THE NEW HAMPSHIRE BOTTOM ASH PAVING DEMONSTRATION
US ROUTE 3, LACONIA, NEW HAMPSHIRE

CRAIG N. MUSSELMAN
CMA Engineers
Portsmouth, New Hampshire

T. TAYLOR EIGHMY
Environmental Research Group
University of New Hampshire
Durham, New Hampshire

DAVID L. GRESS
Department of Civil Engineering
University of New Hampshire
Durham, New Hampshire

MATTHEW P. KILLEEN
Environmental Permitting
Wheelabrator
Environmental Systems
Hampton, New Hampshire

JAMES R. PRESHER
Concord, New Hampshire
Regional Solid Waste/Resource
Recovery Cooperative
Penacook, New Hampshire

MICHAEL H. SILLS
Waste Management Division
New Hampshire Department
of Environmental Services
Concord, New Hampshire

ABSTRACT

A two year demonstration project has been initiated where bottom ash collected from the Concord, NH waste-to-energy facility was used as a 50% aggregate substitute in a binder course asphalt pavement in the reconstruction of US Route 3 in Laconia, NH. The demonstration pavement construction was completed in May, 1993, and was funded in part by the U.S. Environmental Protection Agency and the U.S. Department of Energy.

The demonstration project includes significant testing of potential environmental impacts and pavement performance both in the laboratory and at the demonstration roadway. Data being gathered include analytical data on groundwater and surface water quality impacts, surface run-off and suction lysimeter samples. Asphalt plant air emissions testing was also conducted. Physical roadway performance is being monitored through remote sensing using strain, resistance and temperature probes as well as in situ and destructive pavement analysis.

INTRODUCTION

In May, 1993, a 2,000 linear foot section of US Route 3 in Laconia, New Hampshire was reconstructed in part utilizing bottom ash from a waste-to-energy facility as a substitute for 50% of the natural aggregate in a binder course asphalt pavement. This pavement demonstration was preceded by several years of research regarding the physical and environmental characteristics of bottom ash and the formulation of effective asphalt mix designs. Following completion of the demonstration roadway construction, a two year monitoring program is being completed. Field data is being generated and analyzed regarding potential surface water and groundwater quality impacts and physical roadway performance.

This research and demonstration project has been funded by Wheelabrator Environmental Systems, Inc.; the Concord Regional Solid Waste/Resource Recovery Cooperative, a consortium of 27 New Hampshire municipalities; and the City of Laconia, New Hampshire. Additional funding and support is being provided by the US Environmental Protection Agency; the US Department of Energy, National Renewable Energy Laboratory; and the New Hampshire Department of Transportation.

The research project has been under the direction of the University of New Hampshire, through the UNH Environmental Research Group and the Department of Civil Engineering. The US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory is assisting in certain materials testing and pavement performance evaluations. CMA Engineers, Inc., of Portsmouth, New Hampshire provided planning, permitting, engineering and public participation assistance. The asphalt plant used for the demonstration project was provided by Pike Industries, Inc., a regional northern New England asphalt paving firm.

BACKGROUND

Utilizing waste-to-energy ash as an aggregate substitute in asphalt paving is not a new concept. In the late 1970's and early 1980's, research by the Federal Highway Administration successfully demonstrated the feasibility of utilizing bottom ash in pavement applications from a physical performance standpoint. Demonstration roadways were constructed in Massachusetts, Pennsylvania, Washington, DC, Texas and Florida. These successful demonstrations did not lead to widespread utilization of ash in the United States. Through the 1980's, a combination of federal and state regulatory and testing uncertainties, along with local controversy in some places, have resulted in general ash management practices consisting of combining bottom ash with fly ash and scrubber residues with disposal of this combined ash in lined "monofills," or ash-only landfills. As regulatory uncertainties continue to be resolved, the utilization of bottom ash in an environmentally sound manner is an option which merits further consideration.

The utilization of bottom ash is a standard practice in certain European countries. It has been estimated that over 50 percent of bottom ash generated in the Netherlands, Denmark and Western Germany was utilized in 1989 in road subbase construction, wind barriers, sound barriers, land reclamation and in asphaltic and portland cement paving applications. Most of these utilization scenarios entail segregating bottom ash from fly ash, scrubber products, riddlings and siftings and utilizing screened and aged bottom ash from which ferrous materials have been removed.

The potential for the utilization of significant quantities of bottom ash in the United States is significant. About 60–70% of ash generated in a typical waste-to-energy facility could potentially be utilized in a manner as outlined herein. Successful front end recycling programs are capable of removing 20 to 40 percent of materials from the wastestream. The successful utilization of bottom ash has the potential for increasing the recycled component by up to an additional 30 percent of the total wastestream over and above the materials recycled prior to combustion. This may be accomplished while saving scarce lined landfill capacity for those materials which require such disposal and conserving natural resources through reduced use of natural aggregates. In areas of the country where natural aggregate prices are high due to scarcity of materials, cost savings may also be realized.

ASH CHARACTERISTICS

The bottom ash used for the research and the demonstration pavement described herein was generated by the 500 ton per day waste-to-energy facility located in Concord, NH. The combustion units are of a reciprocating grate design. Typically, grate ash and riddlings are collected from a wet ash quench trough through an inclined conveyor. Fly ash and dry lime scrubber product from fabric filters are combined with the bottom ash at the top of the conveyor. For demonstration purposes, the riddlings, economizer ash, fly ash and scrubber residues were segregated, allowing use of quenched bottom (grate) ash only. The ash used for the roadway demonstration was screened to 3/4 inch minus using a portable vibrating screen. Ferrous materials are not removed at the facility and thus were present in all ash samples.

An extensive sampling and analysis program was initiated to define ash characteristics and to assess the time dependent variation (i.e., by the day of the week or season of the year) of both physical and environmental characteristics of importance in considering ash utilization in asphalt paving. Over a period of 18 months, hourly and composite bottom ash samples were gathered on 18 separate days. These bottom ash samples included riddlings and economizer ash and were not screened to 3/4 inch minus. The average physical characteristics for selected parameters based on a summary of the 18 sampling events are presented in Table 1. The ash was demonstrated to be reasonably consistent over time in terms of grain size distribution, mass passing the 3/4 inch sieve, specific gravities and most other physical characteristics. The average values for a wide variety of physical characteristics indicate that bottom ash is generally acceptable for ash asphalt pavement purposes.

One physical characteristic in Table 1 bears particular note. The LA Abrasion test results show 47.3 and 43.4%. This is in comparison to a typical standard of 50% for binder course pavement aggregates. The bottom ash appears to meet this specification, but most New Hampshire aggregates yield lower LA Abrasion test results. The LA Abrasion test entails abrading a sample using steel balls placed with the test material in a rotating steel container to evaluate the structural soundness of the aggregate. As was determined here, and experienced as described later in this paper, the ash was shown to be more subject to abrasion than most strong natural aggregates. This is not considered to be of significance with respect to physical performance in binder course asphalt pavement but may have relevance in formulating bottom ash asphalt mix designs and in asphalt plant operations when using bottom ash aggregate.

Figure 1 indicates the average grain size distribution of various blends of bottom ash and natural aggregate compared to maximum and minimum values required by the New Hampshire Department of Transportation. The bot-

TABLE 1 BOTTOM ASH PHYSICAL CHARACTERISTICS

	Number of Samples	Minimum	Maximum	Average
Mass < 3/4"	72	49.8	79.2	67.0
Moisture Content (%)	72	22.4	60.6	37.9
Specific Gravities:				
Bulk (Fine Fraction)	72	1.5	2.22	1.86
Bulk (Coarse Fraction)	72	1.93	2.44	2.20
Loss on Ignition (%)	72	3.2	10.0	6.4
Ferrous Content (%)	72	11.8	39.6	25.8
Passing #4 Sieve (%)	72	42.0	62.1	51.1
Passing #200 Sieve (%)	72	1.5	5.8	3.9
LA Abrasion (Grading B) (%)	2	-	-	47.3
LA Abrasion (Grading C) (%)	2	-	-	43.4
Soundness < No. 4 (%)	4	10.4	14.3	11.9
Soundness > No. 4 (%)	4	2.5	2.8	2.6
CBR @ 0.1 inch (%)	18	74.0	85.5	79.8
CBR @ 0.2 inch (%)	18	104.5	116.1	110.3
Maximum Proctor Density (pcf)	18	106.9	110.2	108.6

TABLE 2 BOTTOM ASH AND SOIL ELEMENTAL COMPOSITION (mg/kg)[c]

	Bottom Ash[a]		Soils[b]	
	Range	Average	Range	Average
Al	34,400-64,800	52,530	10,000-300,000	71,000
Ca	51,200-102,900	78,275	7,000-500,000	13,700
Fe	56,400-114,950	82,940	7,000-550,000	38,000
Si	182,500-274,000	233,000	230,000-350,000	320,000
Na	20,200-48,000	37,200	750-7,500	6,300
K	7,200-11,600	9330	400-30,000	8,300
Ba	785-1,480	978	100-3,000	430
Mg	1,900-10,700	7,555	600-6,000	5,000
Cl	1,105-4,190	2,289	20-900	100
Br	16.65-126	45.5	1-10	5
Mn	605-1,560	1,033	20-3,000	600
Ti	3,490-9,500	7,085	1,000-10,000	4,000
Sr	0.0-1,000	581	50-1,000	200
As	17.9-189	42.0	1-50	5
Sb	60-283	118.0	-	-
V	31.6-123	57.5	20-500	100
Mo	20-161	45.4	0.2-5	2
Co	21-43	29	1-40	8
Cr	867-2,005	1,419	1-1,000	100
Cu	1,140-6,980	2,414	2-100	30
Ni	249-855	610	5-500	40
Zn	2,198-7,640	3,500	10-300	50
Pb	1,200-6,600	2,855	2-200	10
Cd	2.62-70.6	18	0.01-0.70	0.06
Hg	0.0-2.25	0.95	0.01-0.30	0.03

[a] Data based on 18 daily composites collected to date.

[b] Data based on compilation by Lindsay (1979) for a wide variety of soils.

[c] Riddlings and economizer ash were not excluded from these samples.

tom ash averages, including those for 100% bottom ash aggregate, fall within the specifications, as did virtually all individual data points.

The elemental composition of the bottom ash in comparison to data available on a variety of soils is presented in Table 2. Again, the bottom ash was found to be reasonably consistent over time with ranges for most elements being more narrow than ranges reported for typical soils. The concentrations of most heavy metals in bottom ash were elevated with respect to those levels in typical soils. It should be noted that these heavy metal concentrations are significantly lower than are typically found in fly ash and/or combined ash and the leachability of these metals is significantly reduced by asphalt encapsulation as described below.

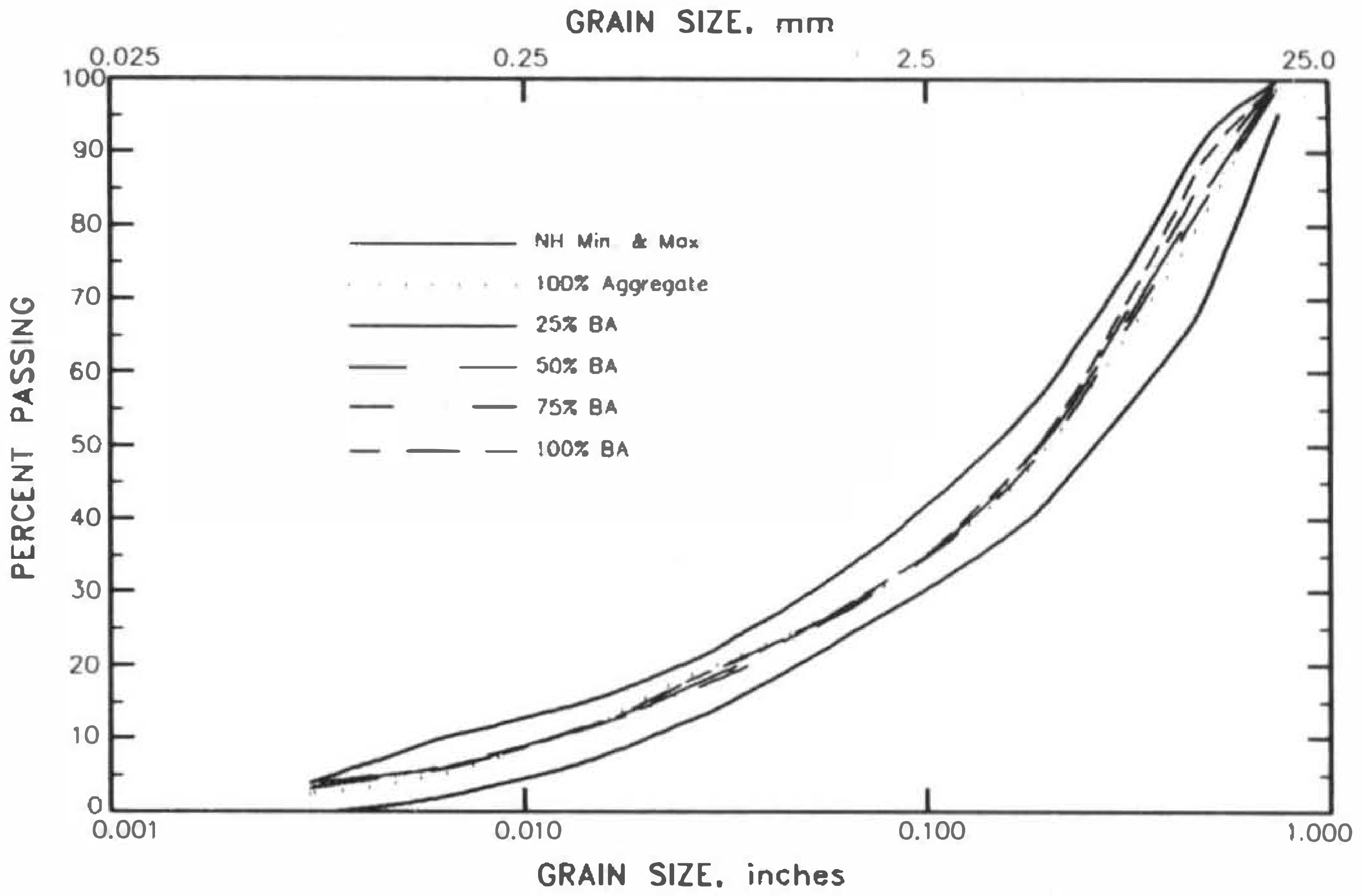

FIG. 1 MASTER GRADATION CURVES OF THE MARSHALL TEST BLENDS

TABLE 3 LYSIMETER LEACHING DATA

	Parameter	Combined Ash (BA/FA/DLSP[1])	Bottom Ash	25% Bottom Ash/ Asphalt
A.	**Low L/S Ratio (ie "First Flush")**	.08	.07	.07
	pH	11.8	6.4	7.1
	Conductivity (mhos/cm)	42,600	8,322	165
	Chloride (mg/l)	18,000	1,700	24
B.	**Higher L/S Ratio (ie 2nd year)**	1.31	1.42	1.31
	pH	12.0	8.1	8.0
	Conductivity (mhos/cm)	18,000	2,479	98
	Chloride (mg/l)	2,800	39	5

(1) Dry lime scrubber product

A significant body of both field and laboratory data has been generated through this research regarding the leaching potential of contaminants present in bottom ash. Lysimeters (or modified "dumpsters" in this case) filled with combined ash, bottom ash, and bottom ash/asphalt "chunks" (with 25% of the aggregate consisting of bottom ash) have been located outdoors at UNH, and therefore exposed to precipitation, for the past two to four years. Leachate from these lysimeters has been sampled and analyzed periodically. Table 3 presents a summary of the leachate quality from the various materials, for two individual sampling events, first at a liquid: solid (L : S) ratio of about 0.07 (shortly after placing the lysimeter) and secondly at an L:S ratio of 1.3–1.4, after several years of leaching. The L:S ratio is the ratio of the cumulative mass of liquid (precipitation) passing through a given fixed mass of solid (i.e., ash or asphalt chunks). The encapsulating effect of the asphalt is evident. The data for conductivity and chloride concentrations in the leachate, indicative of the most mobile potential contaminants, indicate a significant reduction in leachate concentration for bottom ash in comparison to combined ash and a further significant reduction, perhaps to background levels, in the bottom ash/asphalt leachate. This was the case for the first leachate samples gathered and for all subsequent samples over a two year period.

BOTTOM ASH ASPHALT MIX FORMULATION

Initial efforts to formulate an effective bottom ash asphalt mix design were based on conventional Marshall mix testing procedures. The top line in the graph in Figure 2 presents the relationship between percent bottom ash and optimum percent asphalt content based on the Marshall test procedures. Based on these test results, a 50% bottom ash/9% asphalt cement blend was manufactured, and a test patch was paved within the footprint of the lined landfill in Franklin, NH. The resultant mix flowed easily and would probably have exhibited rutting failure.

Following the first test patch paving experience, additional laboratory work was undertaken utilizing gyratory test methods (GTM), a process which essentially kneads the sample rather than impacting it as in the Marshall mix test. The resulting mix designs using the GTM test were dramatically different, predicting a 7 percent optimum asphalt cement content for a 50% bottom ash/50% natural aggregate blend. A second test paving was completed successfully with this blend, and the same mix was subsequently used in the reconstruction of US Route 3.

Figure 2 indicates that the optimum asphalt content is about 5 percent for these aggregates when 100% natural aggregate is utilized, using either the Marshall or GTM methods. The two percent additional asphalt required when utilizing a 50% bottom ash blend represents that portion of the asphalt cement which is absorbed by the bottom ash particles. The additional asphalt cement required is an economic factor which will need to be considered in full scale applications, to be offset by the savings represented by the use of bottom ash aggregate and the costs of bottom ash storage and handling.

US ROUTE 3 PAVING DEMONSTRATION

In May, 1993, 2,000 linear feet of US Route 3 in the City of Laconia, New Hampshire was reconstructed using, in part, bottom ash aggregate in a binder course pavement. US Route 3 in this area is a two lane secondary roadway having an average daily traffic which varies seasonally from about 5,000 to 20,000 vehicles per day.

Of the 2,000 linear feet of reconstruction, 1,150 linear feet was reconstructed using natural aggregate both in the 2 inch binder course and the 1 inch wearing course. The 850 linear foot test section was constructed using a 50% bottom ash/50% natural aggregate blend in the 2 inch binder course pavement. A 1 inch wearing surface of 100% natural aggregate was applied over the bottom ash asphalt binder course such that, in this demonstration, the bottom ash asphalt is not exposed to traffic or the environment.

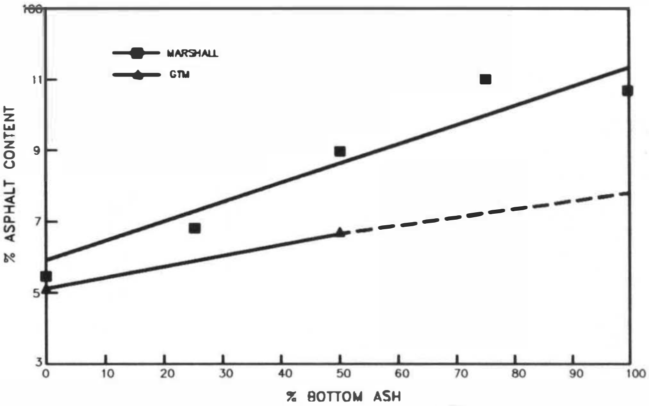

FIG. 2 OPTIMUM ASPHALT CONTENT

A plan view of this section of US Route 3 is presented as Figure 3, showing the test demonstration and control sections. The binder course pavement for the first 100 feet on either side of the transition point between the two pavements was constructed to a four inch depth to allow the installation of strain gauges; moisture, resistance and temperature probes; and traffic counters. The wearing course remained at a one inch thickness through this 200 foot transition section.

The land use in the control section is commercial, including a resort/conference center, several smaller motels, a restaurant, and retail businesses. In the test section, abutting properties were largely undeveloped. Paugus Bay, a part of the Lake Winnipesaukee system, is in close proximity to the test section.

Over a two year research period, the demonstration roadway, including the control and test sections, will be monitored through the sampling and analysis of both upgradient and downgradient groundwater monitoring wells on each of the roadway sections. Also indicated on the plan are the locations of surface water monitoring stations, roadway runoff collection manholes, and suction lysimeters which were installed several feet beneath the pavement surface.

A cross section of the test section pavement is presented as Figure 4. This figure shows the bottom ash binder course with the natural aggregate wearing course above. Below the bottom ash asphalt is a layer of about three inches of recycled asphalt consisting of recompacted "cold planings" from the original asphalt surface. The bottom ash asphalt is thus surrounded by relatively impervious natural aggregate materials above and below.

The roadway construction entailed utilization of conventional asphalt paving and compaction equipment and procedures. The bottom ash asphalt compacted well to specified densities with some additional non-vibratory compactive effort, and the pavement has performed well

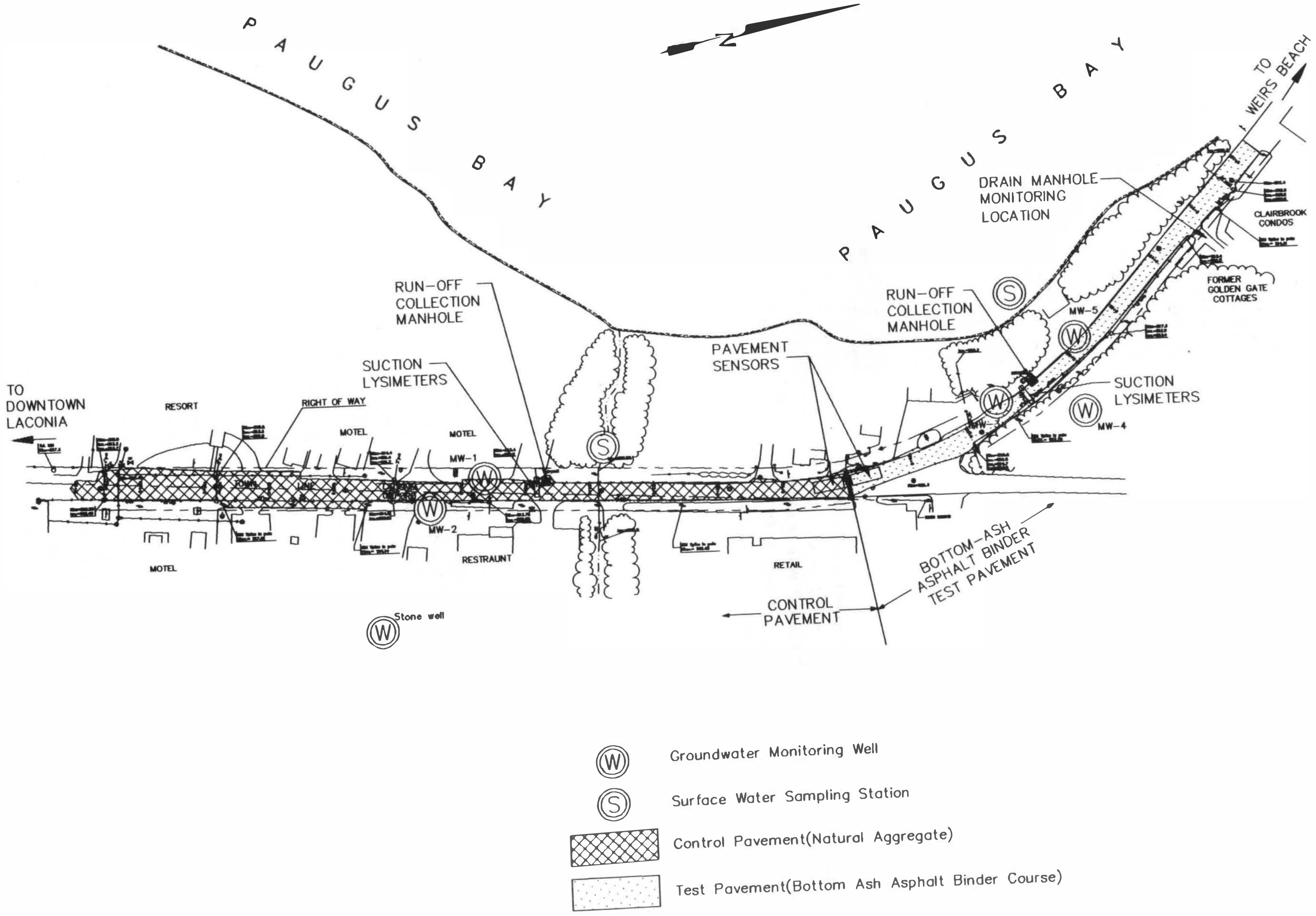

FIG. 3 U.S. ROUTE 3 PLAN

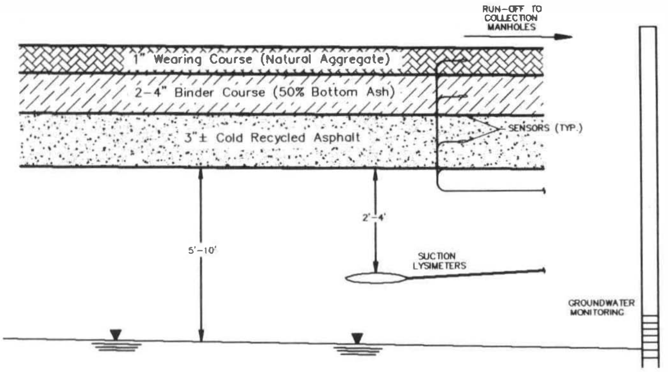

FIG. 4 PAVEMENT CROSS SECTION

through six months of use. A photograph of the completed test section of the roadway is presented as Figure 5.

Although the roadway construction itself presented no significant challenges, the operation of the asphalt plant did present challenges during the manufacture of bottom ash asphalt.

The asphalt plant utilized was equipped with a rotating cylindrical drum dryer for drying the aggregate and an air pollution control system consisting of a fabric filter/baghouse. The plant is normally operated at a rate of about 200 tons per hour. During the manufacture of the bottom ash asphalt, the plant throughput rate was decreased to 140 tons per hour because of the high moisture content in the ash. This helped to avoid extinguishing the flame of the No. 6 fuel oil fired gun used to dry the aggregate. The aged bottom ash was determined to have a moisture content of 23 percent while the natural aggregate had a moisture content of two percent. The paving demonstration was completed in early spring when the bottom ash moisture content was near its highest level due to spring snowmelt and rainfall conditions. Using a bottom ash asphalt blend of less than 50%, and/or utilizing bottom ash at a lesser moisture content, would allow the asphalt plant to operate at, or close to, its normal operating capacity.

The second operating challenge experienced at the asphalt plant pertained to the generation and transport of fines in the aggregate drum dryer. It was mentioned earlier herein that the bottom ash met typical LA Abrasion specifications but was more subject to abrasion than natural aggregate. The drum dryer appears to have functioned as a large "LA Abrasion machine," abrading the bottom ash to some extent. The fines transport system at this asphalt plant was found to be an operating constraint due to the quantity and light weight of the fines in comparison to normal natural aggregate operating experiences. A vacuum truck was required to be connected to the plant's ductwork to periodically withdraw fines. The mix manufactured for the demonstration had about 6% passing the #200 sieve, which was acceptable for the binder course paving. It should be noted that the additional fines did not result in significant increases in particulate emissions as described below. The fines generated can be reduced in future work by decreasing the bottom ash percentage to a level which does not create material handling constraints, if required.

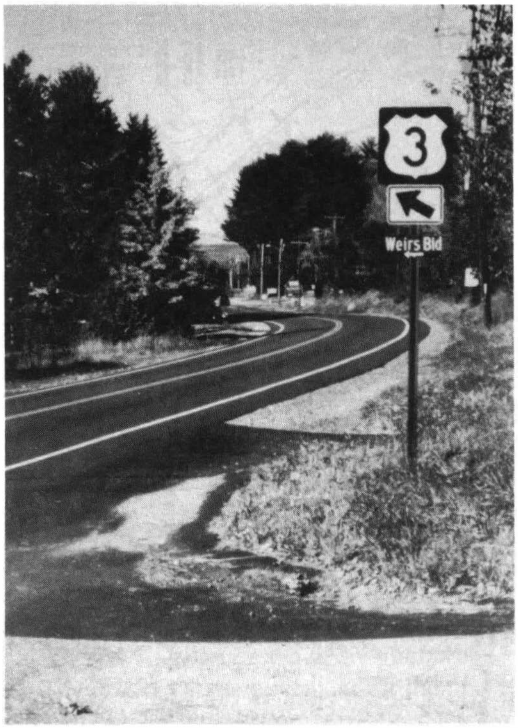

FIG. 5 COMPLETED DEMONSTRATION ROADWAY, LACONIA, NH

Stack testing was completed at the asphalt plant during the manufacture of both natural and bottom ash aggregate asphalt. The results are presented in Table 4. The length of the sampling runs were limited to the amount of time required to manufacture the needed quantity of ash asphalt, and therefore were shorter than the three 90 minute replications which might otherwise be desired for a full air test. The observed opacity was within specified New Hampshire standards for asphalt plants. Particulate levels were somewhat higher when bottom ash asphalt was being processed, but the particulate concentrations for both bottom ash and natural aggregate were within the New Hampshire asphalt plant standard of 0.04 gr./dscf, uncorrected. The facility was capable of controlling particulate emissions despite the build-up of fines on the plant side of the baghouse. Emissions tests for multiple metals showed all metals at low levels regardless of aggregate source. Six metals were slightly higher for the natural aggregate runs (cadmium, lead, arsenic, mercury, chromium, and nickel) and four were slightly higher for the bottom ash aggregate runs (beryllium, copper, selenium, and zinc).

TABLE 4 ASPHALT PLANT AIR TESTING RESULTS

	Natural Aggregate Asphalt	Bottom Ash/Asphalt
Number of Sampling Runs	2	2
Length of Sampling Runs (Minutes)	43, 80	80, 70
Opacity (NH Standard:<20%)	<20%	<20%
Particulate Emissions (gr/dscf) (NH Standard: 0.04 gr/dscf)	0.00643	0.0165

ONGOING RESEARCH

During a two year period following the completion of the reconstruction, an extensive monitoring program will be completed. Water quality samples from groundwater monitoring wells and surface water sampling stations and from suction lysimeters beneath the roadway are being analyzed for an extensive list of parameters, both for regulatory compliance and research purposes. There is negligible potential that any water quality impacts will be detectable in the field due to the encapsulating effect of the asphalt and the nearly impervious nature of the materials surrounding the ash asphalt. It has been calculated that the quantity of chloride added in the ash asphalt is equivalent to that which is applied over one or two snowstorms through road salting. Due to the use of leaded fuels over the years, and other sources, the roadside soils contained significant concentrations of lead prior to the demonstration. The mass of lead per unit area applied with the bottom ash asphalt, in an encapsulated form, was about equivalent to the quantity of unencapsulated lead contained in about 5 inches of depth of roadside soil at the surface soil lead concentration determined at one of the soil sampling stations. The two year research program will include laboratory analysis of pavement samples to be saw cut from the roadway to assess lead concentrations in the recycled asphalt below and in the wearing surface above the bottom ash asphalt. This will provide data on the mobility, or suspected immobility, of lead in the bottom ash asphalt. Monolith leaching studies are also being completed to further the fundamental understanding of leaching potential and pathways in ash/asphalt.

The physical performance of the roadway is being monitored through in situ as well as destructive testing methods. Data collected from the remote probes may identify differences between the two asphalts relative to performance. Falling weight deflectometer testing has been performed by the US Army Corps of Engineers on the subgrade and recycled asphalt and continues to be performed on the pavement surface over time to evaluate the relative strength of the pavements. Through the two year research period, destructive samples will be removed from the control and demonstration sections and examined in the laboratory for both physical and environmental properties.

The environmental, physical performance and fundamental research data generated are being evaluated. Additional papers are planned to be presented in appropriate forums to disseminate the information gathered.

APPROVAL PROCESS

In other areas of the country where similar demonstrations have been proceeding, the concept of ash utilization has been controversial. In this process, both local and state approvals were sought and obtained without controversy. Several meetings were held solely with abutters to the roadway to discuss the project in detail. A well advertised neighborhood public hearing was held and attended by about 10 residents, to describe the project and answer questions. Two publicized Laconia City Council meetings were held as the City deliberated entering into required agreements for implementation of the demonstration project. The City Council voted unanimously to enter into the agreement with the Solid Waste Cooperative. The offer to remove the pavement and reconstruct the roadway with natural aggregate in the event that applicable groundwater drinking water quality standards are exceeded due to the ash asphalt was a key point in local decision-making.

The project was facilitated by the New Hampshire Department of Environmental Services by the issuance of a research and development permit for a two year monitoring period. Neither air nor groundwater permits were required, although these potential impacts have been monitored by regulatory staff through the agency's research and development permit review process.

CONCLUSIONS AND RECOMMENDATIONS

Based on the data available to date from the New Hampshire Bottom Ash Paving Demonstration, the following conclusions and recommendations are made:

- The use of screened bottom ash as a partial substitute for natural aggregate in binder course paving appears to be a viable ash utilization technology.
- A bottom ash percentage of somewhat less than 50 percent is recommended for future demonstrations and full scale utilization for asphalt plant operational reasons to control moisture and to address materials handling issues.
- Gyratory test methods appear to better predict pavement performance at a lower asphalt cement content in comparison to Marshall test methods.
- Public acceptance of the concept of ash utilization in this fashion was obtainable for this demonstration project.
- Additional demonstrations appear warranted and may be needed to lead to widespread utilization to allow re-

finement of asphalt plant operating procedures and to develop general public acceptance.

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