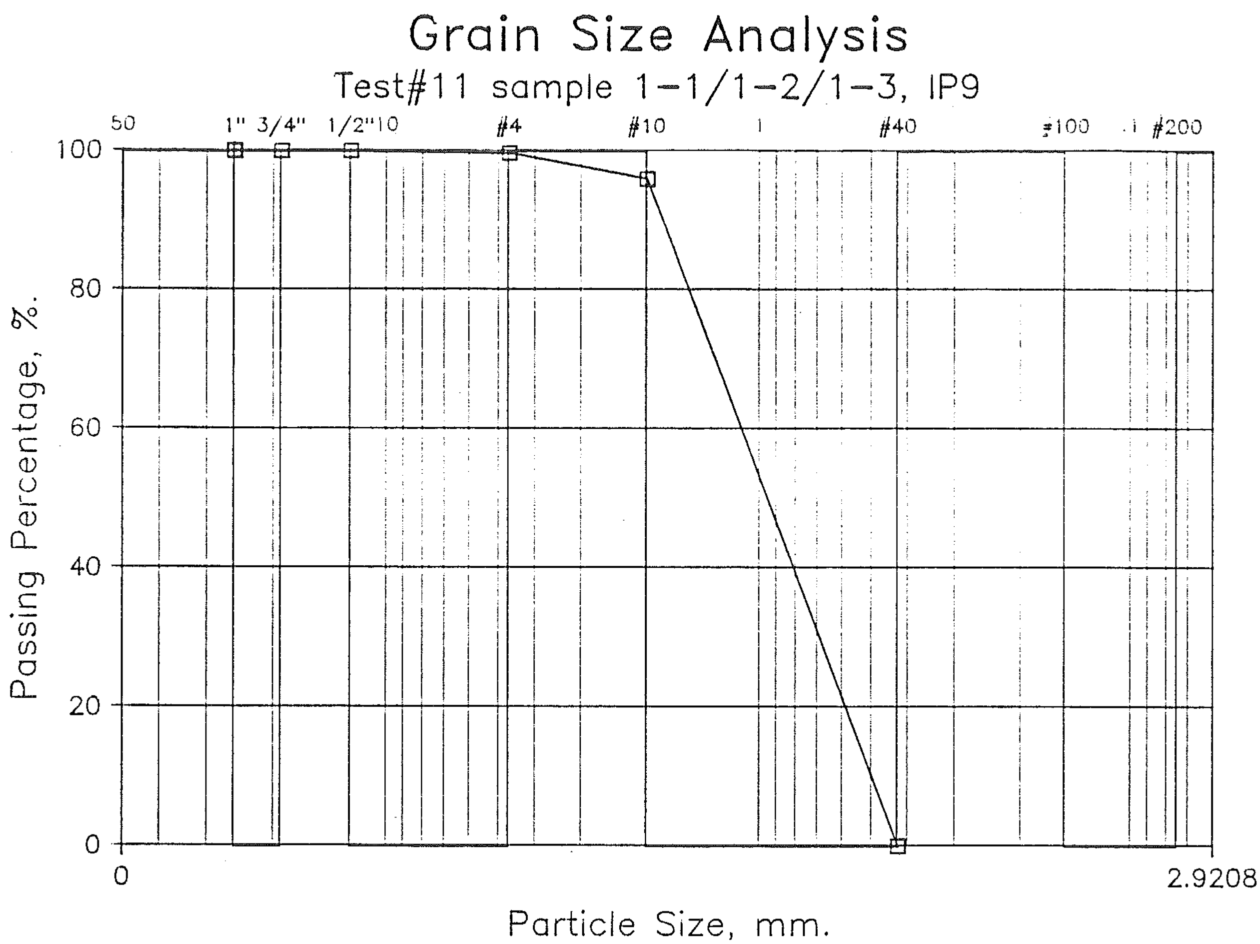
Erosion cell, before test#11, IP9

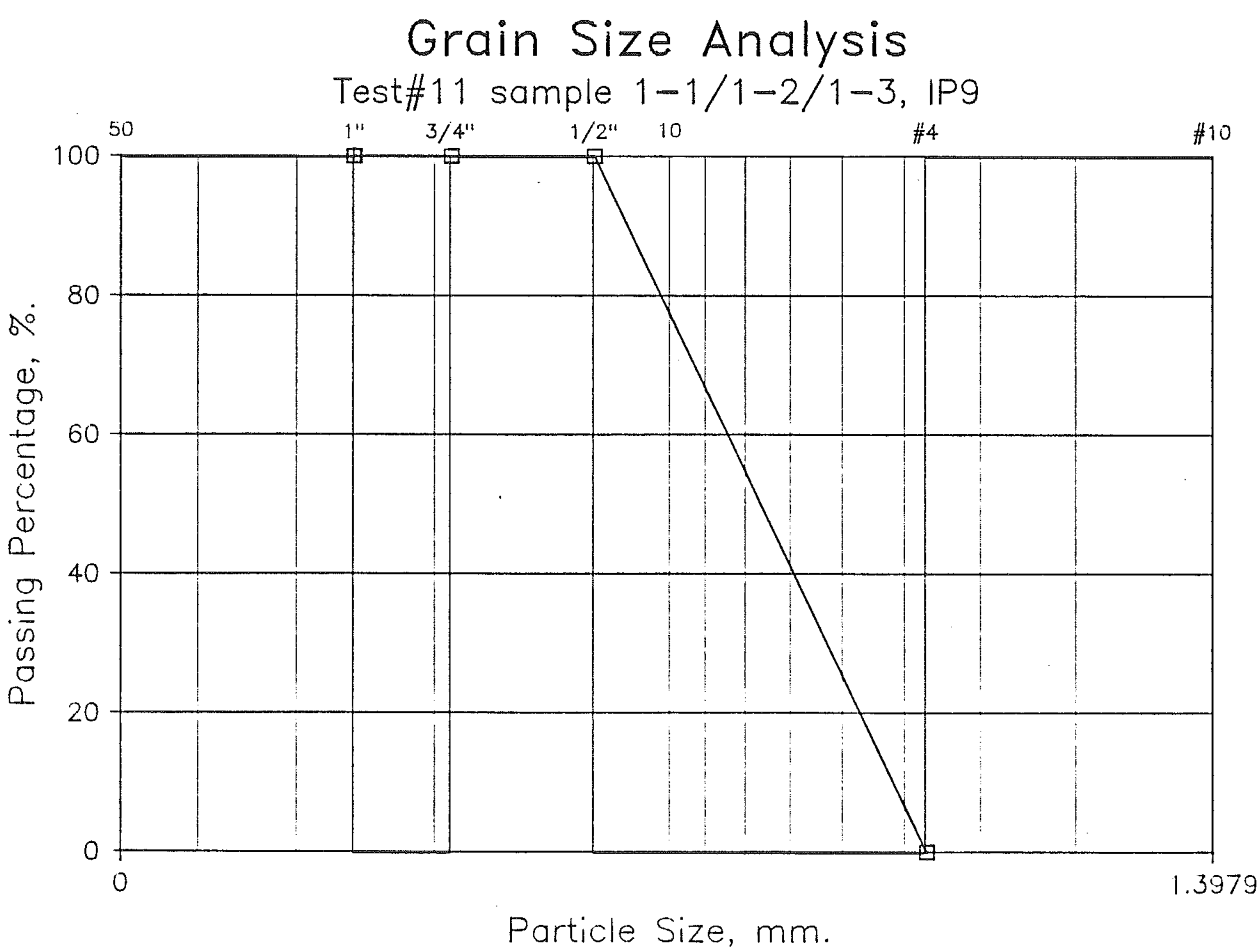


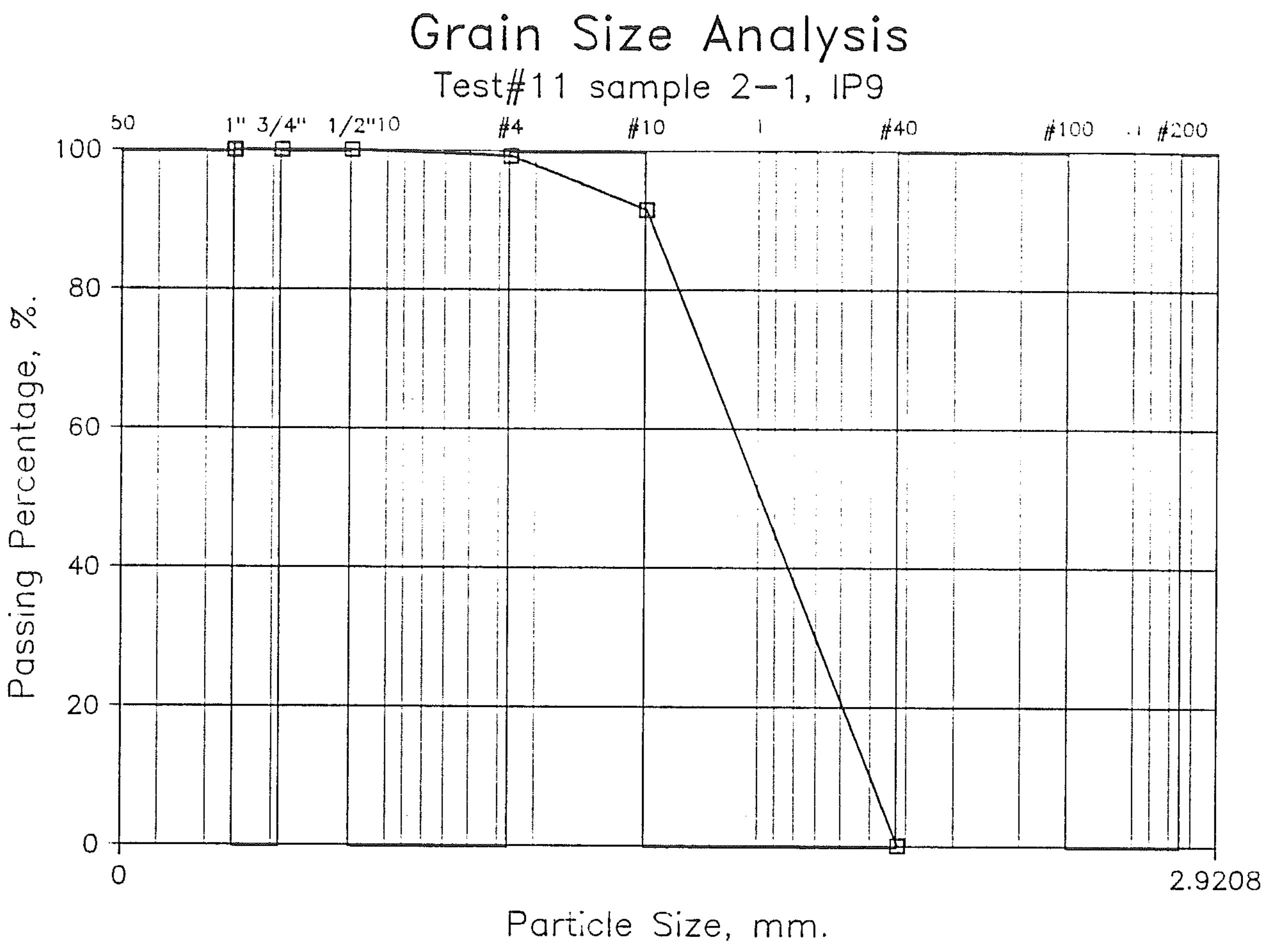
Grain Size Analysis

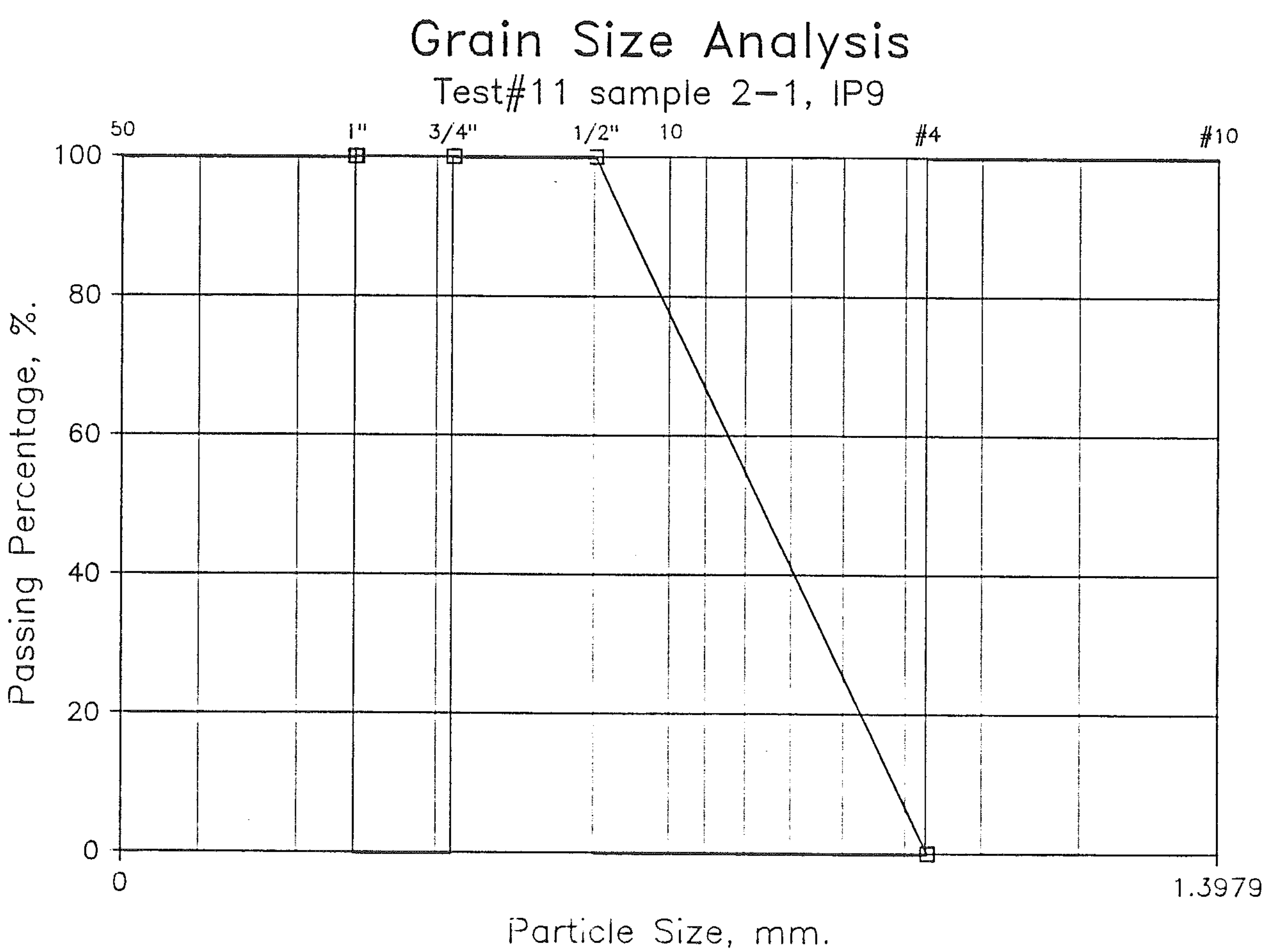
Erosion cell, before test#11, IP9

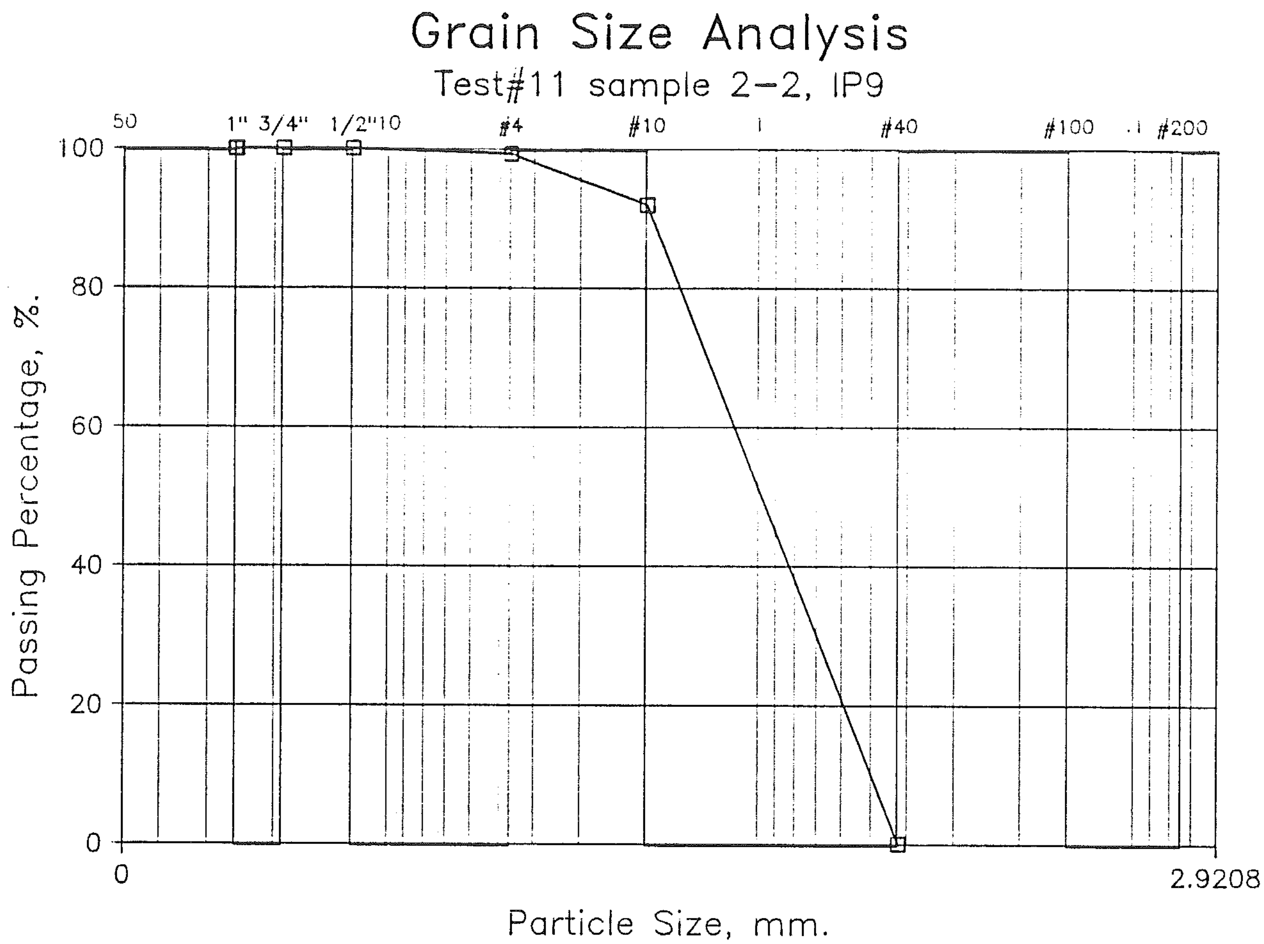


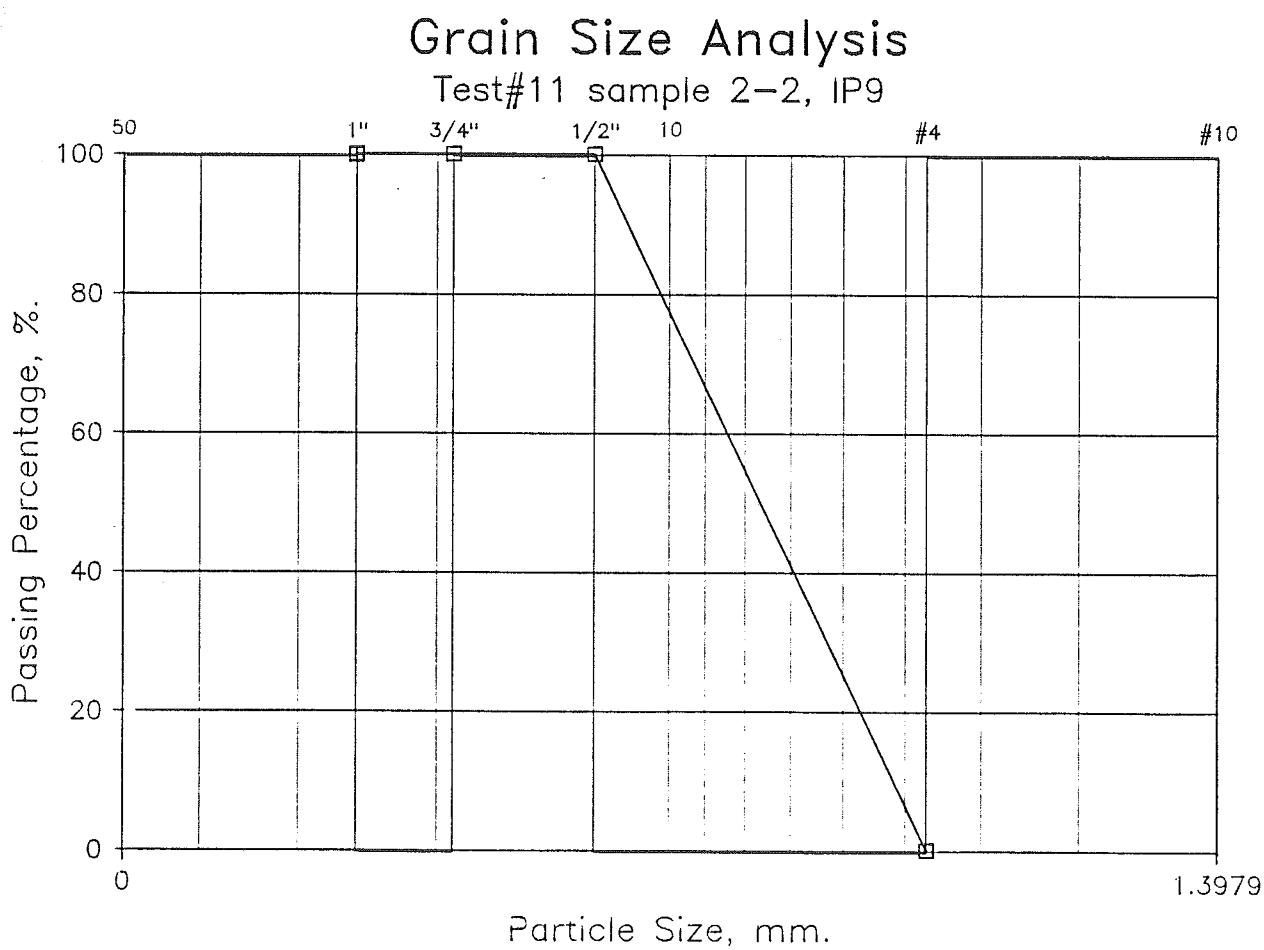

Grain Size Analysis
Test#11 sample 1-1/1-2/1-3, IP9
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
0
2.9208
Passing Percentage, %.
Particle Size, mm.

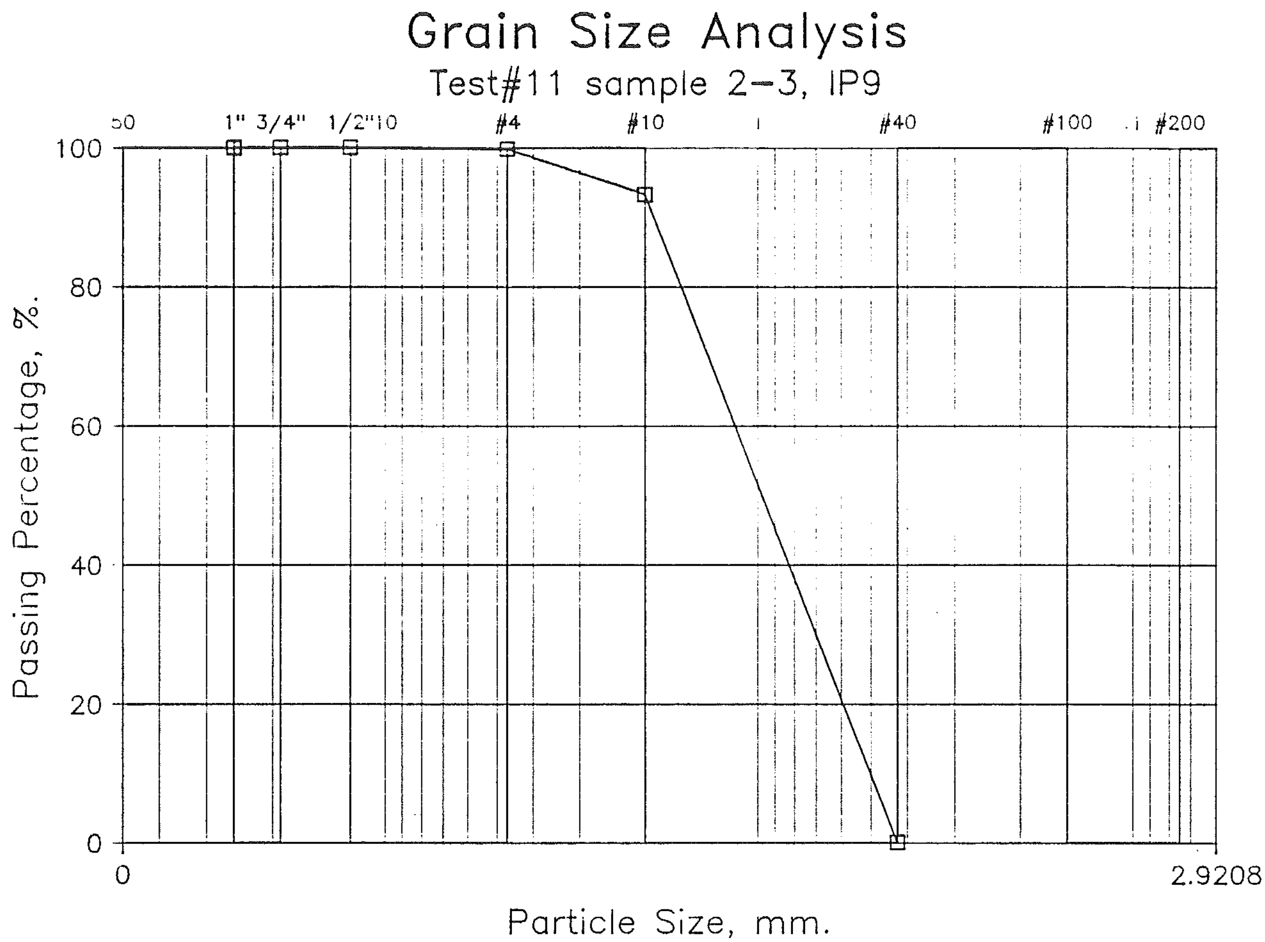

Grain Size Analysis
Test#11 sample 1-1/1-2/1-3, IP9
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
0
1.3979
Passing Percentage, %.
Particle Size, mm.

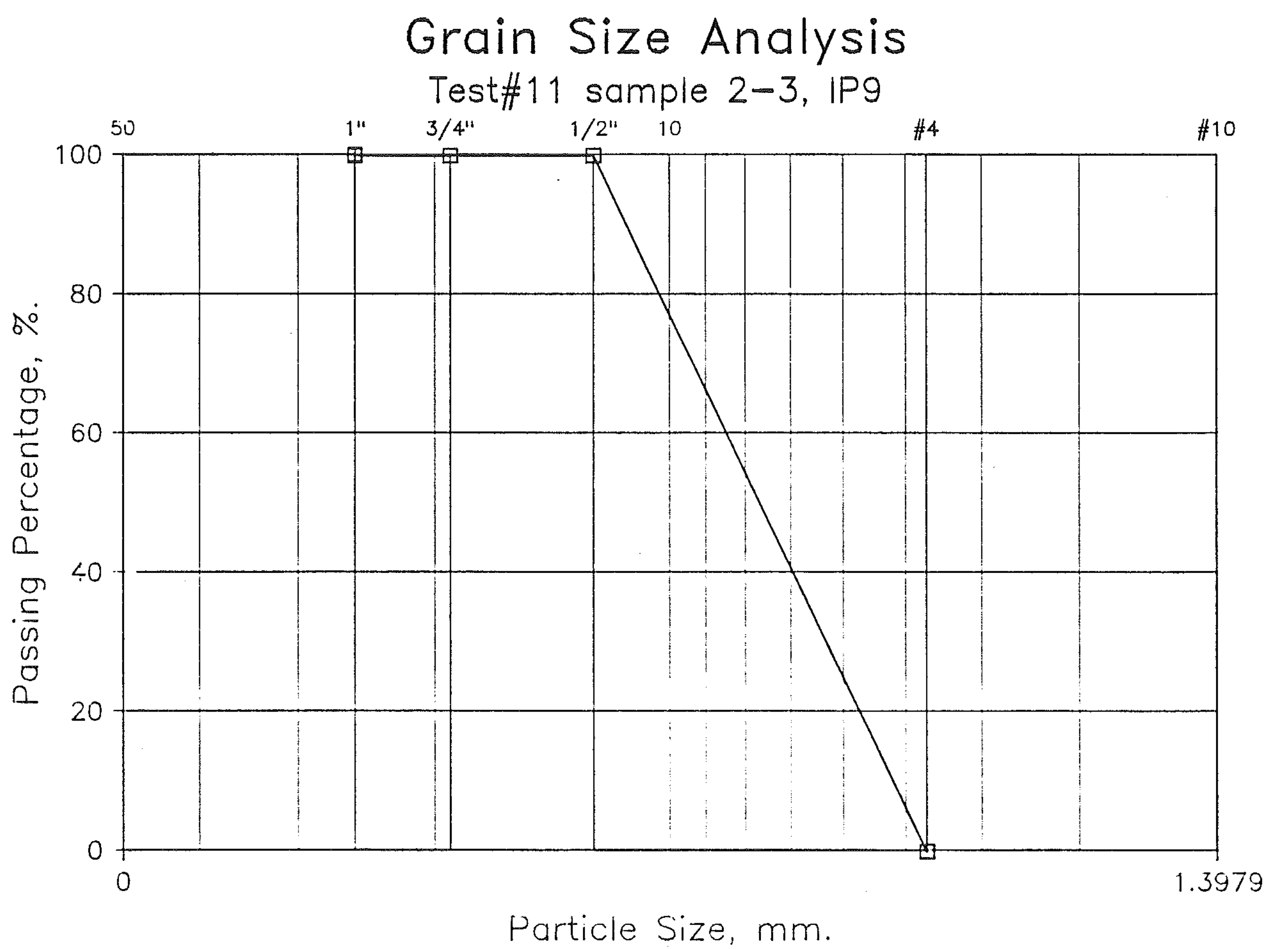

Grain Size Analysis
Test#11 sample 2-1, IP9
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

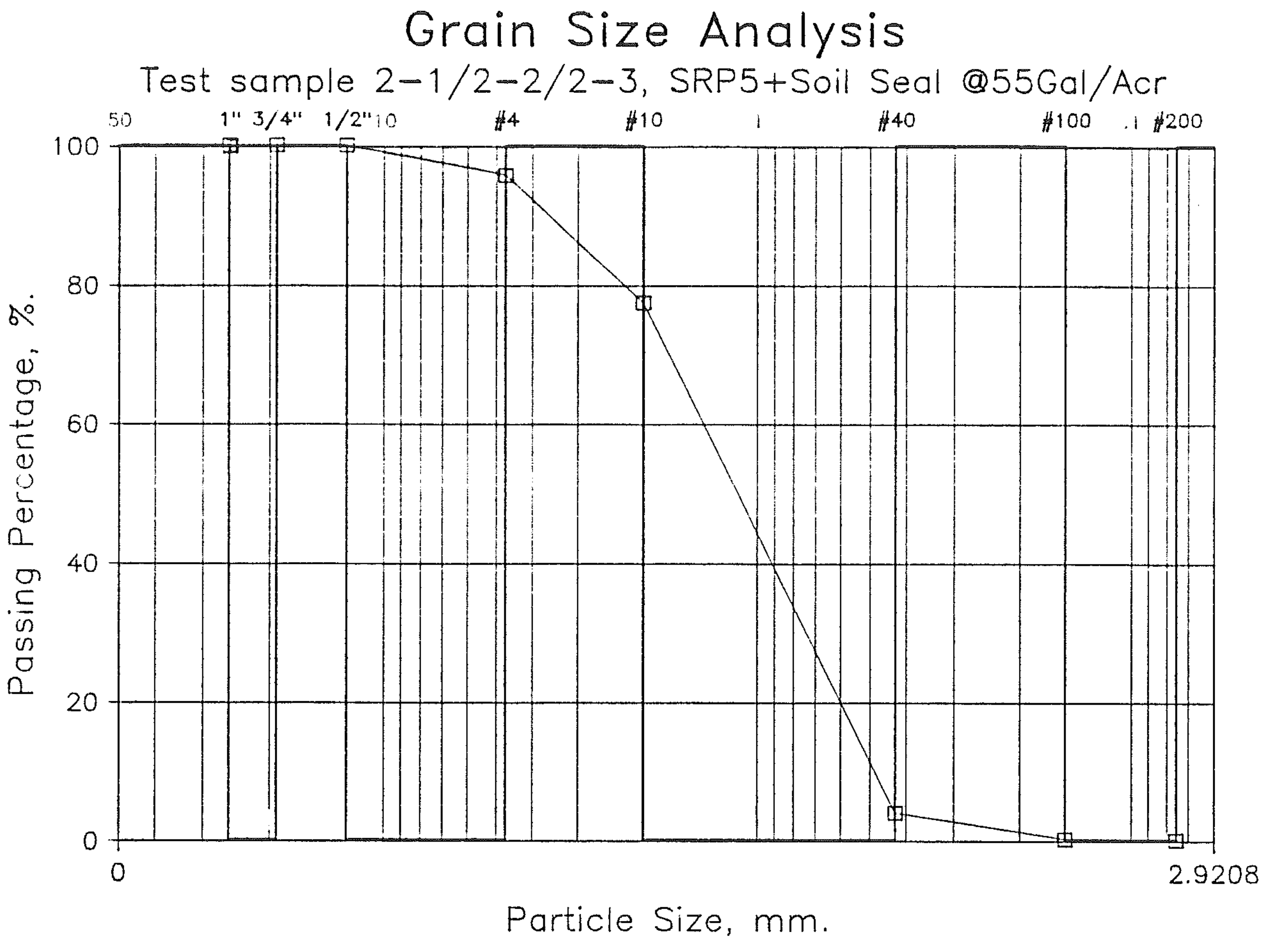

Grain Size Analysis
Test#11 sample 2-1, IP9
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.


Grain Size Analysis
Test#11 sample 2-2, IP9
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test#11 sample 2-2, IP9
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

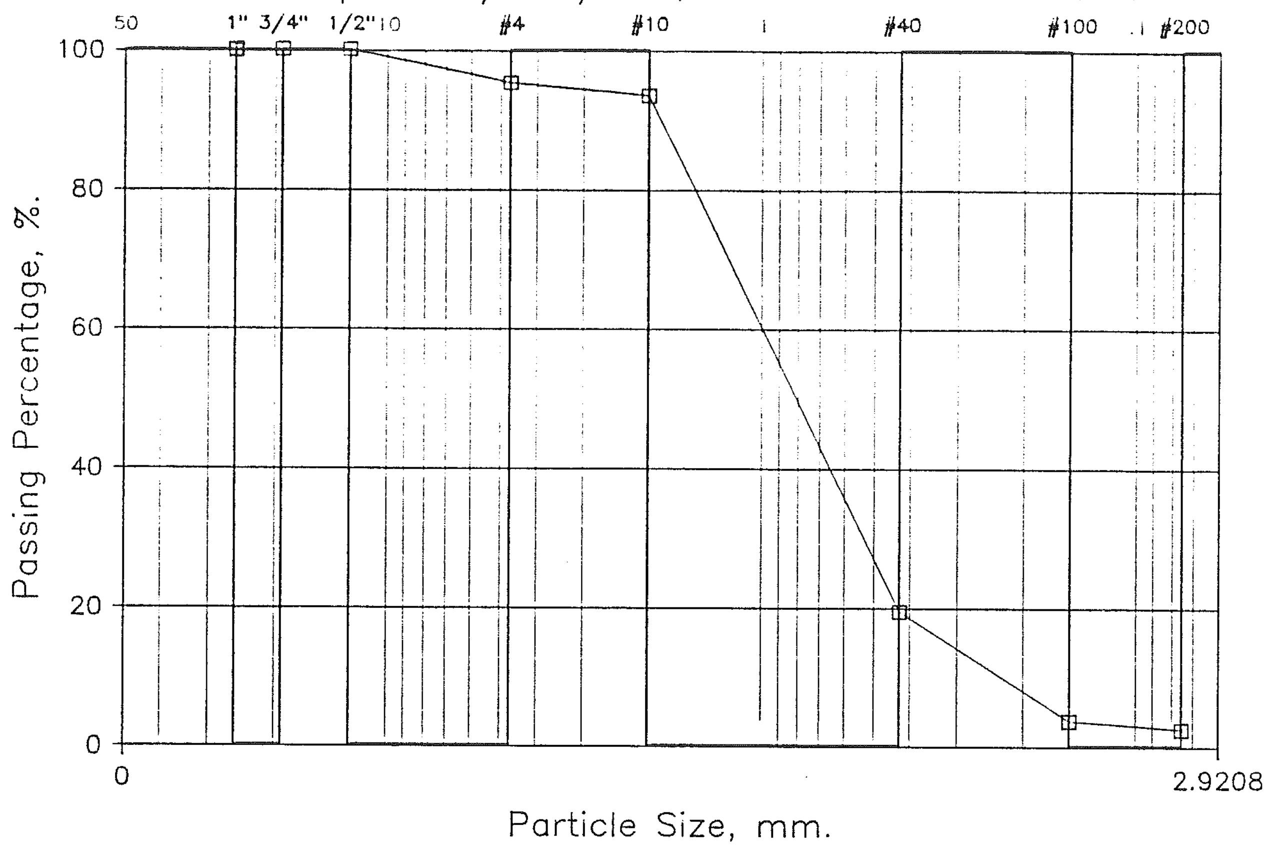

Grain Size Analysis
Test#11 sample 2-3, IP9
50
1"
3/4"
1/2"
10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

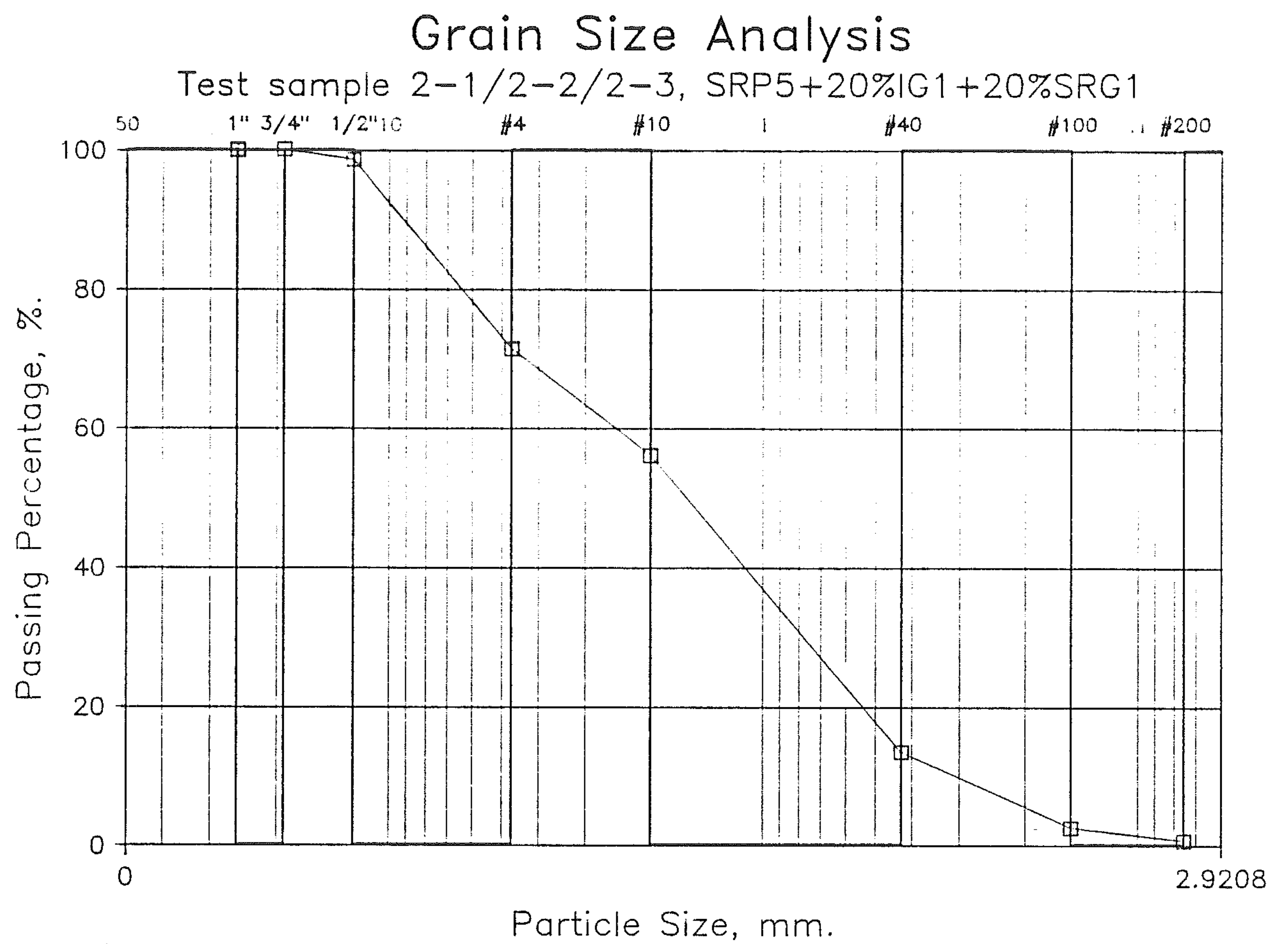

Grain Size Analysis
Test#11 sample 2-3, IP9
50
1"
3/4"
1/2"
10
#4
#10
100
80
60
40
20
0
Passing Percentage, %.
0
1.3979
Particle Size, mm.

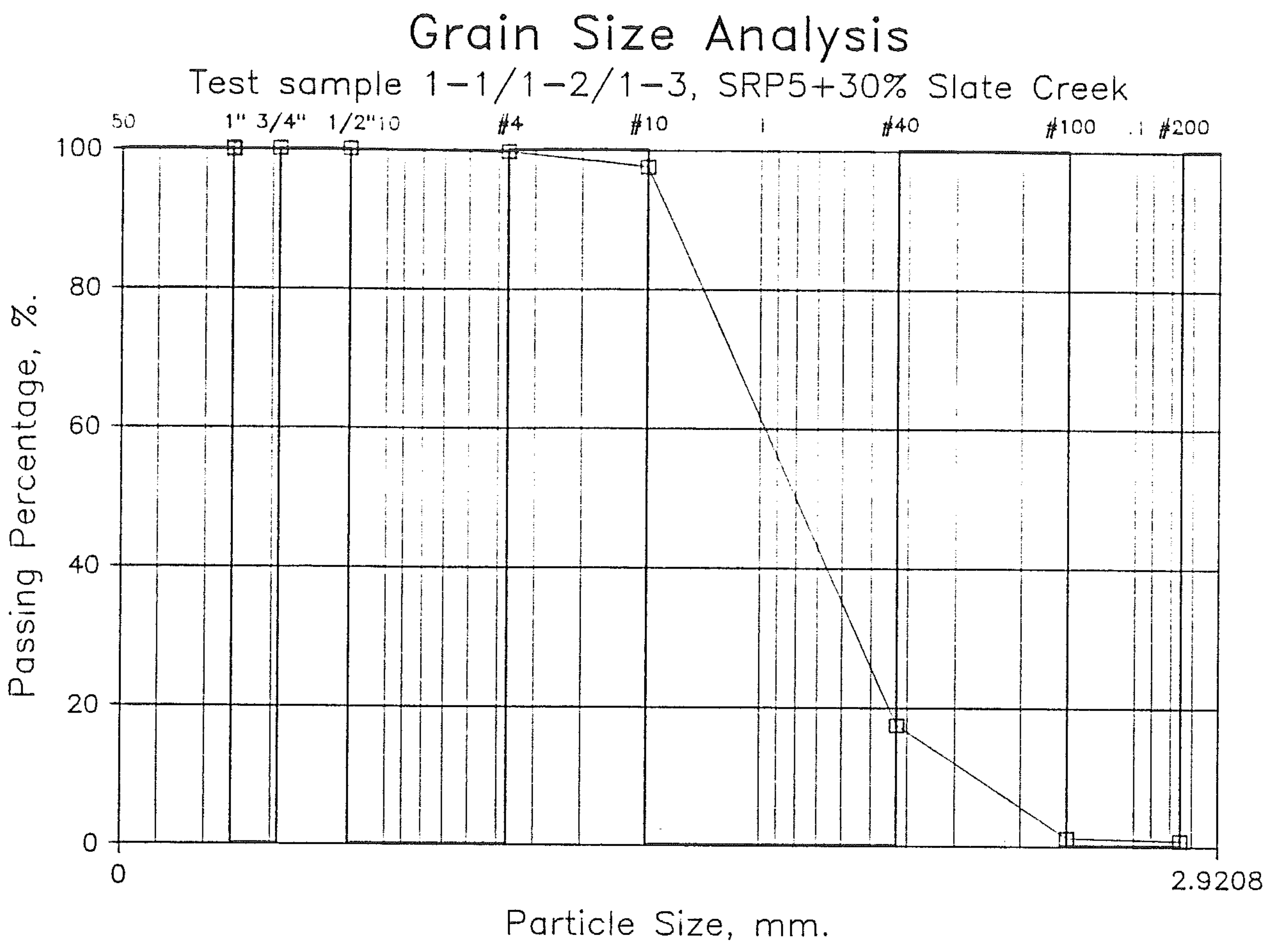

Grain Size Analysis
Test sample 2-1/2-2/2-3, SRP5+Soil Seal @55Gal/Acr
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

Grain Size Analysis

Test sample 1-1/1-2/1-3, SRP5+20%IG1+20%SRG1

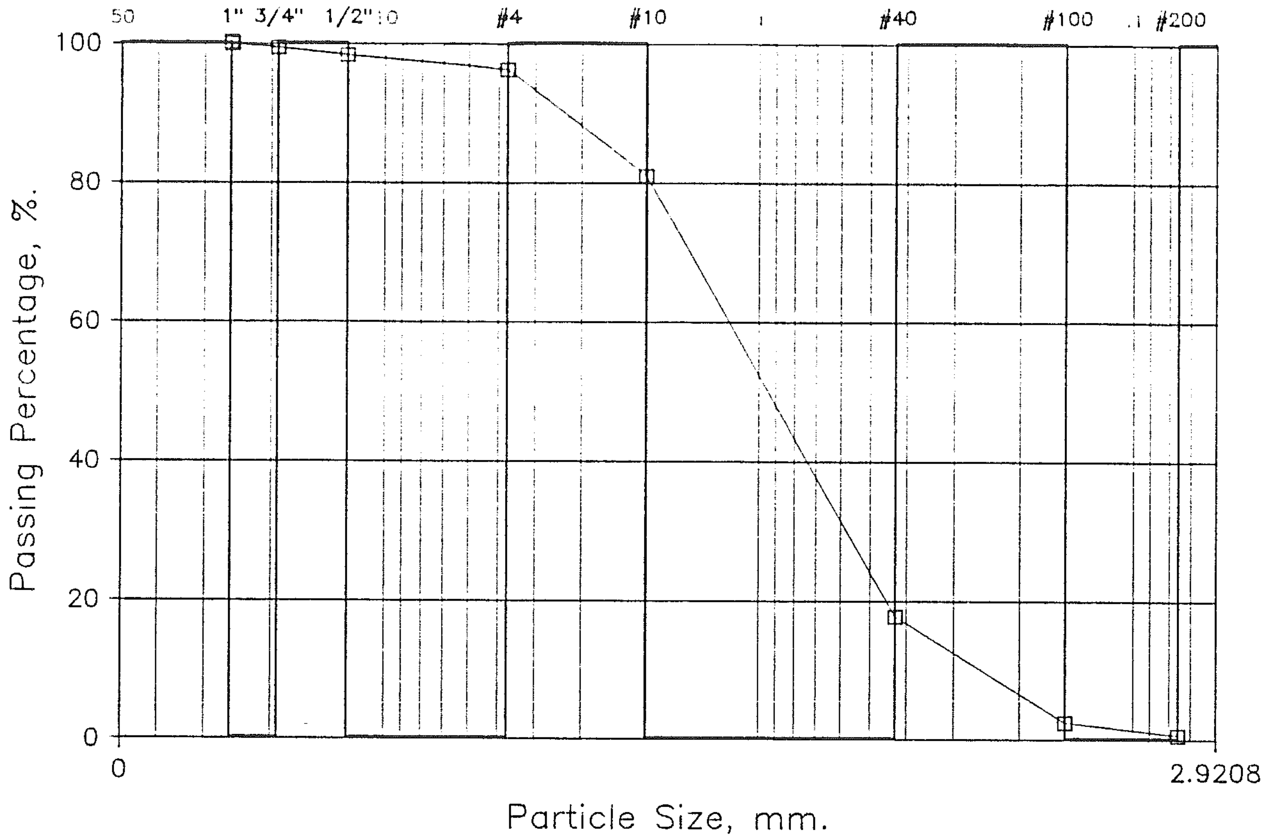


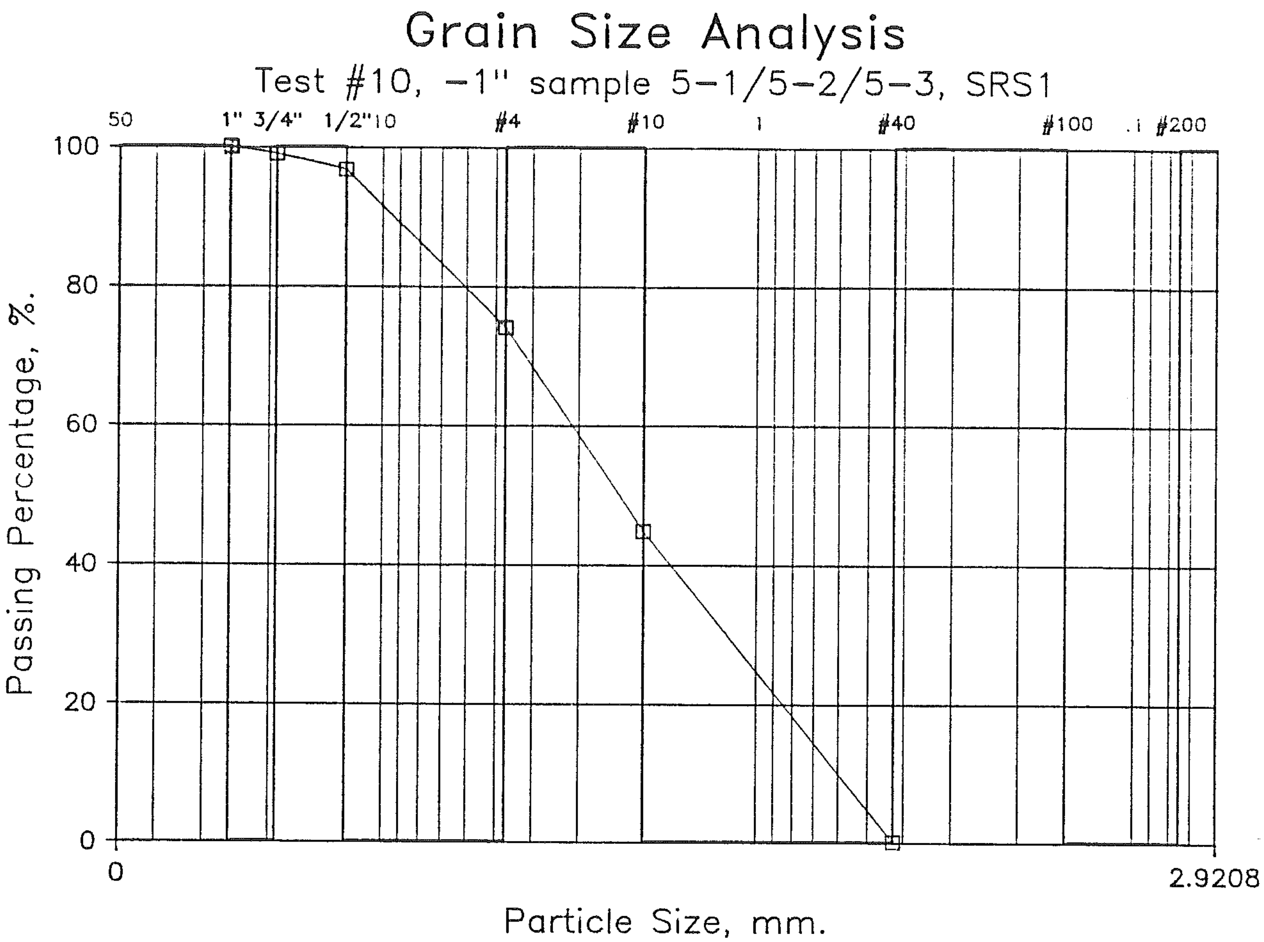

Grain Size Analysis
Test sample 2-1/2-2/2-3, SRP5+20%IG1+20%SRG1
50
1" 3/4" 1/2"
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

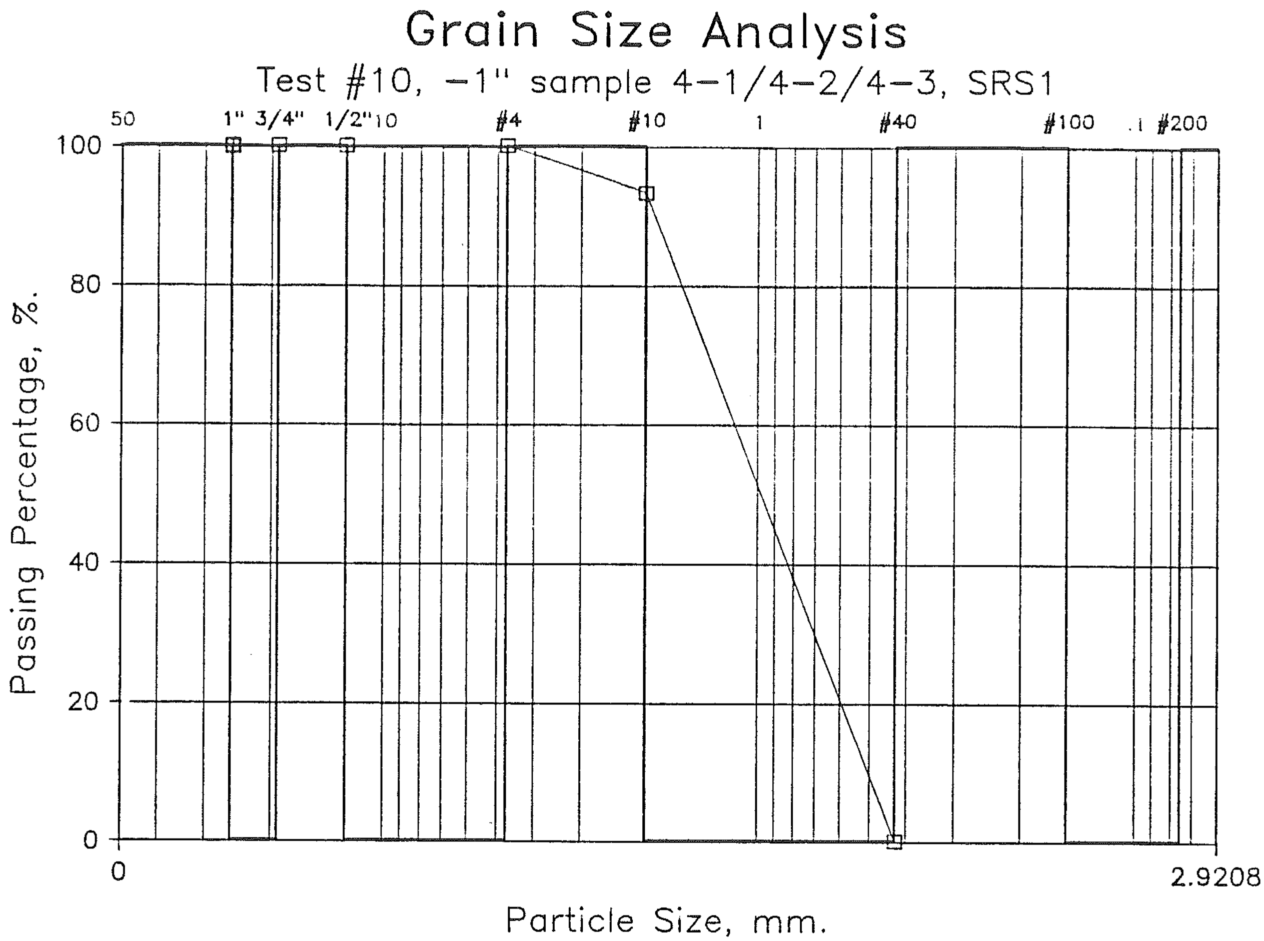

Grain Size Analysis
Test sample 1-1/1-2/1-3, SRP5+30% Slate Creek
50
1" 3/4" 1/2" 10
#4
#10
#40
#100
#200
100
80
60
40
20
0
0
2.9208
Passing Percentage, %.
Particle Size, mm.

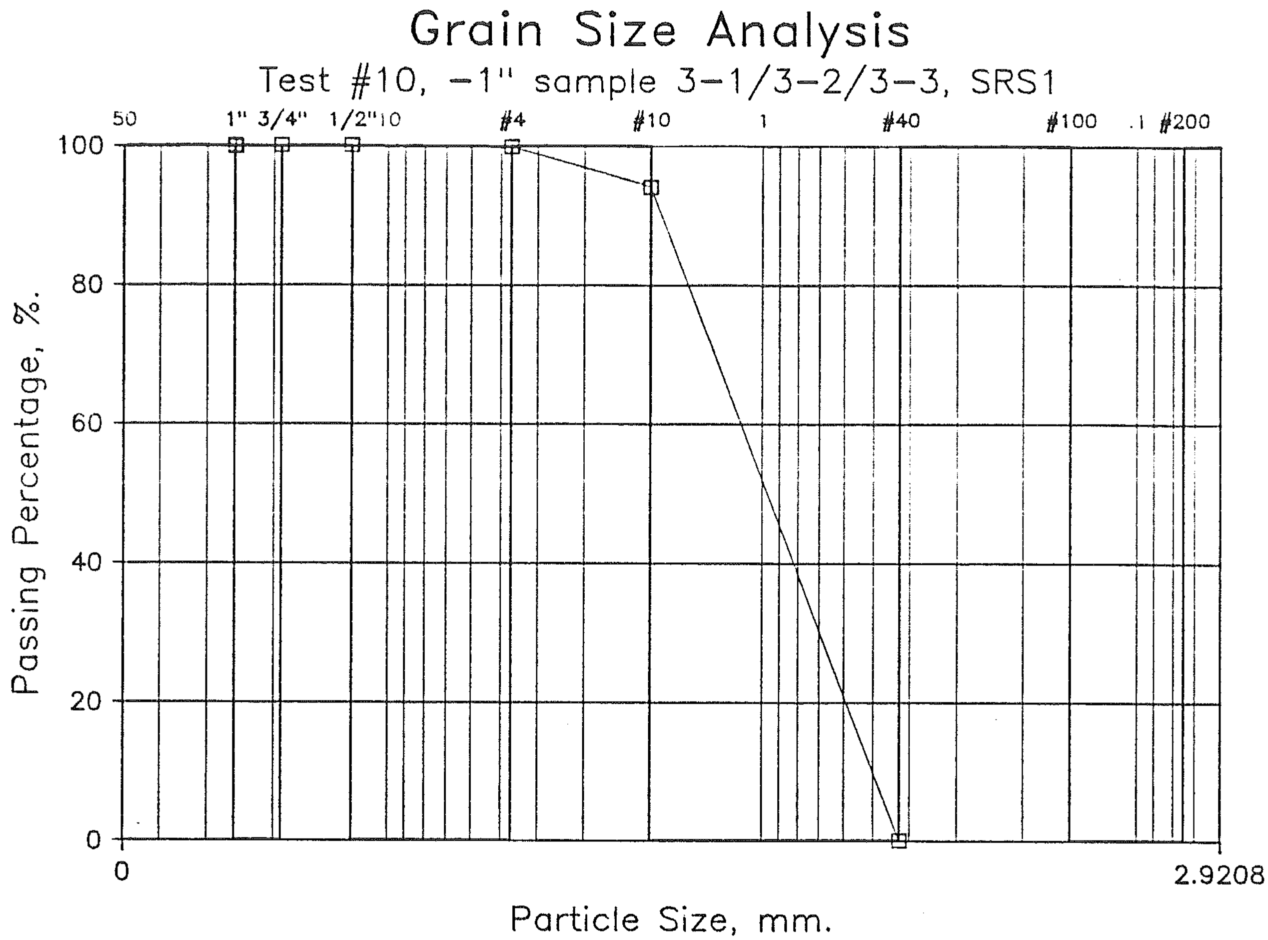
Grain Size Analysis

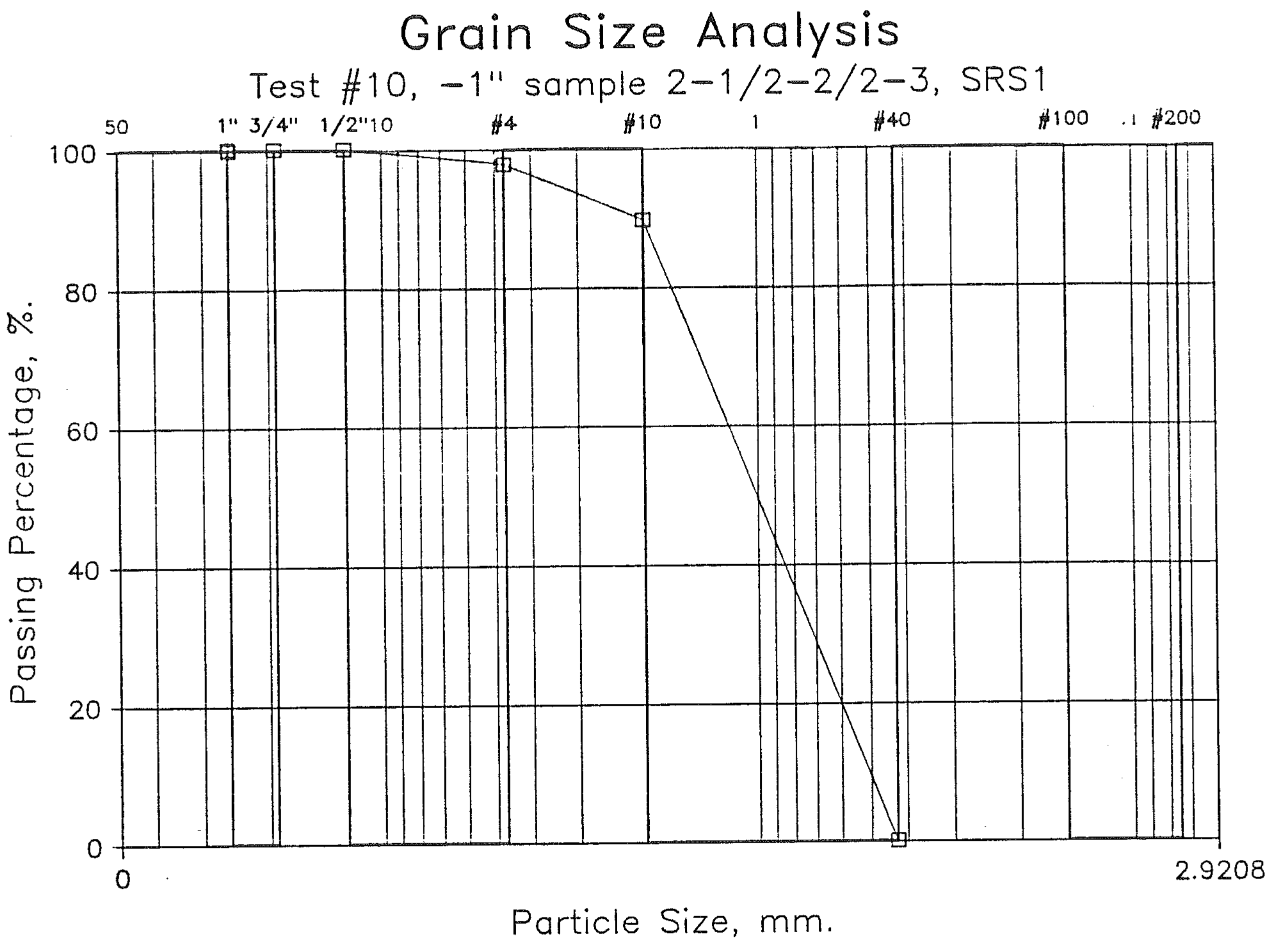
Test sample 2-1/2-2/2-3, SRP5+30% Slate Creek

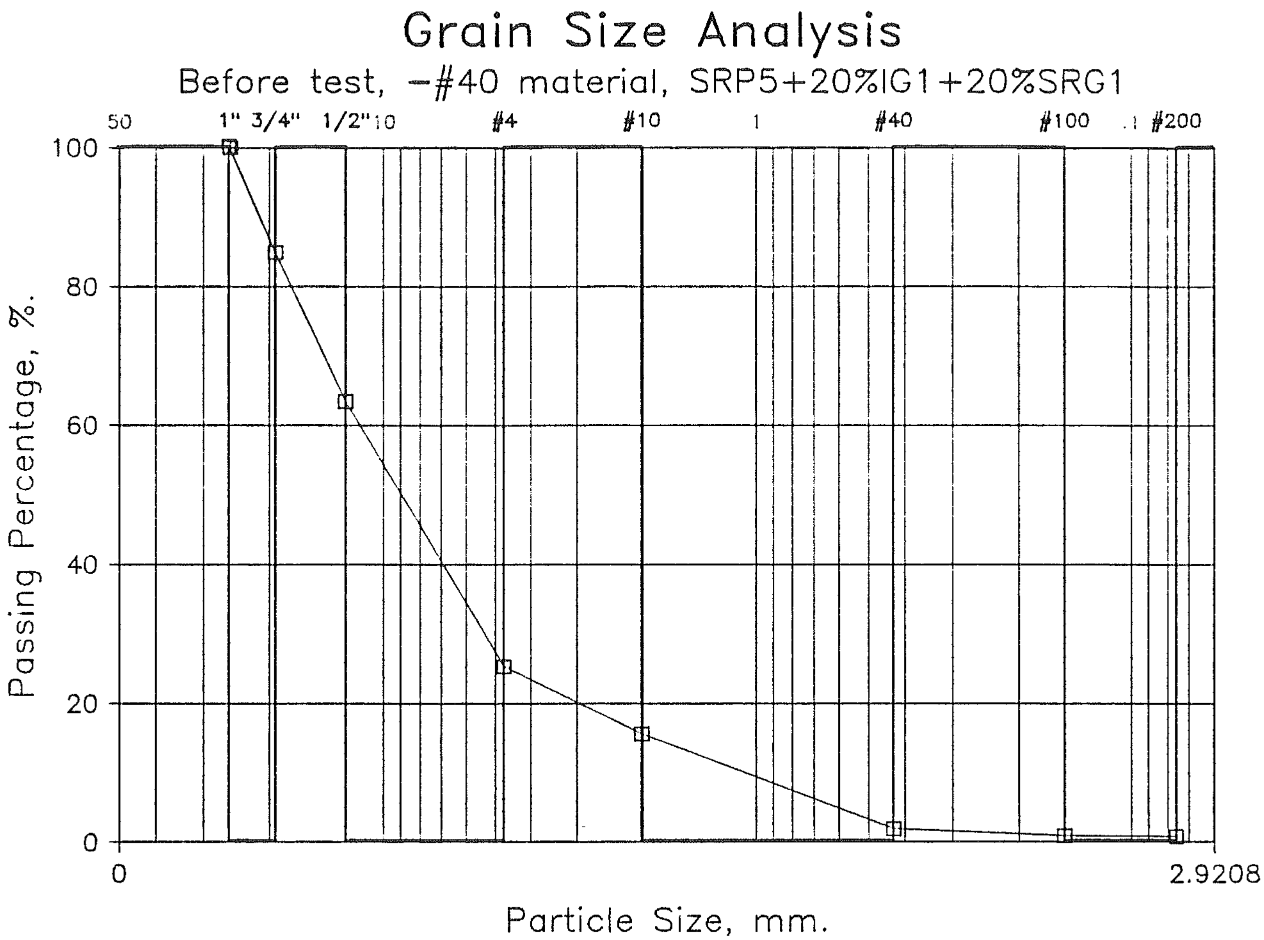



Grain Size Analysis
Test #10, -1" sample 5-1/5-2/5-3, SRS1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test #10, -1" sample 4-1/4-2/4-3, SRS1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test #10, -1" sample 3-1/3-2/3-3, SRS1
50
1"
3/4"
1/2"
10
#4
#10
1
#40
#100
.1
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

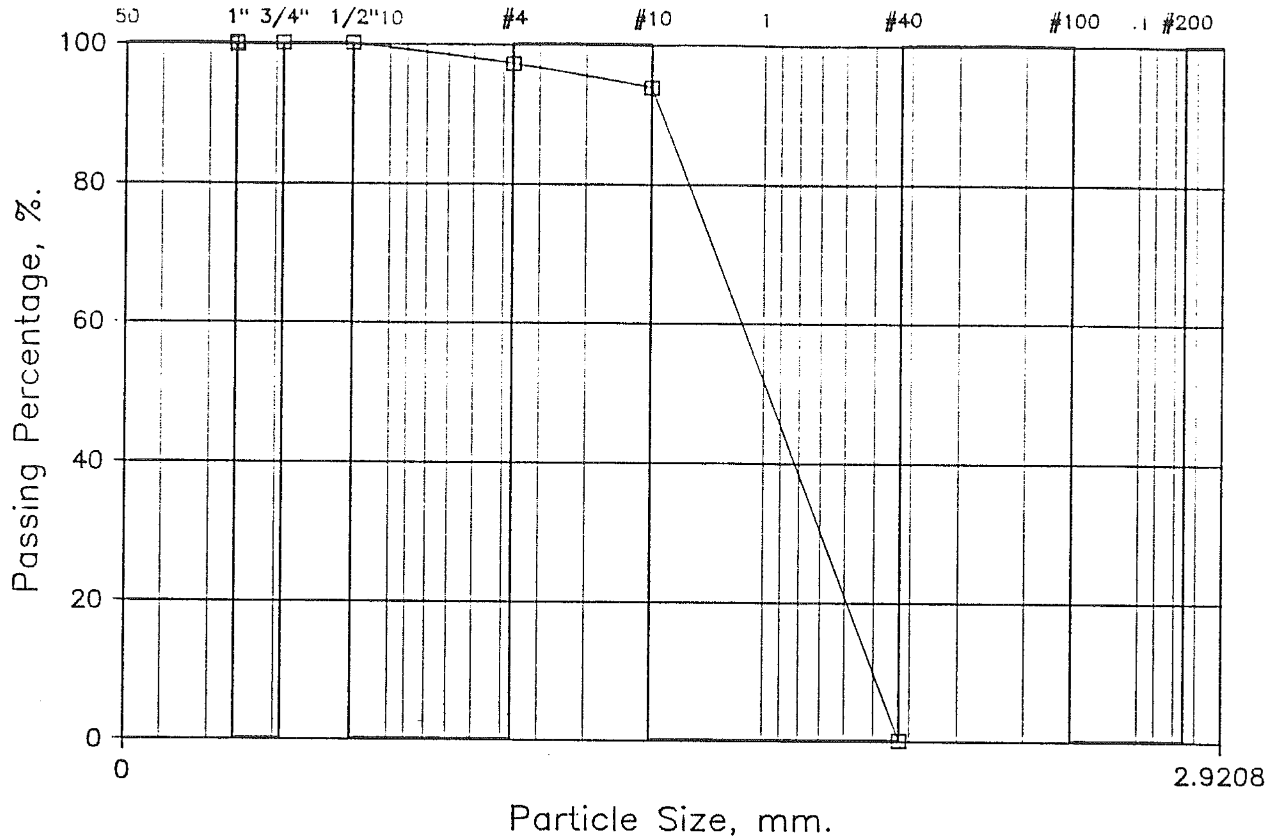

Grain Size Analysis
Test #10, -1" sample 2-1/2-2/2-3, SRS1
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

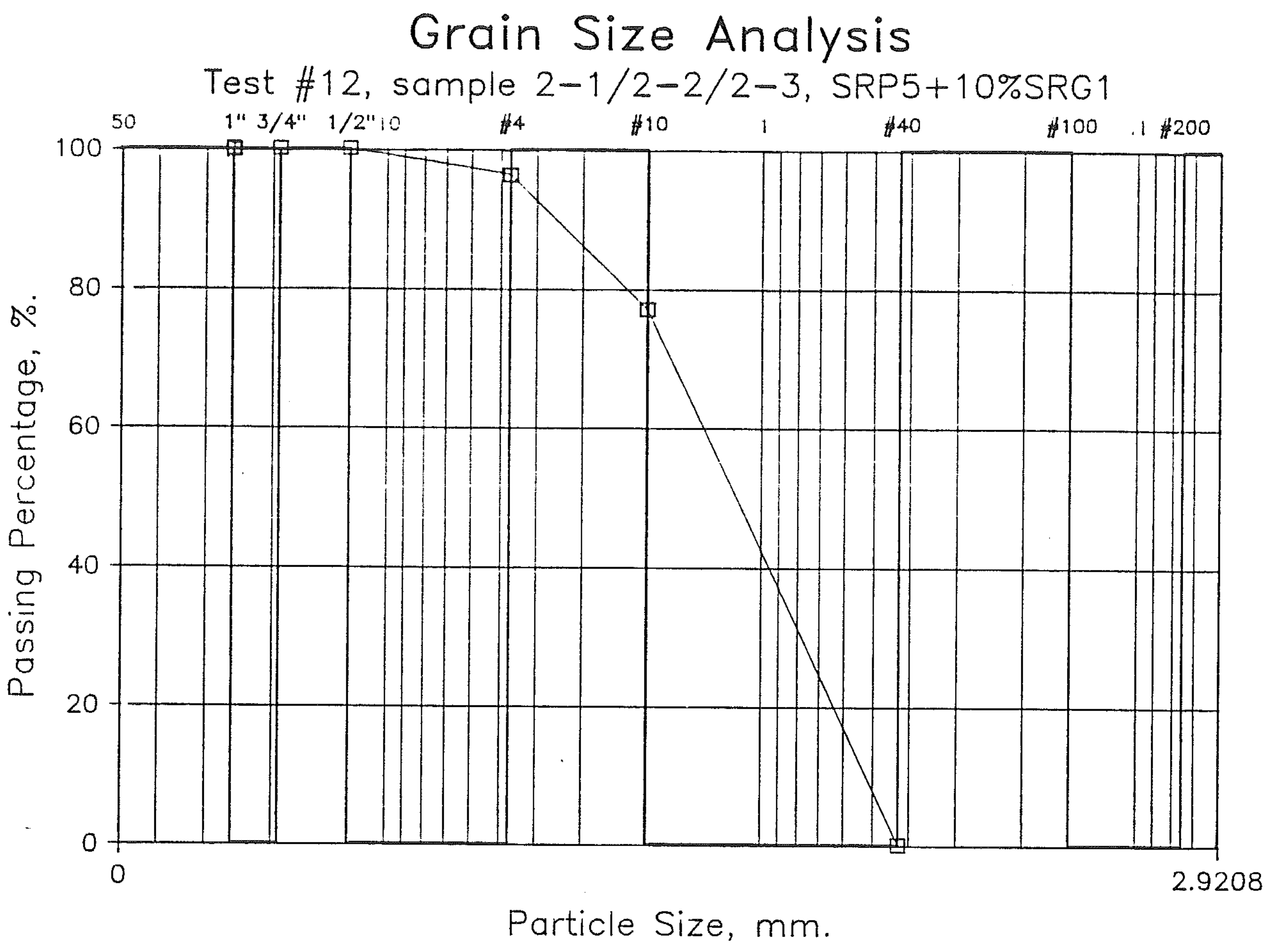


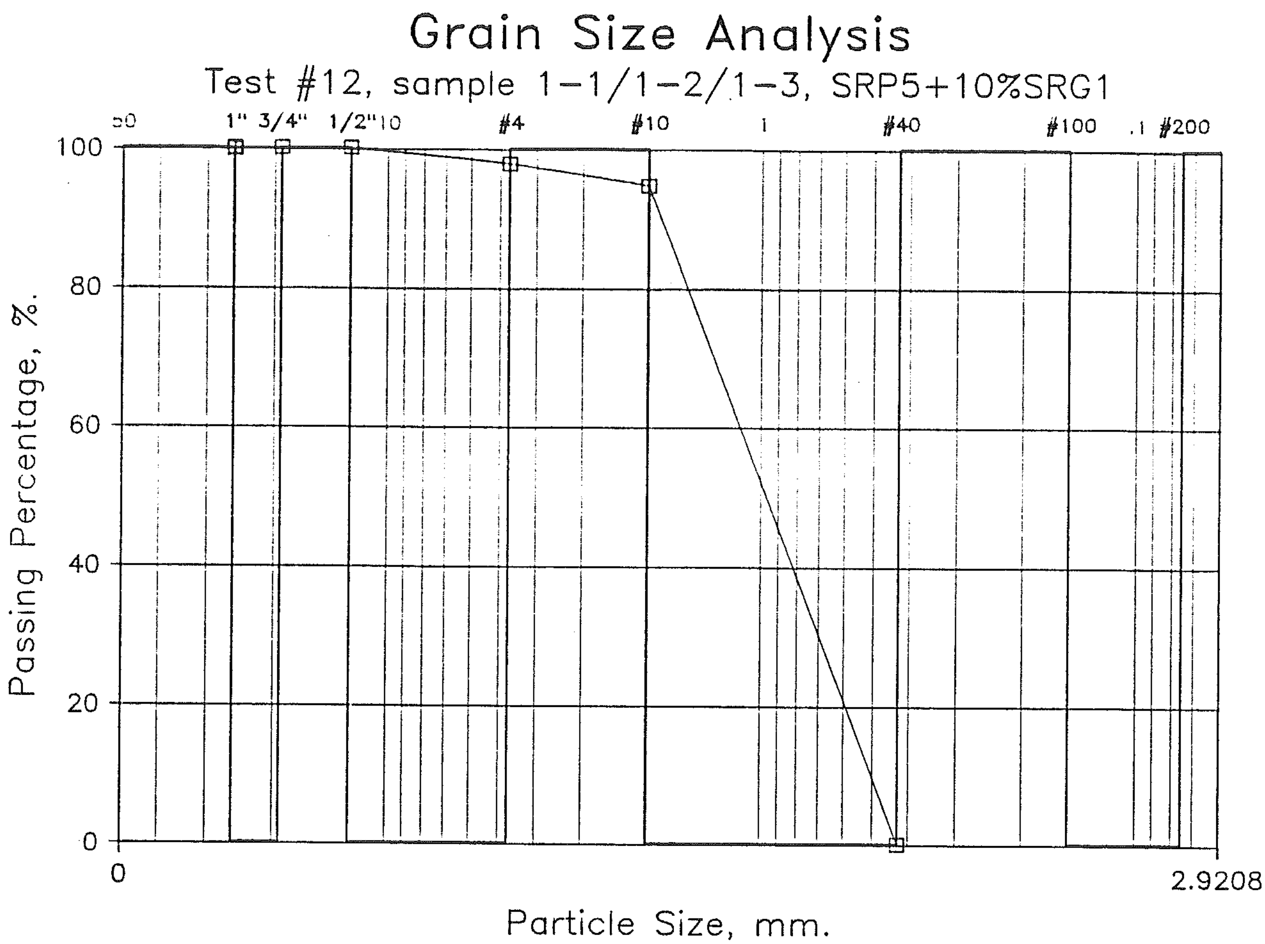
Grain Size Analysis
Before test, −#40 material, SRP5+20%IG1+20%SRG1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

Grain Size Analysis

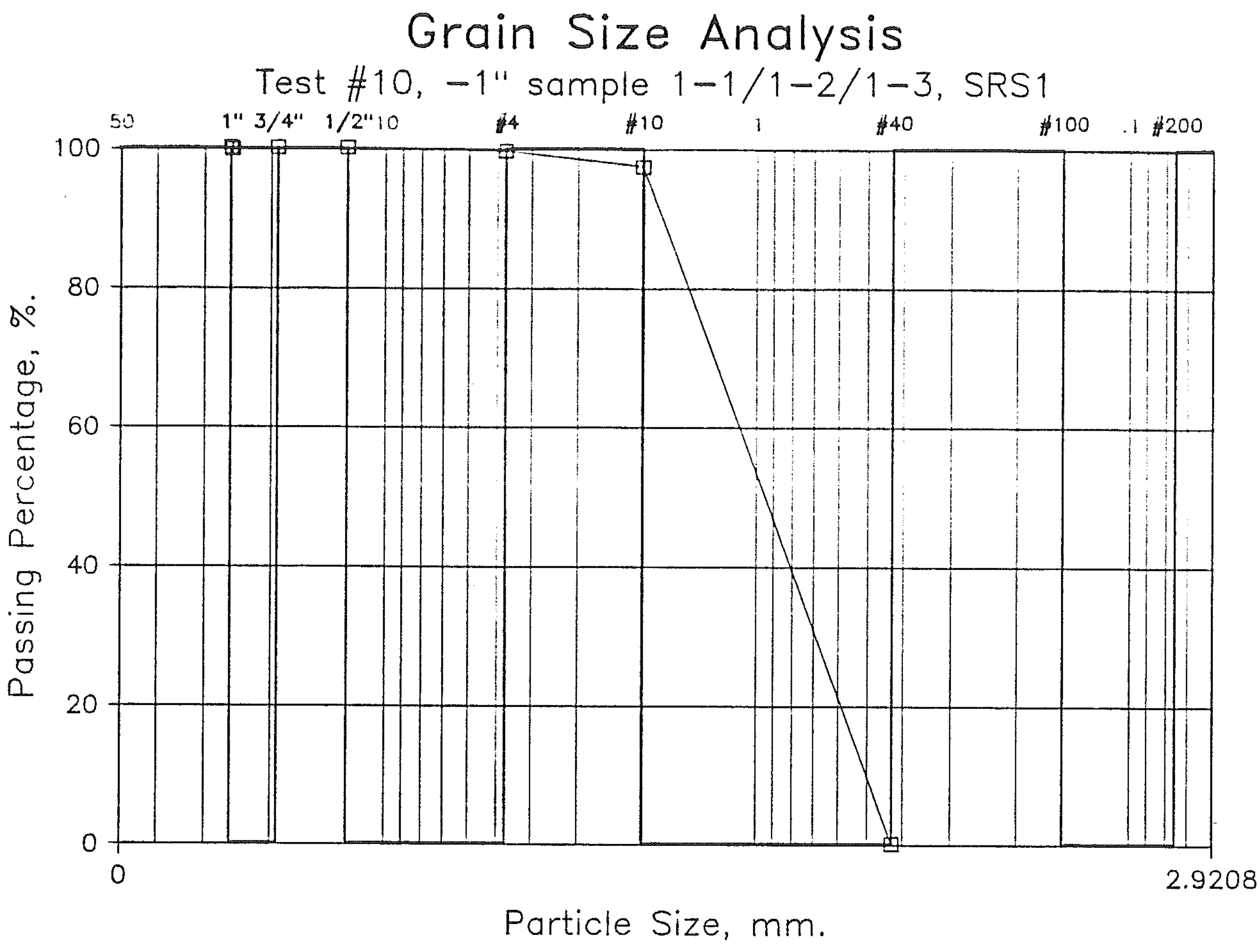
Test #14, sample 1-1/1-2/1-3, SRP5+10%IG1+20%SRG1

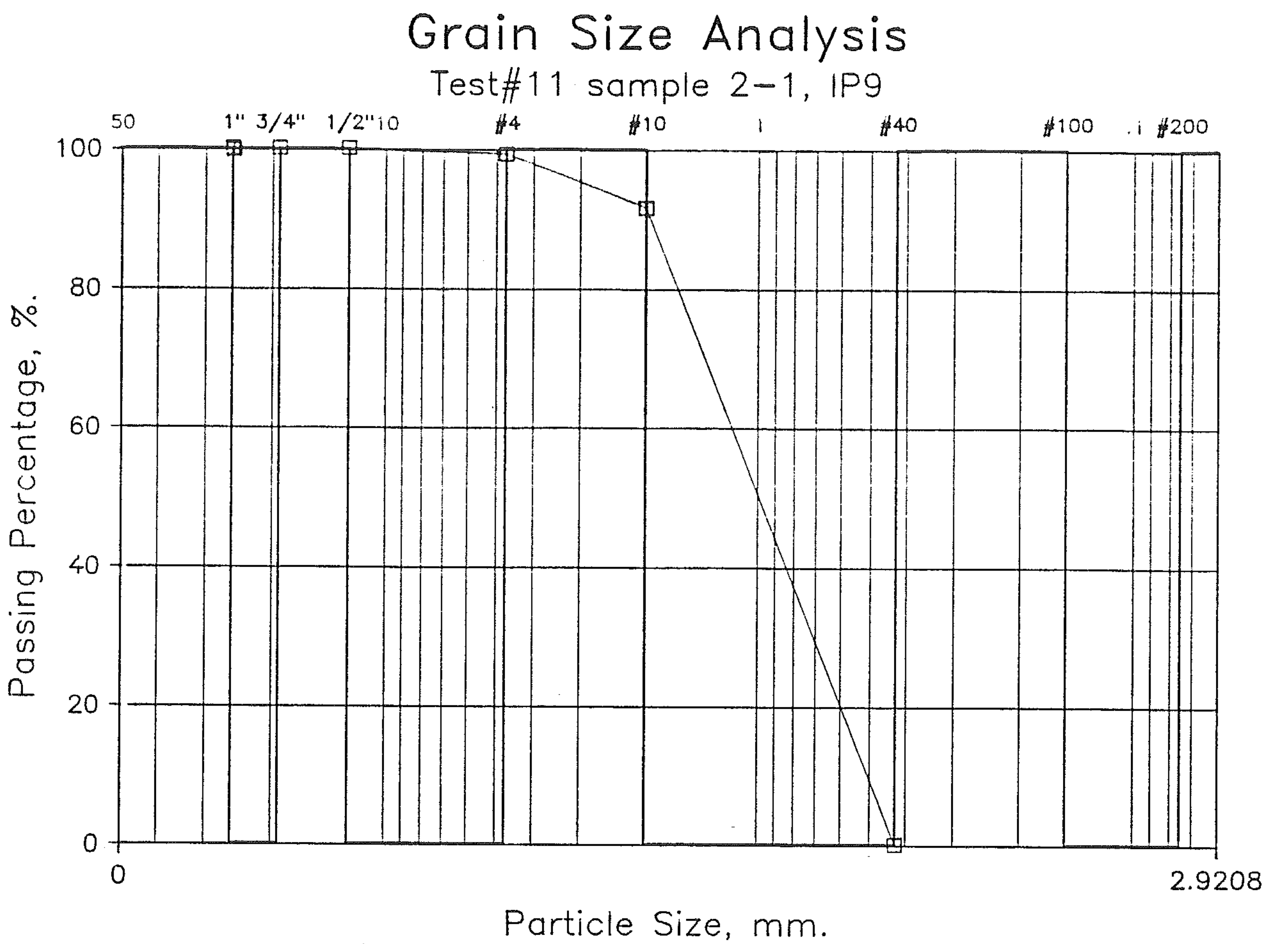



Grain Size Analysis
Test #12, sample 2-1/2-2/2-3, SRP5+10%SRG1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.



Grain Size Analysis
Test #12, sample 1-1/1-2/1-3, SRP5+10%SRG1
1" 3/4" 1/2" 10 #4 #10 1 #40 #100 .1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

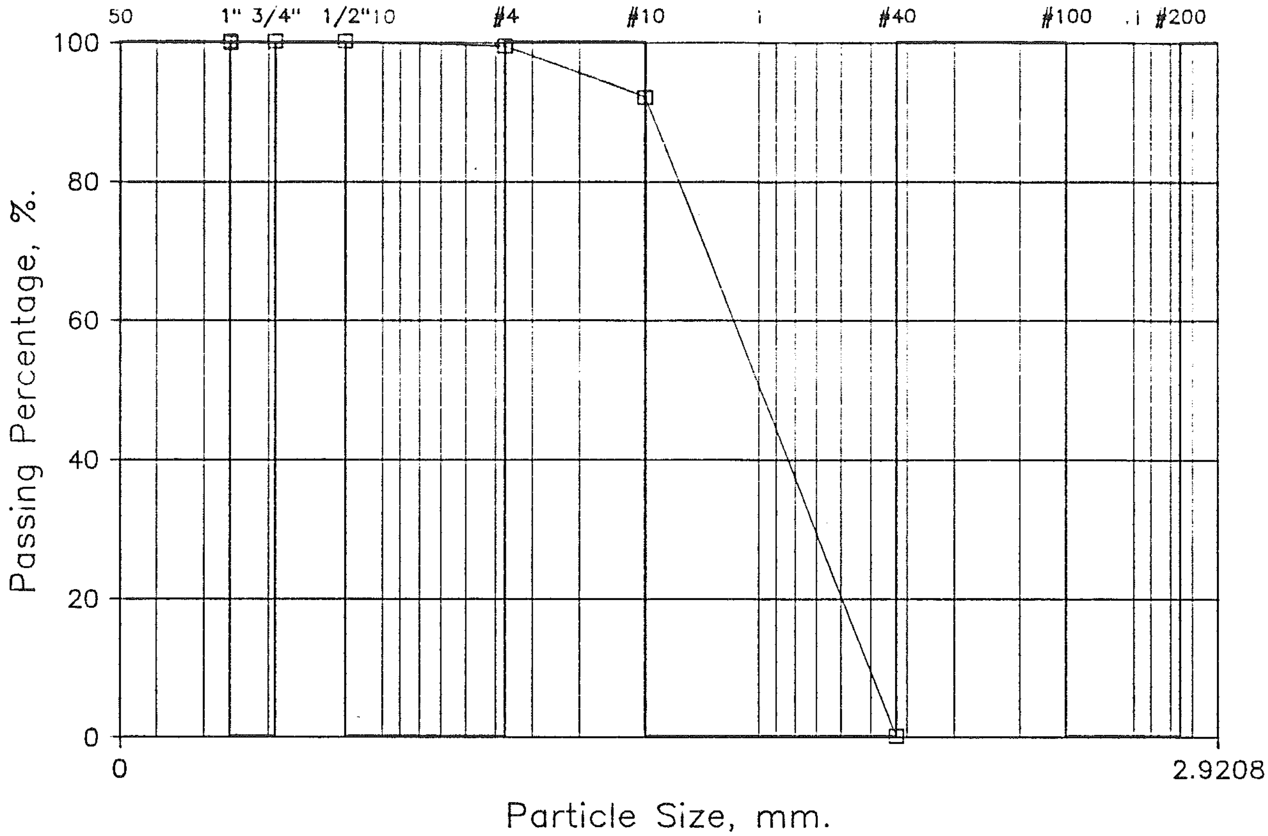

Grain Size Analysis
Test #10, -1" sample 1-1/1-2/1-3, SRS1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

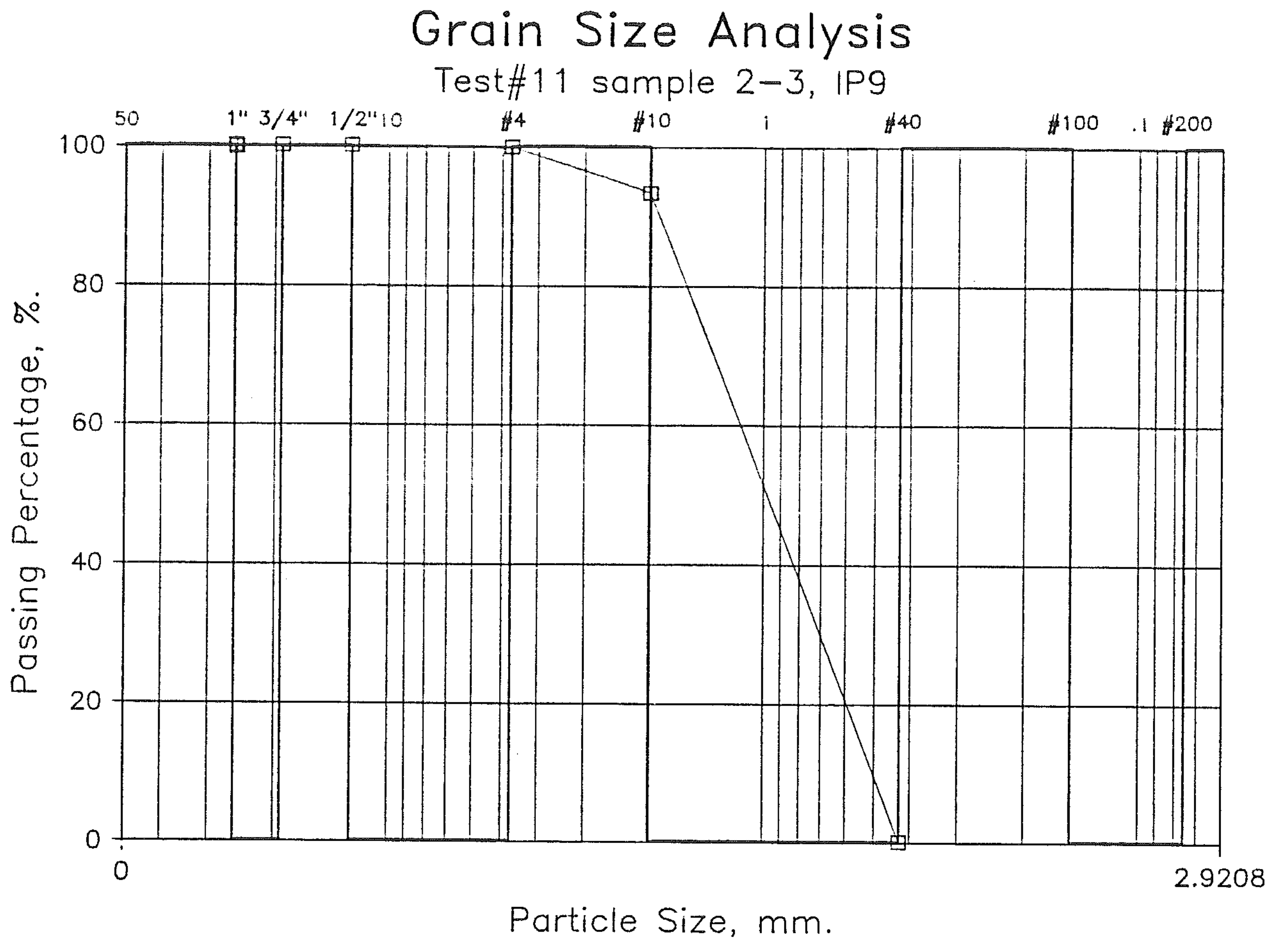


Grain Size Analysis
Test#11 sample 2-1, IP9
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

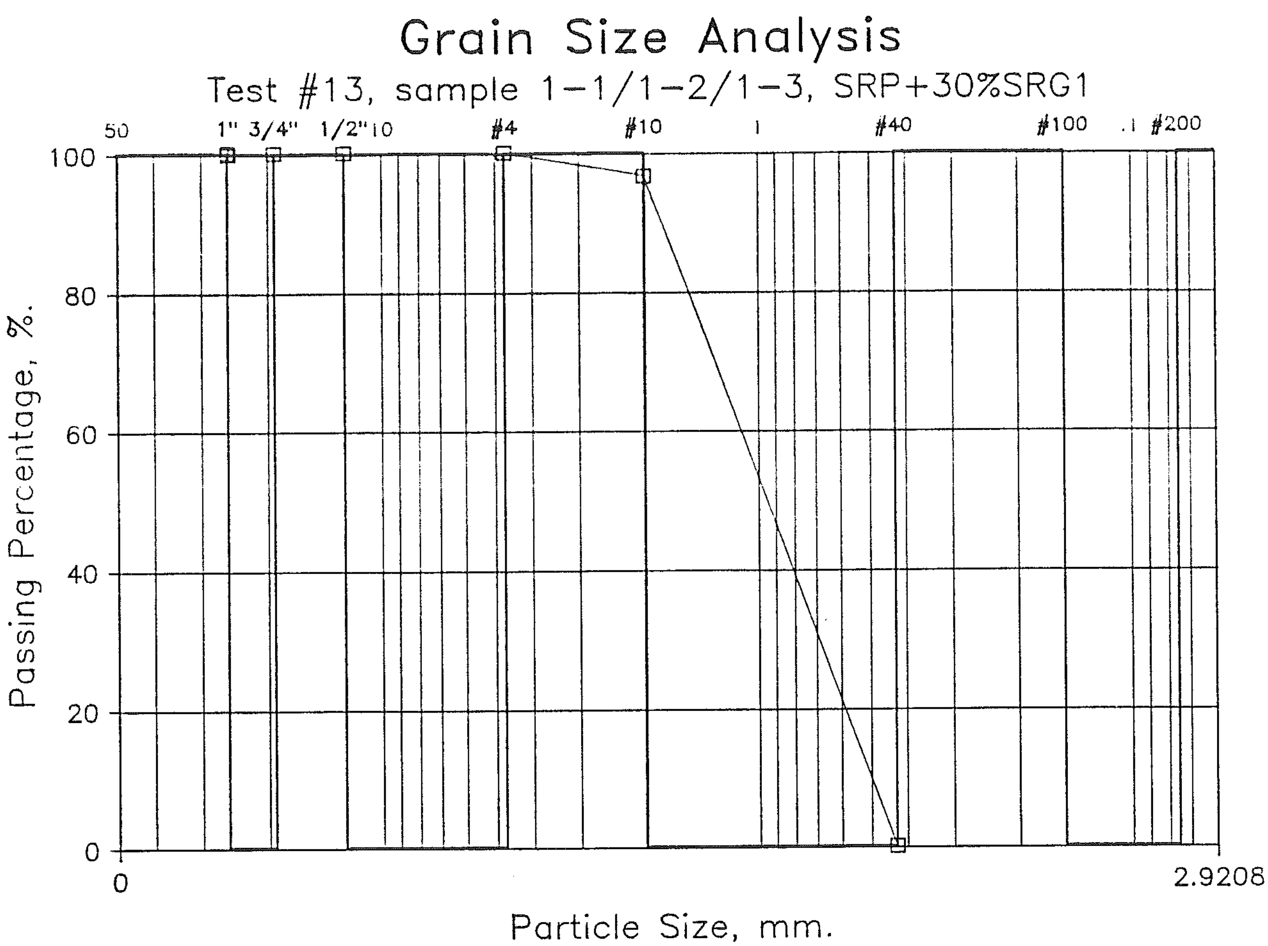
Grain Size Analysis

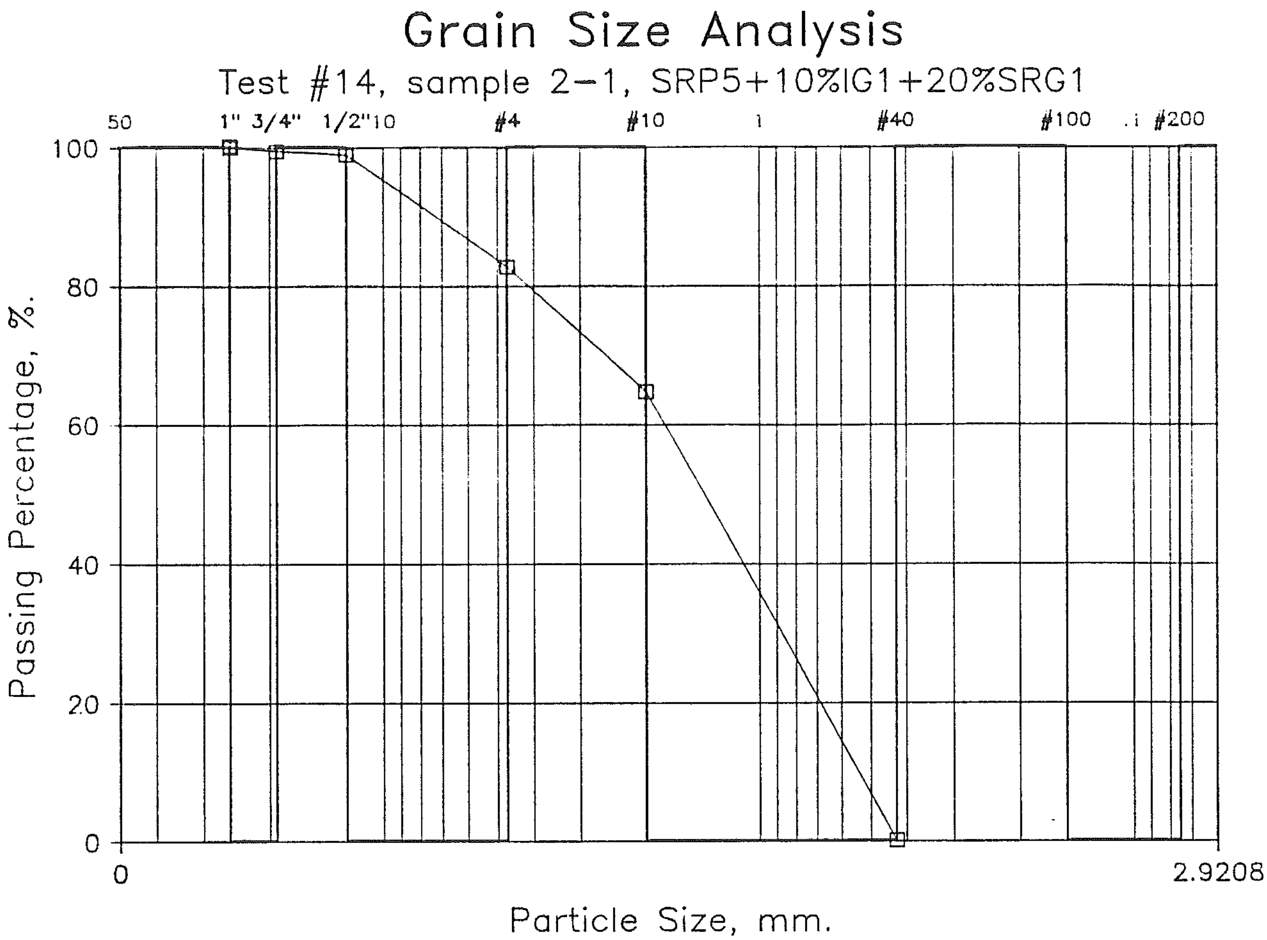
Test#11 sample 2-2, IP9

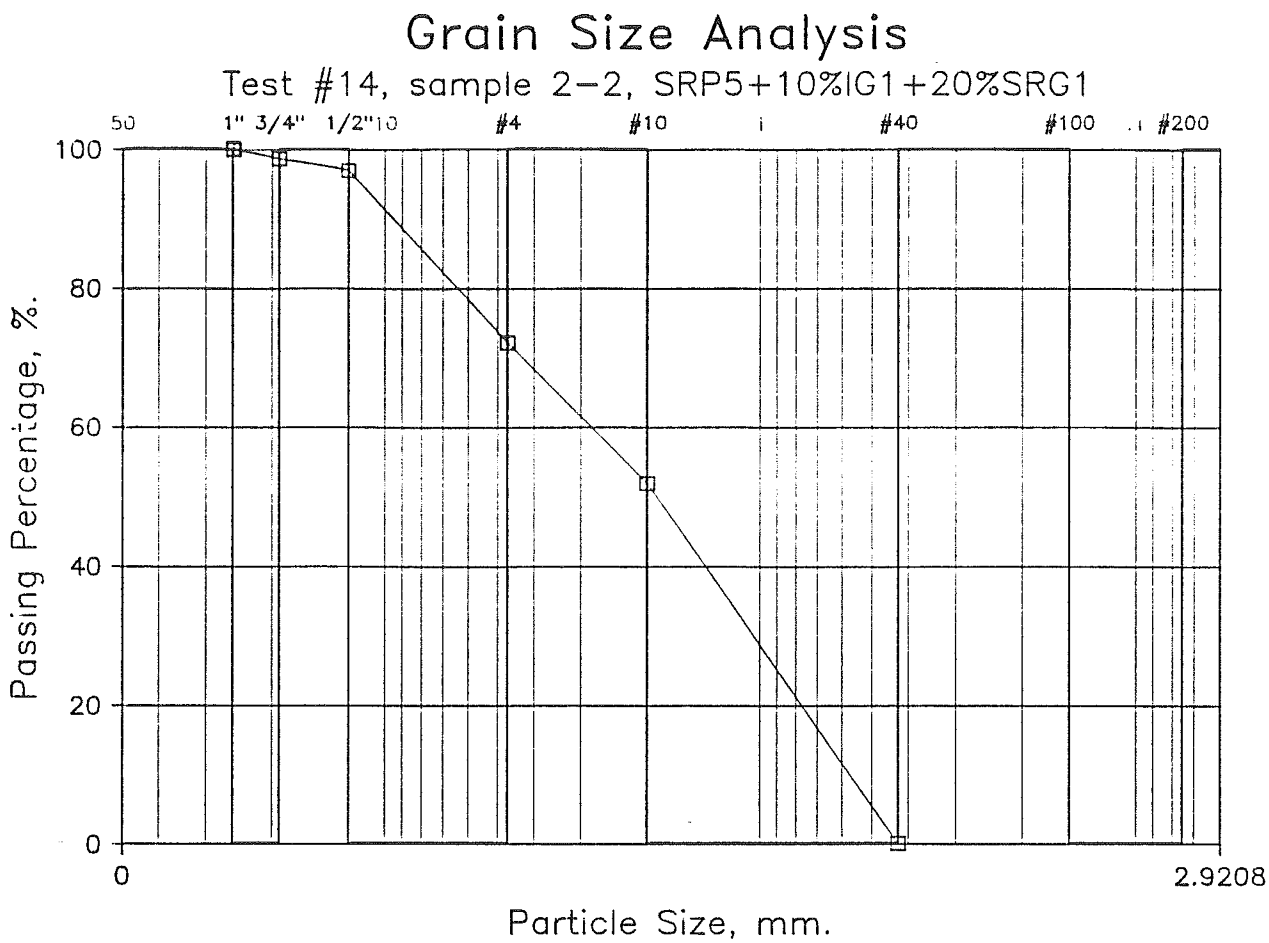




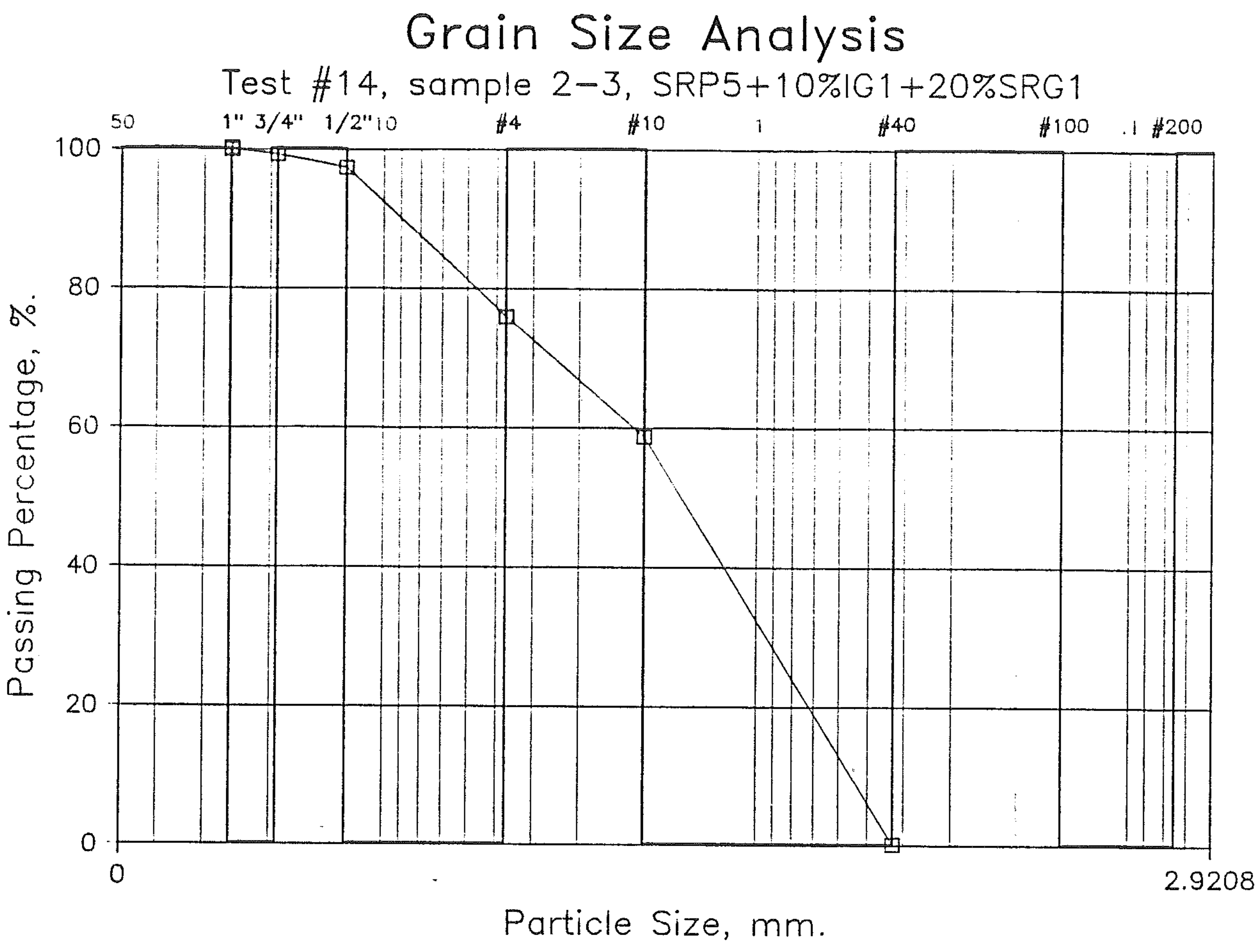
Grain Size Analysis
Test#11 sample 2-3, IP9
50
1" 3/4" 1/2" 10
#4
#10
#40
#100
.1 #200
100
80
60
40
20
0
0
2.9208
Passing Percentage, %.
Particle Size, mm.


Grain Size Analysis
Test #13, sample 1-1/1-2/1-3, SRP+30%SRG1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test #14, sample 2-1, SRP5+10%IG1+20%SRG1
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

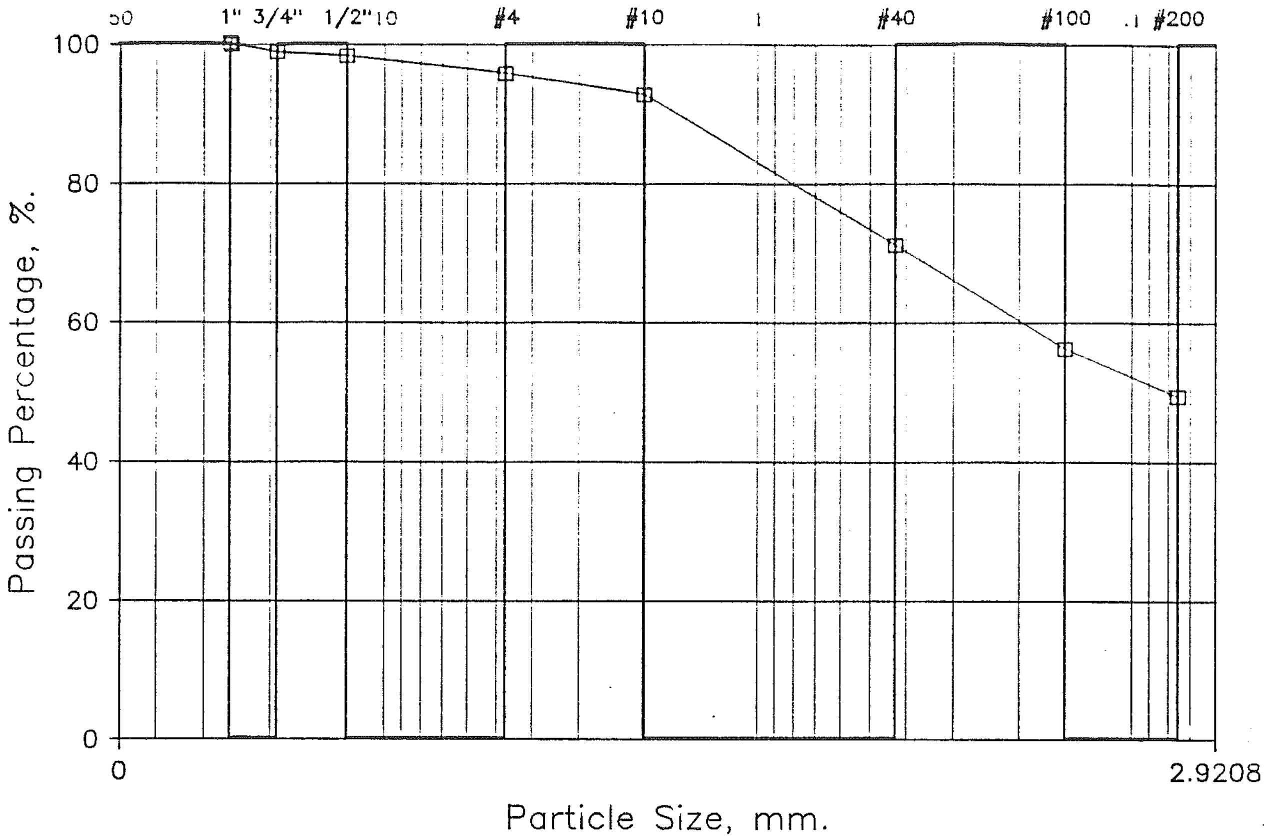


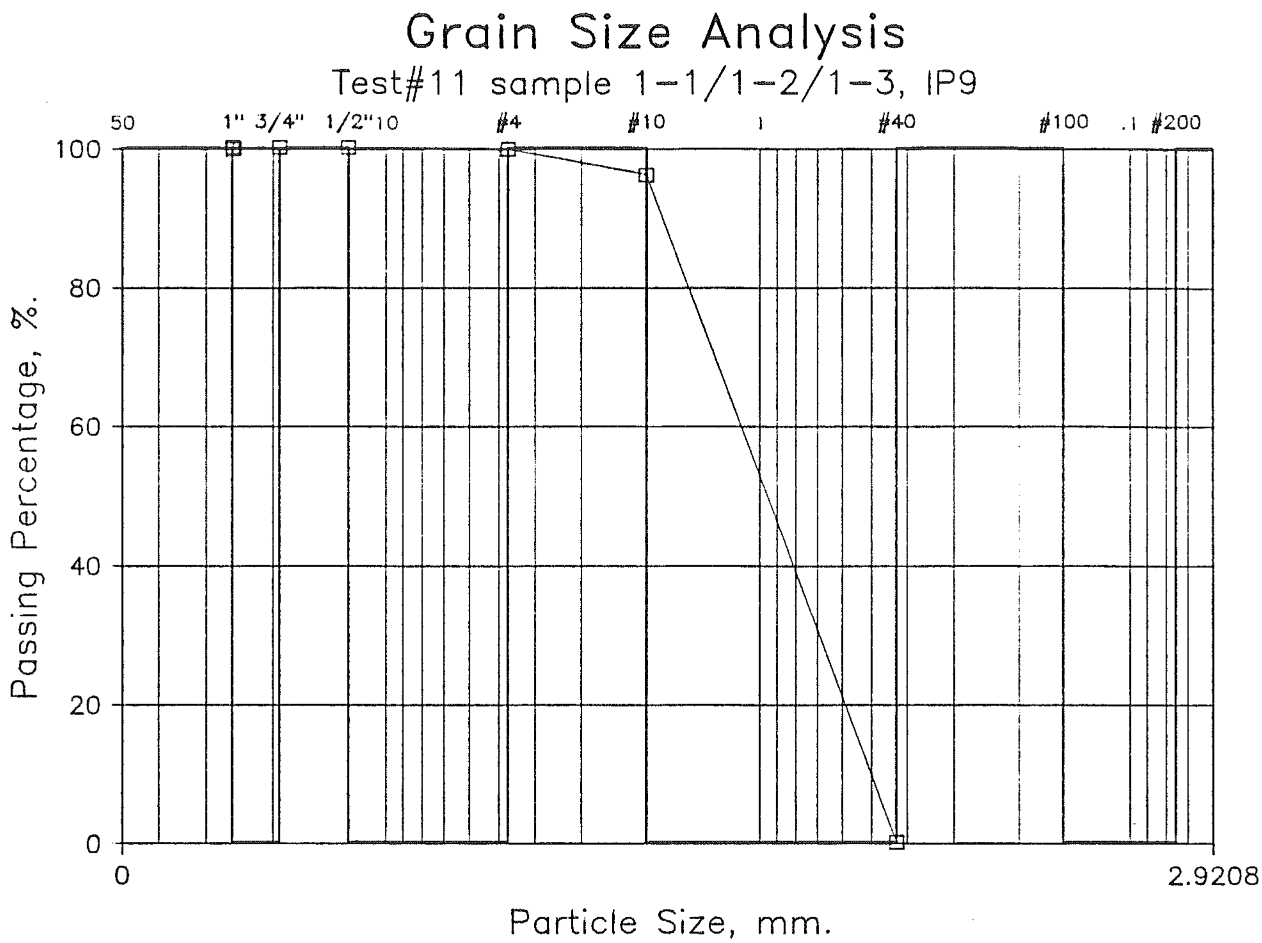
Grain Size Analysis
Test #14, sample 2-2, SRP5+10%IG1+20%SRG1
50
1" 3/4" 1/2"10
#4
#10
#40
#100
#200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Grain Size Analysis
Test #14, sample 2-3, SRP5+10%IG1+20%SRG1
50
1" 3/4" 1/2" 10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.

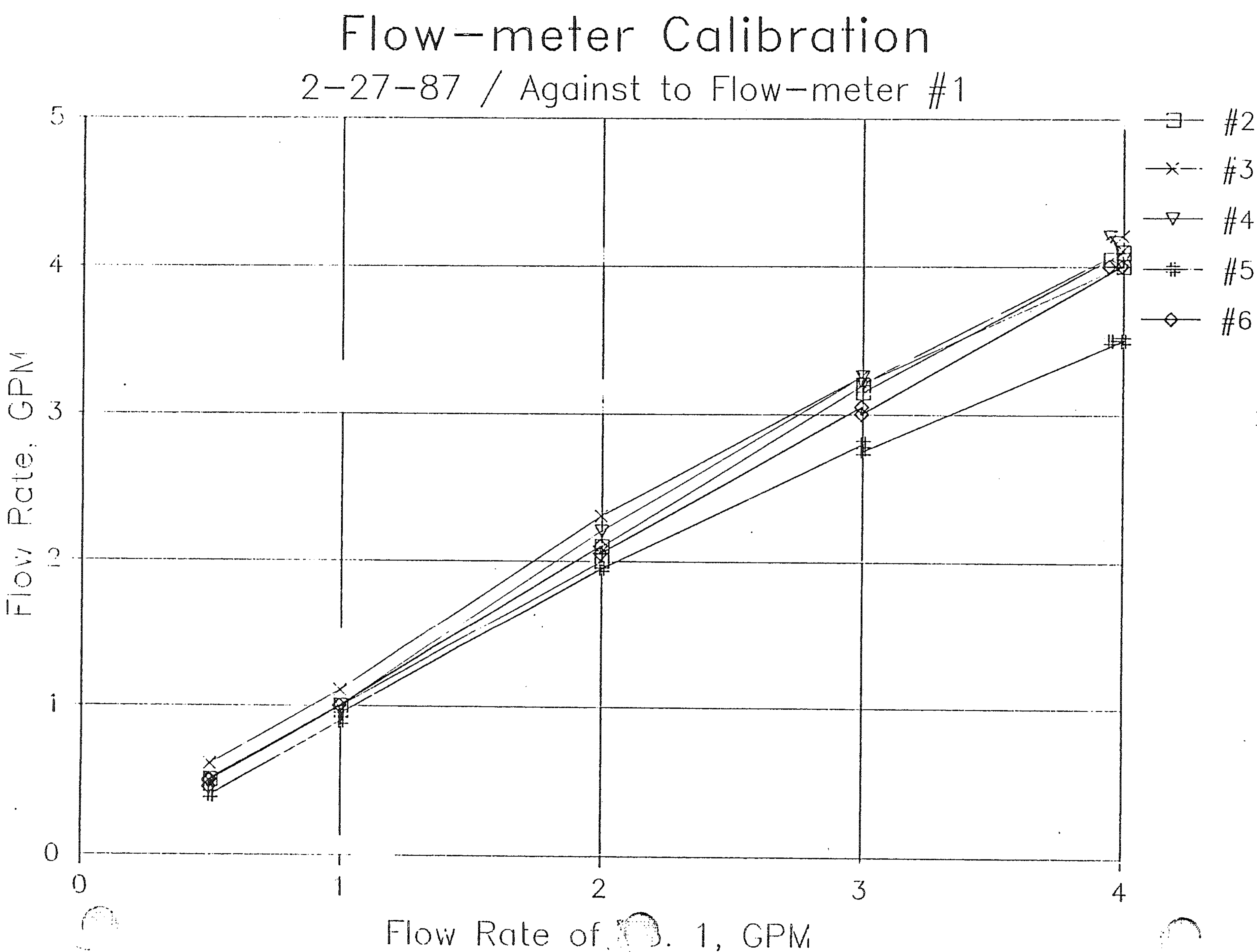
Grain Size Analysis

IP9





Grain Size Analysis
Test#11 sample 1-1/1-2/1-3, IP9
50
1" 3/4" 1/2"10
#4
#10
1
#40
#100
.1 #200
100
80
60
40
20
0
Passing Percentage, %.
0
2.9208
Particle Size, mm.


Flow-meter Calibration
2-27-87 / Against to Flow-meter #1
Flow Rate, GPM
Flow Rate of
. 1, GPM
0
1
2
3
4
5
#2
#3
#4
#5
#6