THE UNIVERSITY OF CALGARY

The Impact that Superpave Aggregate Specifications will have on the Calgary Asphalt Industry

by

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Abstract

The Strategic Highway Research Program spent 150 million dollars between October 1987 and March 1993 to develop a better way to design asphalt pavements. This new design procedure and the mix it produces has been labeled Superpave (Superior performing asphalt pavements).

The focus of this paper was to examine the aggregate component of Superpave and evaluate the impact this would have on the industry in The City of Calgary. What I identified was that The City of Calgary materials operation has a good source of stone and the existing crushed material meets the minimum requirement for a major roadway like Stoney Trail. However The City of Calgary plant has not produced any Superpave mix materials. All of the Superpave material placed in The City of Calgary since 1995 have been produced by contracted suppliers, who have had to upgrade aggregate stock piles to provided compliant materials.

The question that should be raised is, should The City of Calgary asphalt plant be given the opportunity to bid on the production of asphalt mix in all of the Superpave contracts?

Acknowledgments

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Notations

crush	- a crushed stone product that contains all of the fractured pieces
DP	- dust proportion
ESALs	- Equivalent Single Axle Loads
fracture face	- any fractured surface greater than 25% of the area of the outline of the aggregate particle visible in that orientation.
G_b	- specific gravity of the binder
G_{mb}	- bulk specific gravity
G_{mm}	- maximum theoretical specific gravity
G_{se}	- effective specific gravity
G_{sa}	- apparent specific gravity
G_{sb}	- bulk specific gravity
IDT	- Indirect Tensile Tester
minus product	- all material less than the specified size
N	- number of gyrations, values assigned for initial, design and maximum
P_b	- percent of binder
P_s	- percent of aggregate
P_{bi}	- percent (by weight of mix) of binder
SGC	- Superpave Gyratory Compactor
S_n	- the nominal maximum sieve size of the aggregate blend (mm)
SST	- Superpave Shear Tester
Superpave	- an acronym for **Su**perior **per**forming asphalt **pave**ments
T	- temperature
T_{20mm}	- highest pavement temperature 20 mm below the surface
T_{min}	- lowest temperature at the pavement surface
V_a	- volume of the air voids
V_{ba}	- volume of asphalt binder absorbed, cm^3/cm^3 of mix

VFA	- Voids Filled with Asphalt
VMA	- Voids in the Mineral Aggregate
V_{se}	- volume of the effective binder, cm^3/cm^3 of mix
W_s	- weight of the aggregate, grams

CHAPTER1
INTRODUCTION

1.1 A Move to Performance Based Asphalts

The development of a performance based asphalt pavement was started in 1987 with the Strategic Highway Research Program. This program conducted a 150 million dollar effort to improve the design and testing practices associated with the production of asphalt pavements. This new mix design and analysis system was referred to as Superpave which stood for superior performing asphalt pavements. The emphasis was to produce a system of design and testing procedures that would accurately predict the performance of the asphalt mix. This would allow the roadway agencies to design mixes and then compare the cost of production of those mixes to the performance predicted by the testing.

Through this process, it was hoped that the agencies would be able to evaluate the expected life time costs of the pavement surface. It was felt that these lifetime cost evaluations would support the move to tighter aggregate specifications and improved consensus and source properties for most agencies. The City of Calgary was, and still is, faced with this decision.

1.2 Study Objectives

This project examines the physical impacts that Superpave specifications will have on the Calgary aggregate industry. It will look at the source aggregates that exist within the Calgary area and the crushing operation from both the perspective of the contractor and the City. This will determine three things:

a) if Superpave aggregates can be produced

b) if so, what the ramifications are for both parties

c) if existing City of Calgary materials meet Superpave requirements.

If existing City aggregates can be blended to meet Superpave requirements, then a 12.5 mm Superpave mix design will be completed.

A significant amount of the information contained in this document was gathered from discussions and meetings held with different members of the Calgary asphalt industry over the past three years. It was a very interesting exercise to see how the different sections of the industry have reacted to the recommended changes. Testing firms see their operations benefitting from the additional work required to evaluate the mix designs but must also invest heavily in equipment in order to complete the advanced testing required for performance predictions. Aggregate producers see the tightened aggregate specifications as higher quantities of waste materials, or possibly changes in equipment to provide a more cubical material.

Finally the caretakers of these public assets must justify any increase in the cost of testing and production by a balance that is predicted in increase life and lower life cycle costs. These changes will not occur over night because it will take 10 to 15 years for the actual savings to be realized.

1.3 Brief History of the Strategic Highway Research Program and Superpave

The Strategic Highway Research Program conducted a 150 million dollar research effort between October 1987 and March 1993. The focus of this project was to tie the material properties to the pavement structural properties in such a way that the actual pavement performance could be modelled. The benefit of this new system would allow evaluation of materials, mix designs, asphalt modifiers and other products on a cost versus predicted performance basis.

The Superpave mixture design and analysis is very complex and requires extensive testing to accurately predict performance. To balance the cost associated with the mix design and the type of road on which the mix was to be placed, three levels of design were established. These levels were established based on the traffic level or volume and loading that the pavement would be subjected to. Each of these design level in the Superpave model builds on the preceeding level. For example, all roadways will require a Superpave Level One mix design. If volume or loading indicated the roadway requires a Superpave Level Two design, then the Level Two work is completed after the Superpave Level One work is complete.

The Superpave Level One mix design is considered adequate for traffic volumes less than one million (10^6) equivalent single axles loads (ESALs). This would be considered a local or low volume roadway for which the asphalt pavement would deteriorate because of age hardening of the bitumen or wear on the surface of the road versus failure due to axle loading. The Superpave Level One mix design is based only on volumetric properties and does not involve advanced testing that will allow performance predictions. The volumetric design consists of fabrication of mixes based on consensus and source properties of the aggregate. These selected materials must also meet specific gradation requirements. These requirements are laid out as control points and a restricted zone which are plotted on a 0.45 power chart (see Figure 1 below). The asphalt content is selected based on air voids, voids in the mineral aggregate (VMA), voids filled with asphalt (VFA) and the ratio of dust to effective asphalt content (DP). The final process in the design is to check the aggregates for moisture susceptibility.

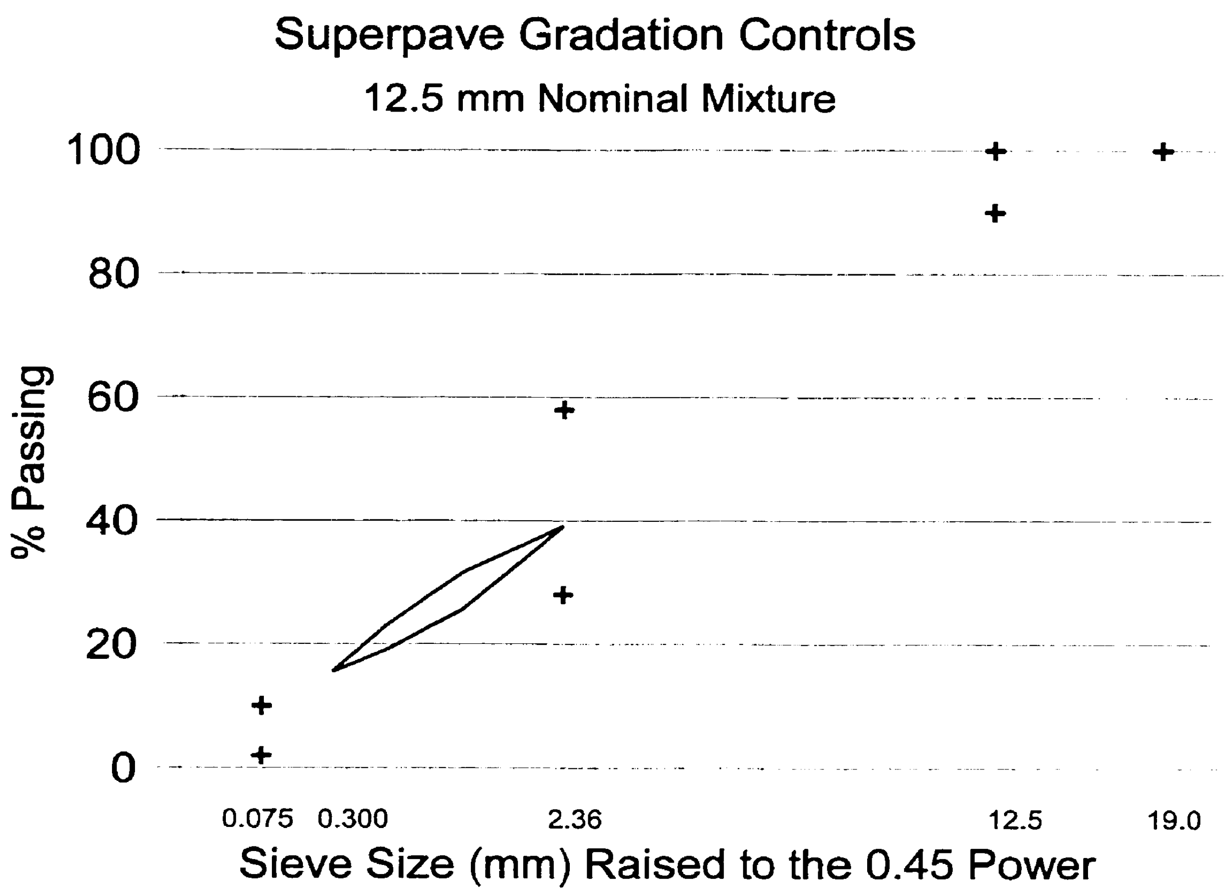


Figure 1

The Superpave Level Two mix design is for roadways with traffic volumes between one million (10^6) and ten million (10^7) ESALs. The Superpave Level Two mix design builds on the level one by adding performance prediction testing. This advanced testing is completed on two pieces of equipment called the Superpave Shear Tester (SST) and Indirect Tensile Tester (IDT). These two units will be described in more detail later in this section.

The final design level is Superpave Level Three and it is required for all roadways with over ten million (10^7) ESALs. This Level again builds on all the testing required in the previous levels and adds additional SST and IDT testing at a wider variety of temperatures and confined specimen testing on the SST equipment. This comprehensive range of tests provides an enhanced and more reliable level of performance predictions.

As mentioned above, the equipment used to complete the Superpave Level Two and Three testing will now be described very briefly. The Superpave Shear Tester or SST is used to load a sample and measure the response of the specimen with linear variable differential transducers that are affixed to the samples. The testing is carried out in an environmental unit in which the air pressure and temperature can be controlled. Confined sample testing can also be configured using a special rubber membrane. The five tests that are used for Superpave mix designs and can be performed on the SST are:

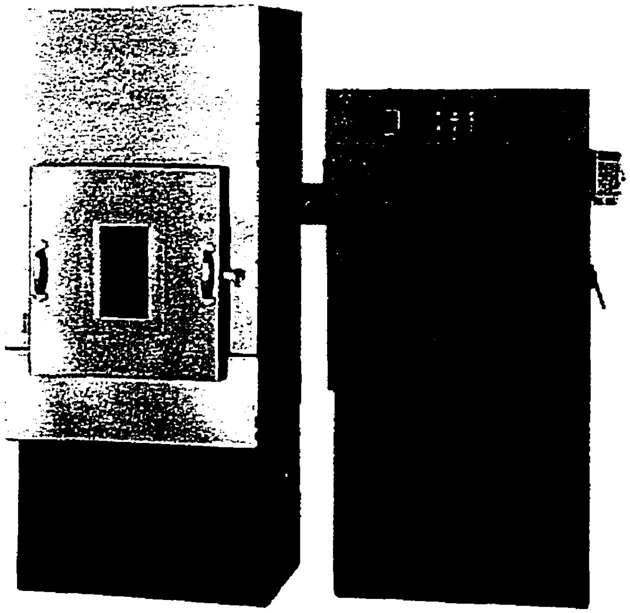


Figure 2 Interlaken Technology Corporation SST

1. volumetric test,
2. uniaxial strain test,
3. repeated shear test at constant stress ratio,
4. simple shear test at constant height, and
5. frequency sweep test at constant height.

The volumetric and uniaxial strain tests make use of the constraining rubber membrane to provide the confining pressure required.

The Indirect Tensile Tester or IDT measures the creep compliance and strength of mixtures using an indirect tensile loading technique. This equipment also has an environmental control unit and can test samples at intermediate to low temperatures. The three test performed by the IDT are:

1. IDT Creep Compliance and Strength at Low Temperatures and
2. IDT Strength at Intermediate Temperatures.
3. Fatigue by Repetitive Cycling.

All of these tests performed on these two pieces of equipment are used to arrive at a series of go/no go performance predictions.

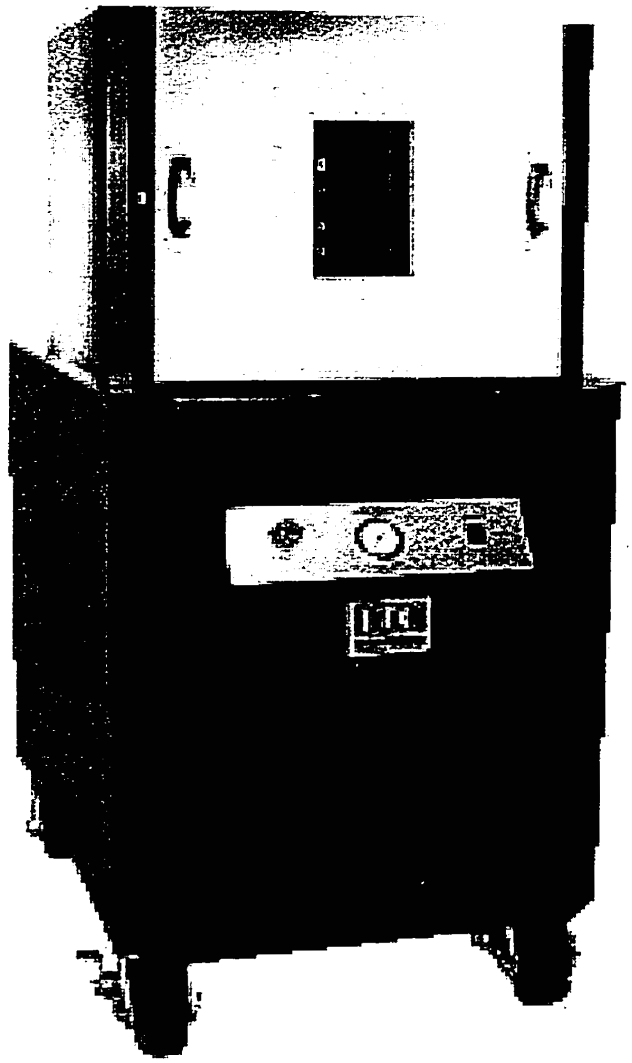


Figure 3 Interlaken Technology Corporation IDT

CHAPTER 2

AGGREGATES IN NORTHWEST CALGARY

The City of Calgary has within its corporate boundaries an abundance of good construction aggregates. One of the biggest challenges is to extract or mine the material before the land is used for other purposes. Some of the new developments in the northwest quadrant of The City of Calgary are built on top of large deposits of gravel. The development of Citadel has already begun in the lower portion of section 23 and Inland will be closing their pit in this area and moving to a new pit in the east half of section 27. The section map, shown below, is the extreme north west corner of The City of Calgary. The dashed lines represent The City of Calgary corporate boundaries and the horizontal dashed line is 144 Av NW and the vertical dashed line is Rocky Ridge Rd. This provides a graphic layout of the different gravel pits around The City of Calgary Spyhill Pit located in Section 26.

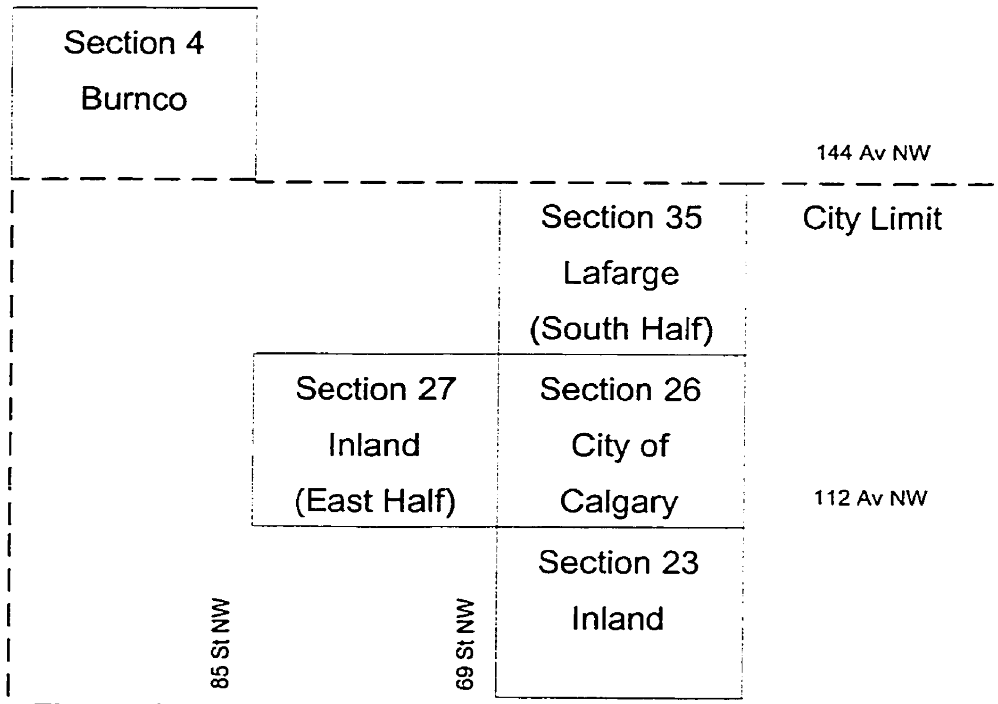


Figure 4

2.1 The City of Calgary Spyhill Pit

The aggregates found in the northwest section of Calgary can be from two sources in time. The first and most common are gravel deposits that originated as glacial outwash. The second is gravel of a preglacial origin, set in place by an erosion system such as a river. The City of Calgary gravel deposits does not contain any glacially transported rock or other debris. There is a 1.0 to 1.5 meter transition zone of glacial till that contains common clays that rests on top of the gravel structure. This transition zone is made up of a higher percentage of clay at the top and an increasing percentage of stone as one moves to the bottom. These stones are from the preglacial deposit that were moved by the over-riding glacial ice. It is from this preglacial deposit that The City of Calgary derives its source of the gravel in the Section 26 Spyhill pit (Moell, 1986, 11).

The gravel deposits are fluvial in origin and represent a coarse grained sediment placed by a major river system. The gravel deposit thickness is up to 32 meters in depth, which indicates that the river was established over a very long time. These deposits proved to be more resistant than the surrounding geologic material and by differential erosion the former river valley eventually became a topographical high spot.

There were three drainage channels that were carved into the level plateau by northeast flowing streams. These streams were considered to be preglacial and the present flow volumes do not account for the depth and width of the channel valleys. Because these were preglacial, the bases of these channels now contain varying thicknesses of residual gravels similar in composition and grain size as the main gravel deposit. These channels were then partially filled with glacial till.

The gravel content of the pit was considered to be 70 to 80 percent gravel which was poorly graded and composed of rounded or sub-rounded particles. The only component missing was the general absence of intermediate size sands. The general material characteristic indicated that the material would be satisfactory for the production of granular base and asphaltic and Portland cement concrete mixes when the initial pit investigation was completed. The petrographic analysis indicated that the predominant material of the coarse aggregates were fine and coarse grained quartzite and limestone. The predominant materials found in the fine aggregate portion (less than 0.5 mm) was also quartzite and limestone. The detail petrographic analysis can be found in Appendix A (Almor, 1987, Appendix E). This information has been summarized in Table 1 below.

Petrographic X-ray Diffraction Analysis	
Course Aggregates	
Quartzite	68%
Limestone	
Calcite	21%
Dolomite	6%
Plagioclase	4%
K Spar	1%
Illite	Nil to Trace
Fine Aggregates	
Quartzite	62%
Limestone	
Calcite	10%
Dolomite	10%
Plagioclase	6%
Illite	6%
K Spar	2%
Chlorite	1%
Smectite	1%
Trace Minerals	2%

Table 1

From the material in the granular resource study and geologic investigation work, the aggregate in The City of Calgary Spyhill pit is considered to be a very good candidate for a Superpave aggregate production source.

2.2 Lafarge Spyhill Pit

The Lafarge Construction Materials group also operates an aggregate pit in the north west quadrant of The City of Calgary (Section 35). Their pit is located in the same geological structure, across the valley from The City of Calgary pit. I met with their materials staff to discuss the implications of Superpave and the acceptability of their existing aggregates. They provided a petrographic analysis of a 20 mm aggregate that contained all of the crushed material (no portion had been screened out). The mineral make-up is similar to The City of Calgary aggregates. The detailed information can be found in Appendix B (Brzoza, 1998, page 3) and the petrographic analysis portion has been summarized in the Table below.

Petrographic Analysis of a Lafarge Spyhill Pit 20 mm Crush	
Course Aggregates	
Quartzite	71.1
Limestone	18.1
Sandstone	6.4
Chert	4.4
Fine Aggregates	
Quartzite	78.9
Limestone	17.5
Sandstone	1.9
Chert	1.6

Table 2

Lafarge was concerned that the Superpave requirement to have at least one fresh broken surface on one side or face of the aggregate, referred to as a fracture face, would come at a very high cost. These concerns will be further documented in the section on aggregate production.

2.3 <u>Inland Construction Ltd. Spyhill Pit</u>

Inland Construction Ltd. also operates a pit in section 23 of northwest Calgary. I was unable to meet with them, but did obtain job mix formulas from consulting firms which indicate that Inland Construction Ltd. produces an acceptable material for a Superpave mix design. What I was unable to assess was the impact that it would have on the aggregate production process.

CHAPTER 3
AGGREGATE PRODUCTION

3.1 The City of Calgary Spyhill Pit

The City of Calgary Materials group must crush material for a number of different applications for which a traditional asphalt or concrete supplier may not have to. Rather than crush the material and then screen it into three or four size categories, The City of Calgary sets up the production run to produce a specific product. All of the screens and crushing equipment are configured to meet the requirements of the end product as efficiently as possible, based on the characteristics of the source materials. The City produces the materials, shown below in Table 3, at the Spyhill operation and all of these can be used for the production of asphalt.

City of Calgary Spyhill Materials	
Material	Gradation Description
4.75 mm Manufactured Sand	fully graded material
9.5 mm Crush	fully graded material
9.5 mm Sanding Chip	less than 8% passing the 300 micron sieve
16 mm Clear Rock	less than 1% passing the 2.36 mm sieve
25 mm Clear Rock	less than 5% passing the 4.75 mm sieve

Table 3

One example of a product that is specially crushed is the 9.5 mm Sanding Chip. It is produced for the Roads Maintenance group to use on the road surface for traction during the winter months. This material requires high fracture faces and a cubic shape to provide traction during icy conditions. This same product must also be clean because a high proportion of fines will reduce the effectiveness of the product on the road (produce a slimy surface when mixed with melting snow) or produce a lot of dust when the road is returned to a dry state. As a result, the production of this material produces a considerable amount of fine material that must be screened out and is considered waste. This increases the overall cost of producing the material.

I met with The City of Calgary Aggregate Production group to discuss how they presently produce aggregates. The existing configuration is to use a jaw crusher as the primary crusher and reduce the material to a four (4) inches or 100 mm product. The material is then crushed to size by recirculating the material through a short head cone crusher. If a more cubical material is required, then the material is brought to the final size using a bar mag crusher. Typical production run output for The City of Calgary equipment is listed below (Sutherland, 1997, meeting).

City of Calgary Equipment and Production Rates		
Material Produced	Equipment Used	Production
32 - 9.5 mm & 9.5 mm crush	Jaw & Short Head Cone	190-210 tonnes/hr
16 - 9.5 mm & 9.5 mm crush	Jaw & Short Head Cone	140-160 tonnes/hr
9.5 - 0 mm sanding chip	Jaw & Short Head Cone & Bar Mag	80-110 tonnes/hr

Table 4

As the Table above shows, the production of a more cubical material, 9.5 mm sanding chip, cuts the production output close to one half. This reduction in output and the increase in wasted material results in an increased cost of production.

With the present Superpave flat and elongated particle ratio of 5 to 1, the material produced in The City of Calgary pit from the short head cone meets the requirements set out for the coarse aggregate. Any reduction to the ratio will rule out use of the short head cone crusher. The materials produced on the bar mag crusher will all pass the present ratio for flat and elongated, and reductions to this ratio would not significantly reduce the acceptability of this material.

The fine portion of the crushed material produced by the short head cone does not meet the angularity requirements for a surface mix on roadways with over one million equivalent single axle loads. This will mean that fine aggregates produced with the short head cone crusher must be washed to eliminate the dust portion. By contrast, the fine aggregates that are produced on the bar mag equipment passed all fine aggregate angularity requirements.

3.2 The Lafarge Spyhill Pit

The Lafarge Materials Group produce gravels for both their asphalt and concrete operations out of their Spyhill pit located just north of the City's pit. At a meeting with their production personnel, I was informed that they use a jaw and cone crushing combination. All of the source material smaller than 12 inches (300 mm) goes through a jaw crusher and at that point they have the ability to screen off any size of material. The remaining material is circulated through a cone crusher and screen deck combination. The screen deck separates the material into the four size categories that are listed in Table 5 below. The Lafarge Spyhill pit also has a source of natural sands present at their site. This material can be blended or washed and then blended with the manufactured materials.

Lafarge's Crushed Material Stockpile Sizing Limits
Size
32 - 15.5 mm
15.5 - 11 mm
11 - 0 mm
Manufactured Sand

Table 5

Lafarge reports that the material produced by their operation has a fracture face count of 60 to 65 percent single face crush. This is at or just below the minimum requirement for a road with less than 1 million ESALs, but well below the next level of 75 percent one face fracture that is required for a road above 1 million, but below 3 million ESALs.

To produce aggregate products for Superpave mix design the Lafarge group screens and rejects all material that is smaller than 50 mm. This results in rejection of approximately two thirds of the source aggregate. The resulting aggregate has a 99 percent crush count on a single face. This product is then blended at the plant with the standard asphalt aggregates to produce a blend with an 80+ percent single face crush count .

Lafarge has suggested that an alternate method of producing a Superpave grade aggregate would be to crush and then reject all the material less than 12.5 mm. The resulting material would meet the high fracture face count required, but would generate a significant waste pile of aggregate that is 12.5 mm and less in size. The production staff indicate that the present high amount of reject could be accommodated because of the limited number of Superpave jobs being completed. If all asphalt was specified as Superpave, there would be a significant jump in the costs of crushing aggregates.

The Lafarge Materials section could not see the City benefitting from the high crush count, and the Lafarge staff felt that the present City of Calgary specifications are possibly better than the Superpave specifications. The City specifications are a bit more open and give a bit more lee way in the gradation requirements.

CHAPTER 4
PHYSICAL CHARACTERISTICS OF THE AGGREGATES

4.1 City of Calgary Spyhill Pit

The physical characteristics of the aggregate are what Superpave groups as the source properties. These are those characteristics that can not be change by crushing and screening. The physical characteristic or source properties were obtained for The City of Calgary Spyhill pit. The following Table contains information which has been averaged from a number of samples that were taken during the site evaluation (see Appendix A for detail).

Physical Characteristics of City Spyhill Aggregate			
Test Description	**Material size**	**Results**	**Specifications**
LA Abrasion	Coarse	13.4% loss	CSA Limit 35%
	Fine	21.2% loss	
Magnesium Sulfate Soundness	Coarse	3.1% loss	CSA Limit 12%
	Fine	9.7% loss	CSA Limit 16%
Asphalt Coating & Stripping	-------	Good Coating	
Clay Content - Sand Equivalent	Fine	94.3%	

Table 6

All of the results exceed the required specifications.

4.2 Lafarge Spyhill Pit

The physical characteristics or source properties were also obtained for the Spyhill pit operated by Lafarge. The detail information can be found in Appendix B, but Table 7 below summarizes this data.

Physical Characteristics of Lafarge Spyhill Aggregate			
Test Description	**Material size**	**Results**	**Specifications**
LA Abrasion	-------	25.1%	CSA Limit 35%
Magnesium Sulfate Soundness	Coarse	4.3% loss	CSA Limit 12%
	Fine	7.2% loss	CSA Limit 16%
Organic Impurities in Sand	-------	Colour Plate #1	CSA Limit #3

Table 7

Again the source data from the Lafarge Spyhill pit exceeds the specifications.

CHAPTER 5
SUPERPAVE MIX DESIGN

A large part of the time spent on this thesis project was in the University of Calgary Materials laboratory designing a Superpave mix using existing City of Calgary aggregates. All of the aggregate components were available at The City of Calgary's asphalt plant except the washed sand. During the summer of 1999 The City of Calgary contracted Inland Construction Ltd. to wash a 4.75 mm manufactured sand because the City does not own a material washing facility. The washed sand used in this report came from the stockpile at the Inland Construction wash facility. This material was extremely wet at the time it was obtained (approximately 5% water by weight) and had to be oven dried before it could be used as part of the mix design.

To establish parameters for the laboratory mix design, a roadway had to be selected to establish the traffic loading requirements. The newest construction project that was in progress at the time was the construction of Stoney Trail between the TransCanada Highway (16 Avenue NW) and Crowchild Trail (see Figure 5 on the following page). An advantage to selecting this site was that the base course and some of the surface course were specified in the contract to be completed using a Superpave mix design.

The design parameters for the wearing or surface course were for a 12.5 mm nominal size mix on a major roadway. The expected traffic loading would be 500 equivalent single axle loads (ESALs) per day in the design lane. The road was to be designed for a 15-year life.

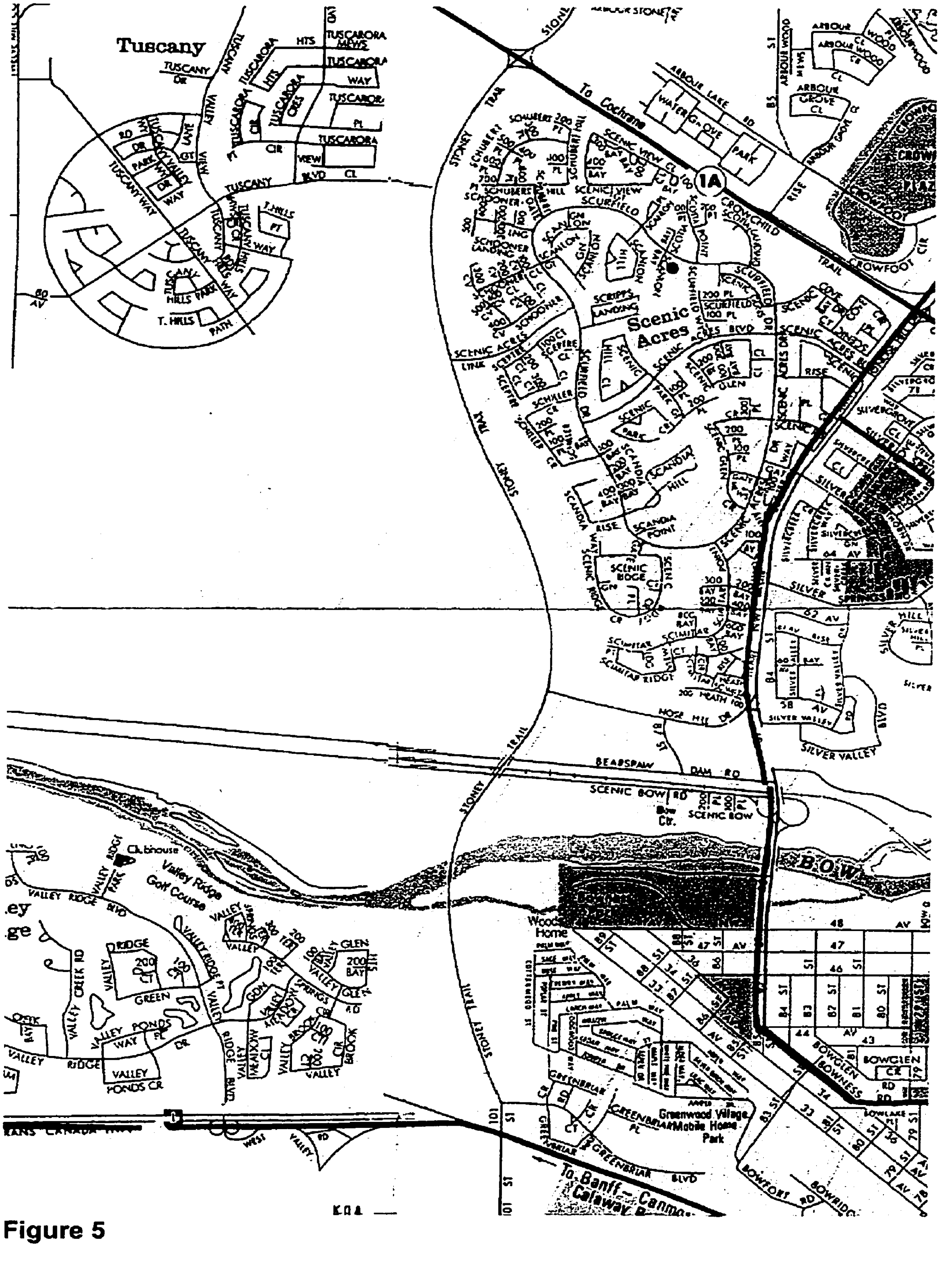

Tuscany
Scenic Acres
To Cochrane
1A
Crowchild Trail
Stoney Trail
Bearspaw Dam Rd
Scenic Bow Rd
Valley Ridge Golf Course
Clubhouse
Valley Ridge Blvd
Greenwood Village Mobile Home Park
Bowfort Rd
Bowness Rd
To Banff – Canmore

Figure 5

The remainder of this paper will walk the reader through the design procedure for a Superpave Level 1 mix design. The main steps in the design are:

1. selection of materials (binders, aggregates, modifiers),
2. selection of a design aggregate structure,
3. selection of a design asphalt binder content.

The final step in the design procedure is to evaluate the moisture sensitivity of the design mixture. It has been well documented for all of the materials produced from the Spyhill pit in Northwest Calgary that there is not a moisture sensitivity issue (see Table 6).

5.1 Material Selection

5.1.1 Binder Selection

Information from the Environment Canada weather station at the Calgary Airport was obtained to find the average 7 day maximum and the single day minimum air temperature in The City of Calgary. The following Table contains the specific temperature information and Appendix C contains the annual meterological summaries from which the data was extracted.

Local Superpave Air Temperature Data Points		
August 2 to 8, 1971	32.1°C	Average 7 day maximum air temperature
January 11, 1997	-39.7°C	Single coldest day air temperature

Table 8

Based on these starting air temperatures, the two Superpave pavement temperatures can be calculated. The first T_{20mm} is the highest pavement temperature 20 mm below the pavement surface and T_{min} is the lowest temperature at the pavement surface. The formulas and calculated values are listed below:

$T_{20mm} = (T_{air} - 0.00618\ lat^2 + 0.2289\ lat + 42.2) * (0.9545) - 17.78$

where, T_{20mm} is the pavement temperature at a depth of 20 mm in °C,

T_{air} is the maximum average high air temperature during the hottest seven-day period in °C , and

lat is the project latitude in degrees.

therefore: **T_{20mm} = 48 °C** when T_{air} = 32.1 °C and lat = 54°

$T_{min} = T_{air}$ **or** Canadian SHRP $T_{min} = 0.859T_{air} + 1.7$ °

where, T_{min} is the minimum pavement design temperature in °C,

T_{air} is the minimum air temperature in an average year in °C.

therefore: **T_{min} = -39.7 °C or**

Canadian SHRP T_{min} = -32.4 °C when T_{air} = -39.7 °C

For our evaluation, we will use the Canadian SHRP T_{min} value. Figure 6, located on the following page, contains a table of all of the Superpave binder grades (McGennis, 1995, p34). To select the proper PG graded asphalt, we must select an high temperature grade that is greater than our calculated T_{20mm} and a low temperature grade lower than our calculated T_{min}.

For intersections or other areas of low speed or stationary traffic, it is recommended that the high temperature grading be increased by one or two grades. Based on the calculated values and the above recommendations, the following Performance Graded binders, shown in Table 9, should be used in The City of Calgary.

Table III-1. Superpave Binder Grades

High Temperature Grade	Low Temperature Grade
PG 46-	34, 40, 46
PG 52-	10, 16, 22, 28, 34, 40, 46
PG 58-	16, 22, 28, 34, 40
PG 64-	10, 16, 22, 28, 34, 40
PG 70-	10, 16, 22, 28, 34, 40
PG 76-	10, 16, 22, 28, 34
PG 82-	10, 16, 22, 28, 34

Figure 6

Recommended City of Calgary PG Graded Asphalts	
Pavements	PG 52 - 34
Intersections	PG 64 - 34

Table 9

Unfortunately the asphalt supplier for The City of Calgary was not able to provide a PG52-34 in time for this mix analysis. Rather than not do the work, I was able to obtain a PG52-28 from the same supplier. Appendix D contains the PG grading of their existing penetration graded products and the viscosity/temperature graph for their A-Grade asphalt used in this study.

5.1.2 <u>Mineral Aggregate Selection</u>

Superpave aggregates are evaluated under two categories: consensus properties and source properties. The consensus properties are aggregate characteristics that are critical and must be achieved for the resulting asphalt mix to perform well. There was agreement across the industry on the importance of these properties and specified values or limits were established. The source properties are also important, but there was not the same agreement on specified values because these were often associated with the source of materials available in the region. The specific values for the source properties must be established by the local agencies. The Table below outlines the different aggregate properties examined under the two different categories.

Aggregate Material Properties	
Consensus Properties	**Source Properties**
coarse aggregate angularity fine aggregate angularity flat, elongated particles, and clay content.	toughness, soundness, and deleterious materials.

Table 10

The first of these two groups of aggregate properties that we will look at are the source properties. These properties have been well documented for aggregates from the Spyhill pit and show that the stone is both tough and sound and have, at most, only a trace amount of deleterious material. Information on the source properties can be found in Table 6 presented earlier in this paper. No additional testing of these attributes were undertaken as part of this evaluation.

The second group of material properties will require additional work on my part. Laboratory evaluation must be undertaken to ensure that the City aggregates meet the established guidelines. These consensus properties are associated with the Superpave design criteria and reflect the importance of a cubical or fractured aggregate surface. The coarse aggregate angularity is a physical count of the fractured faces on the individual aggregate pieces. Coarse aggregate is defined as material greater in size than 4.75 mm. The fine aggregate angularity is measured as a function of the air voids. A fixed volume is filled with the aggregate and weighted. The greater the angularity of the fine material the greater the air voids and the lower the weight of the sample. The flat and elongated test examines the length to width ratio of the aggregate. This test is to ensure that the fractured material is not made up of splintered aggregates. The final consensus property is the clay content. This is a measure of clay to other fine particles in the fine aggregate. This information has been well documented and measured for the City aggregates and the information presented in Table 6 exceeds the minimum Superpave requirement of 45% sand equivalent for any traffic loading level.

To establish the consensus properties values, the design life of the road in single equivalent axle loadings (ESALs) must be calculated. The section of Stoney Trail under consideration should be designed for the following:

Lifetime ESALs = 500 ESALs/day * 365 days/year * 15 years = 2.7 million ESALs

The following Table contains the Superpave aggregate consensus requirements for a roadway with a design life between one (1) million and three (3) million ESALs.

Superpave Consensus Properties for < 3 million ESALs 12.5 mm Surface Mix	
Coarse Aggregate Angularity	75% one fractured face/-- two fractured face
Fine Aggregate Angularity	minimum 40% air voids
Flat, Elongated Particles	maximum 10%
Clay Content	minimum 40% sand equivalent

Table 11

To allow greater flexibility when deciding on the mix gradation, I decided to evaluate the consensus properties of each of the source materials used in the 12.5 mm asphalt mix from the Spyhill pit. Each of the aggregates,16 mm clear, 9.5 mm crush, 9.5 mm sanding chip, and 4.75 mm manufactured sand, were evaluated and the results are shown in the Tables below.

Coarse Aggregate Angularity - minimum 75% one face/-- two face	
Material	Measured result
16 mm clear	100% one face / 89.8% two faces
9.5 mm crush	100% one face / 94.6% two faces
9.5 mm sanding chips	100% one face / 95.7% two faces

Table 12

These coarse aggregates meet the angularity requirement for a road which could carry up to 30 million ESALs over the design life.

Flat and Elongated Particle Evaluation - must be less than 10%	
Material	Measured result
16 mm clear	2.5%
9.5 mm crush	2.7%
9.5 mm sanding chips	0.0%

Table 13

These materials exceed all of the minimum requirements for flat and elongated particles. It is interesting to note that the cubical materials crushed with the bar mag (9.5 mm sanding chips) have zero percent flat and elongated.

Fine Aggregate Angularity Evaluation - must be greater that 40% air voids	
Material	Measured result
9.5 mm crush	43.1%
9.5 mm sanding chips	46.1%
4.75 mm manufactured sand	49.4%

Table 14

Again all of the aggregates met the minimum fine aggregate angularity requirements. Because all of the individual materials met each of the mineral aggregate property specifications, there will be no constraints on the combinations of materials that could be used to meet the gradation requirements.

The final aggregate properties required for the calculations in the Superpave mix design are the material specific gravities. These were determined for each of the materials and the results are shown in Table 15 below.

Spyhill Material Specific Gravities		
Aggregate	Bulk Specific Gravity	Apparent Specific Gravity
16 mm clear	2.603	2.686
9.5 mm crush	2.592	2.691
9.5 mm sanding chip	2.561	2.677
4.75 mm manufactured sand	2.591	2.695

Table 15

5.2 Aggregate Structure Design

5.2.1 Aggregate Blend Gradation

The gradation for a Superpave design is plotted on a 0.45 power gradation chart which also contains specific control points and a restricted zone. These control points function as a master range through which the gradation must pass. They are placed on the nominal maximum size, an intermediate size (2.36 mm) and the dust size (0.075mm). The restricted zone forms a band on the maximum density line under the intermediate size and represents an area on the chart that contains mixtures that exhibit a tender nature or have a tendency to rut (see Figure 1 presented earlier in the paper).

The Superpave aggregate blending process starts by selecting three different blends that meet the requirements of the control points and the restricted zone. These are mathematically designed from the available materials to produce fine, intermediate and coarse aggregate blends. Since each of the individual aggregates met all of the requirements for the consensus and source properties, the individual blended materials will not have to be evaluated. Table 16 lists the aggregates and the percentages used to make up each of the aggregate blends. These blends are then plotted on a 0.45 power gradation chart and shown in Figure 7. Note that the control points and restricted zones are denoted by black dots or lines.

Trial Blend Proportions			
Material	Fine blend	Intermediate Blend	Coarse Blend
16 mm clear	20%	35%	52%
9.5 mm crush	20%	30%	30%
9.5 mm sanding chip	45%	20%	0%
4.75 mm manufactured sand	15%	15%	18%

Table 16

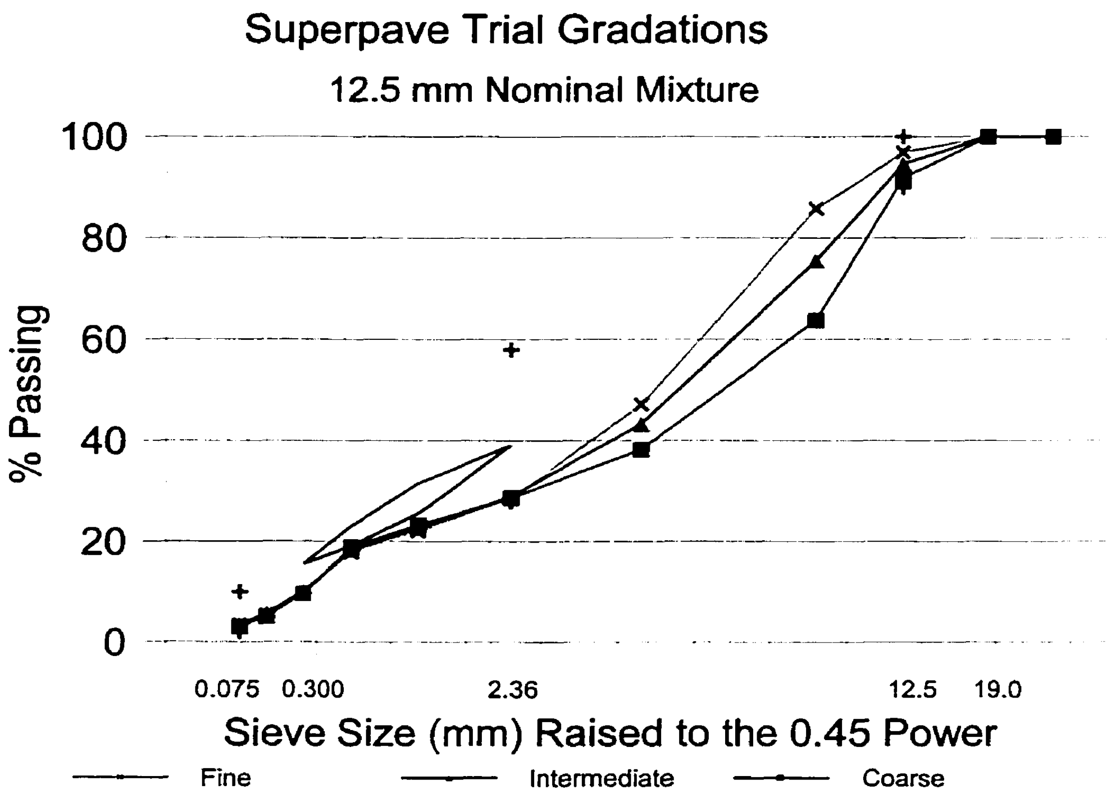


Figure 7

From the graph in Figure 7 it becomes apparent that there is a slight problem with the aggregates presently available from The City of Calgary Spyhill pit. There is a bump in all the blends at the 600 μm sieve. This bump was created because of the gradation characteristics of the 4.75 mm manufactured washed sand. This product had 62.8 percent passing the 600 μm sieve, but only 21.4 percent passing the 300 μm sieve. This meant that 41.4 percent of this product falls between these two sieves. It has been recommended that this product be adjusted to ensure that the resulting production asphalt mixes do not move up and into the bottom of the restricted zone.

The next step is to calculate the bulk (G_{sb}), apparent (G_{sa}), and effective (G_{se}), specific gravity for each of the blended materials. The bulk and apparent specific gravities are a percentage make-up of the specific gravity of each feed stock. The effective specific gravity is calculated from the blended bulk and blended apparent specific gravity using the following formula. Table 17 below contains the calculated values.

$$G_{se} = G_{sb} + 0.8 * (G_{sa} - G_{sb})$$

Specific Gravities for the Trail Blends			
Material	Bulk Specific Gravity G_{sb}	Apparent Specific Gravity G_{sa}	Effective Specific Gravity G_{se}
Fine Blend	2.58	2.68	2.66
Intermediate Blend	2.59	2.69	2.67
Coarse Blend	2.60	2.69	2.67

Table 17

5.2.2 <u>Initial Binder Calculation</u>

At this point it becomes necessary to calculate the initial trial asphalt binder (P_{bi}) content for all three trial blends. The following four equations are used to first calculate the volume of the asphalt binder absorbed (V_{ba}), the effective binder (V_{se}), the weight of aggregate (W_s) and finally the trial asphalt binder required:

$$V_{ba} = \frac{P_s * (1 - V_a)}{\left(\frac{P_b}{G_b} + \frac{P_s}{G_{se}}\right)} * \left(\frac{1}{G_{sb}} - \frac{1}{G_{se}}\right)$$ - volume of asphalt binder absorbed, cm^3/cm^3 of mix

where:

P_b - percent of binder (assumed 0.05),

P_s - percent of aggregate (assume 0.95),

G_b - specific gravity of the binder,

V_a - volume of the air voids (assumed 0.04 cm^3/cm^3 of mix).

$$V_{se} = 0.176 - 0.0675 * [\ln(S_n)]$$ - volume of the effective binder, cm^3/cm^3 of mix

where:

S_n - the nominal maximum sieve size of the aggregate blend in millimeters.

$$W_s = \frac{P_s * (1 - V_a)}{\left(\frac{P_b}{G_b} + \frac{P_s}{G_{se}}\right)}$$ - weight of the aggregate, grams.

where:

G_{se} - effective specific gravity of the blend.

$$P_{bi} = \frac{G_b * (V_{be} + V_{ba})}{(G_b * (V_{be} + V_{ba})) + W_s} * 100$$ - percent (by weight of mix) of binder

The following Table contains the results of all of these calculations for the three trial blend:

Binder Content for Trial Blend				
Material	Binder Absorbed V_{ba}	Effective Binder V_{be}	Weight of Aggregate W_s	Trial Binder P_{bi}
Fine Blend	0.0272 cm^3/cm^3	0.102 cm^3/cm^3	2.248 g	5.54%
Intermediate Blend	0.0254 cm^3/cm^3	0.102 cm^3/cm^3	2.251 g	5.46%
Coarse Blend	0.0237 cm^3/cm^3	0.102 cm^3/cm^3	2.254 g	5.38%

Table 18

5.2.3 <u>Gyratory Compaction of Blend Samples</u>

At this point the material specifications and the calculated values are molded into the first trial samples and compacted in the Superpave Gyratory Compactor (SGC). Two 4500 gram samples are made to compact in the SGC and one 2000 gram sample is constructed to measure the maximum theoretical specific gravity of the mix for each of the three blends. To set up the gyratory compactor, one must enter the number of gyrations to reach maximum compaction. This was originally based on the design average high air temperature and traffic levels . Figure 8 below contains a scanned image of the original gyratory compaction effort table (McGennis, 1995, p 70).

The table would suggest the values for the initial ($N_{initial}$), design (N_{design}) and maximum ($N_{maximum}$) number of gyrations for a 2.7 million ESAL roadway with an average design high air temperature less than 39 °C would be 7, 86 and 134 respectively. New research suggests that the average high air temperature does not impact the compactive effort required. New tables were introduced in the fall of 1998 by the Federal Highway Administration. The only copy that I was able to obtain at the time

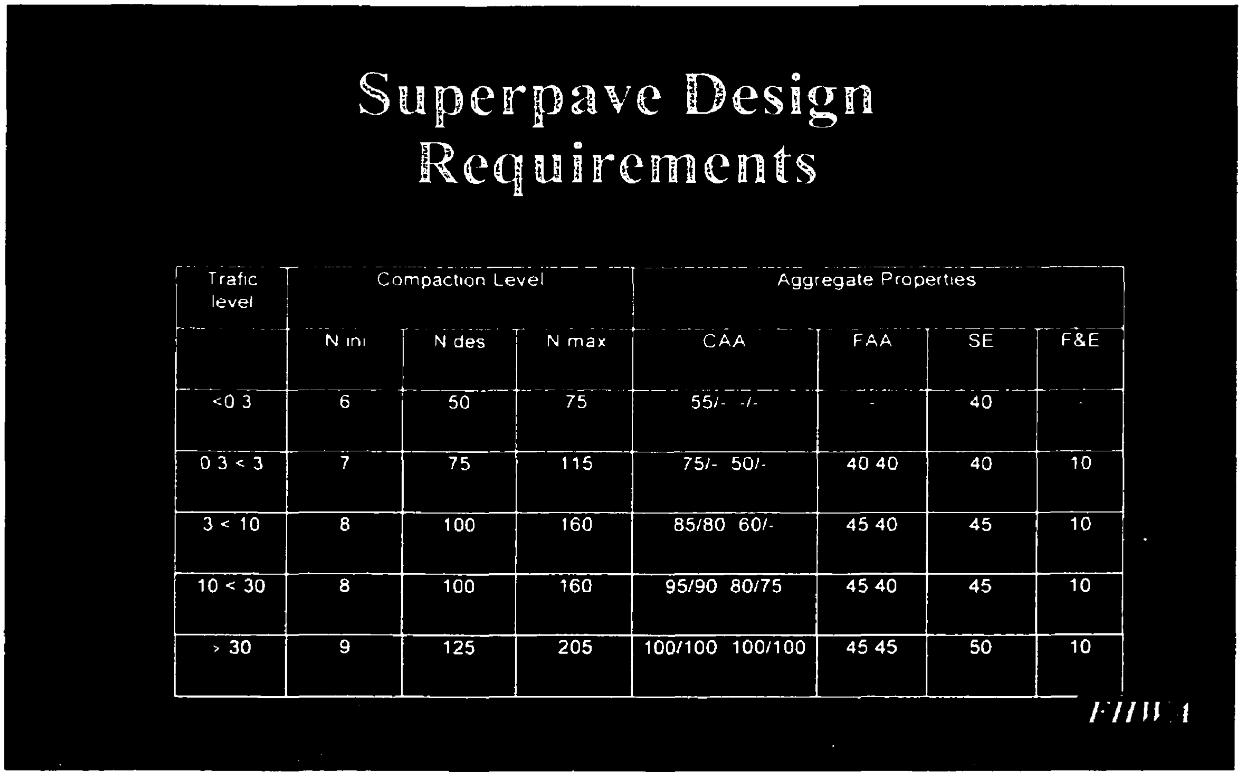
Table V-1. Superpave Gyratory Compaction Effort

Design ESALs (millions)	Average Design High Air Temperature											
	<39°C			39 - 40°C			41 - 42°C			43 - 44°C		
	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}	N_{ini}	N_{des}	N_{max}
< 0.3	7	68	104	7	74	114	7	78	121	7	82	127
0.3 - 1	7	76	117	7	83	129	7	88	138	8	93	146
1 - 3	7	86	134	8	95	150	8	100	158	8	105	167
3 - 10	8	96	152	8	106	169	8	113	181	9	119	192
10 - 30	8	109	174	9	121	195	9	128	208	9	135	220
30 - 100	9	126	204	9	139	228	9	146	240	10	153	253
> 100	9	142	233	10	158	262	10	165	275	10	172	288

Figure 9

was from a Power Point presentation. The slides, shown in Figures 9 and 10, give values for the compacted effort required for our 2.7 million ESAL roadway as $N_{initial}$ = 7, N_{design} = 75 and $N_{maximum}$ = 115. Since then the new tables have been formalized in the AASHTO Provisional Standards Interim Edition, page 35.

Figure 8



Superpave Design Requirements

Trafic level	Compaction Level			Aggregate Properties			
	N ini	N des	N max	CAA	FAA	SE	F&E
<0 3	6	50	75	55/- -/-	-	40	-
0 3 < 3	7	75	115	75/- 50/-	40 40	40	10
3 < 10	8	100	160	85/80 60/-	45 40	45	10
10 < 30	8	100	160	95/90 80/75	45 40	45	10
> 30	9	125	205	100/100 100/100	45 45	50	10

FHWA

Figure 10

The software package with the Troxler gyratory compactor collects all of the compaction data and provide analysis on the mix design. Unfortunately, with the changes to the number of gyrations for maximum density, the software interprets the reduced number as an error and cannot complete the necessary calculations. All of the raw data had to be downloaded off of the SGC and the mix calculation completed on a spreadsheet.

The data from the gyratory compaction of the three blend samples has been summarized in Tables 18, 19 and 20 on the following pages. These tables contain the maximum theoretical specific gravity G_{mm} for the mixture, the bulk specific gravity G_{mb} and compaction detail for each sample. The densification curves are plotted in Figures 11, 12 and 13, which are located below the associated table.

$G_{mm(meas)}$ = 2.43	Fine Trial Blend Densification Data									
	Specimen 1				Specimen 2				Avg
Gyration	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	$\%G_{mm}$
5	136.2	1.981	2.005	82.5%	136.3	1.978	2.002	82.4%	82.5%
7	134.3	2.009	2.034	83.7%	134.5	2.005	2.029	83.5%	83.6%
10	132.3	2.039	2.065	85.0%	132.5	2.035	2.059	84.7%	84.9%
15	130.1	2.074	2.099	86.4%	130.3	2.069	2.094	86.2%	86.3%
20	128.5	2.099	2.126	87.5%	128.8	2.093	2.118	87.2%	87.3%
30	126.4	2.134	2.161	88.9%	126.7	2.128	2.154	88.6%	88.8%
40	124.9	2.160	2.187	90.0%	125.2	2.154	2.179	89.7%	89.8%
50	123.8	2.179	2.206	90.8%	124.2	2.171	2.197	90.4%	90.6%
60	122.9	2.195	2.222	91.5%	123.3	2.187	2.213	91.1%	91.3%
70	122.1	2.209	2.237	92.1%	122.5	2.201	2.227	91.7%	91.9%
75	121.8	2.215	2.243	92.3%	122.2	2.206	2.233	91.9%	92.1%
80	121.5	2.220	2.248	92.5%	121.9	2.212	2.238	92.1%	92.3%
100	120.5	2.239	2.267	93.3%	120.8	2.232	2.259	93.0%	93.1%
115	119.8	2.252	2.280	93.8%	120.2	2.243	2.270	93.4%	93.6%
$G_{mb(meas)}$ = 2.28					$G_{mb(meas)}$ = 2.27				

Table 19

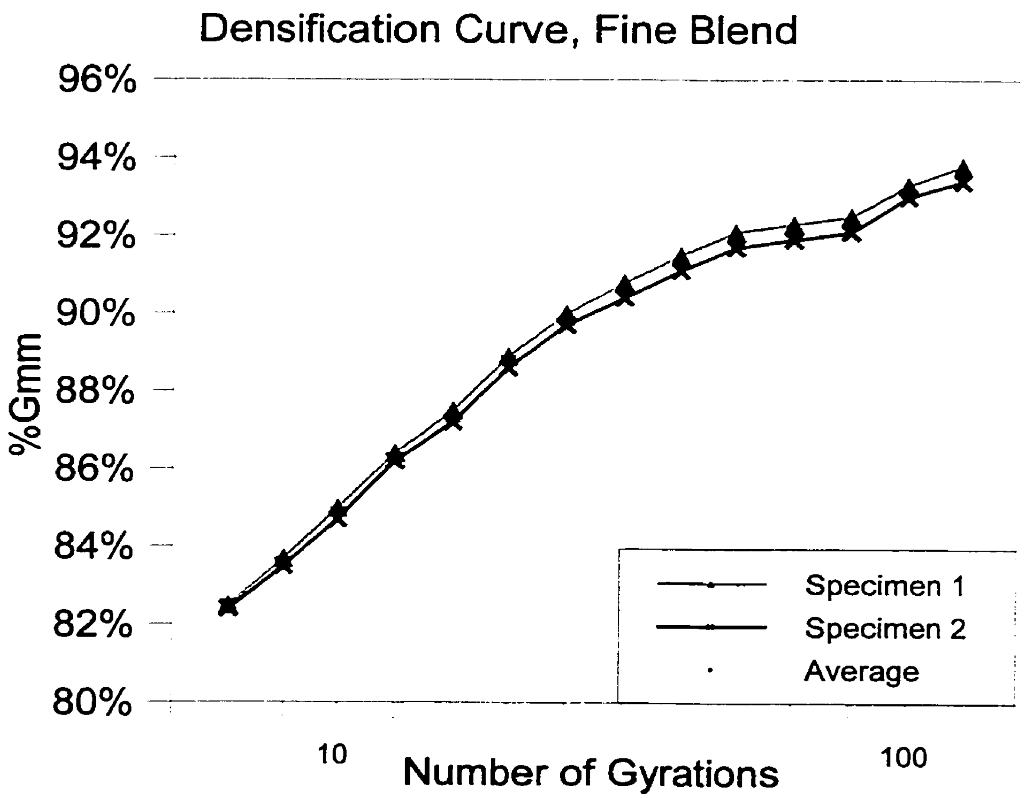


Figure 11

$G_{mm(meas)}$ = 2.431	Intermediate Trial Blend Densification Data								
	Specimen 1				Specimen 2				Avg
Gyration	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	$\%G_{mm}$
5	132.4	2.034	2.085	85.7%	129.5	2.081	2.111	86.8%	86.3%
7	130.6	2.063	2.113	86.9%	127.8	2.108	2.139	88.0%	87.5%
10	128.7	2.093	2.145	88.2%	126	2.138	2.169	89.2%	88.7%
15	126.6	2.128	2.180	89.7%	124	2.173	2.204	90.7%	90.2%
20	125.1	2.153	2.206	90.8%	122.6	2.198	2.229	91.7%	91.2%
30	123	2.190	2.244	92.3%	120.6	2.234	2.266	93.2%	92.8%
40	121.6	2.215	2.270	93.4%	119.2	2.260	2.293	94.3%	93.8%
50	120.5	2.235	2.290	94.2%	118.1	2.281	2.314	95.2%	94.7%
60	119.7	2.250	2.306	94.8%	117.3	2.297	2.330	95.8%	95.3%
70	119	2.264	2.319	95.4%	116.6	2.311	2.344	96.4%	95.9%
75	118.7	2.269	2.325	95.6%	116.3	2.317	2.350	96.7%	96.2%
80	118.4	2.275	2.331	95.9%	116	2.323	2.356	96.9%	96.4%
100	117.4	2.294	2.351	96.7%	115.1	2.341	2.375	97.7%	97.2%
115	116.8	2.306	2.363	97.2%	114.6	2.351	2.385	98.1%	97.7%
$G_{mb(meas)}$ = 2.363					$G_{mb(meas)}$ = 2.385				

Table 20

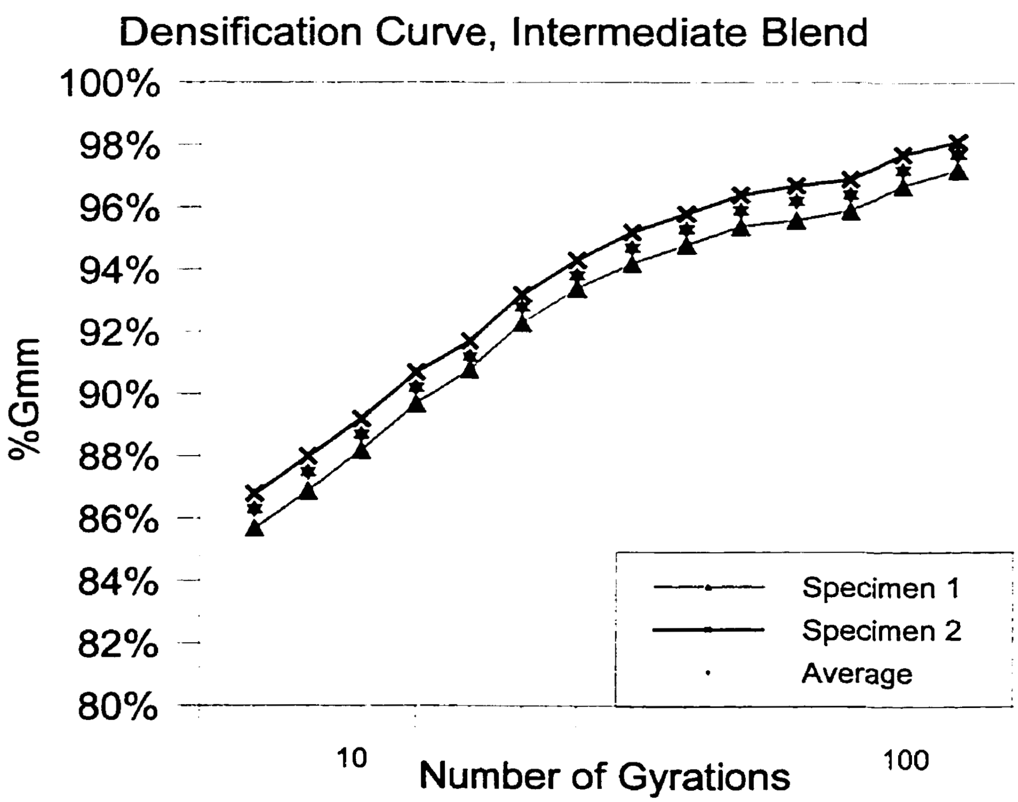


Figure 12

$G_{mm(meas)}$ = 2.429	Coarse Trial Blend Densification Data								
	Specimen 1				Specimen 2				Avg
Gyration	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	$\%G_{mm}$
5	126.6	2.126	2.158	88.8%	129.3	2.081	2.128	87.6%	88.2%
7	124.9	2.155	2.187	90.1%	127.6	2.109	2.156	88.8%	89.4%
10	123.1	2.187	2.219	91.4%	125.8	2.139	2.187	90.0%	90.7%
15	121.1	2.223	2.256	92.9%	123.8	2.174	2.222	91.5%	92.2%
20	119.7	2.249	2.282	94.0%	122.3	2.201	2.250	92.6%	93.3%
30	117.9	2.283	2.317	95.4%	120.4	2.235	2.285	94.1%	94.7%
40	116.7	2.307	2.341	96.4%	119.1	2.260	2.310	95.1%	95.7%
50	115.8	2.325	2.359	97.1%	118	2.281	2.332	96.0%	96.6%
60	115.1	2.339	2.374	97.7%	117.2	2.296	2.348	96.7%	97.2%
70	114.5	2.351	2.386	98.2%	116.6	2.308	2.360	97.1%	97.7%
75	114.3	2.355	2.390	98.4%	116.3	2.314	2.366	97.4%	97.9%
80	114	2.361	2.397	98.7%	116	2.320	2.372	97.7%	98.2%
100	113.2	2.378	2.413	99.4%	115	2.340	2.393	98.5%	98.9%
115	112.8	2.386	2.422	99.7%	114.5	2.351	2.403	98.9%	99.3%
$G_{mb(meas)}$ = 2.422					$G_{mb(meas)}$ = 2.403				

Table 21

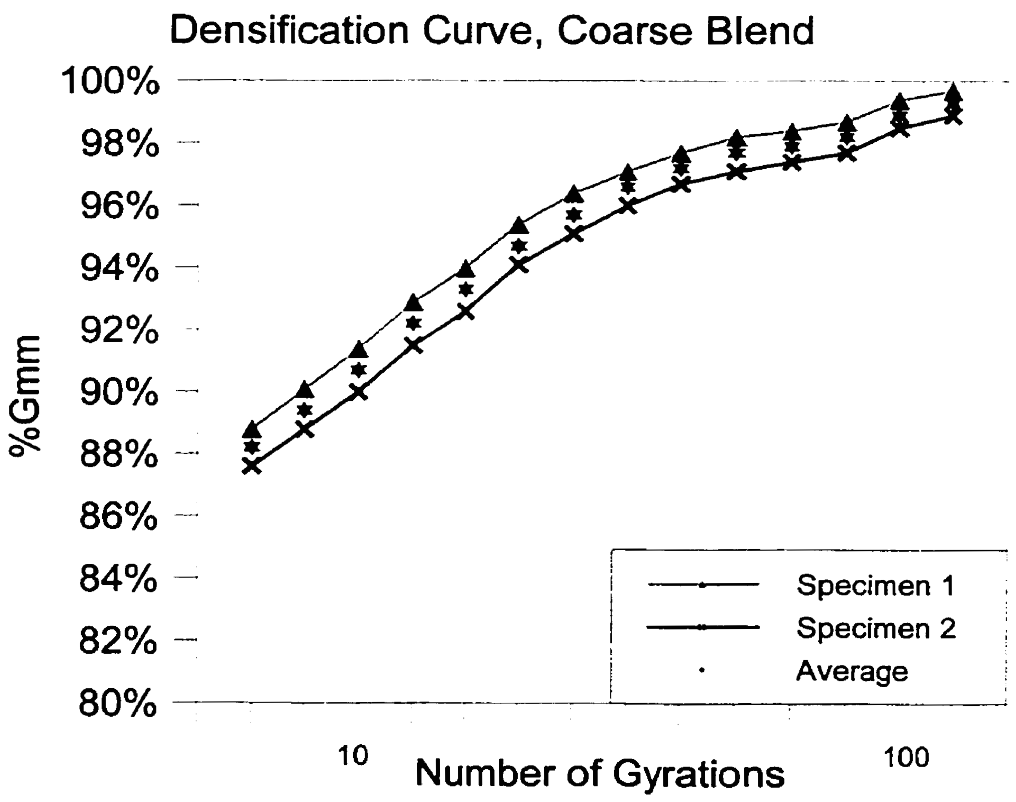


Figure 13

The air voids in the blended samples were designed to be 4.0%. Now that the samples have been created, the actual volume of air voids and the voids in the mineral aggregate (VMA) are determined at N_{design} or N = 75. These values are calculated using the following formulas:

$$\% \text{ Air voids} = 100 - \%G_{mm} @ N_{design} \quad \text{and}$$

$$\%VMA = 100 - \left(\frac{\%G_{mm} @ N_{design} * G_{mm} * P_s}{G_{sb}}\right)$$

where:

P_s - percent of aggregate ($1 - P_{bi}$).

The key information collected from the compacted trial blend samples has been extracted from the previous three tables and is summarized with the calculated values in Table 22 below.

Trial Blend Measured Data Summary

Material	% AC	$\%G_{mm}$@ N=7	$\%G_{mm}$@ N=75	$\%G_{mm}$@ N=115	% Air Voids	%VMA
Fine Blend	5.54%	83.6%	92.1%	93.6%	7.91%	18.1%
Intermediate Blend	5.46%	87.5%	96.2%	97.7%	3.84%	14.6%
Coarse Blend	5.38%	89.4%	97.9%	99.3%	2.10%	13.4%

Table 22

We cannot compare the individual blends at this point because it was assumed that the right amount of oil was added to each blend to give 4.0 percent air voids. From the table above, the 7.9 percent air void in the fine blend indicates that this is not the case. Using the information generated from the trial blends, the binder content, VMA, VFA, $\%G_{mm}$ at N_{ini} and N_{max} can be estimated. The equations used for these estimates are listed below.

$$P_{b,\ estimated} = P_{bi} - (0.4 * (4 - V_a))$$

$$\%\ VMA_{estimated} = \%VMA_{initial} + C * (4 - V_a)$$

$$\%VFA_{estimated} = 100\% * \frac{(\ \%\ VMA_{estimated} - 4.0\ )}{\%\ VMA_{estimated}}$$

where: P_{bi} is the initial (trial) percent binder,

V_a is the percent air voids at N_{design}.

C is a constant (0.1 if $V_a < 4.0\%$ or 0.2 if $V_a > 4.0\%$)

$$\%G_{mm\ estimated} @ N_{ini} = \%G_{mm\ trial} @ N_{ini} - (4.0 - V_a)$$

$$\%G_{mm\ estimated} @ N_{max} = \%G_{mm\ trial} @ N_{max} - (4.0 - V_a)$$

The values calculated with the equations from above are listed in Table 23 below.

Trial Blend Estimated Summary @ 4.0% Air Voids

Material	Trial % AC	Est. %AC	% Air Voids	% VMA	% VFA	$\%G_{mm}$@ N=7	$\%G_{mm}$@ N=115
Fine Blend	5.54%	7.10%	4.0%	17.3%	76.9%	87.5%	97.5%
Intermediate Blend	5.46%	5.40%	4.0%	14.6%	72.6%	87.3%	97.5%
Coarse Blend	5.38%	4.62%	4.0%	13.6%	70.6%	87.5%	97.4%

Table 23

The only component missing before the blends can be compared is the dust proportion calculation. First the effective asphalt binder must be calculated, and then the dust proportion, using the following formulas:

$$P_{be,\ estimate} = - (P_s * G_b) * \frac{(G_{se} - G_{sb})}{G_{se} * G_{sb}} + P_{b,\ estimated}$$

$$DP = \frac{P_{.075}}{P_{be,\ estimate}}$$

The calculated values are shown in Table 24 below.

Dust Proportion Data		
Material	Estimated Effective Binder $P_{be,\ estimate}$	Dust Proportion DP
Fine Blend	6.0%	0.58
Intermediate Blend	4.3%	0.81
Coarse Blend	3.6%	0.83

Table 24

We now have all of the information that is required to evaluate the three trial blends. The key volumetric and densification criteria for the Stony Trail Superpave mix are:

% Air Voids	4.0%
% VMA	14.0% minimum
%VFA	65 - 78%
$\%G_{mm}$ @ N_7	less than 89%
$\%G_{mm}$ @ N_{115}	less than 98%
Dust Proportion	0.6 - 1.2

These mix design criteria eliminated the fine blend because the dust proportion, DP of 0.58, is below the accepted range of 0.6 - 1.2 (see Table 24). The coarse blend is also eliminated because the percent voids in the mineral aggregate, %VMA of 13.6%, is below the minimum value of 14.0% (see value in Table 23). Therefore the design aggregate structure that will be used for the mix will be the intermediate blend. I will refer to this as the aggregate or aggregate blend for the remainder of this document.

5.3 Selection of the Asphalt Binder Content

The final step in the level one design process is to select the proper asphalt binder content. This is undertaken in a fashion very similar to the compaction of the blend samples, but instead of trying to keep the air voids the same and varying the aggregate, we will use the aggregate blend we have selected and vary the oil above and below the estimated asphalt binder content. This value, from table 23, was calculated to be 5.4 percent binder per weight of the mix. The process requires samples to be made at binder content 0.5 percent above and below the estimated value and 1.0 percent above. The first samples were prepared with an asphalt binder content of 5.9 percent which is 0.5 percent above the estimated binder content. The richness of this mix combined with earlier observations indicated that a mix at 1.0 percent above the estimated value would be very rich. For this reason, the samples for 1.0 percent above the estimated binder content were not prepared.

Two 4500 gram samples were prepared for each of the asphalt contents of 4.9%, 5.4% and 5.9% and compacted in the gyratory compactor. One 2000 gram sample was also made for each of the different asphalt content and the maximum theoretical specific gravity measured. Figure 14 and 15 below show pictures of the top of 4500 gram gyratory compacted samples. Figure 16 is a side view of both of the compacted samples and Figure 17 is the loose 2000 gram sample that is used to calculate G_{mm}.

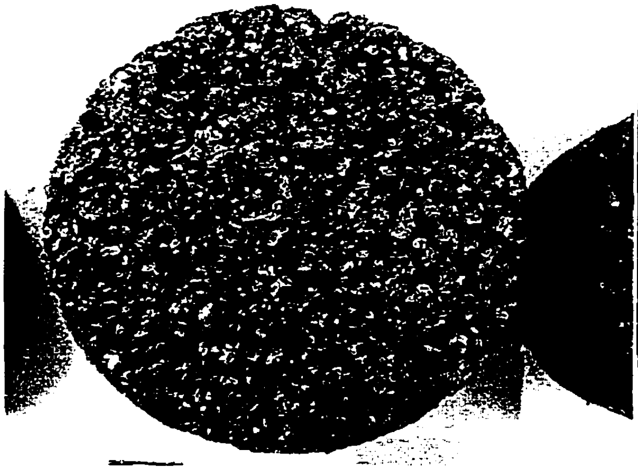


Figure 14 Intermediate Blend - 5.46%
Top of Compacted Sample A

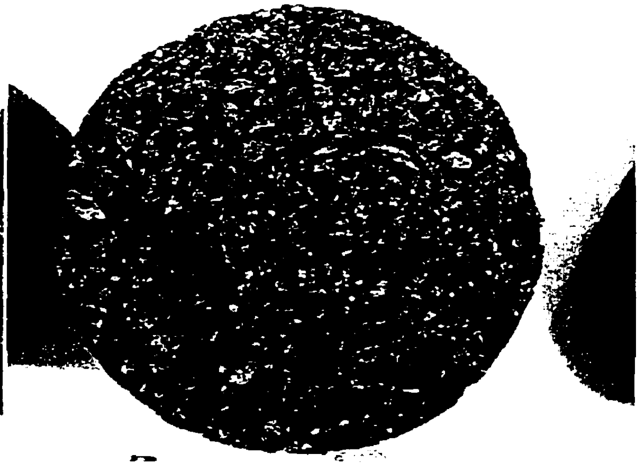


Figure 15 Intermediate Blend - 5.46%
Top of Compacted Sample B

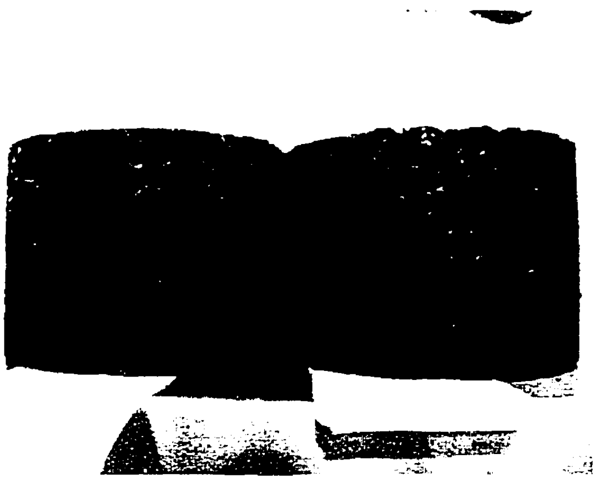


Figure 16 Intermediate Blend - 5.46%
Sides of Compacted Samples

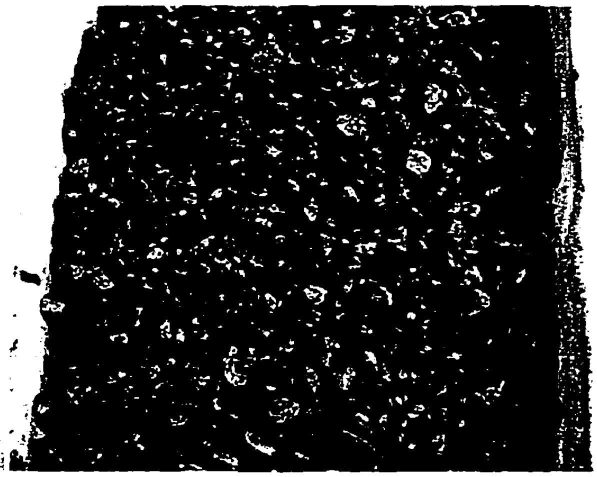


Figure 17 Intermediate Blend - 5.46%
Loose sample for G_{mm}

Densification data and graphs were developed for each of the samples. This information is similar to the data presented in Tables 29, 30 and 31 and Figures 22, 23 and 24. The information was not included in the main text, but can be found in Appendix E. The information from this data has been summarized, and is shown in Table 25.

Binder Blend Volumetric Properties at N_{design}				
% AC	%Air Voids	%VMA	%VFA	Density (kg/m^3)
4.90%	6.3%	15.7%	59.7%	2295
5.40%	2.6%	13.2%	80.0%	2375
5.46%	3.8%	14.6%	73.8%	2338
5.90%	1.6%	13.8%	88.7%	2372

Table 25

I have also included information from the aggregate selection process when the selected oil content was 5.46%. I did not like the original results generated by the 5.40% sample and repeated the evaluation, but I obtained similar results. The information in the table above was plotted on the following three graphs. The red points or dots in the graphs are the actual data points, and the red lines are the best fit lines or curves. Any blue lines are design limits that have been included to assist in the asphalt content selection. It is from these graphs that the actual design asphalt content will be selected.

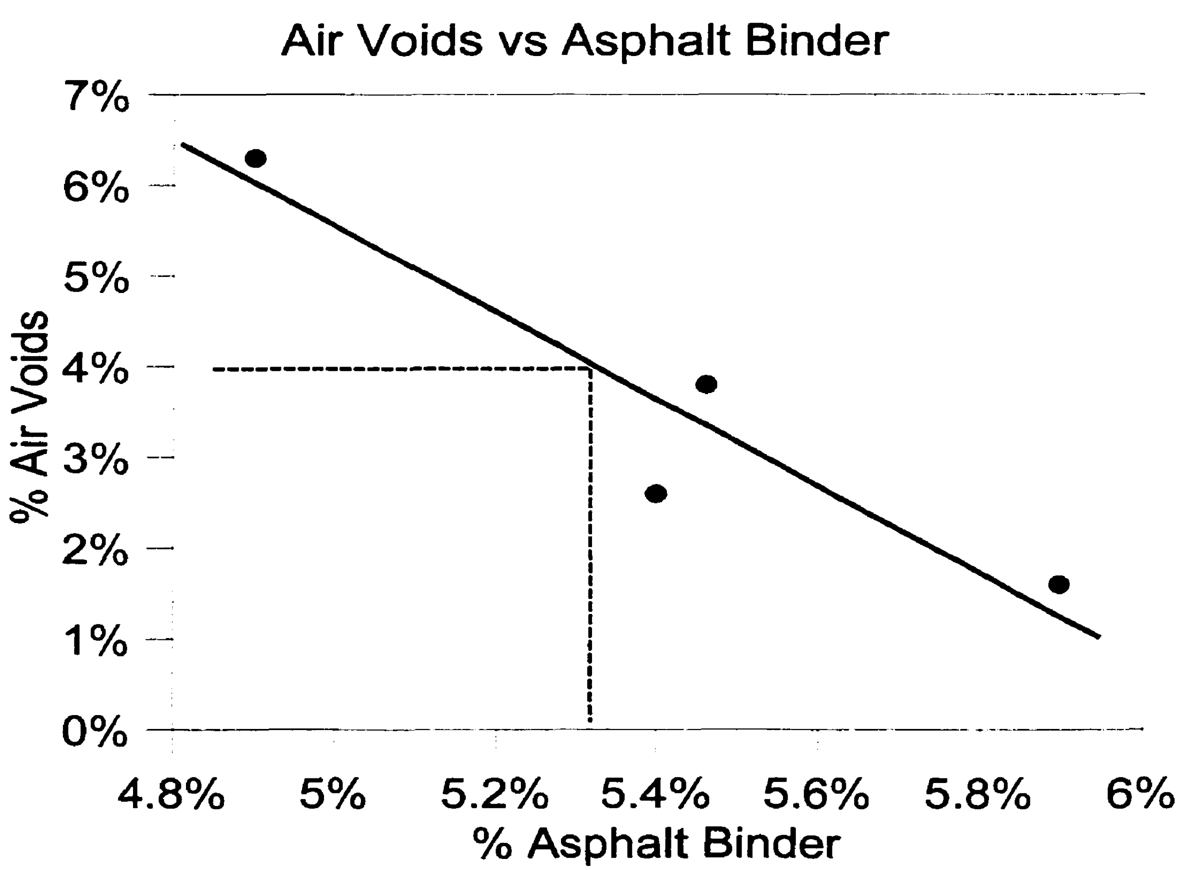


Figure 18

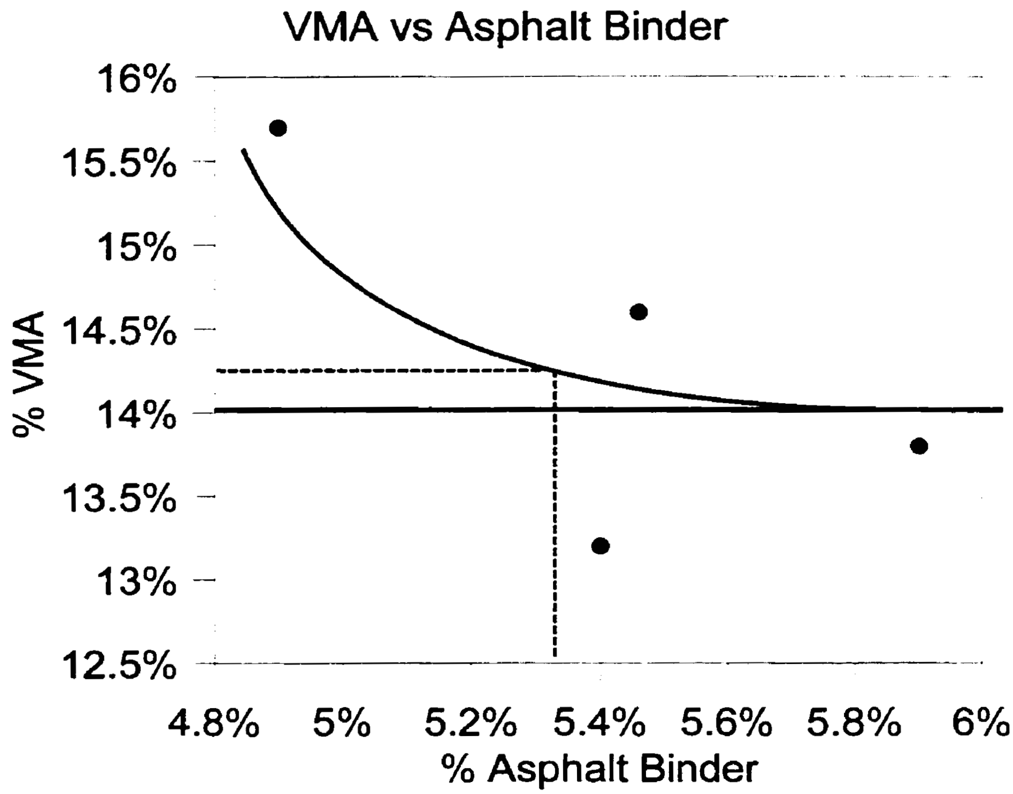


Figure 19

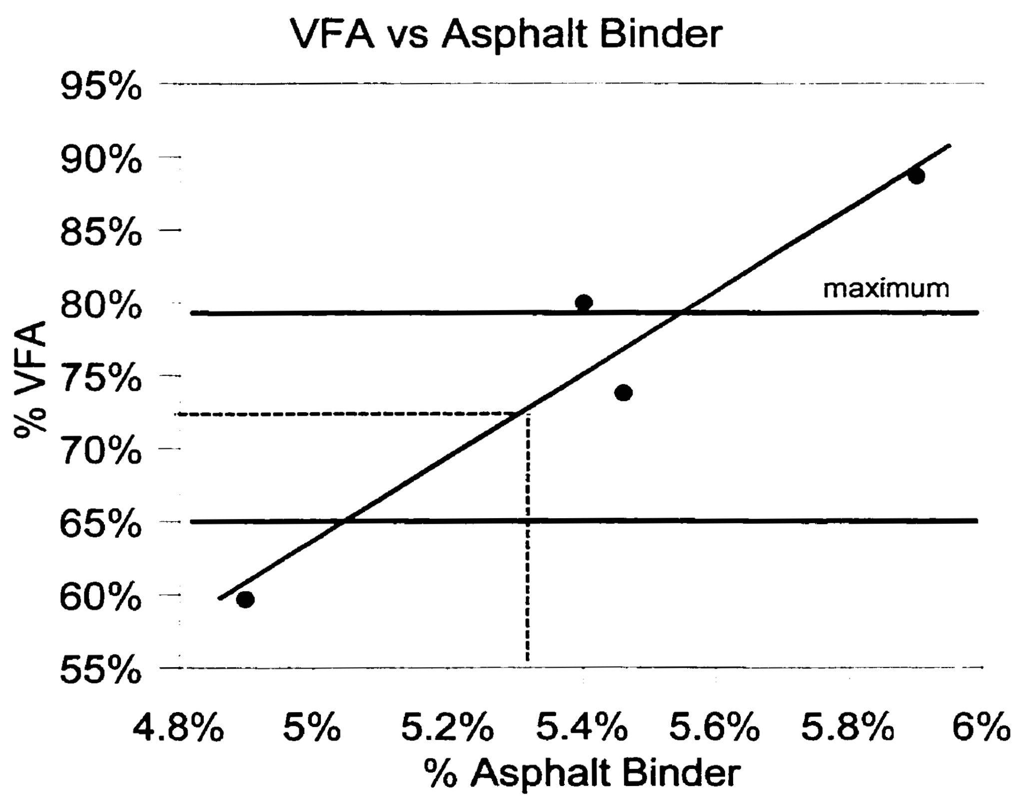


Figure 20

The binder content for the mix is determined by drawing a line horizontally from the 4.0% Air Voids mark on the y axis of the Air Voids VS Asphalt Binder graph (Figure 18) until the line meets the plotted line. A vertical line is then dropped to the x axis and the value on this axis is the design asphalt binder content. From Figure 18 this vertical line falls approximately at 5.3% asphalt binder content. This value is then plotted on the VMA and VFA graphs (Figures 19 and 20) to insure the VMA and VFA requirements are met. From Figure 19, the VMA value is slightly over the 14 percent minimum and from Figure 20 the VFA value is right in the middle of the acceptable range. Therefore the design asphalt binder content that provides 4.0% air voids in the selected 12.5 mm aggregate blend at N_{design} = 75 is 5.3% asphalt binder by weight of the mix.

The full mix design specifications are summarized below.

City of Calgary 12.5 mm Superpave Asphalt Mix Design	
Properties	Design Values
Aggregate Blend	
16 mm clear	35%
9.5 mm crush	30%
9.5 mm sanding chip	20%
4.75 mm manufactured sand	15%
Bulk Specific Gravity	2.589
Apparent Specific Gravity	2.687
Effective Specific Gravity	2.667
N initial	7
N design	75
N maximum	115
Binder content	5.3%
VMA	14.3%
VFA	72.5%
Dust Proportion	0.83

Table 26

5.4 Comparison to Other Mix Designs

The selection of Stoney Trail was extremely valuable because I was able to obtain a 12.5 mm Superpave mix design for an actual mix that was placed on Stoney Trail. The full mix, which was released to The City of Calgary, can be found in Appendix F. The table below summarized the key design values.

Stoney Trail 12.5 mm Superpave Asphalt Mix Design Comparison		
Properties	City Design Values	EBA Design Values
Binder content	5.3%	5.6%
VMA	14.3%	15.1%
VFA	72.5%	73.0%
Dust Proportion	0.83	1.0

Table 27

At first glance the values are very close, with only a few subtle differences. The binder content, VMA and dust proportion are all a little higher. A more detailed look at the aggregates reveal that The City of Calgary Spyhill coarse aggregates are slightly better than, but the fine aggregates are slightly inferior to, the Inland Construction products. The answer to the differences in the mix design is found in the dust proportion end of the gradation chart. The Inland aggregates contain approximately 5 percent $P_{0.075}$ materials and The City of Calgary only contain 3.5 percent. This factor has a direct correlation to the higher dust proportion number, and this could also account for the higher binder requirements. The difference in the VMA may be attributed to the bump that exists in The City of Calgary blend at the 600 μm sieve. The Inland material has a very even material gradation distribution.

The final comparison that I would like to make is between the gradation of the 12.5 mm Superpave mix just designed and the existing City of Calgary 'B' mix gradation limits. The 'B' mix is a size classification similar to the 12.5 mm mix. These limits were taken from the 1997 Plants Material Dossier and are shown in Table 28.

City of Calgary 'B' Mix Gradation Limits		
Sieve Size	Lower Limit	Upper Limit
16 mm	100	100
12.5mm	98	92
10 mm	91	85
4.75 mm	68	62
2.36 mm	51	45
1.18 mm	41	35
600 μm	31	25
300 μm	20	14
150 μm	13	7
75 μm	8	6

Table 28

The gradation of both the 12.5 mm Superpave and City 'B' are shown in Figure 21 below.

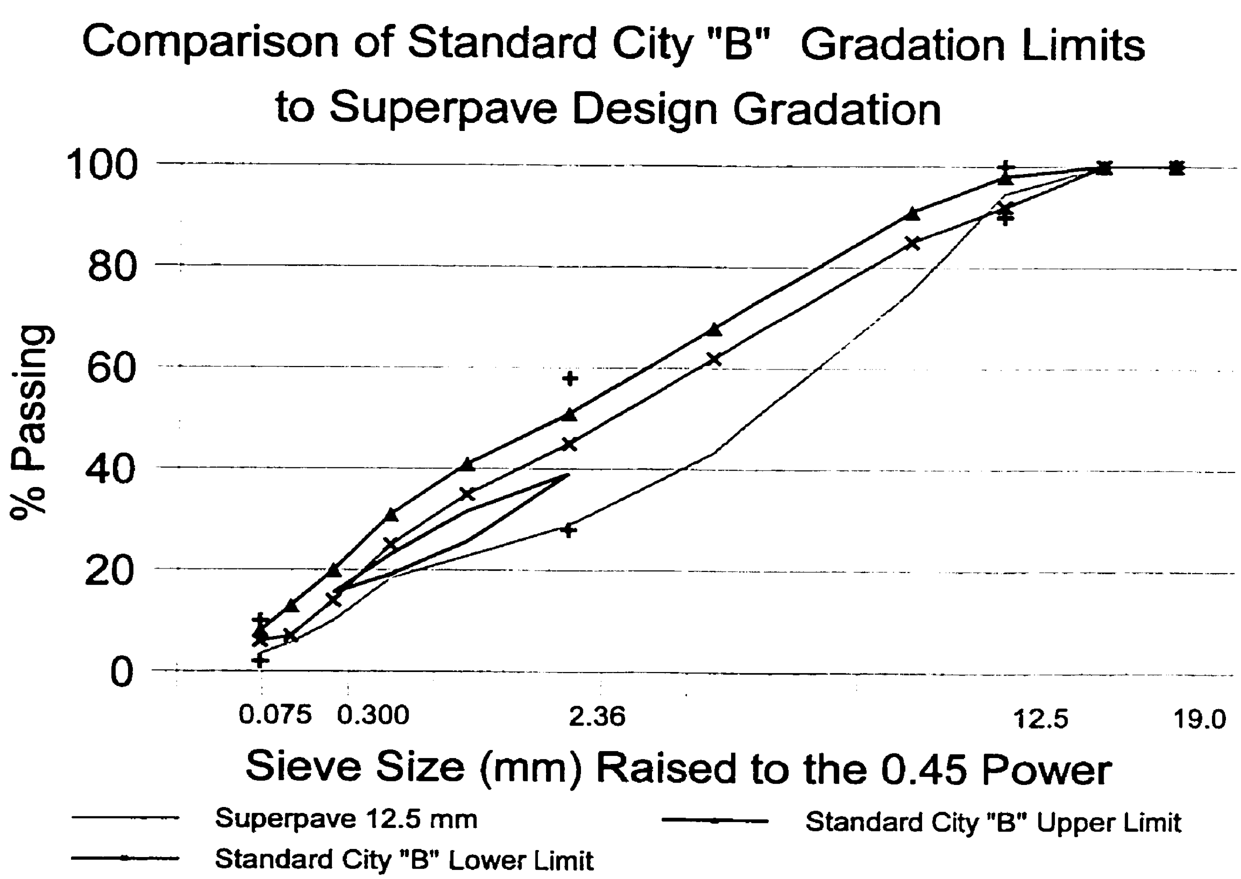


Figure 21

The existing City of Calgary 'B' mix satisfies the control points on the 0.45 power gradation chart, but comes very close to the lower end of the restricted zone. The biggest difference is that it passes over the top of the restricted zone, where it has been recommended that for good aggregate contact the mixes go under this zone. Gradations below the restricted zone provide a course aggregate structure that supplies better rock on rock contact within the mix.

CHAPTER 6
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The purpose of this project was to evaluate whether Superpave aggregates were readily available and, if they were, to complete a Superpave mix design. The paper also was to examine the impact that moving to a Superpave specification would have on the aggregate producers in Calgary.

I was very pleased to find that all of the coarse aggregates being produced at The City of Calgary Spyhill pit meet the requirements for a 3 million ESAL roadway like Stoney Trail. In fact, the course aggregate angularity met the requirements for a 30 million ESAL roadway, and the flat and elongated particles met the requirements for any volume roadway. The fine aggregates from the Spyhill pit met the requirements for a Stony Trail roadway, but will require adjustment to meet the requirements of a roadway carrying over 3 million ESALs.

The other pits located in the vicinity of the City Spyhill pit did not produce coarse aggregates that met the coarse aggregate angularity. Special crushed products had to be manufactured which resulted in up to 60 percent waste materials. These special products were then blended with the standard aggregates to meet the Superpave requirements. This additional crushing and waste added to the cost for contractors to produce Superpave asphalt mixes. Some of the contractors with whom I spoke with would prefer that The City of Calgary not adopt the full Superpave aggregate requirements and allow exceptions in course and fine angularity.

A Superpave 12.5 mm asphalt mix was designed as a surface course for Stoney Trail using City of Calgary Spyhill pit materials. The mix design was compared to a consultants mix design completed for a contractor for this same section of road. The differences between the two mix designs are documented in Table 27. Unfortunately The City of Calgary plant was unable to produce any of this material for use in the 1999 paving season. I was disappointed because I would have liked to have included documentation on production of the actual mix. This will have to wait until the year 2000 paving season.

6.2 Conclusions and Recommendations

The City of Calgary has an abundance of good gravel and, for this reason, the Superpave aggregate specification should not be altered or relaxed. The industry has already seen some of the results from the Long Term Pavement Performance (LTPP) studies that is being completed in all of the climatic zones across North America.
I recommend that The City of Calgary implement the full Superpave specifications on any Superpave project.

Superpave is a very big change in a very big industry, and this will not occur quickly. The City of Calgary must document, in detail, all work undertaken to ensure that the full impact of the changes can be measured. Superpave advocates lower life cycle costs, but when the life cycle is 15 years, the person implementing the change may never see the resulting savings.

The only Superpave mix weakness in The City of Calgary Aggregate Operation is the fine aggregate portion. This was evident by the bump in the gradation curve between the 600 micron and 300 micron sieves. The aggregate operation must see if changes can be made in the crushing or washing operation to eliminate this problem.

All of the aggregate producers must re-evaluate how aggregates are being produced. To special crush material to blend back into feed stocks to meet Superpave requirements is a bandage solution. Producers must look at equipment, equipment configuration or the source materials to economically produce high volumes of Superpave compliant aggregates.

The final point of interest is that The City of Calgary produces Superpave quality aggregates (for a 3 million ESAL roadway), but has not produced any Superpave asphalt. The contractors have had to upgrade aggregates to meet the requirements, and they have been placing Superpave mixes in Calgary since 1995. All of the Superpave projects thus far have been let out to contract. My final recommendation is that The City of Calgary plant be allowed to bid on the supply of asphalt for future Superpave projects.

As one of the caretakers of this publicly-owned infrastructure, I would like to see our industry continue to improve to ensure that we can afford the highways we have come to depend on.

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APPENDIX A

The City of Calgary Spyhill Granular Quality Test Data

and Petrographic Analysis

(Scanned copy of Original)

LABORATORY QUALITY TESTING
DATA SUMMARY

Test Description	---------- % Loss ----------					% Allowable Loss
1) LA Abrasion	TH #3	TH #8	TH #11	TH #14	TP #6	13.4%
Coarse Aggregate						
(1 1/2" & 1") grading	9.3	16.8	8.0	13.7	19.4	50
Fine Aggregate						
(1/2" & 3/8") grading	19.9	23.1	18.1	21.1	24.0	50
2) Magnesium Sulfate Soundness	TH #3	TH #8	TH #11	TH #14	TP #6	
Coarse Aggregate	2.1	2.7	2.8	4.5	3.4	18
Fine Aggregate	8.3	5.8	7.5	13.6	13.1	15

3) Specific Gravity & Absorption of Coarse Aggregate	TH #3	TH #8	TH #11	TH #14	TP #6
Bulk specific gravity (SSD Basis)	2.63	2.62	2.63	2.64	2.64
Absorption	1.4%	1.6%	1.1%	0.8%	0.9%

4) Specific Gravity & Absorption of Fine Aggregate	TH #3	TH #8	TH #11	TH #14	TP #6
Bulk specific gravity (SSD Basis)	2.63	2.61	2.62	2.60	2.62
Absorption	1.4%	1.6%	1.4%	0.9%	0.8%

5) Unit Weight of Coarse & Fine Aggregate	TH #8	TH #11	TH #14	TP #5	TP #6
(kg/m3)	2051	2066	2172	1936	2049

6) Lightweight Pieces	---------- % by Weight ----------				
	TH #8	TH #11	TH #14	TP #5	TP #6
Coarse Aggregate	0.0	0.0	0.0	0.0	0.0
Fine Aggregate	0.06	0.05	0.05	0.08	0.04

7) Scratch Hardness of Aggregate

	TH #11	TH #14	TP #1	TP #5	TP #6
1" - 1 1/2" grading					
soft particles (% by weight)	0.0	0.3	0.4	0.2	1.2
(% by number of particles)	0.0	0.8	0.9	0.8	1.3
1/2" - 3/4" grading					
soft particles (% by weight)	0.0	0.7	0.4	2.1	0.0
(% by number of particles)	0.0	1.2	1.2	2.9	0.0
Weighted average percentage	0.0	0.5	0.4	0.7	0.7

8) Organic Impurities of Fine Aggregate

TH #3	TH #8	TH #11	TH #14	TP #5	TP #6
Pass	Pass	Pass	Pass	Pass.	Pass

(less than 3 on organic plate)

9) Asphalt Coating & Stripping Test

TH #3	TH #8	TH #11	TH #14	TP #6
Good Coating	Good Coating	Good Coating	Good Coating	Good Coating

10) Petrographic Analysis

a) X-Ray Diffraction Analysis

Coarse Aggregate	TH #3	TH #8	TH #11	
Quartz	74	73	56	65
Plagioclase	11	2	Trace	4
K Spar	Trace	4	Trace	1
Calcite	13	8	41	21
Dolomite	2	13	3	6
Illite	Nil	Trace	Nil	

b) X-Ray Diffraction Analysis

Fine Aggregate	TH #3	TH #8	TH #11
Quartz	60	66	59
Plagioclase	7	5	5
K Spar	Trace	5	2
Calcite	10	8	12
Dolomite	10	7	14
Kaolinite	Trace	1	Trace
Illite	9	4	6
Chlorite	1	2	1
Smectite	1	2	1
Mixed Layer Clays (Swelling)	Trace	Trace	Trace
Dolomite (Ferroan)	2	—	Trace
Apatite	—	Trace	—

c) Clay Separation by Floatation

	TH #3	TH #8	TH #11
Material Less than 2 Microns:	4.5%	8.9%	3.6%
Material Greater than 2 Microns	95.5%	91.1%	96.4%

d) Relative Weight Percentage of Coarse Aggregate

	TH #3	TH #8	TH #11
Lithic Sandstones	10.6%	9.1%	11.0%
Calcareous Sandstones	6.1%	3.8%	5.7%
Chert	4.2%	12.2%	7.5%
Dolomite (including Arenaceous Dolomites)	2.5%	7.3%	1.7%
Fine & Coarse Grained Quarzites	65.4%	63.6%	62.5%
Limestone	9.8%	3.6%	10.2%
Igneous (& *Metamporphic clasts)	1.4%	*0.4%	1.4%

e) Breakdown of Fines Portion of Aggregate (Less than 0.5mm Portion) Based on a 300 Point Count Analysis

	TH #3	TH #8	TH #11
Quartz	45	38	40
Polycrystalline Quartz	7	3	2
Feldspar	1	1	1
Chert	16	17	17
Rock Fragments	7	16	5
Limestone	15	5	23
Calcareous Sandstone	2	2	5
Dolomite	6	10	8
Dolomitic Sandstone	1	6	1
Arenaceous Limestone	—	1	—
Metamorphic and Igneous Rocks	—	1	—

ii) Compressive Strength Data on Cores Obtained from Bulk Conglomerate Samples

TP	Depth (m)	Core Dia	Compressive Strength in MPa. (adjusted for l/d ratio)
#2	4.7	100mm	30.2
		100mm	19.7

APPENDIX B

Lafarge Spyhill Granular Quality Test Data

and Petrographic Analysis

(Scanned copy of Original)

EBA Engineering Consultants Ltd.

May 5, 1998

Lafarge Construction Materials
P.O. Box 1180, Station "T"
Deerfoot Trail and Southland Drive SE
Calgary, Alberta
T2H 2H5

EBA File: 0304-30266

Attention: Mr. Martin Darby

Dear Sir:

Subject: Aggregate Analysis of 20 mm Road Gravel
From Spy Hill Pit

Please find enclosed the results of testing performed on 20 mm Road Gravel delivered to EBA Engineering Consultants Ltd.

SPY HILL 20 mm ROAD GRAVEL
EBA SAMPLE #2571

Test Performed	Result	Specification
Soundness by Magnesium Sulphate	Coarse 4.3% Fine 7.2%	CSA Limit 12% CSA Limit 16%
Petrographic Analysis	See Attached	
Los Angeles Abrasion (Grading B)	25.1%	CSA Limit 35%
Organic Impurities in Sand	Colour Plate #1	CSA Limit #3
Gradation Analysis	See Attached	

6111 - 36th Street S.E. Calgary, Alberta T2C 3W2
• Telephone (403) 236-9700 • FAX (403) 236-7033 •

We trust this information meets your present requirements. Should you have any questions, please contact our office.

Respectfully submitted,

EBA Engineering Consultants Ltd.

Mick E. Brzoza, C.E.T.
Technical Supervisor

Randy H. Gifford, P.Eng.
Project Engineer

MEB:RHG:lsm

Attachments

EBA Engineering Consultants Ltd.

TABLE 1

SUMMARY OF PETROGRAPHIC ANALYSIS OF COARSE AGGREGATE

LAFARGE CONSTRUCTION MATERIALS
0304-30266
20 mm Road Gravel

SPY HILL - 2571

Date Received:April, 1998

ROCK TYPE	Petrographic Multiplier	28 - 20 mm % in fraction	20 - 14 mm % in fraction	14 - 10 mm % in fraction	10 - 5 mm % in fraction
GOOD					
QUARTZITE	1		68.2	69.3	77.7
LIMESTONE	1		14.6	21.6	17.5
SANDSTONE	1		4.4	3.3	1.6
CHERT	1		6.8	2.1	1.6
FAIR					
QUARTZITE	3		4.1	0.6	1.2
SANDSTONE	3		1.9	3.1	0.3
POOR					
DELETERIOUS					

PETROGRAPHIC NUMBER :	112	107	103
PERCENT OF FRACTION IN SAMPLE:	12.4	29.4	20.3

WEIGHTED AVERAGE PETROGRAPHIC NUMBER: **107**

WEIGHTED AVERAGE CHERT CONTENT: **1.8 %**

WEIGHTED AVERAGE CLAY IRONSTONE CONTE **0 %**

eba

APPENDIX C

Environment Canada Annual Meterological Information

1971 Daily Maximum Temperatures

1997 Daily Minimum Temperatures

(Scanned copy of Original)

FROM:ENVIRONMENT-CANADA ID:4032993594

ANNUAL METEOROLOGICAL SUMMARY
for
CALGARY - ALBERTA

DAILY MAXIMUM TEMPERATURES 1971

DATE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	26	30	14	37	68	66	75	90	69	59	37	44
2	21	29	42	43	63	71	63	93	63	65	39	48
3	12	21	34	38	70	75	61	87	69	65	45	35
4	15	15	44	47	72	57	69	85	73	69	41	26
5	29	14	21	55	55	65	68	95	82	77	16	26
6	37	16	28	65	55	56	64	89	70	76	21	18
7	42	38	47	50	75	68	60	87	71	57	44	18
8	42	41	39	52	72	66	68	92	78	76	43	29
9	-2	46	41	53	60	61	71	78	57	75	49	29
10	-11	43	42	46	65	68	64	84	78	67	52	10
11	-22	36	43	43	76	71	69	88	62	69	57	-5
12	-20	50	46	50	81	73	67	89	67	60	41	-4
13	-19	48	41	57	70	66	72	69	60	57	50	16
14	-21	47	41	69	55	61	79	91	57	34	51	26
15	-1	41	43	48	62	67	84	81	51	30	35	-1
16	30	40	39	44	50	62	84	84	48	35	41	34
17	8	36	36	42	51	63	78	74	57	48	38	27
18	44	37	37	51	56	65	80	77	65	47	42	24
19	50	29	42	61	62	65	87	85	50	57	54	32
20	30	31	27	56	62	75	86	88	48	51	53	25
21	25	42	14	59	61	76	81	86	58	50	57	2
22	28	42	15	57	70	79	84	81	67	60	50	-3
23	24	43	20	60	71	71	87	73	69	55	36	-15
24	9	40	18	60	76	72	67	78	63	50	39	-8
25	15	28	13	55	76	74	69	76	56	57	23	-8
26	42	24	18	44	75	66	82	74	43	47	43	16
27	42	17	29	49	72	59	67	83	40	16	21	27
28	47	9	42	43	62	65	67	67	54	21	22	28
29	45		40	44	73	68	77	73	40	42	24	22
30	1		29	58	61	72	85	71	44	36	41	34
31	5		29		50		82	74		34		31
Mean	18.5	33.3	32.1	51.2	65.4	67.4	74.1	82.1	60.3	53.0	40.2	18.5

DAILY MINIMUM TEMPERATURE SUMMARY
SOMMAIRE TEMPERATURE MINIMALES QUOTIDIENNES

Environment Canada Environnement Canada

CALGARY, ALBERTA 1997

DATE	JAN JANV	FEB FEVR	MAR MARS	APR AVR	MAY MAI	JUN JUIN	JUL JUILL	AUG AOUT	SEP SEPT	OCT OCT	NOV NOV	DEC DEC
1	-21.8	-12.5	-13.6	-5.8	1.9	12.7	7.8	10.2	6.7	4.0	-2.1	-8.5
2	-14.1	-7.8	-14.7	-6.5	0.8	8.2	7.1	7.2	7.2	6.7	-5.8	-11.4
3	-18.1	-8.8	-18.5	-6.1	-2.0	2.8	6.0	9.4	13.2	3.6	3.2	-11.4
4	-14.8	-14.8	-20.7	-9.8	-0.3	11.0	6.9	9.5	8.8	-2.8	-0.9	-14.9
5	-18.1	-13.5	-23.2	-12.8	0.6	8.8	10.0	10.9	3.7	0.3	-0.9	-14.9
6	-14.3	-13.7	-18.9	-12.2	2.7	8.2	8.2	13.1	7.4	-4.4	-1.3	-18.8
7	-1.6	-14.6	-8.1	-12.8	-1.3	5.5	6.9	12.9	4.4	-2.0	-6.8	-20.7
8	-14.0	-10.9	-4.7	-13.8	-0.9	10.0	13.5	6.7	2.7	-3.9	-11.8	-17.3
9	-22.2	-8.0	-7.7	-11.4	5.4	9.7	12.0	4.9	4.9	-3.4	-12.9	-8.4
10	-29.9	-8.9	-3.2	-13.4	2.6	9.7	6.2	2.8	4.7	-2.8	-14.2	-7.8
11	-39.7	-14.7	-10.6	-12.6	0.3	8.6	2.7	9.3	9.0	-1.3	-13.7	-6.1
12	-29.4	-9.1	-17.9	-7.2	3.7	11.3	5.5	7.4	4.9	-3.5	-6.7	0.3
13	-17.7	-10.4	-23.3	-3.9	3.0	11.2	7.6	7.5	1.4	-6.9	-10.5	1.9
14	-15.1	-10.4	-26.9	-4.2	4.1	11.3	6.8	10.6	5.3	3.7	-11.0	-5.2
15	-21.5	-5.0	-22.5	-5.7	10.0	8.7	7.6	8.0	5.8	2.1	-12.9	-7.0
16	-23.7	4.8	-16.3	4.6	5.1	9.8	8.7	8.4	4.0	6.6	-10.7	-8.4
17	-19.2	-6.1	-18.5	0.2	-0.2	9.6	9.2	7.9	1.6	-1.6	-9.3	-5.4
18	-3.4	-7.9	-12.2	-4.5	-0.2	9.6	10.4	5.2	0.5	-1.8	-12.3	-14.2
19	-9.7	-6.9	-1.6	0.3	-2.6	5.2	5.8	7.4	-1.9	-6.3	-12.1	-16.4
20	-8.0	-3.2	-1.7	0.4	-0.5	4.9	9.3	5.8	3.1	-8.1	-7.1	-6.1
21	-15.1	-6.8	-3.6	0.9	-1.7	7.8	10.5	11.6	4.4	0.2	-12.1	-14.4
22	-17.4	-7.9	-2.9	-2.3	-1.6	8.6	11.0	8.7	3.9	-2.1	-10.1	-15.6
23	-26.4	-4.4	-4.3	-5.3	3.3	7.2	9.5	5.7	8.6	-3.7	-9.9	-1.7
24	-34.0	-1.6	-6.0	-0.2	4.0	6.3	6.7	9.0	7.6	-5.5	-3.1	-5.9
25	-38.6	-2.3	5.0	-1.7	5.2	6.5	9.0	8.6	3.0	-4.8	-8.6	-8.0
26	-35.7	-5.1	-1.0	-1.0	5.3	9.5	7.9	7.2	8.2	5.1	-10.7	-6.9
27	-32.2	-7.5	-2.8	2.0	7.4	5.7	6.8	11.4	6.8	-2.5	-12.1	-2.3
28	-23.4	-12.7	-3.2	0.9	2.6	5.3	7.9	8.2	8.6	-5.6	-5.2	-1.4
29	-12.3		-4.9	-3.2	6.4	5.7	12.5	6.9	3.7	-2.8	-10.2	-4.9
30	-0.9		0.9	-2.5	8.4	5.5	14.3	3.0	2.3	1.7	-8.8	-12.8
31	-2.4		0.2		11.3		11.2	6.0		3.3		-3.3
MEAN	-19.2	-8.2	-9.9	-5.0	2.7	8.2	8.6	8.1	5.2	-1.2	-8.4	-9.0

APPENDIX D

Moose Jaw Asphalt Inc.

PG Asphalt Grading and Viscosity/Temperature Graph

(Scanned copy of Original)

Moose Jaw Asphalt Inc.

May 21, 1997

Fax: (403) 268-4384

COPY

City of Calgary
Engineering & Environmental Services Dept.
Streets Division #31 - Asphalt Plant
P.O. Box 2100, Stn. M
Calgary, Alberta
T2P 2M5

Attention: Duane Sutherland/Joe

Dear Duane:

As discussed, please find enclosed the information related to temperature/viscosity curves and PG grading of our 'A' grade asphalts. If you or Joe have any questions or require more information, please give me a call at **(306) 691-7815**.

Regards,

MOOSE JAW ASPHALT INC.

Dale R. Paton
Marketing Manager

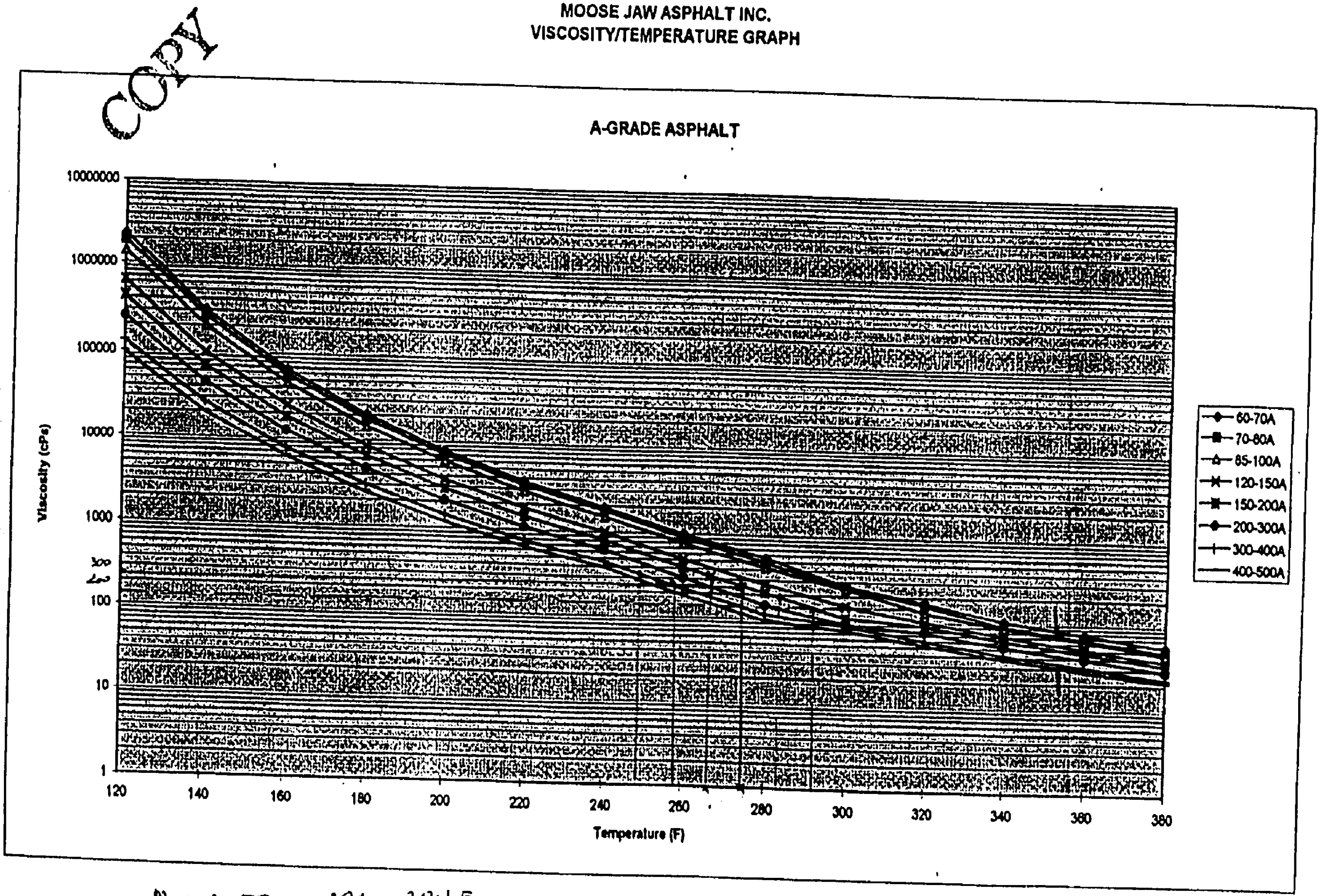
DRP/sw

Enclosure

RECEIVED
MAY 29 1997
THE CITY OF CALGARY
ENGINEERING & ENVIRONMENTAL
SERVICES DEPARTMENT
STREETS DIVISION / MATERIAL PLANTS

PRODUCT	SHRP GRADING
60-70 A	64-22
120-150 A	58-28
150-200 A	58-28
200-300 A	52-34
300-400 A	46-34
400-500 A	40-40

MOOSE JAW ASPHALT INC.
VISCOSITY/TEMPERATURE GRAPH



MIXING TEMP: 284 - 291' F
COMPACTION TEMP: 263 - 271' F

A-GRADE ASPHALTS

APPENDIX E

Densification Information for Binder Content Selection

$G_{mm(meas)}$ = 2.45				**Binder Content Densification Data - 4.9%**					
	Specimen 1				Specimen 2				Avg
Gyration	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	$\%G_{mm}$
5	133.4	1.984	2.063	84.2%	133	1.987	2.046	83.5%	83.9%
7	131.7	2.010	2.089	85.3%	130.9	2.019	2.079	84.9%	85.1%
10	129.8	2.039	2.120	86.5%	128.9	2.050	2.111	86.2%	86.4%
15	127.7	2.073	2.155	88.0%	126.6	2.087	2.150	87.7%	87.8%
20	126.3	2.095	2.179	88.9%	125.1	2.112	2.175	88.8%	88.9%
30	124.3	2.129	2.214	90.4%	123	2.148	2.213	90.3%	90.3%
40	122.9	2.153	2.239	91.4%	121.6	2.173	2.238	91.3%	91.4%
50	121.8	2.173	2.259	92.2%	120.5	2.193	2.258	92.2%	92.2%
60	121	2.187	2.274	92.8%	119.7	2.208	2.274	92.8%	92.8%
70	120.3	2.200	2.287	93.4%	119	2.221	2.287	93.3%	93.4%
75	119.9	2.207	2.295	93.7%	118.6	2.228	2.295	93.7%	93.7%
80	119.6	2.213	2.301	93.9%	118.4	2.232	2.299	93.8%	93.9%
100	118.6	2.232	2.320	94.7%	117.4	2.251	2.318	94.6%	94.7%
115	118.1	2.241	2.330	95.1%	116.8	2.262	2.330	95.1%	95.1%
$G_{mb(meas)}$ = 2.33					$G_{mb(meas)}$ = 2.33				

Table 29

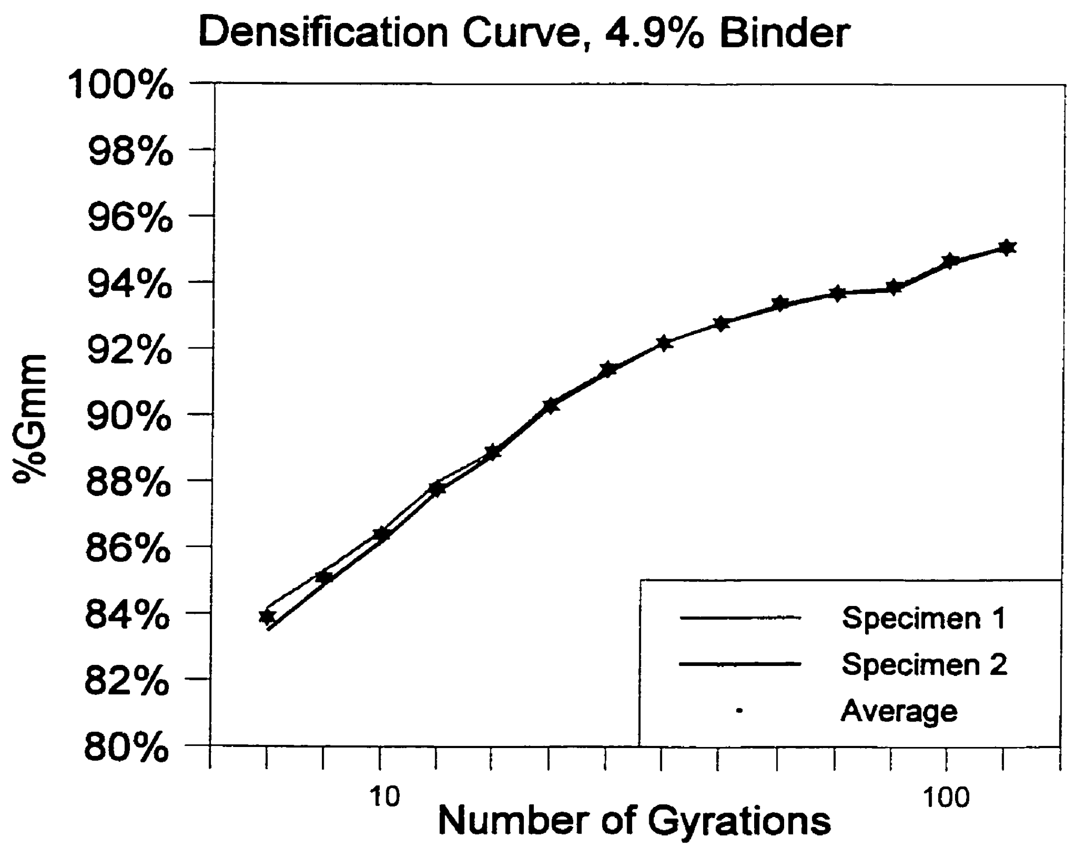


Figure 22

$G_{mm(meas)}$ = 2.44	Binder Content Densification Data - 5.4%								
	Specimen 1				Specimen 2				Avg
Gyration	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	%G_{mm}	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	%G_{mm}	%G_{mm}
5	128.8	2.062	2.119	86.8%	128.2	2.078	2.131	87.3%	87.1%
7	127.0	2.092	2.149	88.1%	126.4	2.107	2.162	88.6%	88.3%
10	125.0	2.125	2.183	89.5%	124.4	2.141	2.196	90.0%	89.7%
15	122.9	2.161	2.220	91.0%	122.2	2.180	2.236	91.6%	91.3%
20	121.5	2.186	2.246	92.0%	120.7	2.207	2.264	92.8%	92.4%
30	119.5	2.223	2.284	93.6%	118.6	2.246	2.304	94.4%	94.0%
40	118.1	2.249	2.311	94.7%	117.2	2.273	2.331	95.5%	95.1%
50	117.1	2.268	2.330	95.5%	116.2	2.292	2.351	96.4%	95.9%
60	116.3	2.284	2.346	96.2%	115.4	2.308	2.368	97.0%	96.6%
70	115.7	2.296	2.359	96.7%	114.8	2.320	2.380	97.5%	97.1%
75	115.4	2.302	2.365	96.9%	114.5	2.326	2.386	97.8%	97.4%
80	115.1	2.308	2.371	97.2%	114.3	2.330	2.390	98.0%	97.6%
100	114.2	2.326	2.389	97.9%	113.4	2.349	2.409	98.7%	98.3%
115	113.7	2.336	2.400	98.4%	112.9	2.359	2.420	99.2%	98.8%
$G_{mb(meas)}$ = 2.40					$G_{mb(meas)}$ = 2.42				

Table 30

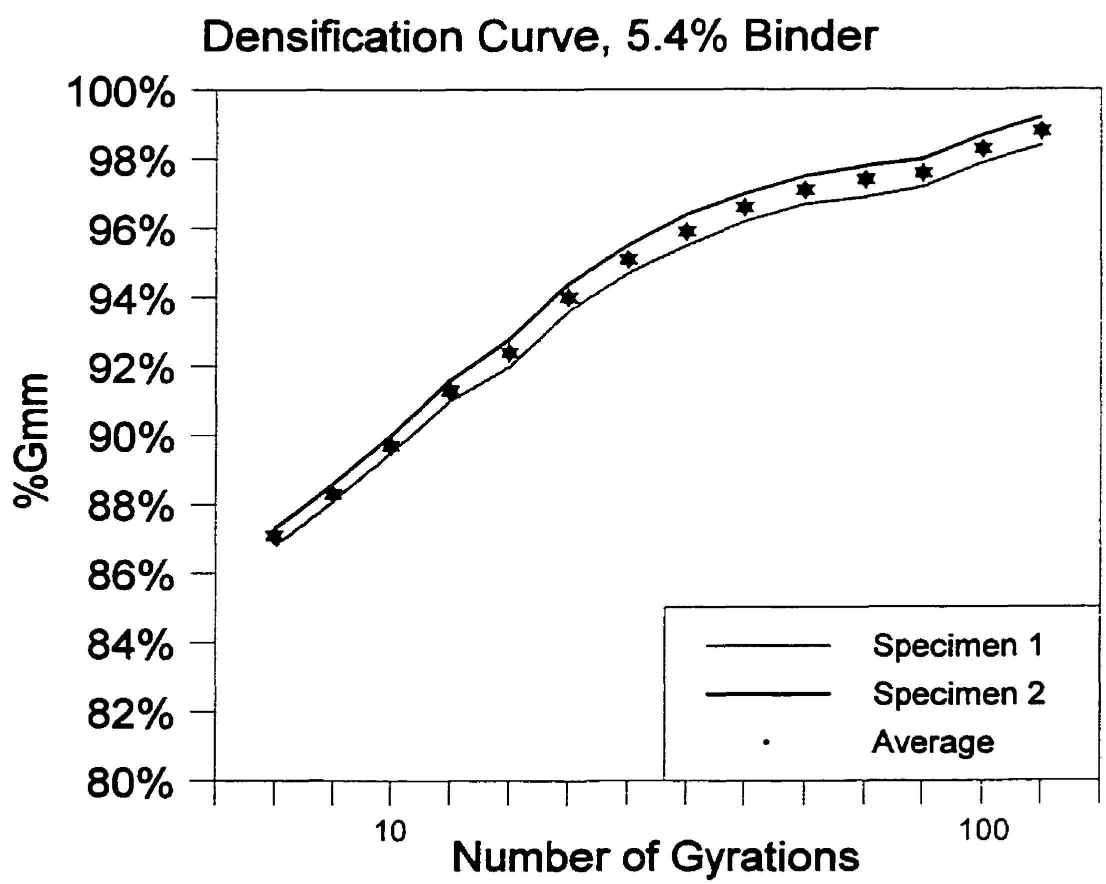


Figure 23

$G_{mm(meas)}$ = 2.41					Binder Content Densification Data - 5.9%				
	Specimen 1				Specimen 2				Avg
Gyration	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	Ht, mm	$G_{mb(est)}$	$G_{mb(corr)}$	$\%G_{mm}$	$\%G_{mm}$
5	130.0	2.056	2.104	87.3%	130.3	2.055	2.099	87.1%	87.2%
7	128.0	2.088	2.137	88.7%	128.5	2.084	2.129	88.3%	88.5%
10	125.9	2.123	2.173	90.2%	126.3	2.120	2.166	89.9%	90.0%
15	123.6	2.162	2.213	91.8%	123.9	2.161	2.208	91.6%	91.7%
20	121.9	2.192	2.244	93.1%	122.2	2.191	2.238	92.9%	93.0%
30	119.7	2.233	2.285	94.8%	119.9	2.233	2.281	94.7%	94.7%
40	118.2	2.261	2.314	96.0%	118.4	2.262	2.310	95.9%	95.9%
50	117.1	2.282	2.336	96.9%	117.3	2.283	2.332	96.8%	96.8%
60	116.3	2.298	2.352	97.6%	116.4	2.301	2.350	97.5%	97.6%
70	115.6	2.312	2.366	98.2%	115.7	2.315	2.364	98.1%	98.1%
75	115.3	2.318	2.372	98.4%	115.3	2.323	2.372	98.4%	98.4%
80	115.0	2.324	2.379	98.7%	115	2.329	2.379	98.7%	98.7%
100	114.1	2.342	2.397	99.5%	114.1	2.347	2.397	99.5%	99.5%
115	113.5	2.355	2.410	100.0%	113.5	2.359	2.410	100.0%	100.0%
$G_{mb(meas)}$ = 2.41					$G_{mb(meas)}$ = 2.41				

Table 31

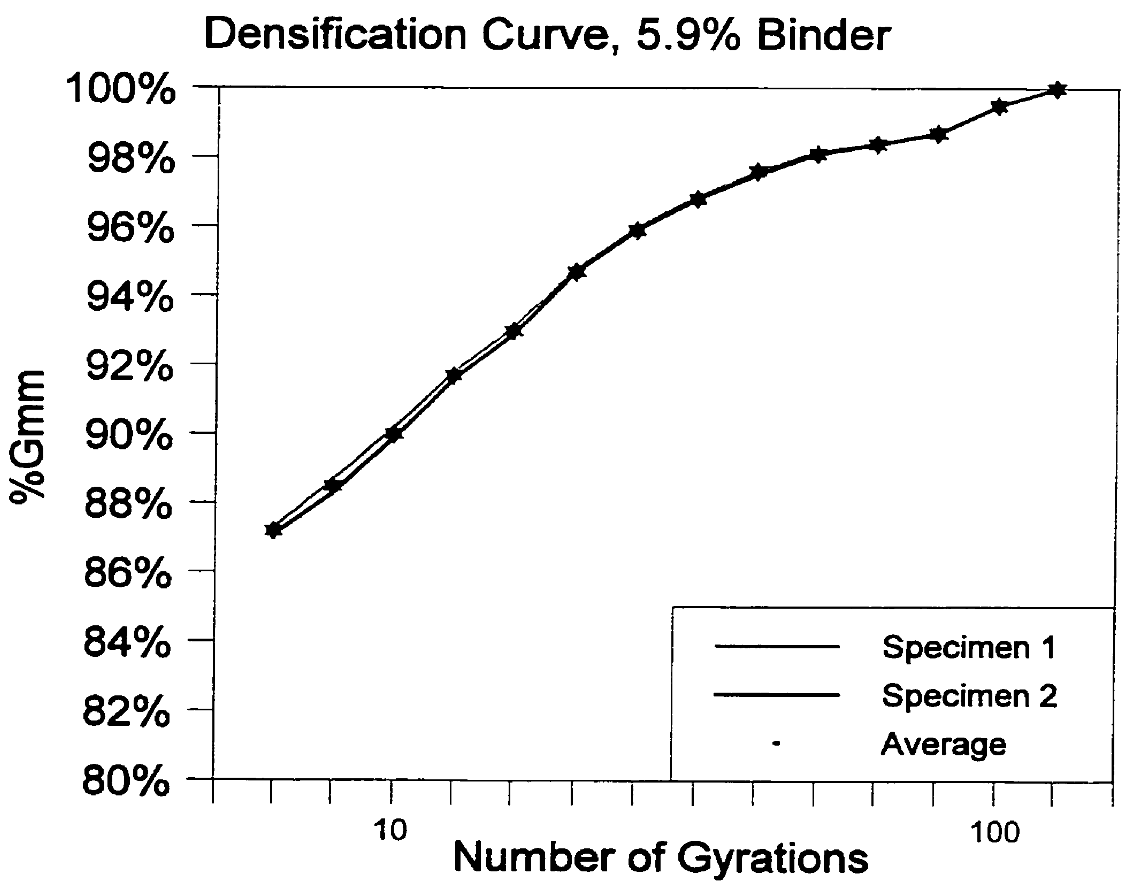


Figure 24

APPENDIX F

Inland Construction Ltd 12.5 mm Superpave Mix Design

(Scanned copy of Original)

EBA Engineering Consultants Ltd.

June 18, 1999

Inland Construction Ltd.
5340 - 1 Street SW
Calgary AB T2H 0C8

EBA File: 0404-99-42356

Attention: Mr. Jim Hovey

Dear Sir:

Subject: Asphalt Concrete Mixture Analysis
Superpave Designation 3-C-12.5

As requested, EBA Engineering Consultants Ltd. (EBA) has undertaken asphalt concrete mixture analysis for the above-captioned Superpave mix type. This letter report serves to provide the results of the analysis.

The volumetric mixture analysis methodology was in accordance with the procedures and criteria documented in the Asphalt Institute manual "Superpave Mix Design (SP-2)". Based on project information provided by Inland Construction Ltd. (Inland), Superpave criteria for traffic level "3" (1 to 3 million equivalent single axle loadings) was utilized for aggregate and mixture evaluation. This corresponds to an initial, design and maximum number of gyrations of 7, 86, and 134, respectively. The objective of the analysis was the determination of a design binder content for the selected 12.5 mm nominal maximum size coarse gradation.

The basis for the job mix formula (JMF) gradation was a blend of 45% 19 mm course aggregate, 37% manufactured fine aggregate, and 18% washed sand, all originating from the Spyhill Pit, Calgary, Alberta. The average gradation of the three aggregate components (based on process quality control data provided by Inland) was used for blending purposes. The gradation of the aggregate components is provided in Figure 1. The JMF blend, as presented in Figure 2, meets the Superpave gradation limits.

The binder utilized was Black Max Paving Grade polymer modified asphalt supplied by Husky Oil.

The following Superpave aggregate consensus properties were determined for the JMF aggregate blend.

Property	Test Result	Superpave Criteria
Coarse Aggregate Angularity		
Two or more fractured faces, %	96	-
One or more fractured faces, %	97	75 min.
Thin / Elongated Particles		
Maximum/Minimum >5, %	7	10 max.
Fine Aggregate Angularity		
Uncompacted Void Content, %	46	40 min.
Clay Content		
Sand Equivalent, %	76	40 min.

As shown, the resulting aggregate properties meet the applicable Superpave criteria.

Mixture volumetric analysis was conducted at three trial binder contents (5.1%, 5.5%, and 5.9% by mass of mix). The resultant mix properties and the densification curves are presented in Table 1 and Figure 3, respectively.

Based on the analysis, a design binder content of 5.6% (by mass of mix) is indicated for the JMF gradation blend. At this binder content, the following mix properties are anticipated. These mix properties were interpolated from the design charts (Figure 4) and associated data.

Property	Design Value	Superpave Criteria
Binder Content (%, by mix)	5.6	-
Bulk Specific Gravity at N design	2.358	-
C initial[1]	86.1	89 max.
C maximum[1]	97.5	98 max.
Air Voids (%)	4.0	4
V.M.A. (%)	15.1	14 min.
V.F.A. (%)	73	65 – 78
Dust Proportion	1.0	0.6 – 1.2

[1] C – Specimen bulk specific gravity as a percentage of maximum specific gravity.

As shown, the required mix properties are achieved at the design binder content.

Laboratory trial mixture design data, presented herein, has been used to determine an initial JMF. Subsequent to establishing the proportions in accordance with the initial JMF at the hot mix production facility, verification testing is recommended. This verification comprising the analysis of plant mix will serve to confirm, or further refine, the JMF such that specification compliance is ensured prior to the commencement of paving operations on the subject project. Until the foregoing verification process is completed, the JMF proposed herein should be accepted as being preliminary only. EBA reserves the privilege of modifying these recommendations upon completion of verification testing.

We trust this information satisfies your present requirements. Should you have any questions, please contact our office.

Respectfully submitted,
EBA Engineering Consultants Ltd.

PROFESSIONAL ENGINEER
MARC J. SABOURIN
ALBERTA

June 18/99

A.G. (Art) Johnston, C.E.T.
Senior Pavement Technologist

Marc J. Sabourin, P.Eng.
Branch Manager

:rcm
Attachments

PERMIT TO PRACTICE
EBA ENGINEERING CONSULTANTS LTD.
Signature
Date June 18/99
PERMIT NUMBER: P 245
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

TABLE 1
SUPERPAVE VOLUMETRIC MIXTURE DESIGN
DESIGNATION 3-C-12.5
SUMMARY OF MIX DESIGN PROPERTIES

PROPERTY				DESIGN VALUES [1]	SUPERPAVE CRITERIA
ASPHALT CONTENT (%, by mass of mix)	5.1	5.5	5.9	5.6	-
BULK SPECIFIC GRAVITY @ N design	2.347	2.356	2.362	2.358	-
C initial	85.5	86.0	86.3	86.1	89 max.
C maximum	98.2	97.9	98.1	97.5	98 max.
COMPACTION CURVE SLOPE	8.6	9.0	9.4	9.1	-
V.M.A. @ N design (%)	15.1	15.1	15.2	15.1	14 min.
AIR VOIDS @ N design (%)	5.1	4.2	3.5	4.0	4.0
VOIDS FILLED @ N design (%)	65.8	72.0	77.1	73	65 - 78
MAXIMUM SPECIFIC GRAVITY	2.474	2.460	2.447	2.457	-
ASPHALT ABSORPTION (%)	0.83	0.85	0.87	0.85	-
FILM THICKNESS (microns)	8.8	9.7	10.5	9.9	-
DUST RATIO	1.14	1.04	0.97	1.0	0.6 - 1.2

NOTE: Basis: Traffic Level 3 (<39 °C) Compaction Criteria (N_i - 7, N_d - 86, N_m - 134)

Aggregate Specific Gravity: 2.622

Asphalt Specific Gravity: 1.02

Aggregate Surface Area: 5.03 sq m./kg

Compaction Temperature: 150 °C

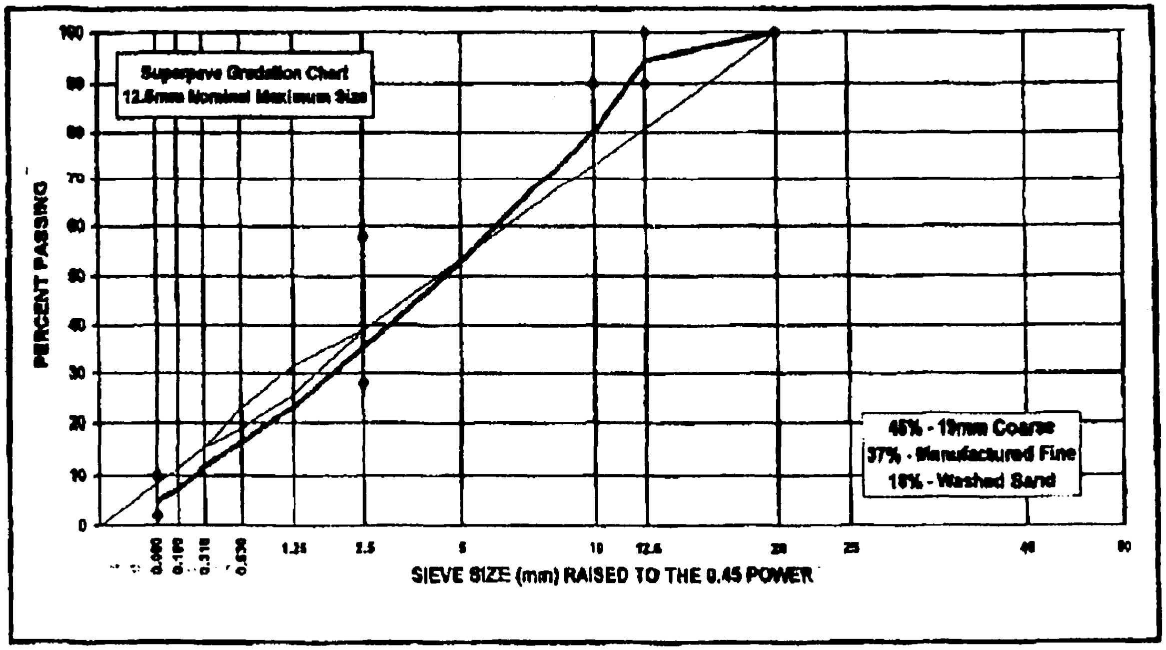
[1] Values Interpolated from Design Charts and Associated Data

FIGURE 2

SUPERPAVE DESIGNATION 3-C-12.5 JOB MIX FORMULA GRADATION

PERCENT PASSING SIEVE SIZE

SIEVE SIZE (mm)	80	40	25	20	12.5	10	5	2.5	1.25	0.630	0.315	0.160	0.080
JMF				100	95	80	53	35	23	16	12	7.2	4.9

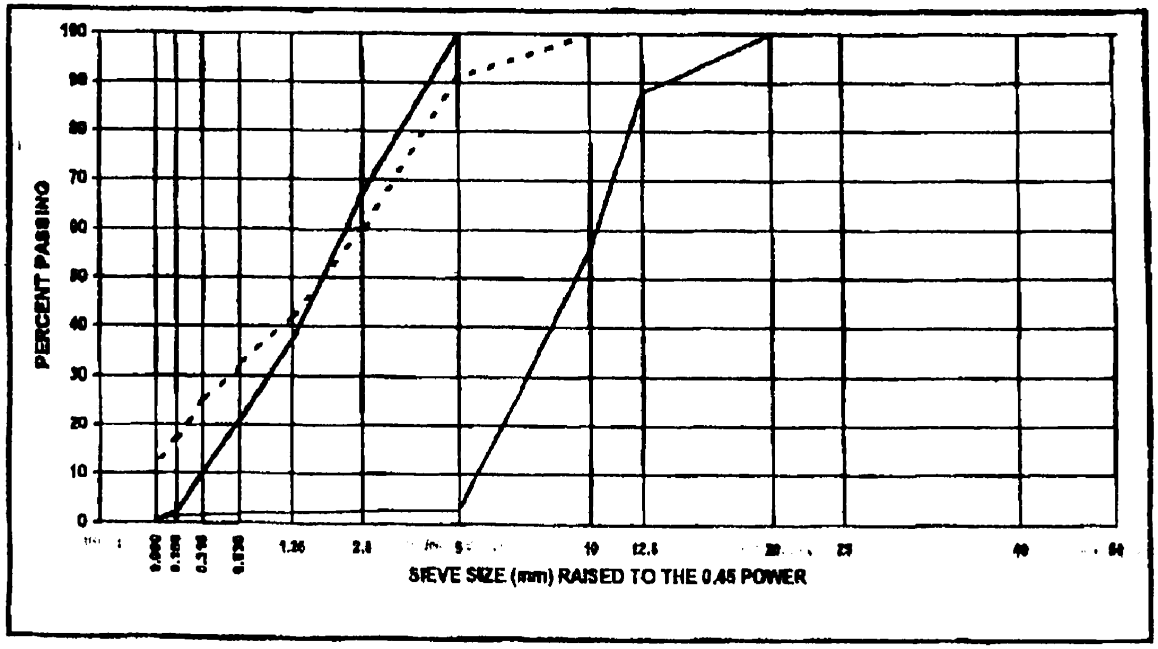


SENT BY: INLAND CONSTRUCTION; 6-18-99 3:07PM; 4032398650 => 2681058; #7
EBH ENGINEERING ID:3288817 JUN 18'99 13:50 No.002 P.06

FIGURE 1

SUPERPAVE DESIGNATION 3-C-12.5 AGGREGATE COMPONENT GRADATIONS

	PERCENT PASSING SIEVE SIZE												
SIEVE SIZE (mm)	50	40	25	20	12.5	10	5	2.5	1.25	0.630	0.315	0.160	0.080
19mm Coarse ————				100	88	56	2.8	2.5	2.0	1.8	1.5	1.2	0.8
Manufactured Fine - - - - - -						100	91	60	42	32	25	17	12
Washed Sand ————							100	67	37	21	10	2.0	0.5



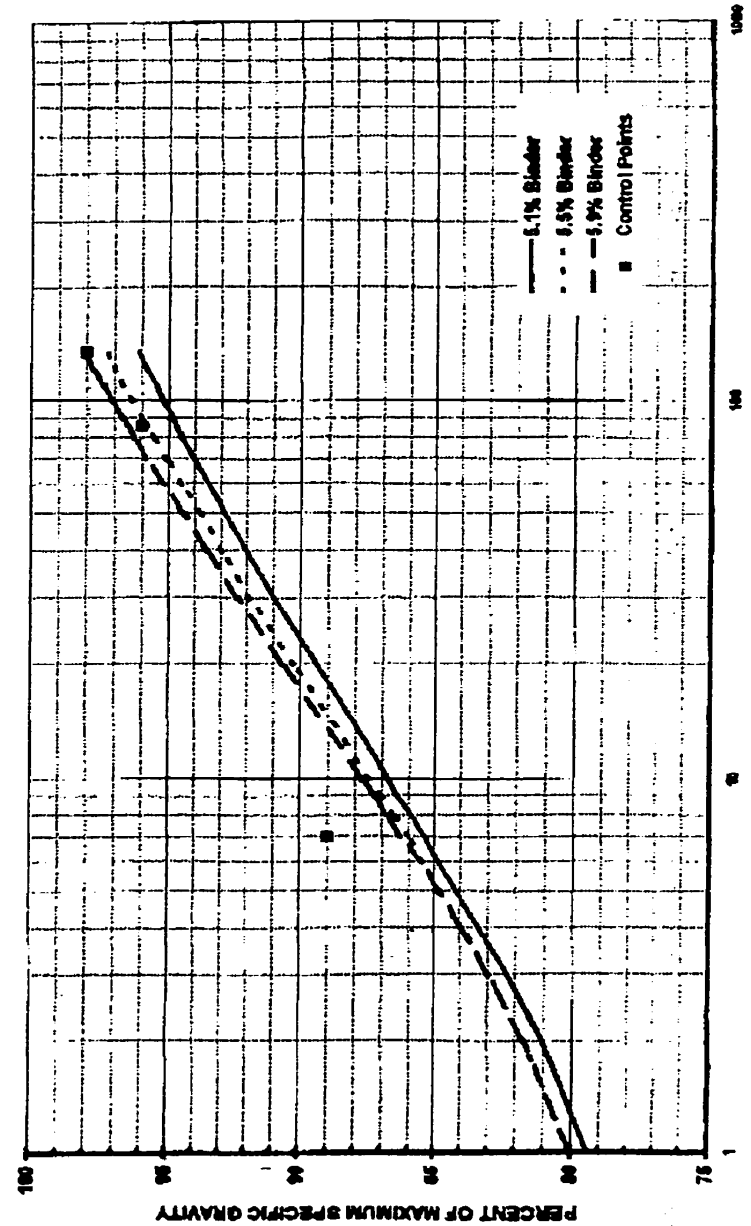


FIGURE 3
GYRATORY COMPACTOR DENSIFICATION CURVES
3-C-12.5 TRIAL ASPHALT CONTENTS

SENT BY: INLAND CONSTRUCTION; 6-18-99 3:08PM; 4032398650 => 2881058; #9

E3A ENGINEERING ID:3288817 JUN 18'99 13:55 No.002 P.08

FIGURE 4

SUPERPAVE VOLUMETRIC MIXTURE DESIGN - DESIGNATION 3-C-12.5