Certified Aggregate Technician Manual

Table of Contents

Chapter Three – Aggregate Properties

Chapter Four – Aggregate Specifications and Requirements

Chapter Five – Aggregate Production

Chapter Six - Statistical Quality Control for Aggregate Processing

Chapter Seven – Quality Control Plan

Chapter Eight – Testing Equipment

Chapter Nine – Sampling

Chapter Ten – Testing

Appendix B

AASHTO Guide Test Methods (Not official documents)

- T 2 Sampling of Aggregates
- T 11 Materials Finer than 75 µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27 Sieve Analysis of Fine and Coarse Aggregates
- T 84 Specific Gravity and Absorption of Fine Aggregate
- T 85 Specific Gravity and Absorption of Coarse Aggregate
- T 112 Clay Lumps and Friable Particles in Aggregate
- T 248 Reducing Field Samples of Aggregate to Testing Size
- T 304 Uncompacted Void Content of Fine Aggregate

ASTM Guide Test Methods (Not official documents)

- D 4791 Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- D 5821 Determining Percent of Fractured Particles in Coarse Aggregates

Appendix C

Quality Control Plans

- Limerock Quarries, Inc.
- Indiana Quality Sand & Gravel, Inc.

Appendix D

Audits

- Certified Aggregate Producer Program Audit Checklist
- Certified Aggregate Producer Program Partial Audit Checklist
- Sampling, Sample Reduction, and Testing Procedures

PROGRAM INSTRUCTORS

Industry Representatives

John Berscheit	Quality Control Rieth-Riley Construction Co.	
Kelly Cook	Levy Technical Laboratories	219-462-2924
Deana Jones	Quality Control I.M.I.	765-473-5578
Robert Jones	Executive Director I.M.A.A.	317- 580-9100
Bob Lingerfelt	Quality Assurance Manager Mulzer Crushed Stone	812- 424-5594
James Schultz	Geologist Hanson Aggregates	502-553-0249
George Williams	Quality Control Manager Rogers Group	812-332-6341

University Representatives

Nelson Shaffer	I.U.P.U.I.

INDOT Representatives

Matt Beeson	Manager Office of Materials Management	317-610-7251 Ext: 204
Bob Dahman	Testing Engineer Ft. Wayne District	260-969-8238
Bob Rees	Geologist Supervisor Office of Materials Management	317-610-7251 Ext: 232
Kurt Sommer	Testing Engineer Crawfordsville District	765-361-5625
Bart Williamson	Materials Technician Office of Materials Management	317-610-7251 Ext: 259

CERTIFIED AGGREGATE TECHNICIAN TRAINING COURSE AGENDA

Title – Time	Subjects	Instructor	Reference

Monday Morning
Moderator: Bob Rees

Introduction

10:00 to 10:30	Opening Comments Agenda/Manual Update	Matt Beeson (Bob Rees)	

CAPP Technician Program Responsibilities

10:30 to 10:45	Industry Perspective	Robert Jones	

Math for Aggregates

10:45 to 11:15	Round-Off Rules Calculator Operation Mean Standard Deviation Moving Average	Bob Rees	Chp 1

Geology

11:15 to 12:00	Origin	Nelson Shaffer	Chp 2

12:00 to 1:00 ** LUNCH **

Monday Afternoon
Moderator: Bob Rees

Aggregate Quality

1:00 to 2:00	Aggregate Types & Terms	Bob Rees (Mike Bramblett)	Chp 2
	Properties		Chp 3
	Quality Requirements		Chp 4
2:00 to 2:15	** BREAK **		

Tests for Quality Rating

2:15 to 3:00	Absorption	Bob Rees	Chp 4/Chp 10
	Abrasion Resistance		
	Soundness		
	Deleterious Materials		
	Special Requirements		
3:00 to 3:15	**BREAK**		

Test for Quality Rating (continued)

3:15 to 4:30		Bob Rees	
5:00	**DINNER**		

Help Session

7:30 Holiday Inn Express: Bob Lingerfelt/George Williams/Deana Jones/Mike Blackwell

Tuesday Morning
Moderator: Bob Rees

Math Homework Review

8:00 to 8:10	Answers & Discussion	Bob Rees	

Processing

8:10 to 8:45	Extraction	Bob Lingerfelt Jim Schultz George Williams	Chp 5
	Crushing		
	Other Benefaction		
	Screening		
	Sand Production		
	Segregation		
	Stockpiling and Handling		
	Degradation		
	Contamination		
	Retrieval		

Segregation

8:45 to 9:00	Video	George Williams	

Test Equipment

9:00 to 9:30	Suggestions	Bob Lingerfelt (Kelly Cook)	Chp 8
	Manufacturers & Cost		Handout

9:30 to 9:45 ** BREAK **

Lab Layout

9:45 to 10:15	Suggestions	Bob Lingerfelt Jim Schultz George Williams	

Tuesday Morning (continued)

<u>Test Equipment Verification</u>

10:15 to 10:45	Procedures	Kelly Cook (Bob Rees)	Chp 8 ITM 211-9.0 Appendix A

<u>Production Sampling</u>

10:45 to 11:15	Sampling Techniques	Bob Lingerfelt Jim Schultz George Williams	Chp 9

<u>Stockpile Sampling</u>

11:15 to 11:45	Safety	Bob Dahman Kurt Sommer	Chp 9
	Sampling Technique		Chp 9/Video
	Sample Reduction & Sample Size		Chp 9/Video

<u>Aggregate Testing</u>

11:45 to 12:00	Decant	Bob Dahman Kurt Sommer	Chp 10/Video
	Sieve Analysis		Chp 10/Video
	Sieve Analysis (Dense Graded)		Chp 10/Video
	Fineness Modulus		Chp 10
	Moisture		Chp 10
	Coarse Aggregate Angularity		Chp 10
	Non-Durable Particles		Chp 10
	Flat and Elongated Particles		Chp 10
	Frequency		Chp 11
	Homework Problems		Handouts

12:00 to 1:00 ** LUNCH **

Tuesday Afternoon
Moderator: Bob Rees

Aggregate Testing (continued)

1:00 to 2:30		Bob Dahman Kurt Sommer	Chp 10/Chp 11
2:30 to 2:45	** BREAK		

Aggregate Testing (continued)

2:45 to 3:45		Bob Dahman Kurt Sommer	Chp 10/Chp11

Diary

3:45 to 4:00	CAPP Requirements Typical Diary Examples	Bob Lingerfelt Jim Schultz George Williams	ITM 211 (10.0) Chp 11

Help Session

7:30 Holiday Inn Express: Bob Lingerfelt/Deana Jones/George Williams/ Kelly Cook/Jon Havens/Mike Blackwell

Wednesday Morning
Moderator: Bob Rees

Aggregate Testing Homework Review

8:00 to 8:15	Answers & Discussion Math Revue	Matt Beeson (Bob Rees)	Handout

Quality Control Plans

8:15 to 8:45	CAPP QCP Requirements INDOT QCP Checklist QCP Addenda	Matt Beeson (Bob Rees)	Chp 7
8:45 To 9:15	Producer QCP	Bob Lingerfelt George Williams Jim Schultz	Chp 7

Aggregate Production Statistical Control

9:15 to 9:30	CAPP Requirements	Matt Beeson (Bob Rees)	ITM 211

9:30 to 9:45 ** BREAK **

Aggregate Production Statistical Control (continued)

9:45 to 12:00	Statistical Quality Control Statistical Concepts Z Value Percent Compliance	Bob Rees (George Williams)	Chp 6

12:00 to 1:00 ** LUNCH **

Wednesday Afternoon
Moderator: Bob Rees

Aggregate Production Statistical Control (continued)

1:00 to 2:00	Control Chart Concepts Control Chart Construction Control Chart Interpretation	Bob Rees (George Williams)	Chp 6 ITM 211 (13.4)
2:00 to 2:15	** BREAK **		
2:15 to 4:00	Product Set Up Process Control Understanding the Process & Steps for Managing Quality	George Williams	Chp 6

Help Session

7:30 Holiday Inn Express: Bob Lingerfelt/George Williams

Thursday
Moderator: Bob Rees

Lab Demonstration at INDOT Materials Management
(Bus leaves at 7:30)

8:00 to 12:00		Bob Rees Jim Schultz, Mike Blackwell Eric Woodings, Scott Woodard Bart Williamson, Chris Bell	
12:30 to 1:30	** LUNCH **		

Statistical Homework Review

1:30 to 1:45	Answers & Discussion	Bob Rees	Handout

Audits

1:45 to 2:00	INDOT Audits	Bob Rees	Appendix D
2:00 to 2:15	** BREAK **		

Customer Expectations

2:15 to 3:30	Producer Perspective/ Contracotr Perspective	George Williams/John Berscheit	

Review Session (Voluntary)

3:30 to 5:00		Bob Rees	

Help Session

6:30	Holiday Inn Express:	Bob Lingerfelt/George Williams/Mike Blackwell Eric Woodings/Jon Havens/Kelly Cook

Friday Morning
Moderator: Bob Rees

Course Exam

8:00
to
12:00

CERTIFIED AGGREGATE TECHNICIAN PROGRAM

PROCEDURES and POLICIES

MANUAL

SEPTEMBER, 2016

INDOT
CERTIFIED AGGREGATE TECHNICIAN PROGRAM

Objectives

The Indiana Department of Transportation (INDOT) has established a Quality Control/Quality Assurance (QC/QA) program for aggregates for the purpose of properly assigning the responsibility of manufacturing and overall improving the consistency of aggregates. The QC/QA program for aggregates requires that all aggregates supplied for INDOT use be supplied by a Certified Aggregate Producer. The Certified Aggregate Producer Program (CAPP) is a program whereby a qualified mineral aggregate Producer requesting to supply material to INDOT assumes all of the Plant site controls, and INDOT monitors the Producers production, sampling, and testing procedures. The CAPP requires that a Certified Aggregate Technician supervise all sampling and testing for process control.

The principal objective of the Certified Aggregate Technician Program is to provide the necessary training to Producer personnel so that they may administer the Quality Control requirements of the CAPP. Knowledge of aggregate production, materials, sampling, testing, statistics, and documentation are provided.

Administration

The training program is administered by INDOT, the Indiana Mineral Aggregates Association (IMAA). Specific duties of each agency include:

<u>INDOT</u>

1. Writing and Maintenance of the Training Manual
2. Proctoring Examination
3. Notification to Students of Examination Results
4. Mailing Certificates
5. Maintenance of Certified Aggregate Technician List
6. Retesting
7. Recertification

<u>IMAA</u>

1. Course Announcement
2. Student Registration
3. Manual Printing
4. Training Facility Arrangements
5. Meal and Refreshment Arrangements
6. Providing Training Course Materials
7. Certificate Preparation
8. Miscellaneous Administrative Tasks

INDOT - Research

1. Grading the Examination

Program Committee

The Program Committee acts as the steering committee which establishes the needs for the certification program and provides technical assistance for course materials and examinations. The committee is composed of representatives from INDOT, FHWA, IMAA.

Certification Committee

The Certification Committee is responsible for revocation or suspension of certifications for technicians. Their tasks include reviewing the violations of standard policies, rendering judgement of the seriousness of the violation, and hearing any subsequent appeal. The committee is composed of the following members:

Manager, Office of Materials Management
1 Aggregate Producer Certified Technician appointed by the IMAA Technical Committee

Certification Requirements

A technician is required to pass a written examination to become certified. Participation in the certification training course is required for the technician to take the examination.

Training Course Announcement

The announcement for the training course will be made on August 1 of each year that the course is offered.

Certification Examination

The certification examination is given upon completion of the training course. The examination time is limited to a maximum duration of four hours and the examination is open book/open note. There are two parts of the examination. Part I consists of multiple choice, and fill in the blank questions, and Part II consists of word problems. A minimum score of 70 percent is required on each part to pass the examination.

A technician that has failed the certification examination will be allowed one retake of the exam. Only the part(s) failed are required to be retaken. A duration of 1 ½ hours for Part I and 2 ½ hours for Part II are allowed. The retake examination will be open book/open note and consist of a format similar to the original examination. The retake examination will be given at the INDOT Office of Materials Management within 30 days of notification of the technician's results of the original examination. A minimum score of 70 percent on each part is required to pass the retake examination. Technicians failing either part of the retake examination will be required to participate in the training course and pass the examination to become certified.

The examinations will be retained by INDOT Division of Research for a period of one year after such time the examinations will be destroyed. Technicians may review their examinations in the presence of an INDOT representative within one year of the examination date. Arrangements for review of the examination shall be made with INDOT.

Recertification Requirements

The certification is valid for three years as determined from the date of initial issuance. A technician is required to pass a written examination to become recertified. If the technician does not renew the certification, the certification will expire. Renewal of the certification may be made within the subsequent year after expiration by passing the recertification examination or retake examination, if required. If the technician requests to become recertified after one year but less than two years from the expiration of the certification, renewal of the certification may be made by passing both parts of the certification exam or retake examination, if required. If the technician requests to become recertified after two years from the expiration of the certification, the Certification Committee will review the request and render a decision on the certification requirements.

Technicians that have successfully demonstrated the proficiency of the tests required for the CAPP source they are assigned to will become recertified and are not required to take a written examination. The proficiency check will be required each of the three years since the latest certification date for the technician and will be conducted through the INDOT Independent Assurance Program.

The certified technician will be notified of the recertification procedures prior to the expiration of the certification. The technician is responsible for applying for certification renewal. A current address is required to be on file with INDOT. Address revisions are required to be sent to:

Geologist Supervisor
Indiana Department of Transportation
Office of Materials Management
120 S. Shortridge Rd.
Indianapolis, IN 46219
317-610-7251, ext: 232
Fax: 317-356-9351

A recertification refresher course will be offered prior to the examination. Course attendance is on a voluntary basis for the technician.

Recertification Examination

The recertification examination may be taken in an INDOT District or at the site of the refresher course upon completion of the training. The examination is limited to a duration of two hours, and is open book/open note. The examination consists of word problems, and a minimum score of 70 percent is required to pass the examination. Notification of the examination results will be made within 10 days of the examination date.

A technician that has failed the recertification examination will be allowed one retake of the examination. Two hours is allowed for the examination. The retake examination will be open book/open note and consist of a format similar to the original recertification examination. The retake will be given at the INDOT Office of Materials Management within 30 days of notification of the technician's results of the original recertification examination. A minimum score of 70 percent is required to pass the retake examination. Technicians failing the retake examination will be required to participate in the certification training course and pass the certification examination to become certified.

The examinations will be retained by INDOT Division of Research for a period of one year. After that period the examinations will be destroyed. Technicians may review their examinations in the presence of an INDOT representative within one year of the examination date. Arrangements for review of the examination are required to be made with INDOT.

Fees

The fee for attending the certification training course will be established by the Program Committee. The fee will cover a training manual, course materials, refreshments, and several meals.

The refund policy for the certification course fees is as follows:

1. An administration fee of $100 will be charged for cancellation by the technician within 7 days of the course.

2. Lack of attendance of the course will result in no refund of fees.

3. Unforeseen emergencies that result in absences during the course will result in a refund of the course fee.

The fee for attending the refresher recertification course will be established by the Program Committee. The fee will cover a training manual, course materials, refreshments, and one lunch. No refunds will be given for the recertification course; however, unforeseen emergencies that result in absence of the course will result in a refund of the course fee.

Failure to pay the training course or examination fees will result in suspension of the certification.

Cancellation Policy

If a scheduled certification or recertification refresher course is cancelled because of insufficient class size, the technicians will be notified one week prior to the start of the course. The technicians will be reimbursed the course fee.

Revocation or Suspension of Certification

Certifications awarded may be revoked or suspended at any time by the Certification Committee for just cause. The procedure that will be taken to revoke or suspend a technician's certification is as follows:

1. The technician will be sent written notification of the revocation or suspension of certification by a registered letter. A copy of the written notification will be sent to the technician's employer. The letter will state the grounds for the revocation or suspension, request a written response, and establish a hearing date.

2. The technician will be allowed 60 days from the date of the notification to respond by letter. The response shall include an explanation of why the technician disagrees with the decision to revoke or suspend the certification.

3. After the 60 day time period has elapsed or upon receipt of the response, the case will be reviewed by the Certification Committee on the hearing date. The technician's response letter will be considered and the technician may appear before the Certification Committee.

4. The Certification Committee will issue a decision within one week of the hearing.

5. If the technician does not send a response letter, or fails to appear before the Certification Committee, a default judgement will be issued by the Certification Committee based on the evidence available. The revocation or suspension may be affirmed, modified, or vacated following the hearing.

The reasons that a technician's certification may be revoked or suspended include:

1. Cheating on recertification examinations

2. Falsification of quality control test results and/or records

The Certification Committee may decide to revoke or suspend the certification depending upon the seriousness of the violation. Violations deemed as unintentional will result in a penalty of a letter of reprimand to the technician and the technician's employer. Subsequent violations will result in suspension of certification for a designated period as determined by the Certification Committee. The certification will return to good standing after the period of suspension expires.

Intentional violations will result in a one year suspension of the certification. Subsequent violations will result in permanent revocation of the certification. If the technician wishes to become recertified after the period of suspension, the technician will be required to participate in the certification training course and pass the certification examination.

1 Introduction

Rounding

The Mean

Standard Deviation

Five-Point Moving Average

Terms Related to Aggregates

Internet Connection

CHAPTER ONE: *INTRODUCTION*

Quality Control/Quality Assurance (QC/QA) is often used synonymously with the term Quality Assurance (QA). AASHTO defines Quality Assurance as "All those planned and systematic actions necessary to provide confidence that a product will perform satisfactorily in service." This definition considers QA to be an all encompassing concept which includes quality control (QC), acceptance, and independent assurance (IA). A better understanding of the QC/QA concept may be made if the characteristics of the specifications are considered. These include:

1) QC/QA recognizes the variation in materials and test methods.

2) QC/QA uses a statistical basis that is applied and modified with experience and sound engineering judgement.

3) QC/QA places primary responsibility on the Producer for production control.

The procedure used by INDOT in the past to accept aggregates required that a stockpile of aggregates be tested to verify compliance with specifications, and the stockpile subsequently approved or disapproved prior to shipment. This pass/fail specification became very confrontational with Producers when failing tests were obtained and shipments delayed or stopped to active contracts. Even when eventually resolved, project delays were inevitable in many cases. A QC/QA procedure whereby Producer's tests could be used for acceptance, and shipments of aggregates made on demand was needed. The Certified Aggregate Producer Program (CAPP) was introduced as the procedure to accomplish both needs.

The CAPP designates specific quantities of material to be tested, material test values, test equipment calibrations, and statistical concepts to be applied to control aggregate products. As such, a standard method for rounding values is required to be established and basic statistical rules be presented. This chapter discusses the procedures for rounding numbers, and the basic statistical calculations.

ROUNDING

When calculations are conducted, rounding is required to be in accordance with 109.01(a) using the standard "5" up procedure. There are two rules for rounding numbers:

1. When the first digit discarded is less than 5, the last digit retained should not be changed.

   Examples: 2.4 becomes 2
   2.43 becomes 2.4
   2.434 becomes 2.43
   2.4341 becomes 2.434

2. When the first digit discarded is 5 or greater, the last digit retained should be increased by one unit.

   Examples: 2.6 becomes 3
   2.56 becomes 2.6
   2.416 becomes 2.42
   2.4157 becomes 2.416

The Certified Aggregate Producer Program requires that test and statistical values be calculated to the nearest decimal place as indicated in Figure 1-1.

Property	**Nearest Whole Unit (0)**	**First Decimal Place (0.0)**	**Second Decimal Place (0.00)**	**Third Decimal Place (0.000)**
Crushed Particles	X			
Flat & Elongated	X			
Percent Compliance	X			
Control Limits*	X	X		
Absorption		X		
Decantation		X		
Deleterious		X		
Gradation		X		
Surface Moisture		X		
Target Mean		X		
5-Point Moving Ave.		X		
Fineness Modulus			X	
Standard Deviation			X	
Z Value			X	
Bulk Specific Gravity				X
Proportionate Factor				X

* May be rounded to (0.0) or (0)

Figure 1-1. Decimal Places.

THE MEAN

The simple mathematical average of any group of numbers is the mean. In other words, the mean is the sum of all the measurement values divided by the number of measurements. The symbol for the mean is $\bar{x}$. As an example, the mean for five numbers would be calculated as follows:

$$\bar{x} = \frac{x_1 + x_2 + x_3 + x_4 + x_5}{5}$$

STANDARD DEVIATION

Whereas the mean is an average of all the data values, the standard deviation is an average value of the dispersion of data from the mean. Standard deviation is usually signified by a small s or the Greek letter Sigma (σ). For the CAP Program σ_{n-1} is used.

The procedure used to compute the standard deviation is to subtract the mean from each value, square this difference, sum, divide by one less than the number of values, and take the square root. These steps may be expressed in terms of a formula as follows:

$$\sigma_{n-1} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

where $\bar{x}$ is the arithmetic mean, n is the number of sample values and $\sum$ indicates the summation of all values.

Note that squaring the deviations from the mean removes the negative signs. Dividing by n - 1 gives us approximately an average squared deviation. Taking the square root puts the result back into the same units as the original values.

Example:

x_i	$x_i - \bar{x}$	$(x_i - \bar{x})^2$
14.3	1.7	2.89
11.2	-1.4	1.96
14.1	1.5	2.25
12.6	0.0	0.00
12.9	0.3	0.09
12.7	0.1	0.01
13.2	0.6	0.36
11.4	-1.2	1.44
12.3	-0.3	0.09
11.6	-1.0	1.00
126.3		10.09 (Sum of squared differences)

$n = 10$

$$\bar{x} = \frac{\sum x_i}{n} = 12.6$$

$$\sigma_{n-1} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{10.09}{9}} = \sqrt{1.121} = 1.06$$

FIVE-POINT MOVING AVERAGE

The moving average is a useful tool for tracking trends of the mean. The CAPP requires that the moving average be the average of the most recent five data points.

For a moving average of five test values, the group of the first five measurements is averaged. When an additional test value is obtained, the first value is dropped, the sixth value is added, and the new group averaged. When a seventh value is obtained, the second value is dropped, and the new group averaged, and so on. An example of this procedure is as follows:

Data: 4.8, 5.3, 5.0, 4.7, 5.1, 5.5, 4.6

$$\text{First Average} = \frac{4.8 + 5.3 + 5.0 + 4.7 + 5.1}{5}$$

$$= \frac{24.9}{5} = 5.0$$

The first number, or 4.8, is dropped and the sixth value, or 5.5, is added and the second average is:

$$\text{Second Average} = \frac{5.3 + 5.0 + 4.7 + 5.1 + 5.5}{5}$$

$$= \frac{25.6}{5} = 5.1$$

Next, the 5.3 is dropped and 4.6 is added:

$$\text{Third Average} = \frac{5.0 + 4.7 + 5.1 + 5.5 + 4.6}{5}$$

$$= \frac{24.9}{5} = 5.0$$

TERMS RELATED TO AGGREGATES

AASHTO - American Association of State Highway and Transportation Officials

Abrasion Resistance - The resistance of coarse aggregates to fracturing under impact and breaking down into smaller pieces from abrasive action

Absorption - The increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass

Adherent Fines - Fine particles smaller than the No. 200 (75 µm) sieve created from handling, or silt or clay that adheres to the coarse aggregate particles

Aggregate Base - A layer of aggregate placed on a subgrade or subbase to support a surface course

Air-Cooled Blast Furnace Slag (ACBF) - Material resulting from solidification of molten blast-furnace slag under atmospheric conditions

Apparent Specific Gravity - The ratio of the weight in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature

ASTM - American Society for Testing and Materials

Bulk Specific Gravity - The ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight of an equal volume of gas-free distilled water at a stated temperature

Artificial Aggregates - Aggregates that are manufactured or by-products of an industrial process. Blast furnace slag, steel slag and wet bottom boiler slag are examples of by-product artificial aggregates.

B Borrow - Material used for special filling such as for displaced peat deposits, bridge approach embankments, and fillings over structures. B borrow is required to be acceptable quality, free from large or frozen lumps, wood, or other extraneous matter. Materials used for B Borrow are suitable sands, gravel, crushed stone, ACBF, GBF, or other approved materials.

Bulk Specific Gravity (SSD) - The ratio of the mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours (but not including the voids between particles) at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature

Category - Source classification used to determine the production quality sampling frequency

Certified Material - An aggregate product produced in accordance with the Certified Aggregate Producer Program (CAPP) for Department use

Certified Aggregate Producer - A Plant/Redistribution Terminal that meets the requirements of ITM 211, continues to be under the same ownership, and is approved by the Department

Certified Aggregate Technician – A Producer or Consultant employee that has successfully completed the Certified Aggregate Technician Training Program and has been certified by the Department

Chert – An aggregate of varied color, composed of glassy silica, and very fined grained quartz. Unweathered chert appears hard, dense, and brittle with a greasy texture. Weathered chert appears chalky and dull. Chert is likely to have concave surfaces with sharp outer edges when freshly broken.

Class A - Quality rating assigned to aggregates which meet requirements for all Department uses except for specified slab on grade concrete applications

Class AP - Quality rating assigned to coarse aggregates cast into concrete beams and subjected to freeze and thaw cycling procedures in accordance with ITM 210. Class AP aggregates are required for concrete pavement and other concrete applications

Classes B, C, D, E, and F - Quality ratings assigned to aggregates with restricted uses

Class G - Quality rating assigned to materials which do not meet requirements for any Department use

Clay Lumps – Materials that are easily crumbled or mashed with the fingers as determined by AASHTO T 112

Coarse Aggregate - Aggregate that has a minimum of 20 percent retained on the No. 4 (4.75 mm) sieve

Coatings – A layer of substance covering a part or all the surface of an aggregate particle. The coating may be of natural origin, such as mineral deposits formed in sand and gravel by ground water, or may be artificial such as dust formed by crushing and handling. (see Adherent Fines)

Composite Stockpiling – Stockpiling of natural fine aggregate from multiple sources into one stockpile

Core Drilling Log - A written field description of a rock core sample and the operations

Core Sample - A rock sample obtained with a bit affixed to a barrel with drill rods that are advanced by a rotary drilling machine

Decantation - A test utilizing water to determine the amount of material that is passing the No. 200 sieve. The decantation test is conducted on both fine and coarse aggregate and is usually done in conjunction with the sieve analysis test.

Deleterious - Undesirable aggregate material

Density - The weight per unit volume of a substance

Dolomite - Carbonite rock containing at least 10.3% elemental magnesium when tested in accordance with ITM 205

DTE – District Testing Engineer

Fine Aggregate - Aggregate that is 100 percent passing the 3/8 in. (9.5 mm) sieve and a minimum of 80 percent passing the No. 4 (4.75 mm) sieve

Fineness Modulus - A factor commonly associated with aggregates used for portland cement concrete that is used to determine the relative coarseness or fineness of the aggregate grading

Gradation - The range and relative distribution of particle sizes in the aggregate material

Granulated Blast Furnace Slag (GBF) - Glassy, granular material formed when molten blast-furnace slag is rapidly chilled, as by immersion in water

Gravel - Unconsolidated deposits of all rock types transported and deposited by glaciers

HMA – Hot Mix Asphalt

Hardness - A measure of the cementing and interlocking quality of an aggregate that controls the resistance of the aggregate to abrasion and degradation. The Mohs Hardness Scale is frequently used for determination of mineral hardness.

Igneous Rocks - Rocks formed from hot volcanic magma-molten mineral material

Independent Assurance – Independent Assurance testing is conducted by District Testing personnel to verify the reliability of the results obtained in acceptance sampling and testing. Certified Aggregate Technicians are checked annually by Independent Assurance Technicians for the sampling and testing procedures that are conducted at the aggregate source.

Lightweight Aggregate – Aggregates that may range in dry loose weight from 6 to 70 pounds per cubic foot and which are used in making lightweight concrete.

Lightweight Chert - Chert that has a bulk specific gravity of less than 2.45 as determined using the saturated surface dry condition

Recycled Foundry Sand - A mixture of residual materials used for the production of ferrous or non-ferrous metal castings and natural sands. Recycled foundry sand is required to comply with the Indiana Department of Environmental Management (IDEM) Class III or Class IV residual sands classification.

Ledge - Any stratigraphic unit which may be separated from adjacent units by lithologic differences

Ledge Sample - Core or face sample taken to represent ledges

Limestone - Sedimentary rock primarily consisting of carbonates of calcium and dolomite

Maximum Particle Size - The sieve on which 100 percent of the material will pass

Metamorphic Rock - Rocks that were originally igneous or sedimentary rocks, but were changed by pressure and/or heat

Mineral Filler - Dust produced by crushing stone, portland cement, or other inert mineral matter having similar characteristics. Mineral filler shall be in accordance with the gradation requirements for size No.16.

Natural Aggregates - Rock fragments which are used in their natural state such as crushed stone, sand, and gravel

Nominal Maximum Particle Size - The smallest sieve opening through which the entire amount of the aggregate is permitted to pass

Non-durable particles - Soft particles as determined by ITM 206 and other particles which are structurally weak, such as soft sandstone, shale, limonite concretions, coal, weathered schist, cemented gravel, ocher, shells, wood, or other objectionable material

Point-Of-Use Sample - Production quality sample obtained at the last opportunity prior to incorporation into the end use

Polish Resistant Aggregates - Dolomite containing less than 10.3% elemental magnesium, crushed limestone, or gravel meeting the requirements of ITM 214. Aggregates meeting these requirements are maintained on the INDOT Approved List of Polish Resistant Aggregates.

Production Quality Sample - An aggregate sample representing finished materials obtained at the aggregate source or the point-of-use

Quality Assurance Materials - Certified Materials controlled by aggregate gradations by the Producer

Quality Control Plan (QCP) - A document written by the Producer that is site-specific and includes the production, policies, and procedures used by the Producer

Qualified Technician - An individual who has successfully completed the written and proficiency testing requirements of the Department Qualified Laboratory and Technician Program

Rating L - A rating for information only

Riprap - Typically large aggregate materials used as a protective coating. Riprap may consist of steel furnace slag for dumped riprap only, sound stone, stone masonry, or other approved materials, free from structural defects and of approved quality.

Sandstone - Sedimentary rock composed of siliceous sand grains containing quartz, chert, and quartzose rock fragments in a carbonate matrix or cemented with silica, calcite, or dolomite

Sedimentary - Rocks formed from the disintegration of other rocks and organic materials. Limestone, dolomite, sandstone, shale, and siltstone are examples of sedimentary rock types.

Sieving - A test procedure that is used to determine the gradation of a material. A sample of the aggregate material being tested is weighed and then passed through a series of sieves to determine the gradation.

SMA – Stone Matrix Asphalt (AS-904.03(a)) an asphalt mix comprised of a significant percentage of durable, coarse (≥ no. 8) aggregate resulting in stone to stone contact.

Soundness - The durability of fine and coarse aggregate and their resistance to the forces of weathering, in particular to alternate freezing and thawing conditions

Source - Facility that processes or handles aggregates. A Redistribution Terminal is classified as a source.

Source Map - A map of the quarry showing critical features and operating areas

Source Sample **-** Production quality sample representing finished materials that are stored at an aggregate source or redistribution terminal

Subbase - A layer of aggregate placed on a subgrade to support an aggregate base

Subgrade **-** The layer below the subbase that may be comprised of various aggregate types

Specific Gravity - The ratio of the mass of a unit volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature

Standard Specification Materials - Certified Materials controlled by aggregate gradations as defined in the Department Standard Specifications and the construction contract documents

Steel Furnace Slag (SF) - A material derived from the further refinement of iron to steel

Subcategory - Source classification based on results of tests conducted on source samples and used to determine the production quality sampling frequency

Structural Backfill - Suitable sand, gravel, crushed stone, air-cooled blast furnace slag, or granulated blast furnace slag used to fill designated areas excavated for structures that are not occupied by permanent work

Wet Bottom Boiler Slag - A material which is a by-product from coal combustion at electrical generating plants

INTERNET CONNECTION

1) www.in.gov/indot/
2) Doing Business with INDOT
3) Contractors/Construction
4) Materials Management Information

2 Aggregates in Indiana

Origin of Aggregates

Gravel and Natural Sands
Crushed Stone
Slag

Distribution of Aggregates

Glacial Deposits
Bedrock Deposits

Aggregate Types

Natural Aggregates
Artificial Aggregates

Classifications of Aggregates

Fine Aggregate
Coarse Aggregate

CHAPTER TWO:
AGGREGATES IN INDIANA

Aggregates play an important role in highway construction. Without aggregate, concrete bridges and structures, Hot Mix Asphalt (HMA) pavements, and concrete pavements could not be constructed and very few roads would sustain the current loads. The use of aggregates in highway construction has literally brought the transportation industry out of the mud.

Aggregates are not used indiscriminately in construction, as not all aggregates are appropriate for every application. Some aggregates do not have the correct chemical or physical properties or the correct size or shape for the job. This chapter includes the requirements that aggregates are required to meet, the tests of INDOT, and the documentation that is required to be completed for the test results.

ORIGIN OF AGGREGATES

The three main sources of mineral aggregates in Indiana, gravel and natural sand, crushed stone, and slag, all have different origins.

GRAVEL AND NATURAL SANDS

Most of the gravels and natural sands used today are a product of the Ice Ages (glaciation). Geologists concur that glaciers may have been up to 1 mile thick. As the glaciers advanced southward, rock was scraped beneath them. When the glaciers melted, the flowing water carried the rock fragments and deposited them downstream. The scraping action of the ice and flowing waters gave the gravels and natural sands the rounded appearance.

In addition, minor amounts of gravel and sand are obtained from postglacial or modern stream deposits. This operation is called fluvial and is largely restricted to the river bars, bottom lands, and flood plains of the Ohio River and the lower reaches of the White and Wabash Rivers.

Gravel and sand are unconsolidated granular materials resulting from the natural disintegration of rocks. They disintegrated primarily from the abrading action of water or ice on rock material. Therefore in Indiana, deposits are likely to be found in stream bottoms, in terraces adjacent to streams, and in outwash plains, all of which are areas beyond the physical limits of the original glaciers.

CRUSHED STONE

Crushed stone produced within Indiana originates from sedimentary bedrock deposits. There are three general classes of rocks: igneous, sedimentary, and metamorphic. Igneous rocks were formed from hot volcanic magma--molten mineral material. Sedimentary rocks were formed from the disintegration of other rocks and organic materials. Metamorphic rocks were originally igneous or sedimentary rocks, but were changed by pressure and/or heat. Across the United States, variations of the above noted rock types are utilized for crushed stone aggregate. Sedimentary rock types, limestone and dolostone, are primarily used as construction aggregates within Indiana. Sandstone from southern Illinois, a sedimentary rock type, is permitted for use in hot mix asphalt surface courses.

SLAGS

There are four main types of slag used as construction aggregate in the state of Indiana:

1) Blast Furnace Slag -- a non-metallic material removed in the molten state of iron production. The further refinement of this blast furnace slag results in three aggregate variations: air-cooled slag, expanded slag, and granulated slag.

2) Steel slag -- a material derived from the further refinement of iron to steel.

3) Wet-bottom boiler slag -- a material which is a by-product from coal combustion at electrical generating plants. A secondary product created at these power plants is a residue in the flue gases known as fly ash.

4) Lightweight aggregate -- a material which is created as a by-product of the manufacturing process of construction brick. The primary constituent is shale, sedimentary rock.

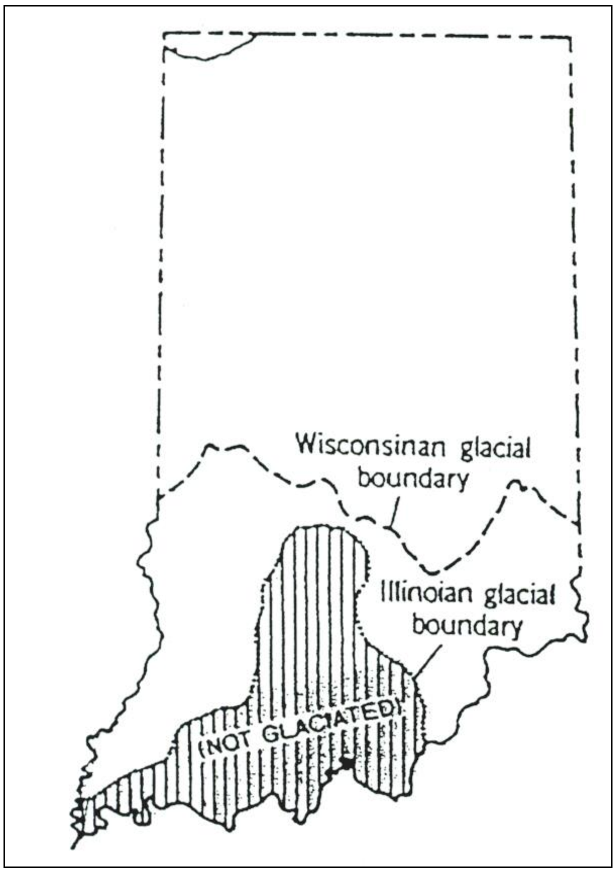
DISTRIBUTION OF AGGREGATES

All types of aggregates are not found in every area of Indiana. The composition of each type of aggregate also varies.

GLACIAL DEPOSITS

Gravel and sand deposits are found along almost any river in Indiana, except the south-central part of the state. At one time glaciers covered five-sixths of Indiana. Figure 2-1 shows the southern boundaries of the two glaciers which moved into Indiana.

The size of the gravel and the type of minerals and rocks found in the deposits varies from place to place. As shown in Figure 2-2, the size of the gravel, in general, tends to get smaller downstream within a drainageway. Statewide, the occurrence of gravel decreases from northeastern to southwestern Indiana.



The composition of a deposit also varies from place to place. In some deposits, 10 to 20 different types of rocks may be found. Granite, gneiss, and schist (igneous and metamorphic rocks) or limestone, dolostone, chert, sandstone, siltstone, and shale (sedimentary rocks) are typically found. Porous chert, siltstone, sandstone, ocher, and shale are deleterious, meaning that the material does not perform well in certain applications in highway construction. The map in Figure 2-3 illustrates the distribution of deleterious materials around Indiana.

Figure 2-1. Southern Boundaries of Glaciers which moved into Indiana.

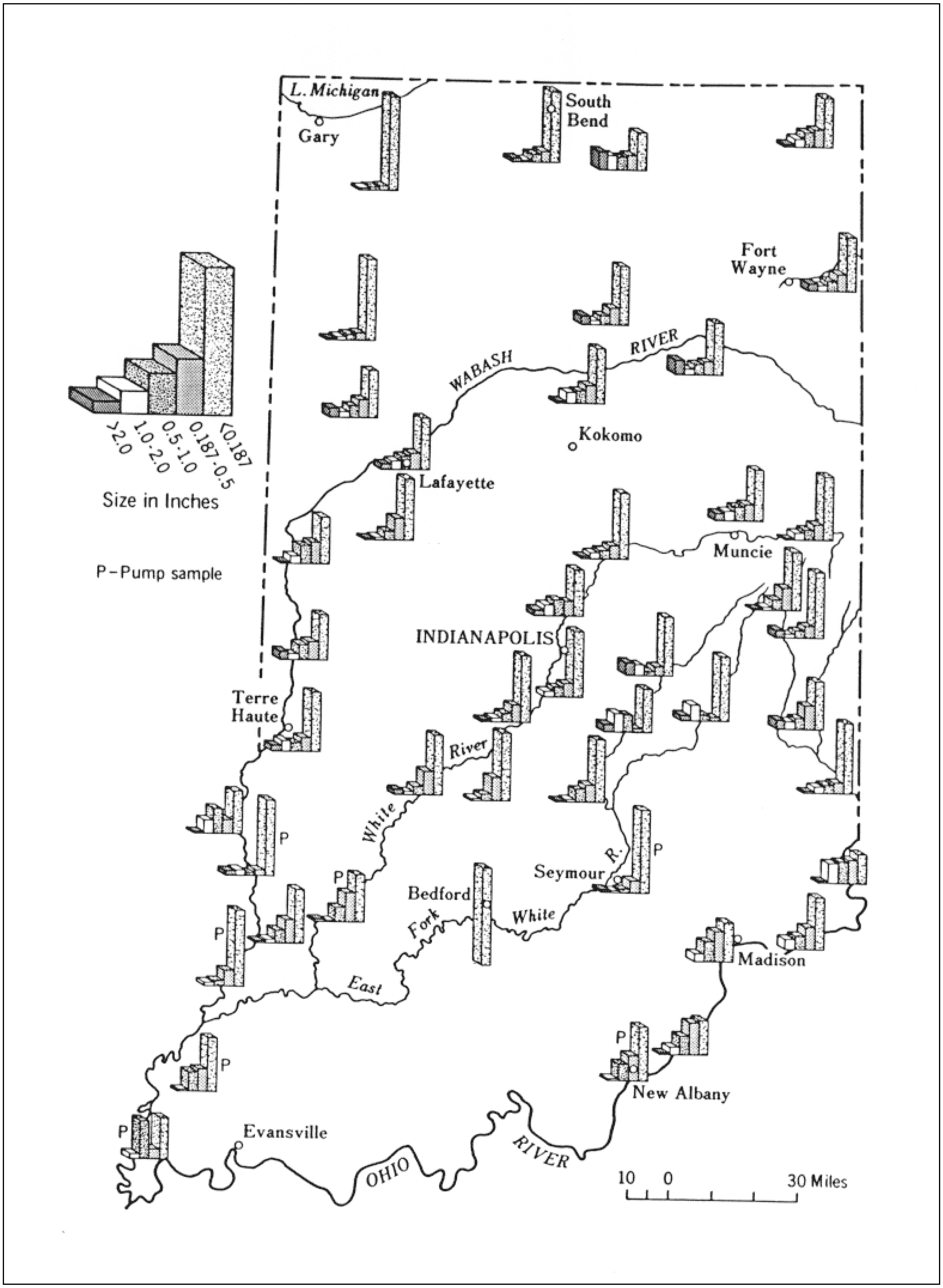


Figure 2-2. Gravel Size Distribution Map of Indiana.

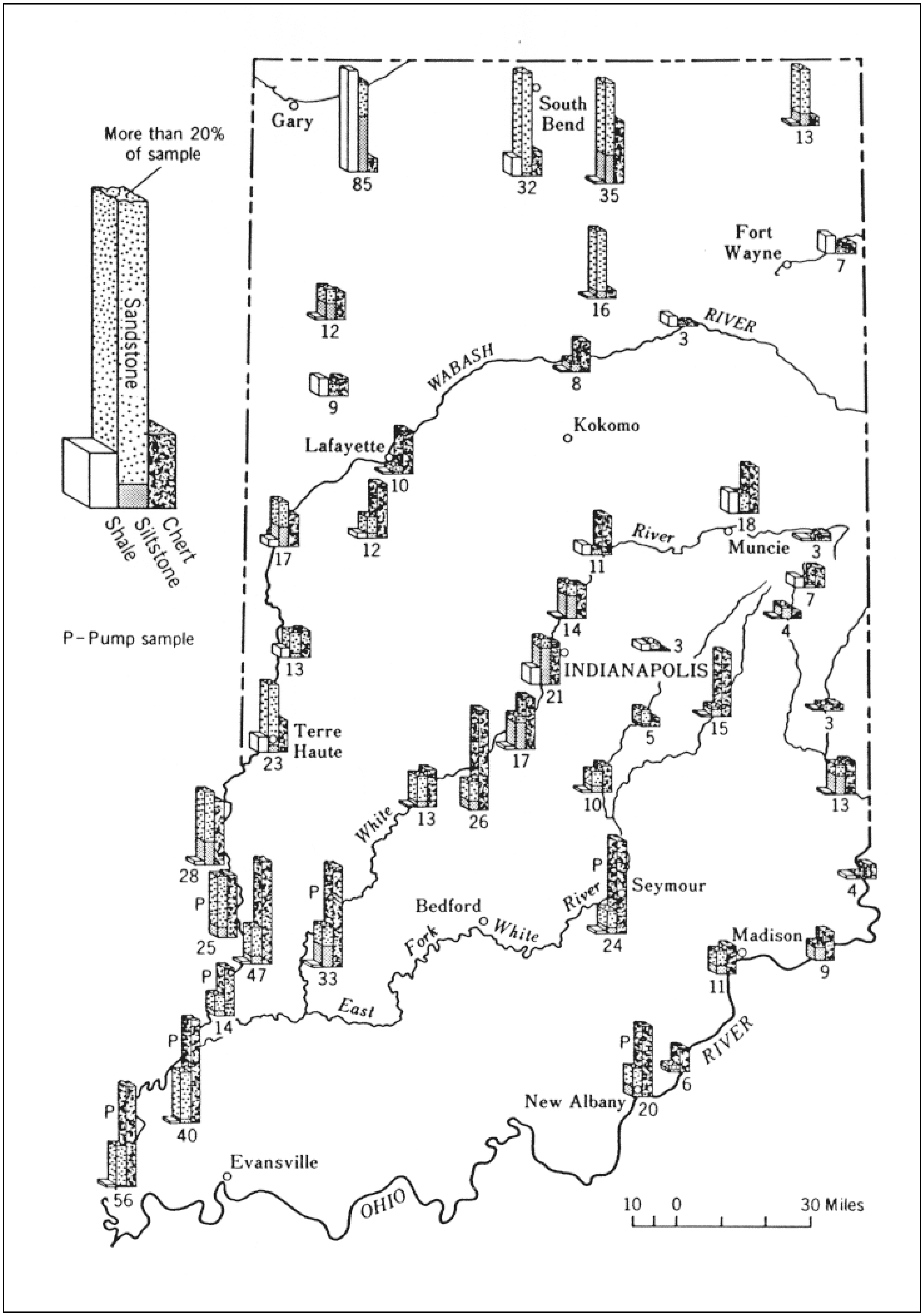


Figure 2-3. Deleterious Materials Distribution Map of Indiana.

BEDROCK DEPOSITS

As shown in the bedrock map of Indiana (Figure 2-4), the bedrock belongs to five geologic periods which are listed from the oldest to youngest: Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian.

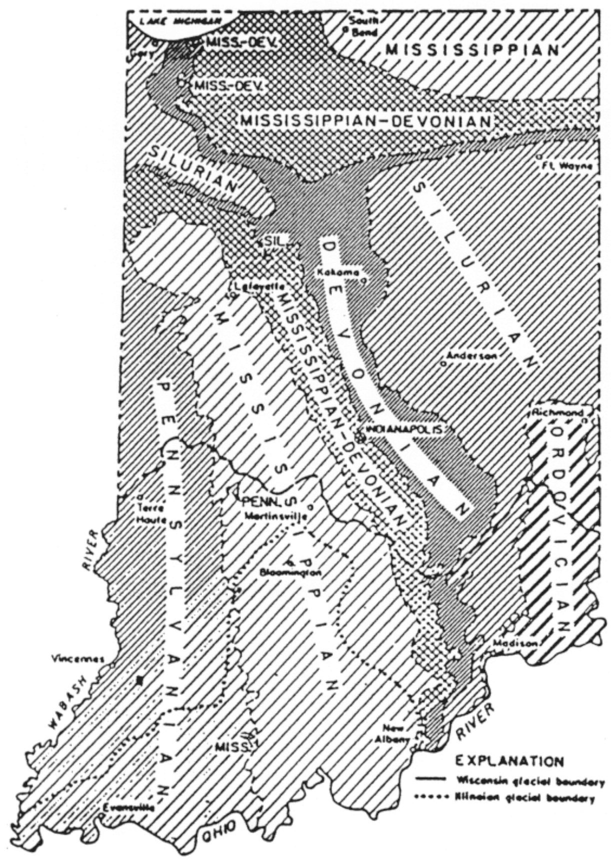


Figure 2-4. Bedrock Map of Indiana.

Comparing the map of the quarry locations (Figure 2-5), to the bedrock map (Figure 2-4), almost all of Indiana's crushed stone quarries are in areas underlain by rock of Mississippian, Devonian, or Silurian Ages (Figure 2-6). During these periods, thick beds of high-grade limestone or dolostone were formed. Rock types formed during other geologic periods are either inaccessible or do not possess the minimum quality requirements needed for highway construction.

Since most of Indiana once was covered by glaciers, the deposits left by these glaciers have also had an effect on the location of quarry sites in the state. Quarry sites are more easily developed in southern Indiana than in northern Indiana where the overburden may reach several hundred feet in depth. In the glaciated parts of Indiana, quarry sites are limited to areas where streams have eroded to bedrock or areas where bedrock was usually high in pre-glacial times, such as ancient coral reefs. Many quarries have been developed in areas where sand and gravel deposits were mined to the bedrock surface.

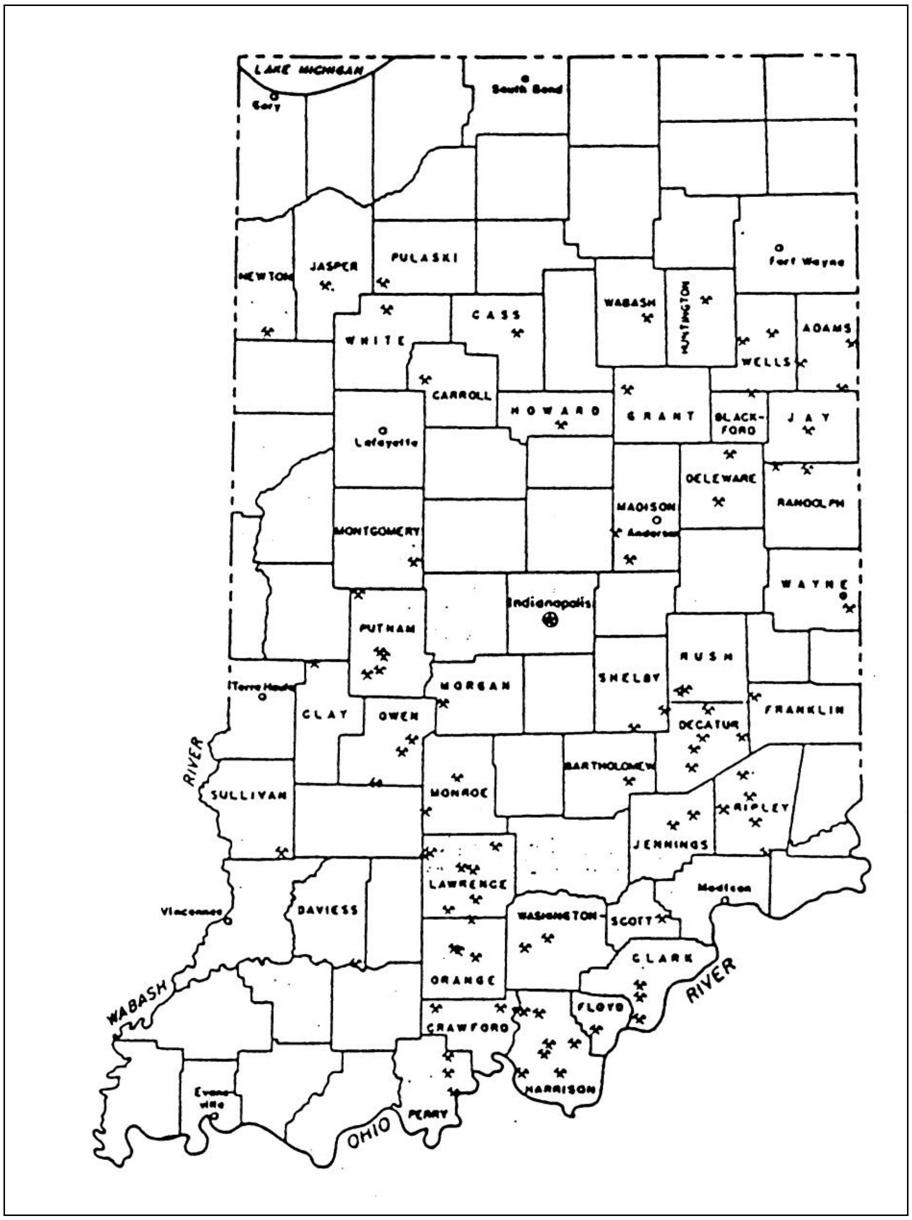


Figure 2-5. Quarry Locations in Indiana

AGGREGATE TYPES

The aggregates used in highway construction are all mineral aggregates. Aggregates are composed of a naturally occurring solid chemical element or compound formed as a product of an inorganic process. There are two distinct types of aggregate: natural, and artificial.

NATURAL AGGREGATES

Rock or stone (either term may be used) fragments which are used in their natural state are considered natural aggregates. Crushed stone, sand, and gravel are natural aggregates.

Crushed Stone

Crushed stone is produced from quarries where the bedrock is blasted (shot) with explosives and further fragmented by mechanical crushing. All crushed stone fragments are angular in shape and all faces of the fragments are created by the crushing operation.

The most common sedimentary rock types found in Indiana are limestone, dolostone, sandstone, shale, and siltstone. Only limestone and dolostone are routinely used for highway construction, although some sandstone from southern Illinois is allowed for high-friction HMA surface.

Sand and Gravel

Sand and gravel are the result of the weathering and erosion of bedrock by natural forces. The two are generally found together, in pockets deposited by a stream or a glacier. These aggregates may be mined from a water-filled pit (a deposit below the water table) or from a cut-bank deposit (a deposit above the water table). If the aggregates come from a pit, the aggregate is referred to as "pit-run" material. A cut-bank deposit is termed "bank-run" material.

Sand from these deposits are often referred to as natural sand, while sand made by crushing stone, pieces of gravel, or slag are commonly called manufactured sand.

The sand and gravel found in the deposits have a variety of assorted sizes. Further processing is required including screening, washing, and some crushing. The crushing is done to produce aggregates of the proper size.

ARTIFICIAL AGGREGATES

Artificial (synthetic) aggregates are manufactured aggregates or by-products of industrial processes. Of the artificial aggregates, INDOT most commonly uses the by-product aggregates. These aggregates are processed either from blast furnace slag, steel slag, or wet bottom boiler slag.

CLASSIFICATIONS OF AGGREGATES

Aggregates are separated into two classifications: coarse aggregates, and fine aggregates. The No. 4 sieve generally determines the difference between coarse aggregate and fine aggregate for most highway construction work.

FINE AGGREGATE

Fine aggregate is defined as aggregate that is 100 percent passing the 3/8 in. sieve and a minimum of 80 percent passing the No. 4 sieve. Natural sand and manufactured sand produced by crushing stone, steel furnace slag, air cooled blast furnace slag and wet-bottom slag are all fine aggregates.

COARSE AGGREGATE

Coarse aggregate is defined as aggregate that has a minimum of 20 percent retained on the No. 4 sieve. Crushed stone, crushed or uncrushed gravel, and crushed blast-furnace and steel slag all fall within this category.

3 Aggregate Properties

CHAPTER THREE:
AGGREGATE PROPERTIES

The origin, distribution, and aggregate types found within Indiana were discussed in Chapter Two. The intent of this chapter is to familiarize the personnel responsible for aggregate testing with:

1) Related physical properties

2) Chemical properties

3) General field characteristics of these aggregates

Recognition of these properties and characteristics assists the Technician in evaluating the different aggregates used in highway construction.

Aggregate particles have certain physical and chemical properties which make the aggregate acceptable or unacceptable for specific uses and conditions. The following are of concern to INDOT.

PHYSICAL PROPERTIES

The physical properties of aggregates are those that refer to the physical structure of the particles that make up the aggregate.

ABSORPTION, POROSITY, AND PERMEABILITY

The internal pore characteristics are very important properties of aggregates. The size, the number, and the continuity of the pores through an aggregate particle may affect the strength of the aggregate, abrasion resistance, surface texture, specific gravity, bonding capabilities, and resistance to freezing and thawing action. Absorption relates to the particle's ability to take in a liquid. Porosity is a ratio of the volume of the pores to the total volume of the particle. Permeability refers to the particle's ability to allow liquids to pass through. If the rock pores are not connected, a rock may have high porosity and low permeability.

SURFACE TEXTURE

Surface texture is the pattern and the relative roughness or smoothness of the aggregate particle. Surface texture plays a big role in developing the bond between an aggregate particle and a cementing material. A rough surface texture gives the cementing material something to grip, producing a stronger bond, and thus creating a stronger hot mix asphalt or portland cement concrete. Surface texture also affects the workability of hot mix asphalt, the asphalt requirements of hot mix asphalt, and the water requirements of portland cement concrete.

Some aggregates may initially have good surface texture, but may polish smooth later under traffic. These aggregates are unacceptable for final wearing surfaces. Limestone usually falls into this category. Dolomite does not, in general, when the magnesium content exceeds a minimum quantity of the material.

STRENGTH AND ELASTICITY

Strength is a measure of the ability of an aggregate particle to stand up to pulling or crushing forces. Elasticity measures the "stretch" in a particle.

High strength and elasticity are desirable in aggregate base and surface courses. These qualities minimize the rate of disintegration and maximize the stability of the compacted material. The best results for portland cement concrete may be obtained by compromising between high and low strength, and elasticity. This permits volumetric changes to take place more uniformly throughout the concrete.

DENSITY AND SPECIFIC GRAVITY

Density is the weight per unit of volume of a substance. Specific gravity is the ratio of the density of the substance to the density of water.

The following chart illustrates these relationships for some common substances.

Typical Values		
Substance	**Specific Gravity**	**Density (lb/ft^3)**
Water	1.0 (73.4 °F)	62.4 lb/ft^3 (73.4 °F)
Limestone	2.6	165 to 170 lb/ft^3
Lead	11.0	680 to 690 lb/ft^3

The density and the specific gravity of an aggregate particle is dependent upon the density and specific gravity of the minerals making up the particle and upon the porosity of the particle. These may be defined as follows:

1) All of the pore space (bulk density or specific gravity)

2) Some of the pore space (effective density or specific gravity)

3) None of the pore space (apparent density or specific gravity)

Determining the porosity of aggregate is often necessary; however, measuring the volume of pore space is difficult. Correlations may be made between porosity and the bulk, apparent and effective specific gravities of the aggregate.

As an example, specific gravity information about a particular aggregate helps in determining the amount of asphalt needed in the hot mix asphalt. If an aggregate is highly absorptive, the aggregate continues to absorb asphalt, after initial mixing at the plant, until the mix cools down completely. This process leaves less asphalt for bonding purposes; therefore, a more porous aggregate requires more asphalt than a less porous aggregate. The porosity of the aggregate may be taken into consideration in determining the amount of asphalt required by applying the three types of specific gravity measurements.

In the example in Figure 3-1, the bulk specific gravity includes all the pores, the apparent specific gravity does not include any of the pores that would fill with water during a soaking, and the effective specific gravity excludes only those pores that would absorb asphalt. Correlation charts and tables provide guidance to asphalt quantities or acceptability of the aggregate.

AGGREGATE VOIDS

There are aggregate particle voids, and there are voids between aggregate particles. As solid as aggregate may be to the naked eye, most aggregate particles have voids, which are natural pores that are filled with air or water. These voids or pores influence the specific gravity and absorption of the aggregate materials.

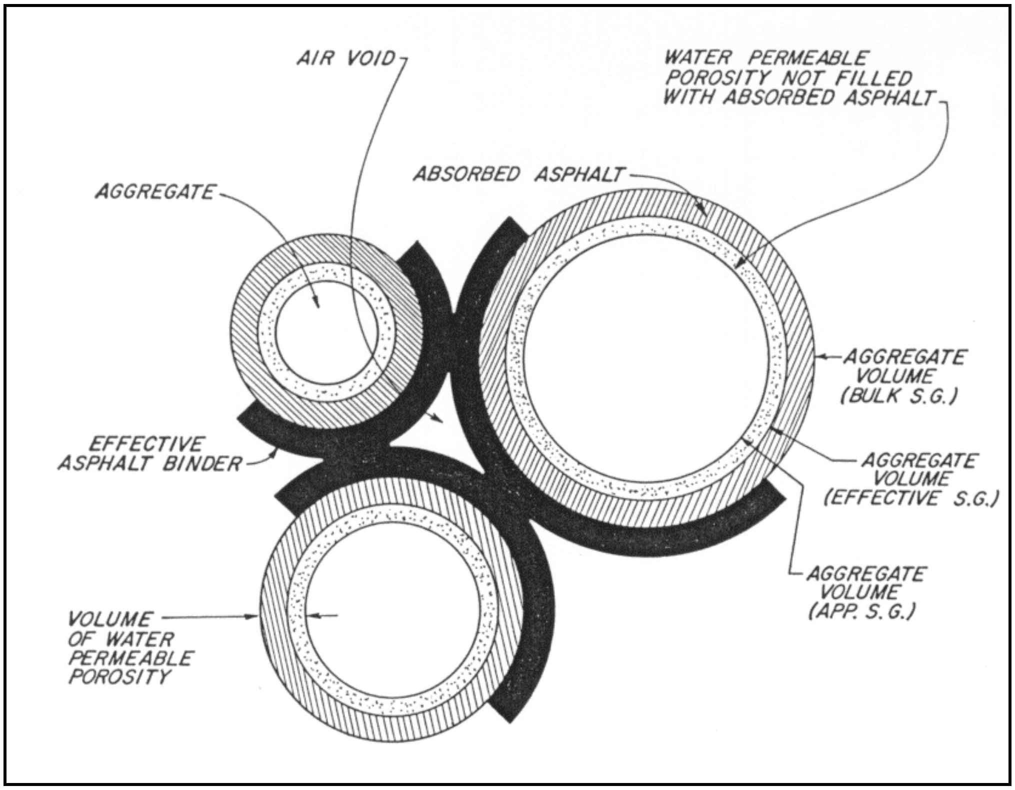


Figure 3-1. Aggregate Specific Gravities.

The voids within an aggregate particle should not be confused with the void system which makes up the space between particles in an aggregate mass. The voids between the particles influence the design of hot mix asphalt or portland cement concrete.

HARDNESS

The hardness of the minerals that make up the aggregate particles and the firmness with which the individual grains are cemented or interlocked control the resistance of the aggregate to abrasion and degradation. Soft aggregate particles are composed of minerals with a low degree of hardness. Weak particles have poor cementation. Neither type is acceptable. The Mohs Hardness Scale is frequently used for determination of mineral hardness (Figure 3-2). Although there is no recognizable INDOT specification or requirement which pertains to Mohs Hardness Scale, the interpretation, concept, and use of this scale is useful for the field identification of potentially inferior aggregates.

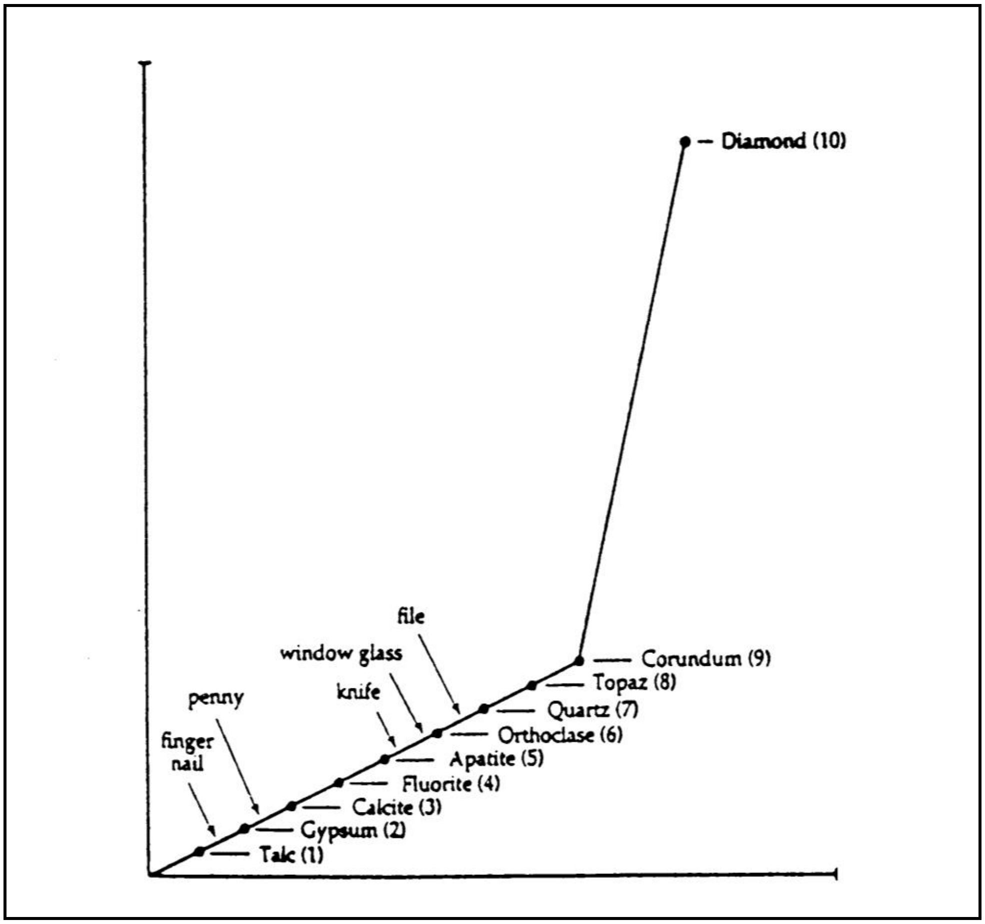


Figure 3-2. Relative Hardness of Minerals in Mohs Scale (numbers in parentheses)

PARTICLE SHAPE

The shape of the aggregate particles affects such things as:

1) The asphalt demands of hot mix asphalt

2) The workability and the strength of both portland cement concrete and asphalt pavements

The best aggregates to use for strength are crushed stone or crushed gravel. Crushed aggregate have irregular, angular particles that tend to interlock when compacted or consolidated.

The crushed stone or crushed gravel aggregate make the asphalt or concrete mix somewhat difficult to place. To improve the workability, many mixes contain both angular and round particles. The coarse aggregate particles are usually crushed stone or crushed gravel, and the fine aggregate particles are usually natural sand. The Standard Specifications detail the requirements for crushed materials for various uses.

COATINGS

Coating is a layer of substance covering a part or all of the surface of an aggregate particle. The coating may be of natural origin, such as mineral deposits formed in sand and gravel by ground water, or may be artificial, such as dust formed by crushing and handling.

Generally when the aggregates are used in hot mix asphalt or portland cement concrete mixes, the aggregates are required to be washed to remove the coating (contaminant) left on the particles. The coating may prevent a good bond from forming between the aggregate surfaces and the cementing agent. The coating could even increase the quantity of bonding agent required in the mixture. If the quantity of the coating varies from batch to batch, undesirable fluctuations in the consistency of the mix may result. Deposits containing aggregates which display a history of coating problems require decantation.

UNDESIRABLE PHYSICAL COMPONENTS

Particles with undesirable physical characteristics include but are not limited to the following:

1) Non-durable soft or structurally weak particles

2) Clay lumps or clay balls

3) Flat or elongated particles

4) Organic matter contaminants

4) Lightweight chert

CHEMICAL PROPERTIES

The chemical properties of aggregates have to do with the molecular structure of the minerals in the aggregate particles.

COMPOSITION

The chemical composition of aggregate is significant in determining the difference between limestone and dolomite. Limestone is a rock consisting mainly or wholly of calcium carbonate and has a tendency to polish smooth under traffic. Therefore, limestone is limited to use in low traffic-volume HMA surface courses. Dolostone under traffic maintains a higher-friction, skid-resistant surface and is used on higher traffic volume locations. Dolostone is a carbonate rock which consists largely of calcium magnesium carbonate. The word dolomite is the mineral calcium magnesium carbonate Ca Mg $(Co_3)_2$. INDOT uses an elemental magnesium (Mg) content test to determine if a rock source is dolomitic. An elemental magnesium content of 10.3 percent or above is required for dolomite aggregates.

Some aggregates have minerals that are subject to oxidation, hydration, and carbonation. These properties are not particularly harmful, except when the aggregates are used in portland cement concrete. As might be expected, iron sulfides, ferric and ferrous oxides, free lime, and free magnesia in industrial products and wastes are some of the common substances. Any of these substances may cause distress in the portland cement concrete and give the concrete an unsightly appearance.

REACTIONS WITH ASPHALT AND CEMENT

There are several types of substances found in mineral aggregates which may have a negative effect on the cementing and overall performance qualities of asphalt and cement. Most are rarely significant but various organic substances may retard hardening, reduce strength development or cause excessive air entrainment in portland cement concrete. These organic substances include, but are not limited to, mica, iron oxide, lightweight chert, shale, coal, and lignite.

SURFACE CHARGE

Aggregate particle surfaces possess either positive or negative electrical charges. Limestone and dolostone generally have a high affection for liquid asphalt.

GENERAL CHARACTERISTICS

Aggregates have three primary uses in highway construction:

1) As compacted aggregates in bases, subbases and shoulders

2) As ingredients in hot mix asphalt

3) As ingredients in portland cement concrete

Aggregates may also be used as special backfill material, riprap, mineral filler, and other less significant uses.

COMPACTED AGGREGATES

Compacted aggregates without the addition of a cementing material may be used as a base or subbase for hot mix asphalt and portland cement concrete pavements. Portland cement concrete pavements are rigid pavements. For these types of pavements, the purpose of the base may be to improve drainage, to prevent pumping, or to cover a material that is highly susceptible to frost. Consequently, gradation and soundness are the primary considerations in selecting or evaluating aggregates for bases under rigid pavements.

The load-carrying capacity is a primary factor in the selection of aggregates for hot mix asphalt pavements. A hot mix asphalt pavement does not carry the load; help from the underlying base courses is required. In addition to gradation requirements, the aggregates are required to also possess the strength to carry and transmit the applied loads.

Aggregates are sometimes used to make up the entire pavement structure. In this type of pavement, aggregates are placed on the natural soil to serve as a base course and surface course. Again, the primary requirement is the gradation.

In many instances, compacted aggregates are also used to construct roadway shoulders and berms. In these applications, gradation and stability are very important.

AGGREGATE FOR HOT MIX ASPHALT

INDOT uses hot mix asphalt in a number of different ways. In all cases the aggregates used should meet five requirements:

1) Strong, tough and durable

2) The ability to be crushed into bulky particles, without many flaky particles, slivers or pieces that are thin and elongated

3) Low porosity

4) Low permeability

5) Correct particle size and gradation for the type of pavement

AGGREGATES FOR PORTLAND CEMENT CONCRETE

There are many uses of portland cement concrete in highway construction. Some of the major uses of aggregates are in rigid-pavement slabs, bridges, concrete barriers, sidewalks, curbs, slopewalls, and other structures.

Aggregates in portland cement concrete are required to always be physically and chemically stable. Other factors to be considered include:

1) The size, distribution, and interconnection of voids within individual particles

2) The surface character and texture of the particles

3) The gradation of the coarse and fine aggregates

4) The mineral composition of the particles

5) The particle shape

6) Soundness abrasion resistance

7) Water absorption

OTHER AGGREGATES

There are other uses for aggregates in highway construction. The requirements are somewhat different from the ones already discussed; however, in most cases, gradation as a controlling factor is common to all applications.

4 Aggregate Specifications and Requirements

Physical Quality Requirements

Fine Aggregates
Coarse Aggregates

Physical Quality Tests

Absorption
Abrasion Resistance
Soundness
Deleterious Materials
Special Requirements

General Usage Requirements

Fine Aggregates
Coarse Aggregates

Gradation Requirements

Fine Aggregates
Coarse Aggregates
B Borrow and Structure Backfilll
Riprap
Aggregate Base
Subbase
Aggregate Pavements or Shoulders
Summary of Gradation Requirements

CHAPTER FOUR:
AGGREGATE SPECIFICATIONS and REQUIREMENTS

The Specifications for aggregates are detailed in Section **904** and other sections for the various types of construction. These specifications are to be followed when inspecting aggregates. There are two general types of requirements for aggregate: quality and gradation.

PHYSICAL QUALITY REQUIREMENTS

Physical quality requirements are all specification provisions other than gradation or usage requirements. These requirements may be divided into five distinct groups as follow:

1) Absorption

2) Abrasion resistance

3) Soundness

4) Restriction on deleterious constituents

5) Special requirements

FINE AGGREGATES

Section **904.02** defines the acceptable limits for all uses of fine aggregates.

Fine aggregates are not divided into classes. The quality ratings assigned to fine aggregates regarding their approval for use on highway construction contracts are:

A5 = approved for all uses

B5 = approved for all uses where manufactured fine aggregate is allowed

G5 = not approved

The "A" rating is for all natural sands. The "B" rating is for manufactured fine aggregates.

COARSE AGGREGATES

Section **904.03** defines the acceptable limits for all uses of coarse aggregates.

Coarse aggregates are divided into classes based on quality requirements as noted in the Classification of Aggregates table. Class AP is the highest class and is assigned to aggregates which meet the requirements for all INDOT uses. Some INDOT contracts specify type AP aggregates for use in specific applications of portland cement concrete. Parameters concerning type AP aggregate are contained in **ITM 210**. Aggregates having restricted approval are rated Classes A, AS, B, C, D, E, and F.

PHYSICAL QUALITY TESTS

Approval and use of aggregates is based upon meeting test requirements in the following physical tests.

ABSORPTION

The absorption quality requirement applies only to coarse aggregates, but this data is necessary on fine aggregate for other purposes, such as mix design and water/cementitious ratios.

All aggregates are porous, but some are more porous than others. How porous an aggregate is determines how much liquid may be absorbed when soaked in water. **AASHTO T 85** defines absorption as the increase in the weight of aggregate because of water in the pores of the material, but not including water adhering to the outside surface of the particles. Absorption is expressed as a percentage of the dry weight.

Absorption requirements are of concern only regarding aggregates used in hot mix asphalt and portland cement concrete. The intent is to avoid using highly porous, absorptive aggregates because extra water and cement or asphalt is needed to make a good mix. However, some aggregates, such as blast furnace slag, may be used despite their high absorptive capacity because of other characteristics that make them desirable, including skid resistance, economics, etc.

ABRASION RESISTANCE

Abrasion resistance applies only to coarse aggregates. Aggregates vary in their resistance to fracturing under impact (toughness) and breaking down into smaller pieces from abrasive action (hardness). The acceptable limits are set by the Los Angeles Abrasion Test **AASHTO T 96**. The limits vary from 30.0 to 50.0 percent, depending on the classification of the aggregate. The percentage is a measure of the degradation or loss of material as a result of impact and abrasive actions. Section **904.03** details the requirements. Abrasion requirements do not apply to blast furnace slag.

SOUNDNESS

The quality of soundness applies to both fine and coarse aggregates. The durability of aggregates or their resistance to the forces of weathering is one of the most important considerations in the selection of a material for highway construction. Alternate freezing and thawing of the aggregates is the major concern.

INDOT uses three different test methods to evaluate soundness:

1) The water freeze and thaw test in accordance with **AASHTO T 103, Procedure A**

2) The sodium sulfate test in accordance with **AASHTO T 104**

3) The brine freeze and thaw test in accordance with **ITM 209**

The water freeze and thaw test requires the aggregate to be sealed and totally immersed in water and then be subjected to *50 cycles* of freeze and thaw. The sodium sulfate test requires the aggregate to be immersed in a sodium sulfate solution and then be subjected to *5 cycles* of alternate immersion and drying. The brine freeze and thaw test requires the aggregate to be enclosed in a bag containing a 3 percent sodium chloride solution and then be subjected to *25 cycles* of freeze and thaw.

The freezing and thawing in water test is the method that most accurately simulates actual field conditions; however, the test requires a long period of time to conduct. The "quick" checks for soundness of the aggregate are the brine freeze and thaw and sodium sulfate tests. If the aggregate fails either the brine freeze and thaw or the sodium sulfate test, the aggregate is tested using the freeze and thaw in water method. An aggregate that passes the freeze and thaw in water test is an acceptable material for use on INDOT contracts.

DELETERIOUS MATERIALS

Certain substances in aggregates are undesirable for use in portland cement concrete. Therefore, the Specifications limit the amount of deleterious constituents to a level consistent with the quality sought in the final product.

Organic impurities are the only concern in fine aggregates. Section **904.02** places a restriction for fine aggregate for use in portland cement concrete and mortar. No restrictions are placed on organic impurities in fine aggregate for use in other types of construction.

The limitations on the amount of organic impurities allowed in fine aggregates are determined by the test method for organic impurities in **AASHTO T 21** and the test method for Mortar Strength in **AASHTO T 71**. According to the Specifications, materials failing the organic impurities test are to be tested for the effect of organic impurities using the mortar strength test. The results of the test are the basis for acceptance or rejection of the fine aggregate.

Section **904.03** includes a general statement regarding deleterious substances that applies to all classes of coarse aggregates. Section **904.03** also details more specific restrictions for other harmful substances as a maximum allowable percentage of the mass of each of the deleterious materials in a total sample of aggregates being tested. Figure 4-1 illustrates the materials which are classified as deleterious and the specification limits for each.

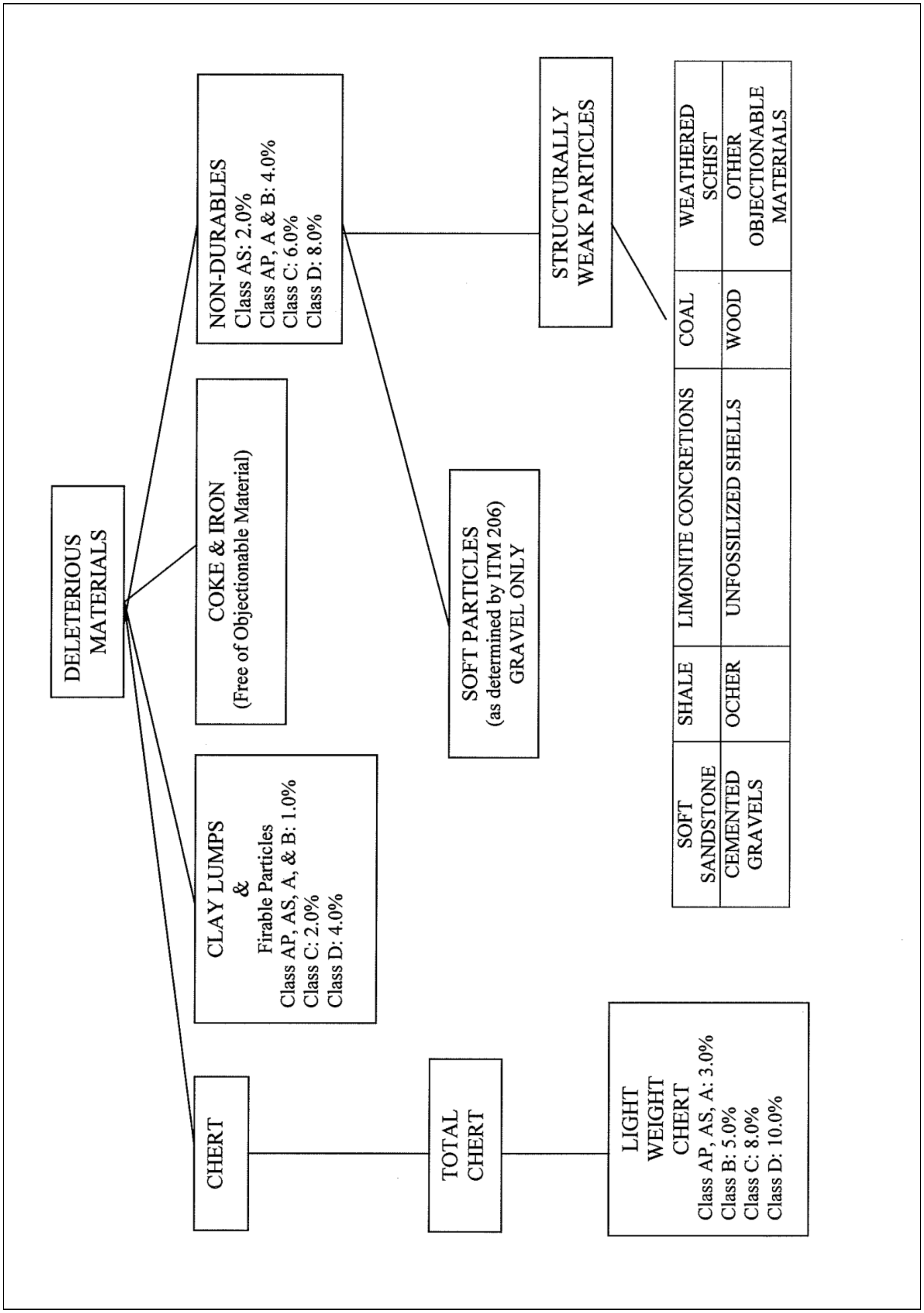


Figure 4-1. Deleterious Materials

Clay Lumps and Friable Particles

Clay lumps and friable particles are materials that are easily crumbled or mashed with the fingers. Testing for these particles is performed by **AASHTO T 112**, Clay Lumps and Friable Particles in Aggregates.

Non-Durable Particles

Non-durable particles are divided into two types: soft materials as determined by **ITM 206**, Scratch Hardness, and structurally weak material as determined by visual inspection. Structurally weak materials include the following:

1) Conglomerates -- cemented gravels

2) Soft sandstone

3) Shale -- laminated rock of clay-size minerals

4) Limonite -- iron oxide ranging in color from brown to black and is frequently a concretion around a soft core

5) Weathered schist -- structurally weak

6) Ocher -- soft rock clay to sand particles cemented with iron oxide which ranges in color from tan, through yellows, reds, and browns (looks and acts like chalk)

7) Shells -- unfossilized shell of fresh water clams

8) Coal, wood, and other foreign materials

9) Materials with loosely cemented grains and/or a weathered coating

Coke and Iron

Coke and iron are of concern only with the slag materials. Coke is an ingredient in the steel making process. Slag from air-cooled blast and steel furnaces normally are free of objectionable amounts of coke and iron.

Chert

Chert is a rock of almost any color and is composed of glassy silica and very fine-grained quartz. Chert breaks into rounded surfaces with sharp edges. Unweathered chert appears hard, dense and brittle with a waxy or greasy texture. Weathered chert appears chalky or earthy and porous with a dull texture.

Lightweight chert is defined as aggregate that has a bulk specific gravity less than 2.45. The bulk specific gravity is determined using the saturated surface dry condition.

SPECIAL REQUIREMENTS

In some cases, aggregates are required to meet special requirements for a particular use in construction as required by various Sections of **904**. Some contracts may specify a unique gradation or aggregate. Details pertaining to this special requirement appear in the Special Provision section of the contract.

Fine Aggregates

The fine aggregate, including blended fine aggregate, used in HMA Surface 4.75 mm mixtures is required to have an acid insoluble content of not less than 40 percent. For air-cooled blast furnace slag or granulated blast furnace slag sand, the acid insoluble content is required to not be less than 25 % for this application. Acid insoluble requirements do not apply to crushed gravel, limestone, or dolomite sands. The acid insoluble content is determined by **ITM 202**.

All fine aggregates used for HMA are required to be in accordance with **904.02** for soundness. If soundness testing cannot be conducted, the aggregate is required to originate from a Category I source in accordance with **ITM 203**.

The total blended aggregate from the fine and coarse aggregates, and recycled materials used in HMA are required to meet the fine aggregate angularity (FAA) requirements of Section **904.02(b)**. The procedure for determining the FAA value is described in Method A of **AASHTO T 304**.

The clay content of the blended aggregate is required to meet the requirements of Section **904.02(b)**. The procedure for determining this value is described in **AASHTO T 176**.

All Coarse Aggregates

A special requirement placed on all coarse aggregates concerns the restriction on the number of *flat and elongated* pieces. Section **904.03** sets the limits for the number of flat and elongated pieces. A flat and elongated piece is defined as one having a ratio of length to thickness greater than five. The test method for determining the actual percentage of elongated pieces is **ASTM D 4791**.

Dolomitic Aggregates

There is a special requirement to be met when dolomitic coarse aggregates are specified in HMA. These aggregates are specified for use under some conditions to obtain high-friction, skid-resistant HMA surface courses. **ITM 205** is used to veify that the aggregate is carbonate rock containing at least 10.3 percent elemental magnesium.

Polish Resistant Aggregates

Aggregates that meet the requirements of **ITM 214** may be used in place of dolomitic aggregates in HMA surface mixtures. The procedure for approval requires initial British Pendulum testing, placement of a test section on an INDOT contract, and subsequent skid testing for two years.

Sandstone Aggregates

Coarse sandstone is required to meet the Class B quality requirements, and may only be used in HMA or SMA surface mixtures. Sandstone is defined as a sedimentary rock composed of siliceous sandgrains containing quartz, chert, and quartzose rock fragments in a carbonite matrix or cemented with silica, calcite, or dolomite.

Slag Aggregates

When slag is furnished as an alternate to natural aggregate and payment is on a weight basis, adjustments are required to be made to compensate for the difference in specific gravity of the slag compared to the specific gravity of the natural aggregate. For any pay item less than 500 tons on a contract, no adjustment is made. The following typical values are used.

TYPICAL VALUES FOR SPECIFIC GRAVITY	
Natural aggregates (both fine and coarse)	**2.6**
Air cooled blast furnace slag coarse aggregate	**2.3**
Air cooled blast furnace slag fine aggregate	**2.6**
Granulated blast furnace slag fine aggregate	**2.1**
Steel furnace slag, both fine and coarse	**3.2**

Type AS Aggregates

Aggregates used for stone matrix asphalt mixtures are required to meet the requirements of AS aggregates in accordance with Section **904.03 (a)**. These requirements include testing with the Micro-Deval abrasion apparatus **(AASHTO T 327)** and determination of the aggregate degradation in accordance with **ITM 220**. Additional requirements for control of the specific gravity of the steel furnace slag are included in Section **904.01**.

Gravel Coarse Aggregates

There is a specific requirement for gravel coarse aggregates regarding crushed particles. This requirement applies, however, only when gravel coarse aggregates are used in HMA, compacted aggregates, and asphalt seal coats except asphalt seal coats used on shoulders. Crushed particles are defined as those particles having one or more sharp, angular, fractured faces. Fractured faces that have an area less than *25 %* of the maximum cross sectional area of the particle are not considered crushed. **ASTM D 5821** is used to determine the crushed particle content. Crushed gravel is required to comply with the requirements in Section **904.03**.

Type AP Aggregates

INDOT requires specific applications of portland cement concrete to be constructed with AP aggregate. Details and parameters concerning AP aggregate are described in **ITM 210**.

GENERAL USAGE REQUIREMENTS

The general usage requirements describe the type of material which is considered acceptable for the type of construction, and the requirements which influence the acceptability of the material.

FINE AGGREGATES

Section **904.02** states that fine aggregate is required to consist of natural sand or manufactured sand produced by crushing limestone, dolomite, steel furnace slag, air cooled blast furnace slag, granulated blast furnace slag, or wet bottom boiler slag. At the time of use, these materials are required to be free from lumps or crusts of hardened or frozen materials.

THE SPECIFIC REQUIREMENTS OF FINE AGGREGATES IN ACCORDANCE WITH SECTION 904.02:	
TYPE OF CONSTRUCTION	***ACCEPTABLE FINE AGGREGATE***
Portland cement concrete for pavement or bridge decks	Natural sand
Portland cement concrete for other construction	Natural sand or crushed limestone, dolomite, or air-cooled blast furnace slag
Hot mix asphalt	Natural sand or manufactured sand. Steel furnace slag sand is permitted only with steel furnace slag coarse aggregate. A combination of natural sand and manufactured sand is permitted. However, not more than 20 percent of the total aggregate used in HMA surface mixtures with ESAL equal to or greater than 3,000,000 may be crushed limestone sand if the limestone sand is from a source not on the Approved Polish Resistant Aggregate List.
Pneumatic placement	Natural sand suitable for use with a pneumatic sand cement gun
Mortar	Natural sand
Mineral Filler	Dust produced by crushing stone, portland cement, or other inert mineral matter
Snow and ice abrasives	Steel furnace slag, air-cooled blast furnace slag, granulated blast furnace slag, natural sand, crushed stone sand, or cinders

COARSE AGGREGATES

Section **904.03** includes the general requirements for coarse aggregate. This section lists several of the types of materials that may be used as coarse aggregate, and their applications and limitations.

CLASS OF COARSE AGGREGATES REQUIRED FOR VARIOUS TYPES OF CONSTRUCTION	
TYPE OF CONSTRUCTION	***REQUIRED QUALITY CLASSIFICATION***
Aggregate Base	Class A, B, C, or D
Subbase	Class A or B (No. 8) Class A, B, C, or D (No. 53)
Aggregate Pavements or Shoulders	Class A, B, C, or D
HMA base coarse	Class A, B, C, or D
HMA intermediate course	Class A, B, or C
HMA surface course	Class A or B
SMA surface course	Class AS
Asphalt seal coat	Class A or B
Portland cement concrete pavement	Class AP
Portland cement concrete structural--exposed	Class A or AP
Portland cement concrete structural --non-exposed	Class A or B
Cover (choke) coarse aggregate	Class A or B

Where more than one aggregate classification is allowed, the Contractor has a choice, unless specified by provisions within a given contract. The class of aggregate may never be less than the lowest class for the designated use. For example, the highest class of aggregate for HMA surface course, Class A, may be used (with no additional payment to the Contractor or Producer). Class B aggregate may be used as the minimum requirement.

GRADATION REQUIREMENTS

The gradation or particle-size distribution of an aggregate is usually specified to be within certain limits for various types of construction. There is a great difference between what is considered an acceptable grading for aggregates for the various HMA mixes, for portland cement concrete, or for base layers. The gradation that aggregates are to meet for specific types of construction is contained in the contract plans, Special Provisions, or Standard Specifications and is usually designated by the aggregate size.

Sections **904.02 and 904.03** contain tables describing the acceptable particle-size distribution for various sizes of both fine and coarse aggregates. Section **904.04** specifies the sizes for riprap and Section **904.05** lists the acceptable gradations for structure backfill.

FINE AGGREGATES

The table found in Section **904.02** is used to accept six aggregates used for HMA mixes, portland cement concrete, pneumatic placement mortar, mortar sand, mineral filler, and snow and ice abrasives. The six sizes of fine aggregates include No. 23, No. 24, No. 15, No. 16, PP, and S&I. No. 16 is the finest aggregate, because 100 percent of the fine aggregate is required to pass the No. 30 sieve. No. 23 is the coarsest of the six sizes. All fine aggregate particles are generally expected to pass the No. 4 sieve.

The aggregates for mortar sand are required to meet the gradation for size number 15 or an approved gradation from a CAPP source. The fine aggregates for pneumatic placement may meet size number 15, PP, or an approved gradation from a CAPP source. Mineral filler for SMA is required to meet size number 16.

Snow and ice abrasives are required to meet the gradation requirements of Section **904.02(f)**.

COARSE AGGREGATES

The table found in Section **904.03** applies to coarse aggregates. The ten sizes of coarse aggregates include No. 2, No. 5, No. 8, No. 9, No. 11, No. 12, No. 43, No. 53, No. 73, and No. 91. No. 2 is the coarsest size and No. 12 is the finest. No. 53 and No. 73 are dense graded aggregates, and No. 91 is used for aggregates in precast concrete. The majority of the coarse aggregate is retained on the No. 4 sieve and larger.

B BORROW AND STRUCTURE BACKFILL

B Borrow and structure backfill requirements are listed in Section **211**.

Materials for B Borrow are required to contain no more than 10 % passing the No. 200 sieve and be otherwise suitably graded as noted in Section **211.02**. The use of an essentially one-size material is not permitted unless approved.

Materials for structure backfill are required to be of acceptable quality, free from large or frozen lumps, wood, or other extraneous matter. Structure backfill gradations are included in Section **904.05**. Aggregate sizes No. 5, No. 8, No. 9, No. 11, No. 12, No. 53, and No. 73 crushed stone or air cooled blast furnace slag are allowed. Additional aggregate sizes permitted for structure backfill are listed in the table in this section. The structural backfill types that allow aggregates and the specific uses of each type are as follows.

Type 1 structural backfill is used in longitudinal or transverse structures placed under, or within 5 ft of, the back of paved shoulders or the back of sidewalks of a new facility. This type is also used for a structure of an existing facility where all existing pavement is to be replaced. Structural backfill in accordance with Section **904.05** may be used for Type 1 applications.

Type 2 structural backfill is used in longitudinal or transverse structures placed under, or within 5 ft of, the back of the paved shoulder or back of the sidewalk where undisturbed existing pavement is to remain. This type is also used for precast concrete three-sided or four-sided structures with a height of cover of 2 ft or more. Crushed stone or ACBF in accordance with Section **904.05** may be used for Type 2 applications, except No. 30, No. 4, and 2 in. nominal size aggregate may not be used.

Type 3 structural backfill is used behind mechanically-stabilized earth retaining walls. Structural backfill in accordance with Section **904.05** may be used for Type 3 applications, except only nominal size aggregates 1 in., 1/2 in., or No. 4. or coarse aggregates No.5, No. 8, No. 11, or No. 12 may be used. No slag other than ACBF is permitted.

RIPRAP

Aggregate used for riprap is included in Section **904.04**. These materials are typically large and are used as a protective coating as specified. Revetment, Class 1, Class 2, Uniform A, and Uniform B Riprap are required to meet the requirements of Section **904.04(f).** The other ripraps listed have general size limitations.

AGGREGATE BASE

Section **301** includes the requirements for dense graded compacted aggregate material. No. 53 aggregate is used for this purpose.

SUBBASE

Section **302** includes the requirements for subbase placed on a prepared subgrade for portland cement concrete pavement. Subbase consists of a No. 8 aggregate as the drainage layer over a No. 53 aggregate as the separation layer. Where a dense graded subbase is required, only No. 53 aggregate is used.

AGGREGATE PAVEMENTS OR SHOULDERS

Section **303** includes the requirements for aggregates when used for pavements or shoulders. No. 53 and No. 73 aggregate are used for this purpose except that No. 73 aggregate is only used for surface courses.

SUMMARY OF GRADATION REQUIREMENTS

The gradation requirements for fine and coarse aggregates as specified in various sections of the Specifications for significantly different types of construction are summarized below. This listing is not all inclusive, but covers the major uses of aggregates.

TYPE OF CONSTRUCTION REQUIREMENTS	GRADATION
Aggregate Base Coarse Aggregate	 No. 53
Subbase Coarse Aggregate	 No. 8, 53
Aggregate Pavements or Shoulders Coarse Aggregate	 No. 53, 73
Asphalt Seal Coat Fine Aggregate Coarse Aggregate	 Nos. 23 or 24 Nos. 8, 9, 11, 12 Nos. SC 11, 12, 16
Portland Cement Concrete Pavement (PCCP)/Structural Concrete Fine Aggregate Coarse Aggregate	 No. 23 No. 8

5 Aggregate Production

Extraction

Stripping
Drilling and Blasting
Shot Rock or Gravel Bank

Crushing

Scalping
Primary Crushing
Secondary and Tertiary Crushing
Impact Crushing

Other Benefaction

Screening

Product Quality
Gradation Control

Sand Production

Natural Sand
Manufactured Sand
Processing

Segregation

Stockpiling and Handling

Cone Stockpiles
Radial Stockpiles
Truck-Built Stockpiles
Layered Stockpiles
Stockpiling - General

Degradation

Contamination

Retrieval

CHAPTER FIVE:
AGGREGATE PRODUCTION

This chapter discusses the total process of aggregate production from extraction through processing. Also discussed is the handling, stockpiling, and shipping of the product up to the point where the material leaves the Producer's control. Processing influences mineral quality and integrity, aggregate physical properties, and, in particular, gradation (size control). Establishing a stable production process may reduce variability of the product.

EXTRACTION

With the exception of slag and other manufactured aggregates most materials for aggregate production come from bedrock or unconsolidated deposits. The vast majority of materials used in the mineral aggregate industry are obtained from surface-mined stone quarries or from sand and gravel pits. How materials are extracted influences their quality.

Extraction Influences on Quality

STRIPPING

- Not clean enough
- Spillage over mining face

DRILLING AND BLASTING

- Hole size, depth, and spacing (pattern)
- Blast delay sequence
- Blast intensity or charge

SHOTROCK OR GRAVEL BANK

- Non-uniform load-out
- Equipment changes
- Geologic variability
- Moisture variability in shotrock
- Above/below-water gravel deposits

STRIPPING

As a first step, a Producer is required to designate a detailed stripping procedure (Figure 5-1) for each and every deposit that is mined. This phase often is overlooked, yet has a great influence on the quality and variability of the product. Inadequate removal of overburden from the mineral deposit often may be the source of excessive variation in minus No. 200 material and may even have a deleterious affect on nearby vegetation and other aspects of the mine.

For example, excessive knobs and depressions on the surface of a stone deposit may necessitate the use of smaller equipment or special techniques to clean the stone. Inexperienced equipment operators may easily corrupt good stripping practices (which are somewhat of an art and site specific). Spillage over the working face and other sloppy practices can also affect the cleaning process.

Figure 5-1. Stripping

Quarry operators commonly design fragmentation shots for safety, economy, ease of use at the primary crusher, and even public relations, but they often forget about quality.

The shot layout is required to be properly engineered, documented, and adhered to for maximum consistency. Varying the shot pattern may mean changes in product size throughout the operation. Smaller shot rock, resulting in less crushing in the secondary and tertiary stages, may mean less improvement through crushing. Therefore, the mineral quality and/or changes in physical properties of the product may be affected.

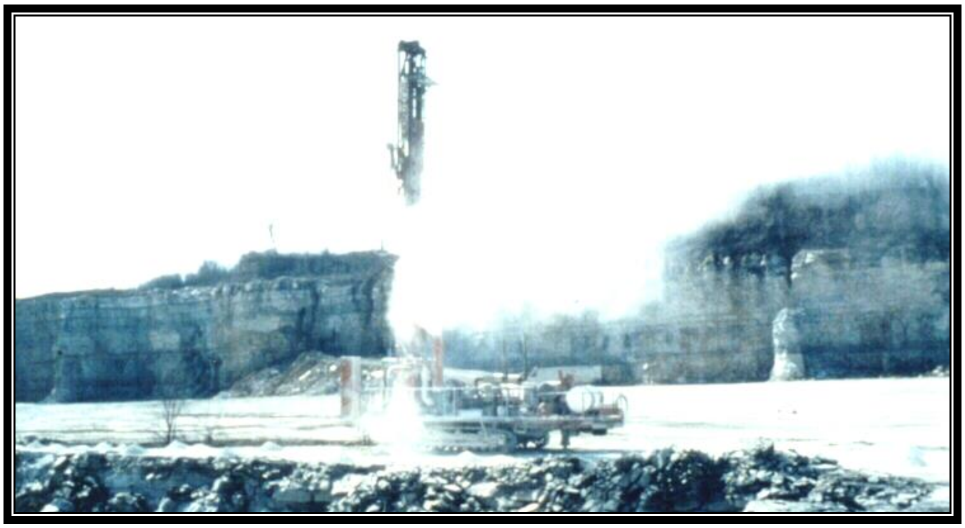


Figure 5-2. Drilling

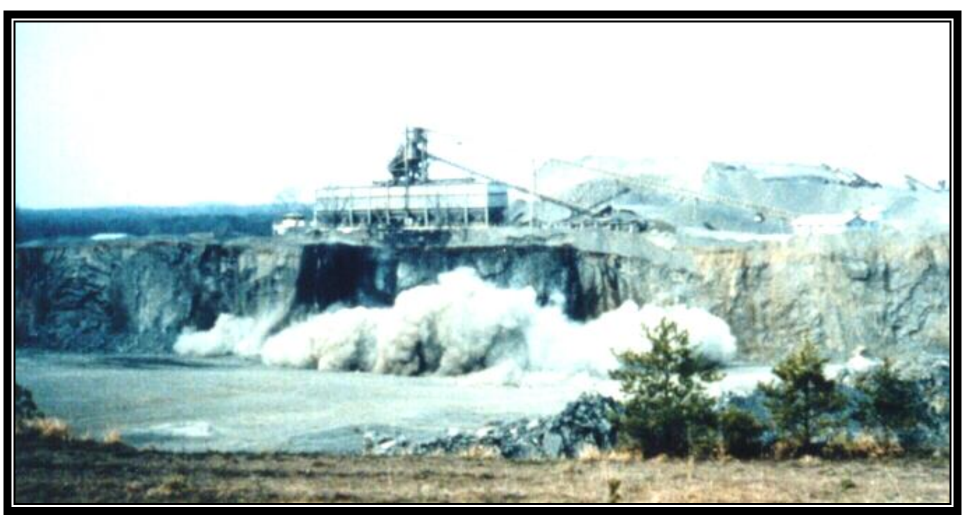


Figure 5-3. Blast or Shot

Hole detonation-sequencing and blast intensity also are required to be properly engineered. Size changes resulting from inattention to detail can have the same effects as mentioned above. Also, an erratic blast that throws the shot rock over a large area tends to cause variation in size gradation that is delivered to the primary crusher. Any deviation from previously established shot patterns, sequencing, and intensity should be carefully thought out as to the effect on product quality. Production changes are required to be documented in the Producer's Quality Control Plan and notification is required to be given to INDOT.

SHOT ROCK OR GRAVEL BANK

A constant problem of gravel pit and quarry operators is the difficulty in maintaining uniform load-out from either the shot rock pile or the gravel bank. Even the best shot has some variation from side to side and from front to back. Only experienced and well-trained equipment operators may accomplish the mixing from around the shot for the most uniform feed to the processing plant.

Subsurface sampling and testing are required to inform gravel-pit managers where the size of the material changes. In many cases, for example, material from both above and below ground water level is required to be blended in a prescribed manner to maintain uniform feed to the plant.

Changes in equipment, if done without thought as to how to maintain uniform sizing, also may have the same effect. Any change in equipment is required to be evaluated for effect. These changes are incorporated into an adenda to the Producer's Quality Control Plan.

Figure 5-4. Loading Quarry Truck

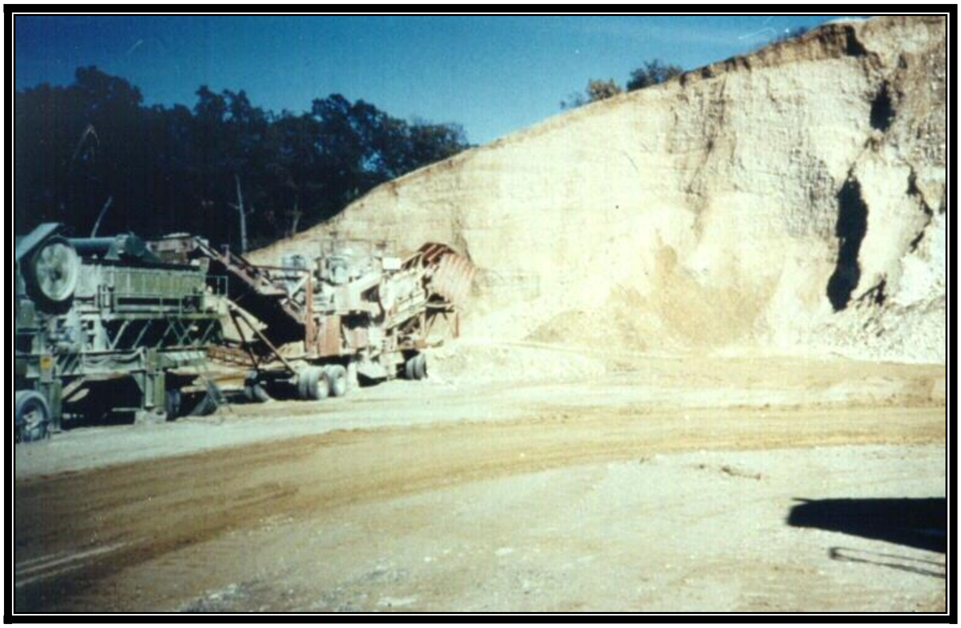


Figure 5-5. Sand and Gravel Excavation

Geologic variability in the deposit may sometimes affect sizing but more often causes a change in mineral integrity and physical properties. If a large variation exists, some products at later stages in the process may require separation.

Moisture variation in shot rock may also cause significant problems during processing. Shot-rock moisture is required to be monitored because significant changes in moisture almost always require changes in downstream processing.

CRUSHING

The first step of processing begins after the extraction from quarry or pit. Many of these steps also are common to recycled materials, clay, and other manufactured aggregates. The first stage in most operations is the reduction and sizing by crushing. Some operations, however, provide a step prior to crushing called scalping.

SCALPING

Scalping (Figure 5-6) most often is used to divert fines at a jaw primary crusher in order to improve crusher efficiency. In this way the very coarse portion is crushed and then recombined with the portion of crusher-run material before further processing. This first step may, however, be an excellent time to improve a deleterious problem. If a deleterious or fines problem exists in the finer fraction of crusher-run material (namely, clay, shale, finely weathered material, etc.) the fall-through of the scalping operation may be totally or partially diverted and wasted, or may be made into a product of lesser quality. In any case, only acceptable amounts, if any, should be returned back into the higher quality product. Consideration of process variables in this early stage may be very important.

Figure 5-6. Scalping

PRIMARY CRUSHING

In stone quarries or in very "boney" gravel pits, large material usually is reduced in size by either a jaw (Figure 5-7) or a gyratory crusher. Both types are compression crushers. Although economical, they have the tendency to create thin, elongated particles. Particle shapes sometimes may be a problem for Producers of hot mix asphalt. In some operations impact crushers are used for primary crushing, but they may have a slightly higher cost per ton. Impact crushers may upgrade poor-quality aggregate and increase separation, such as removal of rebar from concrete in recycling operations.

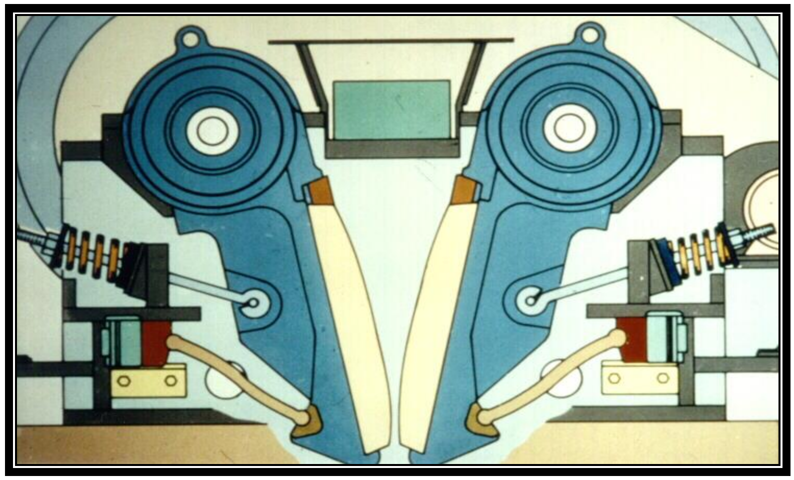


Figure 5-7. Jaw Crusher

After primary crushing/reduction the resulting aggregate generally is placed in a large "surge" pile where the aggregate may be fed into the secondary operation whenever convenient.

Care is always taken when building up and loading out surge piles, as this step may be a major source of segregation of material going to the secondary plant. Variation at this point may affect both mineral quality and gradation. Drawing from an inverted cone over a load-out tunnel works well after material has been deposited and left undisturbed to form the walls of the draw-down cone. If the need ever arises to consume the entire pile, care is taken to thoroughly mix the older material a little at a time with fresh product to make the surge as uniform as possible as the aggregate is being pushed into the tunnel. If the operation relies on end loaders to feed the secondary plant from the surge pile (Figure 5-8), the same care is taken to mix coarse with fine material from the outside to the inside of the pile.

Figure 5-8. Surge Pile

SECONDARY AND TERTIARY CRUSHING

Secondary and tertiary crushing, if necessary, are the final steps in reducing the material to a desired product size. Historically, cone and roll crushers were the most common choice crushers, but in recent years impact crushers are more widely used. These crushers also are sometimes used as primary crushers for fine-grained gravel deposits.

The cone crusher (a compression type) simply crushes the aggregate between the oscillating cone and the crusher wall (Figure 5-9). Clearance settings on this equipment are required to be checked and maintained as part of standard operating procedure.

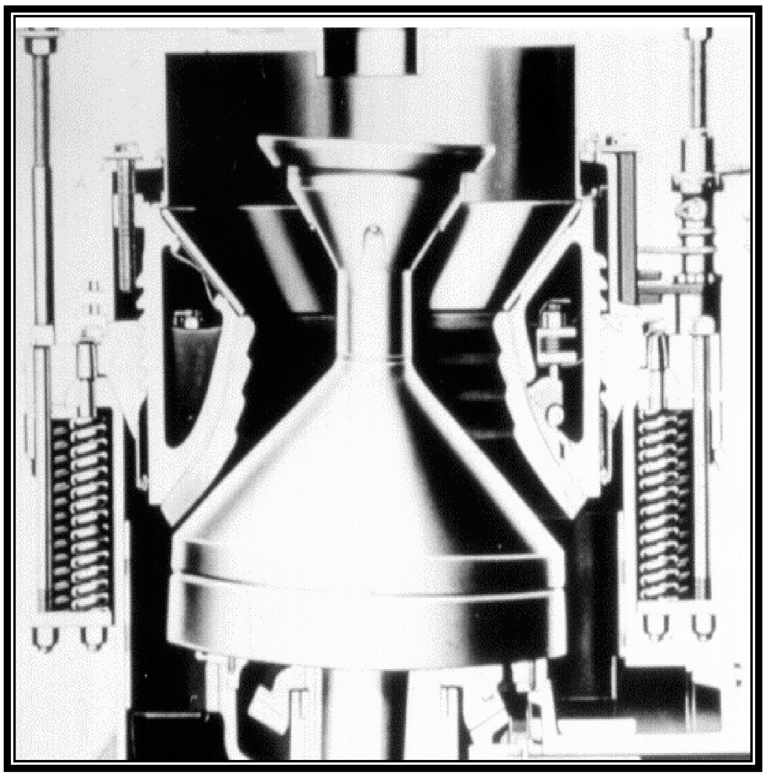


Figure 5-9. Cone Crusher

As with other compression crushers, the cone crusher yields a somewhat elongated and slivery particle shape. This may be minimized, however, by "choke" feeding the crusher. This technique will also make the shape and size more uniform. One way to choke feed is with a surge hopper and a controlled belt-feed to the cone crusher (Figure 5-10). Automatic level controls measure the head of the material over the top of the cone.

Figure 5-10. Crusher Feed System

A roller crusher (Figure 5-11) is another compression type crusher that simply breaks the material by pinching the aggregates. These types of crushers are often found in gravel operations. Roller crushers have constant maintenance problems and are prone to excessive wear. The rollers are required to be checked frequently to insure proper clearance and uniformity across each roller. Rebuilding and re-milling the roller is a standard operating procedure.

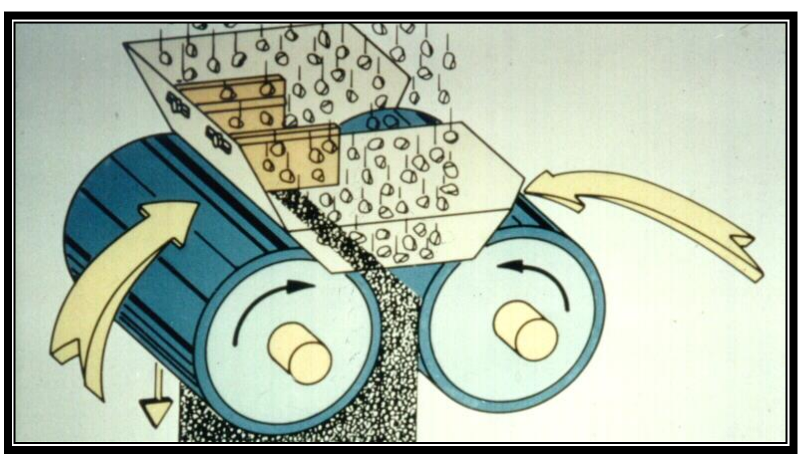


Figure 5-11. Roller Crusher

IMPACT CRUSHING

Impact crushers may be used as primary, secondary, or tertiary crushers. Despite having a somewhat higher operating cost than other crushers, they tend to produce a more uniform particle shape. Impact crushers usually will benefit the aggregate better than compression crushers, and they may generate more fines. Common types are the horizontal shaft (Figure 5-12), vertical shaft, and hammermill impactors.

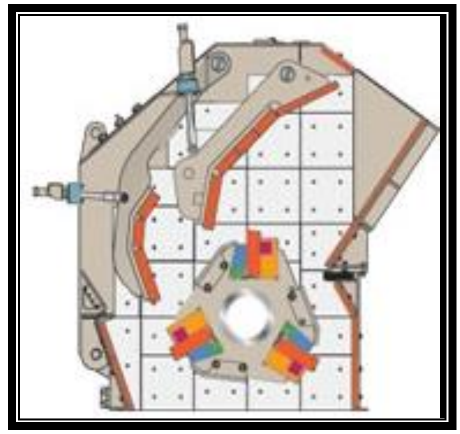


Figure 5-12. Horizontal Shaft Impactor

The horizontal shaft single or double rotor may aggressively handle large and odd-shaped material. Large horizontal impactors sometimes are used as primary crushers. Fracturing occurs at the same time by rock against rotor, rock against breaker bar, and rock on rock**.**

The vertical shaft impactor (Figure 5-13) is operated in rock against anvil, or rock against rock (through the installation of a rock shelf) modes. The Producer is required to decide carefully the mode best suited to the raw material.

Figure 5-13. Vertical Shaft Impactor

The hammermill impactor (Figure 5-14) provides excellent reduction and beneficiation through the impacting and shearing action of the hammers and grates; however, a large amount of fines is produced. This type of crusher is sometimes used in the manufacture of agricultural ground limestone.

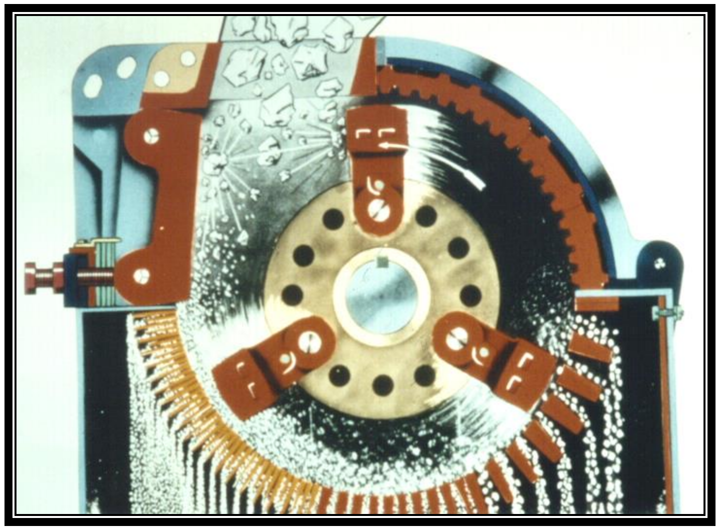


Figure 5-14. Hammermill Impactor

OTHER BENEFACTION

Other forms of benefaction for quality are available to the Producer. These include the log washer, heavy media separator, and attrition mill.

The log washer (Figure 5-15) commonly is used in wet operations to agitate and scrub clay and other objectionable fines from coarse aggregate. A Producer may need to use a log washer when rinsing screens do not remove these objectionable fines.

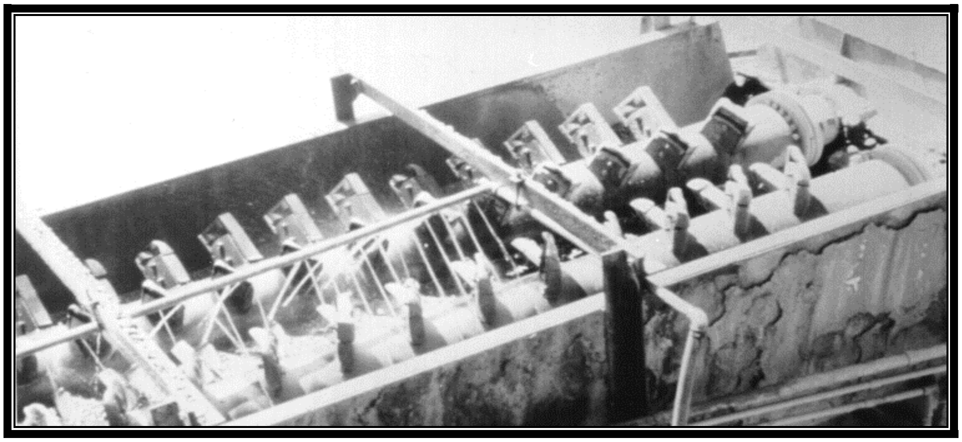


Figure 5-15. Log Washer

Heavy media separation is somewhat costly, but may be the only practical way for a Producer to meet quality requirements. This method works only when the undesirable material has a different specific gravity than the desirable material. The deleterious material is discarded after the media is separated for recycling.

Attrition mills are seldom used but remain an option when the deleterious particles are uniformly softer than the non-deleterious particles. The attrition mill abrades the deleterious particles into fines that may be screened out of the system.

SCREENING

Screening is another technique to control both quality and gradation of the aggregate product.

PRODUCT QUALITY

If deleterious material exists at undesirable levels after crushing and may be identified as being predominantly in one size range that is not needed for product size, the material may be screened out (namely, fines or top size). This step may occur between crushing so that an opportunity exists to recreate the same size downstream, if needed, to create a product. The screened-out lower-quality material may be used for a lower quality product or wasted if no use exists.

The rinse screen (Figure 5-16) is also commonly used. By processing the material over a screen that retains all of the product, the clay and deleterious fines may be rinsed away to make the product acceptable.

Figure 5-16. Rinse Screens

GRADATION CONTROL

The best technique for gradation control is screening (Figure 5-17). Screening may be done wet or dry, depending on the type of aggregate being processed and the degree of consistency required for each product.

Washing, for example, may be necessary to clean a concrete aggregate, but may not be needed for hot mix asphalt products, which may contain more fines. For gradation control alone, however, consistency sometimes may only be maintained by using wet screening. Gradation consistency is usually an overriding factor for a hot mix asphalt customer. Water volume and flow direction are critical in wet screening. Frequent checking of the gradation is a standard operating procedure.

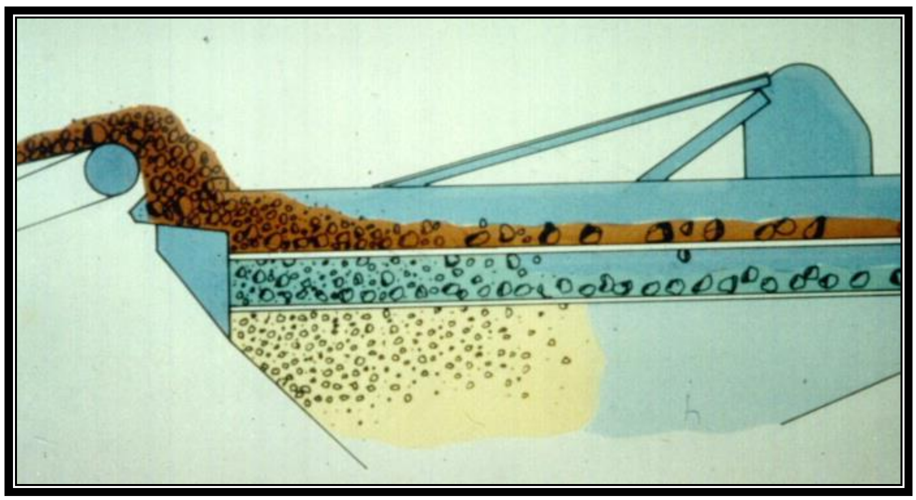


Figure 5-17. Screening

Dry screening is a slight misnomer because the material passing over the screen decks is wet, ranging from slightly damp to very wet, depending on conditions such as rain or subsurface moisture. Non-washed screening is a more accurate description of this screening process. High moisture is a concern because the wet aggregates may cause some material to become sticky and bind together, making the aggregate harder to separate. Furthermore, high-moisture conditions may cause binding of lower screen decks, causing override of the material rather than separation. If these conditions are encountered, the Producer may need to establish a balance between the moisture content of the incoming material and the feed rate through the screens. This balance is required to be made for each hour of operation. If reduced feed rates do not solve the problem or is too costly, washing or an additional screen area may be needed.

Sometimes screening variation is too great even under the most favorable of conditions. When this occurs the Producer is required to check that the equipment and the screen cloth are in good repair. The most common reason for high screening variability is the tendency to push too much material over a screen. The only way to maintain a bed of material thin enough for optimum efficiency is to provide enough screening to allow the desired rate of production. Standard operating procedures should reflect the maximum feed rate for the design of the plant.

For well-graded products having many sieves, (namely, #53s), gradation control may not be done without first separating the material into fractions. Separating the material into numerous small fractions and then back-blending at a set rate for each fraction may be necessary to control the gradation.

Frequent sampling, testing, and control charting are necessary for monitoring because aggregate gradation is subject to so many variables.

SAND PRODUCTION

Sand plays a critical role as a construction aggregate and deserves special attention when considering the means of process control. Unlike coarse aggregate where various types of crushers may be used to upgrade mineral quality, sand basically relies on the same techniques to address both mineral quality and sizing. These techniques are called particle exclusion. Whichever size the Producer decides to eliminate for quality reasons obviously also affects the sizing.

NATURAL SAND

Good quality natural sand is readily available in many areas and may be easy to obtain and process. As with the gravels that they often accompany, the sand deposits may not have been laid uniformly, meaning a potential change in quality and size is possible. In some deposits, sand found below the water table differs in fines content and quality from that found above the water table. Subsurface drilling, sampling, and testing is necessary to know to what degree and where these differences occur. Standard operating procedures in the Quality Control Plan should address the process if differences in size and quality are encountered, as a uniformly graded product of predictable quality is required to be maintained.

MANUFACTURED SAND

Because of the angularity, manufactured sand is very beneficial for use in hot mix asphalt where stability is critical. Many Indiana quarries are high in clay content and often a large amount of dust ends up in the feed stock for manufactured sand. Care is required to be taken to select the appropriate classification equipment that removes the necessary amount of minus No. 200, yet retains other fractions of the sand gradation that are needed. For some uses, particle shape is important. Particle shape is set primarily by the crushing operation for the coarse aggregate. Any changes in crushers or crushing techniques may affect the properties of the manufactured sand product and therefore affect the customer's use of the product.

PROCESSING

Very few sand products are produced by air classification or by direct non-washed screening. Most sands are produced with wash water and water classification. The key to all rinsing and water classifying systems is adequate delivery of water. Inadequate water supply and poor maintenance are the two most common reasons for inconsistent sand gradations.

The most common water classifier is a simple dewatering screw (Figure 5-18) which may make a single "cut" in gradation and float out a certain amount of fines. By altering the through-put and rate of water flow the cut point may be changed.

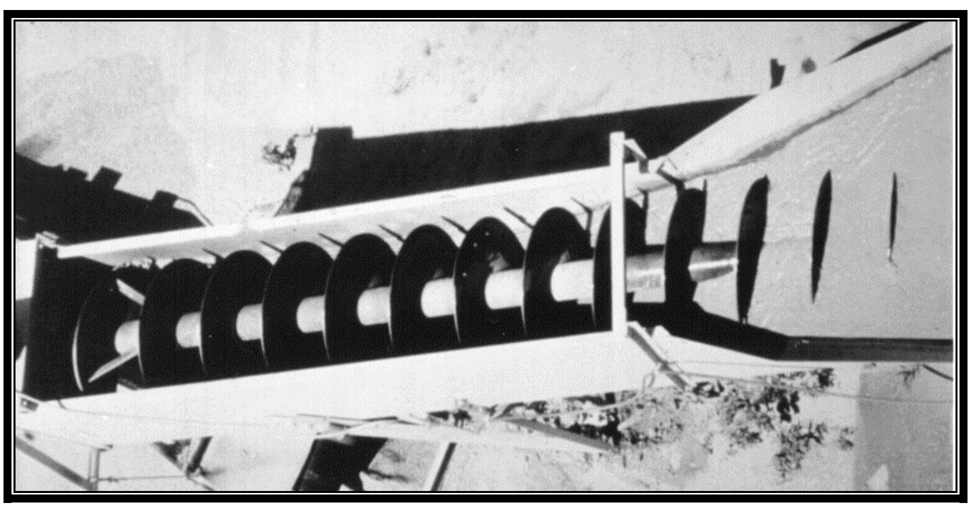


Figure 5-18. Dewatering Screw

A variation of the dewatering screw is the dewatering wheel (Figure 5-19). This device also is capable only of making a cut in the feed stock but may be more finely tuned and may be the better choice when trying to retain as much No. 50 and No. 100 material as possible.

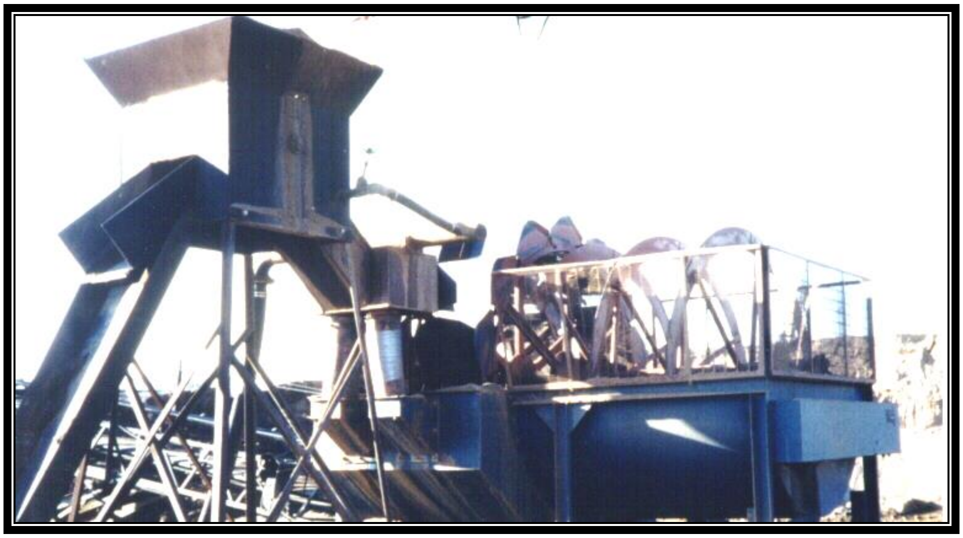


Figure 5-19. Dewatering Wheel

An even more sensitive method of cutting out fines is the wet cyclone (Figure 5-20). The sand slurry in the cyclone is spun at a prescribed velocity. Centrifugal force separates the coarser fraction from the water and fines which exit to the pond.

Figure 5-20. Wet Cyclone

Any of these techniques could conceivably be used with others in tandem or in tandem with rinse screens. The material could then be back-blended to create a desired product. A simpler and probably more cost effective way to control a sand gradation on multiple sieves is the rising current, multiple cell classifier (Figure 5-21). This equipment has numerous cells, each having varying water pressures that for different sizes of material. Any number of cells may then be combined to create the final product. With this type of system a high degree of process control is possible.

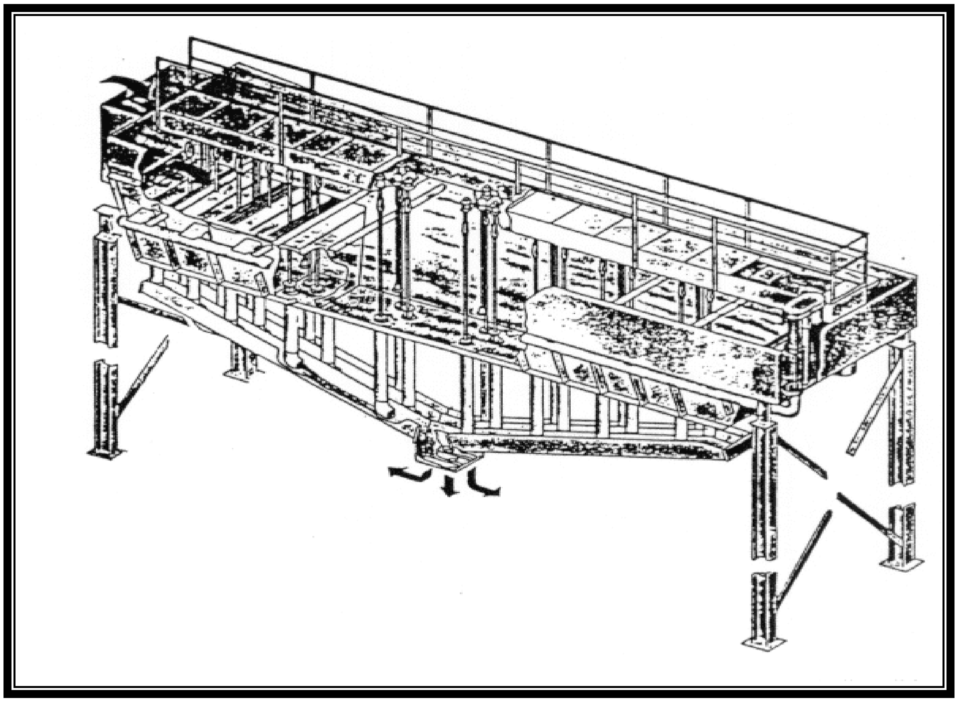


Figure 5-21. Multiple Cell Classifier

SEGREGATION

Product conformity and uniformity may be predicted if all of the inputs into the plant are measured, evaluated, and controlled. Whenever one rock is placed upon another rock, segregation may reduce the uniformity that the Producer so carefully has built into the product.

Segregation begins on the belt where fines vibrate to the bottom and coarse aggregate remains on the top as the material bounces across the idlers (Figure 5-22). At the end of the belt, if left un-deflected, the coarse particles are thrown out and away. Fine particles, on the other hand, tend to drop down or if wet even follow back underneath the conveyor. The greater the speed of the belt, the worse the segregation problem is. This is known as front-to-back segregation and may be addressed by the following methods:

1) Belt wipers underneath the head pulley that reduce carry back

2) Movable stackers kept near the top of the pile to reduce the spread

3) Mixing paddles or deflectors at the head pulley to keep the material together (Figure 5-23)

4) Wider belts at lower velocities to prevent segregation

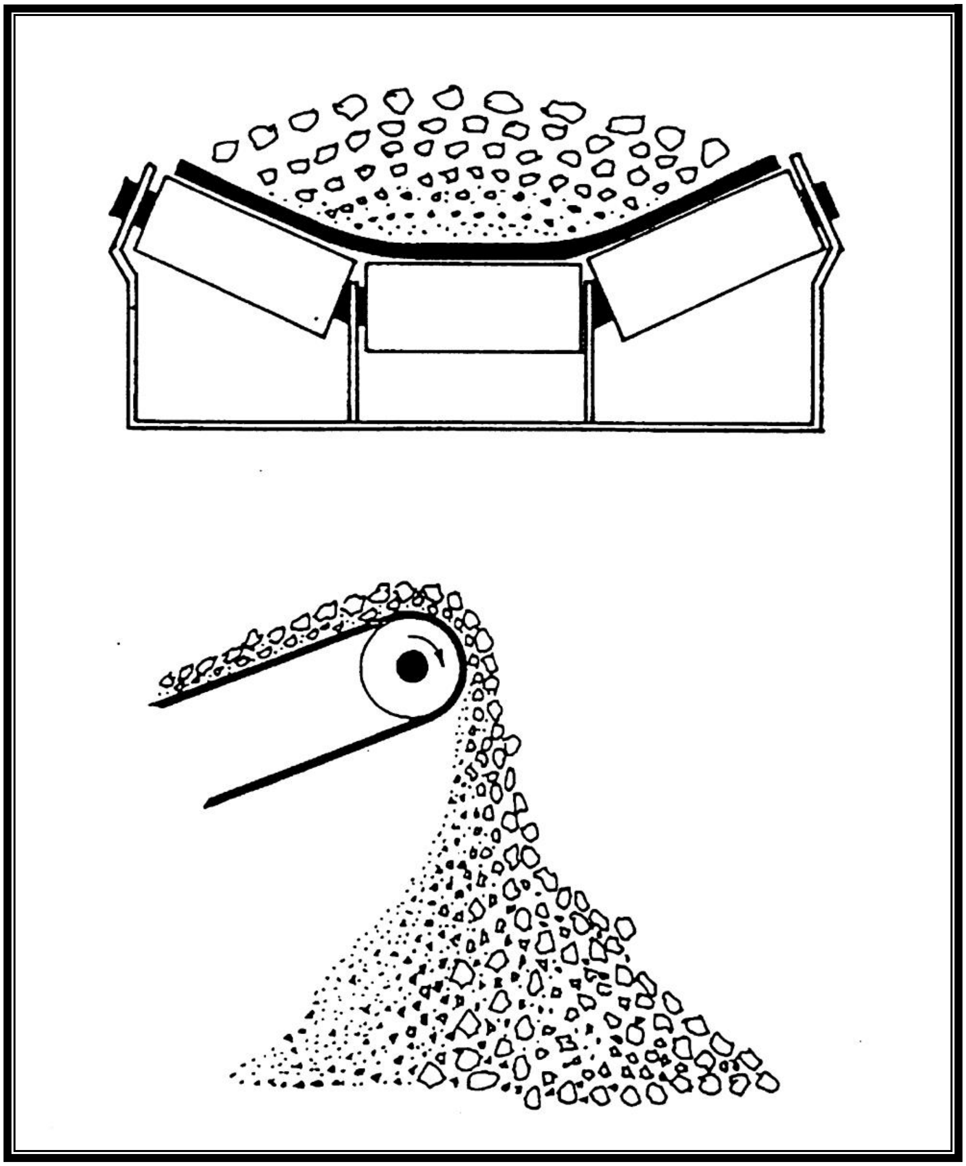


Figure 5-22. Belt Segregation

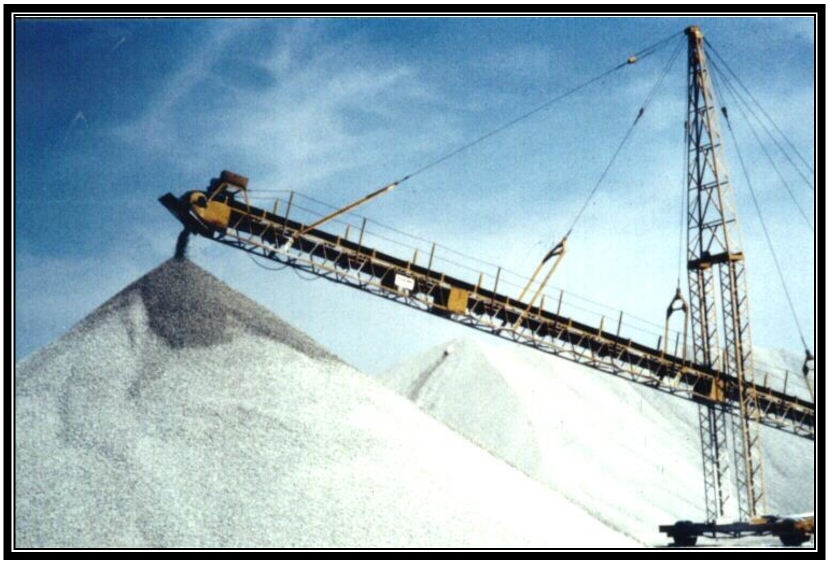


Figure 5-23. Adjustable Conveyor with Mixing Paddle

A second common type of segregation is "roll down," which occurs any time aggregate is piled so that large particles roll down the sloped side of the pile (Figure 5-24). The higher the pile, the worse this problem is. This type of segregation is very obvious in operations with high conical stockpiles, but also occurs in improperly loaded trucks. Keeping storage bins over half-full whenever possible improves the situation.

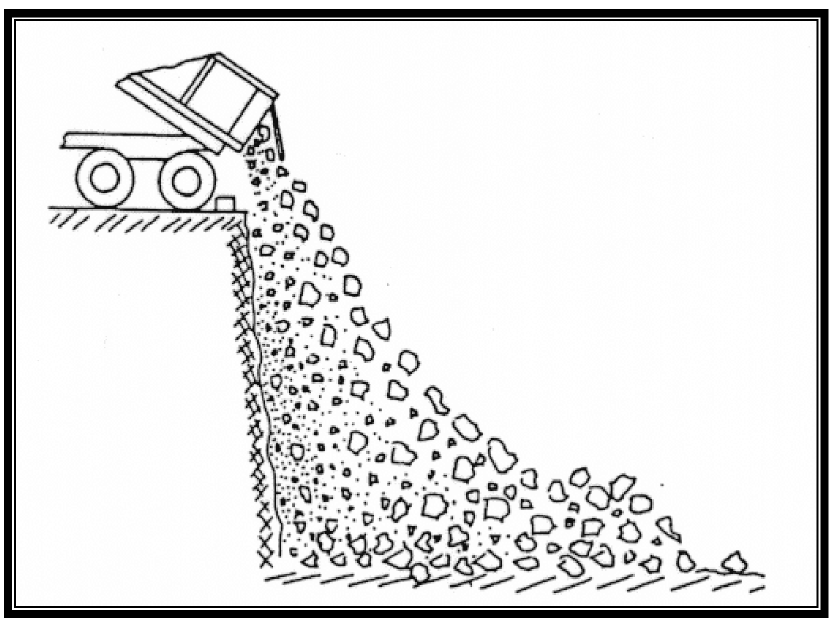


Figure 5-24. End Dump Segregation.

STOCKPILING AND HANDLING

Segregation is probably the greatest problem that occurs because of stockpiling and handling, but certainly other problems such as degradation and contamination may adversely affect product quality. Every possible precaution is required to be taken to protect the product quality from the point of manufacture to the point where the aggregate leaves the Producer's control.

CONE STOCKPILES

Although the cone stockpile is very common in the aggregate industry, two stockpile procedures may easily reduce product integrity. Roll-down segregation obviously occurs in full circle around the pile, and very high piles are difficult to adequately remix before shipping. These piles usually are being replenished with fresh material as old and new material is being removed, which keeps the product size in a state of continual change (Figure 5-25).

Figure 5-25. Material Added to Cone

In some cases the "front-to-back" segregation adds extra coarse material thrown forward and extra fines carried back for even greater variability. In addition, some piles are not fully retrieved for several years and the new product that is added to the old pile may even have different production targets (figure 5-26). Situations like these add up to serious problems for predicting gradation uniformity in the retrieved product.

Figure 5-26. Comingled Cone Piles

The final element of a cone pile that adds to the effects of both the roll-down and front-to-back phenomena is an excessively high drop from the end of a fixed conveyor to the top of the pile (Figure 5-27). This procedure should be avoided. Use of cone stockpiles should be kept to a minimum and used with extreme caution.

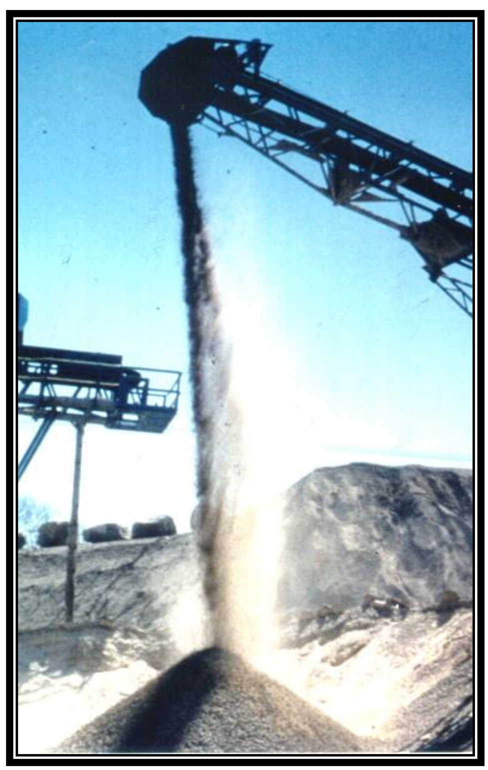


Figure 5-27. High Conveyor Drop

RADIAL STOCKPILES

A radial stacker (Figure 5-28) is a compromise solution for conveyor-built stockpiles, especially if kept less than 20 ft. The proper technique is to keep the end of the movable conveyor less than a meter from the top of the pile and raise the conveyor with the pile to the full height. Then the conveyor is moved horizontally with the pile in small increments. In this manner the pile is constructed at one end while the products are retrieved at the other end.

Figure 5-28. Radial Stacker

Although roll-down segregation does occur from the sides of the pile, a continual remixing of coarse and fine material occurs longitudinally as the pile advances. Proper retrieval may take care of the edges.

TRUCK BUILT STOCKPILES

If piles from the end of the product belts are thoroughly remixed then truck-built stockpiles (Figure 5-29) are capable of greatly minimizing segregation, if the trucks are loaded properly. The best truck-built stockpiles are those that are constructed one dump high with each dump placed against previously dumped material. This procedure, because of the low profile, reduces roll-down segregation and allows remixing during load out. However, these stockpiles require more space than the others mentioned. A technique that may help reduce the required area is to restock some dumps on top of other dumps with a large end loader operating from ground level. In this case, care is required to be taken to place the upper lift back from the edge far enough that a long sloped face is not created that would cause the same kind of roll-down problem that this type of pile is meant to eliminate.

Figure 5-29. Low Profile Truck Stockpiles

LAYERED STOCKPILES

A layered stockpile, if built correctly, may also greatly minimize segregation. Unfortunately these types of stockpiles are very difficult to build properly. Each layer is placed uniformly across the top of the pile in thin horizontal lifts. Care is required to be taken to keep the edge of each new lift set back from the edge of each previous lift so as not to create long sloped edges. This is best done with a large clam shell crane, which is slow and tedious, or with specially made equipment that may place the layers without being on the pile. A compromise is to allow hauling equipment on top of the pile; however, this procedure causes degradation of the product, and the pushing equipment may move the material over the edges causing severe segregation (Figure 5-30). Generally, these activities are poorly managed, and the stockpile takes on the shape of a ramp and spills over. These situations are very detrimental to product quality.

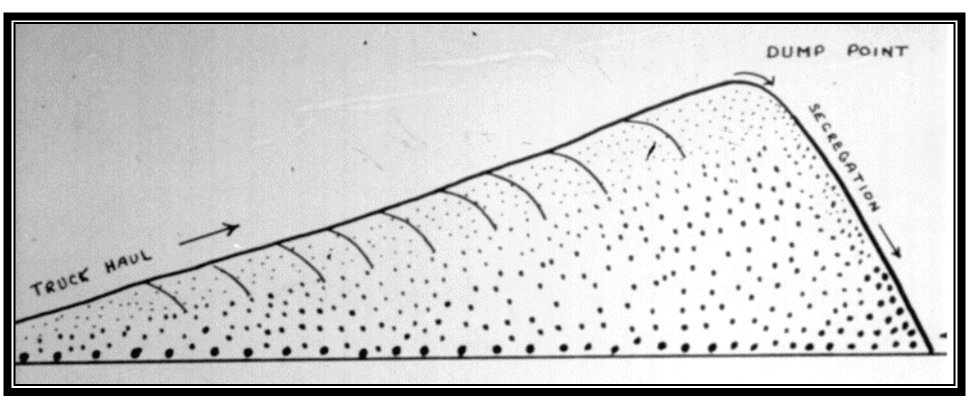


Figure 5-30. Ramp and End Dump

The Producer is required to write standard operating procedures on building stockpiles for each product and to educate all those involved in their responsibilities in the procedure. Most stockpiling problems are created because of inconsistent management. The procedures are required to become part of the Quality Control Plan. Illustrations at the end of this chapter indicate the different techniques that may be used for stockpiling and retrieving. The Segregation Index (S.I.) indicated with each example is a numerical index where the numbers are associated only with the other techniques and indicate greater segregation severity as they become higher.

DEGRADATION

Degradation or breakdown of the product is often caused by equipment running on top of the aggregate when the aggregate is being stockpiled (Figure 5-31). When this occurs, the degraded portion of the pile is required to be discarded before shipping. The difficulty lies in knowing where the "bad" material begins and ends. Extensive sampling and testing in these cases may be needed prior to shipping to determine what product is not good enough to ship. Degradation may also occur during retrieval where some of the lower portion of the pile is carelessly run over with equipment while loading out. A Producer is required to know which products tend to degrade with handling and make appropriate allowances. For example, many stone sands increase in minus No. 200 content each time they are loaded and moved. In some cases old stockpiles may degrade through weathering. Piles two years and older are required to be rechecked for gradation before shipping and possibly even for mineral quality.

Figure 5-31. Equipment on Stockpile

CONTAMINATION

Contamination (Figure 5-32) is usually the result of carelessness and poor housekeeping. In order to save space, stockpiles of different products are placed close together and as they grow in size they grow together. Equipment also may track dirt or other foreign matter into the product pile area. Old piles are subject to wind-blown fines over time and are required to be checked for this before shipping.

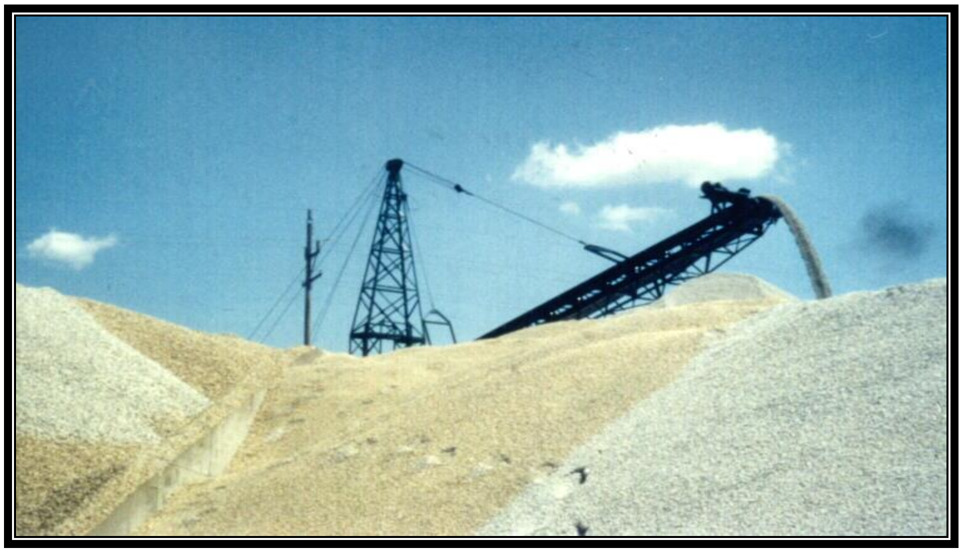


Figure 5-32. Comingled Stockpiles

RETRIEVAL

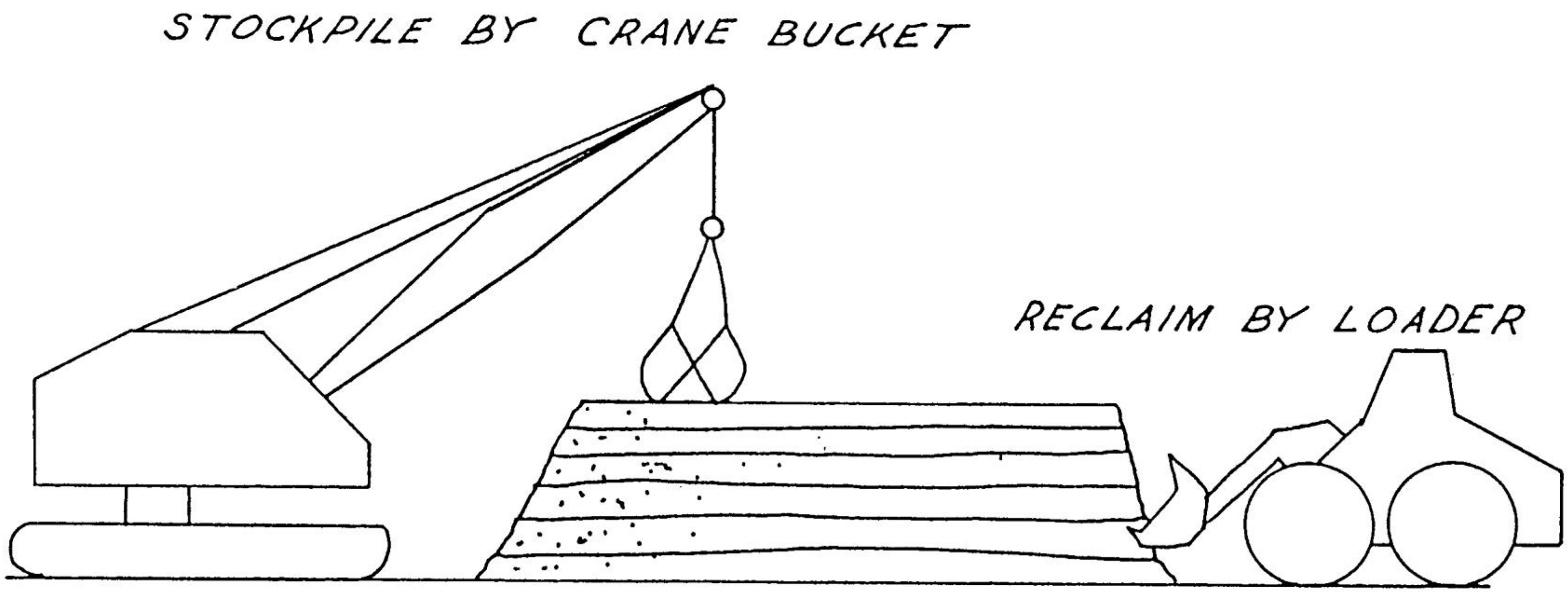
Retrieving material properly from a stockpile is just as important as building the stockpile properly (Figure 5-33). Truckers often force their way into the loading area, causing the loader operator to load from areas other than the working face. This practice is not allowed. Strict procedures for load out are required to be written, adhered to, and become routine as part of standard operating procedures. Loading from the outside of an un-worked pile for the sake of convenience may very quickly result in an unsatisfactory product.

Cone-shaped stockpiles are the most difficult to approach. Once retrieval has begun, no new material is added to the pile. To maintain a representative gradation, exactly one-half of the pile is required to be removed, the edges (coarse) folded into the center (fine), and the entire mass turned over and made into a level pad. The product is then ready for shipping. After shipping the first half of the pile, the procedure is required to be repeated for the second half. New material is required to be placed elsewhere in the meantime.

For radial or tent-shaped stockpiles, retrieval is required to begin at the oldest end while new material continues to be placed at the other end. The first entry into a new pile is handled as described above since the beginning of a radial pile is half-conical shaped. After a face has been established parallel to the stacking conveyor, continued mixing occurs in front of the load out face by pulling material from the center of the pile and mixing the material with the edges. The face is required to be kept as uniform as possible. At no time should new material be placed at the load out face.

For layered stockpiles more than one loader bucket high, remixing is necessary as the height of the pile and type of the product required. For low-profile truck-built stockpiles, only minor remixing is required when encountering the edges.

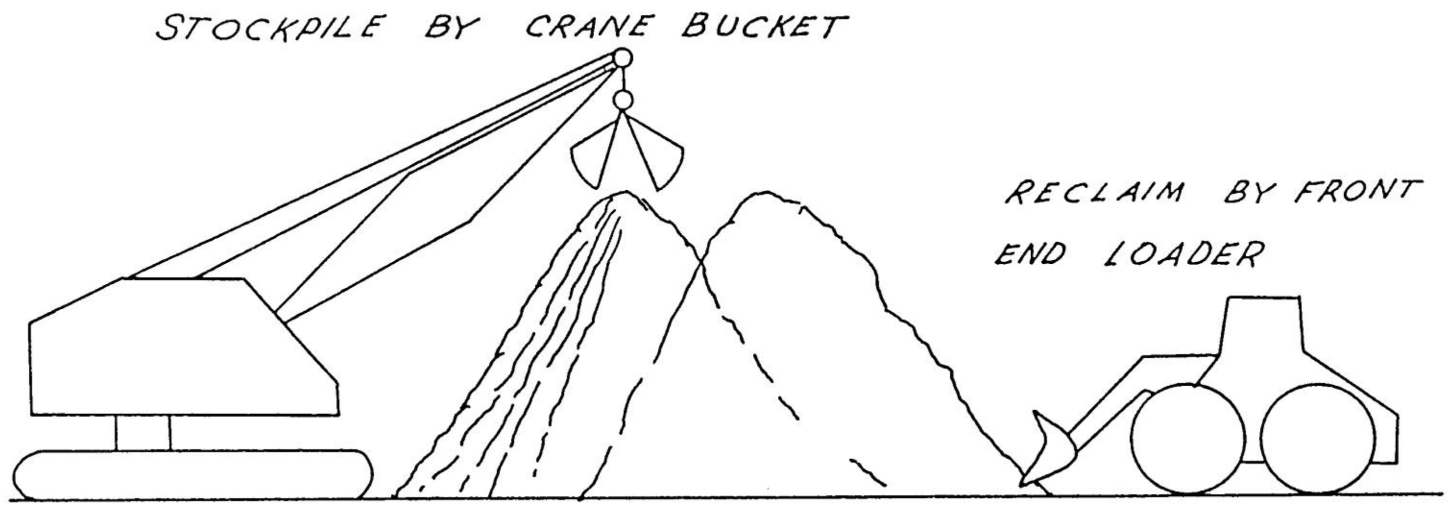
Figure 5-33. Retrieval from Stockpile



STOCKPILE METHOD #1

SPREADING AGGREGATE IN THIN LAYERS WITH CRANE BUCKET

BEST METHOD → SEGREGATION INDEX 1.35



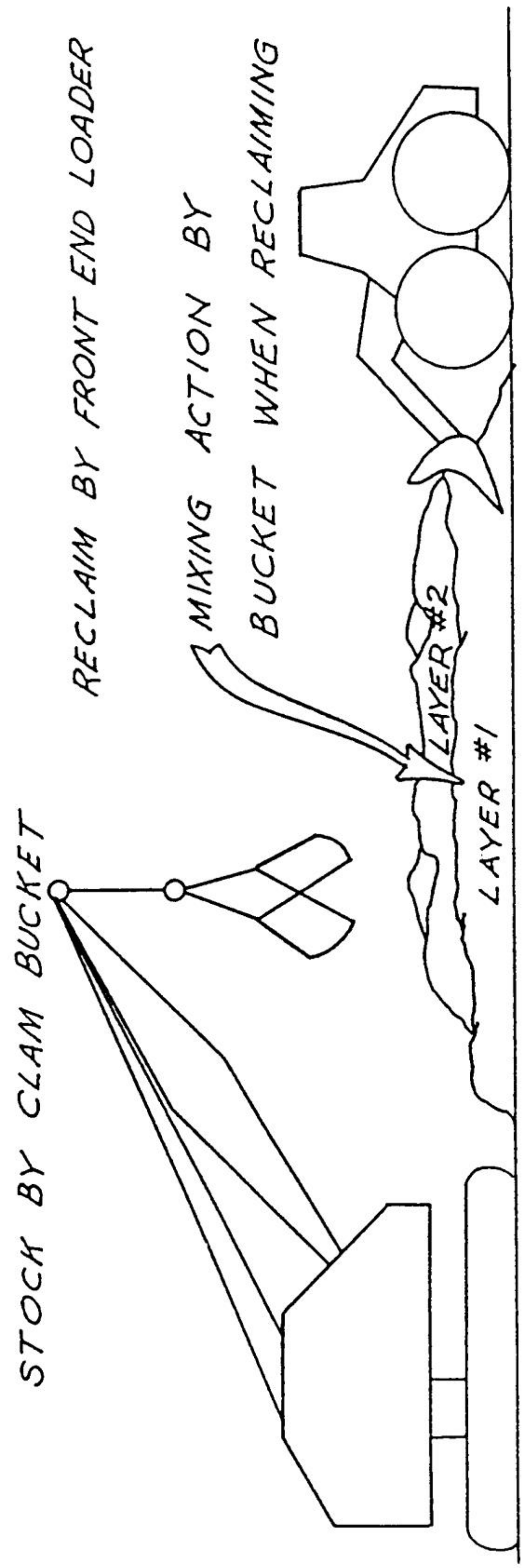
(COARSE GOES TO OUTSIDE OF CONE - FINES TO THE CENTER
RECLAIMING BY LOADER REMIXES COARSE AND FINE)

STOCKPILE METHOD #2

TWO CONES (APPROX. 750 TONS) CONSTRUCTED BY CRANE BUCKET

RECLAIM BY FRONT END LOADER

SEGREGATION INDEX - 16.48

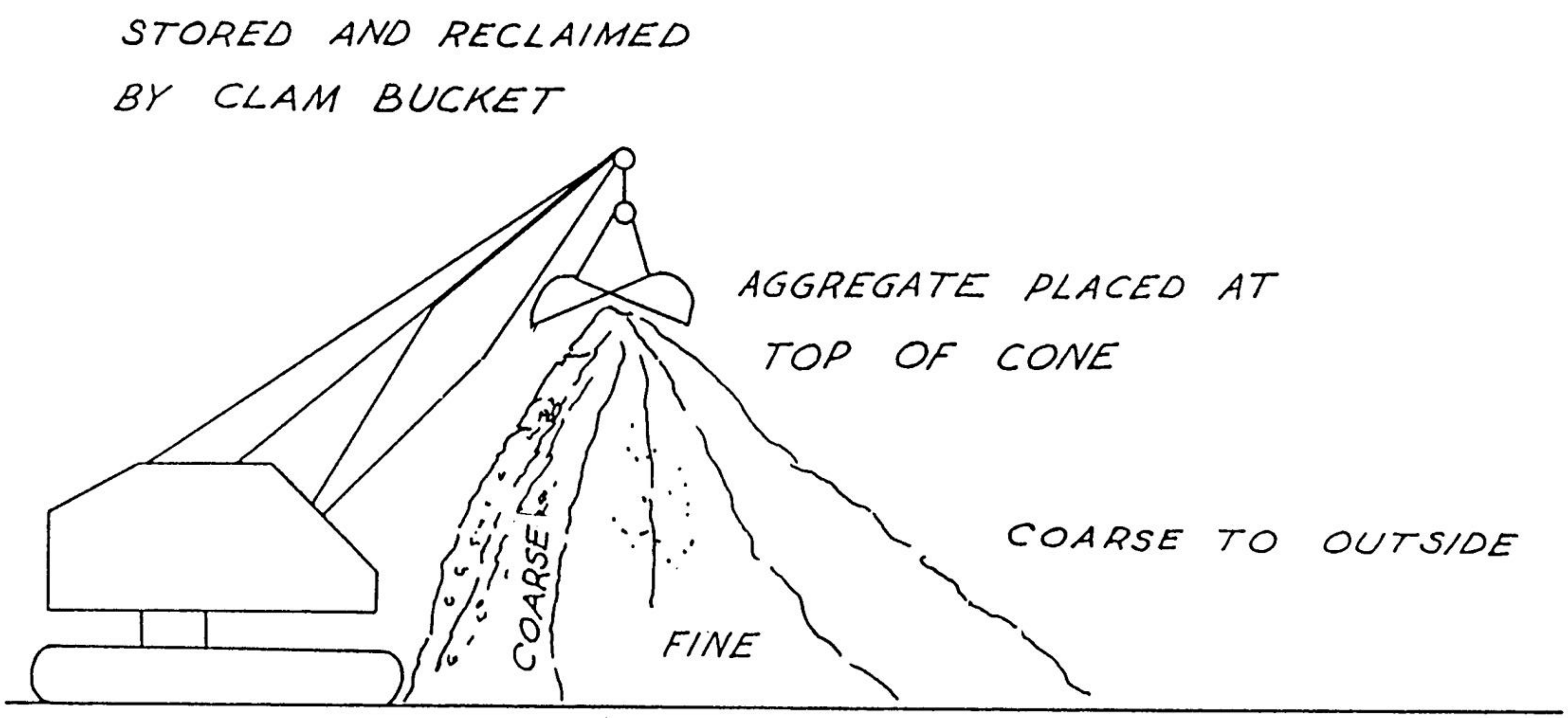


STOCKPILE METHOD #3

FLAT - LAYERED PILE BUILT WITH CLAM BUCKET

RECLAIM WITH FRONT END LOADER

SEGREGATION INDEX - 1.96

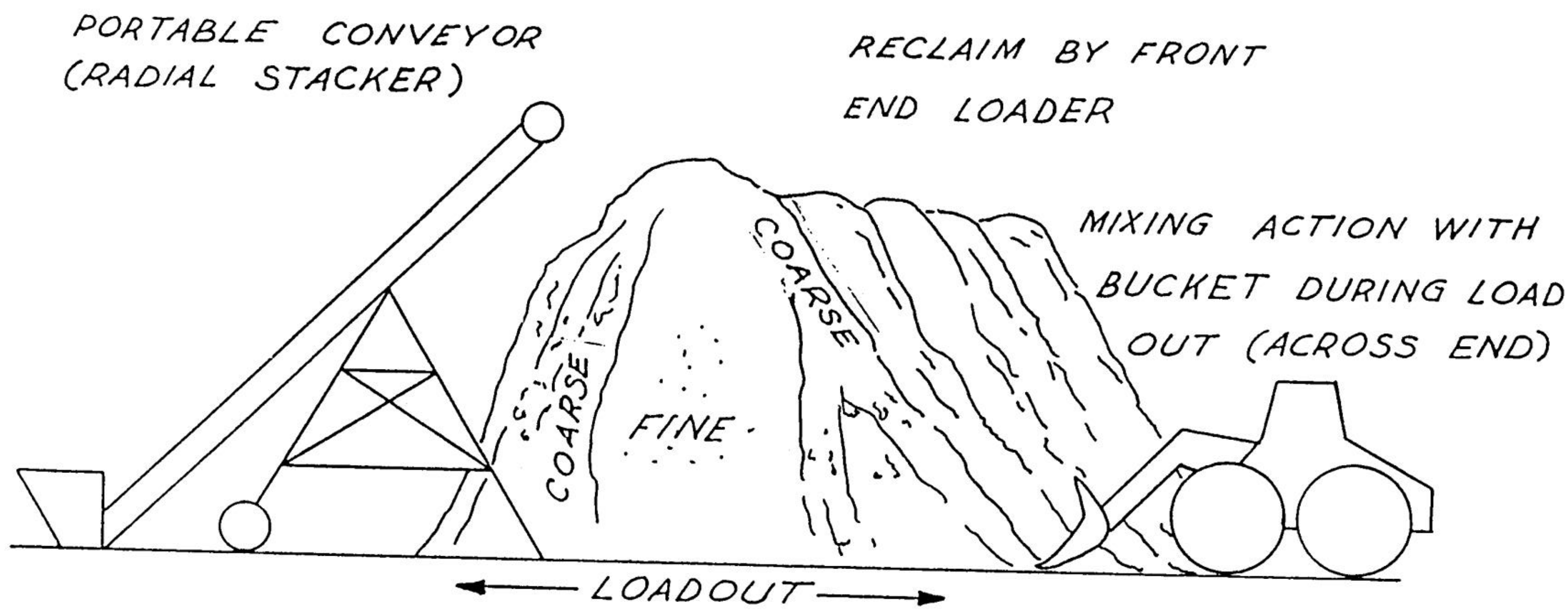


STOCKPILE METHOD #4

SINGLE CONE BUILT WITH CLAM BUCKET (APPROX 1,500 TONS)

RECLAIMED BY CLAM BUCKET IN HORIZONTAL LAYERS

SEGREGATION INDEX - 16.86 (WORST METHOD)



STOCKPILE METHOD #5

TENT SHAPED STOCKPILE - BUILT WITH PORTABLE CONVEYOR

RECLAIMING BY FRONT END LOADER

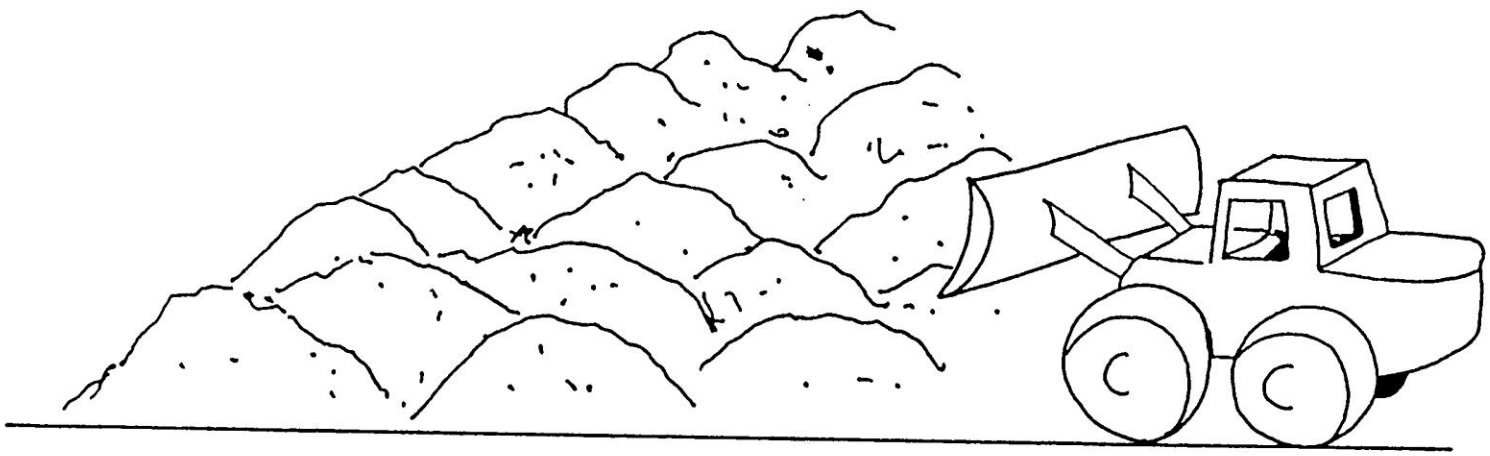
SEGREGATION INDEX - 8.10

LIMITING FACTORS

HEIGHT OF LOADER BUCKET

LARGE AREA REQUIRED

STOCKED AND RECLAIMED BY FRONT END LOADER

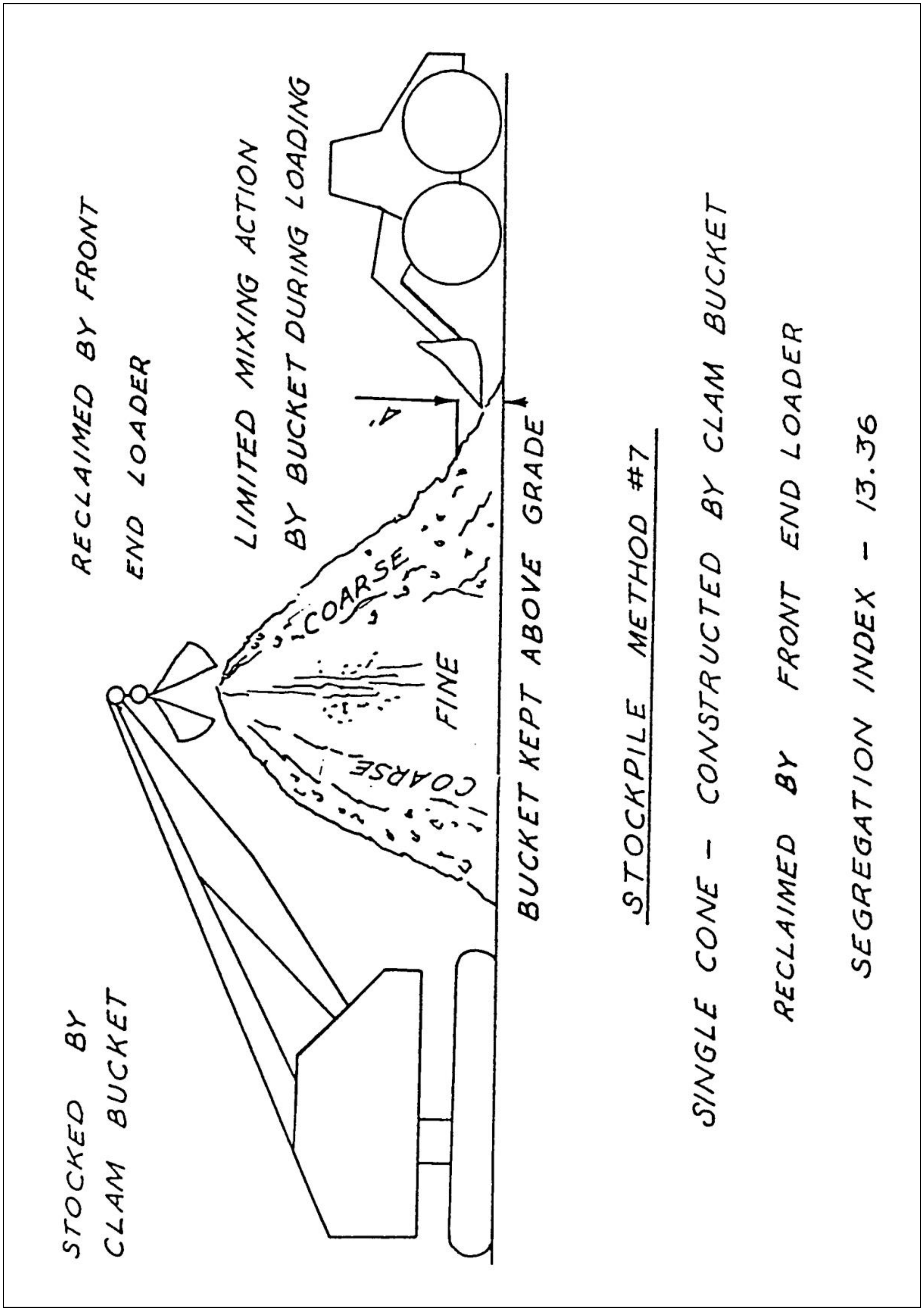


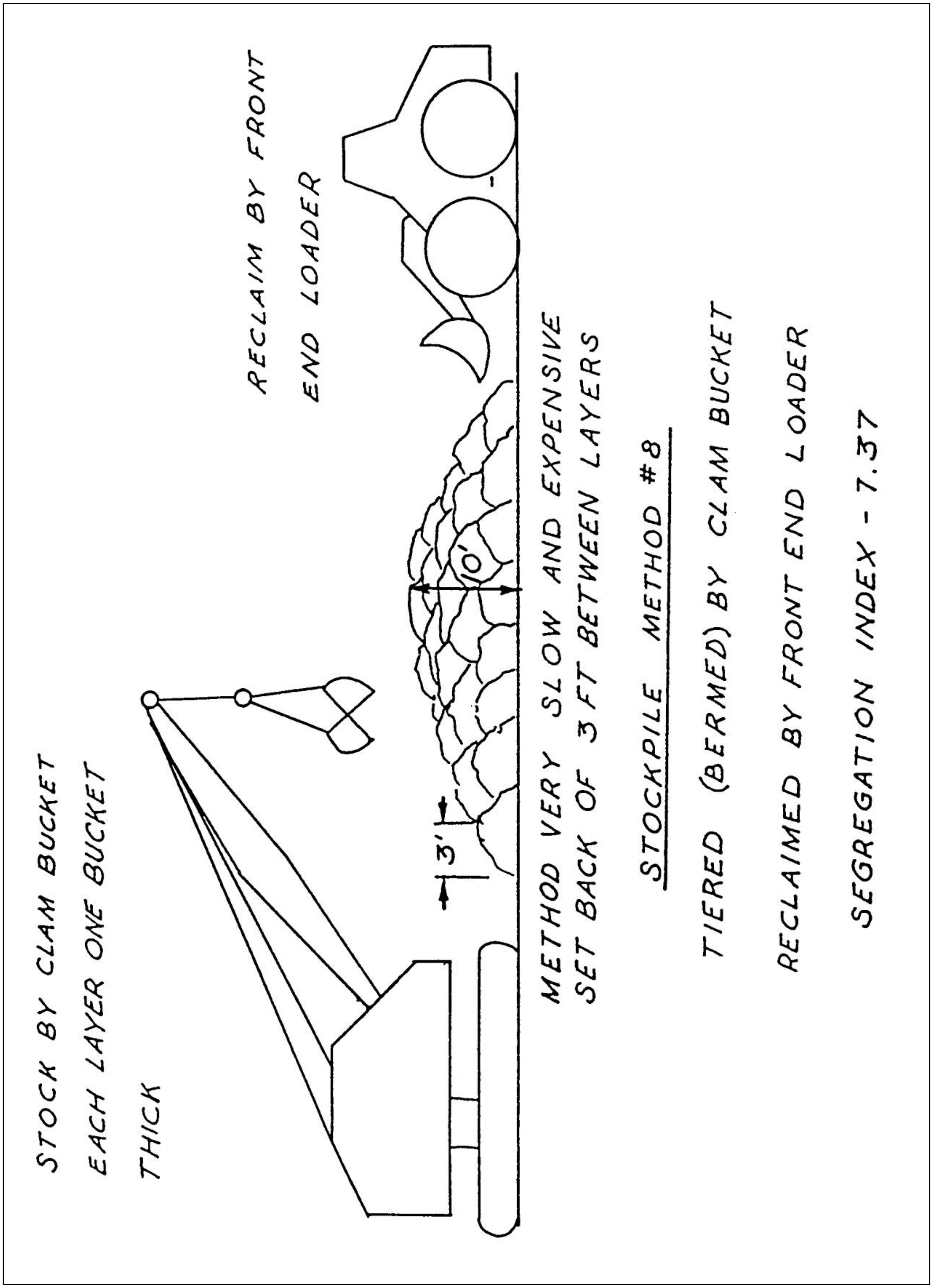
STOCKPILE METHOD #6

FLAT LAYERED CONSTRUCTED BY FRONT END LOADER

RECLAIMED BY FRONT END LOADER

SEGREGATION INDEX - 4.05


STOCKED BY
CLAM BUCKET
RECLAIMED BY FRONT
END LOADER
LIMITED MIXING ACTION
BY BUCKET DURING LOADING
COARSE
FINE
COARSE
BUCKET KEPT ABOVE GRADE
STOCKPILE METHOD #7
SINGLE CONE - CONSTRUCTED BY CLAM BUCKET
RECLAIMED BY FRONT END LOADER
SEGREGATION INDEX - 13.36

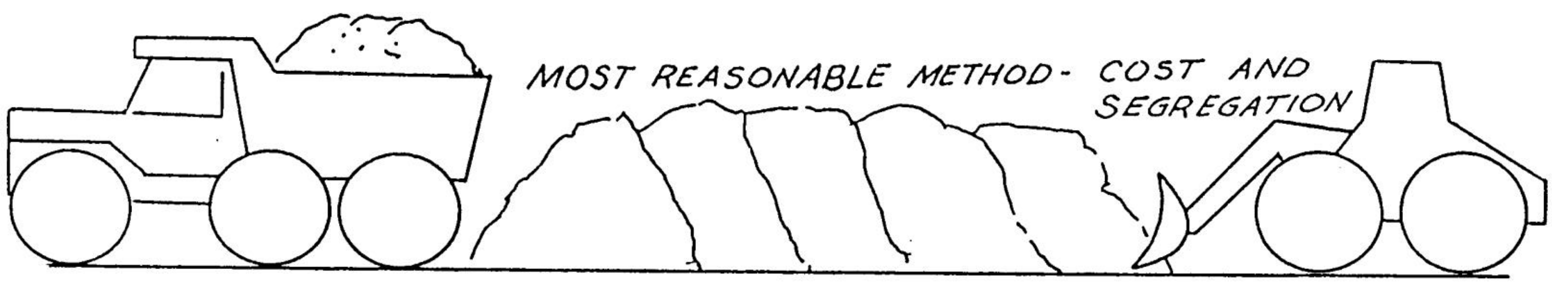

STOCK BY CLAM BUCKET
EACH LAYER ONE BUCKET
THICK
RECLAIM BY FRONT
END LOADER
3'
10'
METHOD VERY SLOW AND EXPENSIVE
SET BACK OF 3 FT BETWEEN LAYERS
STOCKPILE METHOD #8
TIERED (BERMED) BY CLAM BUCKET
RECLAIMED BY FRONT END LOADER
SEGREGATION INDEX - 7.37

STOCKED BY TRUCK BACKED
INTO SIDE OF PRECEDING PILE

RECLAIMED BY FRONT
END LOADER

THIS METHOD CAN BE TIERED

MIXING ACTION BY
BUCKET DURING LOADING

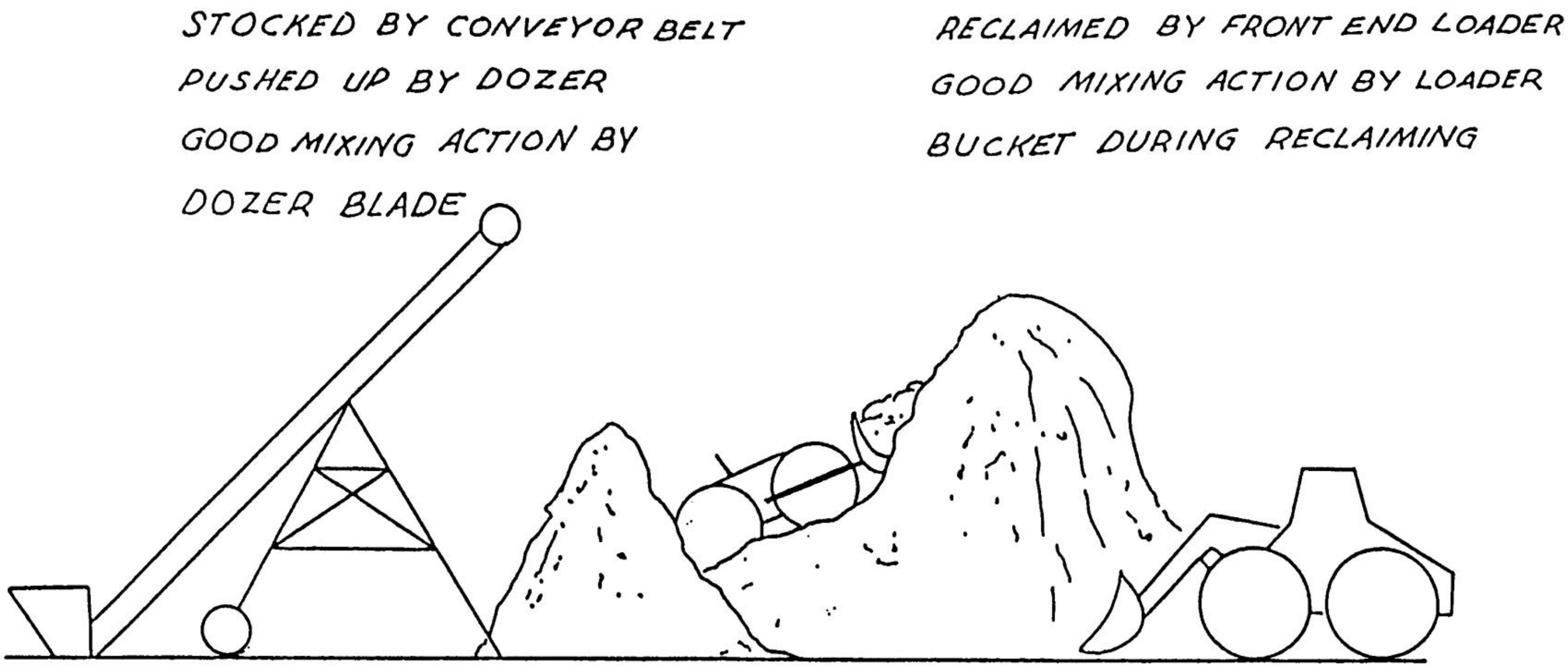


STOCKPILE METHOD #9

TRUCK DUMP SINGLE LOAD - BACKED AND DUMPED

RECLAIMED BY FRONT END LOADER

SEGREGATION INDEX 2.30



STOCKPILE METHOD #10

RAMP BUILT WITH PNEUMATIC - TIRED BULLDOZER

RECLAIMED WITH FRONT END LOADER

SEGREGATION INDEX 1.59

6 Statistical Quality Control for Aggregate Processing

Process Characteristics

Continuous Processing
Product Alteration
Multiple Products

Quality Control

Accuracy
Precision
Capability

Statistical Concepts

Data Sets
The Mean
Standard Deviation
Normal Distribution
Variability
Capability and Compliance

Control Charting

When to Use Charts
Control Chart Legend
Beginning the Control Chart
Plotting the Data
Interpreting Control Charts

Understanding the Process

Current Process
Process Stability
Decision Making
Process Capability
Process Control

CHAPTER SIX:
STATISTICAL QUALITY CONTROL FOR AGGREGATE PROCESSING

The process of producing and shipping mineral aggregate is a relatively simple one. The procedure does not require high technology, and the methods used to control this process are equally as simple. These methods, however, account for all the many difficulties a Producer may encounter in production of aggregate. Each time a decision is made that affects the process, at least three principle characteristics of this industry are required to be kept in mind: continuous processing, product alteration, and multiple products.

PROCESS CHARACTERISTICS

CONTINUOUS PROCESSING

Generally, a continuous run of material is produced which tends to lose identity through stockpiling and shipping. Good controls as far upstream as possible in production are very important.

PRODUCT ALTERATION

All aggregate products degrade and segregate with handling and time. This process occurs from beginning to the end of any production. This process may occur later, such as when the aggregates are used for producing other materials.

MULTIPLE PRODUCTS

Most aggregate operations make more than one product concurrently. A change in one product may affect each and every one of the other products.

QUALITY CONTROL

Generally speaking, the process control techniques that are most desirable are predictive in nature rather than detective techniques that provide information on the product after the material has been stockpiled for shipping. Quality control is the prediction of product performance within pre-established limits for a desired portion of the output. Two principles of quality control that are required to be adhered to are:

1) Make sure the correct target is understood and achievable

2) Control variability within pre-established limits

Once the techniques for prediction of performance are developed, then quality control is required to address three issues: accuracy, precision, and capability.

ACCURACY

If the average of all measurements falls relatively close to an understood point (on target) then the process is said to be accurate.

PRECISION

When all of the measurements over time are very close together, then the process is said to be precise.

CAPABILITY

If the process is both accurate and precise such that the process remains within Specification or other predetermined limits with a high degree of confidence, then the process is said to be capable.

Figure 6-1 gives a graphical representation of accuracy, precision, and capability.

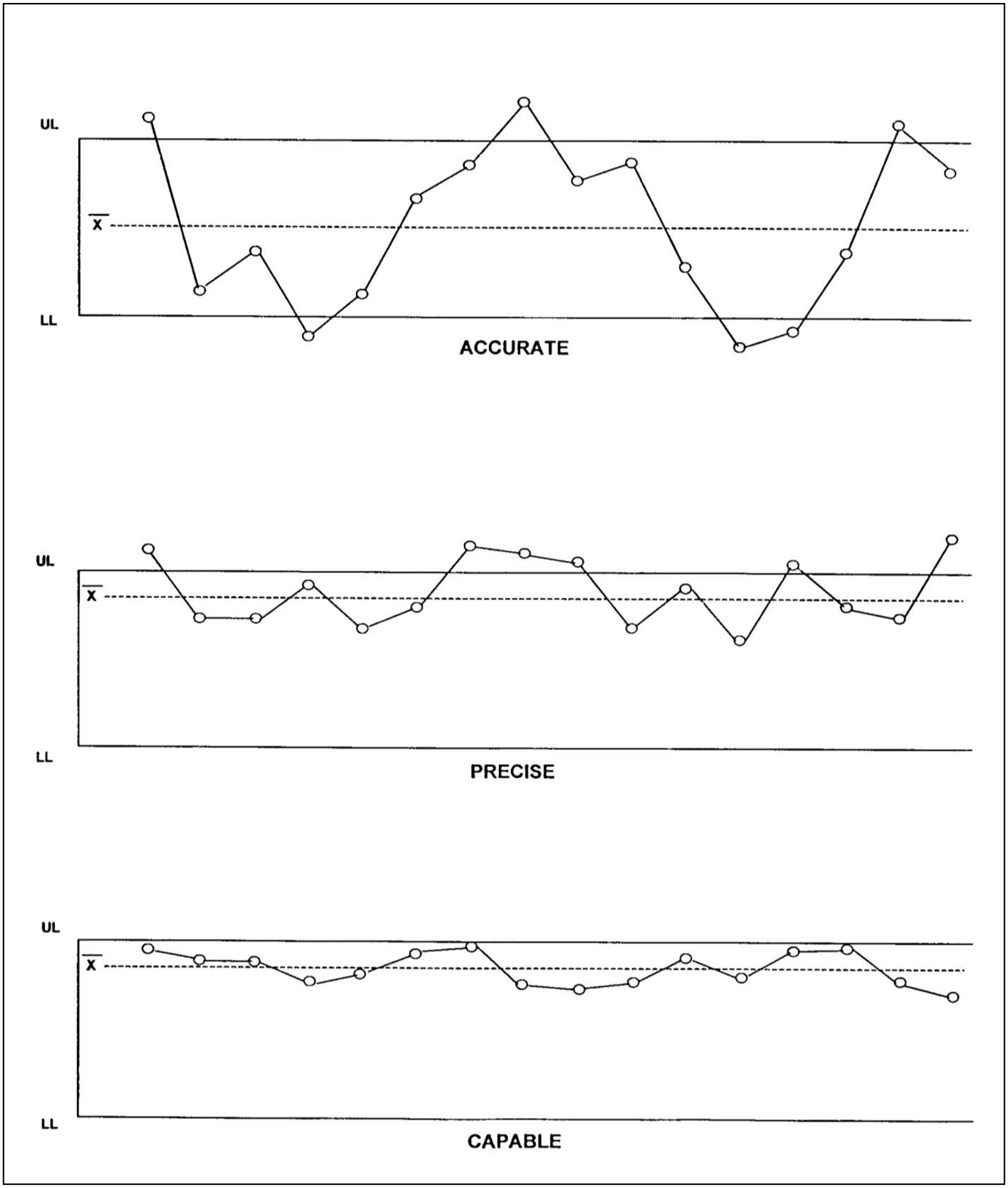


Figure 6-1. Accuracy, Precision, and Capability

STATISTICAL CONCEPTS

Complete control and improvements on any process is made by accurate measurements at critical points within the process. In order to gain confidence, the numbers are required to be generated often at various points so that all the variations of the process are detected. The quantity of measurements accumulates over time and simple tables or listings of these numbers are not enough to evaluate the process. The following statistical tools are used to understand what the numbers mean.

DATA SETS

The numbers from measurements that represent something in common rather than a scattering of unrelated numbers are called a set. When measuring properties of the process that are different, for example, gradation, crush count, or chert count, each property requires a set of numbers. Also, each property has different sets of numbers for different points in the process if the characteristics are known to change. (For example, production gradations versus stockpile gradations). Furthermore, even when properties and points of sampling are the same, a new set of data is required to have to be created if there is a significant sustained change in the process. All of the efforts at understanding, controlling, and predicting the outcome of a process are only as good as the accuracy and make-up of the related data sets. The importance of this step should not be underestimated.

THE MEAN

The average of all the data over time of an unchanged process is sometimes called the "grand mean" or the "population mean". For a shorter snapshot in time, the average may be called the "local mean" or just the "mean". The mean is the center of any distribution of numbers. Figure 1-2 is a graph of a very large group of numbers that are equally distributed on each side of the mean ($\bar{x}$). The graphic representation of these numbers is called a "standard bell curve".

STANDARD DEVIATION

Whereas the mean is an average of all the data values, the standard deviation is an average value of the dispersion of data from the mean. The standard deviation indicates how much the process varies and determines the shape of the bell curve. Small values reflect a tall, narrow curve (good), while large values reflect a flat, broad curve (poor).

NORMAL DISTRIBUTION

To simplify the interpretation of the data sets, the assumption is made that the data mathematically falls into a normal distribution which when plotted resembles the bell shaped curve. Although few actual processes exactly follow this assumption, they are close enough when stable and in control to be useful statistically. By assuming a normal distribution of the data, a few simple formulas may be applied to give the desired picture of the process. Any area under the bell curve falling between certain limits from left to right when expressed as a percentage of the total indicate the portion of that process that conforms to those limits (Figure 6-2). The further data values move right or left from the center of the curve, the less often these values occur.

Some values that serve as handy reference points for the normal distribution are:

1) About two-thirds of the area under the normal curve lies between one standard deviation below the mean and one standard deviation above the mean

2) About 95 percent lies between plus and minus two standard deviations

3) About 99.75 percent lies within three standard deviations of the mean

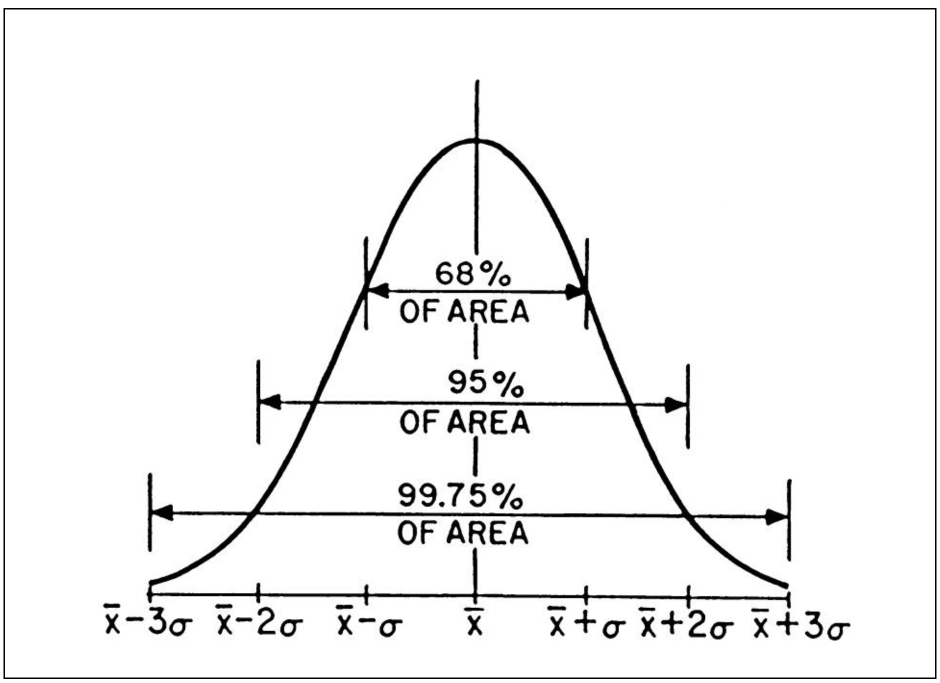


Figure 6-2. Normal Distribution

VARIABILITY

In-control conditions are required to be achieved for each critical characteristic and point in the process. Sources of variability for the same characteristic at different points in the process are cumulative. During the production, handling, and stockpiling of mineral aggregates, the sources of error are potentially many. Therefore, controls are required to be instituted upstream as well as throughout the process. Also, sampling and testing error may affect the variability. Although sampling and testing error will not affect the actual variation of the process, the misleading information may cause incorrect control techniques to be employed and possibly increase variability in the product. The lower the sampling and testing error, the more indicative the data of the process is.

CAPABILITY AND COMPLIANCE

The mean, standard deviation and variance indicate the location of the process and how consistent the process is. This is very important in exercising control. By themselves, however, they do not indicate how well the process meets certain specifications or other limits. The ability of the process to comply with externally imposed limits is called capability. The first useful tool in making this assessment is the Z value. This value indicates the number of standard deviations that the mean is from a particular limit. The greater the Z value, the more compliant or capable the process is (Figure 6-3).

There are two principle applications of the Z value in the Certified Aggregate Producer (CAP) Program:

1) Qualifying a Product -- Before a critical sieve product may qualify for use under the CAP Program, the data generation during new product qualification testing is required to demonstrate a Z value of at least 1.65 or higher within the specification limits of that product.

2) Control and Compliance -- After qualification of a product, the Z value from the data generated during control and shipping is required to result in a compliance level of 95 % or better for all control sieve products within 10 % above and 10 % below the target mean.

The Z Value

$$Z = \frac{X_{Limit} - \overline{X}}{\sigma_{n-1}}$$

$$Z_{Upper} = \frac{UpperLimit - \overline{X}}{\sigma_{n-1}}$$

$$Z_{Lower} = \frac{\overline{X} - LowerLimit}{\sigma_{n-1}}$$

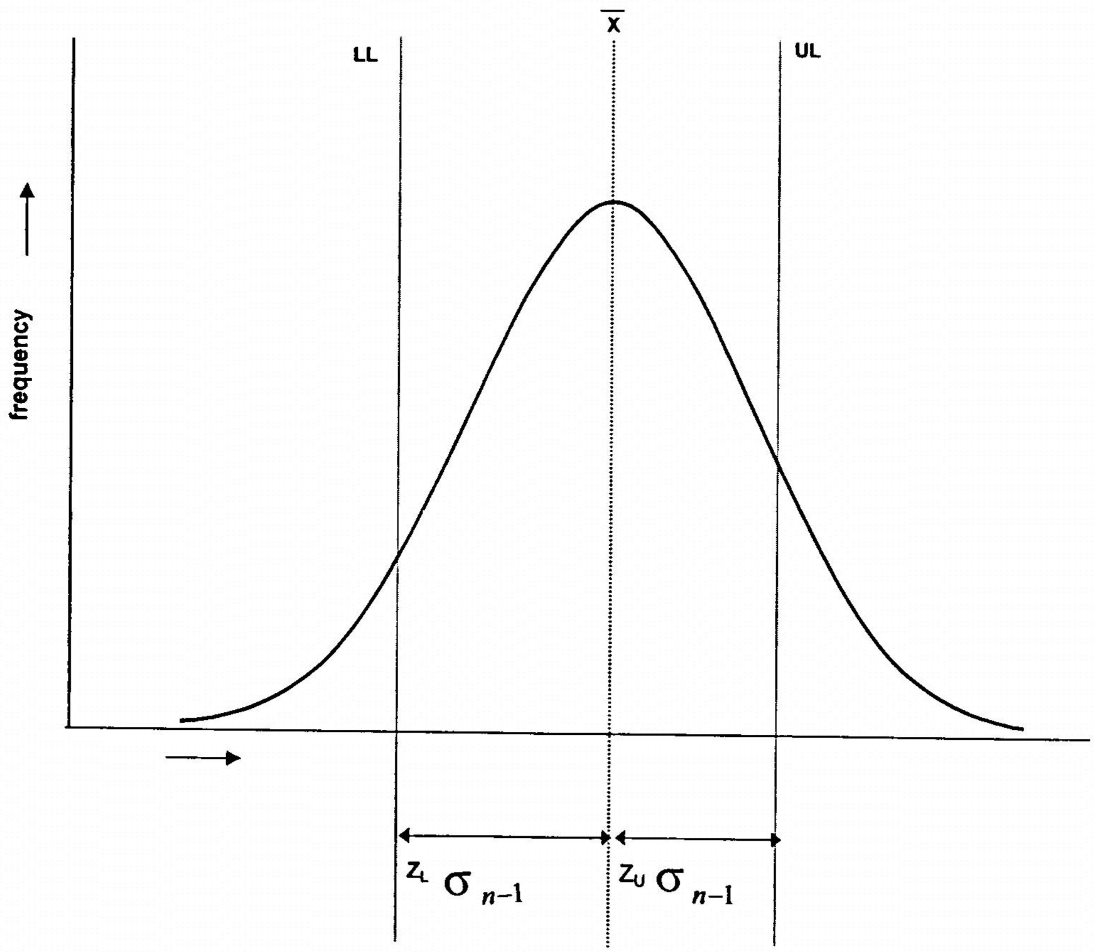
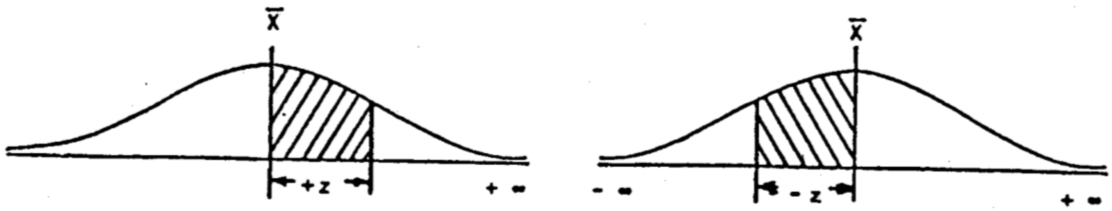


Figure 6-3. The area under the curve between the mean ($\overline{x}$) and another point (x), depends on Z which is the arithmetic difference between x and $\overline{x}$, divided by the standard deviation (σ_{n-1}).

When the Z values to each limit are known, this table indicates the area of probability between limits by summing the area left of the $\bar{x}$ with the area right of the $\bar{x}$ The sum of the two area factors should be multiplied by 100 to give the percent probability of compliance.



	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0159	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2518	0.2549
0.7	0.2580	0.2612	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4083	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4430	0.4441
1.6	0.4452	0.4463	0.4474	0.4485	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4758	0.4762	0.4767
2.0	0.4773	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4865	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4980	0.4980	0.4981
2.9	0.4981	0.4982	0.4983	0.4984	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4986	0.4987	0.4987	0.4988	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990
3.1	0.4990	0.4991	0.4991	0.4991	0.4992	0.4992	0.4992	0.4992	0.4993	0.4993
3.2	0.4993									
3.3	0.4995									
3.4	0.4997									

Table 6-1. Area of Probability Table for Specifications Involving > 0 Percent and < 100 Percent

The CAP Program requires that 95 % of all gradation test results on the critical sieve statistically be between 10 % below and 10 % above the target mean at any one point of sampling. An example of how to calculate percent compliance is as follows:

Product: #8 Stone
Critical Sieve: 1/2 in.
QCP Target Mean: 52.2%

The most recent 30 production sample test results:

55.5	49.4	49.5	55.6	61.3
51.2	46.0	50.8	53.8	49.7
53.2	42.4	50.5	52.8	54.6
56.4	53.1	55.2	53.6	58.1
54.2	65.7	56.1	52.6	56.4
48.1	50.3	59.1	52.1	50.9

$\bar{x} = \underline{53.3}$ $\sigma_{n-1} = \underline{4.53}$

$$Z_{upper} = \frac{(\text{QCP Target Mean} + 10) - \bar{x}}{\sigma_{n-1}} = \frac{(52.2 + 10) - 53.3}{4.53} = 1.96$$

from Table 6-1, 1.96 is .4750

.4750 x 100 = $\underline{47.50}$

$$Z_{lower} = \frac{\bar{x} - (\text{QCP Target Mean} - 10)}{\sigma_{n-1}} = \frac{53.3 - (52.2 - 10)}{4.53} = 2.45$$

from Table 6-1, 2.45 is .4929

.4929 x 100 = $\underline{49.29}$

% Compliance = 47.50 + 49.29 = 96.79 ≈ 97 (Whole Number)

CONTROL CHARTING

Controlling a process with one measurement is not possible. Also, only a few measurements do not provide the level of confidence needed for proper decision-making and a clear picture of the process. The only way control and decisions may be made with confidence is through the use of large data sets. The control chart is a process that may be used to guide the Aggregate Producer on a daily basis. Graphic representation of the data indicated in conjunction with prescribed limits may provide the Aggregate Producer with everything that is needed if used with the proper interpretation techniques.

WHEN TO USE CHARTS

INDOT requires that gradation control charts be maintained for most products made by a certified plant for use on INDOT contracts. Also, any characteristic that is critical to a product is a candidate for control charting. For example, crush count, chert count, or any other characteristics that may apply are characteristics that are considered for charting. In these cases, the items considered and the proposed limits are required to be included in the Quality Control Plan submitted to INDOT for approval.

CONTROL CHART LEGEND

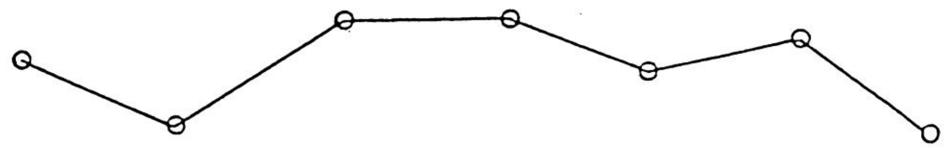
CAPP establishes a legend for specific information to be plotted on control charts. This legend convention is required to be followed, except that any proposed deviation from the procedures may be clearly identified in the Quality Control Plan.

The target mean is represented by a heavy long dash followed by a short dash.

Control limits are represented by heavy solid lines placed at plus and minus two standard deviations, but no greater than plus or minus 10 percent from the target mean.

Upper and lower specification limits are indicated by short dashed lines.

Production plot points are surrounded by small circle and each consecutive point is connected by a solid straight line.



The moving average plot point is indicated by a small triangle and connected by straight lines.

The stockpile load-out plot point is indicated by a small square.

BEGINNING THE CONTROL CHART

The principle purpose of the control chart is to visually depict a repeatable and controlled process. If the new data is expected to be part of the process population, then some definition of the process is required. The entire chart is centered around the target mean value. Ideally, the target mean is the grand mean which would be based on as much data as possible (perhaps a year), providing the process has not changed (Table 6-2 and Figure 6-4). If valid data does not exist on the process, then the control chart is established around a mean calculated from the first ten test results (Figure 6-5). The CAPP requires a QCP Annex to the Quality Control Plan identifying the new target mean to be filed with INDOT. Next, control limits are required to be added at plus and minus two standard deviations from the target mean. In no case may these limits exceed plus and minus 10 %. The Z value is required to be 1.65 or greater. If the Z value is not 1.65 or greater, the process is required to be changed.

A quick check of the location of the target mean in relation to the closest specification limit is to multiply 1.65 times the standard deviation. Then, either add or subtract the value, as appropriate, to the target mean. If the resultant number falls outside the specification band, the current process does not meet the requirements of CAPP (Specification Limit Check in Table 6-2).

PLANT: INDIANA MATERIAL SIZE: INDOT No. 9

SPEC. SIEVE	100 3/4 in.	60 - 85 1/2 in.	30 - 60 3/8 in.	0 - 15 No. 4	0 - 10 No. 8
Mar 19	100.0	68.9	38.4	4.9	2.3
Mar 19	100.0	71.2	40.8	5.2	2.9
Mar 25	100.0	70.8	36.4	3.3	2.8
Mar 25	100.0	69.8	35.2	4.5	3.6
Mar 27	100.0	69.2	37.7	3.9	2.2
Mar 31	100.0	66.3	36.9	3.3	2.1
Mar 31	100.0	70.1	40.1	3.9	2.5
Apr 6	100.0	68.0	37.2	3.6	2.8
Apr 6	100.0	69.7	34.1	3.5	2.8
Apr 8	100.0	71.6	35.1	3.0	1.9
Apr 8	100.0	70.9	37.5	3.7	2.6
Apr 11	100.0	74.8	46.0	4.0	3.1
Apr 15	100.0	77.4	42.9	3.9	1.8
Apr 17	100.0	80.3	49.2	4.9	3.1
Apr 17	100.0	74.0	34.5	3.9	2.4
Apr 20	100.0	73.4	35.4	2.9	1.9
Apr 20	100.0	79.3	40.1	4.4	3.0
Apr 21	100.0	77.5	39.7	4.0	3.2
Apr 21	100.0	78.4	43.1	3.7	2.1
Apr 22	100.0	75.2	39.7	3.6	2.3
Apr 24	100.0	80.9	45.1	4.5	1.9
Apr 24	100.0	80.4	46.5	4.6	2.3
Apr 25	100.0	75.5	38.5	3.5	1.9
Apr 30	100.0	77.2	38.0	5.8	3.6
Apr 30	100.0	76.8	42.2	3.3	2.2
MEAN	100.0	73.9	39.6	4.0	2.5
STD. DEV.	0.000	4.34	4.05	0.71	0.54

For the 3/8 in. Critical Sieve: $n = 25$, $\bar{x} = 39.6$, $\sigma_{n-1} = 4.05$

Specification Limit Check

1.65 times $\sigma_{n-1} = 1.65(4.05) = 6.7$

Upper Specification Limit (USL) check = 39.6 + 6.7 = **46.3 ≈ 46 ≤ 60**

Lower Specification Limit (LSL) check = 39.6 - 6.7 = **32.9 ≈33 ≥ 30**

Z Value Check

$$Z_u = \frac{60-39.6}{4.05} = 5.04 > 1.65$$

$$Z_L = \frac{39.6 - 30.0}{4.05} = 2.37 > 1.65$$

Establish Control Limits

Upper Control Limit (UCL) = $\bar{x} + 2\,\sigma_{n-1} = 39.6 + 2(4.05) =$ **47.7 or 48**

Lower Control Limit (LCL) = $\bar{x} - 2\,\sigma_{n-1} = 39.6 - 2(4.05) =$ **31.5 or 32**

Table 6-2. Historical Data Gradation Analysis

FROM HISTORICAL DATA

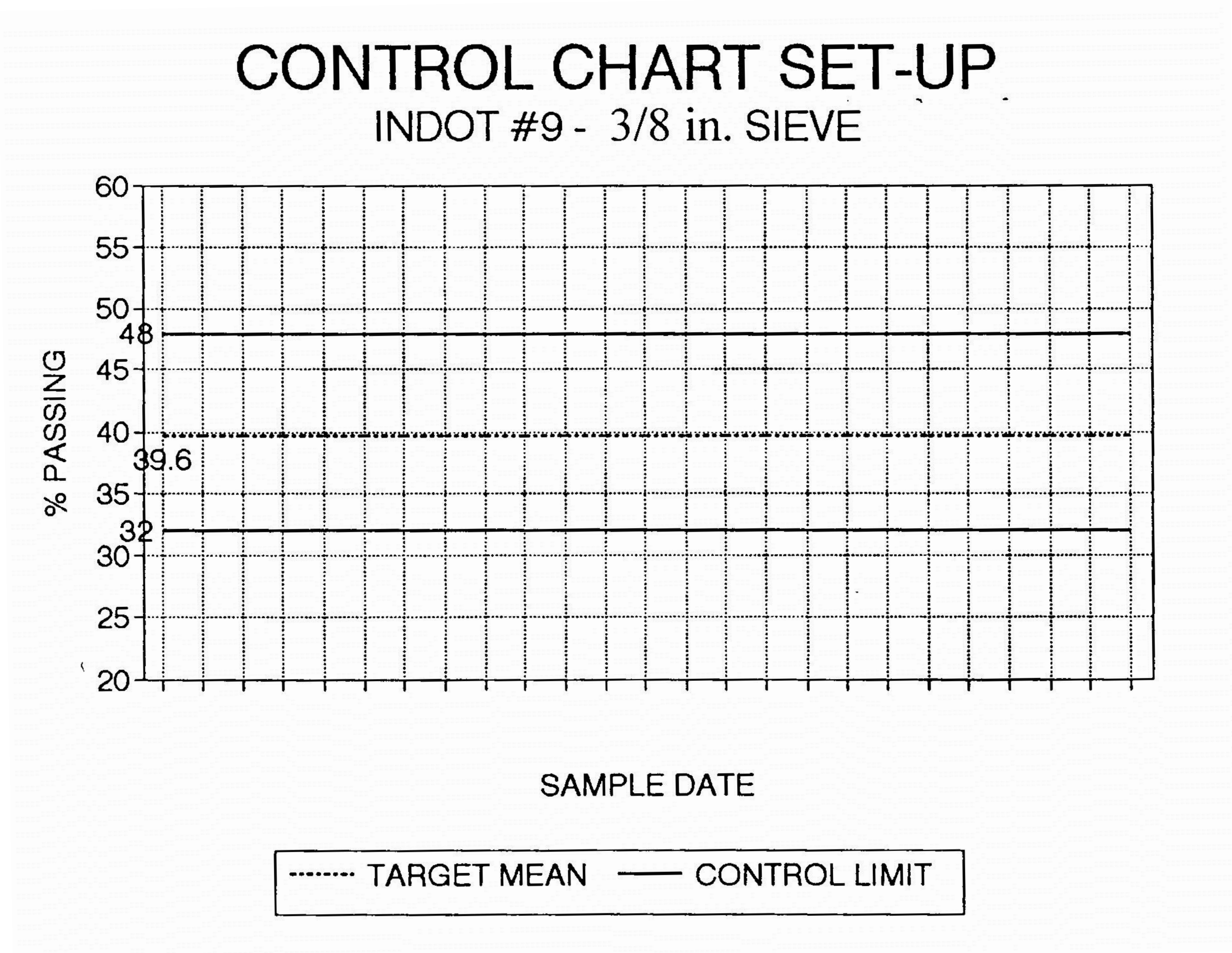


Figure 6-4. Control Chart Set-Up

FROM NEW DATA

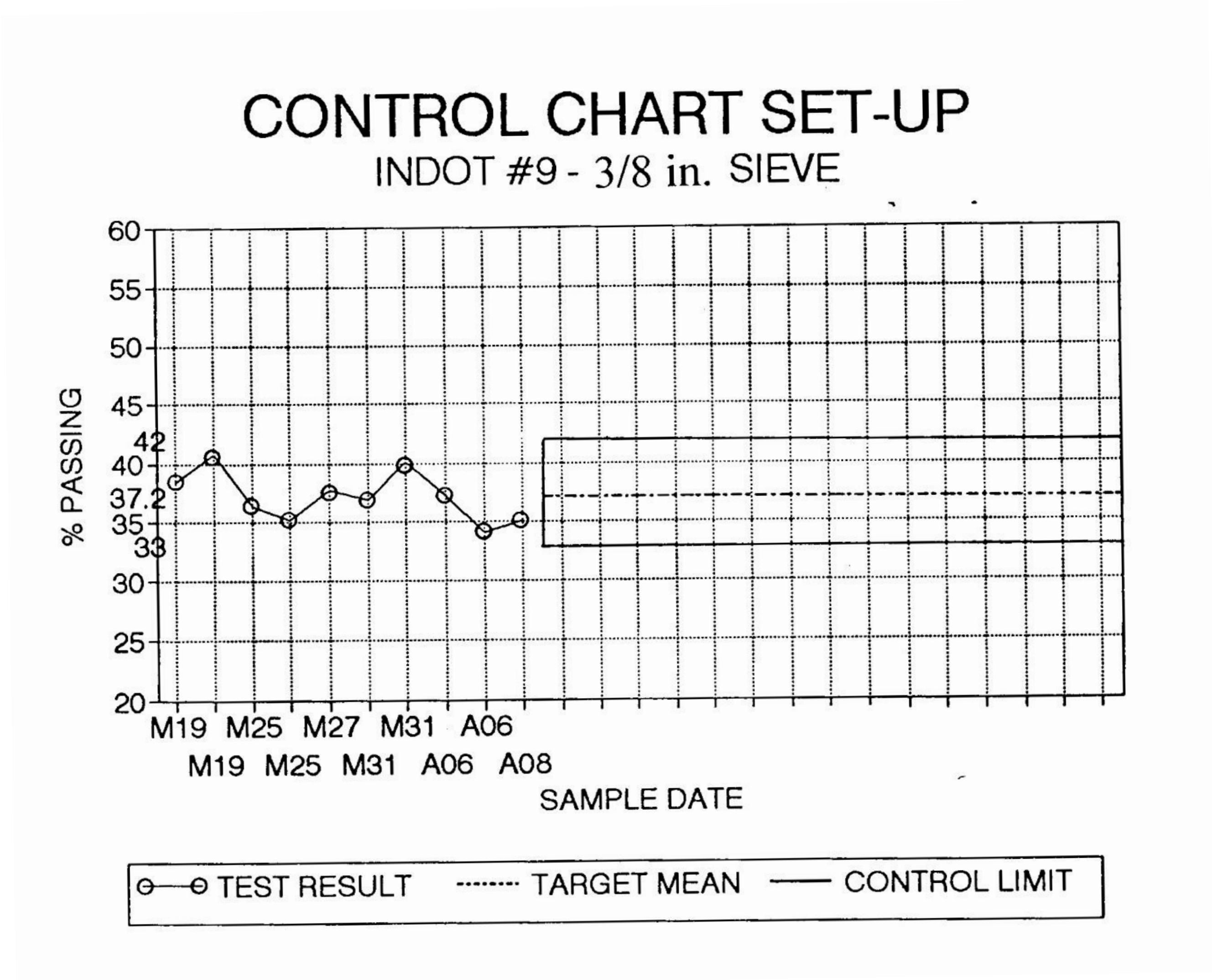


Figure 6-5. Control Chart Set-Up

Control charts indicate constant accuracy and precision if the process is in control and repeatable. The scattering of individual data points give a feel for precision or variability of the process when viewed against the control limits. In addition, a running average of the most current five data points is required to track the accuracy of the process. Averages tend to lessen the effect of erratic data points that could reflect errors not related to the actual material (sampling, testing, etc.) and that distract the viewer away from trends comparing to the target mean. Although this technique is not as accurate as data points that are each comprised of averages of subsets and which require an accompanying chart of ranges, the process works well for the mineral aggregate industry. When aggregates are tested at frequencies of 2000t per sample, the requirement to wait for the accumulation of five tests before generating a single data point is not acceptable. Table 6-3 and Figure 6-6 illustrate how data points and the running average for a product critical sieve are plotted on a control chart with a pre-established target mean and control limits.

ITM 211 requires that non-conforming normal production or load-out tests be followed immediately by a corrective action to include as a minimum an investigation for assignable cause, correction of known assignable cause, and retesting. These retests are not plotted on the control charts.

The check of the specification limits and establishment of the control limits for Table 6-3 are conducted as follows.

For the No. 4 critical sieve for the INDOT Standard Specifications No.11 material:

Data Set Results

$n = 36 \qquad \bar{x} = 14.8 \qquad \sigma_{n-1} = 2.60$

Specification Limit Check

1.65 times σ_{n-1} = 1.65(2.60) = 4.3

USL check = 14.8 + 4.3 = **19.1** $\leq$ **30** OK

LSL check = 14.8 - 4.3 = **10.5** $\geq$ **10** OK

Z Value Check

$Z_u = \frac{30-14.8}{2.60} = 5.85 > 1.65$ OK

$Z_L = \frac{14.8 - 10}{2.60} = 1.85 > 1.65$ OK

Establish Control Limits

UCL = $\bar{x} + 2\ \sigma_{n-1}$ = 14.8 + 2(2.6) = **20.0** or **20**

LCL = $\bar{x} - 2\ \sigma_{n-1}$ = 14.8 - 2(2.6) = **9.6** or **10**

PLANT: INDIANA MATERIAL SIZE: #11

SPEC. SIEVE	100 1/2 in.	75 - 95 3/8 in.	10 - 30 No. 4	5 PT AVG No. 4	0 - 10 No. 8
Jun 3	100.0	87.5	13.1		3.3
Jun 4	100.0	86.7	17.9		4.4
Jun 4	100.0	90.8	17.9		6.1
Jun 5	100.0	85.9	15.1		5.7
Jun 8	100.0	87.1	10.8	**15.0**	3.9
Jun 8	100.0	89.6	15.4	**15.4**	5.1
Jun 9	100.0	84.8	10.4	**13.9**	3.9
Jun 9	100.0	84.8	16.2	**13.6**	3.8
Jun 10	100.0	85.2	14.4	**13.4**	4.9
Jun 10	100.0	88.9	17.8	**14.8**	3.1
Jun 11	100.0	86.2	12.2	**14.2**	4.4
Jun 12	100.0	87.2	14.1	**14.9**	5.3
Jun 12	100.0	86.0	13.0	**14.3**	4.9
Jun 12	100.0	87.7	16.2	**14.7**	4.5
Jun 15	100.0	82.0	16.1	**14.3**	4.2
Jun 16	100.0	88.3	14.4	**14.8**	5.4
Jun 16	100.0	89.7	11.8	**14.3**	3.5
Jun 16	100.0	89.4	12.5	**14.2**	4.7
Jun 17	100.0	86.2	11.5	**13.3**	2.9
Jun 18	100.0	86.1	14.7	**13.0**	4.3
Jun 19	100.0	88.5	11.2	**12.3**	5.4
Jun 19	100.0	86.0	18.7	**13.7**	3.3
Jun 19	100.0	87.4	14.8	**14.2**	5.8
Jun 19	100.0	87.5	12.1	**14.3**	3.3
Jun 22	100.0	85.9	16.0	**14.6**	4.9
Jun 22	100.0	96.3	14.0	**15.1**	4.5
Jun 23	100.0	86.9	11.3	**13.6**	3.7
Jun 24	100.0	88.5	16.3	**13.9**	4.2
Jun 25	100.0	88.6	15.0	**14.5**	5.0
Jun 25	100.0	89.5	16.9	**14.7**	5.5
Jun 26	100.0	86.6	13.9	**14.7**	5.0
Jun 29	100.0	87.9	14.7	**15.4**	5.1
Jun 29	100.0	89.6	16.7	**15.4**	6.2
Jun 30	100.0	90.1	18.2	**16.1**	8.8
Jun 30	100.0	92.3	21.8	**17.1**	8.3
Jun 30	100.0	90.7	14.0	**17.1**	4.1
MEAN	100.0	87.8	14.8		4.8
STD. DEV.	0.000	2.50	2.57		1.27

Table 6-3: Gradation Analysis

GOOD PROCESS CONTROL

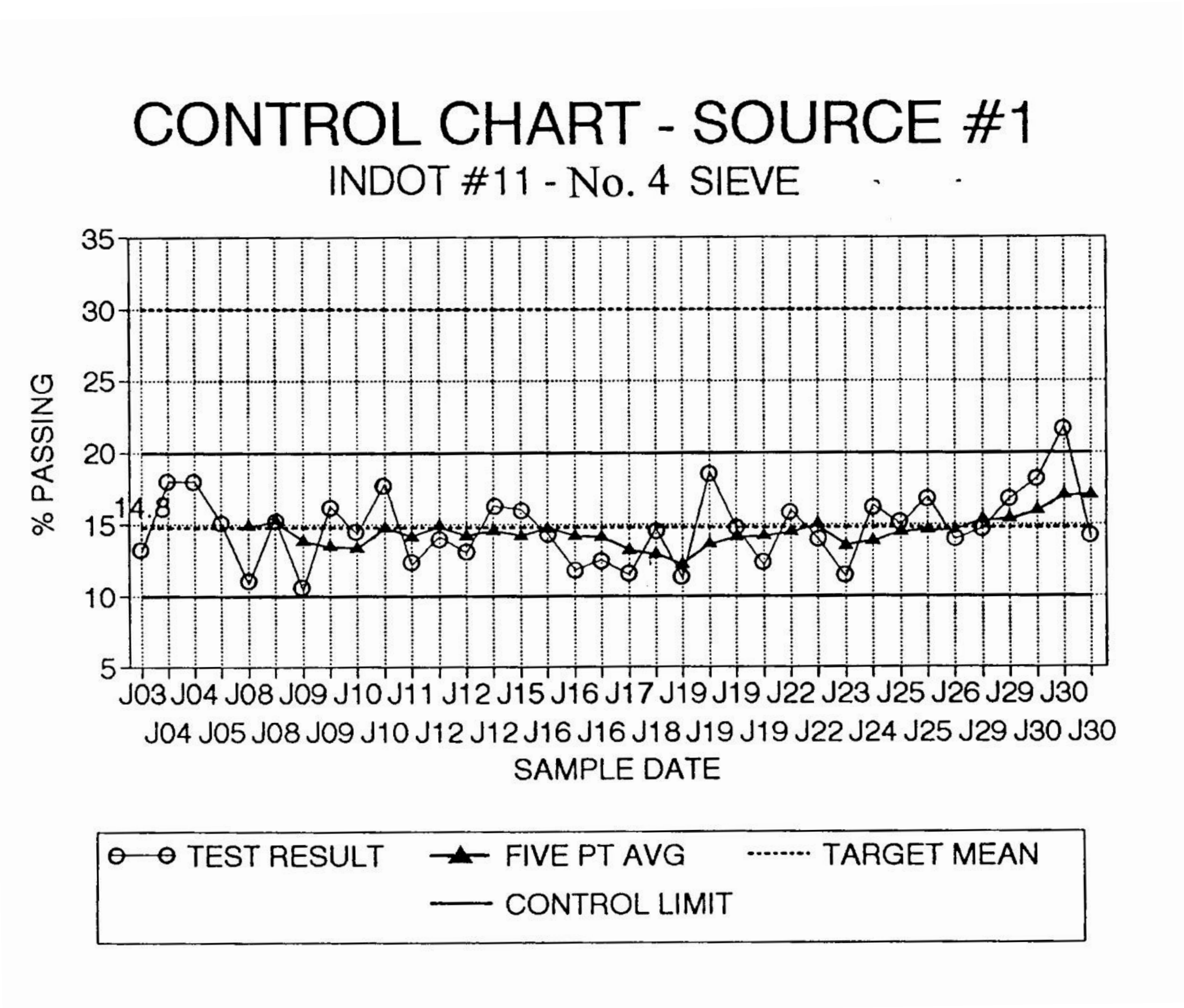


Figure 6-6. Good Process Control

Under the CAP Program, specific treatment of nonconforming tests is required. Action is required to be taken after the first nonconforming test (outside of control limits). These requirements are required to be met in all cases and take precedence over any other control technique. When individual test results, even on an intermittent basis, frequently fall outside the control limits or specification limits, a nonconforming condition exists. A capability calculation in conjunction with whichever limits are being violated may quickly verify the condition. The following trends involving the 5-point moving average points (Figure 6-7) may require investigation by the Producer and as a minimum an entry in the diary to denote the problem.

1) Seven or more points in a row are above or below the target mean ($\bar{x}$)

2) Seven or more points in a row are consistently increasing or decreasing

Finally, the Technician is required to always be alert for a sudden jump in the data, whether the data remains in control or not. This condition usually represents the addition of a completely different process and may be detected immediately without waiting for trends in the moving average (Figure 6-8). Corrective action is required to be taken immediately. If the shift to a new process is done intentionally, then a clean break is required to be made in the control chart by means of a vertical line on the chart. After ten valid test results on the new process, a new target mean $\bar{x}$ is required to be calculated and new control limits established (Figure 6-9).

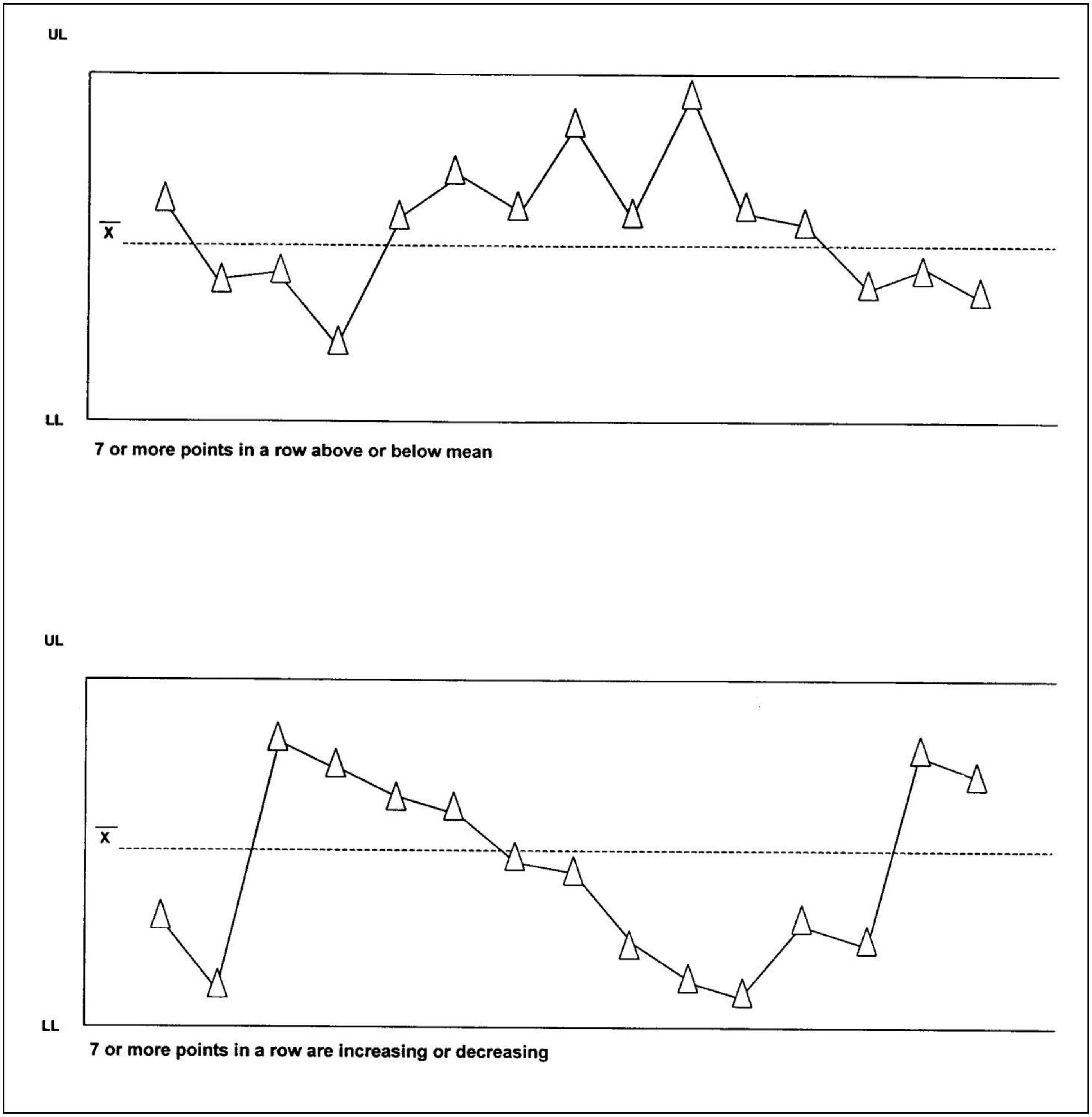


Figure 6-7. Five-Point Moving Average Trends

NONCONFORMING PROCESS

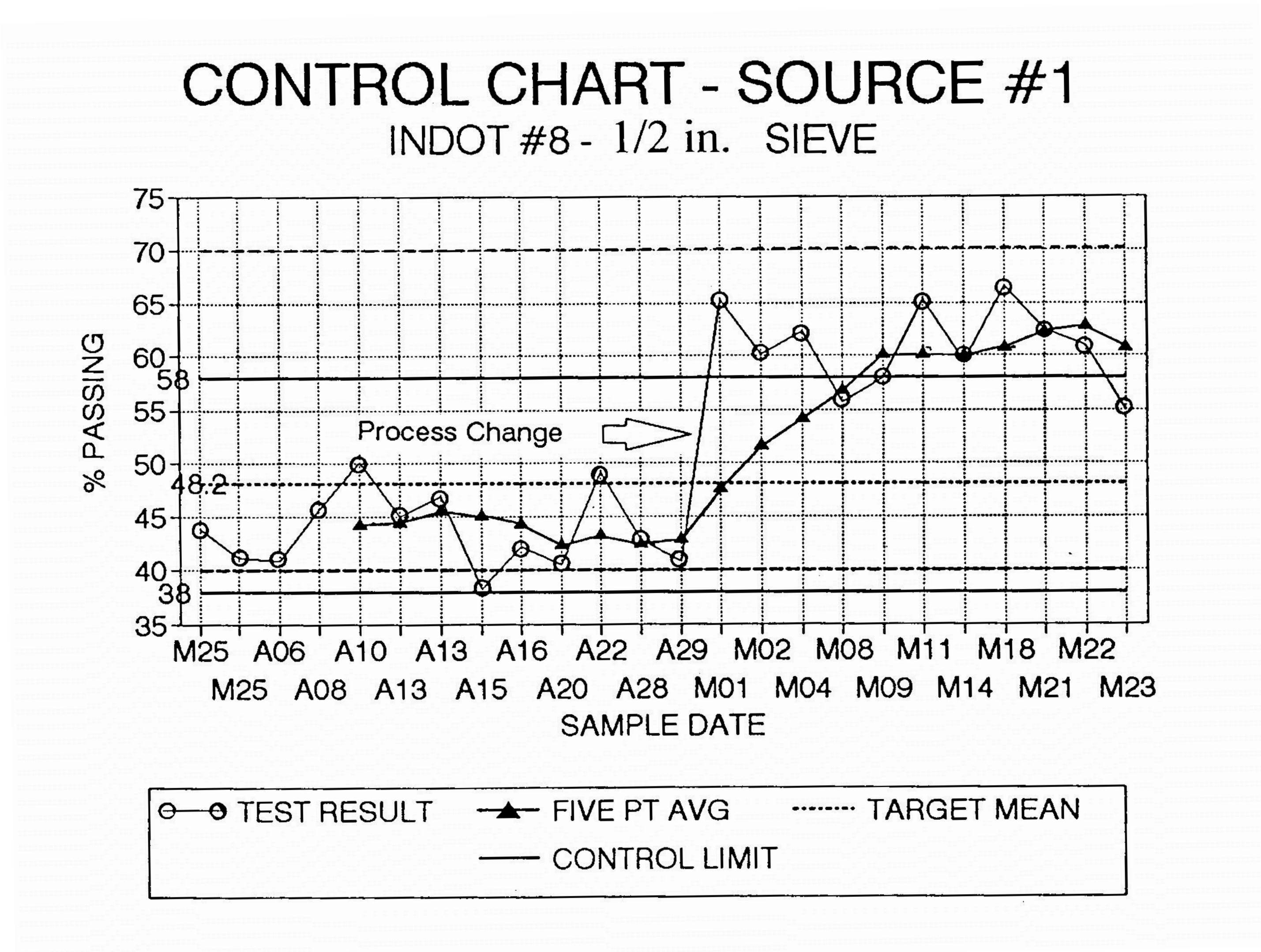


Figure 6-8. Nonconforming Process

PROCESS ADJUSTMENT

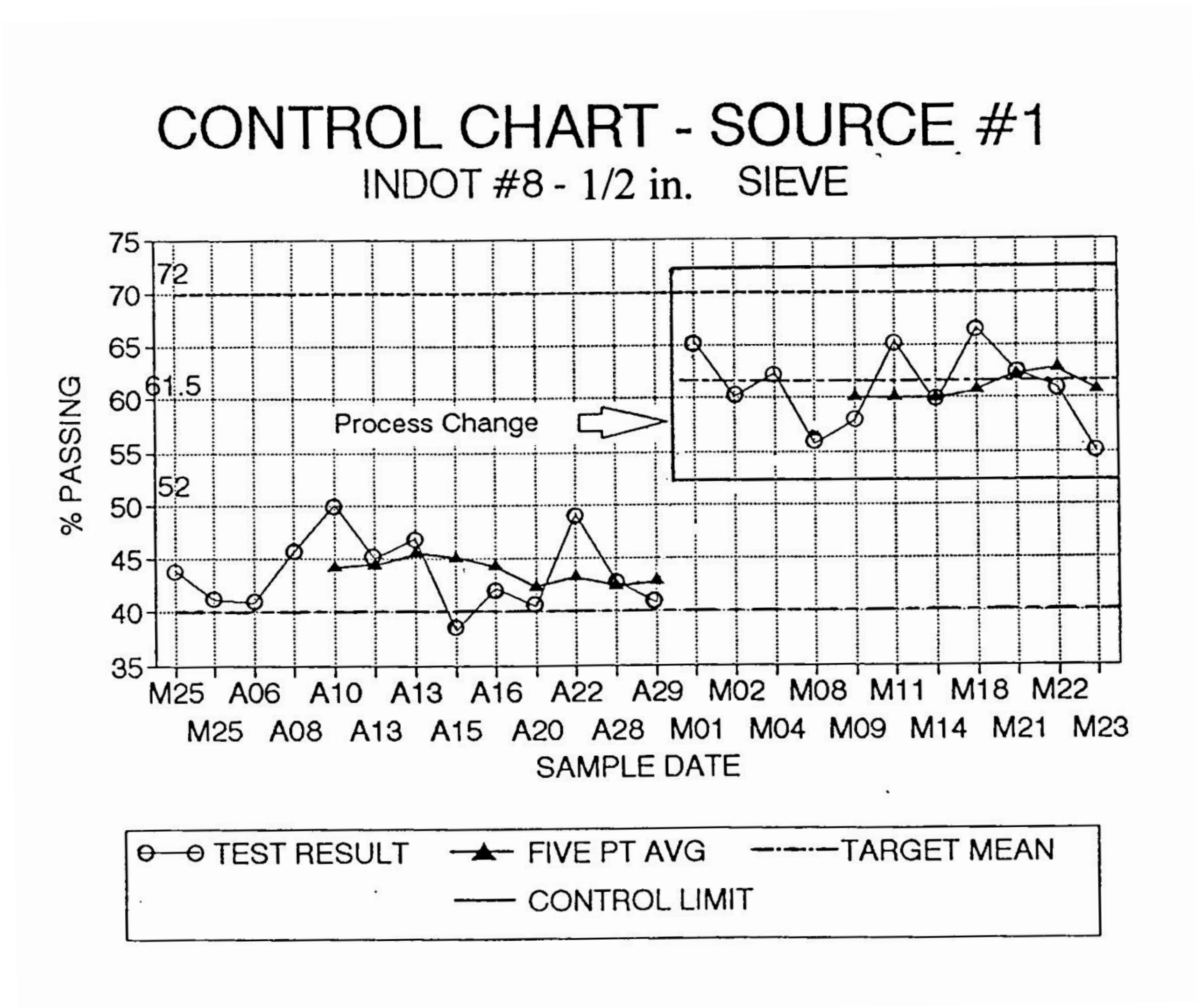


Figure 6-9. Process Adjustment

UNDERSTANDING THE PROCESS

Attempting to control an unstable process is like trying to answer an unsolvable riddle. Nothing is predictable; hence, nothing may be assumed. The Technician is required to follow a logical path to understand how, when, and what controls are necessary. The following path is a series of measurements, observations, communications, and decision-making.

CURRENT PROCESS

The current process is required to be thoroughly understood before making wise decisions on how to make improvements:

1) Gather honest employee input so that management knows what they know

2) Conduct and document visual observations of which elements seem to cause the greatest variability. Excavating or blasting, crushing, screening, total process stockpiling, and hauling, handling, and loading are all items that may affect quality.

3) Learn how and make accurate measurements at uniform intervals over time. Apply statistical principles to determine current stability and capability of the process.

PROCESS STABILITY

The process is required to first be stabilized before any other improvements may be made using the following procedures:

1) Identify the variables that most affect the process, called the Key Process Variables. These variables require the greatest attention from the operations managers (Figure 6-10).

2) Establish standards. The first reduction in variability may be recognized through "Standard Operating Procedures" (S.O.P.'s). These procedures include job descriptions, measurements (type and frequency), protocol for extreme conditions, etc.

3) Determine special causes. An absolute requirement for a stable process is the elimination of special causes of variability, namely, the ones that are external and not a part of the natural process. (e.g. conditions created by personnel)

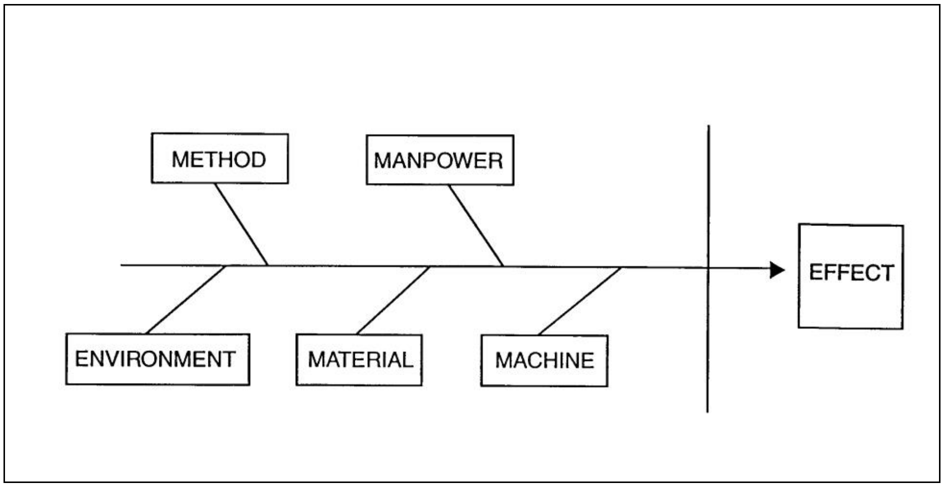


Figure 6-10. Key Process Variables

DECISION MAKING

After operating for some time with a stable process, some important decisions may be made. There are two items that are required to occur first:

1) Communicate with customers so they understand the new stable products. Also, obtain input from the customers on the need for further adjustment.

2) Make concurrent measurements to assess the need for further improvement

PROCESS CAPABILITY

Decisions previously made are required to include any techniques needed to bring the process into desired compliance with a high degree of confidence such as:

1) Establish final desired product targets and limits

2) Reduce common causes of variability as required. This generally means a change in the process.

PROCESS CONTROL

Implement ongoing statistical process control along with continuous improvement.

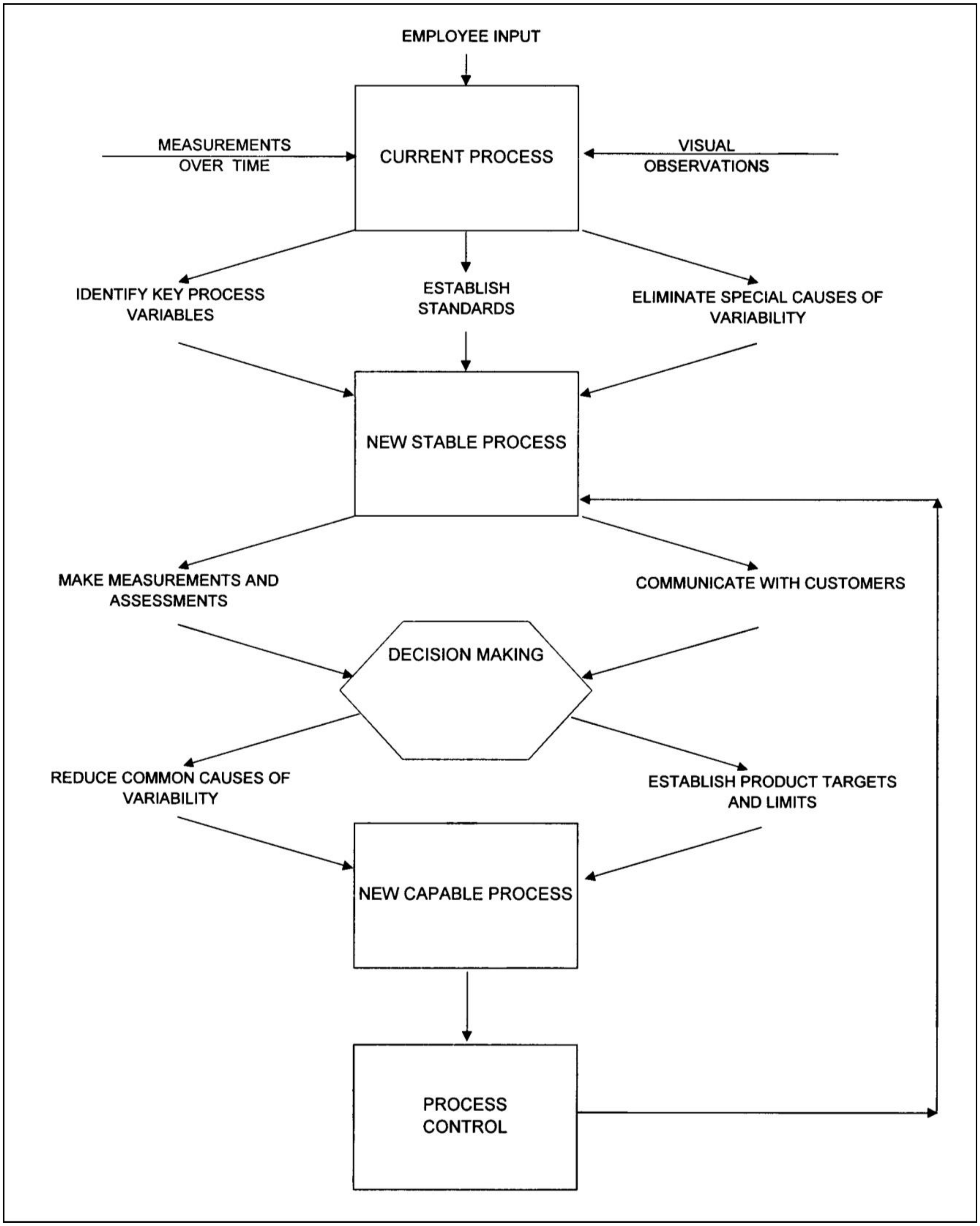


Figure 6-11. Steps for Managing Quality

7 Quality Control Plan

The Quality Control Plan

Development
Details
Addenda
Operational Types

QCP Annex

Quality Control Plan Checklist

CHAPTER SEVEN:
QUALITY CONTROL PLAN

If a single part of the Certified Aggregate Producer Program is considered to be the most important, then that is the Quality Control Plan (QCP). The QCP is required to encompass the total process from preliminary site approval up to the point where the material leaves the Producer's control. The QCP is required to identify and address all products generated and the type, frequency, and limits of sampling and testing to be done. The QCP focuses on a quality product and answers the questions of who, what, when, where, and how.

QUALITY CONTROL PLAN

DEVELOPMENT

The QCP is developed while the Producer is in the Coordinated Testing Phase. When starting to develop the QCP, the Producer is required to refer to this chapter, the model QCP's (Appendix C), INDOT's preliminary site approval letter, the CAP Program (**ITM 211**), and Section **917**.

The QCP is site and plant specific. A QCP for one site would not necessarily be satisfactory for another site.

DETAILS

The following list is provided to assist in the preparation of a QCP; however, the list is not to be considered all-inclusive (ITM 211 Section 14.0). A QCP is required to include:

1. The location and physical description of the site

2. Management Representative and Certified Technician(s) and their CAPP duties and responsibilities

3. A list and description of all portions of the mineral deposit as well as the manner in which each quality class is to be handled

4. A statement regarding AP aggregates. The AP Aggregate Production Control Plan may be included in an Appendix.

5. A statement regarding leachate testing for air cooled blast furnace slag. The requirements are listed in ITM 212.

6. A statement regarding bulk specific gravity testing for steel furnace slag when this material is used in stone mastic asphalt.

7. A statement regarding sampling and testing of natural sand fine aggregate when composite stockpiling multiple sources into one stockpile is done.

8. Identification of and a plan for handling materials having marginal quality characteristics

9. A list of all products produced at the plant. A CAPP category shall be identified for each of the products. This list could also be an appropriate place to identify those products for which no controls or limits are appropriate

10. A generic production flow diagram

11. A sampling plan that includes locations, devices, techniques, frequencies, and test methods

12. A testing plan that includes the types of tests and test methods, and the means to isolate material represented by nonconforming tests

13. A list of the target mean values, standard deviations, and control limits on the critical sieves for each material controlled by critical sieve requirements

14. A description of other process control techniques that are used beyond the minimum required

15. A plan for downstream controls that includes identification of stockpiles by signing, construction of stockpiles, and material retrieval

16. A statement of laboratory capability including the location of the lab, a list of equipment that is verified, and the test methods and frequency of verification

17. A documentation plan with details on control charting, test data, and the diary, etc.

18. The method by which the frequency of production and load-out testing of Certified Materials is verified

19. The location of the reference documents, control charts, diary, test data, material shipment records, and other pertinent information

20. The method of control for each Producer Yard

21. The procedure for handling addenda

22 The Annual Aggregate Source Report in an Appendix

23. An Appendix. As a minimum the Appendix is required to contain an Addenda Summary Sheet

24. Authentication and approval (two signatures required)

A QCP checklist is provided to assure that all the applicable items required in **ITM 211** are addressed in the QCP.

ADDENDA

Addenda are defined as any addition or deletion to the QCP. Each page of the QCP that is revised is required to include the source number, date of revision, and means of identifying the revision. The addenda are required to include a signed and dated authentication page.

Revisions for Certified Material additions, Certified Material deletions, target mean and control limit values, or Certified Aggregate Technicians are submitted in the format of the QCP Annex as they occur. Upon approval by the District Testing Engineer, the QCP Annex is placed in the Appendix of the QCP until such time that the revisions are incorporated into the QCP.

Revisions, other than items on the QCP Annex, are maintained on an Addenda Summary Sheet. The Addenda Summary Sheet is a page of the QCP Appendix that is used to record a brief description of the revision until such time that the revision is incorporated into the QCP.

Addenda may be submitted at the audit close-out meeting or between January 1st and April 1st of each calendar year. The addenda are required to include items on the QCP Annex, items on the Addenda Summary Sheet, and any other necessary revisions at the time of submittal. Upon incorporation into the QCP as addenda, the QCP Annex and items on the Addenda Summary Sheet are required to be removed from the QCP Appendix.

OPERATIONAL TYPES

The CAPP provides for Plants and Redistribution Terminals. The QCP is required to identify the intended type of operation. In some instances a primary source may also sell material produced at another source and therefore would be operating as both a Plant and a Redistribution Terminal.

QCP ANNEX

Company ______________________________________

Source No. ______________________ Q No. _________________________

NEW CERTIFIED MATERIAL ADDITION

Size Designation: ___________________ Specification: Standard or QA (see attached gradation)
Originating SC #: ___________________ Category Rating: IA IB IIA IIB III GS-A GS-B

Circle all that apply

Type: [Stone] [Gvl (Crushed/Uncrushed)] [Sand (Man./Nat./Slag)] [Slag (ACBF/SF)]
[Dolomite Approved (ITM 205)] [Recycled Concrete (Contract #: ________________)]
[Alternate Polish Resistant Aggregate (ITM 214)] [Other _________________________]

Product Quality Rating: AP AS A B C D E F NA

Ledges and/or Area of Production: ____
Does finished product go into Separate or Composite Stockpile? ____________________________
Is material from New Production, Existing Stockpile, or Both? ____________________________
Size of Existing Stockpile: _______________ t Annual Production: <10000 t ≥10000t

EXISTING CERTIFIED MATERIAL REVISION

Current Size Designation: ______________________________ Originating SC #: __________
New Size Designation: ________________________________ Type (see above): _____________
Ledges: ____________________________ Product Quality Rating: AP AS A B C D E F NA

EXISTING CERTIFIED MATERIAL DELETION

Size Designation: ________ Originating SC #: _________ Type (see above): _________________
Product Quality Rating: AP AS A B C D E F NA D# (DTE)_____________________

TARGET MEAN and CONTROL LIMITS REVISION

Certified Material: ____
Current $\overline{X}$: ______________________ Existing Control Limits: ______________________
New $\overline{X}$: ________ σ: __________ # Tests: __________ New Control Limits: _____________

CERTIFIED AGGREGATE TECHNICIAN REVISION

Delete CAT from QCP ____
Add CAT to QCP ____

______________________________ __________ _________________________ __________
District Testing Engineer Date Management Representative Date

3/27/09

CERTIFIED AGGREGATE
QUALITY CONTROL PLAN CHECKLIST

Date __________________

Source No. __________________

Plant/Redistribution Terminal Name ____

Plant/Redistribution Terminal Location ____

[ ] Telephone Number
[ ] Address
[ ] County
[ ] Section
[ ] Township
[ ] Range
[ ] Reference to Identifiable Points

Parent Company Name ______________________________________

[ ] Address

Type of Aggregate Source

[ ] Plant, Redistribution Terminal, or Combination

Organizational Structure

[ ] Management Representative
[ ] Certified Technician(s) by Location
[ ] CAPP Duties and Responsibilities of People Listed

Mineral Deposits

[ ] List
[ ] Description
[ ] Quality Class
[ ] Processing, Handling, & Stockpiling Procedures
[ ] Summary of Ledge Quality Test Letter Date (Stone)
[ ]* Marginal Quality Products and Plan for Control

* Only If Occurs

AP Aggregate *

[ ] Ledges for Stone or Production Zone for Gravel
[ ] General Handling and Crushing Procedures
[ ] Stockpile Signage
[ ] AP Production Control Plan in Appendix (optional)

Air Cooled Blast Furnace Slag -- Leachate Testing*

[ ] Sampling Procedure
[ ] Testing Procedure (ITM 212)
[ ] Frequency

Steel Furnace Slag – Deleterious Testing*

[ ] Sampling Procedure
[ ] Testing Procedure (ITM 219)
[ ] Frequency

Steel Furnace Slag -- Bulk Specific Gravity Testing (SMA)*

[ ] Sampling Procedure
[ ] Testing Procedure (AASHTO T 85)
[ ] Frequency

Composite Stockpiling*

[ ] Sources
[ ] Monthly Summary Report
[ ] Means of Tracking Bulk Specific Gravity and Absorption

Material Categories - Each

[ ] Standard Specifications
[ ] Quality Assurance
[ ] Alternate

Production Flow Diagram

[ ] Points of Sampling
[ ] Symbol Legend

* Only If Occurs

Sampling Plan

[ ] Frequency
[ ] Locations
[ ] Sampling Devices and Techniques
[ ] Test Method Numbers
[ ] Means of Tracking Production and Load-out Tests

Testing Plan

[ ] Gradation
[ ] Decantation (Load-out only)
[ ]* Crushed Particles (Min. 1/Week, None If < 100 t)
[ ]* Deleterious Material (Min. 1/Week, None If < 100 t)
[ ] Procedure for Isolating Non-Conforming Material
[ ] Test Method Numbers

Gradation Control

[ ] Critical Sieve for Quality Assurance Materials
[ ] Target Mean Values - Each
[ ] Standard Deviations - Each
[ ] Control Limits - Each
[ ] Gradation Limits for all Applicable Sieves for Quality Assurance Materials
[ ]* Identification of Materials with no Control Limits
[ ]* Load-Out Target Mean and Control Limits Different from Normal Production Values

Process Control Techniques

[ ]* Types or Greater Frequencies of Testing
[ ]* Mid Stream Sampling & Testing
[ ]* Visual Checks & Monitoring

Downstream Control

[ ] Identification of Stockpiles (Size of Material)
[ ] Stockpile Construction Technique
[ ] Product Retrieval Technique - Loading & Shipping Safeguards

* Only If Occurs

Laboratory Capability

[ ] Location
[ ] List and Description of Verified Equipment
[ ] Verification Test Methods and Frequency

Documentation Plan

[ ] Reference Publications
[ ] Diary
[ ] Control Charts
[ ] Test Data
[ ] Material Shipment Record
[ ] Location of Documents
[ ] Copies of Forms (optional)

Producer Yard

[ ]* Method of Control

Addenda

[ ] Means of Handling Addenda
[ ] Statement Concerning Source Number, Date of Revision, and Means of Identifying Revision

Annual Aggregate Source Report (Stone Only)

[ ] Included in Appendix

Authentication

[ ] Last Page
[ ] Right Hand Signature Block Signed and Dated by Producer Management Representative
[ ] Left Hand Blank & Title – Manager, Office of Materials Management

8 Testing Equipment

Laboratory

General
Sampling
Sample Reduction
Sieve Analysis
Decantation
Deleterious and Chert

Test Equipment Verification

Laboratory Set-Up

CHAPTER EIGHT:
TESTING EQUIPMENT

Before entering the Coordinated Testing Phase of the Certified Aggregate Producer Program, the Producer is required to have a suitable laboratory and testing equipment that has been verified to accomplish the program requirements. Laboratories are checked by an INDOT representative before start-up of the Coordinated Testing Phase and periodically to maintain the integrity of certified production.

LABORATORY

GENERAL

Equipment required for the various general procedures:

1) Electronic balance, Class G2, general purpose balance in accordance with **AASHTO M 231**. The balance is required to be readable to 0.1 g and accurate to 0.2 g or 0.1 percent of the test load, whichever is greater, throughout the range of use.

2) Laboratory oven, (optional) capable of maintaining a temperature of 230 ± 9° F, and ample interior volume to handle the anticipated sample load

3) Metal pans for drying and storage

4) Utensils for washing and drying samples, such as trowels, spatulas, etc.

5) Appropriate data sheets, log books, etc.

SAMPLING

Equipment required for **AASHTO T 2** or **ITM 207**:

1) Square-nose shovel

2) Sampling tube for sand

3) Containers, such as 20 gallon buckets, plastic fiber bag, etc. Galvanized bushel tubs work well and will stand up to oven temperatures.

4) Labels of sufficient size to allow for proper identification of samples

SAMPLE REDUCTION

Equipment required for **AASHTO T 248**:

1) Mechanical splitters

2) Buckets

SIEVE ANALYSIS

Equipment required for **AASHTO T 27**:

1) For coarse aggregates, 15 in x 23 in. or 14 in. x 14 in. sieves are recommended with sieve designations 2 in., 1 ½ in., 1 in., 3/4 in., 1/2 in., 3/8 in., No. 4, No. 8 and pan. For fine aggregates, 8 in. round sieves are standard with sieve designations 3/8 in., No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, No. 200, and pan.

2) Mechanical sieve shaker, appropriate model to accommodate sieves

3) Sieve brushes, wire and bristle brushes (note: never use a wire brush on sieves with openings smaller than the openings on a No. 50 sieve)

DECANTATION

Equipment required for **AASHTO T 11**:

1) Sieves, No. 16 and No. 200. The No. 200 sieve is protected from punctures and tears by covering with the No. 16 sieve.

2) Container, size sufficient to hold the sample covered with water and to permit vigorous agitation

3) Wetting agent, such as liquid detergent, etc. Some fine materials, especially limestone dust, require a wetting agent to break the surface tension of the particles. A drop or two of dishwashing liquid is usually sufficient.

4) Decant machine (may be used provided the results are consistent with those obtained using manual operations)

DELETERIOUS AND CHERT

Equipment required for deleterious and chert:

1) Scratch hardness tester

2) Hydrochloric acid and glass plate

TEST EQUIPMENT VERIFICATION

The test equipment is required to be properly verified and maintained within the limits described in the applicable test method. Verification of the test equipment is required prior to beginning testing in the Coordinated Testing Phase. The Producer is required to also verify the equipment at the minimum frequency as follows:

Equipment	Requirement	Min. Freq.	Procedure
Balances	Verification	12 mo.	ITM 910
Mechanical Shakers	Check sieving thoroughness	12 mo.	ITM 906
Sieves	Check physical thoroughness	12 mo.	ITM 902

LABORATORY SET-UP

Proper organization of the laboratory is required to maximize efficiency and minimize problems and erroneous results. Special consideration to the flow of the work to be done is required. The laboratory should be organized in the direction of this flow. For example, the equipment may be arranged from left to right when conducting sieve analyses as follows:

1) Riffle splitter -- for reduction of incoming samples

2) Oven -- for drying samples after reduction

3) Cooling rack and fan -- for cooling samples when dry (note: make sure that the fan does not blow towards the balance in the weighing area and does not disperse sample fines)

4) Coarse aggregate shaker

5) Fine aggregate shaker

6) Weighing area -- balance should be in an area free from vibration, dust, and air flow

Every laboratory situation is different. Setting up the lab to meet the flow requirements of the most routine tests conducted should be done. Minimizing the need for back-tracking, especially if more than one Technician is working at a time, is beneficial. A little extra time and thought to the set up of the lab significantly increases productivity and decreases turn-around time of test results.

9 Sampling

CHAPTER NINE: SAMPLING

Sampling is perhaps the most important step in assuring that good quality aggregates are being used on INDOT contracts. Since a sample is just a small portion of the total material, the importance that the sample be representative of the material being delivered cannot be overemphasized. Any test conducted on the sample, regardless of how carefully and accurately done, is worthless unless the sample is truly representative of the material used on the contract.

SAFETY

The sampling of materials may expose the Technician to machinery, moving belts, large stockpiles, and other potential dangers. Proper safety practices are always the first concern. When an unsafe condition exists, instructions from the Supervisor on the safety procedures for sampling are required to be obtained.

SAMPLE REFERENCES

A representative sample may be obtained by following the standard procedures detailed in **AASHTO T 2,** or **ITM 207**, Method of Sampling Stockpile Aggregate. Any deviations from the aforementioned procedures will require a detailed description within the QCP (ITM 214 Section 14.2.12).

SIZES OF ORIGINAL SAMPLES

The key to any sample program is to obtain a representative sample. A standard sampling method is required to be followed to obtain uniform samples.

The following is a list of recommended minimum sizes of composite samples to be used as a guide when collecting samples.

MATERIAL	SAMPLE SIZE
No. 1 coarse aggregate	385 lb
No. 2 coarse aggregate	220 lb
No. 5 coarse aggregate	110 lb
No. 8 coarse aggregate	55 lb
No. 9 coarse aggregate	35 lb
No. 11, No. 12 & No. 16 coarse aggregate	25 lb
No. 43 coarse aggregate	110 lb
No. 53 coarse aggregate	135 lb
No. 73 coarse aggregate	80 lb
2 in. Structure Backfill	245 lb
1½ in. Structure Backfill	190 lb
1 in. Structure Backfill	135 lb
½ in. Structure Backfill	60 lb
All sands No. 4 & No. 30 B Borrow	25 lb

The weight of the sample depends on the maximum particle size of the material being inspected. As a rule, a larger top size material requires a larger sample. A 25 lb sample of No. 2 coarse aggregate would not be as representative of that material as a 25 lb sample of natural sand.

TWO IMPORTANT DEFINITIONS TO REMEMBER

Top Size or Maximum Particle Size -- The sieve on which 100 percent of the material passes.

Nominal Maximum Particle Size -- Smallest sieve opening through which the entire amount of the aggregate is permitted to pass.

Although these two definitions are almost identical, the difference is important. An INDOT 53 aggregate, for example, is required to have 100 % of the material passing the 1 1/2 in. sieve. The next smallest sieve by Specification is the 1 in. sieve which requires 80-100 % of the material to pass the sieve. The maximum particle size therefore is 1 1/2 in. since 100 % of the aggregate is required to pass the 1 1/2 in. sieve. The nominal maximum particle size is 1 in. since the 1 in. sieve is the smallest sieve which is permitted to have 100 % of the material pass but is not required.

SAMPLE TYPES

The Technician is required to realize there are different types of samples. The most common sample is a stockpile sample, which is normally the method of load-out sampling under CAPP.

Some samples are required to be taken in the processing operation to assure that the final product is within control limits. These samples are referred to as production samples. The gradation of the production sample may not be the same as a load-out sample at some facilities.

Occasionally, an investigative sample is obtained when verifying a specific feature, such as a certain sieve, oversized material, etc. These tests may consist of many shortcuts and are only used as a quick comfort level check.

Every source may have other types of samples which are unique to their operation.

METHODS OF SAMPLING

Because of the various sampling locations and the availability of equipment, there are several methods of taking aggregate samples. Uniformity of obtaining the sample is very important, since the sampling procedure eliminates one variable in the test results. The Technician should remember that safety comes first.

PRODUCTION SAMPLING

Bin Sampling

Sampling the top of the bin is an extremely dangerous as well as a difficult, if not impossible, method to obtain a representative sample. For this reason, this method of sampling is undesirable.

Discharge Sampling of Bins or Belts

Bin samples may be taken at the discharge chute. In these situations, a number of small samples are taken at short intervals and combined to make the total sample. Each of these samples is required to include the entire cross section of the flow of material from the chute or belt.

Continuity of operation normally does not allow the Technician to control the rate of flow from the discharge chute. A mechanical diversion or slide chute system is the quickest, safest, and most accurate system (Figure 9-1). Unfortunately very few mechanical systems exist. All methods, including manual methods, are required to be included in the Quality Control Plan for the source and the proper safety practices should be designated.

Figure 9-1. Discharge Sampling of Belt

Belt Sampling

Belt sampling consists of taking samples of materials directly from the conveyor belts. This may be done by a mechanical sampling device (Figure 9-2) or manually. The proper procedure for manual belt sampling is designated in **AASHTO T 2** and includes the following:

1) Make sure that the belt is carrying a normal load of material that is not segregated

2) Have the plant operator stop the belt and use proper lock out procedures

3) Take a complete cross section of the material, being careful to include all the material on the belt and only the material in the section. A template is recommended, especially on steeply inclined belts. Remove most of the sample with a scoop or shovel and the remainder with a brush.

4) Take as many complete cross sections as necessary to obtain a sample that meets the minimum sample size.

Figure 9-2. Belt Sampling with Mechanical Device

LOAD-OUT SAMPLING

Coarse Aggregate Stockpiles

Coarse aggregates are recommended to be sampled using **ITM 207**.

Fine Aggregate Stockpiles

Fine aggregate samples normally are obtained in the same method as coarse aggregate samples, except a fire shovel or sampling tube is used to collect the material.

SAMPLING DIRECTLY FROM TRUCKS, RAIL CARS, OR BARGES

Direct sampling from trucks, rail cars, or barges is not recommended. There are a number of factors that may influence the gradation of the material, such as segregation or particle breakdown during loading, transporting, and unloading. Therefore, material being shipped by cars or barges is required to be sampled at the point of delivery. Materials being shipped by trucks for local delivery points also are required to be sampled at the point of delivery.

REDUCING A SAMPLE TO TEST SIZE

The total sample (production or load-out) is required to be reduced to a sample size that may be quickly tested. The procedure is conducted in accordance with **AASHTO T 248**. Time does not allow the Technician to test the total sample. The key to sample reduction is to ensure that the sample remains representative of the material in the stockpile. This practice is commonly referred to as splitting a sample. There are four different methods to reduce a sample to the proper test size.

1) The mechanical splitter is the most accepted method of reducing to test size all coarse aggregate material smaller than No. 2 aggregate, except highly moistened compacted aggregate. To determine if a compacted aggregate sample is too wet, a small portion of the sample is tightly squeezed in the palm of the hand. If the small sample crumbles readily, the correct moisture range has been obtained.

2) The sand splitter is the accepted method of reducing fine aggregate or the minus No. 4 material from compacted aggregate samples that is drier than the saturated surface-dry condition. As a quick check to determine this condition, if the material retains the shape when molded in the hand, the material is considered wetter than saturated surface-dry.

3) The miniature stockpile is the method used for fine aggregate that has free moisture on the particle surfaces.

4) Quartering is the method that is used for highly moistened compacted aggregate or when a mechanical splitter is not available.

MECHANICAL SPLITTER

The mechanical splitter (Figure 9-3) separates the sample into halves as the material passes through the spaces between the bars in the splitter. The same number of each particle size goes into each half of the sample, thus keeping the reduced sample representative of the total collected sample.

Figure 9-3. Mechanical Splitter

In using the mechanical splitter, the splitter bars are adjusted so that the bar opening is approximately 50% larger than the maximum particle size of the material to be split. A No. 5 aggregate has a maximum particle size of 1½ in. Therefore, the recommended bar opening is approximately 2.25 in. INDOT allows the bar opening at 3 in. or 6 bars (each bar is approximately 1/2 in) for all coarse aggregate No. 5 or smaller. The splitter is required to be level to ensure that each half of the split is approximately the same size; within approximately 10 percent of each other by weight.

The splitting procedure is as follows:

1) Properly place the pans under the splitter in such a way that all of the particles diverting in both directions will be caught

2) Pour the sample evenly into the hopper

3) Open the hopper fully and allow the material to free fall through the splitter

4) If wet particles stick inside the splitter, gently tap the splitter with a rubber hammer to loosen them

5) To ensure that the sample has not been segregated during sampling, place both halves of the sample back into the hopper and repeat the splitting operation

6) After the second splitting, the two receiving pans contain approximately the same amount of material. Only one pan is placed back into the hopper and the splitting procedure repeated until a sample of the desired size is obtained. Skillful manipulation of the splitter allows a sample of nearly any size to be made that is still representative of the material in the stockpile.

SAND SPLITTER

The sand splitter (Figure 9-4) is a small version of the mechanical splitter except that the openings are fixed and there are no hopper doors.

Figure 9-4. Sand Splitter

The splitting procedure is as follows:

1) Place the pans under the splitter to catch all of the particles

2) Slowly pour the dry sample into the splitter from the side (never from the end or corner)

3) Recombine the samples and split the sample a second time to eliminate any segregation

4) Reduce the sample to proper size by additional splitting of the material in one of the pans

MINIATURE STOCKPILE

The miniature stockpile (Figure 9-5) method is used for reducing all samples of fine aggregates when the material is in a damp or moist condition. If the sample to be split is dry, then the material is required to be moistened before using this method.

Figure 9-5. Miniature Stockpile

The splitting procedure is as follows:

1) Place the original sample on a clean, dry plate or other hard, smooth, non-absorptive surface

2) Using a trowel or other suitable tool, turn the entire sample over three times

3) Shape the material into a conical pile

4) With a spoon or small trowel, randomly take at least five small portions of material around the pile and one-third way up the cone until the required test sample is obtained

QUARTERING

Quartering (Figure 9-6) is a non-mechanical method of reducing a sample. This is the best method of reducing highly moistened compacted aggregate or when a mechanical splitter is not available.

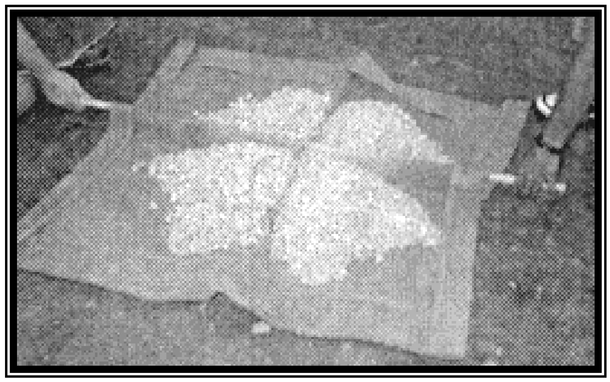


Figure 9-6. Quartering

The quartering procedure is as follows:

1) Place the sample on a hard, clean, level, non-absorptive surface where there will be neither loss of material nor the accidental addition of foreign material.

2) Using a large trowel, shovel, or other suitable tool turn the entire sample over at least three times. Form the sample into a conical pile by depositing individual lifts on top of the preceding lift.

3) Flatten the pile to a uniform thickness by pressing down the apex with a shovel or trowel. Each quarter sector of the resulting pile is required to contain the material originally in the pile. The diameter of the pile should be equal to 4-8 times the thickness of the pile.

4) With a large trowel or other suitable tool, divide the sample into four equal quarters. Remove two diagonally opposite quarters, including all fine material, and brush the cleared spaces clean.

5) Combine diagonally opposite quarters of the material into two samples. All fine materials shall be included by brushing the surface clean. Store one of these two halves. If the remaining material still weighs too much, repeat the entire quartering process until the proper test sample size is obtained

SIZE OF TEST SAMPLE (AFTER SPLITTING)

The original sample is required to be reduced to a test sample size that is within the minimum and maximum weights of the following table.

WEIGHT OF TEST SAMPLE

AGGREGATE SIZE	MINIMUM	MAXIMUM
No. 2	11,300 g	---
No. 5	6000 g	8000 g
No. 8	6000 g	8000 g
No. 9	4000 g	6000 g
No. 11	2000 g	---
No. 12	1000 g	---
No. 16	1000 g	---
No. 43	6000 g	8000 g
No. 53	6000 g	8000 g
No. 73	6000 g	8000 g
No. 91	6000 g	8000 g
B Borrow	4000 g	6000 g
Structure Backfill, 2 in.	11,300 g	---
Structure Backfill, 1 1/2 in. & 1 in.	6000 g	8000 g
Structure Backfill, 1/2 in.	4000 g	6000 g
Structure Backfill, No. 4 & No. 30	300 g	---
Fine Aggregate	300 g	---

10 Testing

Gradation

Sieving
Decantation
Sieve Analysis Test
Fineness Modulus
Sieve Analysis for Dense Graded (Long Graded) Materials

Deleterious Materials

Deleterious Materials in Coarse Materials
Deleterious Materials in Natural Sands

Crushed Particles

Flat and Elongated Particles

Plastic Limit

Total Moisture Content

CHAPTER TEN: *TESTING*

After obtaining and splitting the sample, the next step is to conduct the test. Uniform and consistent testing is required to remove variables in the total operation.

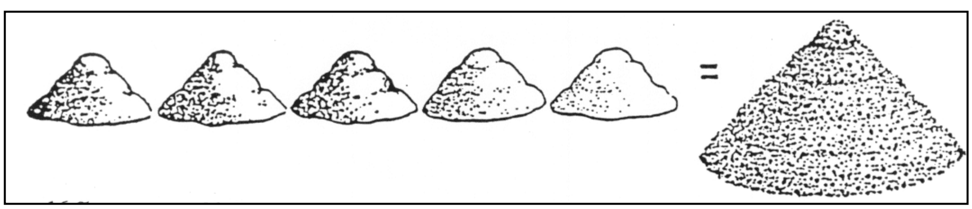
GRADATION

Gradation is the range and relative distribution of particle sizes in the aggregate material.

Range refers to the size limits of an aggregate set and to the number of sizes in that set. For example, the sizes in a set may extend from 1½ in. aggregates to 3/8 in. aggregates and include sizes of 1 in., 3/4 in. and 1/2 in. Another set may extend from 2½ in. aggregates to 1/2 in. aggregates with intermediate sizes of 1½ in., 1 in., and 3/4 in.

The relative distribution refers to the percentage of each particle size in the total material. For example, in a given set of aggregates, 16 percent of the total material could be 1½ in. aggregates, 23 percent could be 1 in. aggregates, 14 percent could be 3/4 in. aggregates and so on.

1½ in. 1 in. 3/4 in. 1/2 in. 3/8 in. Specified Sizes



16 % 23 % 14 % 19 % 28 % 100 %

Sets of graded aggregates are referred to by size number with each having a specified range and relative distribution.

The sizes of fine and coarse aggregates used by INDOT and the gradation requirements for each size are found in Section **904**.

SIEVING

Gradation is determined by sieving. A sample of the aggregate material being tested is weighed and then passed through a series of sieves (Figure 10-1).

Sieve sizes correspond to the size of the openings in the mesh. Range is determined by the number and sizes of sieves used. Relative distribution is calculated by weighing the aggregates retained on each sieve.

The coarser sieves are classified according to the size of the openings, in linear inches. Thus, the 1 in. sieve has openings 1 in. square.

Aggregates coarser than the 1 in. sieve are called plus 1 in. material. Aggregates finer than the 1 in. sieve are called minus 1 in. material. Plus (retained) means coarser than and minus (passing) means finer than. To be retained on any sieve, the aggregates are required to be coarser in every direction than the sieve size.

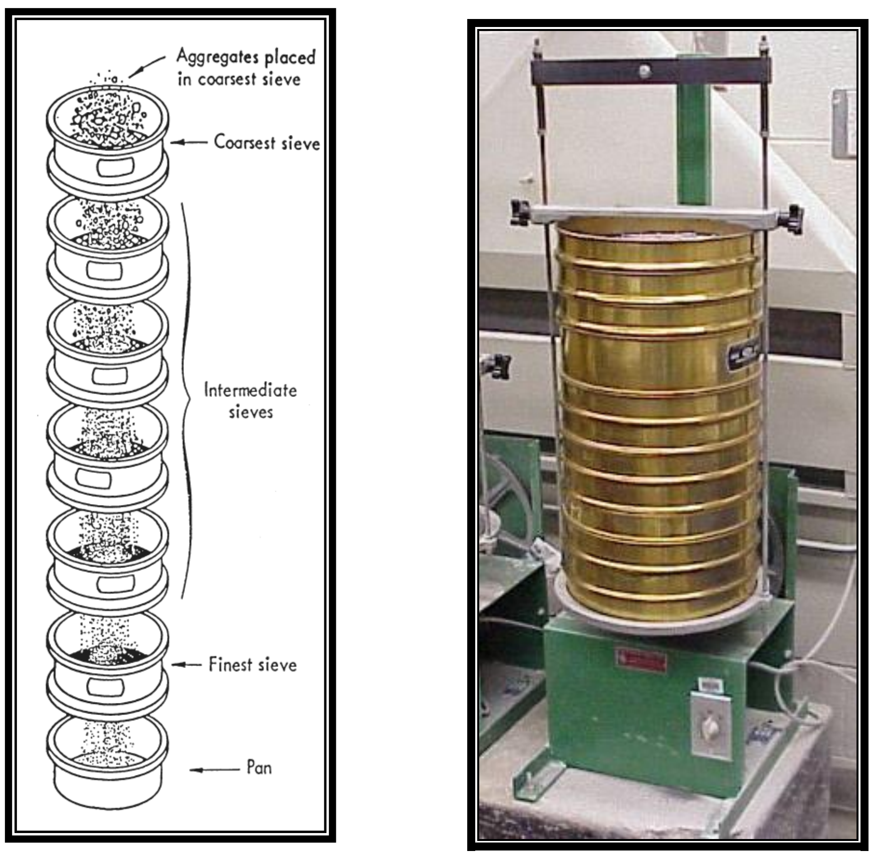


Figure 10-1. Sieves

DECANTATION

The decantation test (Figure 10-2) determines the amount of material finer than the No. 200 sieve. The test is conducted on both fine and coarse aggregate and is usually done in conjunction with the sieve analysis test. The test is conducted according to **AASHTO T 11**, with exceptions noted in Section **904.06**.

Figure 10-2. Mechanical Decant Device

If the total amount passing the No. 200 sieve is required to be determined by the Specifications, the amount is determined by a combination of wet and dry sieving and is represented by the total amount passing the No. 200 sieve following both decantation and dry sieve analysis.

The procedure for decantation is:

1) After the sample has been reduced to the proper size, the sample is thoroughly dried and allowed to cool to room temperature. The weight is recorded on a gradation analysis sheet.

2) The dried material is then placed in a container large enough to hold the sample with adequate wash water and room for agitating the sample.

3) The sample is covered with water.

4) The sample is agitated with a spoon or trowel to separate all particles and to suspend the minus No. 200 material.

5) The wash water is immediately poured or allowed to overflow through a No. 200 sieve. A protector sieve (No. 16) is nested above the No. 200 sieve for protection from the larger particles. Only the wash water (not the sample) is poured on the sieves.

6) The washing and sieving of the wash water is continued until the water runs clear.

7) After the wash water has cleared, the excess water is drained from the sample through the No. 200 sieve. Any residue material is removed from the protector sieve and the No. 200 sieve and placed with the test sample.

8) The washed sample is dried, allowed to cool to room temperature, and weighed. The weight is recorded in the decant section of the gradation analysis sheet.

9) The percentage of material finer than a No. 200 sieve is calculated by using the formula:

$$\% \text{ Decant} = \frac{\text{Original Dry Weight - Dry Weight after Decant}}{\text{Original Dry Weight}} \times 100$$

Example

$$\% \text{ Decant} = \frac{5942.1 - 5885.2}{5942.1} \times 100 = 0.96\% \approx 1.0\ \%$$

Decant	**Original**	**Final**	**Grams Loss**	**% Loss**	**% Req.**
	5942.1	5885.2	56.9	1.0	

Sieve analysis is used primarily to determine the particle-size distribution or gradation of materials. The results are used to determine compliance with the applicable Specification requirements. The test is conducted on both the fine and coarse aggregates and is usually done in conjunction with the decantation test.

The sieve analysis for mineral filler is conducted in accordance with **AASHTO T 37**. Because of the very fine particle-size of mineral filler, this test requires washing the material over the required sieves. The sieve analysis for all other fine aggregates and all coarse aggregates is conducted in accordance with **AASHTO T 27**. Exceptions to **AASHTO T 37** and **AASHTO T 27** are listed in Section **904.06**.

The procedure for the sieve analysis in accordance with **AASHTO T 27** is as follows:

1) The dried (decanted) sample is placed in the top sieve of properly nested sieves. The sieves are nested in sequence with the smallest sieve placed on the pan and stacked by increasing size.

2) The shaking time is required to be sufficient to ensure that the sample is divided into fractional sizes. The actual shaking time is required to be determined in accordance with **ITM 906**. The following times are minimum for shakers used by the industry.

Coarse Aggregate, Size 9 or larger	5 Minutes
Coarse Aggregate, Smaller than Size 9	10 Minutes
Fine Aggregates	15 Minutes

3) At the conclusion of sieving, the material retained on each sieve is carefully transferred to a weigh pan and weighed. The weight retained of the material on each sieve is recorded on the Gradation Analysis sheet. The weight may not exceed the allowable amount on each sieve as indicated in Table 1.

The larger sieves (above the No. 16) are cleaned with a small trowel or piece of flat metal. The sieves between the No. 16 and No. 50 are cleaned with a wire brush. The sieves smaller than the No. 50 are cleaned with a soft bristle brush. Care is required to be taken not to damage the sieves.

TABLE 1
APPROXIMATED SIEVE OVERLOAD

SCREEN SIZE	STANDARD 15 in. x 23in.	STANDARD 14 in. x 14 in.	12 in. DIAMETER	8 in. DIAMETER
3 in.	40.5 kg	23.0 kg	12.6 kg	-------------
2 in.	27.0 kg	15.3 kg	8.4 kg	3.6 kg
1-1/2 in.	20.2 kg	11.5 kg	6.3 kg	2.7 kg
1 in.	13.5 kg	7.7 kg	4.2 kg	1.8 kg
3/4 in.	10.2 kg	5.8 kg	3.2 kg	1.4 kg
1/2 in.	6.7 kg	3.8 kg	2.1 kg	890 g
3/8 in.	5.1 kg	2.9 kg	1.6 kg	670 g
No. 4	2.6 kg	1.5 kg	800 g	330 g

8 in. diameter sieves, No. 8 to No. 200 shall not exceed 200g / sieve

12 in. diameter sieves, No. 8 to No. 200 shall not exceed 469g / sieve

TOTAL WEIGHT: 5942.1g				
SIEVE SIZE	**WEIGHT RETAINED**	**WEIGHT PASSING**	**PERCENT PASSING**	**PERCENT REQUIRED**
1½ in.	**g**	**g**	**%**	**%**
1 in.	**0 g**	**5942.1 g**	**%**	**%**
¾ in.	**690.6 g**	**g**	**%**	**%**
½ in.	**2462.7 g**	**g**	**%**	**%**
⅜ in.	**1368.1 g**	**g**	**%**	**%**
No. 4	**997.0 g**	**g**	**%**	**%**
No. 8	**264.5 g**	**g**	**%**	**%**
No. 16	**g**	**g**	**%**	**%**
No. 30	**g**	**g**	**%**	**%**
No. 50	**g**	**g**	**%**	**%**
No. 100	**g**	**g**	**%**	**%**
No. 200	**g**	**g**	**%**	**%**
PAN	**88.1 g**	**g**	**%**	**%**
DECANT ORIGINAL	**FINAL**	**GRAMS LOSS**	**PERCENT LOSS**	**PERCENT REQUIRED**
5942.1 g	**5885.2 g**	**56.9 g**	**1.0 %**	**%**

4) The weight passing each sieve is calculated next by subtracting the weight retained on the largest sieve from the total sample weight. The weight retained on the next largest sieve is subtracted from the weight of material remaining from the first subtraction. This process is continued for all sieves.

Example:

1 in.	5942.1 – 690.6	= 5251.5
3/4 in	5251.5 –2462.7	= 2788.8
3/8 in	2788.8 – 1368.1	= 1420.7
No. 4	1420.7 - 997.0	= 423.7
No. 8	423.7 - 264.5	= 159.2
Pan material		= 88.1

TOTAL WEIGHT: 5942.1g				
SIEVE SIZE	WEIGHT RETAINED	WEIGHT PASSING	PERCENT PASSING	PERCENT REQUIRED
1½ in.	g	g	%	%
1 in.	0 g	5942.1 g	%	%
¾ in.	690.6 g	5251.5 g	%	%
½ in.	2462.7 g	2788.8 g	%	%
⅜ in.	1368.1 g	1420.7 g	%	%
No. 4	997.0 g	423.7 g	%	%
No. 8	264.5 g	159.2 g	%	%
No. 16	g	g	%	%
No. 30	g	g	%	%
No. 50	g	g	%	%
No. 100	g	g	%	%
No. 200	g	g	%	%
PAN	88.1 g	g	%	%
DECANT ORIGINAL	FINAL	GRAMS LOSS	PERCENT LOSS	PERCENT REQUIRED
5942.1 g	5885.2 g	56.9 g	1.0 %	%

5) The percent passing is calculated for each sieve by using the following formula:

$$\% \text{ Passing} = \frac{\text{Weight Passing Each Sieve}}{\text{Original Dry Sample Weight}} \text{ x } 100$$

Example:

3/4 in. $\frac{5251.5}{5942.1}$ x 100 = 88.4%

1/2 in. $\frac{2788.8}{5942.1}$ x 100 = 46.9% etc.

TOTAL WEIGHT: 5942.1g				
SIEVE SIZE	**WEIGHT RETAINED**	**WEIGHT PASSING**	**PERCENT PASSING**	**PERCENT REQUIRED**
1½ in.	**g**	**g**	**%**	**%**
1 in.	**0 g**	**5942.1 g**	**100 %**	**%**
¾ in.	**690.6 g**	**5251.5 g**	**88.4 %**	**%**
½ in.	**2462.7 g**	**2788.8 g**	**46.9 %**	**%**
⅜ in.	**1368.1 g**	**1420.7 g**	**23.9 %**	**%**
No. 4	**997.0 g**	**423.7 g**	**7.1 %**	**%**
No. 8	**264.5 g**	**159.2 g**	**2.7 %**	**%**
No. 16	**g**	**g**	**%**	**%**
No. 30	**g**	**g**	**%**	**%**
No. 50	**g**	**g**	**%**	**%**
No. 100	**g**	**g**	**%**	**%**
No. 200	**g**	**g**	**%**	**%**
PAN	**88.1 g**	**g**	**%**	**%**
DECANT **ORIGINAL**	**FINAL**	**GRAMS LOSS**	**PERCENT LOSS**	**PERCENT REQUIRED**
5942.1 g	**5885.2 g**	**56.9 g**	**1.0 %**	**%**

6) If the test has been done accurately, the sum of all the fractional weights retained (including the material in the pan) and the weight of material removed by decantation are approximately equal to the original dry weight. If the two weights differ by more than 0.3 percent, based on the original dry sample weight, the results are considered invalid.

$$\frac{\text{Original Dry Weight - Summation Weights Measured}}{\text{Original Dry Weight}} \text{ x } 100$$

Example:

$$\frac{5942.1 - (690.6 + 2462.7 + 1368.1 + 997.0 + 264.5 + 88.1 + 56.9)}{5942.1} \text{ x } 100 =$$

0.2% = valid test

FINENESS MODULUS

The fineness modulus is related to gradation. This term is commonly associated with aggregates for portland cement concrete. The purpose of this value is to determine the relative coarseness or fineness of the aggregate grading.

The fineness modulus is computed in accordance with **AASHTO T 27** by adding the cumulative percentages retained on the 3 1/2 in., 2 1/2 in., 2 in., 1½ in., 3/4 in., 3/8 in., No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100 sieves, and then dividing by 100. A large number indicates a coarse material. A small number indicates a fine material.

Sieve Size	100	-	% Passing	=	% Retained
3/8 in.	100	-	100	=	0.0
No. 4	100	-	100	=	0.0
No. 8	100	-	89.2	=	10.8
No. 16	100	-	68.3	=	31.7
No. 30	100	-	45.1	=	54.9
No. 50	100	-	13.8	=	86.2
No. 100	100	-	2.6	=	97.4
					281.0

281.0 / 100 = 2.81 = Fineness Modulus

SIEVE ANALYSIS FOR DENSE GRADED (LONG GRADED) MATERIALS

Dense graded materials, such as compacted aggregates and some B borrows or subbase, consist of substantial quantities of material retained on and passing the No. 4 sieve.

The procedure for conducting a sieve analysis on a dense graded material is:

1) The entire sample is sieved and weighed in the same manner as well-graded materials, except the smallest sieve is required to be the No. 4 sieve.

2) The portion of the sample passing the No. 4 sieve is weighed.

3) Using a sand sample splitter, the portion of the sample passing the No. 4 sieve is reduced to approximately 500 grams.

4) The reduced sample is weighed and a proportionate factor is determined by dividing the weight of the portion of the sample passing the No. 4 sieve by the weight of the reduced sample. For example, if the total weight of the portion of material passing the No. 4 sieve is 2221.4 grams and the reduced sample weight is 503.4 grams, the proportionate factor would be equal to 2221.4 grams divided by 503.4 grams, which equals 4.413.

5) The reduced sample is sieved for 15 minutes.

6) The material on each sieve is weighed and multiplied by the proportionate factor. The calculated weight is recorded as the total weight of material retained on that sieve.

7) The calculations for percentage passing are completed as for well-graded aggregates.

TOTAL WEIGHT: 6800.8g					
SIEVE SIZE	**LONG GRADED WEIGHT RET.**	**WEIGHT RETAINED**	**WEIGHT PASSING**	**PERCENT PASSING**	**PERCENT REQUIRED**
1½ in.		0 g	6800.8 g	100 %	100 %
1 in.		312.9 g	6487.9 g	95.4 %	80-100 %
¾ in.		877.2 g	5610.7 g	82.5 %	70-90 %
½ in.		1228.3 g	4382.4 g	64.4 %	55-80 %
⅜ in.		580.5 g	3801.9 g	55.9 %	%
No. 4		1072.1 g	2729.8 g	40.1 %	35-60 %
No. 8	222.1 g	940.4 g	1789.4 g	26.3 %	25-50 %
No. 16	g	g	g	%	%
No. 30	192.7 g	815.9 g	973.5 g	14.3 %	12-30 %
No. 50	g	g	g	%	%
No. 100	g	g	g	%	%
No. 200	84.8 g	359.0 g	614.5 g	9.0 %	5.0-10.0 %
PAN	4.2 g	17.8 g	g	%	%
DECANT	**ORIGINAL**	**FINAL**	**GRAMS LOSS**	**PERCENT LOSS**	**PERCENT REQUIRED**
	6800.8 g	6220.7 g	580.1 g	8.5 %	%

PROPORTIONATE FACTOR	**TOTAL WEIGHT PASSING No. 4**	**SAMPLE SIZE**	
	2133.2 g	503.8 g	4.234

DELETERIOUS MATERIALS

Most of the tests for deleterious materials apply to coarse aggregates. The only concern in fine aggregates for deleterious materials is organic impurities.

DELETERIOUS MATERIALS IN COARSE MATERIALS

Deleterious tests for coarse aggregates are based on visual inspection and require training and judgment. Deleterious substances of concern are clay lumps and friable particles, non-durable materials, coke, iron, and chert. Coke and iron are only of concern in slag, and no guidelines are given.

Clay Lumps and Friable Particles

Clay lumps and friable particles are defined as the material remaining after decantation that may be mashed with the fingers. The test is conducted according to **AASHTO T 112**.

A sample consists of material retained on the No. 4 sieve and each sieve above the No. 4 sieve, following decantation of sieve analysis. The sample is soaked 24 hours, plus or minus 4 hours, in distilled water. After soaking, any material or particles that may be broken by the fingers and (Figure 10-4) are removable by wet sieving are classified as clay lumps or friable material. The material retained after wet sieving is dried to constant weight and weighed.

Figure 10-4. Testing for Clay Lumps and Friable Particles

The percent clay or friable material is calculated by:

$$\%\,Clay\ or\ Friable = \frac{\text{Dry Wt.of Sample - Dry Wt.Retained (Wet Sieving)}}{\text{Dry Wt.of Sample}}\ \text{x}\,100$$

Non-Durable Materials

Non-durable materials are divided into two types:

1) Soft material as determined by **ITM 206**

2) Structurally weak material as determined by visual inspection

Both tests are conducted on the sample material retained on the <u>3/8 in.</u> sieve and each sieve above the <u>No. 3/8 in.</u> sieve.

The Scratch Hardness test (Figure 10-5) is conducted on gravel coarse aggregate. Each particle to be tested is subjected to a scratching motion of a brass rod, using a 2 lbf load.

Figure 10-5. Scratch Hardness Tester

Particles are considered soft if a groove is made in the particle without deposition of metal from the brass rod or if separate particles are detached from the rock mass. A particle is classified as soft only if one-third or more of the volume is found to be soft. Structurally weak materials are visually identified and include:

1) Ocher

2) Unfossilized shells

3) Conglomerates -- cemented gravels

4) Shale -- laminated rock of clay-size minerals

5) Limonite -- iron oxide, ranging from yellow-brown to black in color and is frequently a concretion around a soft core

6) Weathered rock that is structurally weak

7) Coal, wood, and other foreign materials

8) Materials with loosely cemented grains or a weathered coating

Particles determined to be soft or structurally weak are combined and the percent by weight of non-durable material is calculated by:

$$\% \text{ Non-Durable} = \frac{\text{Weight of Non-Durable Material above 3/8 in. Sieve}}{\text{Weight of Sample above the 3/8 in. Sieve}} \times 100$$

Chert

Chert is a rock of varied color, composed of glassy silica, and very fine-grained quartz, and is only picked from coarse aggregate. Unweathered chert appears hard, dense, and brittle with a greasy texture. Weathered chert appears chalky and dull. Chert is likely to have concave surfaces with sharp outer edges when freshly broken.

Total chert is picked from the sample following decantation and gradation. Chert is picked from the material retained on the <u>3/8 in.</u> sieve and each sieve above the <u>3/8 in.</u> sieve for aggregate sizes 2 through 8, 43, 53, and 73. For aggregate sizes 9, 11, 12, and 91, chert is picked from the material retained on the <u>No. 4</u> sieve and each sieve above the <u>No. 4</u> sieve. The procedure for determining the total chert includes:

1) All chert, including questionable chert, is picked from the sample.

2) All pieces of questionable chert are further tested by the following procedures:

   a. Scratching glass. Chert pieces scratch glass.

   b. Breaking Pieces. Chert breaks into rounded surfaces with sharp edges. If pieces do not break into rounded surfaces with sharp edges, they are added to the soft or non-durable material.

   c. Reaction with acid. Chert does not react with 0.1 N hydrochloric acid.

3) All material determined to be chert is weighed and the percent of total chert is calculated using the following formulas:

For aggregate sizes 2 through 8, 43, 53, and 73:

$$\%\ \text{Total Chert} = \frac{\text{Weight of Chert above the 3/8 in. Sieve}}{\text{Total Weight of Sample above the 3/8 in. Sieve}} \text{ x } 100$$

For aggregate sizes 9, 11, 12, and 91:

$$\%\ \text{Total Chert} = \frac{\text{Weight of Chert above the No. 4 Sieve}}{\text{Total Weight of Sample above the No. 4 Sieve}} \text{ x } 100$$

The percent chert requirement of **904.03(a)** applies to chert less than 2.45 bulk specific gravity. If the percent total chert exceeds this chert requirement, the sample is tested for lightweight pieces in accordance with **AASHTO T 113** to determine the percent chert less than 2.45 bulk specific gravity (Figure 10-6).

Figure 10-5. Test for Lightweight Chert

DELETERIOUS MATERIALS IN NATURAL SANDS

The purpose of the **AASHTO T 21** test is to provide a warning that further tests of the sand are necessary before the sands are approved for use. The procedure is as follows:

1) A glass bottle is filled with approximately 4½ fl oz of the sand to be tested.

2) A 3 percent sodium hydroxide (NaOH) solution in water is added until the volume of the sand and liquid, indicated after shaking, is approximately 7 fl oz.

3) The bottle is stoppered, shaken vigorously, and allowed to stand for 24 hours.

4) The color of the supernatant liquid above the test sample is compared to reference standard colors.

5) If the color of the supernatant liquid is darker than that of the reference color, the sand may contain injurious organic compounds, and further tests are to be made before approving the sand for use in concrete.

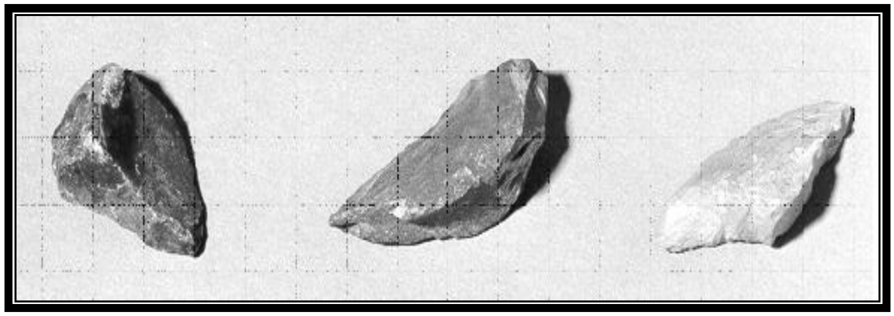
The **AASHTO T 71** test compares the compressive strength of mortar specimens made from the suspect sand to the compressive strength of mortar made from acceptable sand.

The colorimetric test (**AASHTO T 21**) is conducted first (Figure 10-6). If the color in solution is lighter than a standard, the fine aggregate is acceptable. If the color is darker, further testing of the fine aggregate for strength in mortar, **AASHTO T 71**, is required. If the effect of any organic matter reduces the strength no more than 5 percent, the fine aggregate is acceptable. Also, observations are required to be made to determine whether the organic material retards the mortar set or changes the necessary air-entraining admixture dosage.

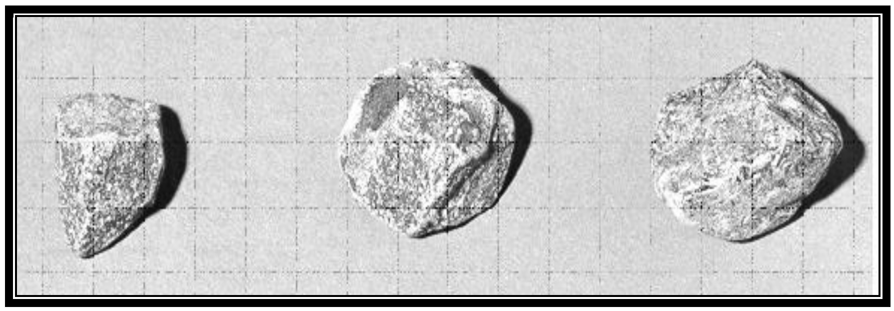
Figure 10-6. Colorimetric Test

CRUSHED PARTICLES

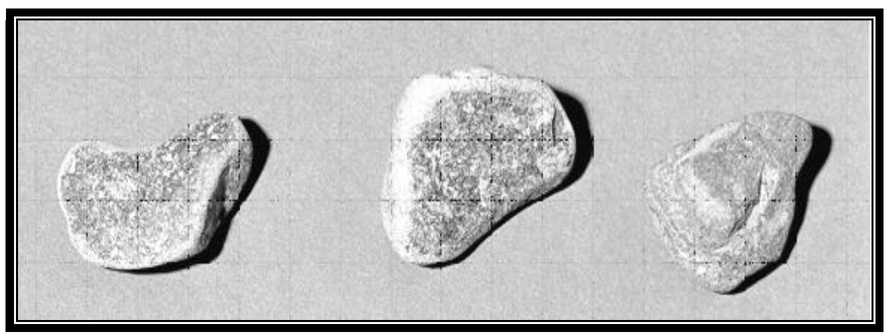
ASTM D 5821 includes the procedure for determining the quantity of crushed particles (Figure 10-7). Crushed particle requirements are used for gravel coarse aggregates in HMA (one and two-faced), compacted aggregates, and asphalt seal coats (except seal coats used on shoulders).



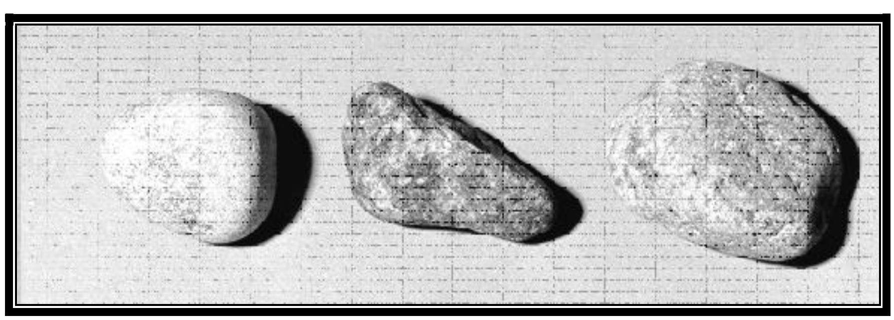
Crushed Particles (Sharp Edges, Smooth Surfaces)



Crushed Particles (Round Edges, Rough Surfaces)



Non-Crushed Particles (Round Edges, Smooth Surfaces)



Non-Crushed Particles (Rounded Particles, Smooth Surfaces)

Figure 10-7. Crushed and Uncrushed Particles

The test applies to all particles retained on the No. 4 sieve and is conducted as follows:

1) The total sample is washed over the No. 4 sieve and dried to a constant weight.

2) Each particle is evaluated to verify that the crushed criteria is met. If the fractured face constitutes at least one-quarter of the maximum cross-sectional area of the rock particle and the face has sharp or slightly blunt edges, the particle is considered a crushed particle.

3) Particles are separated into two categories: (a) crushed particles, and (b) non-crushed particles.

4) When two-faced crushed particles are required for aggregates used in HMA the procedure is repeated on the same sample.

5) The percent of crushed particles is determined by the following formula:

$$P = \frac{F}{F + N} \text{ x } 100$$

where:

P = percentage of crushed particles
F = weight of crushed particles
N = weight of uncrushed particles

FLAT AND ELONGATED PARTICLES

ASTM D 4791 (Method B) includes the procedure for determining the quantity of flat and elongated particles (Figure 10-8). The Specifications define a flat and elongated particle as "one having a length to thickness ratio greater than five".

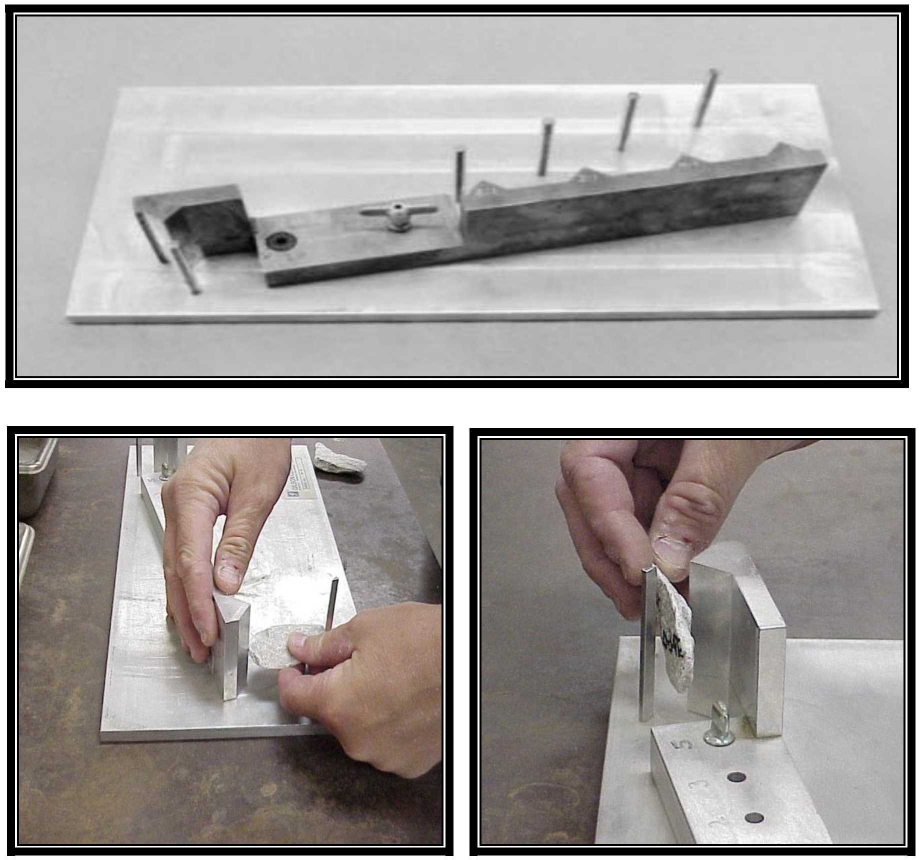


Figure 10-8. Flat and Elongated Test

The test is conducted on particles retained on the 3/8 in. sieve and each sieve above the 3/8 in. sieve as follows:

1) The total sample retained on the 3/8 in. sieve is weighed.

2) Each size fraction above the 3/8 in. sieve present in the amount of 10 % or more of the original sample is reduced until approximately 100 particles are obtained for each size fraction.

3) Each particle is measured with the proportionate caliper device set at the required ratio

4) The flat and elongated particles are weighed for each sieve.

5) The percent of the flat and elongated particles is then determined on each sieve by the following formula:

$$\%\ \text{Flat and Elongated} = \frac{\text{Weight of F \& E Particles for each Sieve}}{\text{Total Weight of Reduced Sample for each Sieve}} \times 100$$

PLASTIC LIMIT

Compacted aggregate materials, fine aggregate for SMA, mineral filler for SMA, and coarse aggregate sizes No. 43, 53, and 73, require tests for determining the plastic limit and liquid limit (Figure 10-9) of minus No. 40 sieve material. The plastic limit test may be conducted accurately only in a laboratory; however, the possibility of a plastic condition may be determined by a field check test. The liquid limit is required to be conducted in the laboratory.

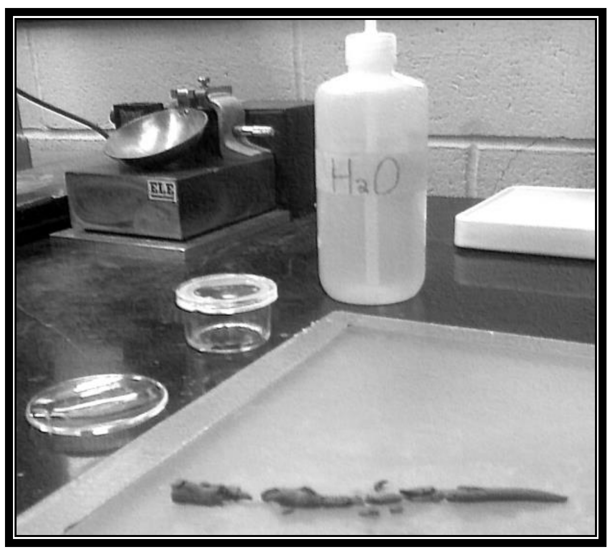


Figure 10-9. Plastic Limit and Liquid Limit

The plastic limit test may not be conducted on the same sample used for any other field tests. Therefore, in addition to the sample selected for the other field tests, the Technician is required to split and dry a sample of approximately 1000 grams. The test is conducted using a small spatula, a ground-glass plate, and an evaporating dish in accordance with **AASHTO T 90** as follows:

1) Using sufficient sieves, remove the material above the No. 40 sieve. All of the minus No. 40 sieve material in the sample is required. Any minus No. 40 sieve material clinging to the larger particles is required to be scraped free and all the dried composite particles retained above the No. 40 sieve is required to be broken up.

2) Thoroughly mix the minus No. 40 sieve material and select a sample of about 20 grams.

3) Place the sample in a suitable container, preferably an evaporating dish, and thoroughly mix with distilled or de-mineralized water until the material becomes plastic enough to be easily shaped into a ball.

4) Take about half of the sample and squeeze and form the sample into the shape of a small cigar. Place the specimen on a ground glass plate. With fingers, using just sufficient pressure, roll the specimen into a thread of uniform diameter throughout the sample length. The rate of rolling will be between 80 and 90 strokes per minute, counting a stroke as a complete motion of the hand forward and back to the starting position. The rolling continues until the thread is 1/8 in. in diameter.

Most compacted aggregate materials do not contain plastic fines. If the specimen cannot be rolled into a thread of 1/8 in. diameter, the Technician may assume that the material is either nonplastic or has a low plastic content, and no additional testing is required. If the specimen may be rolled into a thread of 1/8 in., the material is considered plastic and a sample is required to be sent to the District laboratory for an accurate determination of plasticity index.

TOTAL MOISTURE CONTENT

When aggregates are used in portland cement concrete mixtures, the moisture of the aggregates is required to be determined to adjust aggregate weights for moisture content and to determine the moisture contribution to the mixing water.

When a moisture content is desired, the sample is required to be reduced to test size and the test is conducted as quickly as possible after the sample has been obtained. Any delay in conducting the test after the sample has been selected may allow the material to lose moisture and result in inaccurate results.

The test is conducted in accordance with **AASHTO T 255** as follows:

1) Weigh the sample before drying and record the weight.

2) Dry the sample and cool to room temperature.

3) Weigh the sample and record the weight.

4) Determine the moisture percent using this formula:

$$\%\,\text{Moisture} = \frac{\text{Weight Wet} - \text{Weight Dry}}{\text{Weight Dry}} \times 100$$

Table of Formulas

$$\% \text{ Decant} = \frac{\text{Original Dry Weight - Dry Weight after Decant}}{\text{Original Dry Weight}} \text{ x } 100$$ (0.0) p. 10-4

$$\% \text{ Passing} = \frac{\text{Weight Passing Each Sieve}}{\text{Original Dry Sample Weight}} \text{ x } 100$$ (0.0) p. 10-10

$$\% \text{ Error} = \frac{\text{Original Dry Weight - Summation Weights Measured}}{\text{Original Dry Weight}} \text{ x } 100$$ (0.0) p. 10-12

(>+-0.3% is Invalid Test)

$$\text{Fineness Modulus} = \frac{\text{Cumulative Percentages "Retained"}}{100}$$ (0.00) p. 10-12

DELETERIOUS, CRUSHED, FLAT AND ELONGATED, MOISTURE

$$\% \text{ Clay or Friable} = \frac{\text{Dry Wt. of Sample - Dry Wt. Retained (Wet Sieving)}}{\text{Dry Wt. of Sample}} \text{ x } 100$$ (0.0) p. 10-16

$$\% \text{ Non - Durable} = \frac{\text{Weight of Non - Durable Material above 3/8 in. Sieve}}{\text{Weight of Sample above the 3/8 in. Sieve}} \text{ x } 100$$ (0.0) p. 10-17

$$\% \text{ Total Chert} = \frac{\text{Weight of Chert above the 3/8 in. Sieve}}{\text{Total Weight of Sample above the 3/8 in. Sieve}} \text{ x } 100$$ (0.0) p. 10-18

$$\% \text{ Total Chert} = \frac{\text{Weight of Chert above the No. 4 Sieve}}{\text{Total Weight of Sample above the No. 4 Sieve}} \text{ x } 100$$ (0.0) p. 10-18

$$\% \text{ Crushed (P)} = \frac{\text{Wt. of Crushed Particles (F)}}{\text{(F)} + \text{Wt. of Uncrushed Particles (N)}} \text{ x } 100 = \text{P} = \frac{\text{F}}{\text{F} + \text{N}} \text{ x } 100$$ (0) p. 10-22

$$\% \text{ Flat and Elongated} = \frac{\text{Weight of F \& E Particles for each Sieve}}{\text{Total Weight of Reduced Sample for each Sieve}} \text{ x } 100$$ (0) p. 10-24

$$\% \text{ Moisture} = \frac{\text{Weight Wet - Weight Dry}}{\text{Weight Dry}} \text{ x } 100$$ (0.0) p. 10-26

11 Job Responsibilities

Time Management

Time Consuming Activities
Example Schedule

Frequency of Sampling and Testing

Gradation
Decantation
Crushed Particles
Deleterious Materials
Additional Tests

Diary Requirements

Examples

CHAPTER ELEVEN:
JOB RESPONSIBILITIES

All persons in the chain of command at the processing plant are required to be aware of their responsibilities and how they fit into the overall manufacturing process. As problems occur in the process, each individual in the system is required to perform in a professional manner to insure the final result is a quality product.

TIME MANAGEMENT

The Certified Aggregate Technician may be responsible for more than one plant. Therefore, the Technician and Supervisor are required to know how much time is needed for conducting tests and the travel time between plants before writing the Quality Control Plan. Job duties other than quality control also are required to be addressed.

TIME CONSUMING ACTIVITIES

The approximate times for the various required duties include the following:

ACTIVITY	EXPENDED TIME
Meeting with management to receive production information	1 to 3 hours or more
Notifying the persons involved with process of sampling	5 minutes to 1 hour
Sampling the material per size	5 minutes to 1 hour or more
53, 73, and B borrow: splitting, drying, decant, drying, calculation, and charting per size	3 hours or more

ACTIVITY	EXPENDED TIME
5, 8 9, 11, 12 and fine aggregates: splitting, drying, decant, drying, calculation, and charting per size.	1 hour or more
Checking problems in the plant that may have caused a gradation problem	1 hour or more
Checking the quality control in the pit daily	1 hour or more
Notifying supervisor of any problems	5 minutes to 1 hour or more
Travel time	5 minutes to 1 hour; more than 1 hour will affect test time
Diaries	5 minutes to 1 hour
Cleaning lab	30 minutes to 1 hour

EXAMPLE SCHEDULE

Every morning or at the beginning of the shift, the Technician should meet with the Supervisor to schedule the production and stockpile testing. The mining area the material is being produced, and if the material is required to meet any special requirements are necessary to know.

If process control is maintained at one or more locations, a time schedule is required to be established to meet the testing frequency of products at each location.

EXAMPLE OF A TYPICAL DAY	
1.	Meet with supervisor to receive production information
2.	Notify the persons involved with the process of sampling from production or stockpile (plant operator, stockpile driver, loader operator)
3.	Sample the material using the approved method and equipment
4.	Check stockpiles for any contamination or segregation problems, and check the mining area to make sure what material is being produced and what quality control procedures are being followed
5.	Record all the sample information in the log book and start testing procedures
6.	Notify the Supervisor of any failures and make copies of gradation analysis for customer, Supervisor, and file
7.	Plot all test results on the control charts and conduct statistical analysis before the end of the day
8.	Maintain a daily file on all tests conducted and keep a clean and orderly lab

Day-to-day operations may be interrupted by unexpected occurrences, such as customer relations, special requests, writing reports, or working with INDOT personnel.

FREQUENCY OF SAMPLING AND TESTING

The most time consuming activity required by the CAPP is the sampling and testing of the aggregates.

Each Plant/Redistribution Terminal is required to determine the frequency of sampling and testing based on the control required to assure that the customer is obtaining the product specified.

The term certified material is defined as a product produced under the CAP Program intended for INDOT use. A frequency is required to be established for each certified material in the Quality Control Plan.

GRADATION

The minimum frequencies of sampling and testing for gradation include three time periods: Start of Production, Normal Production, and Load-Out.

The minimum requirement for sampling and testing a certified material during Start of Production is:

1) One test per 1000 t for the first 5000 t produced

2) A maximum of two per calendar day

The minimum requirement for sampling and testing a certified material during Normal Production is:

1) One test per 2000 t

2) A maximum of two per calendar day

The minimum requirement for sampling and testing a certified material during Load-Out is:

1) One test per 8000 t shipped

2) A minimum of one test per month for any certified material shipped that exceeds 1000 t

DECANTATION

All load-out samples are required to be decanted. Unless specific problems are encountered, start of production and normal production samples do not require a decant test.

CRUSHED PARTICLES

The minimum requirement for determining the amount of crushed particles is one test per week for each size of material during start of production and normal production. No test is required if the week's production is less than 100 t.

DELETERIOUS MATERIALS

The minimum requirement for determining the percentage of deleterious materials is one test per week for each size of material during the start of production and normal production. No test is required if the week's production is less than 100 t.

ADDITIONAL TESTS

The exact frequency of sampling and testing is source specific and is required to be defined in the Quality Control Plan.

Each Plant/Redistribution Terminal may conduct additional tests to maintain control of their operation. More testing may provide an additional assurance that the product being shipped is within the controls established.

DIARY REQUIREMENTS

Each Plant/Redistribution Terminal is required to maintain a diary. Test reports do not substitute for a diary. The diary is required to be an open-format book with at least one page devoted to each day that there is a material related operation. Entries into the diary are required to include:

1) General weather conditions

2) Area of extraction-location and ledges or pit area

3) Estimated quantity of materials produced

4) Time test samples obtained and tested, and corrective action if there were problems

5) Changes in key personnel, if any

6) Changes in equipment, plant, screens, etc., which may affect the current statistical results of aggregate materials

7) Any significant events or problems

8) Any nonconforming condition, as well as the action taken to correct the condition, if needed.

The diary entry is to be routinely signed each day by the Certified Aggregate Technician or Management Representative. On occasion the diary may be signed by another person; however, the diary is required to then be counter-signed by the Certified Aggregate Technician or Management Representative. Examples of diaries are shown on the following pages.

CAPP' DIARY

LOCATION: DATE: ______ START: ______

INDOT #: CAPP #: ________ STOP: ______

WEATHER: ______________________________ DOWN DATES: ______

IDLE TIME: ____________ (HOLIDAYS), ____________ (WEEKENDS)

GRID: ______________ : ____________

SAMPLES PULLED		
SIZE	TYPE *	TIME

TONS PRODUCED TODAY AND MONTHLY RUNNING TOTALS (MRT)

SIZE											TOTAL
TONS											
MRT											

SUPERINTENDENT'S (OR REPRESENTATIVE) REMARKS

CHANGES – PLANT, GRID, KEY PERSONNEL, ETC: ____________________________

EVENTS – PROBLEMS WITH PLANT, SCREENS, EQUIPMENT, ETC; ______________

(INITIALS ____)

***SAMPLE TYPES**

S = START UP FREQUENCY

N = NORMAL FREQUENCY

L = LOAD-OUT FREQUENCY

M = MISC.

R = RESAMPLE

CERTIFIED AGGREGATE TECHNICIAN'S REMARKS ____________________________

/

(NAME - PRINTED) (SIGNATURE)

FN: DIARY355

CAPP' DIARY - ADDITIONAL REMARKS

SOURCE #: DATE:

SUPERINTENDENT'S (OR REPRESENTATIVE) REMARKS – CONTINUED

( )
INITIALS

CAT'S REMARKS - CONTINUED

/
(PRINTED NAME) (SIGNATURE)

08/95

AGGREGATE TECHNICIAN PLANT DIARY

COMPANY:								
SOURCE & Q #:								
DATE: MONDAY TUESDAY WEDNESDAY THURSDAY FRIDAY SATURDAY SUNDAY								
WEATHER: CLOUDY, SUNNY, RAIN, THUNDER STORM, SNOW, COOL, COLD, WARM								
MATERIAL PRODUCED & TONS:								
VISUAL INSPECTION: TIME:/ INITIAL				1 ST VISIT 7AM	2ND VISIT 9:45AM	3RD VISIT 12:55PM	4TH VISIT 3:00PM	START - UP TIME
STOCKPILE/LOADOUT:								
DEGREDATION				YES/NO	YES/NO	YES/NO	YES/NO	SHUT-DOWN TIME
SEGREGATION				YES/NO	YES/NO	YES/NO	YES/NO	
CONTAMINATION				YES/NO	YES/NO	YES/NO	YES/NO	
LEDGE/LIFT:				PLANT CHANGES:				
SHOT LOCATION:								
PIT AREA:								
SAMPLES PULLED PRODUCTION:				OBTAINED DATE:	OBTAINED TIME:	COMPLETED DATE:	COMPLETED TIME:	PASS/FAIL COMMENTS:
1000 / 2000	LAB #	FREQ	SIZE					
FREQUENCY								
S = START-UP								
N = NORMAL								
I = INFO								
A=AUDIT								
LOADOUT:								
8000								
RESAMPLE:								
PROBLEMS:/ ACTION TAKEN AND CHANGES IN PLANT OR KEY PERSONNEL:							SIGNATURE	
							AUDIT SAMPLED BY	

TOTAL WEIGHT | GRAMS | LBS. | Report No. | Contract No. | RS 4-95

SOUTHERN INDIANA STONE CO.

SIEVE SIZE	LONG GRAD. WEIGHT RET.	WEIGHT RETAINED	WEIGHT. PASSING	PERCENT PASSING	CONTROL LIMITS	CUSTOMER SPECS.
3" (75 mm)						
2 1/2" (63 mm)						
2" (50 mm)						
1 1/2" (37.5 mm)						
1" (25 mm)						
3/4" (19 mm)						
1/2" (12.5 mm)	P/F					
3/8" (9.5 mm)						
No. 4 (4.75 mm)						
No. 6 (3.35 mm)						
No. 8 (2.36 mm)						
No. 12 (1.70 mm)						
No. 16 (1.18 mm)						
No. 20 (850 um)						
No. 30 (600 um)						
No. 50 (300 um)						
No. 60 (250 um)						
No. 80 (180 um)						
No. 100 (150 um)						
No. 140 (106 um)						
No. 200 (75um)						
No. 270 (53 um)						
No. 325 (45 um)						
PAN	ORIGINAL	FINAL	GRAMS LOSS	% LOSS		
DECANT						

NON-DURABLE	TOTAL WT. 3/8" UP	WT. OF NON-DUR.	% NON-DUR.	LONG GRADED MATERIAL	TOTAL WT. PASS No. 4	SAMPLE SIZE	PROPORT. FACTORS	AUDIT SAMPLED BY
AGG SIZE 5, 8, 57, 53, 73					GM	GM		
TOTAL CHERT	SAMPLE WT. 3/8" UP	WT. OF TCT CHERT	% TOTAL CHERT	TOTAL CHERT	SAMPLE WT. No. 4 UP	WT. OF TOTAL CHERT	% TOTAL CHERT	1. Stock/Stockpile 2. Bin or Tank 3. Processing Equipment 4. Truck, Barg, or Car 5. Inplace, Jobsite 6. Ledge or Pit 7. Customer Yard
AGG SIZE 5, 8, 57, 53, 73				AGG. SIZE 9, 11				
MECH. CRUSHED	SAMPLE WT. NO. 4 UP	WT. OF MECH. CRUSHED PT.	% MECH. CRUSHED	TOTAL CRUSHED	SAMPLE WT. No. 4 UP	WT. TOTAL CRUSHED	% TOTAL CRUSHED	

SAMPLE FROM | PLANT

TEST NO. | LOCATION

LEDGES | SHOT LOCATION #

OBTAINED DATE Mo. Day | TIME OBTAINED

COMPLETED DATE Mo. Day | TIME COMPLETED

MATERIAL | Moisture (CAS) (CAB) % | FREQUENCY ☐ START-UP ☐ NORMAL

SPECIFICATION | 93 - 1993 95 - 1995 | SP - SPEC. PROV. | PURPOSE | 73 - JOB CONTROL 75 - INFORMATION

SAMPLED BY | SUPERINTENDENT | TONS REP. BY TEST | PR. ☐ SP. ☐ DELETERIOUS TESTS PERFORMED | YES - 3 NO - 4

MATERIAL STATUS | K2 ACCEPTED | K6 REJECTED | K7 VISUAL | L1 INFO | WEATHER

QUALITY CHECKS AND CORRECTIVE ACTION	MATERIAL PRODUCED	MATERIAL SAMPLED
TOO FINE		
TOO COARSE		
CRUSHER SETTINGS		
JAW SETTING		
SCREEN CHANGES		
SEGREGATION		
CONTAMINATION		
WASH SAMPLE		
	LEDGE AND STOCKPILE INSPECTION TIMES	
DRY SHAKE		
	AM	PM
RESAMPLE	AM	PM

REMARKS

Appendices A-D

Appendix A - Indiana Test Methods

1. ITM No. 202
2. ITM No. 203
3. ITM No. 205
4. ITM No. 206
5. ITM No. 207
6. ITM No. 209
7. ITM No. 210
8. ITM No. 211
9. ITM No. 212
10. ITM No. 214
11. ITM No. 219
12. ITM No. 220
13. ITM No. 221
14. ITM No. 223
15. ITM No. 224
16. ITM No. 902
17. ITM No. 906
18. ITM No. 910

Appendix B - AASHTO Test Methods

1. AASHTO T2
2. AASHTO T11
3. AASHTO T27
4. AASHTO T84
5. AASHTO T85
6. AASHTO T112
7. AASHTO T248
8. AASHTO T304

ASTM Test Methods

1. ASTM D 4791
2. ASTM D 5821

Appendix C - Quality Control Plans

1. Limerock Quarries, Inc.
2. Indiana Quality Sand & Gravel, Inc.

Appendix D

Audits:

a. CAPP Audit Checklist
b. CAPP Partial Audit Checklist

Sampling, Sample Reduction & Testing Procedures

a. AASHTO T11 Form
b. AASHTO T27 Form
c. AASHTO T112 Form
d. AASHTO T248 Form
e. ASTM D 5821 Form
f. Blended Aggregate Form
g. ITM 206 Form
h. ITM 207 Form