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NEW JERSEY DEPARTMENT OF TRANSPORTATION

Division of Research and Development

Bureau of Structures, Materials and Applied Mechanics Research

STORAGE OF HOT BITUMINOUS CONCRETE MIXES

by

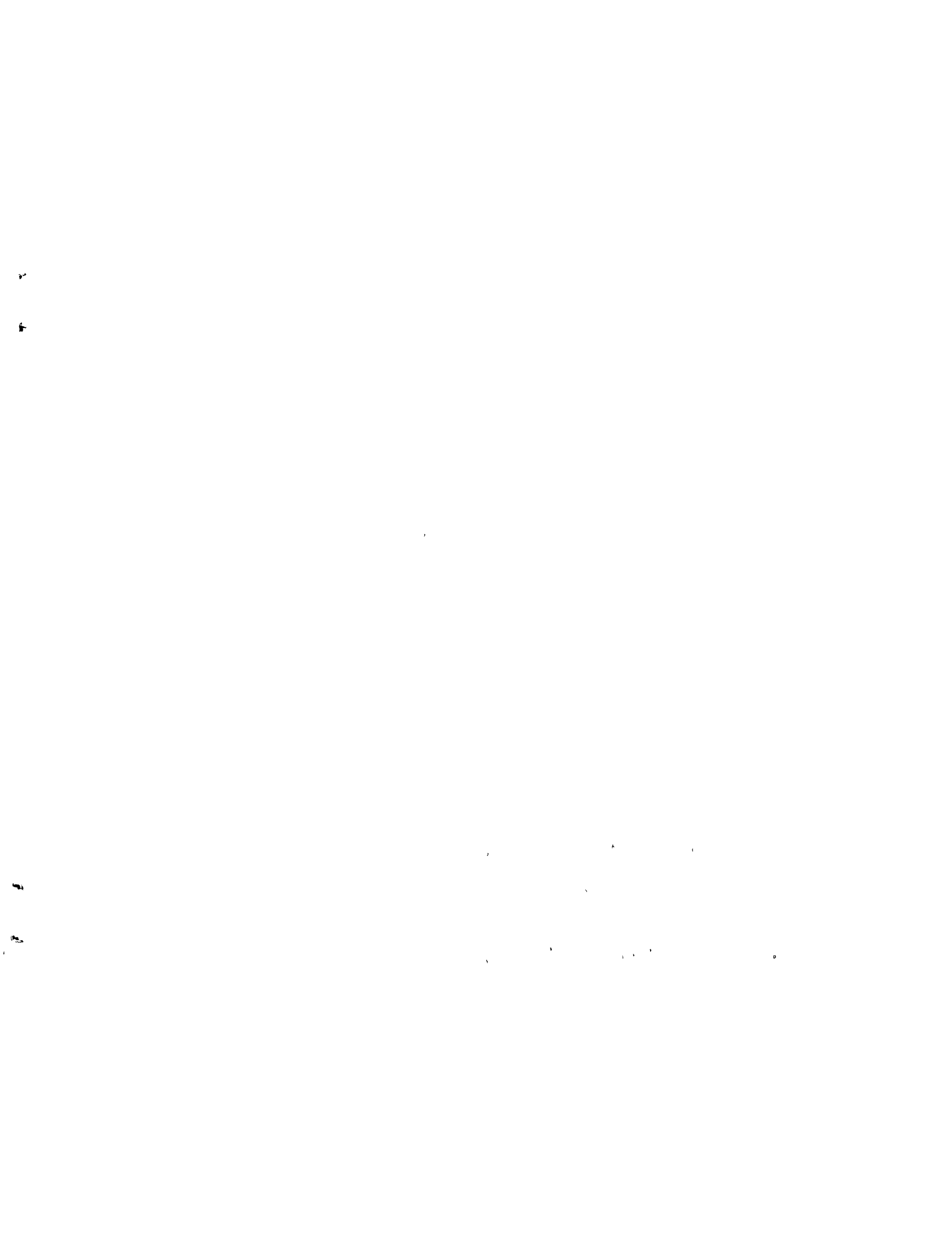
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ABSTRACT

With the recent proliferation of surge and storage units for the retention of hot bituminous concrete mixtures, many requests were being received by the New Jersey Department of Transportation for their permitted use. The Department, while fully aware of the potential advantages of surge-store units, was duly concerned with the possible effects on the physical characteristics of the mixtures when coursed through such a system.

This investigation was initiated to ascertain what limits or definitive specifications would be necessary to assure that the quality of "binned" mix, when placed as a mat, would be comparable to a mix delivered from the pugmill.

A testing plan was developed around the criteria of segregation, asphalt migration, loss in temperature, and loss in penetration. The adequacy of the procedure was then investigated in the field at several bin installations. Fine and coarse aggregate mixtures were tested for surge and storage use in bins of round and rectangular configurations. Surge testing varied from one to seven hours of retention time in an air atmosphere. Storage testing was conducted in both air and "inert" gas atmospheres with a maximum duration of ninety-six hours. No retarder type additive was used in the asphalt cement. The mixes were sampled as discharged from the pugmill and the bin. Temperatures were recorded and the samples tested for composition, penetration, viscosity and ductility. Thin film oven tests were conducted on the original and recovered asphalts.

The results showed that asphalt migration is not a problem when mixed in conformance with the general specification. Segregation does occur in coarse aggregate mixtures; the severity and tonnage effected is dependent on the type of bin and the accessory equipment used for discharging the mix. Substantial heat loss can occur in the uppermost region of the "binned" material, the degree of loss being a function of time, moisture content and the extent of supplementary heat. A detrimental loss in penetration (hardening) of the asphalt cement occurred in the topmost portion of the bin when stored overnight in an air atmosphere.

The specific aim of the project was achieved. A procedure was developed to enable the Bureau of Inspection, Plant and Project to evaluate field installations of surge and/or storage systems and define the specific limits of acceptance for use on State sponsored projects. Secondly a suggested general specification has been written to assure a quality of mix equal to that delivered from the pugmill.

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I. INTRODUCTION

Surge bins for the retention of hot bituminous concrete mixes have been used in Europe for many years and the plant without a surge bin is the exception rather than the rule. Almost all of the European bins are of either a square or rectangular configuration ranging from a miniscule 25 ton unit up to units of 300 tons. Conversely only a few isolated units were found in the United States until about a decade ago.

Over the past six years, greater interest has been generated due to the proliferation of papers offered at technical meetings, in trade journals and the almost weekly barrage of brochures from zealous equipment manufacturers extolling the golden opportunity for extensive economic rewards.

In the last two to three years the use of surge bins has increased at a very rapid rate in the State of New Jersey and reflects a trend that is occurring throughout the United States. As a result requests were received by the New Jersey Department of Transportation for permission to use surge or storage bins on State sponsored jobs.

The Director of the then Division of Materials while acknowledging the potential advantages of the surge bin, also realized that prolonged storage could pose additional problems. He therefore requested of the State Highway Engineer that the Division of Research and Development undertake an investigation to ascertain the effects of surge-store equipment on hot bituminous concrete and determine what limits or definitive specifications may be necessary.

Information from a preliminary study was sufficient to warrant the encouragement of surge and storage bin use. Interpretation of the results of previous investigations showed that an initial in-service evaluation was necessary to establish the adequacy and limitations of any given unit.

In order of priorities then, it became manifest to first define the specific aim and secondly develop an appropriate plan of investigation.

A. Specific Aim

The purpose of this investigation was to determine if hot bituminous concrete mixes processed through surge or storage bins could be approved for use on state sponsored projects and to:

1. Develop a procedure whereby the Bureau of Inspection, Plant and Project can evaluate field installations of surge and/or storage bins, and establish the criteria for acceptance or rejection of these installations.

2. Develop a general specification for surge and storage bin systems.

B. Research Approach

The normal avenues of approach were employed to determine the latest "state of the art" on the storage of hot bituminous concrete mixes. A literature search was conducted; letters were sent to all Highway Departments and Turnpike Authorities for reports, technical memoranda, general notes and/or specifications. The National Associations were contacted and a personal survey conducted of those producers in New Jersey employing the type of equipment under investigation. Discussions

were held with Division and Bureau personnel within the Department of Transportation who had a direct or indirect interest in the project.

From the literature search, it was determined that segregation of mix, loss of temperature, asphalt hardening (loss in penetration), and asphalt migration were viable criteria.

Hardening can be readily influenced by the type of mix, the source and grade of asphalt, the addition of "silicones" and by storage in an "inert" atmosphere. In this investigation both air and "inert gas" atmospheres were studied. The use of a silicone addition to the asphalt cement was excluded since silicones are not acceptable on state jobs.

A notable point of interest is the common and all too casual interchange of the term surge and storage. In this investigation surge use will be considered from one to eight hours of retention time or limited to same day use. The term storage will designate overnight and longer periods of retention time.

"Inert gas" (as erroneously accepted by this industry) will signify the dehydrated flue gas produced through the combustion of natural gas in a special burner.

There was an 86 percent response to the written request with only seven states having standard specifications regarding the use of surge and storage units. The specifications ranged from extremely

detailed equipment specifications to broadly interpreted general specifications permitting the use of "other methods and equipment." In summary these specifications were either severely restrictive, meaningless or relied too much on the judgment of the Inspector or Engineer.

Based on the information extracted from all the forementioned sources a preliminary procedure for evaluating surge-store systems was developed. The adequacy of the procedure was then investigated through trial application at several bin installations.

Results from mixture quality tests conducted through these trials were used to develop the suggested end product specification requirements having definitive limits on changes in the physical properties of hot bituminous mixes when coursed through a surge or storage bin system.

C. Significance of Work

The use of surge or storage bins provides for a more continuous operation. A continuous operation usually reflects a more uniform product over a start and stop operation. Secondly, it eliminates truck "bunch ups" and permits uniform delivery to the paving train allowing a more consistent laydown by the paving crew.

Aside from the potential improvement in quality, the overall efficiency provided by increased production and lower hauling and laydown costs could have a favorable effect on competitive bidding.

These potential benefits however can only be of value to the State providing that the equipment delivers a product equal to or better than that delivered directly from the pugmill.

II. LITERATURE REVIEW

A. Equipment

The characteristics of the available equipment for surge-storage systems are multifarious. For the sake of brevity, the general description rather than the possible combinations of each individual option will be discussed.

The bin configuration can be either square, round or oval. It can be open topped, partially closed, or fully closed with a hatch cover. The bin may be unheated, insulated-unheated, or insulated with partial or total heating by either electric or hot oil.

Conveying of the hot mix from the pugmill to the bin is by either a continuous or a batch method. The continuous method employs either rubber belt, inclined screw, bucket elevator or drag slat conveyor. The batch method is by skip hoist powered by a hoist winch or a hydraulic drive. In filling the silo(s) only the skip hoist allows a mass dump of the whole batch from the pugmill. The continuous system can either be a direct drop or into a receiving hopper which makes a simulated mass dump at a predetermined weight. For multi-bin units, the conveyor may dump into a horizontal screw, or a flip flop diverter for transferring the material to the bin selected for filling. The continuous conveyor can be open or closed, unheated or heated, by electric, oil or hot air.

Various appurtenances to the bin as internal splitters, articulating rotary conveyors, cylindrical sections (to reduce the horizontal component of velocity), inverted pyramid type hoppers, a steeply tapered cone hopper, an inverted cone within a hopper, single or double discharge gates (both round and square) and vibratory bin actuators or weigh batchers for unloading, are proffered. All the fore-going coupled with an atmosphere of air or "inert" (low-activity) gas offers a fair description of the variables in considering an equipment specification.

B. State of the Art

The effect of the surge-storage of hot bituminous concrete mixes as reported by other researchers show variable results. It has been generally stated, "that safe storage periods are a function of the nature and uniformity of the mix rather than the bin design."⁽¹⁾ It has also been claimed that, "the allowable storage time in a heated bin depends on the rate of asphalt hardening; and that hardening of the asphalt will vary with the coarseness of mix, source and grade of asphalt, treatment of asphalt with silicone and the atmosphere in the bin."⁽²⁾

Comprehensive tests on mixes from surge and storage bins were conducted by the Florida Highway Department⁽³⁾ and the National Asphalt Producers Association (NAPA) in 1966⁽⁴⁾ and 1967.⁽⁵⁾ Various types of mixes were employed in the forementioned tests. The mixes were both open and dense graded, ranging in gradation from fine to coarse. The fine mixes (1/2 inch maximum size) were of crushed gravel, gravel and sand. Coarse mixes (1-1/2 inch maximum size) were of crushed stone and stone fines. The binders were penetration grade asphalts, grade 40/50, 60/70 and 85/100.

The following is offered in summation:

1. General

- a) There is no migration of asphalt in storing mix at temperatures up to 325°F. Some migration has been reported when storage was attempted at 340°F.
- b) Coarse or open graded mixes segregate more and harden faster than fine graded mixes.
- c) Discharge temperature of the mix in surge use is essentially the same as the mix's input temperature. In storage the temperature tends to level off and become quite uniform after four hours, at a level 10° to 20°F below the mixing temperature.
- d) Silicone and/or inert gas extends storage time.

2. Specific

- a) There is no change in asphalt content except when associated with segregation. Samples finer than the average gradation were higher in asphalt content, the coarser samples being lower.
- b) There is no segregation in fine mixes below a 1/2 inch top size when the bin delivers essentially a vertical mass flow action. Significant segregation occurred in coarse mixes between 1/2 inch and 1-1/2 inch top size; the last load out being considerably coarser.
- c) In an unheated surge bin, holding time depends on how fast the mix at the bottom of the cone cools and sets up. Holding

time in a heated bin is dependent on the rate of asphalt hardening.

- d) A silicone addition at the rate of two ounces per 1000 gallons of asphalt cement prevents migration of the asphalt.
- e) A silicone (DC-200) addition of one ounce per 5000 gallons of asphalt in an air atmosphere increased the safe holding time from two to six hours. (three fold increase)
- f) An inert gas atmosphere increased storage time from two to 24 hours. (12 fold increase)
- g) The use of an inert gas atmosphere and a silicone addition increased storage time from six to 72 hours. (12 fold increase)
- h) That the use of both silicone and an inert gas atmosphere is necessary for more than one day storage of coarse mixes.

The results of these tests led to proposed specifications from NAPA's Quality Improvement Committee which will be discussed later.

C. Unpublished Data

In the past few years many states became concerned as to how the use of bins would affect the quality of their bituminous mixtures. Segregation, loss in temperature and penetration, and storage times were the items of primary interest.

Segregation received the most attention and many difficulties were encountered when bins were first introduced. As a result of adjustments in bin construction and the attendant transfer equipment much of this problem has been eliminated. This is especially true in bins of the

mass flow design when not emptied below the cone.

Loss in temperature is dependent on bin use and ambient temperature. In uninsulated surge units, losses up to 80°F have been reported when the ambient temperature fell below 50°F. On the other hand, material stored in heated bins for as long as 12 days showed virtually no loss in temperature.

In viewing the specifications received, surge-storage times vary from same day use, to 10 days for silicone treated asphalt mixtures in heated bins having an inert gas system.

The subject of hardening (loss in penetration) is a difficult point to broach. Most studies of asphalt hardening show there is considerable question as to whether a drop in penetration necessarily implies a corresponding loss in quality.

Data from other states show that a 85/100 penetration grade material (92 actual) was stored for eight days with a recovered penetration of 58, or 63 percent of original; another series showed a recovered penetration of 55 after four days storage which was 62.5 percent of the original (88). A New Jersey producer using a silicone addition in an air atmosphere showed a recovered penetration of 38 after four days storage which was 41.3 percent of the original. From the files of New Jersey Department of Transportation's Bureau of Quality Control, sixty-four cored pavement samples taken in 1953 (non-storage material) had an average recovered penetration of 64.8 or 70.5 percent of the original average (91.9). A more recent study based on TFOT (thin film oven test) shows an average penetration of 58 for 26 samples, or 60 percent of their original (94.9).

Recently committees of National Organizations have suggested that the lower limit on penetration of a recovered asphalt be based on a percentage of the original value after the thin film oven test (TFOT). The AASHO and ASTM requirements for an 85/100 pen asphalt are 50 percent and 47 percent respectively. This would permit acceptance in New Jersey of penetration values of 43 and 40; a value considerably below the 58 as shown in our laboratory figures.

III. RESEARCH PLAN RESOLUTION

A. Discussion

"Since a mix that has gone through a surge or storage bin will be put to the same service as a mix hauled directly to the job site, it is logical that the mix in both cases should meet the same specifications."⁽²⁾ Considering this statement as being a practical qualification and sensing the enormity and cumbersomeness of an equipment specification, it became evident that an end product specification would be the most effective method for both testing and control. In view of the consensus of opinion of prior researchers and the scope of the general provisions of Addenda A to the 1961 New Jersey Standard Specifications, the criteria of penetration, segregation and temperature become requisites for formulating a bin evaluation procedure and determining those limits of definitive specifications that may be necessary.

1. Penetration

The ordinary controls and the general requirements for bituminous material do not give any assurance that excessive hardening would not

occur in storage which may have a deleterious effect on the mix.

Most agencies do not apply penetration limits to a bituminous mix because of the time consumed in the recovery procedure and the lag between sampling and the test results. Some agencies do not have the facilities for testing and others simply rely on specifications recommended by National or Trade associations. Specifications therefore, have been written which tend to be over restrictive, rely too much on human judgment, or are munificent.

The State of New Jersey has no provisions for the use of surge-storage units nor limits on penetration of recovered asphalt. In viewing the large differences in penetration that may occur it is imperative that limits be established to prevent the acceptance of a less serviceable material than that delivered from the pugmill.

The phenomenon of hardening or loss in penetration is not thoroughly understood. It is generally accepted that the chief factors relating to deterioration of asphalt cement are oxidation and volatilization. Both of these factors are influenced by a time-temperature relationship which was not taken into consideration by some researchers, leading to inaccurate results and misleading conclusions. The use of dry ice (CO₂) to chill the samples should stop these reactions and more correctly indicate the true physical properties at a given point in time.

2. Segregation of Mix

It has been demonstrated that segregation can occur with different mixes in a particular bin and that bin configuration itself can cause segregation. (6) It is also possible then, in bins of the same

configuration containing internal splitters, when the height is increased (for greater capacity) the resulting differences in splitter heights, might effect a segregative response. Therefore each bin should be tested individually for each mix. If the coarsest material were tested first and found to be acceptable within the job mix formula, it may not be necessary to check mixes of a finer gradation. However, with a stabilized base where the mix may be of stone or gravel, (different internal frictions) approval of one should not guarantee automatic approval of the other.

3. Temperature

Reports show that surged and stored mixes have been held for various periods of time with little loss in temperature. Suggested specifications for retention times on "start up" for unheated and heated bins range from two to 144 hours. It is conceivable that a limit established at a 90°F ambient temperature may not be acceptable at 40°F in an unheated unit. While the bulk of the material may be held within acceptable limits, steep gradients occurring at the extreme ends (both top and bottom) could detrimentally effect compaction in the pavement. It is also quite possible that chilling at the shell interface of uninsulated units could cause caking and a subsequent discharge of lumpy material as the bin is emptied. A final point which has been given very little consideration is that of wet aggregate. One manufacturer has reported a 75°F drop in mix temperature over a 12 hour period in a heated unit when wet aggregate was used. As a frame of reference, it requires approximately 1000 BTU's to convert one pound

of water to a pound of steam. If the aggregate in a 150 ton unit contained 1% trapped water which was converted to steam, the mass of material could sustain a 3-1/4 million BTU loss.

In summation it can be stated that due to the great number of variables that may be encountered in a surge or storage bin system, it is judged incumbent that each unit be tested for each type of mix before either a tentative or permanent approval be given. Furthermore, the approval should be contingent upon normal prototype usage, that is, if the testing is for surge use then long term storage would not be allowed. If storage is the consideration then approval would be for any time within the interval tested. From the survey conducted among the producers in New Jersey, it was determined that 96 hours represented 100% of the maximum anticipated storage time.

B. Sampling and Testing Plan

A tentative evaluation procedure for surge-storage units was developed and subjected to trial applications at several asphalt plants. The sampling and testing conducted during each trial is described in general terms below and more completely in Appendix "C". All testing was in accordance with the standard procedures as outlined by AASHO, ASTM or the New Jersey Department of Transportation.

1. Bin Loading

Samples of the paving mixes were taken from the receiving containers (skip bucket or auger hopper) immediately after dropping from the pugmill. The number of samples taken during loading of the bin ranged from six to eight depending on the capacity of the unit being

tested. A bucket of bituminous mix was collected by sampling the top, middle and bottom of the heaped material. The temperature was measured by two thermometers, an inspector's dial type asphalt thermometer and a two inch needle type probe pyrometer (50-400°F range - 20 second full scale response) calibrated against a mercury thermometer in a hot oil bath. The samples were prepared as prescribed in article 9.1.22 of Addenda A of the 1961 New Jersey Standard Specification. Two 8 x 8 x 2 inch blocks weighing approximately eight pounds apiece were made from each sample, one for extraction, one for recovery. Three to five minutes elapsed from the time the mixes were sampled and the blocks were formed. The blocks were immediately chilled by placing a 9 x 9 x 1 inch slab of dry ice under and over the block sample. After two to three minutes the steel band forms were removed and the dry ice sandwiched samples were placed in a styrofoam chest for transfer to a deep freeze at the laboratory. Initially all samples from the pugmill were frozen but this practice was discontinued for the sake of economy and only the samples tested for asphalt recovery were so treated for the balance of the investigation.

2. Bin Unloading

As the bin was unloaded, samples were taken from the truck coincident (on the weight out basis) with the samples obtained on loading. The first and last loads out received additional incremental sampling at 1/2 and/or 1/3 the load.

3. Tests

All the bituminous mix samples, both pugmill and bin, were tested by extraction and recovery. The asphalt cements were subjected

to the normal specification tests and thin film oven residue tests. Additional tests such as the recovery of asphalt from Marshall plugs and others were designed for further supportive information.

IV. FIELD INVESTIGATION

The tentative procedure as developed was empirically evaluated in the field. Only minor changes were made to increase the precision as new information was generated.

A. Equipment

The bins evaluated were of round and rectangular configuration. The capacities ranged from 150 to 200 tons. No two units were identical. The following illustration shows the distinguishing features of each particular system.

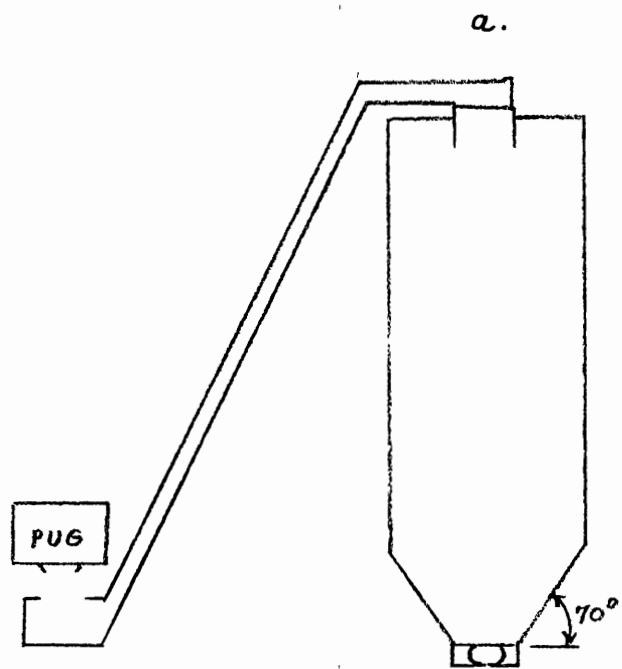
B. Bituminous Mixes

Eight tests were completed out of ten attempted. Two were aborted due to mechanical delays at the plant. Three of the Standard Bituminous concrete mixes, New Jersey #1, #2, and #5 as outlined in the green or yellow Addenda A to the New Jersey Department of Transportation Standard Specifications were employed during the investigation.

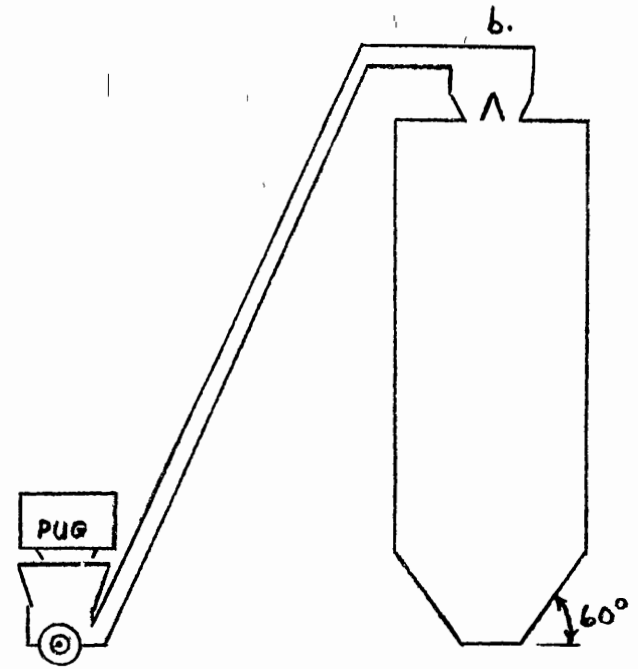
The three evaluations conducted in 1971 used an 85/100 penetration asphalt cement as the binder. The five evaluations in 1972 were conducted with the viscosity graded AC-20 asphalt cement.

C. Retention Time

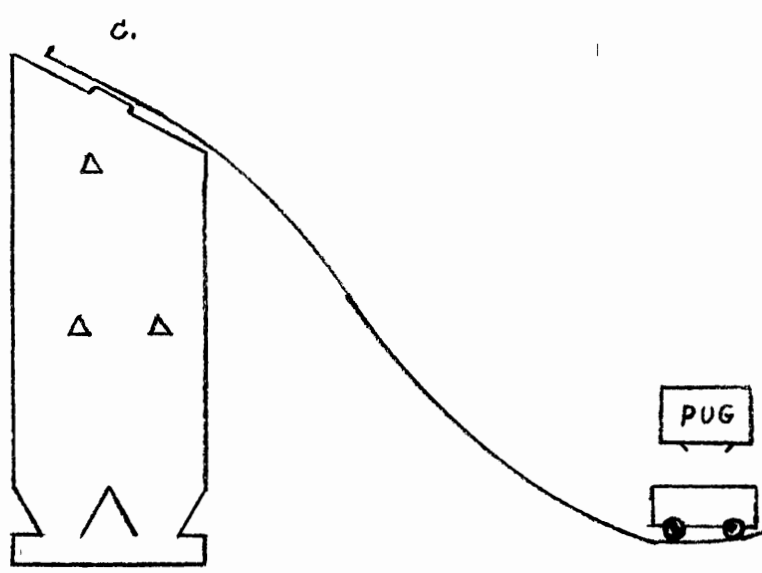
Three evaluations were made for storage, one with a #5 and two with #1 mixes; the retention times ranging from 16 to 94 hours. The other five evaluations were for surge or same day use incorporating the #1, #2 and #5 mixes, retention times being from 1 to 7 hours.



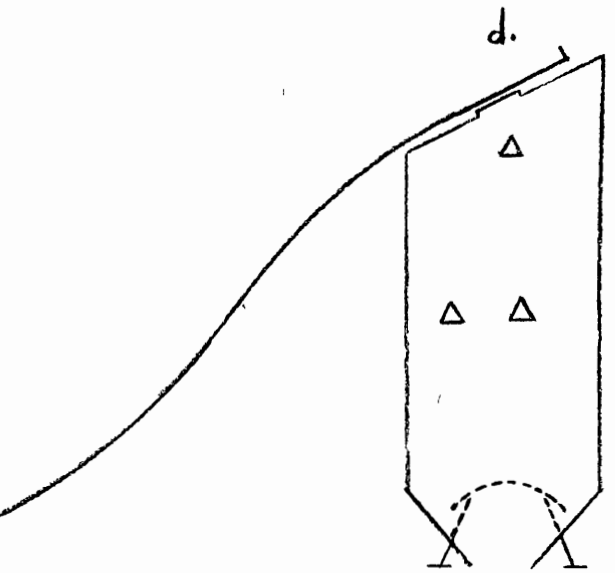
Totally Heated Oil Jacket
 Insulated
 Inert Gas Available
 Air Locks (Seals Top and Bottom)
 Enclosed Drag Flight Conveyor (Heated)
 Central Drop



Heated Cone (Electric)
 Insulated
 Air Atmosphere
 Enclosed Drag Flight Conveyor (Unheated)
 Anti Segregation Mix Dispenser



Partially Heated by Oil (40% on Three Sides)
 Insulated
 Air Atmosphere
 Internal Splitters
 Skid Hoist Fed
 Dual Inverted Pyramid Hopper
 Emptying into a Batch Hopper



Partially Heated (40% on Four Sides)
 Insulated
 Air Atmosphere
 Internal Splitters
 Skip Hoist Fed
 Vibra Screw Bin Actuator for Discharge

V. DISCUSSION OF RESULTS

The results of the field investigation fully demonstrated that segregation, loss of temperature and loss of penetration are valid criteria in evaluating surge and storage systems and aid in establishing the limits necessary to assure acceptable material.

Initially the uniformity of gradation of the fine mixes caused some consternation as to whether the procedure was truly capable of detecting mixture segregation. This apprehension was quickly dispelled as dramatically exhibited in Figure 4 and the subsequent trials of coarse mixes.

The use of dry ice for the rapid chilling of the bituminous concrete samples irrefutably shows the existence of a time-temperature relationship concerning loss of penetration and questions much of the literature written over the past 30 years regarding the "loss" attributable to the pugmill.

The data is presented for ready reference in the form of figures, tables and explanations of the not so obvious. The presentation is by criteria, the order indicating its rank of importance to an evaluation.

A. Segregation

1. Evaluation Data

Table I shows the results of the extraction test on a surged #5 mix. The gradation of both the pug and surge bin samples while not within the tolerances of the job mix formula exhibit good conformity. The bin material being more uniform and slightly finer. The gradation number shown represents the sum of the percentage passing each sieve. The higher the number the finer the gradation of the mix.

TABLE NO. I

Extraction Test Data, Surged No. 5 Mix
PUG SAMPLES

Sieve % Passing	1	2	3	4	5	6	Design	Job Mix Formula
1/2"	100	100	100	100	100	100	100	100
3/8	98	96	96	98	98.5	98	97	90-100
4	68	57	56	59	57.5	59	65	60-80
8	49.5	43.7	43.2	44.0	44.5	42.8	48	43-53
50	21.4	19.8	17.7	18.7	18.9	19.8	20	16-24
200	6.1	5.4	5.6	6.4	6.3	7.8	6.3	4.3-8.3
Grada- tion #	343.0	321.9	318.5	326.1	325.7	327.4		313-365
Bitumen	6.31	6.9	6.12	6.13	6.15	6.18	5.8	5.3-6.3

Variable	Mean	Std. Dev.	Maximum	Minimum	Range
3/8	97.417	1.114	98.50	96.00	2.50
4	50.417	4.364	68.00	56.00	12.00
8	44.608	2.466	40.50	42.80	6.70
50	19.383	1.261	21.40	17.70	3.70
200	6.258	0.848	7.80	5.40	2.40
Bit	6.164	0.078	6.31	6.09	0.22

SILO SAMPLES

Sieve % Passing	1	2	3	4	5	6	7	Job Mix Formula
1/2"	99	100	100	100	100	100	100	100
3/8	97	98	94	99	99	98	99	90-100
4	61	62	59	59	62.5	60	60	60-80
8	40.6	45.5	46.9	44.9	46.6	43.4	42.9	43-53
50	20.5	20.1	20.1	19.2	20.1	17.7	17.9	16-24
200	6.5	6.1	5.9	6.8	6.9	7.0	7.2	4.3-8.3
Grada- tion #	324.6	331.7	325.9	328.9	341.4	326.1	327.0	313-365
Bitumen	6.19	6.15	6.04	6.28	6.30	6.14	5.62	5.3-6.3

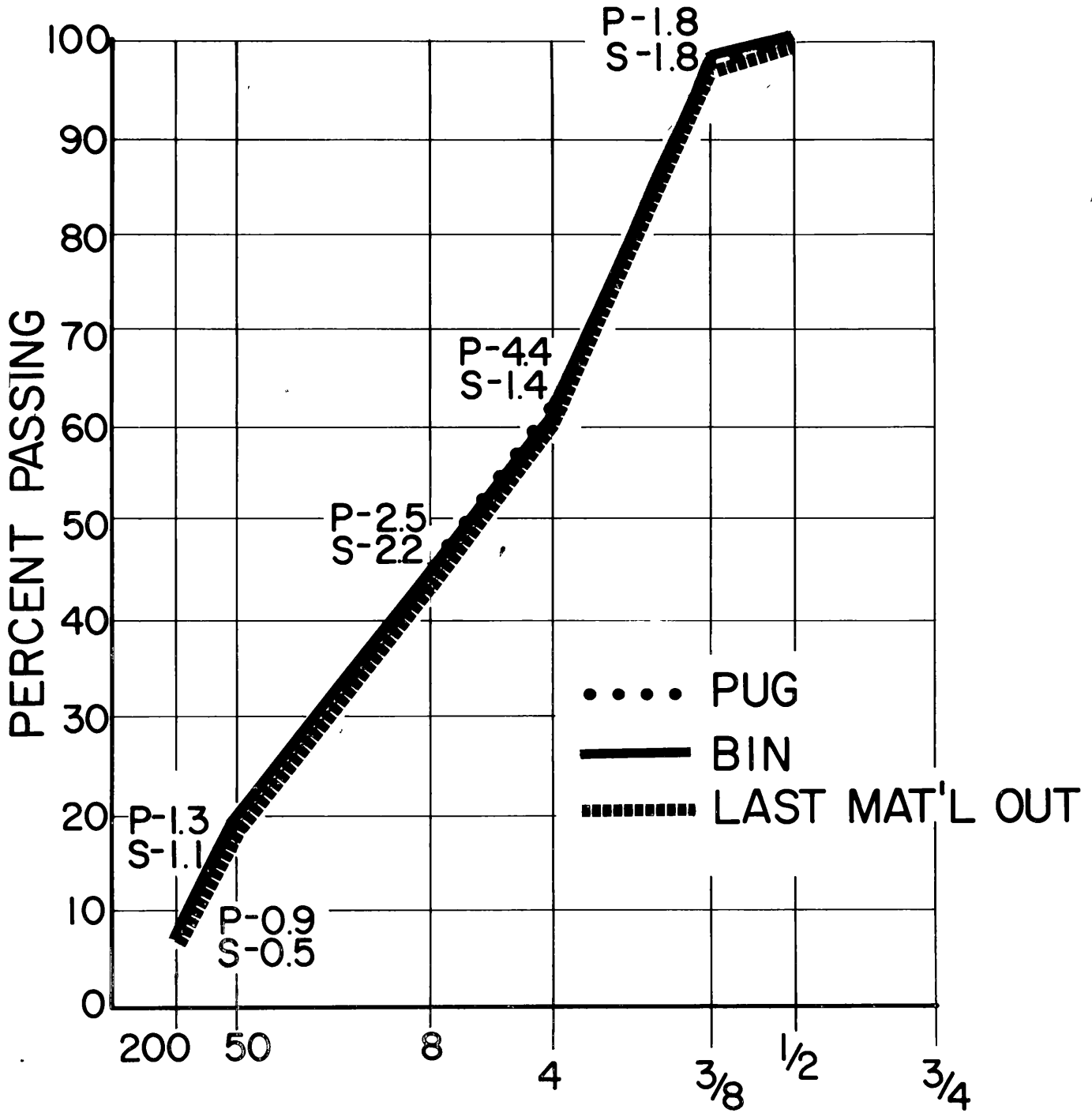
Variable	Mean	Std. Dev.	Maximum	Minimum	Range
3/8	97.857	1.773	99.00	94.00	5.00
4	60.500	1.384	62.50	59.00	3.50
8	44.393	2.237	46.90	40.60	6.30
50	19.364	1.139	20.50	17.70	2.80
200	6.621	0.478	7.20	5.00	1.30
Bit	6.103	0.230	6.30	5.62	0.68

Figure 1 is a gradation chart with the sieve sizes raised to the 0.45 power and compares the average gradations of the pugmill samples, the bin samples and the last material out. The number beside each point is the standard deviation for the particular sieve. The results were so close that the plot for all practical purposes could have been represented by a single line.

Figure 2 is a plot of the percent asphalt versus the gradation number, the larger box represents the master range as shown in Table 3 of ASTM: D1663, (Composition of Asphalt Paving Mixtures) the smaller box the tolerances of the job mix formula. This plot indicates the mix was on the coarse side with a slightly higher bitumen content than designed.

Table II shows the extraction results of a #5 mix tested for storage up to 94 hours in an inert gas atmosphere. This particular test requires a more detailed explanation. On the day of the test the plant was making two mixes; a #2 mix for a maintenance job and a #5 mix for the evaluation. As a result of switching back and forth between the mixes, the trucks and storage, it took four and a half hours to fill the bin. When the 126th ton was sampled it showed that 21 tons of the #2 mix had been inadvertently placed in the bin. It was decided to continue with the test and 48 tons of #5 mix were added to fill the bin.

The bin was unloaded in 21 ton truckloads at predetermined time intervals within the 96 hours scheduled. By judicious observation and incremental sampling the deleterious mix was eliminated from the bin. At 106 tons, two percent coarse aggregate was found on the 1/2 inch sieve (Sample 5D). The coarsest mix occurred at 124 tons (Sample 6D).



SIEVE SIZES RAISED TO 0.45 POWER

FIGURE I

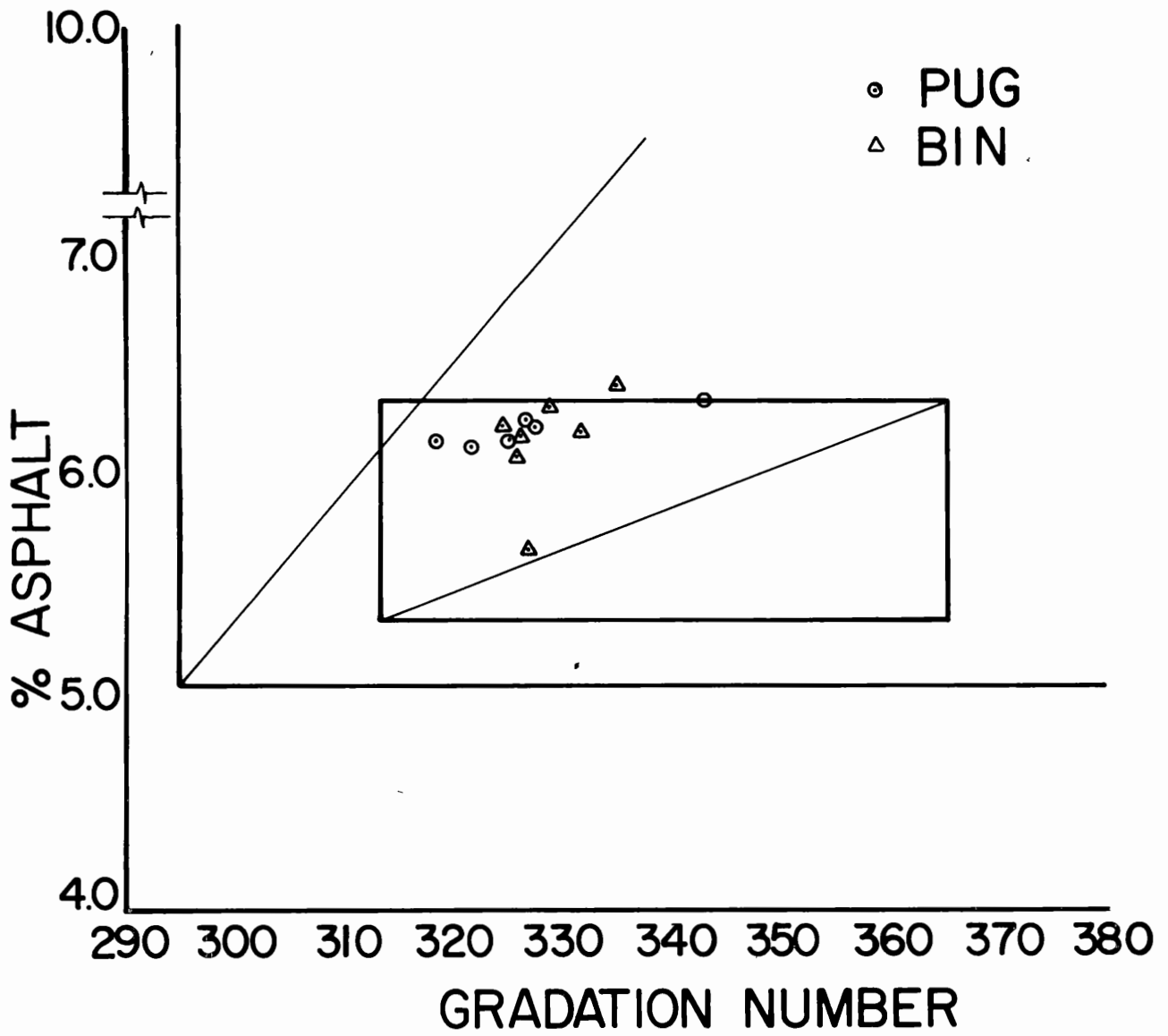


FIGURE 2

TABLE NO. II
EXTRACTION TEST DATA, SURGED NO. 5 MIX
PUG SAMPLES

Sieve % Passing	1B	2B	3B	4B	5B	6B*	7B	8B	Design	Job Mix Formula
1/2"	100	100	100	100	100	85	100	100	100	100
3/8"	98	98	99	97	97	79	94	99	97	90-100
4	60	57	57	61	59	44	60	65	65	60-80
8	43.9	39.3	43.3	46.9	42.7	30.6	46.2	44.8	48	43-53
50	12.3	17.2	15.0	16.7	15.5	12.1	16.7	14.7	20	16-24
200	3.3	7.3	4.4	4.0	4.8	4.6	3.2	3.1	6.3	4.3-8.3
Gradation #	317.5	318.8	318.7	325.6	319.0	255.3	320.1	326.6		
Bitumen	5.76	5.65	5.51	5.84	5.56	5.71	5.84	5.71	5.8	5.30-6.30

Variable	Mean	Std. Dev.	Maximum	Minimum	Range
3/8"	97.429	1.718	99.0	94.0	5.0
4	59.857	2.734	65.0	57.0	8.0
8	43.871	2.518	46.9	39.3	7.6
50	15.443	1.677	17.2	12.3	4.9
200	4.300	1.472	7.3	3.1	4.2
Bitumen	5.696	0.130	5.84	5.51	0.33

<u>SILO SAMPLES</u>													
Sieve % Passing	1B	2B	3B	4B	5B	5D	6D*	7B	7D	7F	8B	8D	Job Mix Formula
1/2"	100	100	100	100	100	98	84	100	100	100	100	100	100
3/8"	98	97	97	97	96	93	76	97	99	97	98	99	90-100
4	63	55	60	64	61	59	46	62	64	62	66	59	60-80
8	46.2	39.7	45.3	54.0	45.5	44.0	33.8	45.8	47.6	47.7	48.3	42.9	43-53
50	12.8	17.9	17.1	20.3	16.8	17.3	12.8	16.1	17.5	16.7	17.9	16.9	16-24
200	3.4	8.2	4.8	4.4	4.5	4.9	4.7	4.0	4.1	3.6	4.3	4.0	4.3-8.3
Gradation #	323.4	317.8	324.2	339.7	323.8	316.2	257.3	324.9	332.2	327.0	334.5	321.8	
Bitumen	6.28	5.9	6.1	6.05	5.84	5.71	5.89	5.54	5.68	5.74	5.90	5.78	5.30-6.30

Variable	Mean	Std. Dev.	Maximum	Minimum	Range
3/8"	97.5	0.972	99.0	96.0	3.0
4	61.6	3.098	66.0	55.0	11.0
8	46.3	3.711	54.0	39.7	14.3
50	17.0	1.867	20.3	12.8	7.5
200	4.53	1.354	8.2	3.4	4.8
Bitumen	5.881	0.217	6.280	5.54	0.74

*6B and 6D are not included in mean and standard deviation calculations.

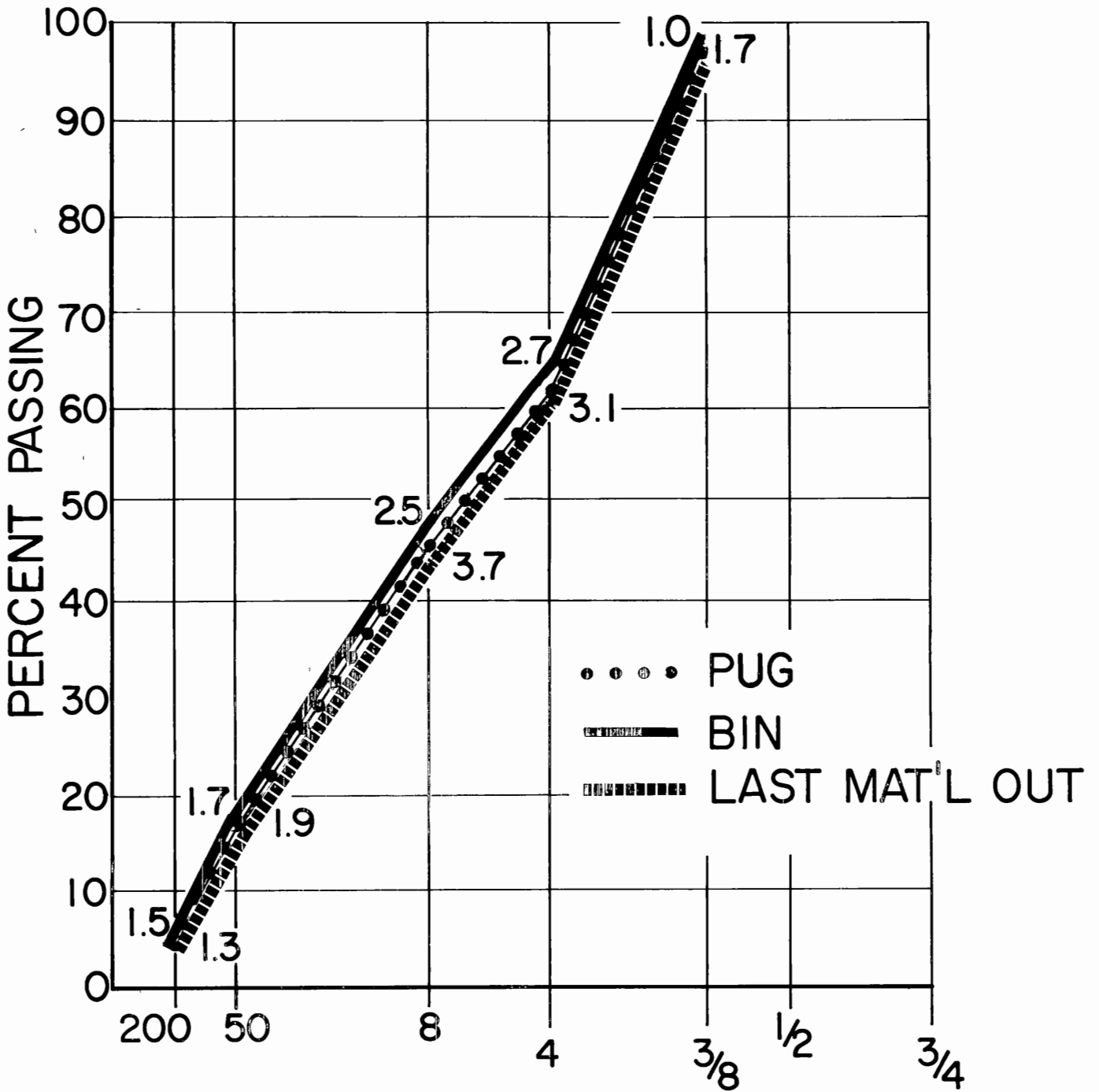
At 129 tons the mix appeared normal. Sample 7B taken at 134 tons denoted the material to be back in specification. This demonstrates that an intermixed zone of material existed for at least three tons and somewhat less than eight tons above the theoretical end point.

Sample for sample the pugmill and storage bin gradations showed good conformity for both the #5 and the intrusive #2 mixes. Sample 8D (last material out) is slightly coarser than the corresponding pug sample and indicates minor segregation. This concept is further augmented by bin Sample 8B which is akin to the last material added to the bin (Pug 8B) but finer than the last material out 8D. This suggests that funneling (material flows primarily in the center) has occurred in the hopper.

Eliminating the gradations attributable to the #2 mix, the plot of the screen analyses, Figure 3, again shows good conformity; the bin samples being slightly finer than the pugmill samples and the last material out being slightly coarser.

The plot of the percent asphalt versus gradation number, Figure 4, clearly shows the shift from the #5 mix to the #2 mix and back again. The gradation number 255 of the pug sample 6B and the gradation number 257 of the corresponding bin sample 6D show excellent correlation and attests to the validity of the sampling procedure. Tests one and two were conducted in a round bin as shown in Figure A of the illustration.

The third tests was conducted in a 200 ton rectangular bin having a Vibra Screw Bin Actuator for discharging the mix. The details are shown in Figure C of the illustration. The mix was New Jersey #2 (comparable to 3A of ASTM: 1663) with an 85/100 asphalt cement as the



SIEVE SIZES RAISED TO 0.45 POWER

FIGURE 3

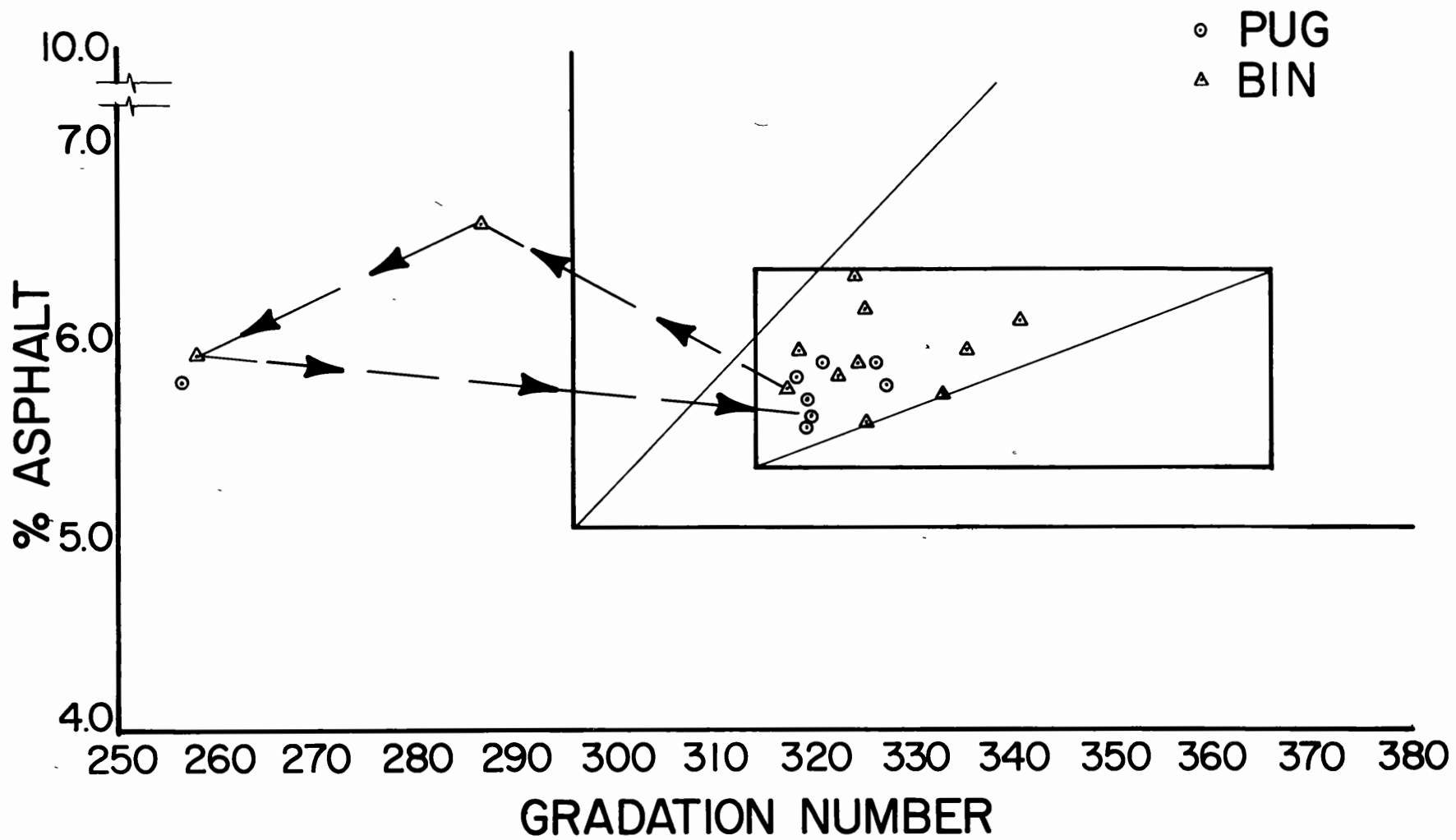


FIGURE 4

TABLE NO. III
EXTRACTION TEST DATA, SURGED NO. 2 MIX

PUG SAMPLES

Sieve % Passing	1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	Design	Job Mix Formula
1-1/2"	100	100	100	100	100	100	100	100	100	100	100	100	100
1"	100	100	96	100	100	100	98	98	93	98	100	98	90-100
1/2"	76	71	75	80	85	80	77	74	75	76	76	70	60-80
4	39	35	37	41	47	39	41	41	40	40	37	38	25-60
8	31	27.6	28.9	32.4	35.4	30.2	32.1	37.3	35.5	30.2	29.1	32.8	26.8-38.8
50	8.4	8.2	8.1	7.8	9.7	9.7	9.8	10.9	10.3	9.4	9.2	9.5	5.5-13.5
200	2.9	3.0	2.9	2.6	3.2	3.1	3.5	3.8	3.7	3.9	3.4	3.0	1.0-5.0
Grada- tion #	357.3	344.8	347.9	363.8	380.3	362.0	361.4	365.0	357.5	357.5	354.7		
Bitumen	5.08	4.98	5.03	4.85	5.34	4.97	5.18	4.63	4.93	4.87	4.85	4.8	4.20-5.40
Sieve	Mean		Std. Dev.		Maximum			Minimum		Range			
1"	98.455		2.252		100			93		7			
1/2"	76.818		3.710		85			71		14			
4	39.727		3.101		47			35		12			
8	31.791		3.106		37.3			27.6		9.7			
50	9.227		0.990		10.9			7.8		3.1			
200	3.273		0.420		3.9			2.6		1.3			
Bitumen	4.974		0.188		5.34			4.63		0.71			

SILO SAMPLES

Sieve % Passing	1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	Job Mix Formula	
1-1/2"	100	100	100	100	100	100	100	100	100	100	100	100	
1"	100	100	98	100	100	100	100	97	100	97	98	90-100	
1/2"	77	78	78	78	87	78	69	69	75	51	51	60-80	
4	39	41	41	44	49	42	36	36	41	26	25	25-60	
8	31.4	31.7	32.4	33.9	38.0	34.0	28.8	29.3	32.2	21.9	20.6	26.8-38.8	
50	9.5	9.7	9.0	9.7	10.4	10.0	8.7	9.0	9.4	8.0	7.5	5.5-13.5	
200	3.5	3.6	3.4	3.3	3.6	4.0	2.9	3.3	3.3	2.9	2.8	1.0-5.0	
Grada- tion #	360.4	364.0	361.8	368.9	388.0	368.0	345.4	343.6	360.9	306.8	304.9		
Bitumen	4.88	5.04	5.06	5.08	5.63	5.03	4.52	4.65	4.98	3.77	3.75	4.20-5.40	
Sieve	Mean		Std. Dev.		Maximum			Minimum		Range			
1"	99.444		1.130		100			97		3			
1/2"	76.556		5.411		87			69		18			
4	41.000		4.000		49			36		13			
8	32.422		2.744		38			28.8		9.2			
50	9.489		0.535		10.4			8.7		1.7			
200	3.433		0.300		4.0			2.9		1.1			
Bitumen	4.988		0.312		5.63			4.52		1.11			

*10 and 11A are not included in mean and standard deviation calculations.

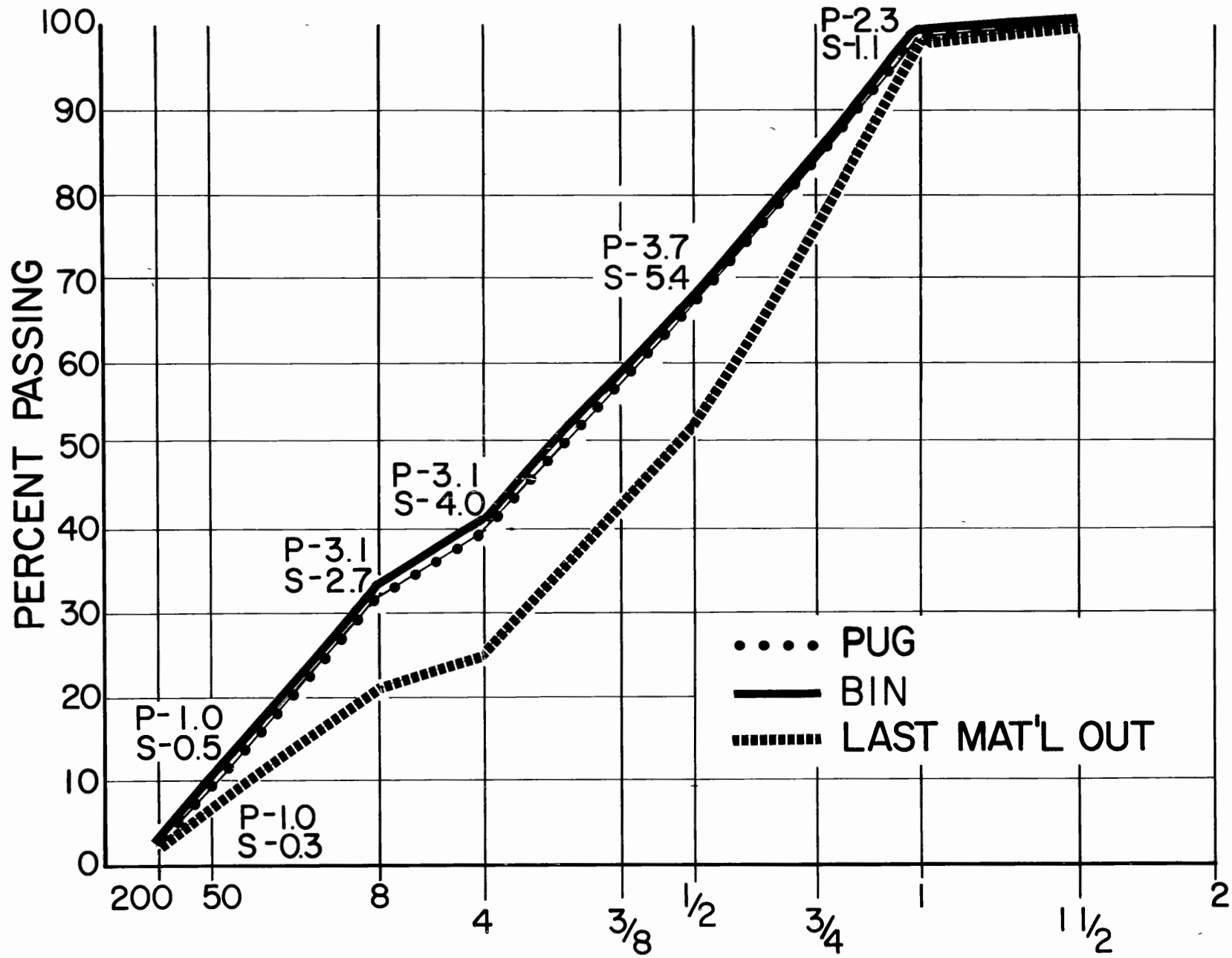
binder. The gradations in Table III show good conformity except for bin samples 10A and 11A which indicate extreme segregation has occurred in the last 11.5 tons. These last two samples had almost identical gradations, with gradation numbers approximately 56 points below the average for the other samples.

It was quite obvious at the time of sampling that segregation had taken place. The sieve analysis confirmed these observations.

The plots of the average screen analyses for the pug and bin samples (excluding last two bin samples), Figure 5, are very close; the bin samples again being finer. The last two samples out of the bin are represented by one line which exhibits gross segregation probably exacerbated by the 60,000 pound vertical thrust of the bin actuator.

The plot of percent asphalt versus gradation number, Figure 6, shows the last two samples out of the job mix specification and the master range as well.

The fourth test was conducted in a similar rectangular 200 ton unit (Figure D in illustration). Discharge is out of dual hoppers into a weigh hopper which in turn empties into the truck. The bituminous concrete was a New Jersey #2 mix with an AC-20 asphalt cement binder. Table IV shows that six of the eleven pug samples and five of the ten bin samples out of specification on the 1/2 inch and number 8 sieves. The gradations of silo samples 8AS, 9AS and 11AS indicate the coarsening trend to out of specification material due to segregation. As a frame of reference, pug samples 9AP, 10AP and 11AP give no such indication. Sample 10AS is missing due to the operator not splitting the last load as prescribed.



SIEVE SIZES RAISED TO 0.45 POWER

FIGURE 5

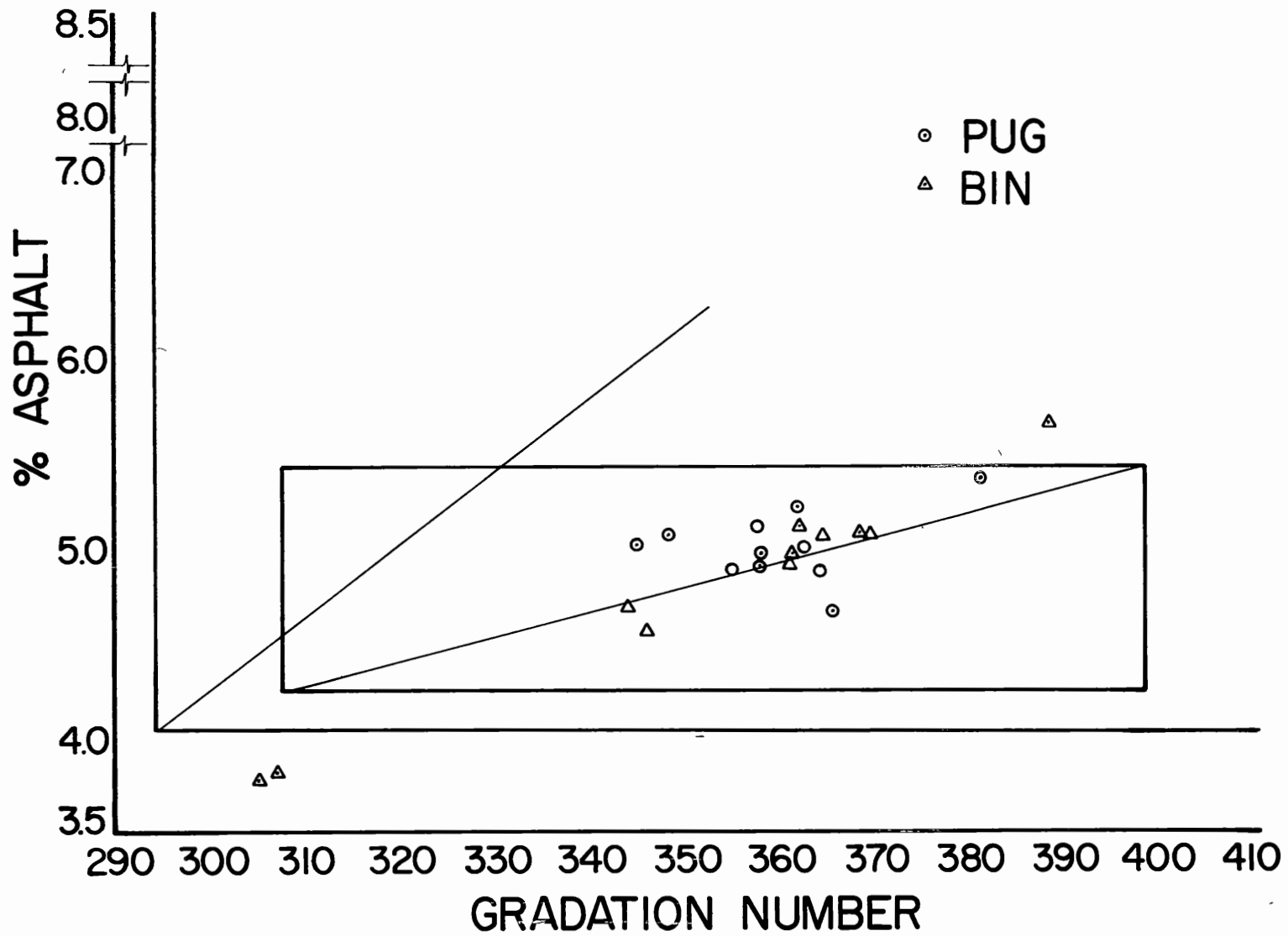


FIGURE 6

TABLE NO. IV
EXTRACTION TEST DATA, SURGED NO. 2 MIX

PUG SAMPLES

Sieve % Passing	1AP	2AP	3AP	4AP	5AP	6AP	7AP	8AP	9AP	10AP	11AP	Design	Job Mix Formula
1-1/2"	100	100	100	100	100	100	100	100	100	100	100	100	100
1"	100	100	100	97	100	96	100	98	100	100	100	100	90-100
1/2"	77	74	81	70	73	71	81	71	79	83	71	71	60-80
4	50	51	51	49	48	43	50	47	52	56	53	45	25-60
8	44	45	44.5	46.5	41.5	36.5	41.5	40.0	43.5	46.4	44.5	38	32-44
50	13.0	13.5	14.0	15.0	14.0	12.0	11.0	12.0	13.0	14.3	13.5	13.5	9.5-17.5
200	3.2	3.5	4.1	3.3	3.0	4.0	3.8	3.3	3.4	5.6	4.1	3.0	1.0-5.0
Grada- tion #	387.2	387.0	394.6	380.8	379.5	362.5	387.3	371.3	390.9	405.3	386.1	370.5	
Bitumen	5.35	5.25	4.25	4.85	4.85	4.70	5.00	4.80	5.25	5.48	5.00	5.1	4.4-5.8
Sieve	Mean		Std. Dev.		Maximum		Minimum		Range				
1"	99.182		1.471		100		96		4				
1/2"	75.545		4.803		83		70		13				
4	50.000		3.376		56		43		13				
8	44.000		3.860		51.5		36.5		15				
50	13.209		1.171		15.0		11.0		4				
200	3.755		0.720		5.6		3.0		2.6				
Bitumen	4.980		0.348		5.48		4.25		1.23				

SILO SAMPLES

Sieve % Passing	1AS	2AS	3AS	4AS	5AS	6AS	7AS	8AS	9AS	11AS	Job Mix Formula	
1-1/2"	100	100	100	100	100	100	100	100	100	100	100	
1"	98	97	100	100	98	100	100	95	98	100	90-100	
1/2"	81	69	76	84	70	80	75	76	69	61	60-80	
4	53	46	50	56	48	53	49	51	47	35	25-60	
8	47.5	41.5	44.5	46.5	40.5	46.0	42.5	43.5	42	31.5	32-44	
50	14.5	13	13.5	13.5	12	14	13.5	13	13	10.5	9.5-17.5	
200	4.1	3.5	4.1	4.8	3.6	4.2	4.5	4.0	3.6	3.0	1.0-5.0	
Grada- tion #	398.1	370.0	388.1	404.8	372.1	397.2	384.5	382.5	372.6	341.0		
Bitumen	5.55	4.85	5.20	5.45	4.80	5.45	4.90	5.05	4.80	4.05	4.4-5.8	
Sieve	Mean		Std. Dev.		Maximum		Minimum		Range			
1"	98.444		1.740		100		95		5			
1/2"	75.556		5.457		84		69		15			
4	50.333		3.240		56		46		10			
8	43.833		2.437		47.5		40.5		7			
50	13.333		0.707		14.5		12.0		2.5			
200	4.044		0.433		4.8		3.5		1.3			
Bitumen	5.117		0.304		5.55		4.8		.75			

*11 is not included in mean and standard deviation calculations.

The pugmill and bin average gradation values (excluding last two bin samples) were practically identical and are depicted as a single line in Figure 7. The "next to last" and "last out" samples graphically illustrate the trend toward segregation.

Figure 8 shows the mix to be on the fine side. The triangular point to the lower left represents the last material out. This sample while only slightly out of specification (coarse) on gradation, was much more so on bitumen content. Surface area is a function of fineness, that is, the finer the particle the greater the surface area per unit weight. The gradation number is a function of fineness. With a given weight of aggregate and asphalt cement (within the precision of the weighing equipment) the surface area would be coated with a unit weight per square foot. Therefore, when segregation occurs the coarser material having less surface area per unit weight will also have less bitumen per unit weight. From a free hand fit curve it appears to be highly correlative. While beyond the scope of this investigation, it may be possible to develop the gradation number as an index for measuring segregation or for predicting the required asphalt content for different gradations.

The fifth test was on our coarse, dense graded #1 stabilized base mix (comparable to the ASTM-2A designation) with an AC-20 asphalt cement. The bin was the same round unit used in the first two tests. Table V gives the gradations based on the 1968 Addenda A.

Figure 9 shows the average of the pug samples to be slightly finer than the material out of the bin. The individual samples in every case were also of a slightly finer gradation. It is thought

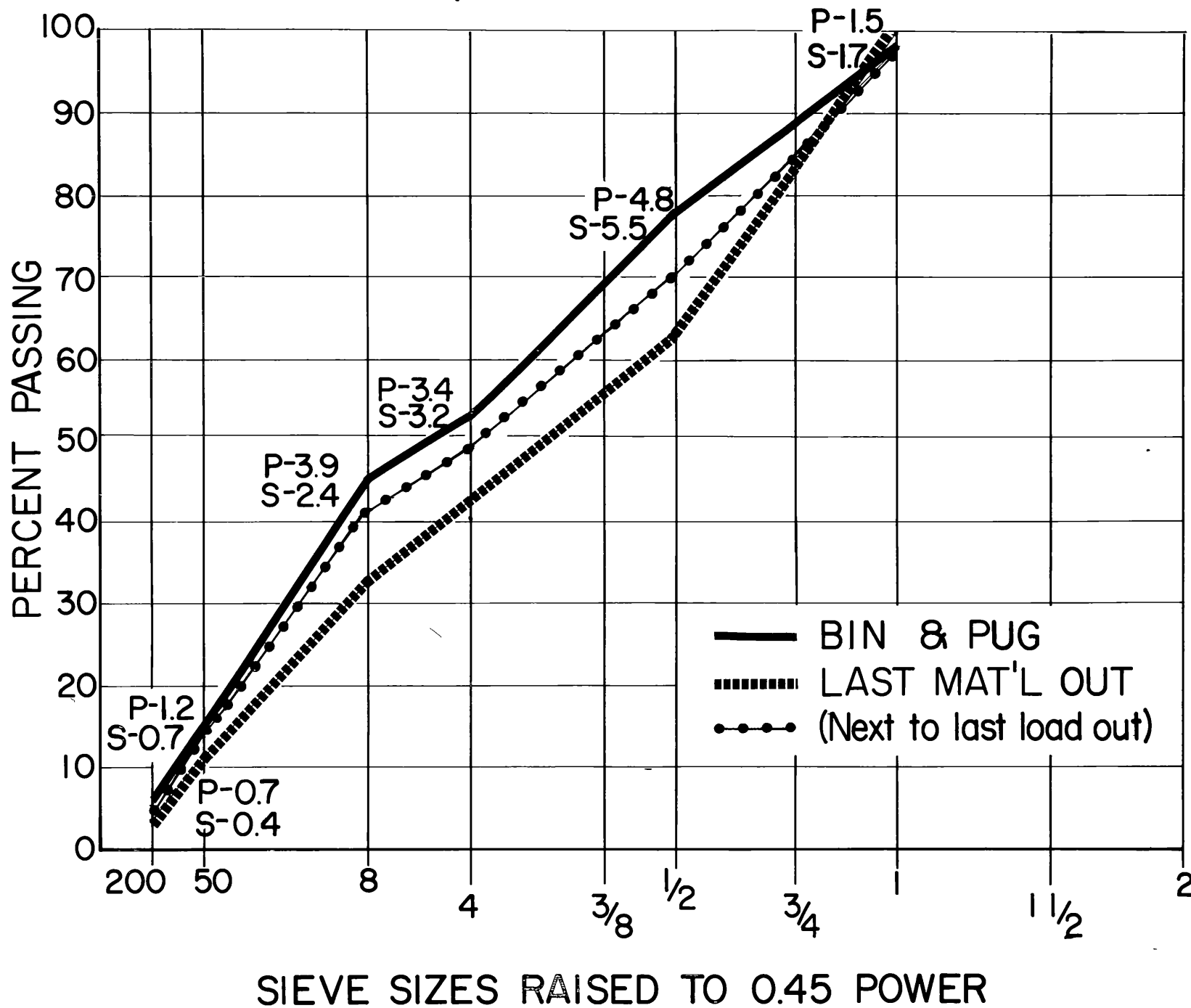


FIGURE 7

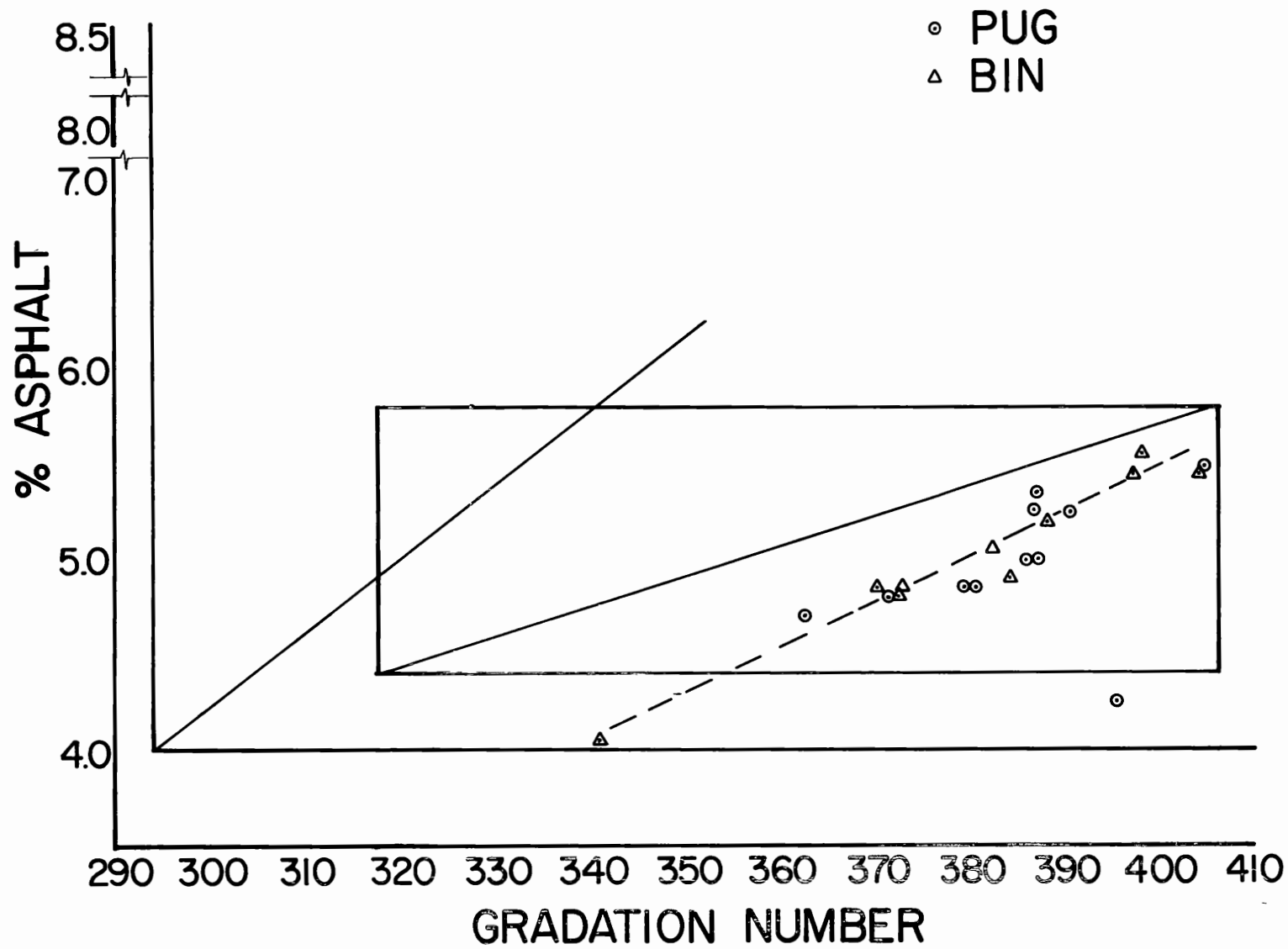


FIGURE 8

TABLE NO. V
EXTRACTION TEST DATA, SURGED NO 1 MIX

PUG SAMPLES

Sieve % Passing	1A	2	3A	4	5	6A	7	8	Design	Job Mix Formula
2"	100	100	100	100	100	100	100	100	100	100
1-1/2"	100	100	100	100	100	100	100	100	100	90-100
3/4"	83.5	79.0	80.5	78.0	81.0	80.5	82.0	80.5	82	60-100
4	58.5	51.5	51.5	53.0	53.0	53.5	57.0	58.5	42	25-60
8	51.75	44.75	44.25	47.00	46.50	46.00	48.25	50.75	35	27-43
50	16.75	13.75	14.00	15.50	13.75	15.00	15.00	16.75	16	11-21
200	7.2	6.7	7.25	6.65	6.65	7.70	7.75	8.00	6	4-8
Grada- tion #	418.2	393.7	397.2	402.3	401.1	402.7	409.6	414.0		
Bitumen	5.40	4.85	4.90	5.00	5.10	5.075	5.225	5.525	4.6	4-5.2
<u>Sieve</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Range</u>					
3/4"	80.625	1.685	83.5	78.0	5.5					
4	54.562	2.969	58.5	51.5	7.0					
8	47.406	2.692	51.75	44.25	7.5					
50	15.062	1.223	16.75	13.75	3.0					
200	7.475	0.693	8.75	6.65	2.1					
Bitumen	5.134	0.236	5.525	4.85	0.675					

SILO SAMPLES

Sieve % Passing	1A	2	3A	4	5	6A	7	8A	Job Mix Formula
2"	100	100	100	100	100	100	100	100	100
1-1/2"	100	100	100	100	100	100	100	100	90-100
3/4"	75.5	79.0	79.5	80.0	75.5	76.5	77.5	77.0	60-100
4	50.0	53.5	54.0	53.0	48.0	49.0	49.5	52.0	25-60
8	49.0	44.0	45.5	46.0	41.8	42.8	42.5	44.8	27-43
50	14.5	15.5	14.8	15.0	12.8	12.5	11.0	14.5	11-21
200	7.15	7.65	7.50	7.00	6.20	6.10	4.35	7.30	4-8
Grada- tion #	391.9	400.1	402.0	377.2	385.2	386.6	385.0	395.8	
Bitumen	4.60	4.88	4.95	4.80	4.58	4.90	4.53	4.90	4-5.2
<u>Sieve</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Range</u>				
3/4"	77.562	1.761	80	75.5	4.5				
4	51.125	2.280	54	48	6.0				
8	44.550	2.330	49	41.8	7.2				
50	13.825	1.551	15.5	11	4.5				
200	6.656	1.090	7.65	4.35	3.3				
Bitumen	4.767	0.170	4.95	4.53	0.42				

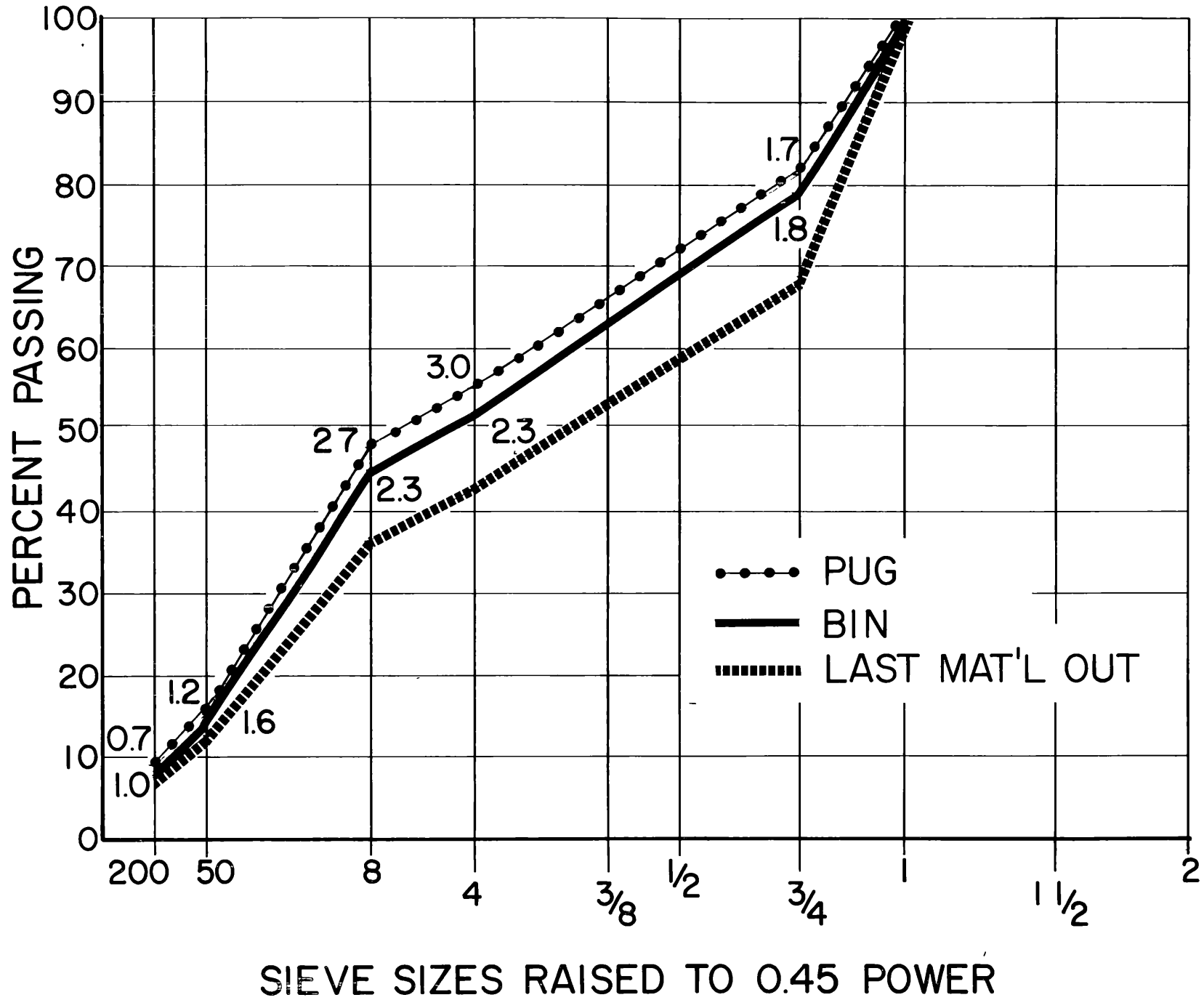


FIGURE 9

that with a coarse mix there is a slight amount of segregation connected with unloading the pugmill. When the discharge gates open, the bulk of the mix drops from the center. As discharge continues a slightly finer mix ensues from the corners. Thus the discharge in conjunction with the small cross-sectional area of the transfer hopper effects a biased sample of slightly finer gradation. A sample taken at five tons before the last material out coincided exactly with the silo average curve. The last material out indicates minor segregation although it is still within specification on gradation.

Figure 10 indicates that the mix was on the fine side. Samples taken by another bureau during production also showed the mix to be on the fine side and out of specification on the #8 sieve. The pugmill samples outside of the job mix formula box signify slightly biased samples. The last material out while in specification on gradation was out by 0.3 percent on bitumen content.

The sixth and last test for segregation was on a #1 stabilized base mix having an AC-20 asphalt cement binder. The bin was a round, insulated, cone heated unit (Figure B) fed by a slat conveyer. The discharge cone has a 60° angle. The distinguishing feature of this unit is an anti-segregation dispenser which collects material from the conveyer and splits the material into two equal holding compartments. When a preset quantity of mix has been accumulated, the gates open simultaneously purportedly discharging the two masses of mix over the cross section of the silo.

The gradations (Table VI), show good conformity between the pugmill and bin samples for the first 132 tons discharged. Bin samples 8A and 8B are virtually identical and represent

TABLE NO. VI
EXTRACTION TEST DATA, SURGED NO. 1 MIX

PUG SAMPLES

Sieve % Passing	1A	2A	3A	4A	5A	6A	7A	8A	9A	Design	Job Mix Formula
2"	100	100	100	100	100	100	100	100	100	100	100
1-1/2"	100	100	100	100	100	100	100	100	100	100	90-100
1"	100	98	100	100	98	93	100	100	94	97	80-100
1/2"	71	67	62	64	68	63	75	66	64	62	50-85
4	53	51	48	46	51	49	57	53	51	50	25-60
8	42	40	37.5	36.5	39.5	36.5	42.5	39.5	37.5	41.5	33.5-49.5
50	13	12	13	12	13.5	11.5	14.5	14.5	13	15.0	10-20
200	4.9	4.7	4.6	4.4	5.7	5.1	5.9	5.4	6.2	6.5	4.5-8.5
Gradation #	483.9	472.7	465.1	462.9	475.7	458.1	494.9	478.4	465.7		
Bitumen	5.1	4.7	4.5	4.6	4.75	4.35	5.10	4.75	4.50	4.8	4.1-5.5
Sieve	Mean		Std. Dev.		Maximum		Minimum		Range		
1"	98.111		2.759		100		93		7		
1/2"	66.667		4.183		75		62		13		
4	51.000		3.202		57		46		11		
8	39.056		2.228		42.5		36.5		6		
50	13.000		1.061		14.5		11.5		3		
200	5.211		0.625		6.2		4.4		1.8		
Bitumen	4.706		0.259		5.1		4.35		0.75		

SILO SAMPLES

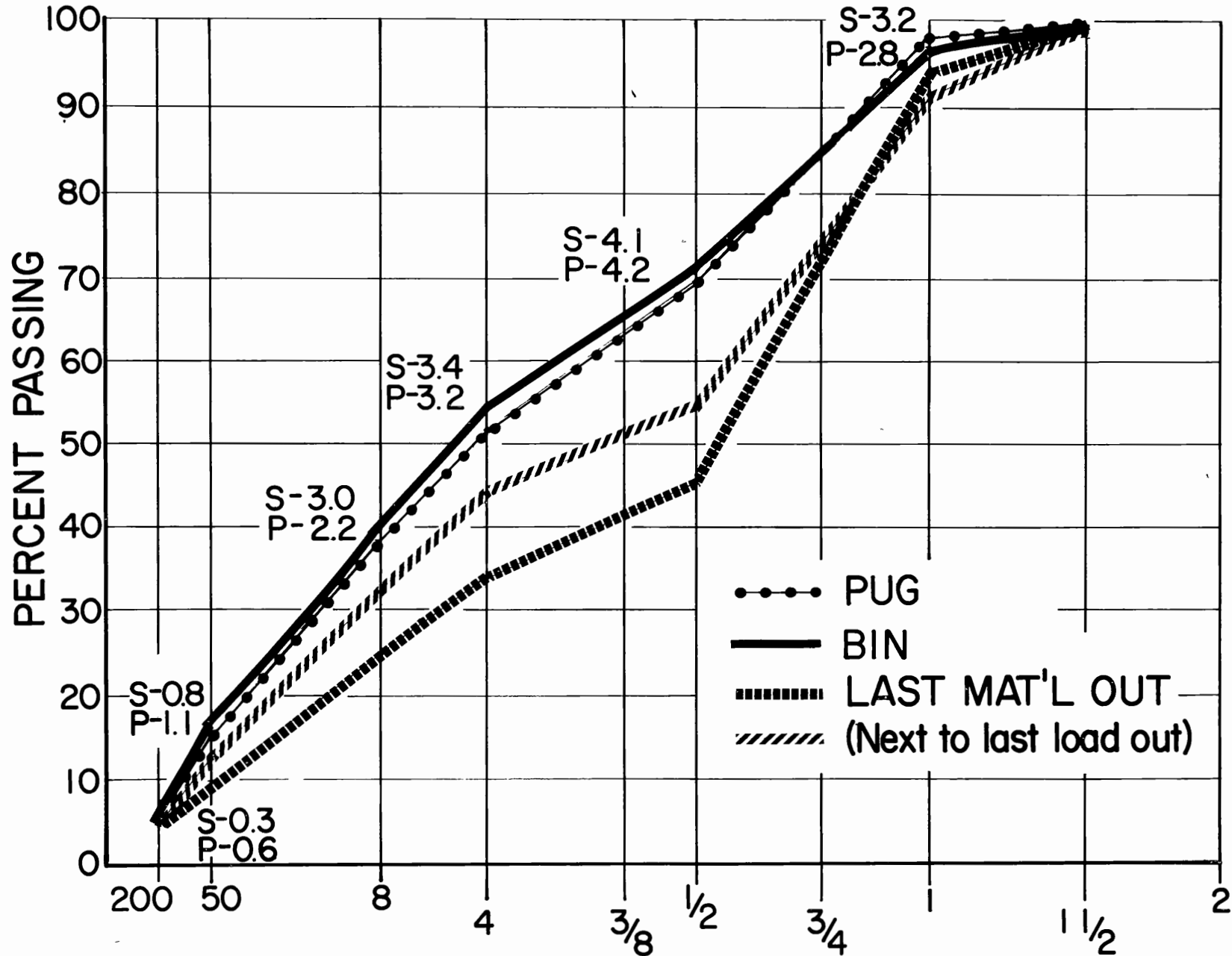
Sieve % Passing	1A	2A	3A	4A	5A	6A	7A	8A	8B	9A	Job Mix Formula
2"	100	100	100	100	100	100	100	100	100	100	100
1-1/2"	100	100	100	100	100	100	100	100	100	100	90-100
1"	100	100	100	99	96	92	95	90	91	94	80-100
1/2"	76	69	67	63	65	68	67	52	52	44	50-85
4	60	53	50	50	52	54	53	42	43	33	25-60
8	46.5	42	39	38.5	38.5	40.5	38	31.5	32.5	25.5	33.5-49.5
50	15	14	14	13	13	13	13.5	11.5	11.5	10.0	10-20
200	6.5	5.9	5.8	5.5	5.7	5.8	6.0	5.0	5.2	4.5	4.5-8.5
Gradation #	504.0	483.9	475.8	469.0	470.2	473.3	472.5	432.0	435.2	411.0	
Bitumen	5.45	4.9	4.6	4.65	4.7	4.75	4.65	3.95	4.10	3.45	4.1-5.5
Sieve	Mean		Std. Dev.		Maximum		Minimum		Range		
1"	97.429		3.155		100		92		8		
1/2"	67.857		4.100		76		63		13		
4	53.143		3.388		60		50		10		
8	40.429		3.020		46.5		38		8.5		
50	31.643		0.748		15		13		2		
200	5.886		0.313		6.5		5.5		1		
Bitumen	4.811		0.297		5.45		4.6		0.85		

*8A, 8B and 9A are not included in mean and standard deviation calculations.

the 140 and 148 tons respectively. Sample 9A the last material out (152 tons) shows gross segregation. The coarseness is indicated by a lessening of 24, 20 and 15 percent thru the 1/2 inch, #4 and 1/8 inch sieves and a drop of approximately 60 points in the gradation number. Segregation started to occur between the last 12 to 20 tons out of the bin. This is believed to be due mainly to the anti-segregation device forming two cones on complete filling of the bin. The cylindrical bin acts as a plug flow unit until the material enters the tapered hopper. The frictional conditions of the hopper wall and the material allow the central portion to flow out faster than the side portion resulting in funneling. Dual cones (heaped material) in this location in the bin aided by the flatter 60° angle would tend to exaggerate the funneling. The results of this test when compared with the previous test of a centrally filled cylindrical bin supports this hypothesis.

Figure 11 graphically illustrates the segregative trend to out of specification material. The next to last material out, plot, is representative of both the 140 and 148 ton samples.

A free hand fit curve of the plot in Figure 12 shows excellent correlation between percent asphalt and gradation number (surface areas). The three triangular points (bin samples) to the lower left show the trend of segregation to out of specification material. The triangular point to the upper right representing the first material out could be construed to be a selective bin sample, however, it is felt that this is a real value exhibiting slight segregation due to the effect of the dual off center charging system.



SIEVE SIZES RAISED TO 0.45 POWER

FIGURE II

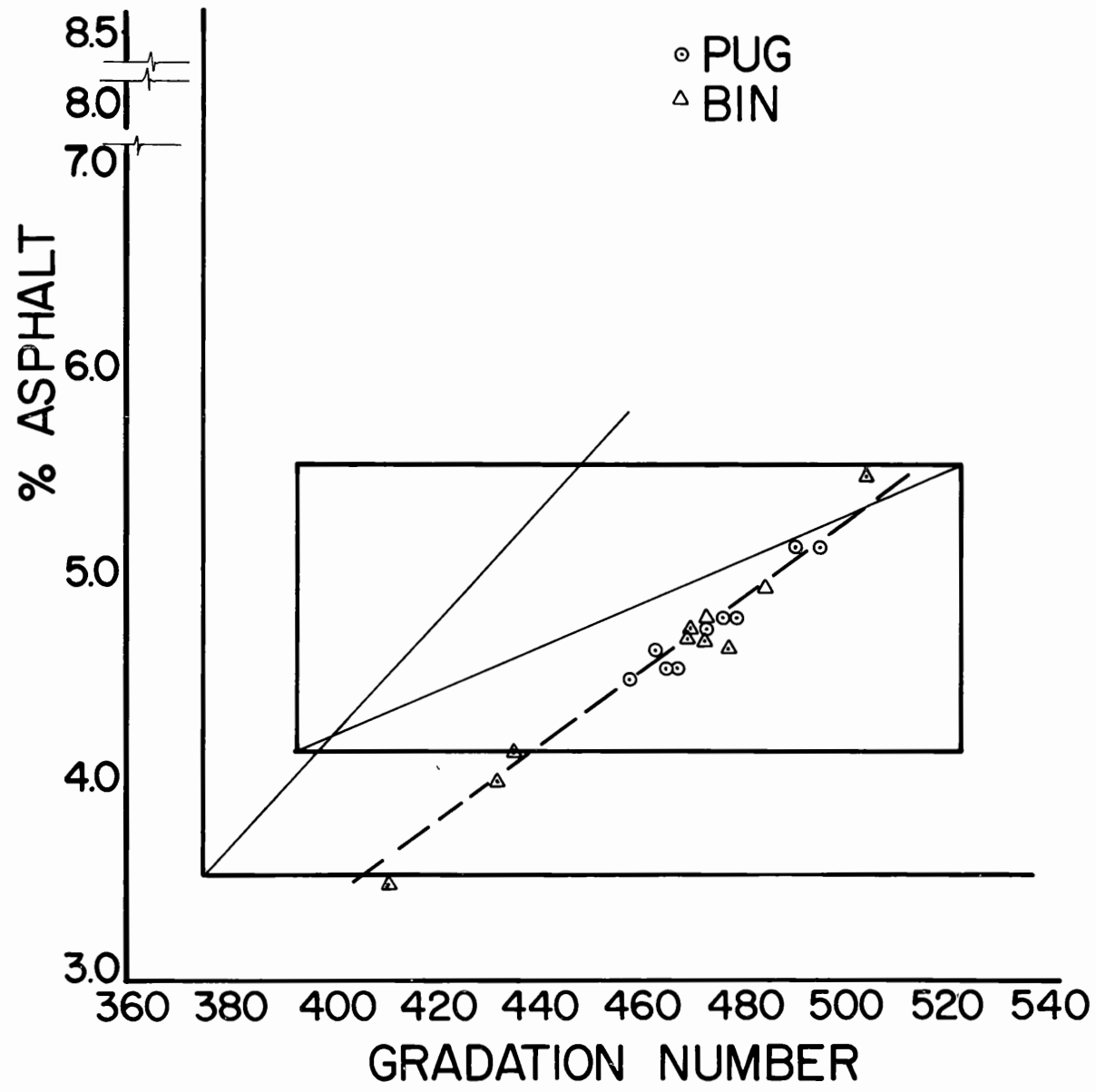


FIGURE I2

2. Statistical Verification Method

To further augment the validity of the testing procedure for determining segregation, the sieve analyses were treated statistically. Of the methods available, the treatment of the samples as possible outliers in rejecting observations appeared most apropos to the situation.

The theory of Rejection of Observations in a Single Experiment--The Studentized Range Procedure⁽⁷⁾, was utilized. The bin samples were considered as a population whose mean and standard deviation were unknown; the pug samples as the available independent external estimate of the standard deviation. The procedure is as follows:

- a) Choose α , the probability or risk we are willing to take in rejecting an observation that really belongs in the group. An α of ten percent was selected.
- b) From selected tables (A-10 percentiles of the studentized range) find $q_{1-\alpha}(n,v)$ where n is the number of observations in the sample (bin), and v is the degrees of freedom for S_v (pug), the independent external estimate of the standard deviation obtained from concurrent or past data (pug)---not from the sample in hand.
- c) Compute $w = (q_{1-\alpha})S$.
- d) If $X_n - X_1 > w$, reject the observation (range of bin samples).

Sample calculation - Table VI, sample 9, #8 sieve.

$$q_{1-\alpha}(n,v)$$

$$\begin{aligned} n &= \text{bin samples} = 10 \\ v &= n - 1 = \text{number of pugmill} \\ &\quad \text{samples minus one } (9 - 1) \end{aligned}$$

$$q_{.90}(10, 8) = 5.13$$

$$w = (q_{1-\alpha})S = 5.13 \times 2.23 = 11.44$$

$$X_n - X_1 = 46.5 - 25.5 = 21.0 > 11.44 \text{ therefore reject}$$

Sample Number

Sieve Size	9A		8B		8A		7A	
	w	$X_n - X_1$	w	$X_n - X_1$	w	$X_n - X_1$	w	$X_n - X_1$
1"	14.1	10.0	13.8	10.0	13.1	10.0	12.9	8.0
1/2"	21.5	32.0*	20.7	24.0*	20.5	24.0*	19.4	13.0
#4	16.4	27.0*	16.0	18.0*	15.5	18.0*	14.9	10.0
#8	11.4	21.0*	11.1	15.0*	10.8	15.0*	10.4	8.5
#50	5.4	5.0	5.3	3.5	5.1	3.5	4.9	2.0
#200	3.2	2.0	3.1	1.5	3.0	1.5	2.9	1.0
bit.	1.3	2.0*	1.3	1.3	1.3	1.5*	1.2	0.9

*Reject: 8, 8B and 9

The statistical analyses help affirm the judgment that segregation does indeed occur in the coursing of bituminous concrete mixes through a storage bin system. The degree to which it occurs is dependent on the type of mix, the bin configuration and the method of loading and unloading the bin.

B. Temperature

Figure 13 shows the mixture temperatures recorded on the surging and storage of a #5 mix in an insulated, heated bin. For clarity and quick reference the corresponding pug sample temperature has been placed above the bin discharge sample. The surge bin, Figure 13a showed a 15°F loss in temperature of the first material out after one hour retention time. The last material out was 6°F lower than the prior truckload but slightly higher than the charged temperature. The average loss in temperature between input and discharge was 6°F after seven hours retention time.

The storage test (13b) again showed a loss of 15°F in the first material out after one hour. The temperatures remained quite uniform over the next 93 hours. The last 15 tons exhibited a gradient, dropping 20°F

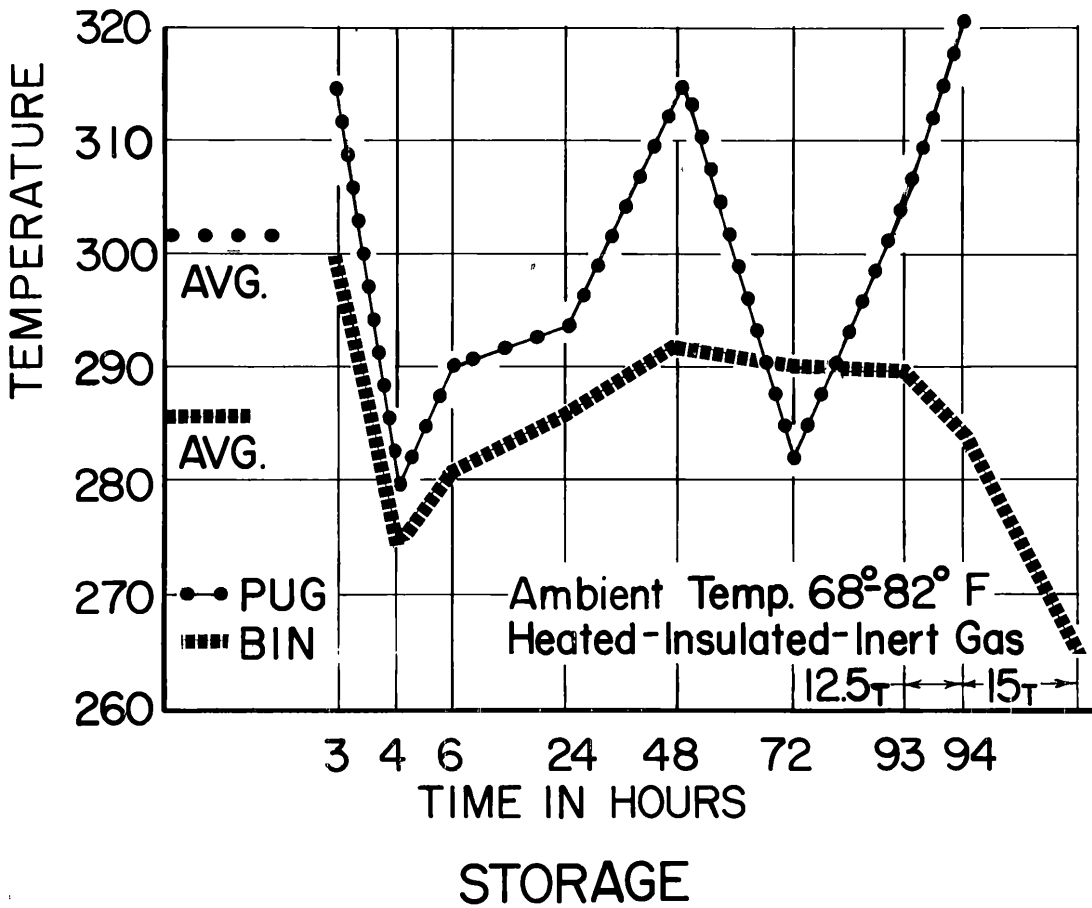
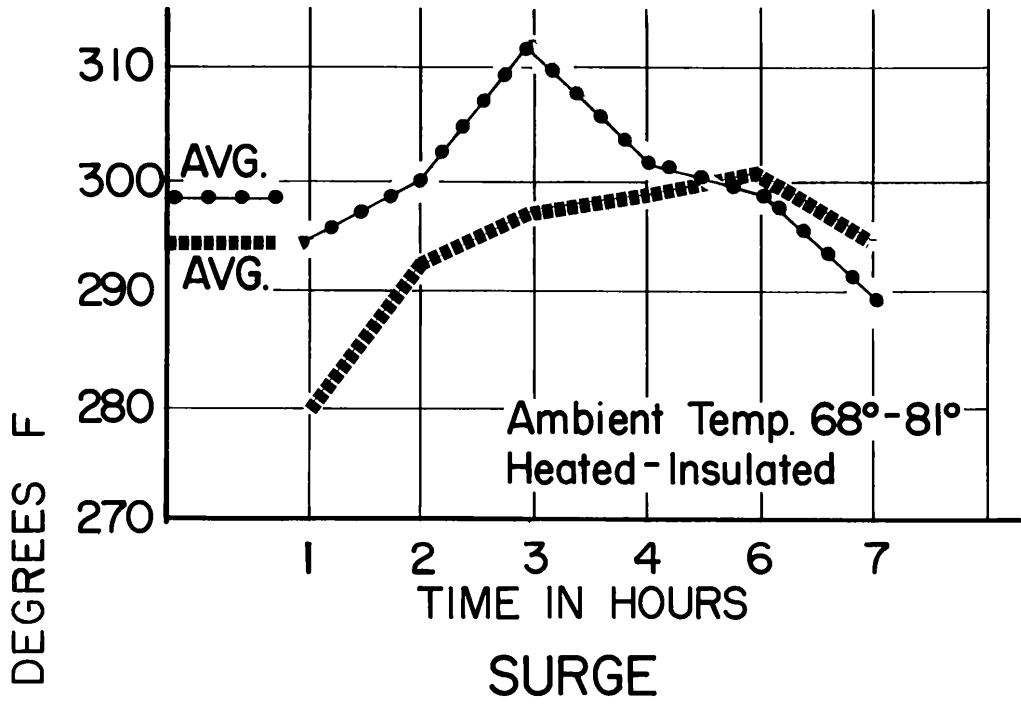


FIGURE 13

from 285°F to 265°F. The average loss between input and discharge over the 94 hour period was 16°F.

Figure 14 shows two #2 mixes in bins of the same rectangular configuration. The bin in Figure 14a was heated, 14b unheated. The heated unit had an average temperature loss of 16°F of input versus discharge over a seven hour period. The unheated unit sustained a 5°F loss in the same seven hour period. What differs dramatically is the last material out of these bins. The heated bin showed a temperature drop of 53°F in the last 15 tons from 304°F to 251°F. The unheated bin temperature dropped from 291°F to 200°F in the last 15 tons despite a 24° higher ambient temperature. It must also be noted that the first 21 tons out of the unheated bin exhibited a temperature gradient from 242°F at the two ton level to 281°F at the 12 ton level and 301°F at the 21 ton level. This undoubtedly was due to heat being drawn out of the mix by the cool steel cone.

Figure 15 shows the result of the #1 mix in a cone heated, insulated, round unit. The average temperature of the pug samples was 303°F versus 299°F for the discharge samples. The last four tons of material out exhibited a 35° drop to 260°F. Total retention time was less than 2-1/2 hours.

Figure 16 depicts a run that was made basically for penetration values. This was a #1 mix stored for 67 hours in a heated bin having an inert atmosphere. The average temperature loss of input over discharge was 14°F. The last material out showed a 33°F drop in the last 10 tons (285°F - 252°F). It must be noted that only 48 tons of mix had been placed in the bin.

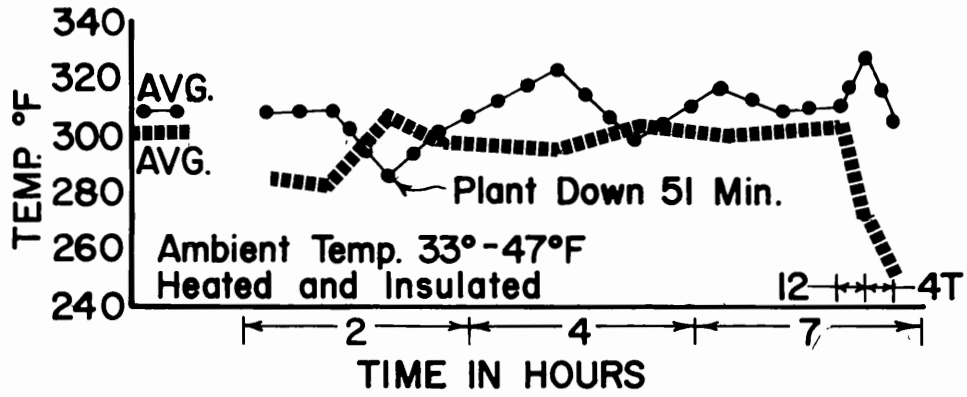


FIGURE 14A

●— PUG
 ■— BIN

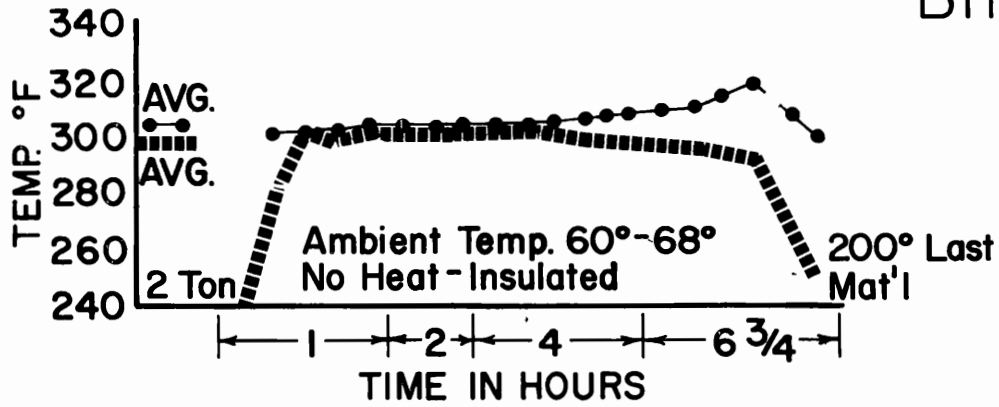


FIGURE 14B

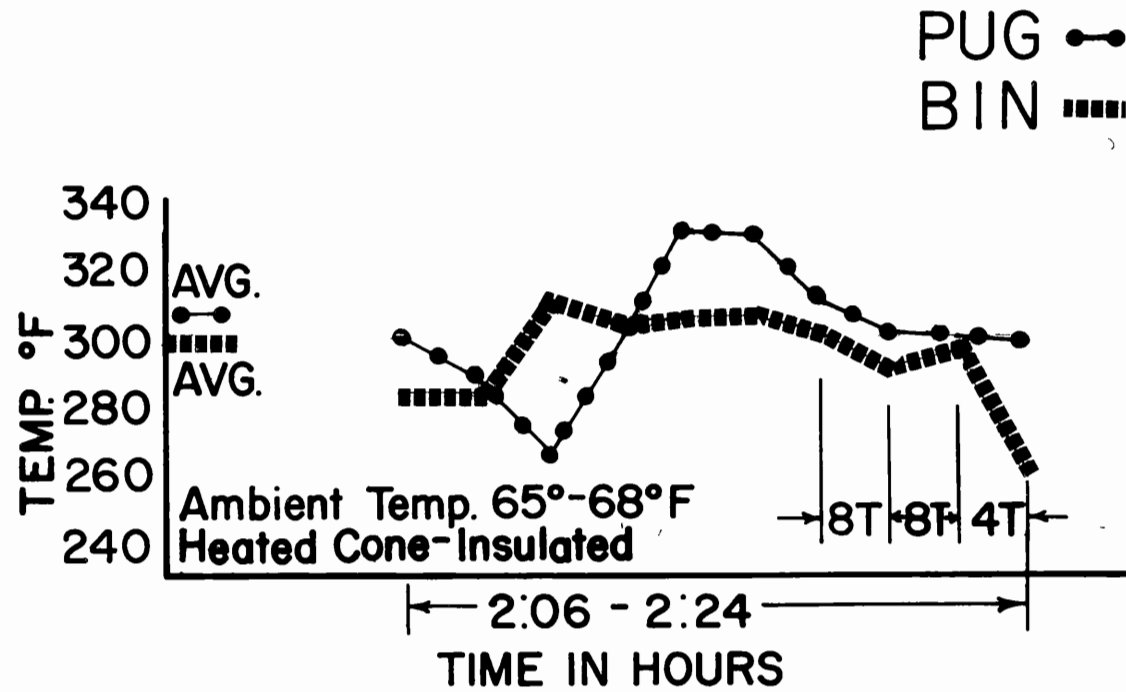


FIGURE 15

PUG ●—●
BIN ■■■■

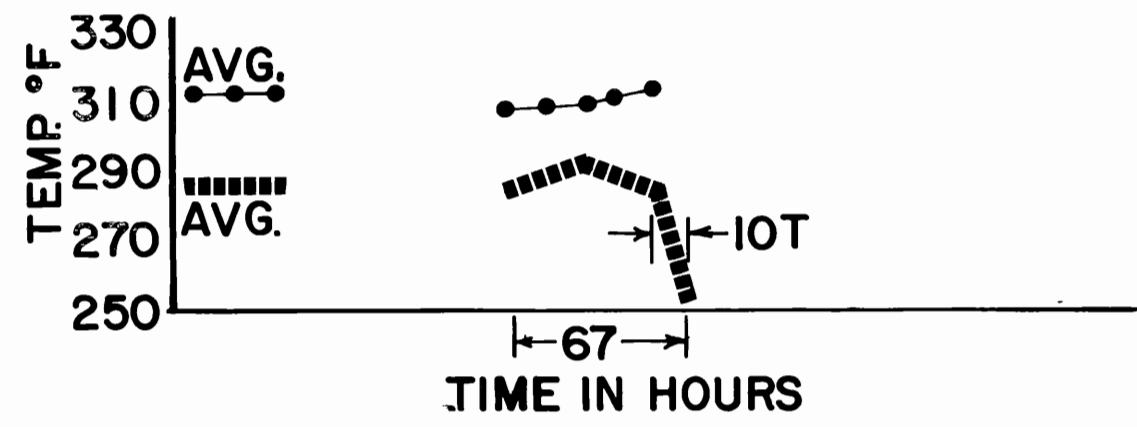


FIGURE 16

Figure 17 shows the results of surging a #1 mix for six hours in a heated, insulated bin. The sample of the first two tons out was 21°F below the 12 ton input temperature; the 12 ton discharge temperature being 12°F below the input temperature after two hours. The average temperature loss on discharge over input was 16°F. The last 9 tons out dropped 14°F from 276°F to 262°F.

Figure 18 depicts a #1 mix stored overnight (heated, inert gas unit). The retention time varied from 15-1/2 to 21-1/4 hours. The average temperature loss between input and discharge was 21°F. The last 9 tons showed a 44°F temperature loss from 274°F to 230°F. The last 4 of the 9 tons dropped 5°F from 235°F to 230°F. The 21°F average temperature loss was higher than the #1 mix that had been stored for three times this retention time (Figure 16). It is felt that the results are highly significant in as much as the mix was made during a tremendous downpour of rain. After the bin was filled the hatch cover could not be closed for a half hour due to the high steam emission from the bin. This relates to citations in the literature where wet aggregate caused drops in temperature up to 55°F in a six hour period.

C. Penetration

Figure 19 shows the penetration versus storage time data of a #5 mix with an 85/100 AC binder stored in an inert gas atmosphere for 94 hours. The original penetration of the asphalt cement was 91. The average penetration of the recovered pugmill samples was 87. The penetration of the stored material remained quite stable over the 94 hour retention period with the exception of the last material out. This material showed a nine point decrease to a value of 64. This

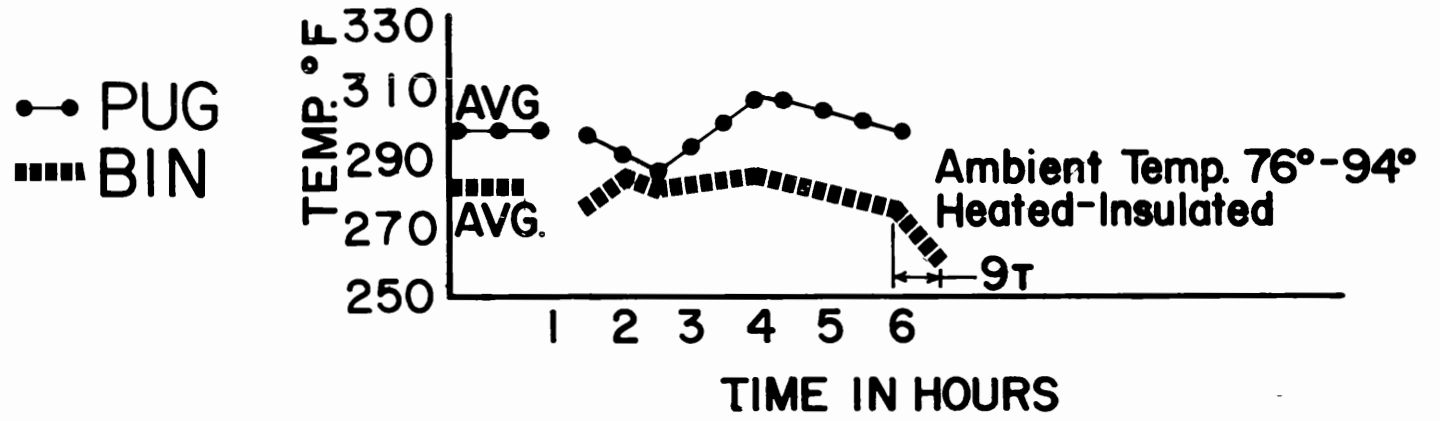


FIGURE 17

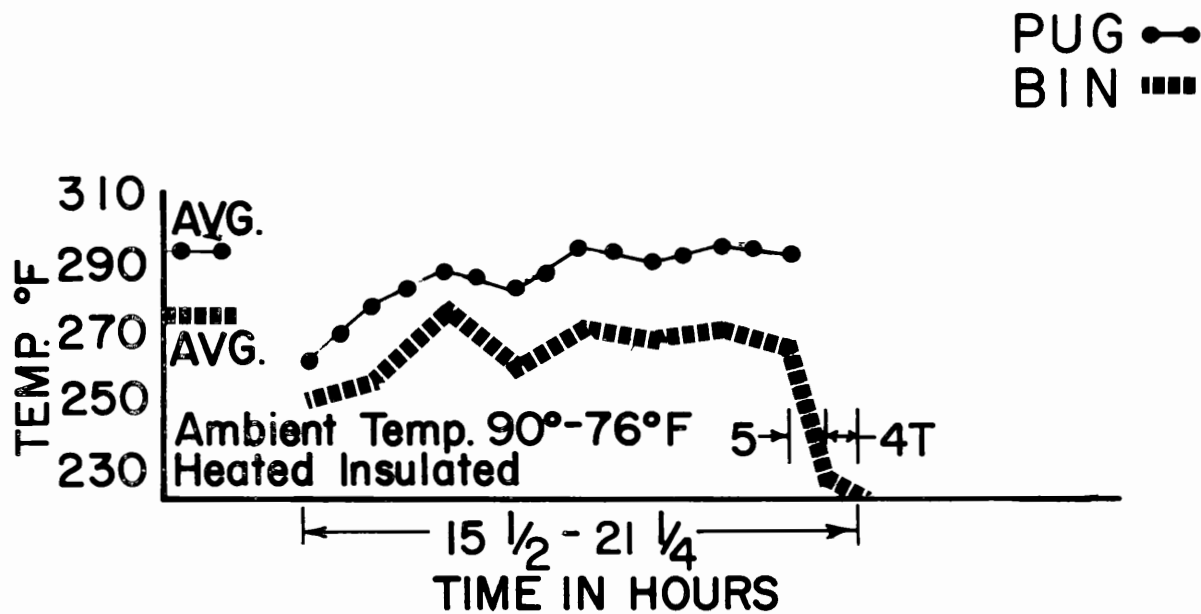
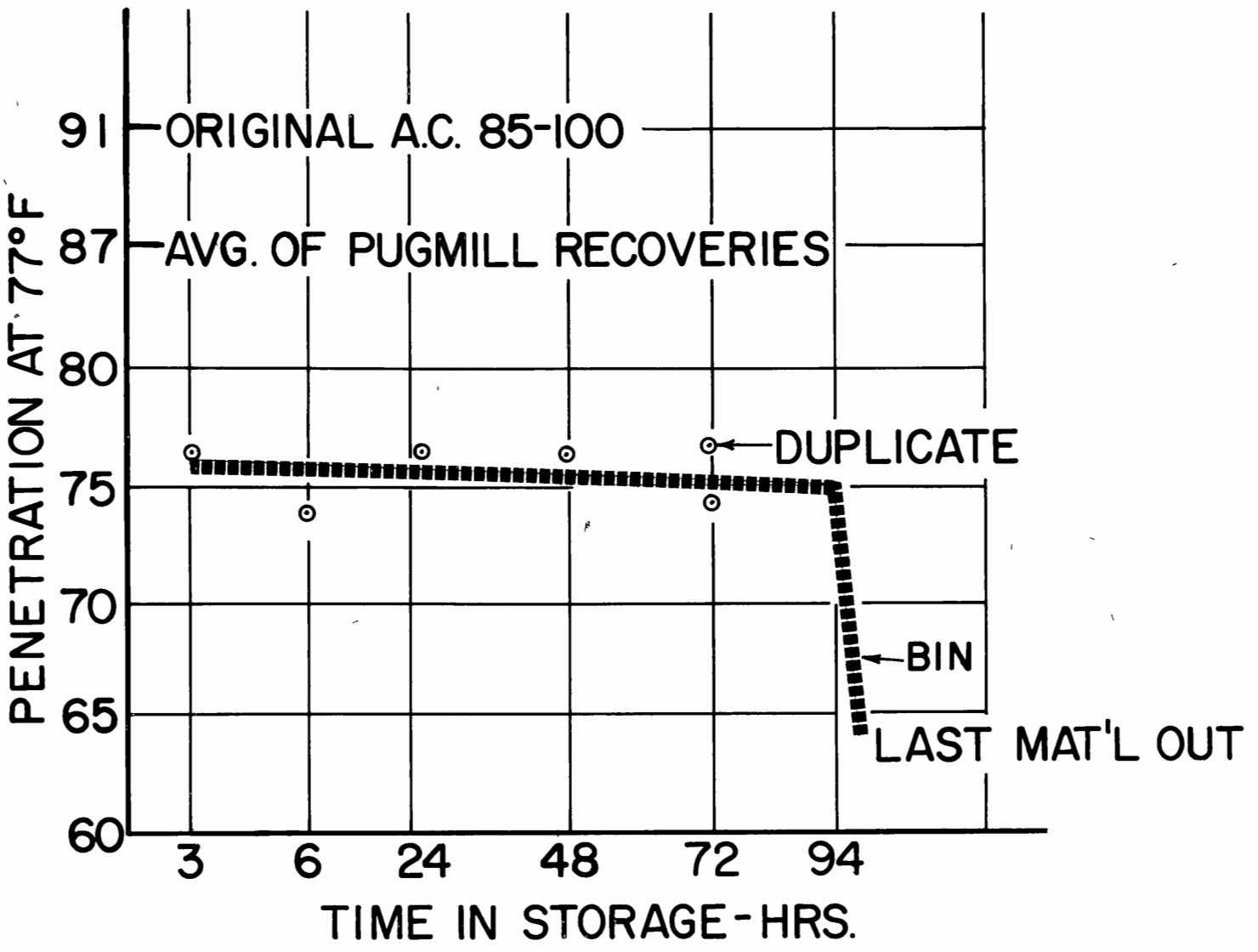


FIGURE 18



FABC #5 INERT ATMOSPHERE

FIGURE 19

value is basically what would be expected of an 85/100 penetration asphalt cement when recovered from a pavement core shortly after placement. Pavement cores, of material placed directly from the pugmill and after 96 hours of storage, were taken 15 months after placement. The recovered penetrations were virtually the same being 45 and 46 respectively.

Figure 20a depicts the results of a #2 mix employing an 85/100 penetration asphalt cement (original pen 96) in an air atmosphere. The average recovered penetration values of the pugmill samples was 84. After two, four and seven hours retention time the recovered penetrations of the stored mix was 82, 73 and 60 in given order. The last material out dropped an additional 8 points to a pen of 52. It is believed that the large loss in penetration was due to the fact that the unit has no air locks and cannot accommodate an inert gas atmosphere.

Figure 20b shows the results of a #2 mix with an AC-20 asphalt cement binder. While the configuration of the bin is the same as the previous unit, the discharge is through a more positive gate arrangement with less air exposure of the mix. There is virtually no difference in the average recovered penetration of the pug and bin samples. The penetration values over the entire seven hour retention period were quite uniform with a slight drop in the last material out. The drop from the original asphalt penetration was 16 points. The 50 penetration value of the two hour bin sample appears to be a real value since the corresponding pug value was 54. The pug Sample 9C was a split sample, one half was frozen, the other half was allowed to cool normally to

PENETRATION AT 77°F

AIR-ATMOSPHERE #2 MIX (BINDER)

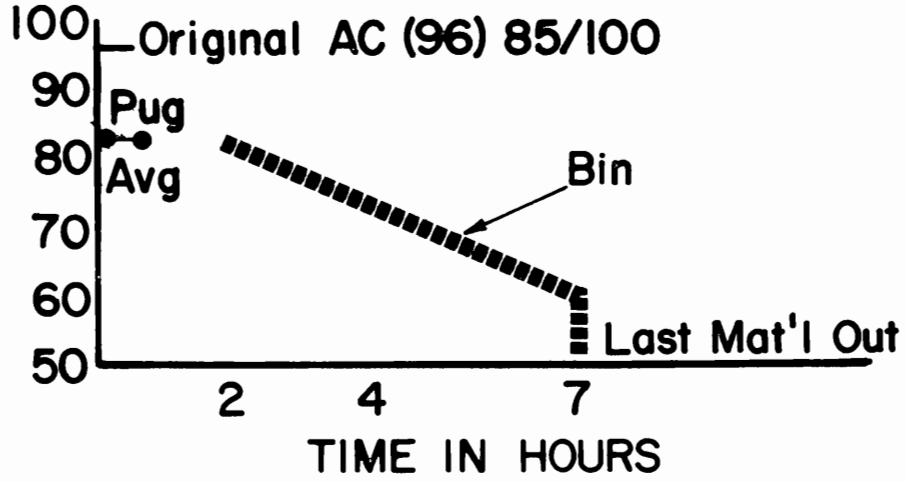


FIGURE 20A

AIR-ATMOSPHERE #2 MIX

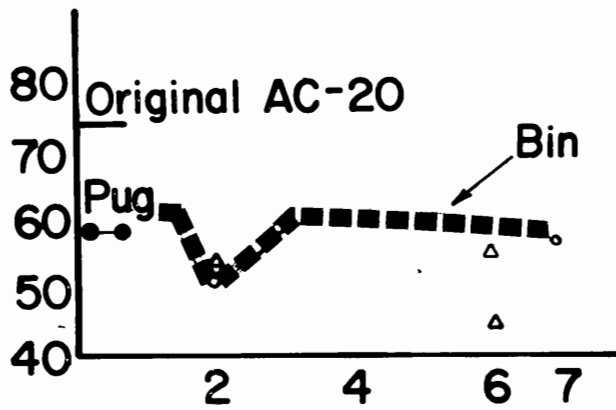


FIGURE 20B

ambient temperature. Recovered penetrations of the frozen and air cooled samples were 56 and 45 respectively. A laboratory test was also performed to confirm the difference in loss of penetration due to air curing versus rapid chilling by dry ice. The results are summarized below:

Sample	Air Cured	Pen@ 77°F	Visc@ 140°F	Visc@ 275°F	Duct@ 60°F
#2	1 day	47	3071	582	96
#3	2 weeks	44	3462	582	125
<u>Frozen</u>					
#5	1 day	52	2604	454	73
#4	2 weeks	68	2124	351	150+
#1	x2 weeks	68	2021	440	150+
Original Asphalt	---	72	1760	372	150+

x under dry ice blanket

These instances and others indicate that dry ice is effective in stopping the chemical and thermal reactions and allowing a truer picture of the physical properties at a given time.

Figures 21 and 22 indicate an anomaly, that is, the recovered penetration of certain samples being higher than the penetration of the original asphalt cement. The penetration values might have been suspect except that the viscosities corresponded accordingly. A thorough investigation of this seemingly inexplicable behavior brought to light a practice that was heretofore unknown. After a tanker (asphalt cement delivery truck) is unloaded at a plant, three to four gallons of fuel oil are aspirated through the truck pump to clean the pump and connecting hose. The net result is that with a positive displacement pump the bulk

of the fuel oil (except for a little drainage) is introduced into the plant storage tank. The amount of fuel oil, the location of the inlet and outlet ports and the level of asphalt in the tank would all be factors in how the asphalt cement would be affected. At this particular plant the inlet and outlet ports were approximately three feet apart. Since the tank had been filled prior to the test, the first asphalt out of the tank would come from the zone of dilution. This theory is supported by the inordinately higher recovered asphalt penetration (pugmill) values as shown in Figure 21. It should be noted that the loss in penetration between the pugmill and bin sample is more directly related to the penetration of the asphalt cement used in making the mix rather than time in storage. This relationship was readily observed in Figures 20a and b.

The next test at the same plant, Figure 22, shows that the highest penetration occurred at 105 tons. The field notes show that a delivery truck had started to pump over a load of asphalt cement somewhere after the twelfth ton of mix had been sampled; the time of disconnect however was not indicated. The diluted asphalt cement, as a result of the injected fuel oil, was siphoned out in a short period of time due to the close proximity of the inlet and outlet ports. It was estimated that ten to fifteen tons of mix was produced having as much as two to three percent of fuel oil in the asphalt cement. Subsequent laboratory experiments indicated that a three percent addition was approximately correct. In spite of the dilution the first, second, fourth and fifth points (pugmill curve) are considered to be true values.

PENETRATION AT 77°F

INERT ATMOSPHERE #1 MIX (STABILIZED BASE)

PUG ●—●
BIN ■■■■

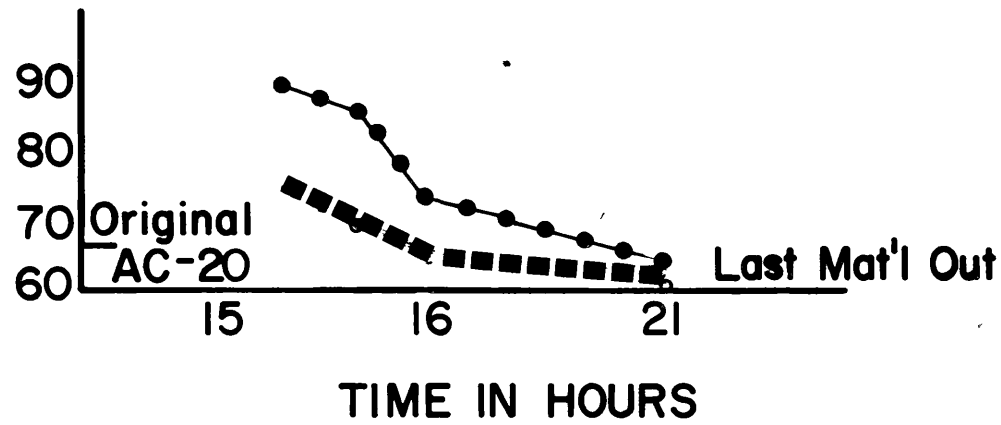
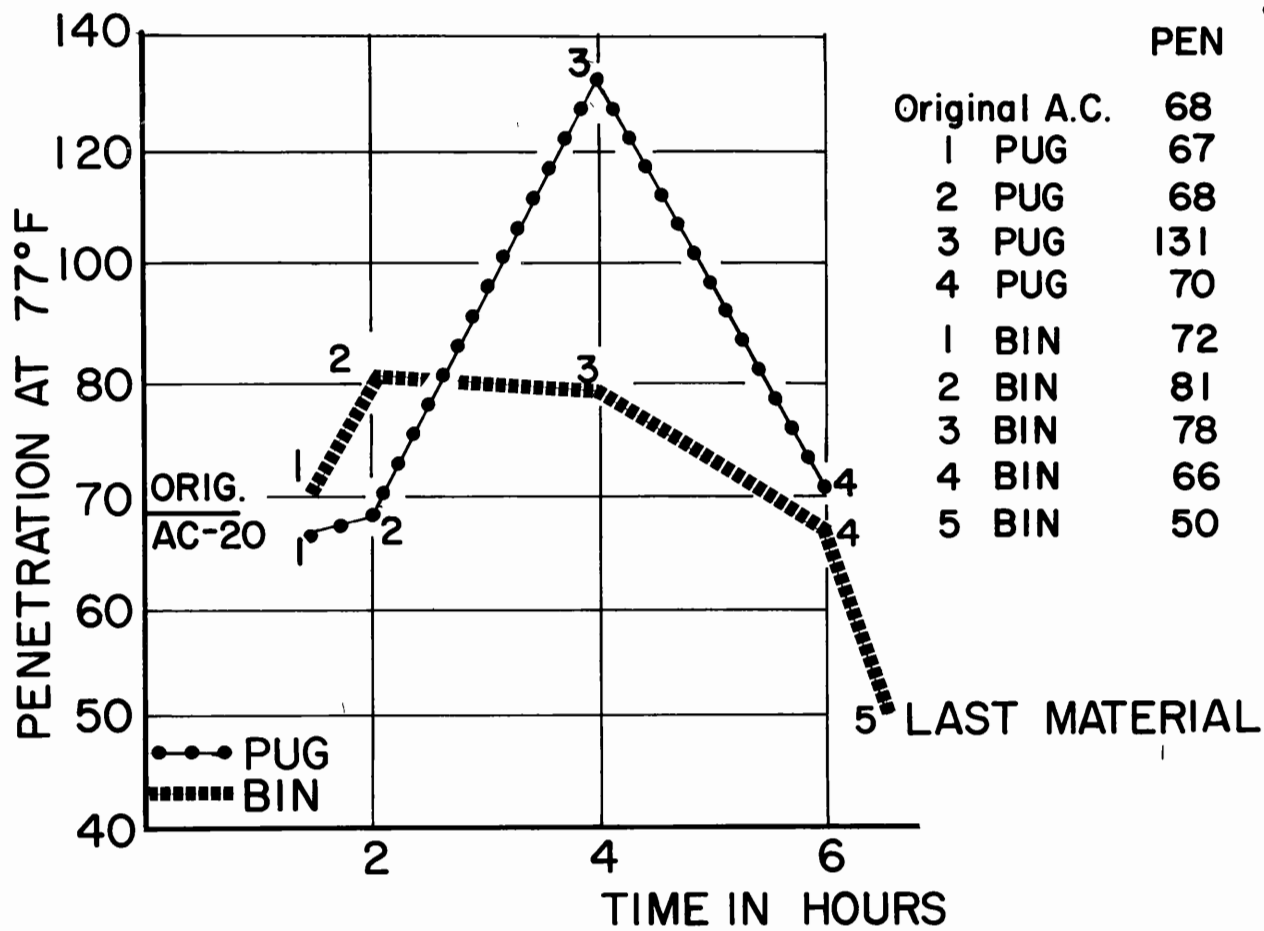


FIGURE 21



	PEN	Vis. at 140° F In Poises
Original A.C.	68	2068
1 PUG	67	2140
2 PUG	68	2069
3 PUG	131	915
4 PUG	70	2021
1 BIN	72	1852
2 BIN	81	1643
3 BIN	78	1654
4 BIN	66	1845
5 BIN	50	3243

FIGURE 22

The last test which was conducted at another plant also exhibited a disparity in recovered penetrations of the pugmill samples. Since the asphalt cement had been placed in the storage tank prior to the test, it was impossible to ascertain whether there had been an infusion of fuel oil into the asphalt tank. A tank truck which delivered a load of asphalt cement subsequent to the evaluation test had the pump and hose purged with four gallons of fuel oil. Based on this observation and the erratic penetration results it is safely assumed that the prior truckload has been treated in a like manner.

The penetrations of the recovered asphalt samples from both the pugmill and the storage bin were higher than the original asphalt cement sampled from the tank (67 pen). The viscosities were correspondingly lower with the exception of Sample 5B, the last material out of the bin. Figure 23 shows a plot of the viscosities at 140°F and 275°F versus the penetrations. A free hand curve was drawn for both plots. The tank sample (taken at the tank sampling port) in both plots appeared suspect as not being representative of the asphalt cement used in the production of the mix, the dilution by fuel oil notwithstanding. The asphalt cement producer was contacted for information regarding penetration and viscosities for the particular lot and tank number shown on the delivery slip. The penetration value was 76 or nine units higher (softer) than the sample removed from the plant storage tank. When the penetration and the viscosities values obtained from the producer were plotted they coincided more closely to the free hand curve than the sample removed from the storage tank. This again indicates that the tank sample was not representative (with or

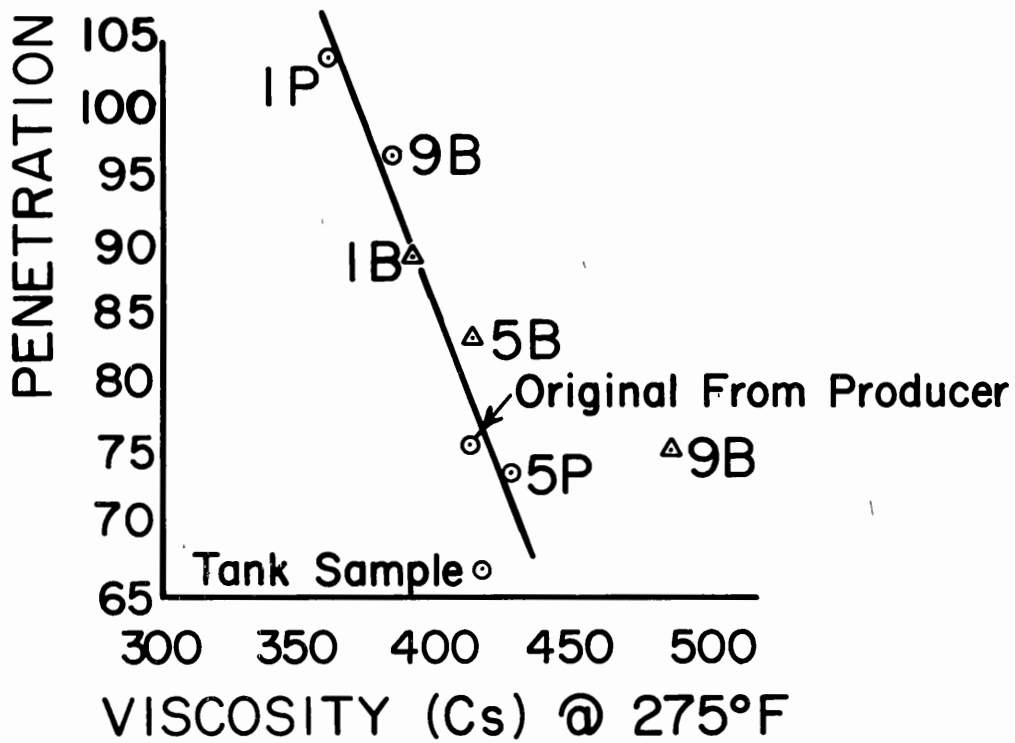
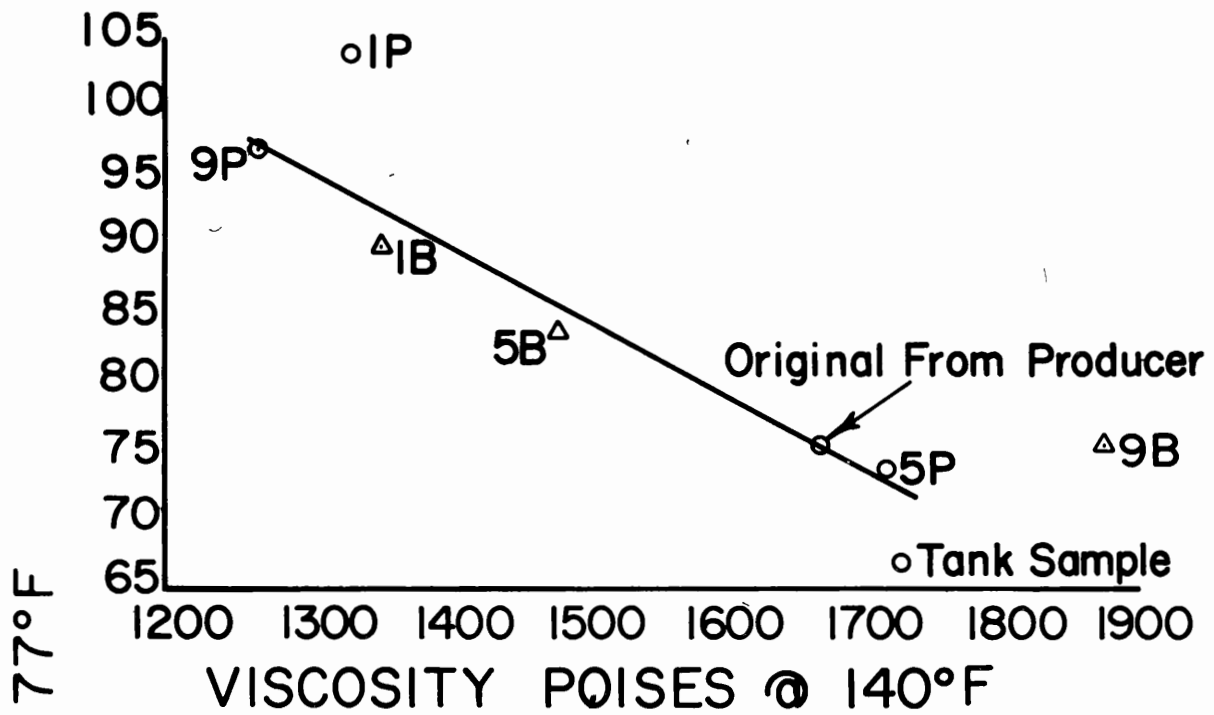


FIGURE 23

without dilution by fuel oil) of the asphalt cement used in producing the mix.

Sample 9B representing the last material out of the bin is widely displaced from the curves of both plots. This displacement in all probability is due to excess oxidation. Another oddity is that pug sample 5P is of a lower penetration value than that of the stored sample. As explained previously, segregation was quite apparent in this particular bin. The possibility of funneling or channeling would allow some of the softer penetration material above to discharge disproportionately from the way it was loaded.

During the course of this investigation it was observed that the distance between inlet, outlet, sample port and return line vary considerably from tank to tank. The methods of heating differ greatly and there are no provisions to insure positive blending of the asphalt cement. Under these conditions there is no guarantee that the tank sample is truly a representative sample.

Presently the New Jersey Department of Transportation has no limits on penetration of recovered asphalt. At the onset of this investigation it was proposed that such a limit be imposed. The collected data showed not only was this necessary but demonstrated that a 55 penetration be established as the lower limit for mixes coursed through a surge or storage bin. This however could unjustly penalize the bituminous concrete producer since he merely handles a bitumen approved by the Department.

With the adoption of viscosity graded asphalt cements came acceptance of lower minimum penetration values. The first lots of grade AC-20 produced had penetration values ranging from the mid seventies to the high eighties and was not too unlike the 85/100 penetration grade used in the past. Over the past two years there had been a general downward trend toward the lower limit of 60 as set forth in the specification requirements. Since the hardest asphalt possible within specification for an AC-20 grade has not been tested, a value lower than 55 may be mandated acceptable. In order to prevent subjecting the bituminous concrete producer to the aforementioned unjust penalization, the penetration value of the stored material must, of necessity, be related to the penetration of the asphalt cement used in making the mix. Therefore a value 15 percent below the average of the recovered penetration values of the pugmill samples will be used tentatively as the limiting criterion for determining the retention time.

D. Marshall Stability

The data generated during the investigation with respect to mixture stability was less than was planned. The tests that had been designed specifically for penetrations and Marshall stabilities went awry with the introduction of the diluted asphalt cements. The information gathered does indicate interesting phenomena which suggest further study.

The tests conducted in 1971 with the 85/100 penetration asphalt showed no difference in stability between mix taken directly from the pugmill and mix surged up to six hours. In the case of mix stored for ninety-four hours, a 500 pound increase in stability was noted. All the tests in 1972 were conducted with AC-20 viscosity graded asphalt. Marshall plugs of a #2 mix were water quenched, frozen and air cured (normal procedure used by Department inspectors) with the following results.

	<u>PUG</u>			<u>BIN</u>	<u>BIN</u>	
	Stability	Flow			Ret. Time	Stability
Frozen	372	15	Frozen	2 hours	350	19
Water Quench	1344	10	Frozen	4 hours	1070	13
Air Cured	2480	10	Frozen*	6 hours	1080	13

*inadvertently frozen

Frozen and air cured Marshall plugs of a #1 mix from both the pugmill and storage samples yielded the following:

	<u>PUG</u>			<u>BIN</u>	<u>BIN</u>	
	Stability	Flow			Ret. Time	Stability
Frozen	532	22	Frozen	15-20 hours	1362	15
Air Cured	2007	17	Air Cured		1539	16

Laboratory Results of #5 mix @ 345°F

	Stability	Flow	Pen@ 77°F	Pen@ 60°F	Visc@ 140°F	Visc@ 275°F	Duct@ 60°F
Frozen	1180	17	57	12	2665	536	85
Air Cured	3230	12	48	12	3177	577	49

Several interesting facts were brought out in this series of tests.

1. Rapid chilling with dry ice reduces the stability tremendously.
2. The practice of water quenching (as sometimes practiced in the field) has a similar effect as that of the dry ice but to a lesser degree.
3. Storage over two hours causes an increase in the stability of quickly chilled specimens (bin versus pugmill).
4. Stored material when made into Marshall plugs and cured in the normal manner has a stability that is higher than its rapidly chilled counterpart but lower than plugs made directly from the pugmill.
5. The higher the mix temperature, the higher the stability and the lower the penetration.

E. Bitumen Content

The bitumen content of the surge and storage bin samples had approximately the same degree of variation as the pugmill samples except where segregation had taken place. A standard deviation of 0.35 or less is considered good control for binder (#2) and base coarse (#1) mixes; 0.30 or less for a surface (#5) coarse mix.

The maximum standard deviation for the fine aggregate #5 mixes was 0.230 for bin samples and 0.130 for the pugmill samples, 0.304 and 0.348 for the #2 binder mixes, and 0.30 and 0.26 for the #1 base coarse mixes.

VI. CONCLUSIONS

A. Segregation

The results of this investigation indicate that segregation of hot bituminous concrete mixes does occur when processed through a surge or storage bin. The degree of segregation can be dependent on one or more factors. The factors influencing segregation are bin configuration, the manner in which the bin is charged, the way the bin is unloaded and the type of mix. In all cases segregation took place within the last twenty tons out of the bin. The degree of segregation ranged from a definitive change in gradation to out of specification material. The conclusions based on observed performance of specific bin characteristics are:

1. A bin of a round configuration with central point charging and a seventy degree (70°) tapered cone will produce an acceptable product of both fine and coarse mixes. Minor segregation of a coarse (#1) mix occurred within the last five tons.
2. A bin of a round configuration with dual mass dump charging hoppers and a sixty degree (60°) tapered cone caused segregation in the last twelve and half tons of a coarse (#1) mix.
3. A rectangular bin with internal splitters and multi-hopper discharge caused segregation to occur within the last sixteen tons of coarse (#2) mix.
4. A similar rectangular unit employing a vibratory discharge actuator caused the most severe segregation of #2 mix. The last eleven and a half tons being out of specification.

B. Temperature

The general effect of a storage bin on temperature is to moderate erratic mix temperatures as delivered from the pugmill. After about four hours, the temperature of the mix becomes quite uniform at a level ten to fifteen degrees below the average of the mix from the pugmill. The first material in and the last material out can have unacceptable temperature losses. Heat loss is a function of time, ambient temperature, moisture content of the aggregate, and the degree of supplemental heating. Specific conclusions relative to maintenance of adequate temperature are;

1. An insulated, totally heated bin can store a #5 mix up to 94 hours and deliver an acceptable product except for the last few tons. An insulated, heated bin can store a #5 mix for seven hours and deliver a totally acceptable product.

2. An insulated, totally heated bin can store a #1 mix up to sixty-seven hours and deliver an acceptable product except for the last six tons.

3. An insulated, partially heated bin will store a #2 mix up to seven hours and deliver an acceptable product except for the last four tons out.

4. A cone heated, insulated bin can store a #1 mix up to two and a half hours and deliver an acceptable product except for the last four tons.

5. An unheated, insulated bin can store a #2 mix up to seven hours and deliver an acceptable product except for the first and last eight tons.

C. Penetration

Loss in penetration is a function of time, type of asphalt and bin atmosphere. Aside from these parameters, the last material out of the bin in every case exhibited a further loss in penetration per given time interval. Since pressure varies in proportion to the vertical distance to the surface, it is hypothesized that the loss of volatiles is greater at or close to the surface and that the loss of volatiles is responsible for the extra loss in penetration. It is important to note this occurrence since the later addition of more mix to the bin, as would occur in normal operation, could allow for the acceptance of less than desirable material.

Although the Department of Transportation no longer has an interest in penetration grade asphalts, it is felt that the results should be recorded for historical and comparative purposes. Based on the results of the sampling conducted during this study, it is concluded that:

1. A #5 mix made with an 85/100 penetration grade asphalt can be stored for as long as seven hours in a bin with an air atmosphere and produce an acceptable product. A like mix stored in a bin with air locks and inert gas atmosphere will provide a product of acceptable penetration for any interval up to ninety-four hours of storage.

2. That #1 and #2 mixes made with an AC-20 viscosity graded asphalt may be stored for seven hours in a bin having an air atmosphere and deliver a product of acceptable penetration.

3. That coarse mixes (#1 and #2) can be stored in a bin with air locks and an inert gas atmosphere up to sixty-seven hours and deliver a product of acceptable penetration.

D. Bitumen Content

1. There is no migration of asphalt cement in the surging or storing of fine or coarse bituminous concrete mixes when produced at temperatures up to 320°F.

2. The bitumen content of samples from the bin showed no more variation than from the pugmill except where segregation takes place.

E. Relating to the Specific Aims of the Project

The results of this investigation prove conclusively that with certain limits, hot bituminous concrete mixes processed through surge or storage bins, can be approved for use on State sponsored projects.

1. The procedure developed (see Appendix A) will allow the Bureau of Inspection Plant and Project to evaluate field installations of surge and/or storage bins and define the specific usage limits.

2. The problems of mixture segregation, loss in temperature, and loss in penetration are indeed real and by the implementation of effective limits, the acceptance of less than desirable material will be prevented.

3. A general tentative specification can be written for this coming paving season to assure a quality of mix equal to that delivered from the pugmill.

VII. RECOMMENDATIONS

A. Immediate

1. Every surge or storage bin must be evaluated and the specific conditions and/or limitations be defined before any bituminous concrete

mix is accepted for a state sponsored job. The evaluation to be followed is outlined in Appendix A.

2. Inform those producers that are currently operating on temporary approval (some which have been operating for as long as two years) that this approval is withdrawn.

3. A minimum penetration value be established from the average penetrations of the recovered pugmill samples. This value will be the determinant for the approval of retention time regarding hardening of the asphalt cement.

4. The evaluation of bins should be a joint investigation by the Bureau of Inspection Plant and Project and the Bureau of Structures, Materials and Applied Mechanics Research for a period of one year. During this period additional information on asphalt cements from other producers as well as the effects of loading partially filled bins will be studied. Research personnel time is estimated to be two man months.

5. The practice of using fuel oil to purge the transfer pump and connecting hose to the asphalt tank must be discontinued or provisions made to collect the diluent in a separate container.

6. An asphalt cement sampling port should be placed in the supply line as close to the weigh box as practical.

B. Long Range

Viscosity grading is a complete break from the many years of accumulated experience and service life of bituminous pavements related to penetration grade asphalts. Generally speaking the AC-20

viscosity graded asphalt is harder than the 85/100 penetration grade. There is nothing to suggest that a harder asphalt means a reduction in quality however if a radical departure in temperature susceptibility occurs the problem of cracking due to brittleness may be of future concern.

Due to the inherent differences between the 85/100 penetration grade and the viscosity graded asphalt cements, it is suggested that a control program be established to monitor pavement sections with mixes from the bin evaluations. This would permit a complete historical background should any future adversity present itself.

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APPENDIX AEvaluation ProcedureA. General Criteria

Two sets of plans for the surge or storage system will be required before the evaluation is conducted. One set will be kept on file at the Bureau of Inspection headquarters, the other will be kept on file at the regional Material headquarters office. Prior to an evaluation an inspection of the installation will be made to check for plan conformity. Any future changes from the approved system through maintenance or modification must be reported to the Bureau of Inspection. If a review of these changes show a radical departure from the approved plans a new evaluation should be made.

1. Retention Time

The retention time for the evaluation will be the maximum storage time proposed by the producer.

- a) The term surge will be construed to mean a retention time (normally) of one to seven hours or limited to same day use.
- b) The term storage will be applied to holding a mix over night or any interval thereafter.

2. Sampling

Samples will be taken from both the pugmill and the bin. These samples are to be coincident on a weight basis. Since

the pugmill size and the truck payload will vary from plant to plant, a pre-planned schedule will be necessary in order to achieve coincident sampling. For an evaluation a bin shall be filled to not less than ninety percent of capacity and the mixture shall conform to all the requirements of the job mix formula for the particular mix to be tested.

3. Recording of Data

An onsite record will be kept for each evaluation, as per the sample attached to the procedure.

B. Specific Requirements

1. Number of Samples

- a) Nine samples will be taken representing the production from the pugmill.
- b) In sampling the mix as discharged from the bin it will be necessary to take samples coincident with the pugmill samples plus one additional sample for a total of ten samples. The additional sample will be taken by sampling the last truck twice; once at approximately the mid point of the payload and then again from the last material out.

2. Method of Sampling

- a) The pugmill samples will be taken from the skip hoist bucket or receiving hopper (depending on the system) in a manner to assure a representative sample. Whenever possible follow the manner as described below for the bin samples.

- b) The bin samples will be obtained in the following manner. From the predetermined conical pile of mixture within the truck, two furrows 180° from each other will be dug three to six inches in depth extending from the top to the periphery of the pile. The furrows will follow the slope of the pile and be formed as near its center as possible. A scoop of approximately equal volume of material will be dug from each furrow representing, the top, middle and bottom third of the pile and placed in a bucket to form one sample. The unit volume weight of the sample shall be a minimum of 20 pounds.
- c) A dial type asphalt thermometer (calibrated against a mercury thermometer in a hot oil bath) shall be inserted in the center of the composited sample and the temperature recorded.
- d) After recording the temperature, the sample will be dumped onto a 30 inch square melamine laminate faced plywood base. Two 8 x 8 x 2 inch specimens will be prepared from the sample in the following manner. The heaped material will be quartered by a trowel and pushed to effect quadrants spaced 1 to 2 inches apart. Each quadrant will be halved by trowel and the mix from the 1st, 3rd, 5th and 7th segments cast into one mold. The mix from the remaining

2nd, 4th, 6th and 8th segments will be cast into the second mold. The mix will be flattened and a metal rim tag bearing the identification code "pinned" to each sample with a 4d box nail. An identification code will consist of the location (pug or bin) followed by a number and letter A or B. The number will signify the sampling sequence; the letter A for extraction, the letter B for recovery. Only the B samples will be rapidly cooled by dry ice (solid CO₂).

3. Cooling and Storage

- a) Rapid cooling will be accomplished as follows: a slab of dry ice (approximately 9" x 9" x 1") will be placed on a 10 x 10 x 1/4 inch piece of plywood, the mold is placed on the dry ice, the mix cast in as described in Paragraph 2d above and a second slab of dry ice placed on the sample. After 4 to 5 minutes the top slab of dry ice is taken off and the strap iron mold removed. The sample and lower slab of dry ice is then placed in the styrofoam insulated chest for transfer to the laboratory freezer.
- b) The frozen samples must be stored in the freezer at zero \pm 10°F until scheduled for recovery.

4. Sampling Schedule

Since the first and last truckloads of mix removed from a surge or storage bin are susceptible to segregation, loss of temperature, and loss in penetration, judicious sampling of these two loads is made mandatory. The first truckload should be sampled at tons 4-6, 8-10 and 20-22. These values are given in ranges to accommodate a schedule for 2, 2-1/2, 3, 4 or 5 ton pugmills and truck capacities of 20 to 22 tons. The bulk of the mix will be sampled in increments of 20-22 or 40-44 tons depending on bin capacity. The 40-44 ton increments will apply only to mid-range sampling, that is between the first and last two truckloads. The last truckload should be sampled twice, at approximately the midpoint and the last material out.

In evaluating long term storage one to two truckloads will be discharged per day depending on the retention time proposed by the producer and the capacity of the bin.

The following examples indicate desirable sampling schedules for a three ton pugmill supplying bins of 150 and 200 ton capacity.

<u>150 Ton Bin (Surge)</u>											
Sample #	1	2	3	4	5	6	7	8	9	10	
Pugmill	6	9	21	42	63	84	105	126	NONE	147	last in
Bin	6	9	21	42	63	84	105	126	<u>136</u>	<u>147</u>	last out

split load

200 Ton Bin (Surge)

Sample #	1	2	3	4	5	6	7	8	9	10	
Pugmill	6	9	21	42	84	126	147	168	NONE	189	last in
Bin	6	9	21	42	84	126	147	168	178	189	last out

split load

150 Ton Bin (Storage for 96 Hours)

Sample #	1	2	3	4	5	6	7	8	9	10	
Pugmill	6	9	21	42	63	84	105	126	NONE	147	last in
Bin	6	9	21	42	63	84	105	126	136	147	last out

split load

Retention time in hours	24 hours		48	72		96			
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All the "A" samples from both the pugmill and the bin will be tested for composition (gradation). The "B" samples for recovery will be tested in an order of priority as follows. Pugmill sample numbers 3, 6, 7 and 10 and bin samples 10, 9, 8, 6, 3, and 1 will be tested in the given order. The balance of samples will be retained in the freezer pending review of the results. If the recovery results appear reasonable and indicate that a valid evaluation can be made the retained samples may be discarded.

C. Cautionary Comments

In establishing the permissible retention time through a monitoring of temperature particular attention must be paid to the first and last truckloads of mix out of the bin. The tonnage of unacceptable material can vary with time, ambient temperature and the

extent of supplemental heating. Normally the last thirty tons of material exhibit a thermal gradient with the last material out having the lowest temperature. In cases where extreme segregation occurs due to rat-holing or funneling it is possible for the last material out to be hotter than one or two prior samples.

Most bituminous concrete producers request an evaluation starting with overnight storage. Experience has shown that the heat loss in partially heated bins will not permit acceptance of the whole charge in the bin. In unheated or cone heated insulated bins, the temperature of the first and last few tons can be suspect after as little as two hours of retention time.

In arranging a schedule for an evaluation of the partially heated bins inform the producer of the possibility of non-acceptance of perhaps the first five and last twenty tons of material to be discharged. If these conditions are deemed unacceptable and a test is demanded then an abbreviated temperature evaluation should be made to prevent repetition of the total testing procedure. A suggested mini-evaluation would be to check the temperature of the first and last thirty tons (in ten ton increments) of the mixture produced, at the pugmill location and when discharged from the bin. Take a sample from the last material out and have it checked for penetration. If the minimum temperature requirements cannot be met then arrange for a full evaluation at a lesser retention time or for surge use.

It should be pointed out to the producer that it is in his own interest to produce the mix at as close to the maximum temperature as permitted (for the particular asphalt cement) since the approved retention time in the main will be dependent on the temperature of the discharged material. This would discourage any argument concerning a re-test should the bin be approved for a minimal retention time.

For overnight storage a seal should be placed on the loading hatch to prevent the addition of fresh hot mix during the evaluator's absence.

D. Guide for Bin Acceptance and Usage

1. Criteria

The criteria of temperature, segregation and loss in penetration may act synergistically or as individual criterion. For example it can be argued that the low temperature of the top material may be brought up to an acceptable temperature through the addition of fresh mix. This argument can be considered valid providing the loss in penetration is not excessive. This could be especially true for a 2-3 hour retention time. In the case of 24 hours of retention time, the uppermost material could probably again be brought to an acceptable temperature by the addition of fresh mix. However it is doubtful in this instance that the reheated mix would have an acceptable penetration if stored in an air atmosphere. Experience to date indicates that successful overnight storage requires an inert gas atmosphere.

Should a mix meet the requirements of temperature and penetration, it must still withstand the test for segregation. If

segregation is pronounced in the latter tonnage discharged, a dual suggestion is offered: The first step is to ascertain the level at which segregation (for the particular mix) takes place and limit acceptance of material to that level. Recharging of the bin above that level will be permitted in a continuous surging operation. However, when the bin is to be emptied, that material below the predetermined level will not be accepted. The second step is to require installation of a bin level indicator at the critical bin level with an adequate warning device such as a light or buzzer relayed to the field inspector's office.

2. Limits

a) Temperature

The mix will be produced within $\pm 20^{\circ}\text{F}$ of the specified temperature for the particular viscosity grade asphalt cement being used.

For determining retention time and mix acceptability, the temperature of the mixture as discharged from the bin shall be not more than 20°F below the average of the pugmill samples.

b) Penetration

For mix acceptance, the penetration of the recovered asphalt of the bin samples shall be not less than 15 percent below the average of the pugmill samples; providing the penetration range of the pugmill samples does not exceed 10 units*.

*If the 10 unit range is exceeded there is the likelihood of non-uniformity of the asphalt cement and the evaluation from the standpoint of penetration must be considered inconclusive.

From the pugmill and bin penetration values the evaluator will determine either the retention time for acceptance of the whole mix or the proportional amount of tonnage not acceptable for that retention time, temperature notwithstanding.

c) Segregation

The gradation (sieve analysis) of all the bin samples must be within reasonable conformity with the average gradation of the pugmill samples. When very noticeable differences are observed in the sieve analysis of the last two or three samples from the bin, the gradation of each questionable sample shall be analyzed to determine if segregation has occurred. Segregation is indicated when a sample's gradation fails to comply with any one of the following.

(1) Tolerances

(a) Fine Aggregate (Percentage Passing #8, #50, and #200 Sieves)

For the fine aggregate the deviation from the average gradation of the pugmill will not exceed the job mix tolerances for individual samples as shown in Table 3-A(1) of yellow (1970) Addenda A.

- (b) Coarse Aggregate (Percentage Passing 1-1/2", 1", 1/2", 3/8", and #4 sieves)

For the coarse aggregate the deviation from the average gradation of the pugmill will not be more than one-half the broad band (master range) of Table 3 of the yellow Addenda A.

(2) Statistical Analysis

The gradation is to be subjected to a statistical analysis based on the outlier test "Theory of Rejection of Observations." The sieves to be so treated are 1/2", 3/8" (where applicable), #4, #8, #50, #200 and the bitumen content.

(3) Test for Outliers

- (a) The standard deviation will be calculated for the sieves mentioned in paragraph (2) for the samples taken at the pugmill.
- (b) From the attached Table A-10, select the number in the left hand vertical column which represents the number of pugmill samples minus one. This number will be eight (8) when sampled according to the procedure.

- (c) Read across the horizontal numbers above the columns until you come to the number representing the number of samples taken from the bin, (ten if following normal procedure). Come down this column until it intersects with row eight. Read the number (5.13 in this case).
- (d) Multiply the number (5.13) by the standard deviation of the pugmill samples for each sieve mentioned in paragraph (2).
- (e) Find the range of the bin samples for the particular sieve. The range is the difference between the largest and the smallest number in the series.
- (f) A comparison of the range [paragraph (e)] and the product from paragraph (d) is made. If the range is greater than the product of paragraph (d), the sample is rejected as being an outlier, that is, it did not come from the assumed pugmill population and indicates segregation.
- (g) Repeat steps (c), (d), (e), and (f) for each suspect sample, remembering that the bin sample number will change and a new factor as outlined in paragraph (c) will have to be found.

3. Sample of Test for Outliers (Segregation)

For the sake of brevity only the mean and the standard deviations for the pugmill samples are shown. The gradation of the bin samples have been reduced to the last four samples taken but the range covers all ten of the samples.

Pugmill Sample Data

Sieve Size	Average of 9 Samples	Standard Deviation
1/2	66.67	4.18
#4	51.00	3.20
#8	39.06	2.23
#50	13.00	1.06
#200	5.21	0.63
bit. content	4.71	0.26

Bin Samples

Sieve Size	#7	#8	#9	#10	Range of 10
1/2	67.0	52.0	52.0	44.0	32 (76-44)
#4	53.0	42.0	43.0	33.0	27 (60-33)
#8	38.0	31.5	32.5	25.5	21 (46.5-25.5)
#50	13.5	11.5	11.5	10.0	5 (15-10)
#200	6.0	5.0	5.2	4.5	2 (6.5-4.5)
bit.	4.65	3.95	4.10	3.45	2 (5.45-3.45)

Calculation for Sample #10

Sieve Size	Standard Deviation	x	Factor	= Product	Range
1/2	4.18		5.13	21.4	32 reject
#4	3.20		5.13	16.4	27 reject
#8	2.23		5.13	11.4	21 reject
#50	1.06		5.13	5.5	5 O.K.
#200	0.63		5.13	3.2	2 O.K.
bit.	0.26		5.13	1.33	2 reject

Sample 9 Factor is 4.99
 Sample 8 Factor is 4.83
 Sample 7 Factor is 4.65

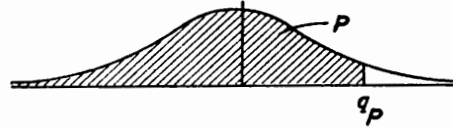
Sieve Size	Sample #9		Sample #8		Sample #7	
	Product	Range	Product	Range	Product	Range
1/2	20.7	24*	20.5	24*	19.4	13
#4	16.0	18*	15.5	18*	14.9	10
#8	11.1	15*	10.8	15*	10.4	8.5
#50	5.3	3.5	5.1	3.5	4.9	2.0
#200	3.1	1.5	3.0	1.5	2.9	1.0
bit.	1.29	1.3*	1.3	1.5*	1.2	0.9

*reject as being outliers

This example shows that Samples 8, 9, and 10 exhibit segregation and are unacceptable. From actual experience Sample #7 represented the 132nd ton and Sample #8 the 140th ton withdrawn. The total charge was 152 tons. This shows that segregation started to occur within the first eight tons of the last truckload out of the bin. Therefore, the last truckload will not be accepted and a bindicator should be installed at the 20 ton level.

TABLES

TABLE A-10. PERCENTILES OF THE STUDENTIZED RANGE, q



$q = w/s$ where w is the range of t observations, and ν is the number of degrees of freedom associated with the standard deviation s .

$q_{.90}$

$t \backslash \nu$	2	3	4	5	6	7	8	9	10
1	8.93	13.44	16.36	18.49	20.15	21.51	22.64	23.62	24.48
2	4.13	5.73	6.77	7.54	8.14	8.63	9.05	9.41	9.72
3	3.33	4.47	5.20	5.74	6.16	6.51	6.81	7.06	7.29
4	3.01	3.98	4.59	5.03	5.39	5.68	5.93	6.14	6.33
5	2.85	3.72	4.26	4.66	4.98	5.24	5.46	5.65	5.82
6	2.75	3.56	4.07	4.44	4.73	4.97	5.17	5.34	5.50
7	2.68	3.45	3.93	4.28	4.55	4.78	4.97	5.14	5.28
8	2.63	3.37	3.83	4.17	4.43	4.65	4.83	4.99	5.13
9	2.59	3.32	3.76	4.08	4.34	4.54	4.72	4.87	5.01
10	2.56	3.27	3.70	4.02	4.26	4.47	4.64	4.78	4.91
11	2.54	3.23	3.66	3.96	4.20	4.40	4.57	4.71	4.84
12	2.52	3.20	3.62	3.92	4.16	4.35	4.51	4.65	4.78
13	2.50	3.18	3.59	3.88	4.12	4.30	4.46	4.60	4.72
14	2.49	3.16	3.56	3.85	4.08	4.27	4.42	4.56	4.68
15	2.48	3.14	3.54	3.83	4.05	4.23	4.39	4.52	4.64
16	2.47	3.12	3.52	3.80	4.03	4.21	4.36	4.49	4.61
17	2.46	3.11	3.50	3.78	4.00	4.18	4.33	4.46	4.58
18	2.45	3.10	3.49	3.77	3.98	4.16	4.31	4.44	4.55
19	2.45	3.09	3.47	3.75	3.97	4.14	4.29	4.42	4.53
20	2.44	3.08	3.46	3.74	3.95	4.12	4.27	4.40	4.51
24	2.42	3.05	3.42	3.69	3.90	4.07	4.21	4.34	4.44
30	2.40	3.02	3.39	3.65	3.85	4.02	4.16	4.28	4.38
40	2.38	2.99	3.35	3.60	3.80	3.96	4.10	4.21	4.32
60	2.36	2.96	3.31	3.56	3.75	3.91	4.04	4.16	4.25
120	2.34	2.93	3.28	3.52	3.71	3.86	3.99	4.10	4.19
∞	2.33	2.90	3.24	3.48	3.66	3.81	3.93	4.04	4.13

Adapted by permission from *Biometrika*, Vol. 46, Dec. 1959, from article entitled "Tables of the Upper 10% Points of the Studentized Range (Accompanied by Revised Tables of 5% and 1% Points)," by James Pachares

TABLE A-10 (Continued). PERCENTILES OF THE STUDENTIZED RANGE, q

9.90

ν \ t	11	12	13	14	15	16	17	18	19	20
1	25.24	25.92	26.54	27.10	27.62	28.10	28.54	28.96	29.35	29.71
2	10.01	10.26	10.49	10.70	10.89	11.07	11.24	11.39	11.54	11.68
3	7.49	7.67	7.83	7.98	8.12	8.25	8.37	8.48	8.58	8.68
4	6.49	6.65	6.78	6.91	7.02	7.13	7.23	7.33	7.41	7.50
5	5.97	6.10	6.22	6.34	6.44	6.54	6.63	6.71	6.79	6.86
6	5.64	5.76	5.87	5.98	6.07	6.16	6.25	6.32	6.40	6.47
7	5.41	5.53	5.64	5.74	5.83	5.91	5.99	6.06	6.13	6.19
8	5.25	5.36	5.46	5.56	5.64	5.72	5.80	5.87	5.93	6.00
9	5.13	5.23	5.33	5.42	5.51	5.58	5.66	5.72	5.79	5.85
10	5.03	5.13	5.23	5.32	5.40	5.47	5.54	5.61	5.67	5.73
11	4.95	5.05	5.15	5.23	5.31	5.38	5.45	5.51	5.57	5.63
12	4.89	4.99	5.08	5.16	5.24	5.31	5.37	5.44	5.49	5.55
13	4.83	4.93	5.02	5.10	5.18	5.25	5.31	5.37	5.43	5.48
14	4.79	4.88	4.97	5.05	5.12	5.19	5.26	5.32	5.37	5.43
15	4.75	4.84	4.93	5.01	5.08	5.15	5.21	5.27	5.32	5.38
16	4.71	4.81	4.89	4.97	5.04	5.11	5.17	5.23	5.28	5.33
17	4.68	4.77	4.86	4.93	5.01	5.07	5.13	5.19	5.24	5.30
18	4.65	4.75	4.83	4.90	4.98	5.04	5.10	5.16	5.21	5.26
19	4.63	4.72	4.80	4.88	4.95	5.01	5.07	5.13	5.18	5.23
20	4.61	4.70	4.78	4.85	4.92	4.99	5.05	5.10	5.16	5.20
24	4.54	4.63	4.71	4.78	4.85	4.91	4.97	5.02	5.07	5.12
30	4.47	4.56	4.64	4.71	4.77	4.83	4.89	4.94	4.99	5.03
40	4.41	4.49	4.56	4.63	4.69	4.75	4.81	4.86	4.90	4.95
60	4.34	4.42	4.49	4.56	4.62	4.67	4.73	4.78	4.82	4.86
120	4.28	4.35	4.42	4.48	4.54	4.60	4.65	4.69	4.74	4.78
∞	4.21	4.28	4.35	4.41	4.47	4.52	4.57	4.61	4.65	4.69

APPENDIX BGeneral Specification

Division III - Materials

Section 903 - Bituminous Concrete

903-02(a) General Requirements for All Mixing Plants

10. Surge and Storage Bins for Bituminous Mixtures

A plant shall be permitted to store hot mixture from its pugmill in a surge or storage bin provided said bin has received prior evaluation and approval by the Department. Use of the bin is to be in conformance with all limitations on retention time, type of mixture, heater operation, bin atmosphere, bin level or other characteristics set forth in the Department's letter of approval.

An evaluation of a surge or storage unit will be conducted by the Department on written request by a plant owner. The evaluation will determine the degree of composition uniformity, temperature characteristics, and degree of asphalt cement hardening of mixture processed through the surge or storage unit. Approval will be granted for bin usage that consistently results in mixture having gradation, temperature and asphalt hardening properties of no lesser quality than acceptable mixtures discharged directly from the plant's pugmill.

However, a penetration loss in storage of up to 10 units will be permitted based on comparative tests (AASHO T49-68) of frozen samples of mixture obtained from the pugmill and bin discharges.

In the event that an approved surge or storage system is changed or altered the Department of Transportation shall be notified of modification. Any radical departure from the approved system will necessitate reevaluation.

APPENDIX C

Sampling and Testing Plan

A. Sample Location

1. As discharged from the pugmill
2. As discharged from the storage bin
3. Pavement cores

B. Asphalt Original

1. Specific Gravity @ 77°f
2. Penetration at 77°F
3. Flash point C.O.C.
4. Ash %
5. Viscosity at 140°F poises (absolute)
6. Viscosity at 275°F C_s (Kinematic)
7. Penetration at 60°F

C. Asphalt (Thin Film Oven Test)

1. % loss in weight
2. Penetration @ 60°F
3. Penetration @ 77°F
4. Viscosity @ 140°F poises (absolute)
5. Viscosity @ 275°F C_s (Kinematic)
6. Ductility @ 60°F 5 cm/min

D. Bituminous Mix

1. Temperature at the time of mix and discharge from bin
2. Extraction
3. Asphalt content
4. Gradation
5. Recovery (Abson method)
 - a) Penetration @ 60°F
 - b) Penetration @ 77°F
 - c) Viscosity @ 140°F poises (absolute)
 - d) Viscosity @ 275°F C_s (Kinematic)
 - e) Ductility @ 77°F
 - f) Ductility @ 60°F 5 cm/min
 - g) % Ash
 - h) Specific gravity @ 77°F

E. Marshall Stability - (Pug and bin samples)

1. Stability
2. Flow
3. % air voids

F. Pavement Cores

1. Penetration @ 77°F
2. Penetration @ 60°F
3. Ductility @ 60°F 5 cm/min
4. Specific Gravity @ 77°F

G. Standard Method Legend

1. Recovery of asphalt by Abson Method	AASHO T 170-70
2. Penetration @ 77°F	AASHO T 49-68
3. Viscosity @ 140°F	AASHO T 202-68
4. Viscosity @ 275°F	AASHO T 201-70
5. Ductility @ 77°F	AASHO T 51-68
6. Ductility @ 60°F	AASHO T 51-68
7. Marshall Stability	ASTM D 1559
8. Thin film oven test	AASHO T 179-68
9. Extraction	New Jersey Department of Transportation
10. % voids	New Jersey Department of Transportation

In view of the data gathered in this research the tests for penetration at 60°F and ductility at 77°F should not be used in future evaluations.

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