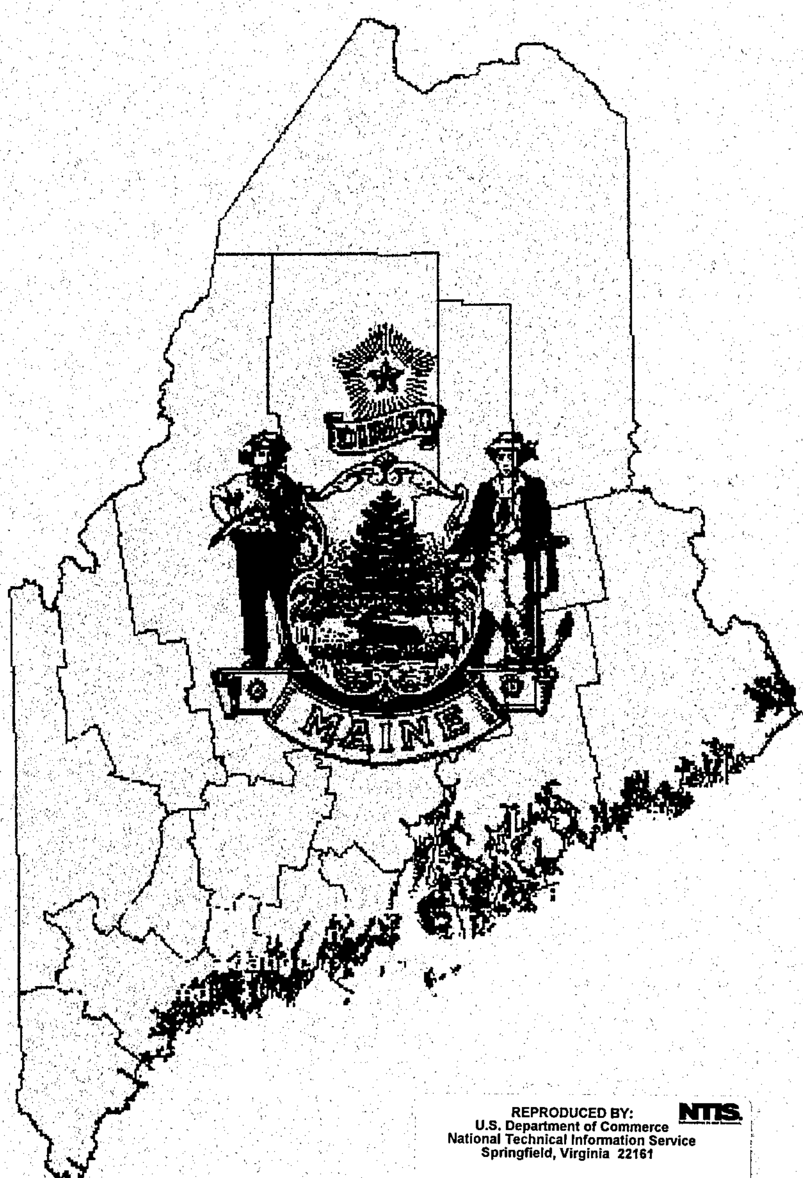
INVESTIGATION OF THE DESIRABILITY

OF USING

MANUFACTURED OR SYNTHETIC AGGREGATES

FINAL REPORT

TECHNICAL REPORT ME 98-4
JUNE 1999



Research

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16. Abstract (Limit 200 words)

Natural aggregate sources in Maine are becoming depleted and in many cases the quality of aggregate materials is declining. Several regions of the state do not have locally available aggregates of the quality necessary for highway and bridge construction.

One possible solution to this problem is the use of synthetic or manufactured aggregates. Synthetic replacements exist for some construction aggregates, and there are industrial and municipal waste/by products which have been found to be suitable for construction purposes.

This report examines the present availability of aggregates in Maine, as well as the availability and suitability of possible replacements. The impact of using low quality aggregates is also discussed.

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INVESTIGATION OF THE DESIRABILITY OF USING MANUFACTURED OR SYNTHETIC AGGREGATES

Introduction

Natural aggregate sources in Maine are becoming depleted and in many cases the quality of aggregate materials is declining. Several regions of the state do not have locally available aggregates of the quality necessary for highway and bridge construction. The problems of low quality paving aggregates in Aroostook County and low permeability of subbase materials statewide are two examples of the problem faced. In addition, environmental and other regulations make the development of new sources difficult or impossible. Finally, cases exist where one supplier controls sources of suitable aggregates in a region, resulting in a lack of competition, possibly affecting material prices.

One possible solution to this problem is the use of synthetic or manufactured aggregates. Synthetic replacements exist for some construction aggregates, and there are industrial and municipal waste/byproducts which have been found to be suitable for construction purposes.

Scope

This report examines the present availability of aggregates in Maine, as well as the availability and suitability of possible replacements. The impact of using low quality aggregates is also discussed.

Methodology

A literature search was conducted to find any research already completed regarding this subject. Studies were obtained from the MDOT library, as well as from other agencies in the United States and Europe.

To determine if aggregate is causing poor performance of hot mix asphalt pavements,a field evaluation of two projects having different levels of aggregate quality was completed. Also, core specimens were obtained from a paving project that failed prematurely to determine if aggregate quality was a factor.

Cost data for hot mix asphalt and portland cement concrete was obtained for a price comparison of various regions within the state.

Pavement Condition Rating data from a number of projects was examined to determine if any differences in pavement deterioration exist between areas with typically poor aggregate compared to areas with good quality aggregate.

Summary of Literature Search

The literature search provided very little useful information. Many reports dealing with aggregate properties and testing were available, but very little about scarcity of good quality aggregates could be found. One document titled *User Guidelines for Waste and By-Product Materials in Pavement Construction* provided information about the use of waste materials as construction aggregates. This is generally seen as a means to recycle an industrial or municipal waste product, as opposed to solving a problem with poor quality aggregates.

NCHRP Report 207, *Upgrading of Low-Quality Aggregates for PCC and Bituminous Pavements* examines a number of methods for improving the quality of marginal aggregates. Methods used include coating aggregate with linseed oil; impregnation with epoxy, kraft lignin, polyethylene glycol, or methyl methacrylate; and acid washing. Although physical properties of the aggregates were improved by some of the treatment in controlled laboratory experiments, the practicality and economics of large scale use were not examined. The study concludes that when aggregate quantities are relatively small, importing suitable material would be more cost effective.

NCHRP 4-19, *Aggregate Tests Related to Asphalt Concrete Performance in Pavements* attempts to relate aggregate test properties to actual pavement performance. Aggregate properties are classified and related to various pavement performance parameters. Recommendations are given as to what aggregate tests are suitable for reducing the occurrence of aggregate related pavement failures.

M.D.O.T. Research Relating to Aggregates

Materials Inventory 92-201 , May 1992

Inventory of MDOT degradation test values throughout Maine indicates that the average degradation value north of 45° 45' (Benedicta) is 28.3, while gravels south of this line average 59.1.

Determination of the Coefficient of Permeability of Subbase Materials, Dec. 1994

This study concludes that the subbase gravels used throughout Maine are unsuitable from a permeability standpoint. Of twenty-two gravels tested, only one had a permeability exceeding the recommended value of 1000'/day; eighteen of the samples had values less than 100'/day.

The study also concludes that the durability of subbase materials is important, since material breakdown during construction can significantly decrease permeability.

Evaluation of Existing Aggregate Base Drainage Performance, March 1995

Testing was performed at four sites to determine the in-situ permeability of subbase materials:

- Lebanon : 5.67'/day
- Passadumkeag : 2.24'/day
- Searsmont : 0.17'/day
- Cyr Plantation : 0.0068'/day

recommended value : >1000'/day

Pavement Condition Ratings, 1984-1997

Pavement condition ratings (PCRs), as determined by the MDOT Pavement Management system showed a tendency to decrease more quickly for a number of projects in Aroostook County than similar projects in other areas of the state. It should be noted that pavement condition ratings are assigned based on measurement of rutting and cracking. According to NCHRP Project 4-19, *Aggregate Tests Related to Asphalt Concrete Performance in Pavements*, the aggregate properties having the greatest effect on rutting and cracking are gradation and particle shape. Aggregate durability is related to potholing, raveling, and popouts, which are not measured when assigning PCRs.

Aggregate Durability Issues

Portland Cement Concrete

Freeze-thaw

Aggregates with high absorption values are known to contribute to decreased concrete durability. Freezing water expanding in the internal pores of aggregate particles can cause popouts and cracking. Also, this can hasten the entry of harmful salts into the concrete structure, damaging the reinforcing steel.

Material sources in Aroostook County generally have high absorption values. There are acceptable supplies of aggregate being used at several concrete plants, although some of the aggregates used at these plants are transported from other areas of the state (i.e., Lane - P.I. uses sand from Stockton Springs, Steelstone hauls sand from Chester). These plants can generally supply any DOT project. It is occasionally necessary to set up a portable plant at a remote location, and if local aggregate does not meet specifications, it must be hauled in.

Recent developments in concrete technology can help improve durability. Use of additives such as silica fume, flyash, and slag cement lower the permeability of the concrete, reducing the amount of water and salts that can enter the structure. Also, new set retarders can now delay the hydration process for hours, allowing concrete to be hauled longer distances.

Because of this, the concrete suppliers presently located in Aroostook County should be able to supply any foreseeable DOT projects. Other regions of Maine generally do not have a problem obtaining acceptable concrete aggregate.

Presently, MDOT uses its own deleterious material test to evaluate concrete aggregate. This is not an AASHTO test and is somewhat subjective; therefore, other tests are being considered for use, such as the micro-deval test.

Alkali-Silica Reactivity

Alkali-silica reactivity (ASR) occurs when a high-alkali cement is used in conjunction with certain reactive aggregates. This expansive reaction can cause extensive cracking in concrete structures, and has been noticed on sections of concrete pavement and several bridge structures in Maine. (Photos in Appendix.)

Presently, an MDOT study is underway that has examined the reactive potential of commonly used concrete aggregates, and will provide guidance as to how to mitigate the problem through the use of such additives as flyash, silica fume, and blast furnace slag. An aggregate specification has been written to address ASR and will be used on future DOT projects.

Hot Mix Asphalt

Potholes, Raveling, and Popouts

These deficiencies are generally believed to be related to (among other things) aggregate durability. Moisture and freeze-thaw damage are more prevalent in pavements containing poor quality aggregate.

Maine uses the MDOT Degradation test to determine the suitability of aggregates for use in HMA. Most regions of Maine have local aggregate deposits meeting the required minimum degradation value of 30, with Aroostook County being the main exception. The only HMA supplier in that region with acceptable material is Lane-Presque Isle. Implementation of the Washington degradation specification eliminated two sources in Houlton (Lane & Steelstone), as well as numerous gravel pits which had previously been used for temporary plant sites, from providing HMA to DOT projects. Indications are that aggregate related problems have decreased since adoption of this specification.

Both of the Houlton plants have supplied mix to DOT projects recently, but aggregate had to be hauled in from acceptable sources. Also, two large paving projects on Interstate 95 (Smyrna-Houlton, 1992, 20 miles, & Island Falls-Oakfield, 1995, 15 miles) were both paved from portable plants set up near railroad sidings, with all of the aggregate being transported to the site from other sources.

MDOT is in the process of evaluating the micro-deval test as a means of determining the acceptability of HMA aggregate (see test protocol in Appendix.) Preliminary results indicate that the material sources in Aroostook County that presently fail the degradation spec will also fail the micro-deval test. In fact, depending on what DOT sets for an acceptance level, some sources that are in use now may be disallowed under a micro-deval spec. If so, other regions of the state may be affected, and transporting of aggregates for use in HMA may become more commonplace.

Superpave

Adoption of the Superpave volumetric mix design method will affect aggregate use. HMA designed under this method will require a higher percentage of crushed stone and less natural sand than mixes presently being produced. Also, the more stringent aggregate properties required will make it more difficult to find suitable material sources. Pits will need to contain a higher percentage of rock in order to be an economical choice. Again, this may increase the practice of transporting aggregates to a plant site rather than producing all aggregates locally.

Some states have augmented natural aggregate supplies with such materials as blast furnace slag. Maine does not have a ready supply of such materials, and it would not be economical to transport them into the state for construction use. Waste materials such as crushed glass are also used in some states. Although they have been used with some success, there have also been problems with asphalt stripping. Incinerator ash has also been used in some states, but it requires extensive processing in order to be used effectively, increasing the cost. A recent proposal by American Ash Recycling to construct an ash recycling facility in Scarborough was turned down by the Maine Department of Environmental Protection (DEP).

A comparison of Pavement Condition Ratings (PCRs) for projects located in northern and southern Maine was completed to determine if northern projects deteriorate more rapidly due in part to the poor quality of local aggregate sources. While the PCR as determined by MDOT does not look at all types of pavement defects, it is the only information available, short of conducting full scale distress surveys of each project. Seven projects constructed in northern Maine and fourteen in southern Maine were examined. An attempt was made to compare projects of similar scope and traffic conditions. The average annual decrease in PCR from the time of construction to present was calculated for each project. These data were analyzed with the following results:

	NORTH	SOUTH
N of cases	7	14
Minimum	0.196	0.066
Maximum	0.390	0.308
Mean	0.272	0.199
95% CI Upper	0.340	0.240

95% CI Lower	0.205	0.158
Standard Dev	0.073	0.072

Comparison of Population Means for North v. South

	North	South
Sample sizes:	7	14
Means:	0.272429	0.198929
Difference:	0.0735	
Computed t:	2.20107	
P-value:	0.0403	

Reject the null hypothesis at alpha = 0.05

Pavement deterioration is not a linear function, so the average annual PCR decrease over several years cannot be used to predict pavement life; however, this statistically significant difference between deterioration rates in the north versus south can be used as an indication that northern projects tend to deteriorate more rapidly. Using this data, an economic analysis was prepared to try to quantify this difference in dollar terms.

Economic Analysis of Annual Project Costs for HMA

(North v. South)

Average annual decrease in Pavement Condition Rating (PCR):

Northern Maine - 0.272
Remainder of state - 0.199

Decrease in PCR from new pavement to terminal serviceability:

5.0-2.3 = 2.7

Average years of serviceability (based on PCR data):

Northern Maine: 2.7/0.272 = 9.9 = 10 years
Remainder of Maine: 2.7/0.199 = 13.6 = 14 years

(Again, this is not intended as a true prediction of actual project life, but as a comparison of the deterioration rate between north and south.)

Equivalent Uniform Annual Cost (based on one mile of full construction at $1,000,000/mile, using an interest rate of 4.00 percent)

Northern Maine: EUAC = $1,000,000 (A/P, 4.00, 10) = $123,300/year

Remainder of state: EUAC = \$1,000,000 (A/P, 4.00, 14) = \$94,700/year

Difference = \$28,600/year

While some of the deterioration is due to factors other than aggregate quality (temperature, weather, geologic conditions, etc.), the poor draining gravel bases and high absorbtion/poor durability paving aggregates used in northern Maine on past projects undoubtedly play a role in the annual cost differential. It would appear that paying a higher initial cost in order to obtain better quality materials in northern Maine would be cost effective when life cycle costs are taken into consideration. Using the calculations shown above, to obtain the same project life in northern Maine as in the rest of the state (14 years) while maintaining the annual cost of \$123,300/year, the initial cost of the project could be increased by 30 percent.

A comparison was made of two projects on Interstate 95 in the towns of Island Falls and Sherman. The southbound project was paved in 1990; northbound in 1991. Both projects were paved by the same contractor, utilizing the same paving crew and hot mix plant on both jobs. The only major difference is that the southbound pavement was constructed using local aggregate from a gravel pit in Crystal; for the northbound project, the plant was set up in a pit in Chester. The Crystal aggregate had a very high fines content and a Washington Degradation value of 12; the Chester Aggregate had a degradation result of 69 and was a clean gravel.

A visit to both projects in June of 1998 showed the northbound project to be virtually free of any potholing, raveling, or popouts, while the southbound section was severely distressed in many areas, including raveling, extensive popouts, and potholes, as well as large patched areas. (See pictures in the Appendix.) Due to the similarities of age and construction techniques, it can be argued that aggregate quality was the definitive reason for the distress present in the southbound lane. In fact, problems with the Crystal aggregate were a major factor in the decision to specify a minimum Washington degradation value of 30 for all hot mix aggregates.

Warranted Projects

Warranted projects have been used on a trial basis in several states. On this type of project, no minimum aggregate qualities are specified. The Contractor must provide a warranty that would require corrective action whenever a maximum amount of distress occurs within the warranty period. This type of specification places the risk associated with using poor quality materials on the Contractor. MDOT awarded its first warranted pavement project in 1998 on Route 1 in Houlton, where past experience has shown local aggregates to be a problem.

Base and Drainage Aggregates

Support strength

While most areas of Maine have good sources of gravel suitable for use as road base material, gravels in Aroostook County generally contain a high percentage of detrimental fines. In some cases, this makes them questionable with regard to support strength. A study performed in 1991, *Field Trial of Gravel Stabilization Methods*, prepared by M. Moreau and D. Humphrey of the University of Maine Civil Engineering Department details several experimental methods that were used to increase the strength of the gravel used on a DOT project in Van Buren. Methods used were soil-cement stabilized base, asphalt stabilized base, and calcium chloride stabilized base. The study concluded that both the cement treated and asphalt treated bases provided superior strength to the untreated gravel section. Calcium chloride did not seem to provide adequate results on this project. Lime-stabilization has also been used effectively in some places. This may be worth considering as there are several sources of lime available in Maine, including Aroostook County. The test sections for this field trial are being evaluated for long term performance.

Permeability

Gravels throughout Maine generally have low permeability. A 1994 study titled *Determination of the Coefficient of Permeability of Subbase Materials*, by Victor Smith of MDOT's geotechnical section concluded that most of the subbase gravels used on MDOT projects have insufficient permeability to provide adequate drainage. The gradation specified for subbase gravel allows up to 30 percent passing the No. 40 sieve, while FHWA recommends a maximum of 8 percent passing the No. 16 sieve. While changing MDOT's subbase gravel spec to provide a coarser base material would help the permeability problem, this could make it more difficult and expensive for contractors to provide acceptable material. In some areas, gravel would have to be washed in order to meet such a specification.

In recent years, MDOT has been specifying Dense Graded Crushed Aggregate material in place of Aggregate Subbase Gravel Type D in northern Maine in an attempt to improve permeability. Test results on a project in Frenchville in 1995 indicated that the permeability of this material was in the range of 30-100 feet/day, an improvement over the 0.0068 feet/day noted previously on standard subbase gravel in this region.

Another issue affecting permeability is aggregate durability. Several recent studies in Maine (listed in the "Summary of Literature Search" section) have noted that aggregate breakdown during construction increased the fines content of the gravel by several percent, making the gravel even more impermeable. Simply changing the gradation specification on gravel may not be sufficient, as aggregate breakdown can change the gradation.

A possible solution may be to utilize a drainage layer of highly permeable material beneath the pavement layer. By rapidly removing water from the pavement structure, the impermeable base material should be less susceptible to freeze-thaw damage. This was tried on a recent project on Route 139 in Fairfield and has been proposed for use on several more projects using various designs. Utilizing a 4" layer of permeable base material rather than trying to provide a 24" layer of permeable subbase gravel would be much more economical. Still, in some areas, suitable aggregate for the permeable base layer will have to be imported. One possible alternative is the use of a drainage geocomposite. This is a layer of synthetic material intended to replace the 4" drainage layer. This has recently been tried on the Frankfort-Winterport Route 1A project, and its effectiveness is being monitored. This same product was also installed at subgrade and 18" below subgrade as a means of keeping the subbase from becoming saturated; initial results are extremely promising, with substantial flow rates being observed.

Other materials being suggested for use as ways of improving permeability include tire chips and synthetic edge drains. Both of these are going to be used on upcoming projects.

Material Costs

In order to determine if material prices in northern Maine are higher than in other areas of the state, prices for class A concrete and hot mix asphalt were reviewed. The concrete prices are from the Bridge Maintenance Division for 1997; the hot mix prices are the statewide averages from Contracts section from 6-01-95 to 6-01-98.

	CONC_PRICE	GRAD_B	GRAD_C	GRAD_D
Minimum	59.00	27.72	26.93	26.55
Maximum	76.00	35.19	34.19	33.90
Mean	67.13	31.48	30.19	29.54
Aroostook County	73.00	34.17	34.19	32.90

Although material prices in Aroostook County were not the highest in each category, they were significantly higher than the state average in each case. Granted, several factors affect prices, but it is possible that difficulty obtaining suitable aggregates and lack of competition play a role.

The cost of some synthetic materials may be comparable to the cost of using low quality local aggregates. The DEP has indicated willingness to pay the difference between the cost of tire chips and a reasonable cost for whatever material they would replace (such as underdrain backfill).

Transportation Costs

The cost of transporting aggregate was discussed with several people including aggregate suppliers and a representative of the railroad industry. General guidelines suggest that if large quantities of aggregate are to be transported (in excess of 50,000 tons) and haul distance exceeds 100 miles, rail transport is more economical than trucks. The approximate cost of hauling by rail is $2.50 to $4.50 per ton, depending on the quantity hauled, haul distance, number of handlings, and distance from source to railhead and from railhead to stockpile. It was indicated by the railroad executive that they were investigating the possibility of hauling quarry stone into Maine for railroad ballast, and that they hoped to make this material available for highway use.

Discussion of Results

All evidence points to the fact that poor aggregate quality reduces project life. The economic analysis indicates that allowing the use of substandard material is not cost effective.

At present, contractors are addressing the aggregate problem by transporting material as needed. This is common practice in many areas, and will likely increase in coming years.

In areas of the state where suitable aggregate does not exist locally, paying the initial price to haul in good material will pay for itself in increased longevity. Aggregate specifications should be set based on sound engineering principles, and should not be altered based on regional considerations. The only case in which substandard materials should be allowed would be a warranted project.

Maine has no readily available sources of synthetic aggregates. Any material such as blast furnace slag would have to be transported from another state. When this becomes cost effective, contractors will pursue it.

Use of recycled asphalt pavement (RAP) in hot mix asphalt can reduce the need for new aggregate. MDOT and many contractors have had positive results with pavements containing RAP. Continued use of this material will contribute to Maine's future aggregate supply.

Geosynthetic products that are found to improve pavement life through improved support strength and drainage should be utilized. In particular, use of products that can keep the subbase properly drained should be encouraged. If the test sections that have been or will soon be constructed utilizing innovative drainage materials and techniques show a significant increase in pavement life, these should be used on a regular basis, as increasing project life will reduce future aggregate needs.

Consideration should be given to specifying a more permeable subbase material in place of Aggregate Subbase Gravel type 'D.' Materials that meet this gradation yet have a high fines content do not allow for proper drainage of the road base.

In areas where quality aggregates are scarce, use of warranty provisions could be used as an alternative to the standard specifications. This would allow contractors the option of using marginal aggregates while reducing the risk to MDOT.

Recommendations

1) MDOT should continue to specify aggregates based on performance related qualities. Findings from recent national studies in this area should be considered, including:

- NCHRP 4-19, *Aggregate Tests Related to Asphalt Concrete Performance in Pavements*
- NCHRP 4-20, *Aggregate Tests Related to Performance of Portland Cement Concrete*
- NCHRP 4-23, *Aggregate Tests for Use in Unbound Pavement Layers*

Use of substandard aggregates should not be allowed because of the increased cost associated with this practice.

2) If positive results are achieved on the warranted pavement project in Houlton, this type of contracting method should be considered as an alternative to standard practices in areas where good materials are scarce.

3) Continue monitoring the Frankfort-Winterport geosynthetic project and the Fairfield permeable base project as well as any other projects where innovative drainage techniques have been employed. Techniques that significantly increase pavement life should be implemented statewide.

4) Appoint a joint committee of Construction Division and Geotechnical personnel to decide if a material such as Dense Graded Crushed Aggregate should replace Aggregate Subbase Gravel type 'D' as the standard subbase aggregate statewide.

APPENDIX

Contents

- Photos of asphalt pavements on two projects having different levels of aggregate quality

- Photos of alkali-silica reactivity in portland cement concrete

- Special Provision (Alkali Silica Reactivity)

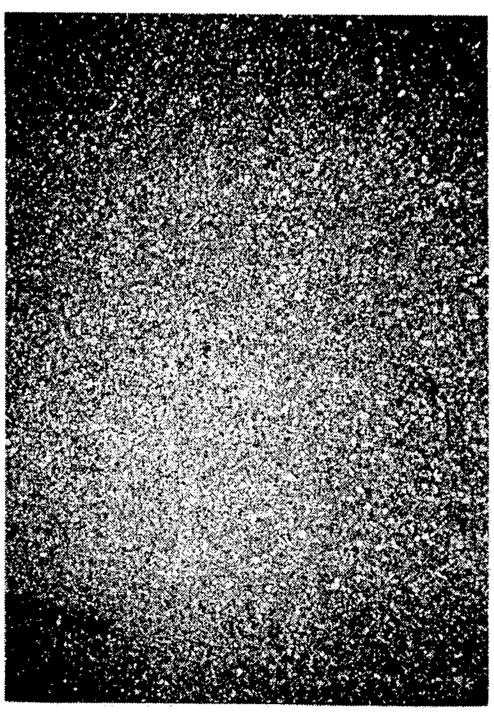
- MDOT Deleterious Materials Test method

- MDOT Degradation Test method

- Micro-Deval test method

I-95 northbound, Chester aggregate

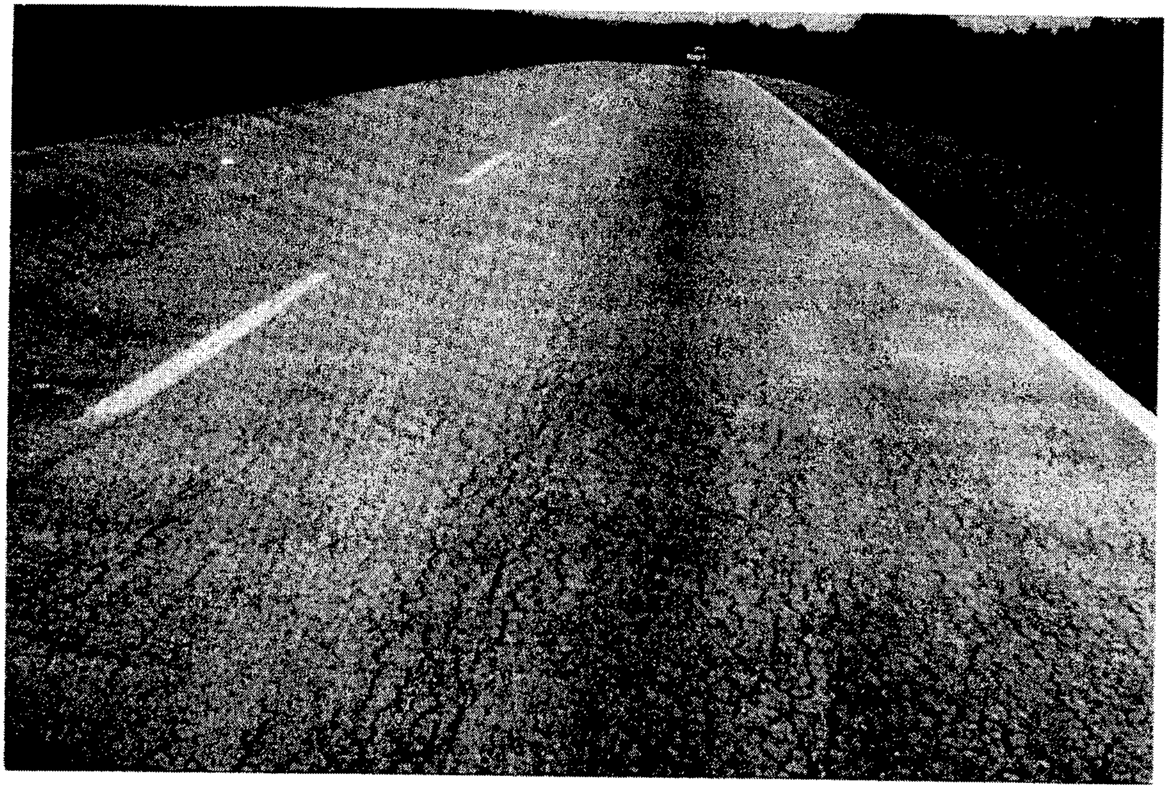
I-95 southbound, Crystal aggregate



Potholing: I-95 southbound, Is. Falls area

Popouts and raveling, same area

Typical pothole depth



Concrete pavement cracking caused by alkali-silica reactivity.

Close-up view of aggregate cracked by ASR gel expansion.

SPECIAL PROVISION
SECTION 703
AGGREGATES
(Alkali Silica Reactivity)

703.02 Coarse Aggregate for Concrete is modified by the addition of the following:

The Contractor shall design and utilize an approved structural concrete mix meeting the requirements of this Special Provision. As part of the concrete mix design approval, the Department will test coarse aggregates proposed for use for Alkali Silica Reactivity (ASR) potential under ASTM C-1260-94 (AASHTO P-214) by the Accelerated Mortar Bar Method. The Department will sample from stockpiles located at the concrete plant. Aggregate approvals will be performed on a three year cycle unless the source or character of the aggregate in question has changed within three years from the last test date.

The Department will maintain a list of pre-approved coarse aggregate and aggregate cement/pozzolan blends which will determine the acceptability of concrete mix designs proposed for use.

In accordance with ASTM C-1260 (AASHTO P-214):

Mortar bars with expansions less than or equal to 0.10 % at 16 days will be deemed innocuous and be allowed with no restrictions.

Mortar bars with expansions greater than 0.10 % will be classified as potentially reactive and will require the use of Cement Pozzolan blends or chemical admixtures with a resulting expansion less than 0.10 % at 16 days before being approved for use.

Acceptable Pozzolans and chemical admixtures shall include, but are not limited to, the following:

A. Class F Coal Fly Ash meeting the requirements of ASTM C 618.

B. Ground Granulated Blast Furnace Slag (Grade 100 and 120) meeting the requirements of ASTM C-989.

C. Densified Silica Fume (powder or slurry) meeting the requirements of AASHTO M-307.

D. Lithium Hydroxide Monohydrate (LiOH-H2O).

The cost of pozzolans, chemical admixtures, or use of a different cement or aggregate necessary to meet the requirements of this Special Provision is incidental to the applicable concrete pay items.

Aggregates classified as potentially reactive by the criteria of this Special Provision may be used provided they meet one of the following criteria:

1. A well documented history shall be provided to the Department of at least 10 structures containing the aggregate proposed for use. These structures must be at least 15 years of age, exposed to moisture in service, contain high alkali cement (greater than 0.80% alkali) and indicate a lack of ASR related distress. Petrographic analysis of cores per ASTM-C856 representing the submitted historical structures must indicate the absence of ASR gel formation, aggregate rimming, and associated micro cracking.

   The locations and sampling of cores will be the responsibility of the Department. Costs for the petrographic evaluation of cores will be the responsibility of the Contractor.

2. Test results from an approved and accredited independent laboratory utilizing the current ASTM C-1260 or ASHTO TP-214 Accelerated Mortar Bar Method indicating a safe alkali aggregate combination meeting the requirements of this Special Provision.

Standard Method of Test - MDOT Deleterious Materials Test

Scope

This procedure covers a method for testing coarse aggregate greater than number 4 for deleterious content.

Apparatus

Steel Plate

The steel plate shall be a piece of flat steel 1/4" x 3" x 3".

Sieve

The sieve shall be an eight inch diameter number 4 constructed of brass wire cloth. The height of the sieve from the top of the frame to the wire cloth surface shall be two inches.

Storage Containers

The storage containers shall be at least 16 ounce cups capable of holding a maximum 700 grams of aggregate plus sufficient water to cover the aggregate.

Balance

All weighing shall be performed on a balance or a scale accurate to 0.01 grams with a total capacity of 700 grams.

Definition Of Deleterious Material

Deleterious material is defined as those particles of aggregate which have an absorption of three percent or greater. The bad pieces are recognized as soft, light in weight, laminated, finely porous and streaks heavily on the steel plate. A bad piece will generally show signs of crumbling upon being scratched on the steel plate. When scratched on the steel plate, the border pieces leave a heavy streak and appears to be sounder than a bad piece. A satisfactory border piece will leave a light streak and sound solid when tapped on the steel plate. A good stone leaves no streak and usually scars the steel plate.

Test Sample

The test sample shall consist of plus number 4 material representative of the stockpile. The aggregate shall be washed and oven dried at 221°F to 230°F to a constant weight (NOTE 1).

NOTE 1. The requirement of washing before and after testing may be waived if the aggregate is essentially free from adherent coatings and dust. The elimination of sample washing seldom reduces the measured loss by more than 0.2 percent of the original sample weight.

Procedure

Listed below are the step by step instructions for obtaining the deleterious content of coarse aggregate.

1.1 Reduce the sample by splitting to approximately 100 stones.

1.2 Scratch each stone on the steel plate and place into one of four groups according to the definition above.

1.3 Weigh and record each group to the nearest 0.01 grams.

1.4 Completely cover the groups of aggregate with water and soak them for 24 hours.

1.5 After 24 hours, remove each group from the water and surface dry.

1.6 Immediately weigh each group to the nearest 0.01 gram.

1.7 Calculate the absorption for each group as follows:

$$\text{Absorption} = \frac{\text{surface dry weight} - \text{oven dry weight}}{\text{oven dry weight}}$$

Groups having three percent or greater absorption are considered deleterious.

Calculation

Step by step instructions are given below for calculating the deleterious content.

2.1 Add the oven dry weights of each group to obtain the total weight.

2.2 Divide any group having an absorption of three percent or greater by the total oven dry weight to determine the percent that group represents of the total sample.

2.3 Add all those groups that have three percent or greater absorption together to obtain the total deleterious for that sample.

An example of a deleterious test is given below:

DELETERIOUS TEST

Total Dry Wt. 138.58	Good	Satisfactory Border	Border	Bad
% of sample			0.26	0.41
Sur. Dry Wt. GM	138.25	0.62	0.38	0.61
Oven Dry	137.04	0.61	0.36	0.57
Difference	1.21	0.01	0.02	0.04
Absorption	0.88	1.64	5.56	7.02

Total Deleterious 0.67%

Samples containing three percent or greater deleterious are considered as unsatisfactory material for use in concrete or bituminous mixes.

Standard Method of Test - MDOT Degradation

JUNE 1993

1. SCOPE

1.1 This method describes a procedure for determining the durability of aggregate. Aggregate may be composed of gravel, ledge or a combination of both. The degradation value is a number indicating the relative resistance of an aggregate to produce detrimental claylike fines when subjected to mechanical agitation in the presence of water.

2. SUMMARY OF METHOD

2.1 This method is adapted from Washington state's degradation test (WSDOT Test Method No. 113) with particular modifications to eliminate ambiguity and reduce the need for operator interpretation. The test was originally developed to provide a relatively quick, inexpensive method of determining the degradability of mineral aggregate.

2.2 The sample of aggregate is mechanically separated to a specific grading, then washed and dried to a constant weight. After drying the test sample is prepared for testing.

2.3 The prepared sample is then mechanically agitated with water for 20 minutes; the resulting wash water and minus No. 200 fines are then collected. This is mixed with a stock sand equivalent solution in a sand equivalent cylinder. After a 20 minute settling time, the level of the sediment column is read and mathematically converted to a degradation value.

3. SIGNIFICANCE AND USE

3.1 Degadation is the physical breakdown of mineral aggregate, by abrasion, to detrimental plastic (or clay-like) fines. Material suceptible to degradation is characterized by its relative softness and affinity for water, which together produce plastic fines when the particles are abraded against each other. This abrasion takes place in roadway materials both during and after construction due to the actions produced by traffic loads and may cause premature deterioration of the roadway structure.

3.2 This method assigns an empirical value to the amount, fineness, and character of clay-like material produced from aggregate when subjected to mechanical degradation.

3.3 This test provides a relatively quick and inexpensive method for determining the degradability of an aggregate.

4. APPARATUS

4.1 MECHANICAL WASHING CONTAINER
A flat-bottomed, straight-sided, cylindrical plastic container conforming to the specifications and dimensions shown in Figure 1.

4.2 AGITATOR
A Soiltest portable sieve shaker, model CL-305A as shown in Figure 2 and modified to oscillate at 300± 5 revolutions per minute with a throw of 1 3/4" in a horizontal direction. (Soiltest will make the above modifications upon request).

NOTE 1 - Comparison testing has shown that the amount of and manner in which energy is imparted to the aggregate specimen during the agitation portion of the test has a significant effect on the resulting degradation value. Therefore, it is critical that the agitator used to perform this testing comply in all respects with the requirements provided in this specification. In addition, an in-use agitator should be inspected at frequent intervals to ensure that wear or other factors have not altered the critical dimensions of the apparatus.

4.3 SIEVES
The sieves shall conform to AASHTO M-92 (ESTM E-11).

4.4 BALANCE
The balance shall meet the requirements of AASHTO M-231, class G-2.

4.5 GRADUATE
500 ml, tall form, graduated in 10 ml intervals.

4.6 FUNNEL
The funnel shall be sufficiently large to allow the sieves to rest inside the funnel.

4.7 SAND EQUIVALENT STOCK SOLUTION
The sand equivalent stock solution shall be prepared in accordance to AASHTO T-176, section 2.7, Plastic Fines in Graded Aggregate and Soil by Use of the Sand Equivalent Test. The sand equivalant stock solution shall have a shelf life of 12 months from date of manufacture.

4.8 SAND EQUIVALENT CYLINDER
The sand equivalent cylinder shall conform to AASHTO T-176, Plastic Fines in Graded Aggregate and Soils by use of the Sand Equivalent Test.

4.9 TIMER
An interval timer with alarm and capable of counting down in time.

4.10 SQUEEZE BOTTLE

5. SAMPLE

5.1 Obtain samples to be tested in accordance with AASHTO T-2.

6. PROCEDURE

6.1 Prepare a sample for testing by mechanically sieving the sample for ten minutes over the following sieves: 1/2", 1/4", No. 10 and pan. Discard the plus 1/2" and pan material. Obtain a representative split of approximately 700g of each fraction for testing. The minus 1/2", plus 1/4" material shall be washed over a 1/4" sieve and the minus 1/4", plus No. 10 material shall be washed over a No. 10 sieve. Dry the material in an oven at a temperature of 110± 5°C to a constant weight.

6.2 Remove the sample from the oven and allow to cool to room temperature. Hand shake the minus 1/2", plus 1/4" material over a 1/4" sieve until less than 0.5% passes the sieve in one minute of hand shaking. Hand shake the minus 1/4", plus No.10 material over a No. 10 sieve until less than 0.5% passes the sieve in one minute of hand shaking. No hand manipulation of individual pieces of aggregate in an attempt to pass the aggregate through a sieve shall be permitted.

6.3 Weigh 500 grams of each aggregate portion and place in the plastic container with 200 ml of tap water at room temperature. Cover tightly and place in the degradation agitator. Agitate the sample for 20 minutes.

6.4 Place the funnel in the graduated cylinder (in such a manner that it does not extend into the graduated portion of the cylinder) with the No. 10 and No. 200 sieve set in the top of funnel. Empty the aggregate sample and water from the container onto the No.10 sieve. Wash out the container and the container cover with a squeeze bottle. Wash the aggragate material by directing the spray from the squeeze bottle onto the material. Hold the No. 10 sieve up over the No. 200 sieve at a slightly tilted angle and wash with the squeeze bottle. Occasionally shake the material on the No. 10 sieve to expose more surface area to washing and rinse any build-up on the No. 200 sieve with the squeeze bottle. Continue to wash with the squeeze bottle until the total volume of fines and water in the gradated cylinder is 500 ml. Care should be taken to slow the washing when within 50 ml of the 500 ml level.

NOTE 2 - It is important in this portion of the test that the material be washed clean with only the amount of wash water necessary to produce a volume of 500 ml in the gradated cylinder, including wash water, water from the container, and fines.

6.5 Pour 7 ml of sand equivalent stock solution into the sand equivalent cylinder.

6.6 Seal the top of the 500 ml graduated cylinder with a rubber stopper, dental dam or any other suitable method of sealing. Bring all solids in the graduate into suspension by inverting the cylinder ten times (five cycles). Care shall be taken to insure no leakage occurs and that the bubble formed while inverting the graduate reaches the top of the graduate before inverting again. Immediately pour from the graduate into the sand equivalent cylinder up to the 15 inch mark. Remove any excess over the 15 inch mark. Stopper the sand equivalent cylinder and mix the contents of the cylinder by inverting the cylinder 20 times (10 cycles) in 35 seconds, allowing the bubble to traverse the length of the cylinder between inversions.

6.7 Place the cylinder on a flat, level, vibration free surface. Remove stopper and start the timer immediately. After 20 minutes, read and record the height of the sediment column to the nearest 0.1 inch.

6.8 Use table 1, "Degradation Value, D", to determine the degradation value by selecting the value in column D corresponding with the measured height of the sediment column in column H. Values may range from Zero to 100 with the higher values indicating less degradable materials.

Suggested revisions to Micro-Deval Test Method, July 13th 1998. AASHTO Technical Subcommittee 1C

Standard Test Method
for

Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

1. Scope

1.1 This method covers a procedure for testing coarse aggregate for resistance to abrasion using the micro-Deval apparatus.

2. Referenced Documents

2.1 *AASHTO Standards:*

T 27 Standard Method for Sieve Analysis of Fine and Coarse Aggregates
M 92 Standard Specification for Wire-Cloth Sieves for Testing Purposes

3. Summary of Method

3.1 The Micro-Deval Test is a measure of abrasion resistance and durability of mineral aggregates resulting from a combination of actions including abrasion and grinding with steel balls in the presence of water. A sample with standard grading is initially soaked **in water** for not less than one hour. The sample is then placed in a jar mill with 2.0 litres of water and an abrasive charge consisting of 5000 grams of 9.5 mm diameter steel balls. The jar, aggregate, water, and charge are revolved at 100 rpm for 2 hours. The sample is then washed and oven dried. The loss is the amount of material passing the 1.18 mm sieve expressed as a percent by mass of the original sample.

4. Significance and Use

4.1 The Micro-Deval Test is a test of coarse aggregates to determine abrasion loss in the presence of water and an abrasive charge. Many aggregates are weaker when wet than dry, and the use of water in this test measures this reduction in resistance in degradation in contrast to some other tests which are conducted on dry aggregate. It furnishes information helpful in judging the toughness/abrasion resistance and durability/soundness of coarse aggregate subject to abrasion and weathering action when adequate information is not available from service records.

4.2 The Micro-Deval Test is a useful test for detecting changes in properties of aggregate produced from a source as part of a quality control or quality assurance process.

5. Description of Terms

5.1 *Constant Mass*: Test samples dried at a temperature of 110 ± 5°C to a condition such that it will not lose more than 0.1 percent moisture after 2 hours of drying. Such a condition of dryness can be verified by weighing the sample before and after successive 2 hour drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5°C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.

6. Apparatus

6.1 *Micro-Deval Abrasion Machine:* A jar rolling mill capable of running at 100 ± 5 rpm (Figure 1).

6.2 *Containers*: Magnetic stainless steel micro-Deval abrasion jars having a 5-litre capacity with a rubber ring in the rotary locking cover. Internal diameter – 194 ± 2.0 mm, internal height = 170 ± 2.0 mm. The inside and outside surfaces of the jars shall be smooth and have no observable ridges or indentations (Figure 1).

6.3 *Abrasion Charge:* Stainless steel balls are required. These shall have a diameter of 9.5 ± 0.5 mm. Each jar requires a charge of 5000 ± 5 g of balls.

6.4 *Sieves*: Sieves with square openings, and of the following sizes conforming to AASHTO M 92 specifications: 19.0 mm, 16.0 mm, 12.5 mm, 9.5 mm, 6.7 mm, 4.75 mm, 1.18 mm.

6.5 *Oven*: The oven shall be capable of maintaining a temperature of 110 ± 5°C.

6.6 *Balance:* A balance or scale accurate to 1.0 g.

6.7 *Laboratory Control Aggrégate*: A supply of standard 'Brechin quarry' coarse aggregate available from the Soils and Aggregates Section, Engineering Materials Office, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario, Canada M3M 1J8.

7. Test Sample

7.1 The test sample shall be washed and oven-dried at 110 ± 5°C to constant mass, separated into individual size fractions in accordance with AASHTO T27, and recombined to meet the grading as shown in section 7.2 below.

7.2 Aggregate for the test shall normally consist of material passing the 19.0 mm sieve, retained on the 9.5 mm sieve. An oven-dried sample of 1500 ± 5 g shall be prepared as follows:

Passing	Retained	Mass
19.0 mm	16.0 mm	375 g
16.0 mm	12.5 mm	375 g
12.5 mm	9.5 mm	750 g

7.3 In a case where the maximum nominal size of the coarse aggregate is less than 16.0 mm, a sample of 1500 ± 5 g shall be prepared as follows:

Passing	Retained	Mass
~~13.2~~ 12.5 mm	9.5 mm	750 g
9.5 mm	6.7 mm	375 g
6.7 mm	4.75 mm	375 g

7.4 In a case where the maximum nominal size of the coarse aggregate is less than 12.5 mm, a sample of 1500 ± 5 g shall be prepared as follows:

Passing	Retained	Mass
9.5 mm	6.7 mm	750 g
6.7 mm	4.75 mm	750 g

8. Test Procedure

8.1 Prepare a representative 1500 ± 5 g sample. Record the Mass 'A' to the nearest 1.0 g.

8.2 Saturate the sample in 2.0 ± 0.5 litres of tap water (temperature 20 ± 5°C) for a minimum of 1 hour either in the micro-Deval container or some other suitable container.

8.3 Place the sample in the micro-Deval abrasion container with 5000 ± 5 g of steel balls and the water. Place the micro-Deval container on the machine.

8.4 Run the machine at 100 ± 5 rpm for 2 hours ± 1 minute for the grading shown in 7.2. For the grading shown in 7.3, run the machine for 105 ± 1 minutes. For the grading shown in 7.4, run the machine for 95 ± 1 minutes.

8.5 Carefully pour the sample over two superimposed sieves: 4.75 mm and 1.18 mm. Take care to remove all of the sample from the stainless steel jar. Wash and manipulate the retained material with water using a hand held water hose and the hand until the washings are clear and all material smaller than 1.18 mm passes the sieve. Remove the stainless steel balls using a magnet or other suitable means. Discard material smaller than 1.18 mm.

8.6 Combine the material retained on the 4.75 mm and 1.18 mm sieves, being careful not to lose any material.

8.7 Oven dry the sample to constant mass at 110 ± 5°C.

8.8 Weigh the sample to the nearest 1.0 g. Record the Mass 'B'.

9. Calculations

9.1 Calculate the micro-Deval abrasion loss, as follows, to the nearest 0.1%.
Percent Loss = (A – B)/A x 100.

10. Use of a Laboratory Control Aggregate

10.1 Every 10 samples, but at least every week in which a sample is tested, a sample of the standard reference aggregate shall also be tested. The material shall be taken from a stock supply and prepared according to Section 7.

10.2 Trend Chart Use: The percent loss of the last twenty samples of control material shall be plotted on a trend chart in order to monitor the variation in results (Figure 2).

10.3 The mean loss of the Brechin control aggregate in multi-laboratory study of the micro-Deval test is 16.9% . Individual test data should fall within the range 15.6 % to 18.3 % loss nineteen times in twenty.

11. Report

11.1 The report shall include the following:

11.1.2 The maximum size of the aggregate tested and the grading used.

11.1.3 The percent loss of the test sample to one decimal place.

11.1.4 The percent loss of the control aggregate, tested closest to the time at which the aggregate was tested, to one decimal place.

11.1.5 The percent loss of the last twenty samples of reference material on a trend chart.

12. Precision and Bias

12.1 The multilaboratory precsion has been found to vary over the range of this test. The figures given in Column 2 are the coefficients of variation that have been found to be appropriate for the materials described in Column 1. The figures given in Column 3 are that limits that should not be exceeded by the difference between the results of two properly conducted tests expressed as a percent of their mean.

Aggregate abrasion loss (percent)	Coefficient of Variation (percent of mean) *A*	Acceptable Range of Two Results (percent of mean) *A*
5	10.0	28
12	6.4	18
17	5.6	16
21	5.3	15

A These numbers represent, respectively, the (1s%) and (d2s%) limits as described in ASTM C670

12.2 Bias The procedure in this test method for measuring resistance to abrasion has no bias because the resistance to abrasion can only be defined in terms of the test method.

Suggested revisions to Micro-Deval Test Method, July 13th 1998. AASHTO Technical Subcommittee 1C

APPENDIX

(Nonmandatory Information)

X1. INTERPRETATION OF TEST RESULTS

X1.1 In studies of the performance of aggregates in this test (1, 2), the limits in Table 1 have been found useful for separating aggregates of satisfactory performance from those of fair or poor performance.

TABLE 1

Application	*Maximum micro-Deval abrasion loss (%)*
Granular sub-base	30[1]
Granular base	25[1]
Open graded base course	17[1]
Asphalt concrete base course and secondary surface course	21[1]
Asphalt concrete surface course	17[1] 18[2]

REFERENCES

(1) Rogers, Chris. "Canadian experience with the micro-Deval test for aggregates". In: Latham, J.-P. (ed) 1998. *Advances in Aggregates and Armourstone Evaluation*, Geological Society, London, Engineering Geology Special Publications, 13, 139-147.

(2) Kandhal, Prithvi S., Parker, Frazier Jr., "Aggregate Tests Related to Asphalt Concrete Performance in Pavements". Final Report prepared for National Cooperative Highway Research Program, Transportation Research Board, Washington, May 1997.

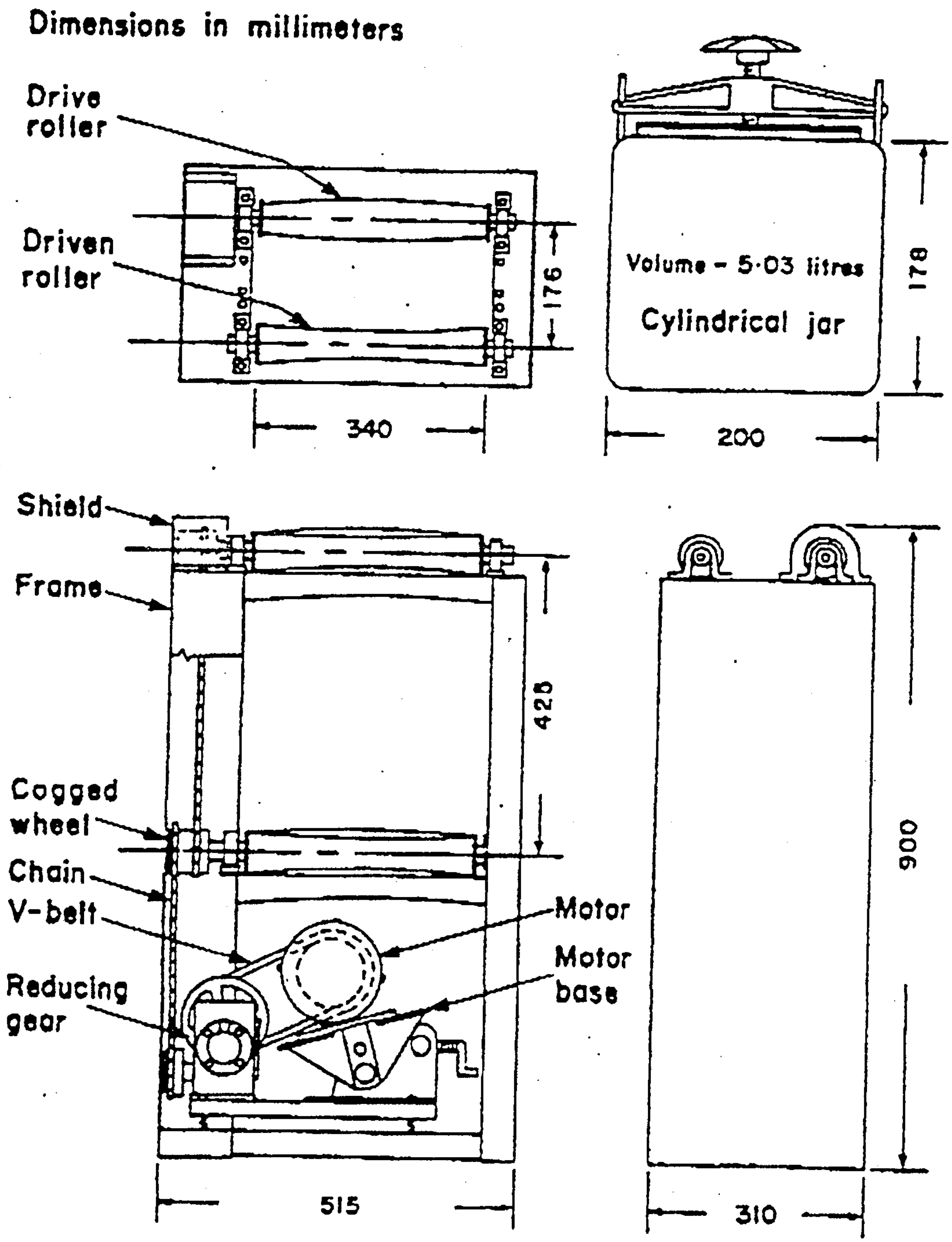


Figure 1

Micro-Deval Abrasion Machine and Container

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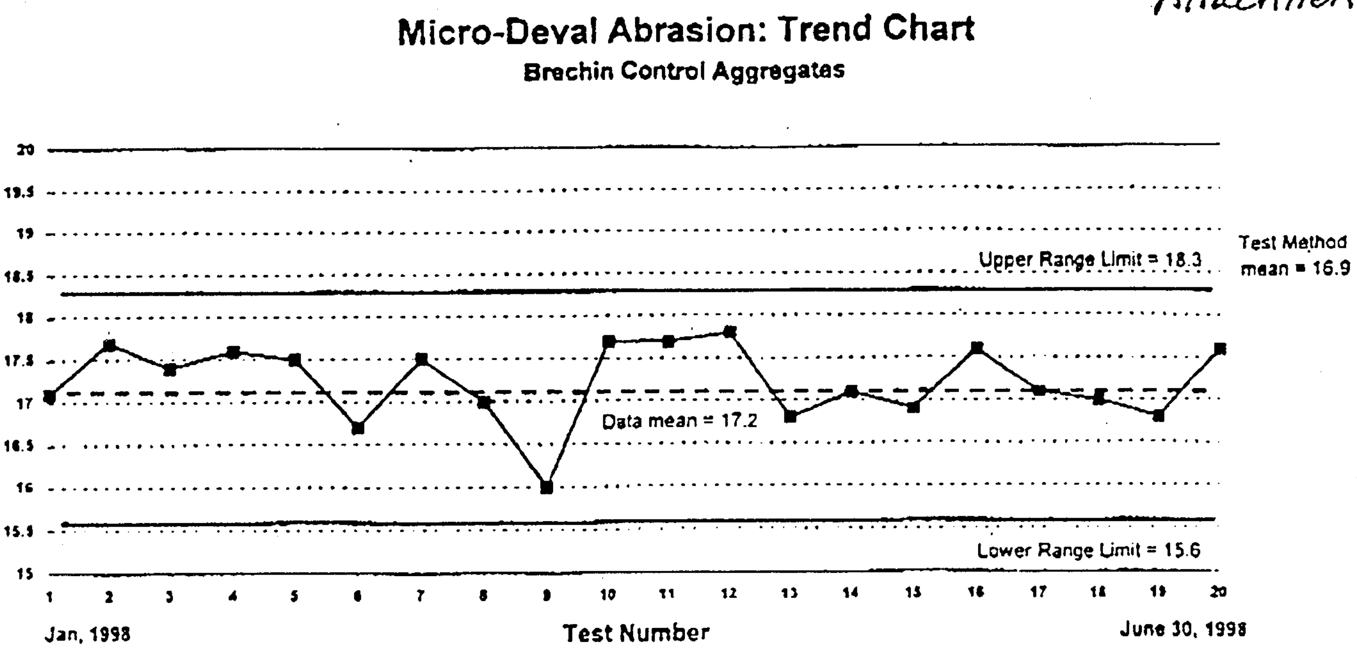

Figure 2. Micro-Deval Abrasion Trend Chart for Brechin Control Aggregates