# Performance of Full-Scale Test Section of Low-Volume Road with Reinforcing Base Layer of Soil–Lime

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**The roads of the rice region of Merin Lake in Uruguay are subjected to low annual average traffic. However, the average daily traffic is approximately 100 trucks during harvest time. The local soils, characterized as clayey silts, are unsuitable for such traffic demands and are generally replaced or reinforced by materials found more than 70 km away, with high transportation costs. An investigation of the performance of a full-scale test section of pavement with a base layer of local silty clay soil stabilized with lime was conducted. The design of the test section consisted of soil selection, determination of lime content for stabilization, compaction, and California bearing ratio laboratory tests. Two test sections, each 50 m, were built, with a base layer of selected soil mixed with 3% lime in one section and with 5% lime in the other. After the rice harvest, the performance of the test sections was evaluated by visual observation of the base layer and deflection measures with a Benkelman beam. Despite some construction difficulties, the deflection average values changed from 244 × $10^{-2}$ cm immediately after the section was built to 77 × $10^{-2}$ cm 4 months later. The use of soil–lime material for base layers of low-volume roads is a technical and economical alternative that provides a significant improvement of the rural road network with socioeconomic benefits.**

The road network of the rice basin of Merin Lake in eastern Uruguay consists of unpaved roads that are subjected to a low annual average traffic. However, it experiences an average daily traffic (ADT) approximately of 100 trucks that carry heavy loads during harvest time (Figure 1). The superficial layer, built with coarse materials, should support the impact of the traffic loads and environment. The predominant local soils are characterized as clayey silts. Their bearing capacity is rather low for use as base materials of pavements, and they are highly deformable. In addition, the subgrades are saturated due to extensive floodplains and poor drainage conditions. The saturation level can reach the base layer, both by capillarity and occasional floods. As a result, the roads deteriorate rapidly and therefore experience continual disruptions for routine maintenance and rehabilitation or reconstruction. To resolve the problem, good-quality materials from quarries an average distance of 70 km away are used. The cost of transportation of this material has a significant impact on the disruptions with respect to budgetary constraints, even when building base layers 10 cm thick.

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A large proportion of the road network in the rice region needs to be rehabilitated throughout the year, before and after the harvest season, at relatively high cost. It is therefore necessary to consider economic alternatives for the entire road network that would free available resources for other needs of the communities. Because high costs of transportation are a major contributor to high maintenance costs, a first consideration for optimization is the use of local materials.

The stabilization of clay soils with lime is one of the oldest techniques for construction of pavements in areas where local soils do not meet the requirements of infrastructure and environment (*1*). The use of lime as road construction material in the United States dates to 1924, when several Midwestern state highway departments sponsored projects in which lime was used as a stabilizing admixture for unsurfaced secondary roads. The lime stabilization of clayey or silty soils is a technique widely used in Europe for the construction or remediation of embankments and pavement layers (*2*). This technique would make more-resistant, less-deformable pavement layers built with more durable materials that reduce transmission of traffic loads to the subgrade. The improvement in structural performance of pavements consequently results in a reduction in the life cycle cost of the facility. Lime–soil mixtures 30 years old have provided high strength and good resistance to environmental effects (*3*). In 1969, a road section with a base layer of lateritic soil stabilized with lime was built in southern Brazil (*4*). After 35 years, the road still provides an acceptable serviceability level.

A research project using local soils from the rice region of Merin Lake was conducted under the sponsorship of the Technology Development Program of the Inter-American Development Bank (IDB) New Technologies for Pavement Rehabilitation and Reconstruction of Low Volume Roads and the support of the municipality of Rocha, Uruguay. One of the main objectives of the project was construction and monitoring of a full-scale test section of road 100 m long, constructed with a reinforcing base layer of soil–lime on the existing pavement, in the vicinity of the city of Cebollatí, Uruguay.

## DESIGN OF TEST SECTION

The full-scale test section with the soil–lime base was constructed near of the city of Cebollatí. Soil in this area is fine silty clay, which is unsuitable for base layers, and the transport distance of currently used materials is the maximum. It was desirable to construct the test section at a site where traffic volume was the highest and drainage conditions were the worst. On the basis of these criteria, it was decided to construct the test section at the location shown in Figure 2.

FIGURE 1 Trucks carrying rice.

Figure 3 shows the conditions of the existing pavement in July 2007. The pavement consisted of a base layer of coarse material and a subgrade of silty clay soil. The coarse material had largely penetrated into the soil of the subgrade because of the traffic loads, so that the maximum measured thickness of the base layer was 7 cm. As Figure 2 shows, some sectors had potholes and the ditches were covered with water.

A decision was made to build a reinforcing base layer of soil–lime 15 cm thick immediately above the existing coarse base layer, with the additional objective of raising the level of the pavement surface. Figure 4 shows the designed pavement structure and the conventional pavement structure.

The soil was extracted from residual materials from building an irrigation canal at a site shown in Figure 2. Soil samples were collected for characterization by grain-size analysis tests in the laboratory that followed the ASTM D422 standard and plasticity limits that were in accordance with ASTM D4318. Table 1 shows the grain size and plastic properties of samples and the classifications according to Universal Soil Classification System and AASHTO classification system. Soil characteristics were ideal for the purpose of the research, that is, to build a base layer of soil–lime.

FIGURE 3 Pavement condition in July 2007 where test section was built.

A commercial lime consisting of 66% calcium oxide, 5% magnesium oxide, and traces of silica and ferric oxide was used. Fine lime, with 100% passing a No. 10 sieve and 93% through a No. 200 sieve was used. The silt fraction constituted 91% of the total dry mass.

The optimum design of the lime–soil mixture was determined by following the pH method of ASTM D6276 (penetration testing of soils) and Thompson's procedure (*5*), but curing in an oven for 48 h at 50°C was replaced with curing at room temperature for 28 days. Figure 5 shows the change in pH of the mixtures as a function of lime content (expressed as dry weight of soil) that results from the application of the ASTM D6276 pH method. Figure 6 shows the unconfined compressive strength (UCS) of soil and

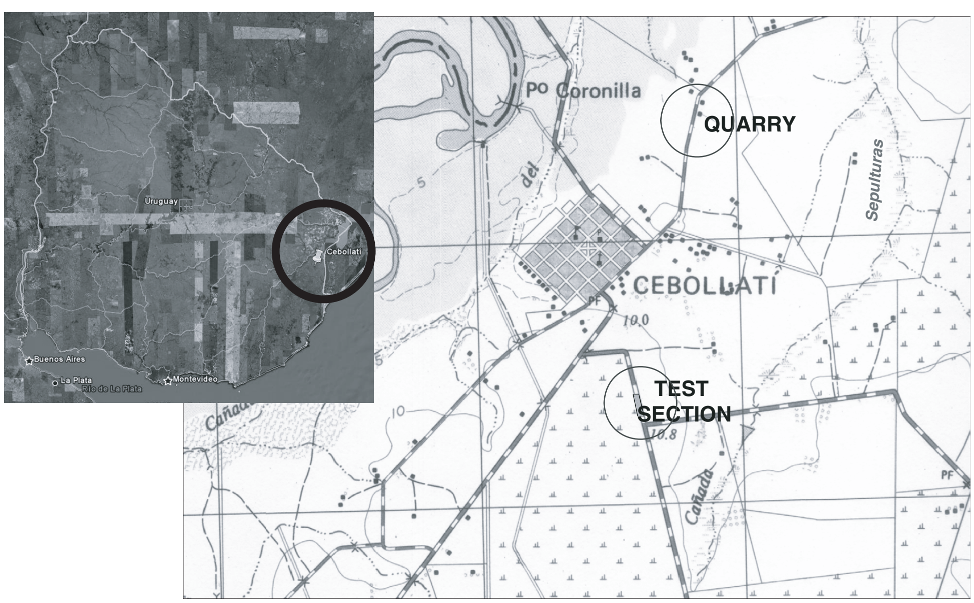


FIGURE 2 Location of full-scale test section.

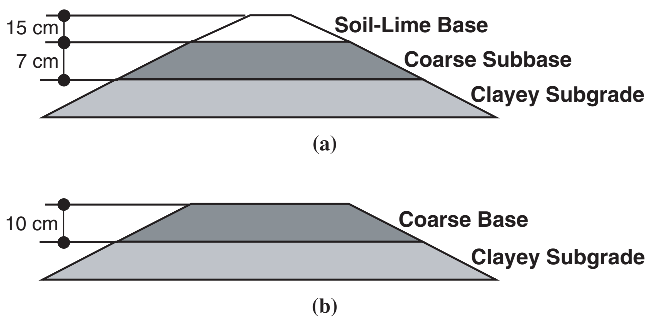


FIGURE 4 Pavement structure (*a*) designed with soil–lime base and (*b*) conventional.

**TABLE 1 Soil Properties**

| Grain-Size Analysis | |
|---|---|
| Sand (> 74 µm) | 8% |
| Silt (74 µm > *x* > 2 µm) | 52% |
| Clay (< 2 µm) | 40% |
| Atterberg limits | |
| Liquid limit | 48% |
| Plasticity index | 30% |
| Classification | |
| USCS | CL |
| AASHTO | A-7-6 |

NOTE: USCS = unified soil classification system; CL = clay, low plasticity.

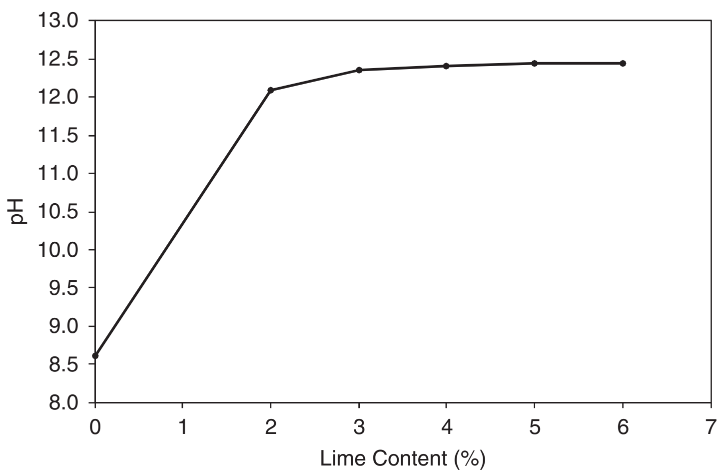


FIGURE 5 pH values as function of lime, according to pH method.

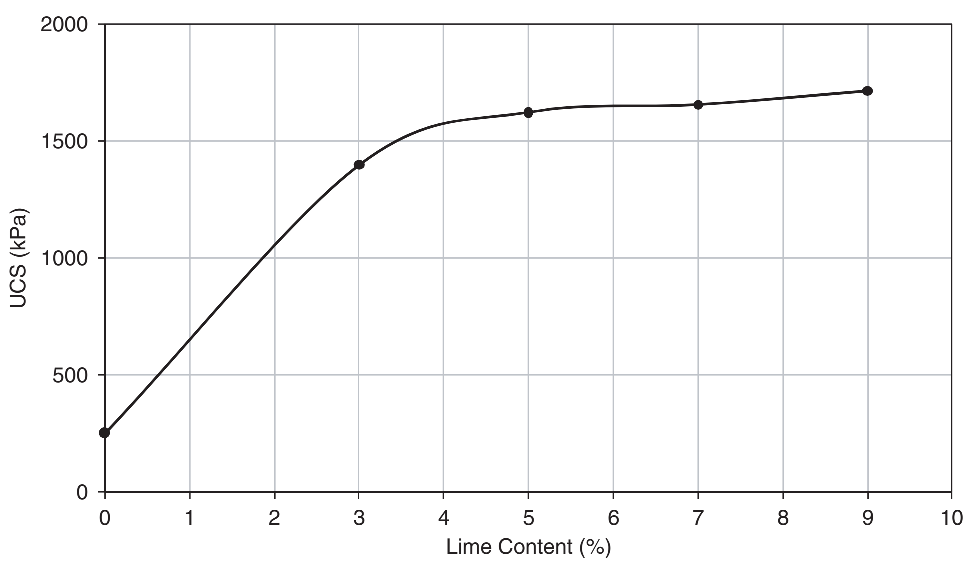


FIGURE 6 UCS of mixtures of soil with different lime content, cured 28 days at room temperature.

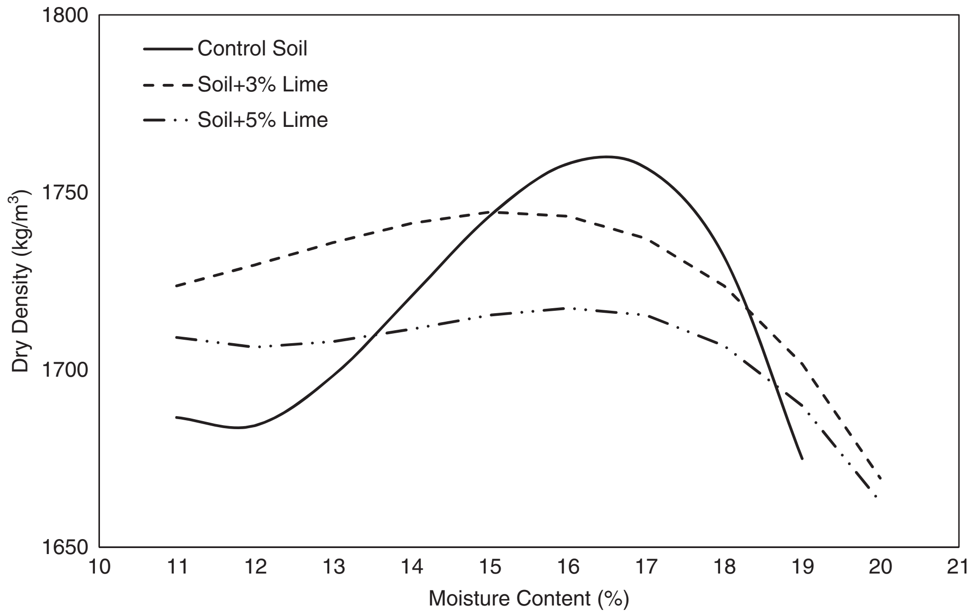


**FIGURE 7 Modified energy compaction curves of control soil and mixtures of soil with 3% and 5% lime.**

mixtures of soil with 3%, 5%, 7%, and 9% lime cured 28 days at room temperature. Thus, the optimum lime content to stabilize the selected soil was found to be 4% by the ASTM pH method and 3% by Thompson's procedure. A lime content of 5% was adopted to take into account the heterogeneities that may occur during the building process of the mixture in place. A significant increase (almost six times as high) in UCS was observed with the addition of 3% lime in comparison with the UCS of the control soil. Although UCS increased steadily with increasing lime content, that increase was gradual.

Optimum compaction parameters of soil mixed with 3% and 5% lime were determined by modified Proctor tests that followed AASHTO T180. The mixtures were compacted in molds of 10 cm in diameter immediately after the addition and homogenization of the water. The results are shown in Figure 7. As expected, when the lime content increased, the maximum dry density (MDD) decreased from 1,744 kg/m$^3$ for a mixture of soil with 3% lime to 1,717 kg/m$^3$ for a mixture of soil with 5% lime. Optimum moisture content was 15.5% for the mixture of soil with 3% lime and 16% for the mixture of soil with 5% lime.

To evaluate the effect of adding lime on the bearing capacity, California bearing ratio (CBR) tests were conducted on samples of control soil and mixtures of soil with 3% and 5% lime, in accordance with the AASHTO T193 standard. The mixtures compacted at modified energy were cured for 28 days at room temperature and then soaked for 96 h before being subjected to the load test. Figure 8 shows the variation in CBR as a function of dry density of the soil and the mixtures. A remarkable increase in the CBR of the mixtures was observed in comparison with the control soil for all dry densities, from a value of 8% for the MDD of the soil to a value of 173% for the same compaction condition of the mixture of soil with 3% lime and a value of 268% for the MDD of the mixture of soil with 5% lime. The CBR values obtained for the mixtures are not realistic for design, being only indicative because the CBR is not appropriate to characterize the strength of cemented materials (*6*). The significant increase in CBR of the mixtures indicates the occurrence of alkaline reactions between the amorphous silica of clay minerals of the soil and calcium ions of the lime; these reactions produce improvements in the bearing capacity of the stabilized soil.

The results of the CBR test indicate the structural performance of a base layer of the mixture of soil with 3% lime. Thus, the initial project consisting of a test section 100 m long with a base layer 15 cm thick was modified to two sections each 50 m long: one section with a base layer of a mixture of soil and 3% lime and the other section with a base layer of a mixture of soil and 5% lime. Both the sections had a base layer 15 cm thick.

## CONSTRUCTION OF TEST SECTION

The test section was built in April 2008. Construction followed the sequence described here. First, the soil was placed along the 100-m length by a motor grader (Figure 9*a*). Then, 25-kg bags of lime were regularly distributed along the section (Figure 9*b*) so as to ensure better homogeneity of the finished mixture. The bags were broken and the lime distributed manually first and then by motor grader.

Then, the dry mixing of the soil and lime was done by successive passes of the tractor with a disc plow, and a motor grader was used to verify their homogeneity. Immediately thereafter, the compaction water was poured by a tank truck with a sprinkler system and the mixture homogenized by successive passes of the tractor with the disc plow and the motor grader (Figure 9*c*). The mixture was compacted with a smooth vibrating roller. However, excessive vibration was minimized because compaction occurred immediately after water addition—but with just enough time for short-term reactions (cationic exchange and flocculation) to develop. In this condition, the soil–lime mixture behaved similarly to compacted fine soils. The pad-foot roller compactor would be more efficient

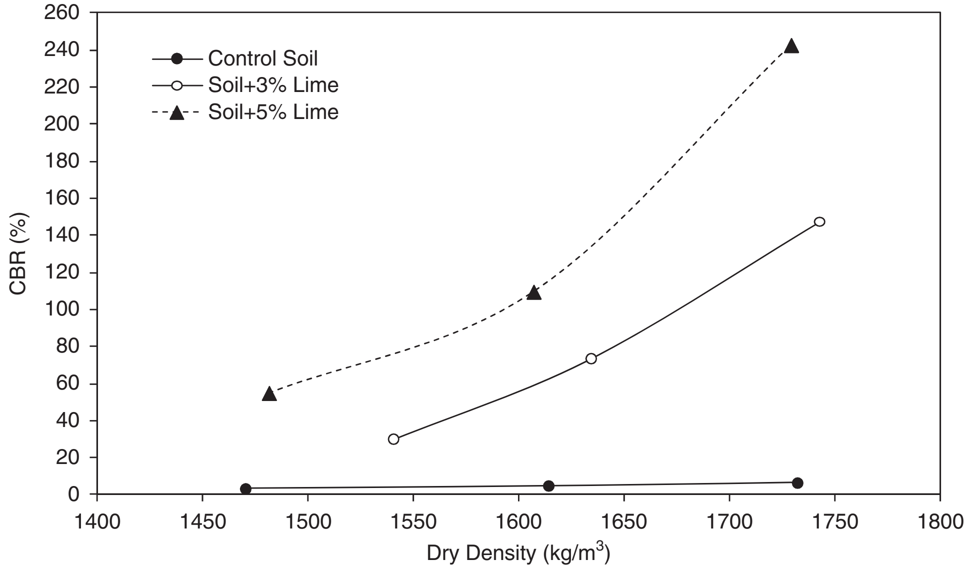


FIGURE 8 Variation of CBR as function of dry density of specimens of soil and soil mixed with 3% lime and 5% lime, cured 28 days.


FIGURE 9 Construction steps of test section.

than the smooth roller compactor. Figure 9*d* shows the final state of the constructed section.

## PERFORMANCE OF TEST SECTION

Control tests of in situ density by the sand cone method (AASHTO T191) and moisture content were performed immediately after the building of the test section was finished. The results of dry density, moisture content, and degree of compaction are shown in Table 2. The compaction moisture content was higher than the optimum moisture content, being another cause of the low compaction degree of both layers.

The structural performance of the test section was evaluated by measurement of deflections by Benkelman beam in accordance with AASHTO T256. One measuring point was established in the section with the base layer of the mixture of soil with 3% lime; the other measuring point was established in the section with the base layer of the mixture of soil with 5% lime. A control point was located near the test section in a typical section without treatment for a comparative analysis of performance.

Readings were made immediately after the section was built, in April 2008, and in August 2008. Table 3 shows the deflection values measured at each point on both dates. Reductions occurred in the deflections measured in the two sections between April and August. These results indicate the occurrence of alkaline reactions between the amorphous silica of the clay minerals of the soil and calcium ions liberated in the hydration of lime. The result is a cementing material that is more rigid and less deformable. This improvement was achieved despite the high traffic volume on the section during the investigation period. If one considers that the section was built when the rice harvest was in full swing and the test section was subjected to the worst traffic conditions immediately after construction, without time for the completion of alkaline reactions to take place, the result is very promising.

The deflection values were similar at each part of the test section, indicating that no major differences existed in structural performance when the lime content varied from 3% to 5%. These values would confirm the result of the dosage of the soil–lime mixture made by the ASTM pH method and Thompson's method, where the optimum lime content would be between 3% and 4%.

Immediately after construction, the deflection measured in the coarse base of the control section was higher than that measured in the test section. The treated base served as a fine material because the alkaline reactions are not fully developed, being less rigid than the coarse base. Four months later, the deflections measured in the test section were less than those measured in the control section. The pozzolanic reactions produced a stiffer material, hence one likely to perform better.

The result of visual inspection of the test section in August was similar to what it was in April 2008 immediately after the construction. Despite the low compaction degree, the high moisture content of the base layers, and the heavy traffic experienced during the rice harvest, no excessive strains were recorded. A common practice is to apply a safety factor to the optimum lime content determined in the laboratory, increasing it to take into account the heterogeneity caused by the craft, the large-scale distribution and the mix of lime, and the impurities in the lime composition. Therefore, a test section with a base layer of soil stabilized with 5% lime was built into the research. However, the verified similar performances of the two tested materials demonstrate that the optimum values are sufficiently reliable, making the inclusion of any safety factor unnecessary. For the case study, the recommended lime content was 3%, which was also the optimal cost solution.

Assurance of good structural performance and serviceability and cost savings are both important factors in ensuring the continued development of the construction experience gained, so as to continue to reduce the building defects identified in this work. Having the right equipment, like pad-foot rollers, improves the efficiency of compaction.

**TABLE 2 Dry Density and Moisture Content of Built Base Layer**

| Section | Dry Density (kg/m$^3$) | Moisture (%) | Compaction Degree (%) |
|---|---|---|---|
| Base of soil + 3% of lime | 1,403 | 18 | 80 |
| Base of soil + 5% of lime | 1,210 | 20 | 70 |

**TABLE 3 Deflection Values Measured by Benkelman Beam**

| | Deflection ($10^{-2}$ mm) | |
|---|---|---|
| Section | Immediate Postconstruction | Postcure Construction |
| Coarse base | 131 | 93 |
| Base of soil + 3% of lime | 264 | 67 |
| Base of soil + 5% of lime | 224 | 65 |

## CONCLUSIONS

The investigation of the test section with the base layer of soil–lime in Cebollatí demonstrates the technical and economic feasibility of building this type of pavement, particularly for low-volume roads with intense traffic in certain seasons.

A condition to ensuring good structural performance of these materials is to conduct an appropriate design in relation to lime dosage and to determine the optimal compaction parameters. Although CBR values are indicative of bearing capacity, other parameters, such as resilient modulus and indirect tensile strength, must be used for a suitable pavement design.

The increase in long-term stiffness and the low deformability found for the bases constructed during this research demonstrate the good performance of the base layer formed by mixtures of fine soil and lime in pavements under similar traffic loads to the test section. These materials are stiffer than the coarse materials typically used in the area, expected to be a better structural performance.

When the construction technique (workers' skill in the use of machinery) is considered, it can be concluded that the use of soil–lime material for base layers of low-volume roads is a technical and economical alternative for regions where there are no natural materials of equal or better quality; these provide a significant improvement to the rural road network with socioeconomic benefits. It is also an environmental alternative that helps enable the preservation of increasingly scarce high-quality materials.

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## REFERENCES

1. Lambe, T. W. Soil Stabilization. In *Foundation Engineering* (G. A. Leonards, ed.), McGraw-Hill, New York, 1962, pp. 351–437.
2. Chea, S., Q. Bollens, and J. C. Verbrugge. Attempt to Forecast the Immediate Bearing Index (IBI) Values of Soils Treated with Lime from Other Soil Parameters. *Proc., 2nd International Symposium on Treatment and Recycling of Materials for Transport Infrastructure* (CD-ROM), Paris, 2005.
3. Detry, J., H. Van Den Bergh, and H. Bollens. Study of a 30-Year-Old Lime-Treated Silt Area: Analysis of Its Mechanical Behaviour and Environmental Influence on the Directly Surrounding Zone. *Proc., 2nd International Symposium on Treatment and Recycling of Materials for Transport Infrastructure* (CD-ROM), Paris, 2005.
4. Nuñez, W. P., R. S. Lovato, R. Malysz, and J. A. P. Ceratti. Revisiting Brazilian State Road 377: A Well-Succeeded Case of Lime-Stabilized Road Base. *Proc., 2nd International Symposium on Treatment and Recycling of Materials for Transport Infrastructure* (CD-ROM), Paris, 2005.
5. Thompson, M. R. Shear Strength and Elastic Properties of Lime-Soil Mixtures. In *Highway Research Record 139,* HRB, National Research Council, Washington, D.C., 1966, pp. 1–14.
6. Thompson, M. R. Soil–Lime Mixtures for Construction of Fine-Grained Soil Pavements. In *Special Report 160,* TRB, National Research Council, Washington, D.C., 1975, pp. 149–165.

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