Unbound Pavement Applications of Excess Foundry System Sands: Subbase/Base Material

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Participant Job Description

Which of the following describes your job?

- Civil Engineer or Environmental Engineer
- Geologist
- Foundry Operator
- Transportation Materials Engineer
- Construction Manager
Participant Background

- Private sector
- Public sector
- Planner
- Designer
- Regulator
- Contractor
- Marketing
UNBOUND PAVEMENT APPLICATIONS OF ESS

Roadway structural systems
  – Working Platform
  – Subbase
INTRODUCTION

Majority of the paved roads in the United States constructed with FLEXIBLE PAVEMENTS.
Deformation during construction on soft subgrade:

- Impede construction equipment
- Complicate placement of subbase, base, and asphalt
- Requires **working platform**
According to Tensar (1989) the soft subgrade problems can be as bad as this!!
Questions:

• How to determine thickness of working platform to limit total deflection to a certain value under construction traffic

• How to determine the thickness of working platform constructed with foundry sands
Equivalency as defined in this research requires that total deflection of the alternative material ($\delta_{ta}$) equal to that of breaker run ($\delta_{tb}$) under the same load at 1000 cycles over soft subgrade.
METHODOLOGY TO SELECT THICKNESS OF WORKING PLATFORM BASED ON $\delta_t$

A chart is developed showing:

- The thickness of each working platform material to limit $\delta_t$ to a certain value

- Equivalency between breaker run and alternative materials in terms of $\delta_t$ ($\delta_t$-alternative materials $= \delta_t$-breaker run)
Design Chart Relating Thicknesses

Alternative Material Thickness, $h_a$ (m)

Breaker Run Thickness, $h_b$ (m)

- **Grade 2 Gravel**
  - $d_t$ (mm) = 50.0
  - $d_t$ (mm) = 37.5
  - $d_t$ (mm) = 25.0
  - $d_t$ (mm) = 12.5

- **F. Slag**
  - (Tap slag)

- **B. Ash**

- **F. Sand with 10% bentonite**
  - (At optimum w (16%))

Note: 1.0 in = 0.025 m
<table>
<thead>
<tr>
<th>Foundry Byproduct</th>
<th>Water Content</th>
<th>Thickness in meters (inches in parenthesis) to limit total deflections to 25 mm (1 in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundry Sand</td>
<td>21%</td>
<td>1.81 (71)</td>
</tr>
<tr>
<td>Foundry Sand</td>
<td>16%</td>
<td>0.32 (13)</td>
</tr>
<tr>
<td>Foundry Slag</td>
<td>Not sensitive to water content</td>
<td>2.55 (100)</td>
</tr>
</tbody>
</table>
Normalized CBR $[\frac{CBR_a}{CBR_b}]$

- $\delta_t = 12$ mm $[h_b = 0.86$ m$]$
- $\delta_t = 25$ mm $[h_b = 0.41$ m$]$
- $\delta_t = 50$ mm $[h_b = 0.20$ m$]$

Note: $CBR_b = 80$

- F. Slag
- B. Ash
- Grade 2 Gravel
- B. Run
- F. Sand (w=16%)
Recap

- What are the requirements for a working platform over soft subgrade: (a) limit total deflections, (b) allow heavy construction traffic without getting bogged down, (c) achieve this only during construction, (d) all of the above?

- True or false: foundry sand bentonite content is not important

- True or false: foundry sand water content is important during construction
OBJECTIVES OF EES AS SUBBASE OF THE ROADWAY STRUCTURAL SYSTEMS STUDY

- To catalog pertinent engineering properties of ESS for use in roadway structural system (both as working platform and subbase) and correlate these properties to index properties.
- To assess effect of water content and compactive effort on engineering properties.
SCOPE OF THE STUDY

- 12 clay-bonded ESS, 1 chemically bonded ESS, a base sand, and 2 reference materials (meeting WisDOT base and subbase specs) were tested in the laboratory.

- ESS from WI, IL, MI & IN

- Tests Conducted:
  - Index Properties
  - Compaction
  - CBR
  - Unconfined Compression
  - Resilient Modulus
INDEX PROPERTIES

- $D_{10}$: 0.002 to 0.18 mm
- $P_{200}$: 1.1 to 16.4%
- Clay Content ($< 2 \mu m$): 0.8 to 10%
- Active Clay Content (methylene blue): 5.1 to 10.2%
- $C_u$ : 1.4 to 130 and $C_c$ : 1.1 to 69
- LL : NP to 27  PI : NP to 8 (required rehydration)
- Particle Roundness: 0.55 to 0.69 (subrounded to subangular)
- $G_s$ : 2.52 to 2.73
- Classify as: SC, SP, or SP-SM or A-2-4 or A-3
Recap

- What is the primary characteristic that varies between foundry sands: (a) sand roundness, (b) fines and clay content, or (c) color?
- True or false: Foundry sands have similar grain size distribution characteristics.
- True or false: Foundry sands are essentially like poorly graded sand or sand with fines.
- True or false: Foundry sand meet the subbase specifications exactly.
Some ESS behave as granular material and some cohesive.

Hydration of compaction samples for 1 week is needed to reactivate the thermally deactivated clay.

Standard Proctor Maximum Dry Unit Weights: 17.26 to 18.39 kN/m$^3$

Optimum Moisture Contents: 9.1 to 13.8%

Vibratory Table Maximum Dry Unit Weights: 16.55 to 17.60 kN/m$^3$
ESS 1
ESS 2
ESS 9
ESS 10
ESS 11
ESS 14

Dry Unit Weight (kN/m$^3$)
Compaction Water Content (%)
S=100% 
(G$\_s$ 2.65)
CBR

- CBR: 4 to 40 at optimum moisture content with an average 20 (20-30 considered very good for subbase)
- Can be estimated empirically from standard Proctor maximum density, percent fines, and roundness:
  \[
  CBR = 32.4 \gamma_{dm} - 1.93P_{200} - 264R_o - 361
  \]
- Comparable to reference subbase
- Modified Proctor gives markedly higher CBR
Recap

- True or false: Compaction curves for foundry sands appear very different than those for soils.
- True or false: Standard compaction procedure for soils can be used for foundry sands.
- True or false: CBR values for all foundry sands rate as “good quality” for subbase purposes.
Resilient Modulus: BC < 6%
Resilient Modulus: BC > 6%
Effect of Compaction Condition: BC < 6%
Effect of Compaction Condition: BC > 6%
RESILIENT MODULUS

Power function best represented the data

$$M_r = K_1 \left( \sigma_b \right)^{K_2}$$

where $\sigma_b$ is bulk stress ($\sigma_b = \sigma_d + 3 \sigma_c$)
RESILIENT MODULUS RELATIONSHIPS

\[ K_1 = 612 \gamma_{dm} - 111 \text{ CBR} \]
\[ K_2 = 0.696 - 2.22 \times 10^{-5} K_1 \]
\[ K_2 = 0.049 P_c - 3.61 D_{10} \]
RESILIENT MODULUS

- Resilient modulus close to reference base material’s for foundry sands with BC < 6%
- Resilient modulus comparable to reference subbase material’s for foundry sands with BC > 6% (for optimum and dry of optimum conditions)
- At low $\sigma_b$ (<200 kPa) which is typical in pavements, $M_r$ of ESS is higher than reference subbase material’s
Deformation after construction:
(Accumulation of plastic shear strain and consolidation of the subgrade)

- Cracking or rutting of the asphalt under repeated traffic loading
\[ SN = SN_1 + SN_2 m_2 + SN_3 m_3 \]

\[ SN_i = a_i \times D_i, \quad a_i = f(M_{r-i}) \]
Structural Contribution as a Subbase

\[ a_3 = 0.227 \log M_{r-3} - 0.839 \]

\[ SN_3 = a_3 \times D_3 \]
Structural Number of the Working Platform, $S_N$

Thickness of the Working Platform, $h$ (m)

- Breaker Run
- Grade 2 Gravel
- Bottom Ash
- Foundry Sand with 10% bentonite (At optimum w (16%))
Permanent deformation analyses using resilient moduli of foundry sands

- Rate of accumulation very low \((\varepsilon \sim 5.0 \times 10^{-6})\) per load application
- Permanent deformation very low, typically \(< 0.01\) mm after 10 million load applications
- Permanent strain comparable to reference subbase, more than reference base
- Minimize rutting & improve performance of rigid pavements
RECAP

- True or false: Excess foundry system sands do not offer a viable and economical alternative as working platform or a subbase material.
- True or false: ESS are not all the same and their properties depend on their fines and active clay content as well as particle shape.
- True or false: Large variety of ESS have resilient modulus comparable or higher than granular subbase material.
Compaction with Padfoot Compactor
<table>
<thead>
<tr>
<th>Station</th>
<th>Control</th>
<th>F/Slag</th>
<th>F/Sand</th>
<th>B/Ash</th>
<th>Control</th>
<th>F/Ash</th>
<th>Geocell</th>
<th>GT</th>
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Maximum Deflection (mm) at 90 kN

May/16/2001
Oct/12/2001
May/15/2002
Oct/21/2002
(b) Working Platform (Subbase)
Season May, 2005

(There are 5 outlier points from 4000 to 10000 MPa in F/Ash Section)