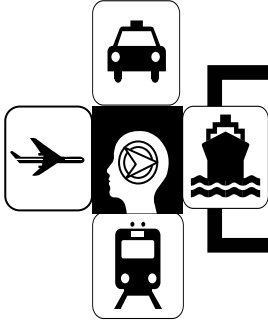


# JERSEY DOT'S

"Turning Problems into Solutions"



## Tech Brief

### Development of a Performance Specification for Granular Base and Subbase Material

Need a solution?  
Think Jersey DOT

FHWA-NJ-2005-003

Feb 2005

SO, HERE'S THE PROBLEM...

- Due to the importance of New Jersey's transportation infrastructure, an enormous emphasis has been placed on the long-term performance of pavements;
- Currently, the NJDOT does not utilize any type of performance specification when selecting materials for pavement construction;
- Unfortunately, the selection of granular base and subbase aggregates for pavement construction is solely based on the material (aggregate) passing a gradation specification;
- It is well known that the gradation of aggregate materials highly influences how the material performs (i.e. – strength, stiffness, drainage);
- Diminishing supplies of virgin aggregates have the NJDOT moving towards using larger percentages of recycled aggregate materials (recycled asphalt pavement – RAP and recycled concrete aggregate – RCA). Unfortunately, limited information is available on their pavement-related performance; and
- Although creating a "true" performance-based specification for the aggregate suppliers would come at a large financial burden for the NJDOT, evaluating the performance of aggregate materials at the NJDOT gradation limits will provide guidance on how to modify the gradation specifications to promote better long-term performance.

AND, HERE'S OUR SOLUTION

- Sample NJDOT approved aggregate suppliers (one from each region – North, Central and South) for NJDOT I-3 and DGABC;
- Sample recycled asphalt pavement (RAP) and recycled concrete aggregate (RCA) from a local supplier;
- Evaluate the performance of the NJDOT I-3, DGABC, RAP, RCA, and virgin/recycled aggregate blends under laboratory tests that characterize the material under pavement related loading conditions. The laboratory testing included:
  - Permeability (drainage);
  - California Bearing Ratio (bearing capacity);

- Triaxial shear strength (static strength/stability)
  - Cyclic triaxial testing (cyclic strength/permanent deformation susceptibility); and
  - Resilient modulus (stress-dependent stiffness).
- Provide recommendations to the NJDOT on how to modify the current gradation specifications to promote better performing base and subbase aggregates, as well as to provide recommendations on utilizing the maximum amount of recycled aggregates without sacrificing the pavement's performance.

We set out to characterize virgin and recycled aggregates under performance-related tests, such as (Figure 1):



(a)



(b)

Figure 1 – (a) California Bearing Ratio (CBR) and (b) Resilient Modulus, Static and Cyclic Triaxial Test Set-up

The virgin, aggregate materials were tested at the extremes (high end and low) and middle of the NJDOT aggregate gradation specification, as well as the natural gradation. The gradations specifications followed are (Figures 2 and 3);

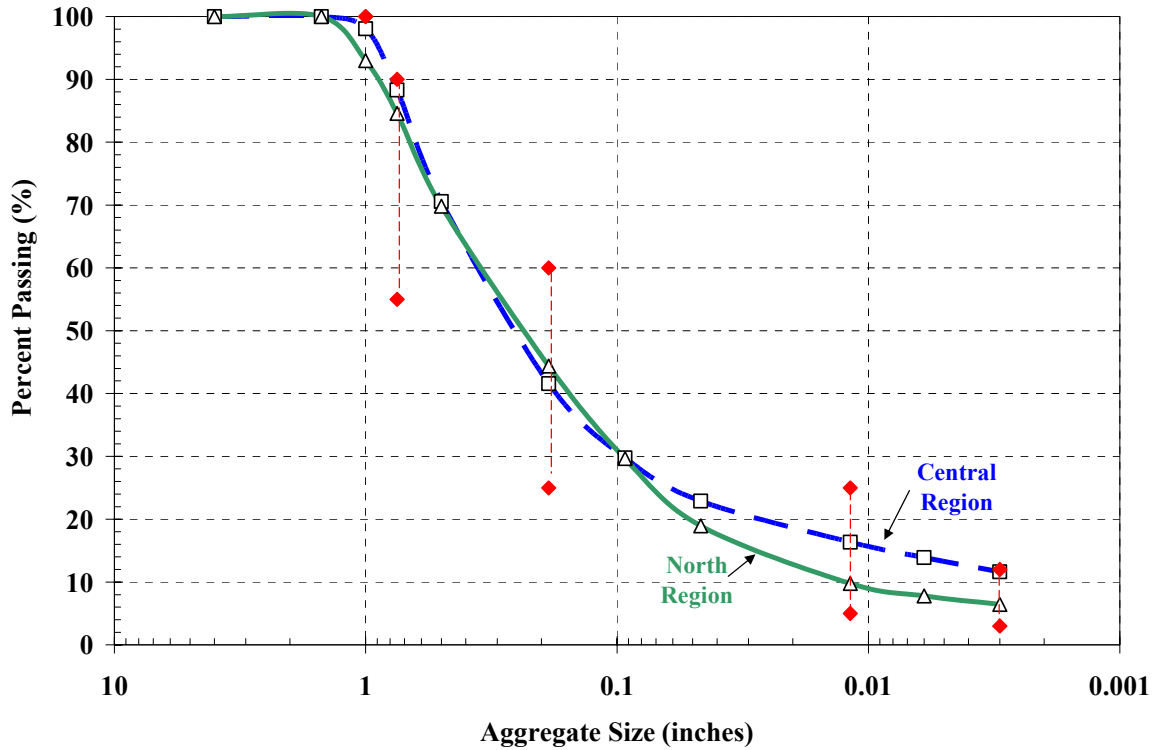


Figure 2 – DGABC Natural Gradations and NJDOT Specifications (Red Lines)

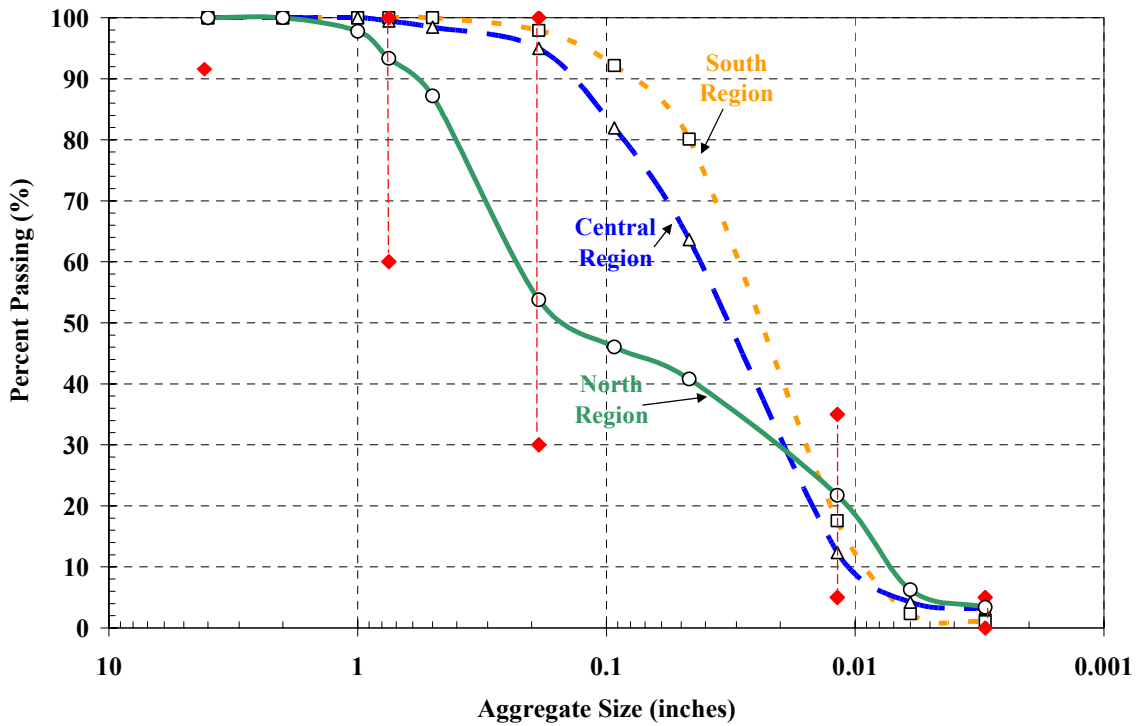


Figure 3 – NJDOT I-3 Natural Gradations and NJDOT Specifications (Red Lines)

The recycled, aggregate materials were tested at their natural gradations (Figure 4).

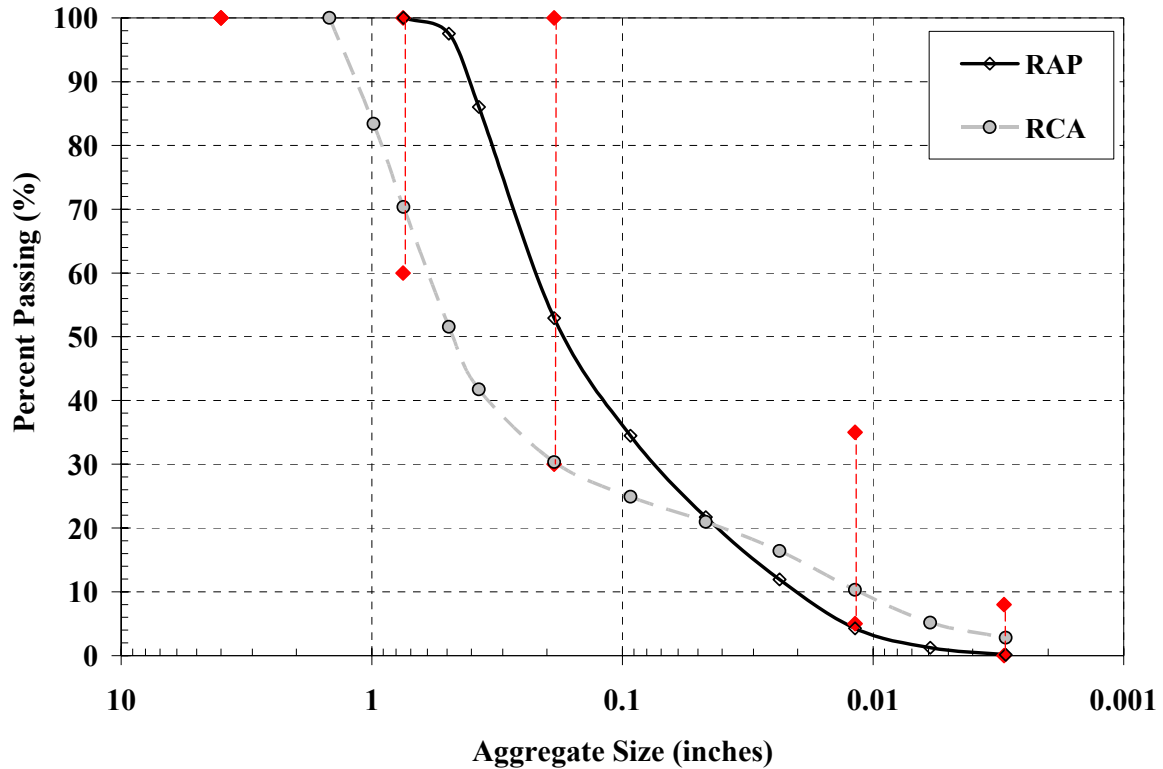


Figure 4 - RAP and RCA Gradations Shown with the NJDOT I-3 Gradation Bands

A large amount of testing was conducted on the different aggregates (NJDOT I-3 and DGABC at the different gradations) and aggregate blends (recycled materials and the recycled/virgin aggregate blends);

- Over 50 gradation tests;
- Over 120 compaction tests;
- Over 70 permeability tests (both Falling Head and Constant Head);
- Over 80 California Bearing Ratio tests;
- Over 75 static triaxial tests;
- Over 35 resilient modulus tests; and
- Over 40 cyclic triaxial tests.

Some samples performed well, while others did not (Figure 5).



(a)



(b)

Figure 5 – (a) NJDOT I-3, Central Jersey High End Gradation Before Cyclic Triaxial Testing

(b) NJDOT I-3, Central Jersey High End Gradation After Cyclic Triaxial Testing

### ***HERE'S WHAT WE CAME UP WITH...***

- The permeability of the DGABC at a natural gradation was approximately three times faster than the NJDOT I-3 at a natural gradation. The permeability of the DGABC and NJDOT I-3 was found to be extremely dependent on the aggregate's gradation. Very fast permeabilities were achieved at the high end of the gradation range ( $> 250$  ft/day for NJDOT I-3 and  $> 2,000$  ft/day for DGABC) while extremely slow permeabilities were found at the Low End of the respective gradations ( $< 7$  ft/day for NJDOT I-3 and  $< 2$  ft/day for the DGABC). For the DGABC, three orders of magnitude in the permeability values can be expected from the extreme ends of the gradation range.
- When the recycled materials were blended with the DGABC, the permeability values decreased. RCA, blended from 25 to 75% of total weight, decreased the permeability by approximately half, while RAP blended at percentages of 25 and 50% lowered the permeability by 1/3. However, the addition of RAP at 75% lowered the permeability to almost less than 1 ft/day. 100% RCA obtained almost no permeability, while the 100% RAP had a permeability value of approximately 16 ft/day.
- The use of either falling head or constant head permeability testing of aggregate materials will provide very similar results until the permeability measured from the constant head test becomes greater than 100 ft/day. Due to the hydraulic gradient within the permeability sample is controlled in the constant head test, Darcy's law is always valid. However, no such control is provided in the falling

head test. Therefore, permeability testing of DGABC aggregates is recommended to be conducted in a constant head apparatus, while permeability testing of NJDOT I-3 aggregates can take place in either constant or falling head devices, as long as the gradation of the NJDOT I-3 does not approach the high end of the gradation band.

- As the addition of RAP increased, the CBR values greatly decreased. Meanwhile, the addition of RCA minimally lowered the CBR values. The 100% RAP sample obtained the lowest CBR value (20) and the 100% RCA sample obtained the largest CBR value (205) of all samples tested. The effect of gradation on the CBR value was much greater in the DGABC material than the NJDOT I-3. For the DGABC samples, the CBR value increased as the gradation moved from the Low End to the High End of the gradation range, with the natural gradation obtaining the largest CBR value (195). Meanwhile, a difference of CBR value equaling 15 was found throughout the gradation range of the NJDOT I-3.
- Results from the static triaxial test showed that the high end, middle, and natural gradations obtained similar shear strength properties for the DGABC and NJDOT I-3, respectively. Within these gradations, the DGABC typically obtained friction angles on the order of 50 to 54 degrees, while the NJDOT typically obtained friction angle on the order of 39 to 45 degrees. The NJDOT I-3 sampled from the North region obtained much larger friction angles than the Central and South regions due mainly to its higher degree of angularity (the North region contained a large fraction of slag material and even shell particles). For both aggregate types, the low end of the gradation band resulted in friction angles almost 15% lower than the coarser gradations.
- Static triaxial tests conducted on 100% RAP and 100% RCA samples showed that the 100% RAP samples obtained shear strength parameters similar to the NJDOT I-3, while the 100% RCA obtained shear strength parameters similar to the DGABC aggregates.
- Resilient modulus test results showed that the addition of recycled aggregates, either RAP or RCA, increased the resilient modulus properties of the DGABC base course material. A 50:50 blend of either recycled aggregate with DGABC showed to increase the resilient modulus by approximately 50% for the pavement scenario used in the comparison. Both the 100% RAP and 100% RCA obtained very similar resilient modulus properties and were also found to obtain the largest values in the study.
- The effect of aggregate gradation clearly influenced the resilient modulus properties of the NJDOT I-3 and DGABC aggregate samples, however, the values were more affected when the gradation was at the respective low end of the gradation band. The high end gradation for the NJDOT I-3 was not able to be tested due to its instability with the first 5 test sequences in the resilient modulus test procedure (AASHTO T46-94). The test specification notes that if 5% accumulated axial strain occurs, the test procedure should be stopped and the sample recompacted and again tested. Each high end gradation sample of the NJDOT I-3 was tested a minimum of two times with the same eventual outcome of excessive accumulated axial strain. The natural gradation was typically found to obtain the largest resilient modulus for both the NJDOT I-3 and DGABC samples.
- Permanent deformation testing of the recycled aggregate blends indicated that the addition of RCA to DGABC lowered the accumulated permanent strain after

- 100,000 loading cycles. In fact, as the percent of RCA increased, the accumulated permanent strain decreased with the 100% RCA obtaining the lowest value of all samples tested. Meanwhile, as the addition of RAP increased in the DGABC, the accumulated permanent strain after 100,000 loading cycles also increased. The 100% RAP sample obtained one of the largest accumulated permanent strains of all natural gradation materials tested in the study (on the same order of magnitude of the NJDOT I-3 samples).
- The permanent deformation testing of DGABC at varying gradations showed that minimal accumulated permanent strain is obtained at the natural, high end and middle gradation range (typically less than 2% for both North and Central source although the middle range of the Central source obtained 4.2%). The low end of the DGABC gradation band accumulated excessive permanent strain (> 13%). The NJDOT I-3 material showed to be extremely unstable at the high end of the gradation band, with samples showing extreme failure (> 30% permanent strain), and also accumulated excessive permanent strains at the low end of the gradation band (> 12% permanent strain). The middle range and natural gradation (which typically fell on the middle area of the NJDOT I-3 gradation band) accumulated the lowest permanent strains, although still somewhat excessive. However, it should be noted that due to its deeper location in the pavement system, the NJDOT I-3 material would most likely be exposed to lower applied stresses than the DGABC, and therefore perform better.

### ***THE BOTTOM LINE...***

#### NJDOT I-3 Aggregate

The gradation specification of the NJDOT I-3 should be tightened to represent more of the middle of the gradation band. Samples at the high end of the gradation band were found to be highly unstable under cyclic loads (similar to past NJDOT problems with non-stabilized open graded, NSOG, aggregates). Meanwhile, when the NJDOT I-3 was at the lower end of the gradation band, the permeability was greatly reduced, the shear strength, CBR, and resilient modulus values were the lowest, and the accumulated permanent strain was excessive.

#### NJDOT DGABC

The gradation specification of the NJDOT DGABC should become coarser. Samples constructed at the low end of the gradation band were found to be highly impermeable, obtain the lowest CBR, shear strength, and resilient modulus, and also accumulate excessive permanent strain. A majority of the problems associated with the low end of the gradation specification for the DGABC can be attributed to the large amount of fines allowed (12%).

### Recycled Aggregates and Blends – RAP

The percent by total weight allowed for RAP blended with DGABC should be limited to 50%. At percentages greater than 50%, permeability and CBR values greatly reduce from the DGABC at natural gradation. An even though the resilient modulus increases with the increase in percent RAP added, the accumulated permanent deformation from the cyclic triaxial test actually increases. This contrast in results can be explained by the resilient modulus test ignoring any permanent strains accumulated during the test, simply relying on resilient or elastic strain to compute modulus (resilient modulus). Shear strength and CBR properties of the 100% RAP samples were also found to be similar to that of the NJDOT I-3 materials, also providing evidence that RAP should be included in limited amounts in the base course aggregate layer.

### Recycled Aggregates and Blends – RCA

The percent by total weight allowed for RCA blended with DGABC can be blended as high as 75%. The addition of RCA showed to increase CBR and resilient modulus properties and also lower accumulated permanent strain. The shear strength of the RCA was also found to be comparable to DGABC at its respective natural gradations. However, the addition of RCA was found to decrease the permeability of the DGABC, although blended percentages of 25, 50, and 75% were found to decrease the permeability of the DGABC:RCA blend almost equally. Even though the permeability of the DGABC:RCA blends decreased the permeability of the naturally graded DGABC by almost 60%, the final permeability of the DGABC:RCA blend was still found to be of similar to greater magnitude than the NJDOT I-3 at its respective natural gradation. Percents greater than 75% RCA may create a very “tight” aggregate structure that will not allow drainage, as shown by the permeability test results of the 100% RCA which was almost impermeable.

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A final report is available online at

<http://www.state.nj.us/transportation/research/research.html>

If you would like a copy of the full report, please FAX the NJDOT, Division of Research and Technology, Technology Transfer Group at (609) 530-3722 or send an e-mail to [Research.Division@dot.state.nj.us](mailto:Research.Division@dot.state.nj.us) and ask for:

### Development of a Performance Specification for Base and Subbase Materials

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