NAVARRO & WRIGHT
CONSULTING ENGINEERS, INC.

February 23, 2015

Via Electronic Mail

Ms. Brenda Reigle, Executive Director
NUCA of Pennsylvania
4400 Deer Path Road, Suite 106
Harrisburg, PA 17110-3908

RE: **Independent Laboratory Testing Results**
Report No.: FHWA-PA-2014-008-PSU WO 12A
Report Title: Evaluation of Hydraulic Plate Compactor
Date: December 26, 2014 (Final Report)
Authors: Tong Qiu, Ming Xiao, and Chaoyi Wang
Thomas D. Larson Pennsylvania Transportation Institute
The Pennsylvania State University
Sponsor: The Pennsylvania Department of Transportation
Bureau of Planning and Research

Dear Brenda:

As requested by NUCA of Pennsylvania, Navarro & Wright Consulting Engineers, Inc. (N&W) has performed a supplemental review of the materials used for the referenced "Evaluation of Hydraulic Plate Compactor" study. Our supplemental review involved a series of laboratory tests conducted on materials recovered from the Lower Paxton Township site during this study. The new laboratory testing results and our conclusions relative to the ramifications of these results are presented herein.

Following moisture conditioning and mixing of the onsite stockpile with the John Deere 544K loader operated by the JOAO & Bradley Construction Company, Inc. on November 21, 2014, the undersigned sampled the PennDOT No. 2A Coarse Aggregate in accordance with applicable portions of PTM No. 607 / AASHTO T2 for sampling from stockpiles. Samples were remixed and quartered at the N&W laboratory in accordance with PTM 625 / AASHTO T248. Following sample preparation, a series of laboratory tests were performed as follows:

Corporate Office:
151 Reno Avenue
New Cumberland, PA 17070
T: 717-441-2216
www.navarrowright.com

Construction Materials Laboratory:
10 Mars Street
Harrisburg, PA 17113
T: 717-348-8820
dgassert@navarrowright.com

Testing Standard	Test Description
AASHTO T27/T11	Sieve Analysis of Fine and Coarse Aggregates
AASHTO T84/T85	Specific Gravity and Absorption of Fine and Coarse Aggregates
PTM 106, Method B	The Moisture-Density Relations of Soils Using a 5.5-lb. Ramer and 12-inch Drop
AASHTO T100	Specific Gravity of Soils
ASTM D4718	Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
ASTM D4253/D4254	Maximum / Minimum Index Density and Unit Weight of Soils Using a Vibratory Table and Calculation of Relative Density

Testing result summaries are attached, and all tests were performed by AASHTO-accredited laboratories. Note: AASHTO does not offer accreditation for the ASTM D4253/D4254 testing procedures.

DISCUSSION

The grain size distribution curve developed by N&W from the materials stockpiled at the Lower Paxton Township site is similar to, but relatively more well-graded than, the grain size distribution curve offered in the "Evaluation of Hydraulic Plate Compactor" study. Both the most recent grain size curve presented herein, along with the curve offered in the Evaluation, technically do not achieve PennDOT Specification criteria for compaction testing by nuclear moisture-density techniques. Consequently, by strict interpretation of PennDOT Specifications, Publication 408, this PennDOT No. 2A Coarse Aggregate must be evaluated by nonmovement criteria as previously discussed in our December 26, 2014 letter to NUCA. Nevertheless, on a practical basis, the most recent gradation curve generated by N&W suggests that the material used at the Lower Paxton Township site was very similar to a material that could have potentially been tested via nuclear moisture-density testing methods as permitted by Publication 408.

The Standard Proctor, PTM 106, Method B, is specified for the evaluation of compacted Embankment or Subbase by Sections 206 and 210 of PennDOT Specifications, Publication 408. The last sentence on page 2 of the Evaluation report reads as follows: "Based on the Standard Proctor compaction test conducted by the quarry (PTM No. 106), the mix had a maximum dry density of 2.17 gram/cm^3 (135.2 pcf) and an optimum moisture content of 7.7%." N&W has identified a significant discrepancy between the maximum dry density determined by the quarry and the maximum dry density determined by the N&W laboratory per PTM 106, Method B. The N&W laboratory determined the maximum dry density to be 126.0 pcf at an optimum moisture content of 5.8%. The precise reason for this discrepancy is currently unknown. This significant discrepancy exists for one or more of the following potential reasons:

1. Fluctuations in material properties at different sampling locations
2. Use of an oversize correction curve, such as ASTM D4718, by the quarry
3. Use of non-standard laboratory testing techniques by the quarry
4. Use of the Modified Proctor instead of the Standard Proctor by the quarry
5. Misinterpretation of the quarry Standard Proctor by utilizing the maximum wet density of the Proctor as the maximum dry density.

PTM 106 does not require an oversize correction such as ASTM D4718 to be applied Standard Proctor, and we have not seen it applied to PennDOT No. 2A Coarse Aggregates in practice. In order to illustrate what the potential maximum dry density and optimum moisture content would be in the event that such an oversize correction is applied, two proctor curves are presented. The base curve remains as 126.0 pcf at 5.8% moisture as physically tested in the laboratory. A curve with the ASTM D4718 correction applied appears above the laboratory curve as 136.9 pcf at 4.3% moisture. Specific gravity testing was performed in order to support the ASTM D4718 calculations. By strict interpretation of the PTM 106, only the base curve with a maximum dry density of 126.0 pcf is correct.

Finally, an alternative laboratory compaction procedure was conducted. The maximum and minimum index densities of the PennDOT No. 2A Coarse Aggregate sampled at the Lower Paxton Township site are 103.8 pcf and 88.6 pcf, according to ASTM D4253 and D4254, respectively. ASTM D698 (The Standard Proctor), Section 1.5 states the following:

> *This test method will generally produce a well-defined maximum dry unit weight for non-free draining soils. If this test method is used for free-draining soils the maximum unit weight may not be well defined, and can be less than obtained using Test Methods D4253.*

Nevertheless, in this case, the Standard Proctor maximum dry density per PTM 106, Method B is greater than the maximum index density per ASTM D4253. The PennDOT No. 2A Coarse Aggregate sampled at the Lower Paxton Township site falls within the limits for a "free-draining soil" as defined in ASTM D4253 and D4254. Free-draining soils, as defined by ASTM D4253/D4254, have less the 15% of their grain sizes passing a No. 200 sieve. The tested sample had 10.5% passing the No. 200 Sieve. Because PennDOT No. 2A is typically used as roadway subbase, it should be free-draining. As quoted above, the Standard Proctor is not intended for non-free draining materials. The maximum dry density determined by the Standard Proctor is commonly regarded to be approximately equivalent to 70% relative density as determined by ASTM D4253 / ASTM D4254. Consequently, standard specifications by the American Institute of Architects, AIA, typically require cohesionless soils used as structural fill and backfill (including trenching) to be compacted to 70% relative density per ASTM D4253 / D4254. The 70% relative density benchmark for the material used for the "Evaluation of Hydraulic Plate Compactor" study is computed as 98.7 pcf, or much less than the Standard Proctor value. Reasons for this discrepancy are offered in the Conclusions and Recommendations to follow.

CONCLUSIONS

1. Based on a revised PTM 106 Method B Standard Proctor maximum dry density of 126.0 pcf at 5.8% optimum moisture content, all nuclear moisture-density compaction tests performed at the Lower Paxton Township site, except for seven (7) tests, demonstrate back-calculated results exceeding 100% compaction.

2. Two (2) of the seven (7) test results that did not achieve 100% compaction were previously noted as aberrations by the study authors due to the direct transmission rod of the nuclear gauge penetrating into the uncompacted 2B stone bedding.
3. The remaining five (5) tests that did not achieve 100% compaction are represented by four (4) test pairs. Three (3) of these four (4) test pairs averaged greater than 100% compaction for each respective pair.
4. Only the test pair for the 24-inch lift over the reinforced concrete pipe did not average greater than 100% compaction for the pair. This pair averaged 98.7% compaction. The nuclear compaction tests for this pair were obtained by scraping techniques, and the actual percentage compaction is likely significantly higher as discussed in our December 26, 2014 letter to NUCA.
5. Based on the field testing results from the "Evaluation of Hydraulic Plate Compactor" study, coupled with laboratory testing results as specified by PennDOT, the Allied Model 1000B Hydraulic Plate Compactor is capable of compacting PennDOT No. 2A Coarse Aggregate to 100% compaction in uncompacted lift thicknesses of at least 24 inches. This conclusion assumes that 100% compaction is relative to PTM 106, Method B and presupposes that errors introduced by scraping techniques are rectified.
6. The maximum dry density determined by PTM 106, Method B for the PennDOT 2A used at Lower Paxton Township is greater than 70% relative density as determined by ASTM D4253/D4254. This relationship suggests that degradation of the coarse aggregate has occurred during the PTM 106 testing process and such degradation is not as apparent in the ASTM D4253/D4254 testing procedures.
7. Mechanical compaction of PennDOT No. 2A Coarse Aggregate, as measured relative to the 100% of the Standard Proctor, will require contractors to break down the aggregate particles in order to achieve the required minimum acceptable dry density/compaction. Such degradation of the aggregate may not be necessary for construction of serviceable backfill sections. Aggregate breakdown and degradation will negatively influence the drainage characteristics of the mechanically compacted material.
8. In order to discourage aggregate degradation, compaction testing relative to the ASTM D4253/D4254 testing procedures should be regarded as more appropriate than assigning field compaction percentages relative to the Standard Proctor. It would not be unreasonable to expect contractors to compact backfill consisting of PennDOT No. 2A Coarse Aggregate to the maximum index density as determined by ASTM D4253.

Yours sincerely,

Navarro & Wright Consulting Engineers, Inc.

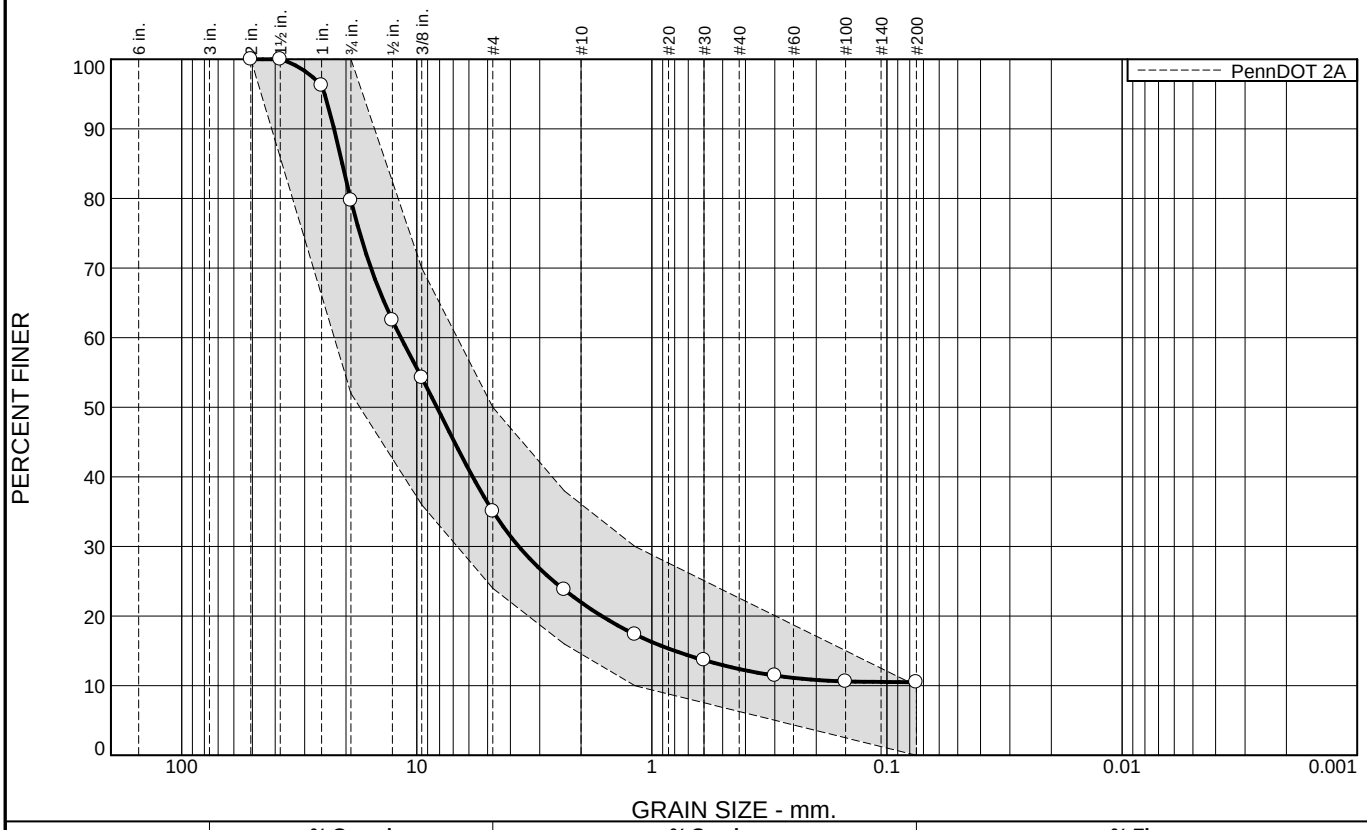
David C. Gassert

David C. Gassert, P.E., LEED AP, QA Department Manager

DCG/RMP/d
Attachments: Grain-Size Distribution Curve and Proctor Curve

cc: Paul J. Navarro, P.E., President and C.E.O.
Robert M. Peda, P.E., Engineering Technology Group Manager

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	20.3	44.6	13.1	9.6	1.9	10.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
2"	100.0	100.0	
1.5"	100.0		
1"	96.3		
3/4"	79.7	52.0 - 100.0	
1/2"	62.5		
3/8"	54.3	36.0 - 70.0	
#4	35.1	24.0 - 50.0	
#8	23.8	16.0 - 38.0	
#16	17.4	10.0 - 30.0	
#30	13.7		
#50	11.5		
#100	10.6		
#200	10.5	0.0 - 10.0	X

* PennDOT 2A

Soil Description

Minimum Index Density (pcf) = 88.6
Maximum Index Density (pcf) = 103.8

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 22.4776 D_{85}= 20.7439 D_{60}= 11.6802
D_{50}= 8.2094 D_{30}= 3.6829 D_{15}= 0.7982
D_{10}= C_u= C_c=

Classification

USCS= AASHTO=

Remarks

Specific Gravity (Dry) = 2.659
Specific Gravity (SSD) = 2.665
Specific Gravity (App) = 2.677 Absorption (%) = 0.3

Location: BK-1
Sample Number: 2A

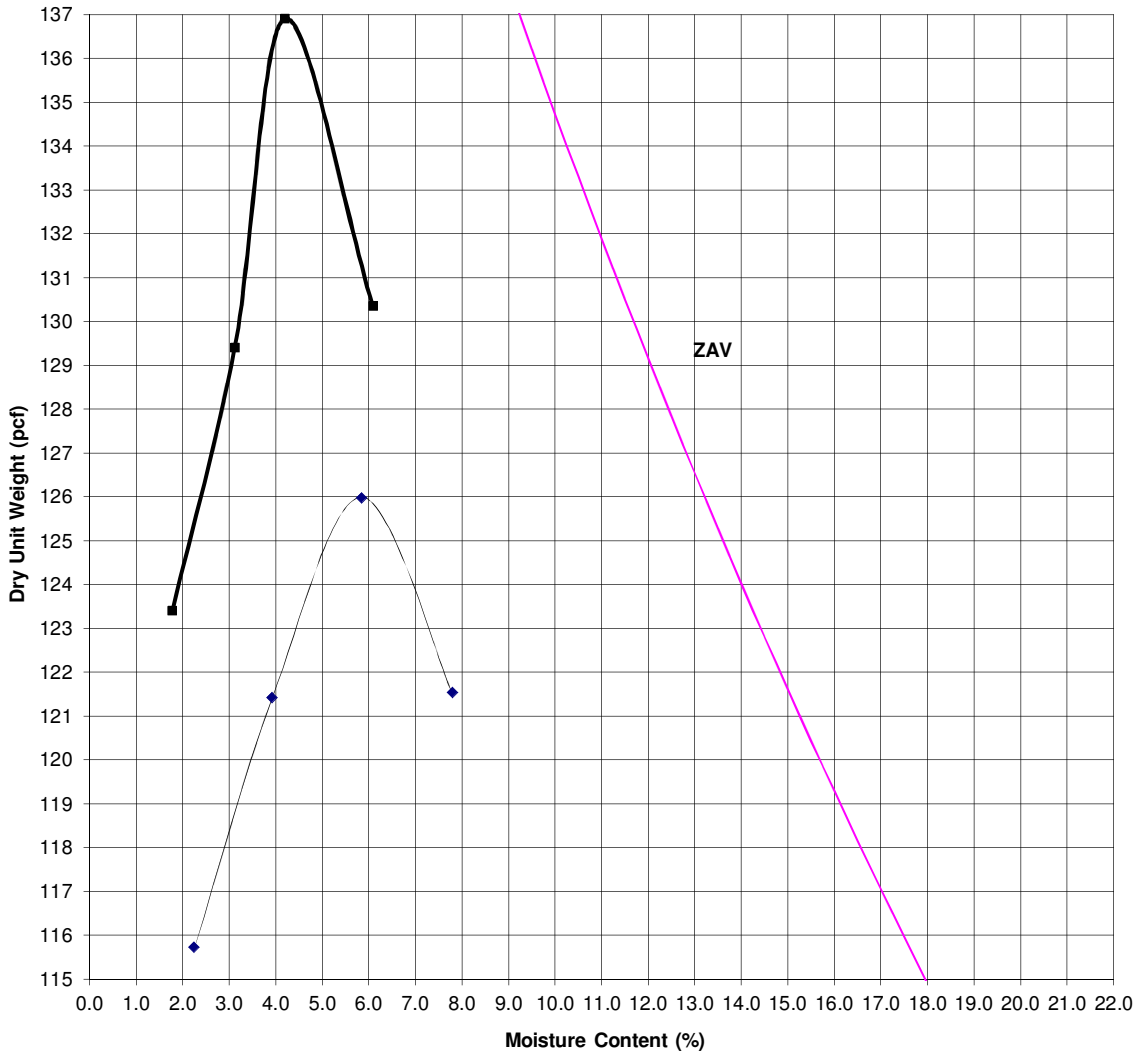
Date: 02/11/2015

PENNONI ASSOCIATES INC.

Client: Navarro & Wright Consulting Engineers< icn.
Project: 1411QA123

Project No: NAWR-1301 **Figure** 127745

Compaction Curve



Project:	Evaluation of Hydraulic Plate Compactor	**Soil Type:**	
Boring No.:	n/a	PennDOT #2A	
Station:	Lower Paxton	**Classification:**	n/a
Offset:	Stockpile	LL = n/a %	PI = n/a %
Sample No.:	BK-1	**Max. Dry Density:**	126.0 pcf
Depth:	n/a ft	**Opt. Moisture:**	5.8 %
		Corrected Curve:	4.3% & 136.9 pcf

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

STANDARD PROCTOR COMPACTION TEST RESULTS

PTM 106 (Method B) & ASTM D 4718