# Full-Depth Reclamation of Asphalt Pavements Using Lime-Activated Class F Fly Ash: Structural Monitoring Aspects

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## ABSTRACT

This study demonstrates the use of Class F fly ash in combination with lime or lime kiln dust in the full depth reclamation (FDR) of asphalt pavements. FDR, in the context of this paper, is a process of pulverizing a predetermined amount of flexible pavement that is structurally deficient, blending it with chemical additives and water, and compacting it in place to construct a new stabilized base course. Test sections of two structurally deficient asphalt pavements were reclaimed using Class F fly ash in combination with lime and lime kiln dust. In addition, control sections were constructed using cement, cement and emulsion, lime kiln dust and emulsion, and mill and fill. The service performance and structural behavior of the FDR pavement test sections were monitored to determine how the fly ash sections compared to other more traditional pavement rehabilitation techniques. Service performance and structural behavior were determined with the use of sensors embedded in the road and Falling Weight Deflectometer (FWD) tests. Monitoring results of the FWD tests conducted up to 2 years after reclamation show that the cement, fly ash+LKD, and fly ash+lime sections exhibited two year resilient modulus values comparable to open graded cement stabilized aggregates (more than 750 ksi). The cement treatment resulted in a significant increase in resilient modulus within 3 weeks of construction and beyond this curing time, the stiffness increase was slow. On the other hand, the LKD+fly ash and lime+fly ash test sections indicated slower shorter-term increase in stiffness but at the end of 24 months of performance, the LKD+fly ash and lime+fly ash sections had performed similar to the cement test section. Additional longer-term testing data will be available from ongoing pavement performance and environmental condition data collection at the two pavement sites.

## INTRODUCTION

The societal emphasis on beneficial recycling of by-products in highway and construction related applications in place of unproductive landfill disposal has resulted in increased research interest and information dissemination by the US Federal Highway Administration [1]. According to FHWA (1997), coal combustion by products can be used in asphalt concrete, Portland cement concrete, granular base, highway embankment or structural fill, stabilized base, and flowable fill applications. The use of low-carbon fly ash in concrete pavements has received significant attention in literature ([2]-[4]), and since the 1960s the use of low-carbon fly ash in rigid (concrete) pavement slabs has increased dramatically. However, high carbon fly ash is not suitable for concrete applications. Finding beneficial uses for these large quantities of high-carbon fly ashes is critical.

In the United States many of the almost two million miles of asphalt roadways are severely distressed and in need of repair or replacement. Over the last few decades, increasing traffic demands combined with decreasing funding for repairs, environmental concerns and an emphasis on safe, efficient, transportation systems have stimulated research and field demonstration projects to explore methods to reuse and recycle pavement materials ([5], [6]).

In response to this need, the Department of Civil and Environmental Engineering and Geodetic Science at The Ohio State University (OSU) partnered with the two fastest growing counties in the State of Ohio (Delaware and Warren) to construct and monitor two county roads in which sections of failing asphalt pavements were reclaimed and recycled. Class F fly ash generated from Ohio coal at the Zimmer power plant was used in the reclamation process.

At both locations the full depth of the asphalt wearing surface plus the base, subbase and a pre-determined amount of the underlying existing subgrade soil were uniformly pulverized, blended with chemical additives (Class F fly ash in combination with lime or lime kiln dust), and compacted to construct a new stabilized base course. An asphalt overlay was then placed over the newly reclaimed and stabilized base. The pavement (subgrade conditions, asphalt overlay thickness, etc.) and traffic characteristics for the different test sections within the Delaware and Warren County pavement sites were similar.

The test sections constructed included two fly ash admixture treatments: fly ash + lime, and fly ash + lime kiln dust (LKD). In addition, four types of control sections were implemented. The control section treatments were: cement, cement + emulsion, lime kiln dust + emulsion, and mill and fill.

The Class F fly ash, a coal combustion by-product [7], provides the silica and alumina needed for cementitious reaction with lime to increase the strength, stiffness, and durability of the stabilized base layer. In addition fly ash acts as a mineral filler to fill the voids in the granular pulverized pavement mix, reducing the permeability of the FDR stabilized base layer.

## OBJECTIVE AND GOAL

The overall objective of this work is to demonstrate the effective use of Class F fly ash in combination with lime or lime kiln dust in the full depth reclamation (FDR) of asphalt pavements. The goal of the proposed program is to establish field-verified relationships for the service performance, structural and environmental behavior of FDR pavements constructed using lime-activated fly ash.

Two highway pavements were constructed and instrumented in 2006, and are being monitored for at least two years. This project demonstrates that when fly ash in combination with lime or lime kiln dust is properly incorporated into FDR reconstruction of a flexible pavement, its use can be economically attractive while offering increased structural and service performance.

## DELAWARE COUNTY PAVEMENT

Delaware County (located 20 miles north of Columbus, Ohio, USA) is the fastest growing county in Ohio. In collaboration with the Delaware County Engineer's Office, Section Line Road between State Route 42 and Home Road was selected for FDR reconstruction in 2006. Fig. 1 shows the failing pavement.

The section of the road selected for study measured 4.1 miles in length. Roadway width is 20 feet with minimal shoulders, with an asphalt surface thickness ranging from 5.25 to 14 inches (average of 10.28 inches). The original pavement was underlain by a base course ranging from 1 to 11 inches (average of 5.18 inches) thick.

The pavement sampling and design was the responsibility of EDP Consultants in collaboration with OSU. Nine sections were constructed using the following six mixes:

- 4-percent lime with 6-percent fly ash, 8-inch stabilization depth (0.7 mile)
- 5-percent lime kiln dust with 5-percent fly ash, 8-inch stabilization depth (0.6 mile)
- 3-percent lime kiln dust with 1.4 gallons per square yard emulsion, 8-inch stabilization depth (0.7 mile)
- 5-percent cement, 12-inch stabilization depth (0.8 mile)
- 2-percent cement with 1.6 gallons per square yard emulsion, 8-inch stabilization depth (0.3 mile)
- 5-inch mill and fill (two 0.1-mile sections at the north and south ends of the project, and a 0.7-mile as well as 0.1-mile sections near the middle of the project).

Fig.1 Failing Delaware County Pavement

The FDR rehabilitation of Section Line Road began in August, 2006. Strawser Paving first milled and removed 5 inches of the existing pavement. Base Construction then pre-pulverized the remaining pavement materials to the appropriate depth as listed above.

The pulverized pavement materials were then treated with the design admixtures (Fig. 2). Water was added to the mix and it was compacted immediately (see Fig. 3). Pavement resurfacing with 5 inches of hot mix asphalt (see Fig. 4) followed a specified curing interval. All work was completed by mid-October.

Fig. 2 Blending fly ash with pulverized base material

Fig. 3 Compaction of FDR base layer

## WARREN COUNTY PAVEMENT

Warren County, near Cincinnati, is the second fastest growing county in the state. The Long Spurling Road (County Road 171) located in the northeastern part of the county in Harlan Township between SR132 and the north driveway to the LM Animal Products Plant was chosen by the Warren County Engineer's Office for FDR construction. The failing pavement was 0.4 miles in length, 20 to 21 feet in width with minimal shoulders and a 2-inch asphalt layer on top of 4 to 6 inches of chipsealed pavement.

As was the case for the Delaware County project, EDP Consultants designed the new pavement system in collaboration with OSU. Two sections were constructed:

- 4-percent lime with 6-percent fly ash, 12-inch stabilization depth (0.32 mile)
- 5-inch mill and fill (0.08 mile)

The FDR rehabilitation of the Long Spurling Road was begun in July, 2006. Strawser Paving milled and removed 4 inches of the existing pavement asphalt surface. Base Construction pre-pulverized the remaining pavement materials to a depth of 12 inches. Lime and fly ash were added to the pulverized pavement materials to a depth of 12 inches. Water was added to the mix and it was compacted immediately. Resurfacing the pavement with 4 inches of hot mix asphalt (see Fig. 4) was completed by mid-September.

Fig.4 Resurfacing with hot mix asphalt

## PAVEMENT INSTRUMENTATION AND MONITORING

During construction, the Delaware and Warren pavement sections were instrumented with the following structural and environmental monitoring devices (see Fig. 5):

- Strain gauges at bottom of asphalt layer (see Fig. 6) for all test sections
- Pressure cells at bottom of stabilized base layer (see Fig. 7) for only fly ash sections
- Pore pressure devices at bottom of stabilized base layer (see Fig. 7) for only fly ash sections
- LVDTs for measuring vertical deflections of pavement (see Fig. 7) for only fly ash sections.
- Lysimeters installed within the stabilized base to monitor leachate quality for all sections.

Data collection from the above monitoring devices was carried out on a quarterly basis.

Falling Weight Deflectometer (FWD) tests (to measure pavement load deflection behavior and calculate the insitu resilient modulus of pavement base) were carried out by the Ohio Department of Transportation. FWD tests were conducted immediately before construction, directly after construction, and will be carried out at least twice a year to determine the longer-term elastic moduli of the various sections constructed in this project.

## MONITORING RESULTS

Falling Weight Deflectometer (FWD) tests were carried out before pavement rehabilitation and for up to 2 years after paving for both the pavement sites.

The FWD test data was processed using MODCOMP [8], a popular FWD back calculation software, to determine the elastic moduli of base layers. MODCOMP uses the FWD deflection profile along with theory of elasticity and an iterative process to fit elastic moduli to the layers of the flexible pavement. The required inputs to the program are the FWD data (including deflections, sensor spacing, etc.), layer thicknesses (determined from borings), and Poisson’s ratio of the layers (usually from 0.35 to 0.45).

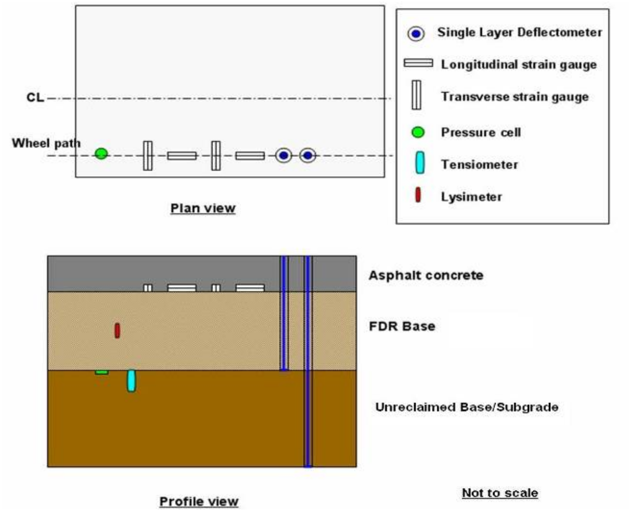


Fig. 5 Pavement Instrumentation

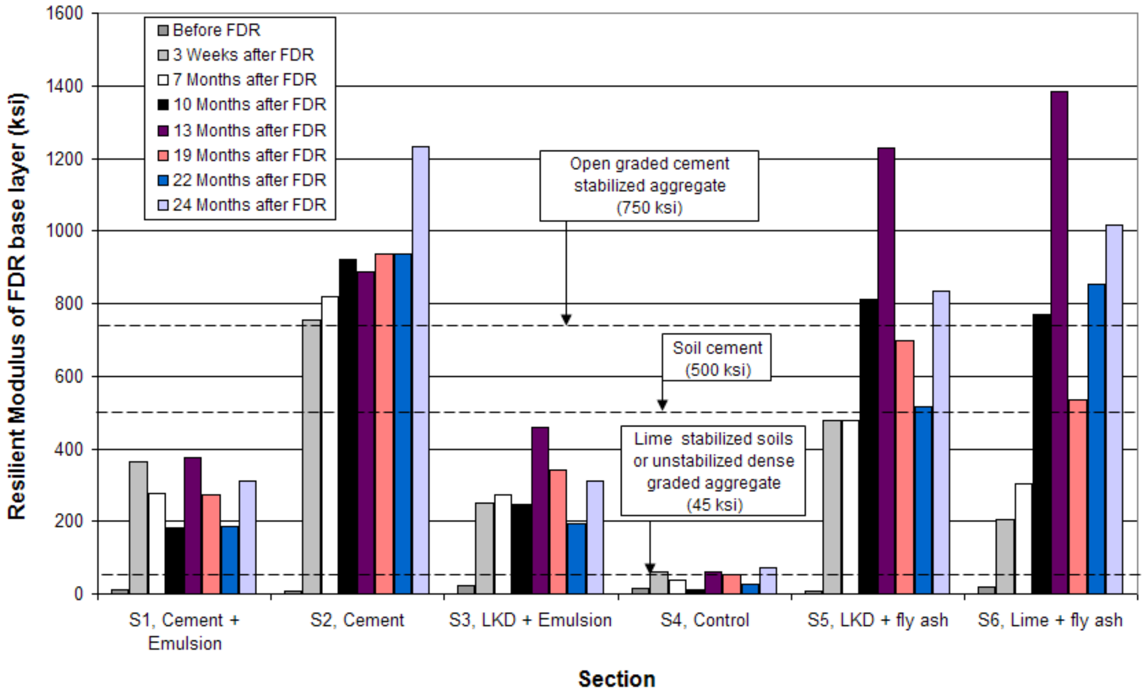
Fig. 6 Placement of strain gauge at top of FDR layer

Fig. 7 OSU pavement instrumentation installed at bottom of FDR layer (left to right) — pressure cell, pore pressure device and LVDT base

Fig. 8 and 9 summarize the FDR base layer resilient modulus values back-calculated using FWD field data for Delaware and Warren counties, respectively. It can be seen that pavement sections stabilized with fly ash showed large increases in stiffness compared to pre-reclamation base stiffness moduli values. Fig. 8 for Delaware County pavement shows a comparison of six different test sections. It can be observed that the control (mill and fill) section indicated little or no increase in resilient modulus values as would be expected. The cement+emulsion and LKD+emulsion mixes were effective but their performance was much lower than the cement, LKD+fly ash, and lime+fly ash mixes. The cement+emulsion and LKD+emulsion resilient modulus values were lower than those typically obtained for soil cement (less than 500 ksi). The cement, LKD+fly ash, and lime+fly ash sections exhibited one to two year curing resilient modulus values comparable to open graded cement stabilized aggregates (more than 750 ksi). The cement treatment resulted in a significant increase in resilient modulus within 3 weeks of construction and beyond this curing time the stiffness increase was slow except for the 24 month value. On the other hand, the LKD+fly ash and lime+fly ash test sections indicated slower shorter-term increase in stiffness but at the end of 24 months of performance, the LKD+fly ash and lime+fly ash sections had performed similar to the cement test section.

Similar trends were observed for Warren county pavement test sections, as shown in Fig. 9. The control (mill and fill) section indicated little or no increase in resilient modulus values. The LKD+fly ash test section stiffness at about one year of service was very high (exceeded 1,600 ksi). By the second year the resilient modulus value had dropped but was still above 800 ksi. Additional FWD tests are planned at both the pavement sites to evaluate the long-term performance of the pavement sections.

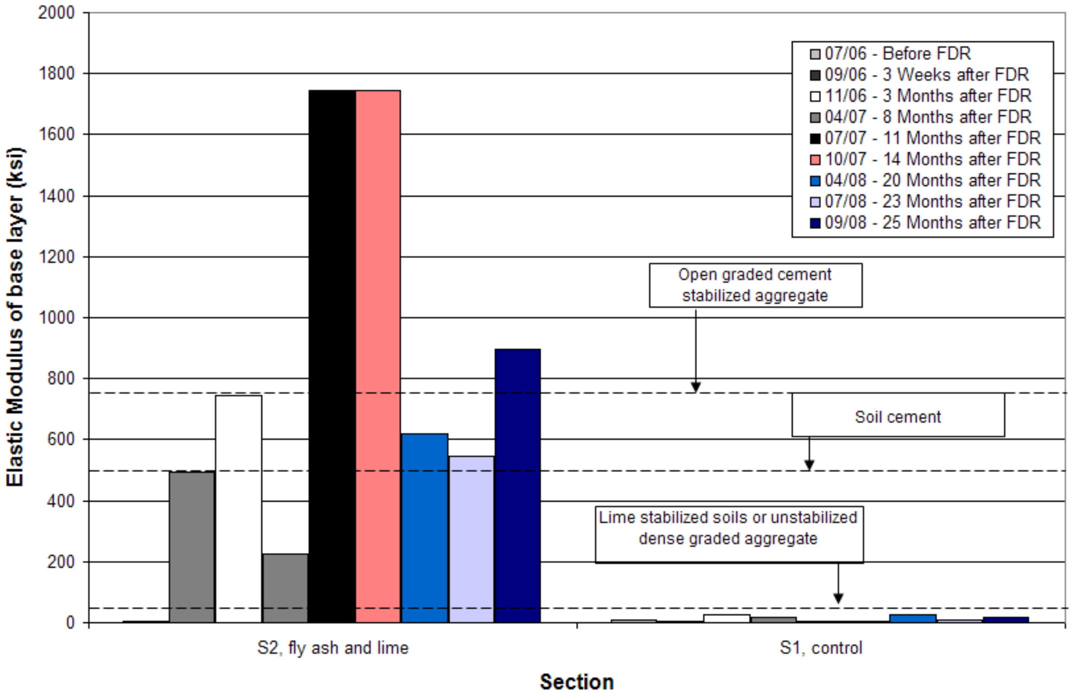
The measured longitudinal and transverse strains at bottom of asphalt overlay under a loaded truck travelling at 45 mph over the Delaware pavement instrumentation 3 months after construction are shown in Fig. 10 and 11. The longitudinal strain (see Fig. 10) is the highest for control as well as cement+emulsion and LKD+emulsion sections. The LKD+fly ash section had lower longitudinal strains, with the lowest values obtained for cement and LKD+fly ash sections. Similar trends were observed for transverse strains measured at the bottom of the asphalt overlay (see Fig. 11).



1ksi = 6,895 kPa

(Note - Resilient modulus values for lime stabilized soils, soil cement, and open graded cement stabilized aggregate are typical values from [9])

Fig. 8 Delaware County resilient modulus



1ksi = 6,895 kPa

(Note - Resilient modulus values for lime stabilized soils, soil cement, and open graded cement stabilized aggregate are typical values from [9])

Fig. 9 Warren County resilient modulus

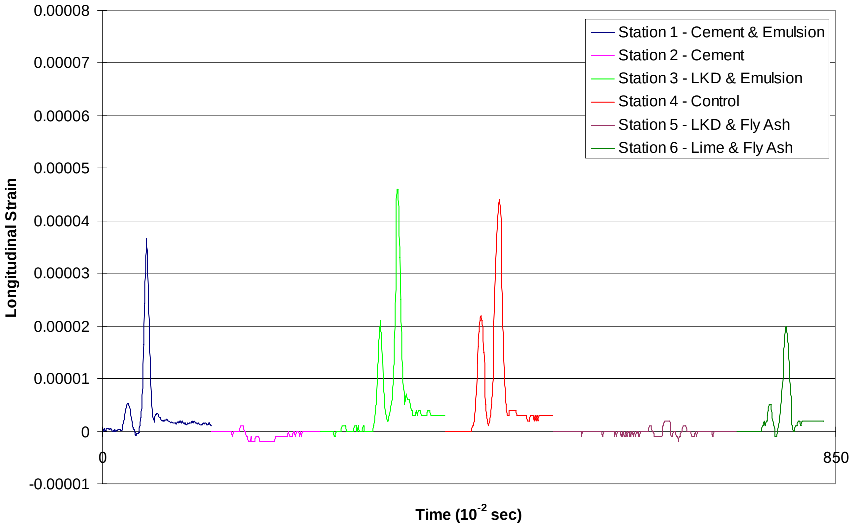


Fig. 10 Longitudinal strain at bottom of asphalt overlay for Delaware pavement under 45 mph loaded truck traffic

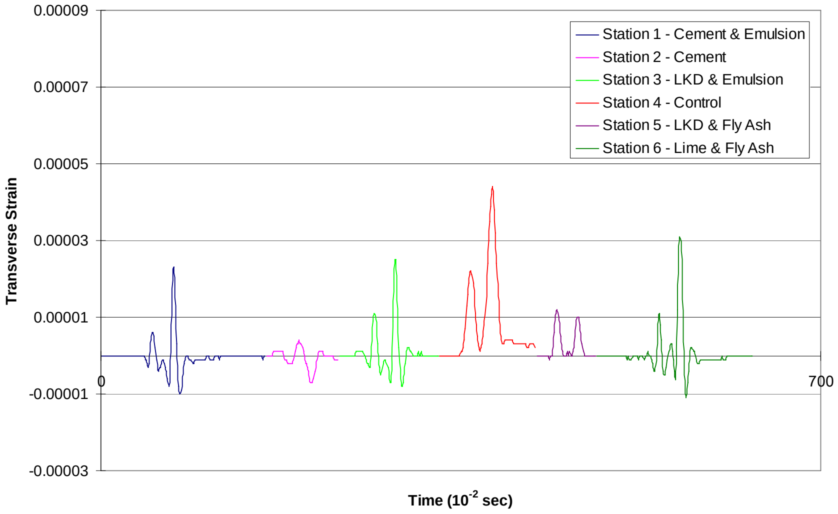


Fig. 11 Transverse strain at bottom of asphalt overlay for Delaware pavement under 45 mph loaded truck traffic

## CONCLUSIONS

In this research program, two test pavements were constructed and monitored to determine how Class F fly ash combined with lime or lime kiln dust (LKD) can be used in Full Depth Reclamation (FDR) of asphalt pavements. The control test sections included cement, cement and emulsion, lime kiln dust and emulsion, and mill and fill mixes. All test sections were constructed using typical construction equipment under the supervision of the respective County Engineer’s office.

Service performance and structural behavior were determined with the use of sensors embedded in the road and Falling Weight Deflectometer (FWD) tests. Monitoring results of the FWD tests conducted up to two years after reclamation show that the sections utilizing fly ash (in combination with lime or LKD) performed similar to the cement test section, while the emulsion sections were not as effective. The mill and fill test section indicated little or no increase in resilient modulus values as would be expected. The cement+emulsion and LKD+emulsion mixes were effective but their performance was much lower than the cement, fly ash+LKD, and fly ash+lime mixes. The cement+emulsion and LKD+emulsion resilient modulus values were lower than those typically obtained for soil cement (less than 500 ksi). The cement, fly ash+LKD, and fly ash+lime sections exhibited two year curing resilient modulus values comparable to open graded cement stabilized aggregates (more than 750 ksi). The cement treatment resulted in a significant increase in resilient modulus within 3 weeks of construction and beyond this curing time, the stiffness increase was slow. On the other hand, the LKD+fly ash and lime+fly ash test sections indicated slower shorter-term increase in stiffness but at the end of 24 months of performance, the LKD+fly ash and lime+fly ash sections had performed similar to the cement test section. Additional longer-term testing data will be available from ongoing pavement performance and environmental condition data collection at the two pavement sites.

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