FOUNDRY
SANDS

Foundry Sand in Subbase Layers

Introduction

Like many states, Wisconsin has areas of soft native soils that make road construction problematic. In fact, 40% of the state has soft silts, while 20% is soft clays. The normal procedure for dealing with soft soils is to remove the upper layers of the material and replace it with 12 inch and greater sized crushed rock in order to provide an adequate working platform for construction traffic. The crushed rock is a select material, meaning it is more expensive than regular fill materials, and sometimes has to be transported at great distance from the quarry to the work site. A working group from the Wisconsin Department of Transportation (WisDOT) considered new techniques to deal with the problem of soft soils, and suggested that a pilot study be conducted to investigate the use of other granular materials for the working platform. One of the materials that was investigated was grey iron foundry sand from Wisconsin's foundries.

Foundry sand is a very high grade sand used for making molds in the metal casting industry. The sand is typically more than 90% silicon dioxide (SiO_2) and is composed of angular grains. Over time, the foundry sand becomes worn, going from angular grains to subangular or subrounded grains which no longer meet foundry sand specifications for casting molds. The worn sand is removed and often sent to landfills (about 880,000 tons per year in Wisconsin) even though the used foundry sand is a valuable material for use as fine aggregate in highway construction applications. The foundry sand used in this project was "Green Sand" which means it contains some bentonite clay used as a binder for making molds, though the sand is actually black from the presence of sea coal, a form of crushed coal which is used as a finishing aid. Using foundry sand as subbase material benefits WisDOT because the sand is much cheaper than crushed rock, and it saves select material for higher value projects. Depending on the project locations, transportation distances may be reduced, which saves fuel and reduces emissions. Using foundry sands is also environmentally beneficial because it reduces the amount of sand going to landfills, saving that space for true wastes, and reduces the water, fuel, and energy consumed to mine new aggregate while at the same time reducing green house gas emissions from mining and transportation equipment.

Project Description

The foundry sand demonstration was constructed as part of a larger demonstration of alternative granular materials along a 0.9 mile segment of Wisconsin State Highway 60 (STH 60) near Lodi, Wisconsin. The foundry sand was placed in bulk along a 166 yard stretch as a 33 in thick subbase layer (Figure 1). It was placed over the native soft clay subgrade, and covered with base layer composed of a 5.5 in thick lower course of crushed reclaimed asphalt and a 4.5 in thick upper course of crushed aggregate base. The top layer was 5 inches of hot mix asphalt. Figure 2 shows the cross section of the foundry sand test section. The control section was identical except that the subbase layer was composed of reclaimed stone from cuts made as part of the STH 60 modifications. The physical and environmental properties of the sections have been monitored for more than 8 years.

Figure 1: Spreading the foundry sand with a bulldozer.

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ENGINEERING PROPERTIES

One component of the pavement design was that the foundry sand and control sections would be structurally equivalent so that their performance could be compared over time. The properties of the foundry sand are shown in Table 1, with the crushed stone base (classified by WisDOT as Grade 2 gravel) shown for comparison. The only difference between the foundry sand section and the control section was the excavated stone subbase, which was reported to include cobbles from 3 to 14 inches in diameter and a soil fraction consisting of approximately 30% gravel, 65% sand, and 5% fines. The 1993 AASHTO Pavement Design Guide was used to determine the layer thicknesses equivalent to a layer with a structural number of 4.2 subjected to 435,080 ESALs. Based on CBR measurements, the foundry sand and control section had the same design thickness.

Note that the D_{10}, D_{60} and C_u values indicate that the foundry sand is very fine with a narrow range of grain sizes. The dry unit weight was only 71% of the gravel, which is a benefit when placed over soft soils because the weight is reduced. The optimum water content was roughly twice that of the gravel, which was due to the bentonite clay content (approximately 10%). This clay content is at the upper end for foundry sand, and many other sands would have a lower optimum water content.

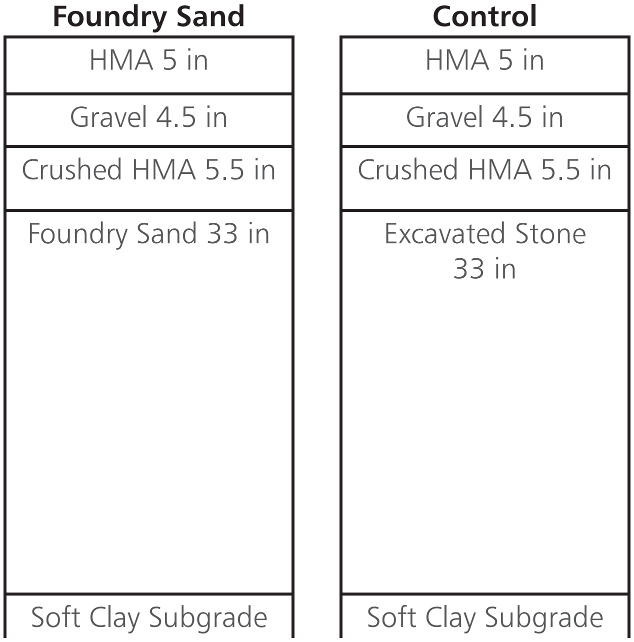

Figure 2: Cross section of foundry sand and control sections.

It is also interesting that the resilient modulus of the foundry sand is higher than would be expected given the CBR values, and is higher than the resilient modulus of the gravel. The CBR is a measure of bearing capacity, and a low CBR value is not surprising given the clay content and fine grained nature of the material. The resilient modulus is a measure of the stiffness of material. The higher the stiffness, the more load a material can support without significant deformation. These results suggest that the foundry sand is a relatively stiff material and provides a good foundation for highways. The only issue is moisture sensitivity due to the bentonite clay, which could possibly soften the layer during wet periods.

Table 1: Summary of Test Procedures and Results

Property	Foundry Sand (Subbase)	Grade 2 Gravel (Base)
Specific Gravity	2.55	2.65
D_{10} (mils)	0.0079	3.54
D_{60} (mils)	9.8	236.2
Uniformity Coefficient (C_u)	1250	66.7
Max. Dry Unit Weight (lb/ft^3)[a]	102.4	143.7
Optimum Water Content (%)	16	8.2
CBR (%)	7	N/D
Resilient Modulus (MN/m^2)[b]	400-900	120-350
[a] Standard Proctor Compaction Test (ASTM D 698)		
[b] AASHTO Resilient Modulus Test (T294-94)		
N/D = Not Determined		

CONSTRUCTION PROPERTIES

Since foundry sand is just that, sand, it was placed and compacted using standard construction equipment. It was placed in 6 inch lifts and compacted with a tamping foot roller and a smooth-wheel roller. After placing and compacting the last lift, the top of each subbase layer was compacted again with steel drum and rubber tired compactors to provide a flat surface. During construction the dry unit was monitored with a nuclear density gauge to verify that compaction exceeded 95% standard proctor compaction. The only construction issue of note was that it rained on the foundry sand during transport and construction, causing compaction problems. The high bentonite content of the foundry sand made it relatively sensitive to water content with regard to compaction. However, after letting the foundry sand dry, the contractor was able to handle and compact the foundry sand without problems.

Construction was complete in October 2000, and a series of falling weight deflectometer tests were conducted immediately after construction, in May 2001 after the spring thaw, and again in October 2001. Deflections in the foundry sand and control sections were comparable after construction, but the foundry sand was about one-half as stiff during the spring. This was likely due to the fine grained nature of the material and the presence of the bentonite, which was on the high side at 10%. However, the foundry sand had regained its original stiffness in the fall. Figure 3 shows a recent photo of the pavement. The section has been monitored for more than 8 years, and the pavement performance has been essentially the same for both foundry sand and control sections.

Figure 3: Surface of STH 60 in Lodi, Wisconsin.

ENVIRONMENTAL PROPERTIES

Water leach tests (WLTs) were conducted on the foundry sand according to ASTM D 3987 to determine the suitability of the sand for use as subbase material. The foundry sand met all the requirements in Section NR 538 of the Wisconsin Administrative Code for byproducts used in confined geotechnical applications. However, questions have persisted about the long-term leaching behavior of foundry sands, so this project included two pan lysimeters underneath the subbase, one at the edge and one at the center line. Figure 4 shows similar pan lysimeters being installed at a different part of the project.

Pan lysimeters are essentially geotextile structures that gather water that has percolated through the pavement structure and sends it to bottles for collection. The reason for using pan lysimeters is that the effluent gathered is representative of the actual porewater concentrations of contaminants that one would expect for the amount of precipitation in the area. This study focused on the metals cadmium, chromium, selenium and silver. Monitoring of the site is on going, though the last cumulative report was issued in December, 2005. In the report, the leachate collected from the lysimeters was compared to Wisconsin groundwater standards, which are much more stringent than the NR 538 standards used to determine the suitability of industrial byproduct materials.

Figure 4: Construction of pan lysimeters similar to those used at the site.

The groundwater quality standards that apply to this project are defined in Section NR 140 (Groundwater Quality) of Wisconsin Administrative Code. The Wisconsin standards are the same as or more strict than USEPA MCLs and are shown for the metals of concern in Table 3. The peak lysimeter concentrations are also shown in Table 3. Only selenium exceeded the ground water standard. Curiously, the selenium levels of both the foundry sand and control both increased with time and then plateaued, suggesting the selenium is coming from the base materials. More information on the leaching data is available from Lee and Benson (2006) and from Sauer et al. (2005).

Table 3. Leaching Criteria and Measured Values for Foundry Sand.

Constituent of Concern	Wisconsin Standard (µg/L)	Peak Lysimeter Concentration (µg/L)
Cadmium	5	2.8
Chromium	100	6.1
Selenium	50	105
Aluminum	50	2.6
µg/L - micrograms per liter		

ECONOMICS

The economics of using foundry sand for subbase materials are not well defined by this project because the foundry sand was not provided as a commodity material but was instead provided at a reduced cost for the demonstration. However, as a general rule, foundry sand is much less expensive the select materials like crushed stone, so it would appear from the results that foundry sand can could be used for the same or less money than using crushed stone, which would provide a cost savings. Of course, the transportation costs must also be considered when conducting an economic analysis.

PROJECT CONTACTS

Foundry Sand Supplier **Grede Foundries** **David Williamson** (608) 524-9556 DWilliamson@grede.com	**Contractor** **H. James and Sons, Inc.** **H James & Sons Inc** (608) 822-6558	**Principal Investigator** **University of Wisconsin** **Tuncer Edil** University of Wisconsin 2226 Engineering Hall 1415 Engineering Drive Madison, WI 53706-1691 (608) 262-3225 edil@engr.wisc.edu
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ASTM D 698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.

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Wisconsin Administrative Code Chapter NR 538: Beneficial Use of Industrial By Products
www.legis.state.wi.us/rsb/code/nr/nr538.pdf

Wisconsin Administrative Code Chapter NR 140: Groundwater Quality
www.legis.state.wi.us/rsb/code/nr/nr140.pdf

Recycled Materials Resource Center foundry sand portal - http://www.rmrc.unh.edu/materials/fs/

FHWA Recycling Webpage - http://www.fhwa.dot.gov/pavement/recycling/