FEASIBILITY OF POZZOLAN-STABILISED PAVEMENTS IN DEVELOPING COUNTRIES

by

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ABSTRACT

Traditional strengthening methods for roads in developing countries require large quantities of high quality aggregates, or hydraulic binders such as Portland cement, which may cause undesirable environmental effects. Alternative binders, such as natural pozzolanic materials (e.g. volcanic ash) can alleviate many of these effects, and lead to significant import savings for the countries where these materials are found.

Based on experiences from a recent road construction project in Tanzania and a pilot study relating to the suitability of locally available pozzolanic materials, a research project is proposed which it is hoped will establish a theoretical model for the structural and functional deterioration of pavements with pozzolan-stabilised bases. The intention is to construct a full-scale test pavement in the Danish Road Testing Machine and to develop an incremental-recursive model for the deterioration of such pavements from the measured stresses and strains. The project findings will provide a solid basis for the design of road pavements in tropical climates with pozzolan-stabilised sand bases.

1. INTRODUCTION

Current trends in the transport sector show a growth in numbers and axle loads on all types of roads in industrialised and developing countries. These trends are natural and important for economic development, but demand that the bearing capacity of roads be improved.

The most important structural pavement layer (the base course) on most rural roads, is a layer of granular material. This granular material may consist of natural coarse-grained aggregate (gravel) or crushed rock. In many parts of the world, however, suitable granular materials are scarce or very costly. To make use of locally available materials, like sand or laterite, the materials must be stabilised. In many countries this is most often done using Portland cement.

Portland cement and bitumen are the traditional binder materials used for road construction. They are so common that we do not consider the alternatives or the consequences of the lim-

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ited options. The market prices at present, which are at about 100 US$/ton for cement and 200 US$/ton for bitumen, are having a serious effect on the developing countries' development of their road infrastructures. They simply cannot afford these materials, and there are no signs of a decrease in this barrier to development in the future.

At the same time, there is some anxiety worldwide about the greenhouse effect. Portland cement, contributing with a release rate of 1.25 tons CO_2/ton of produced cement, constitutes the biggest single factor in the entire global CO_2-emission.

In the light of the overall considerations in development and environmental politics, there are many good reasons to view the former practice with criticism. Is it possible to create genuine development and new employment by using the natural resources of the developing countries? Can improvement of the infrastructure be carried out more quickly and with more consideration for the environment by changing practice?

Using Pozzolan stabilised road construction materials seems to be an obvious possibility.

While all European pozzolan deposits (since their discovery by the Romans and the Greeks) have been and still are being industrially exploited, primarily by the concrete industry as an additive to Portland cement, very large and valuable pozzolan deposits are being unexploited in many developing countries. We have simply forgotten these resources and accustomed ourselves to using factory-made and energy demanding products. Sustainable development is a keyword in the criteria for development projects and the pozzolan concept fully supports this. With the pozzolan concept, simple methods based on the use of local materials combined with volcanic ashes or blast furnace slag are introduced. Many developing countries have for years suffered from an excess of poor materials for road construction and insufficient knowledge of the appropriate use of local material along the road. For these countries, this concept can contribute to an end of the traditional expensive and non-feasible road projects, which has been a barrier to the sustainable improvement/reconstruction of many road networks.

2. DAR-MLANDIZI ROAD PROJECT, TANZANIA

From 1996 - 2001, on behalf of the Danish International Development Agency (DANIDA), the Danish consulting company COWI has designed and supervised the reconstruction of the Dar - Mlandizi Road in Tanzania. The road passes through a coastal area with no natural coarse aggregate of its own. The traditional solution of thick asphalt binder and wearing course on top of a crushed gravel base was shown to be expensive compared to an alternative solution that uses the fine local sand in a blast-furnace slag stabilised base layer, the slag being imported from France. This method allows reduced thickness of asphalt surfacing and brings a reduction of overall costs of 20%, compared with a traditional solution, mostly by removing the need to haul crushed aggregate more than 100 km to the construction site.

The selection of blast-furnace slag as the sole binder, replacing Portland cement, was made after experience from Dar es Salaam International Airport, where French contractors used similar techniques in the construction of the apron and runway extensions in 1981. After almost 20 years in service, the airport is in excellent condition and the project serves as an invaluable reference, a structure that is still performing well under the prevailing conditions.

Figure 1: Compaction of slag stabilised sand base course at the Dar-Mlandizi Road, 1999

3. THE POZZOLAN PILOT STUDY, TANZANIA

During the Dar-Mlandizi project it was suggested that locally available pozzolanic materials (e.g., volcanic ash), mixed with lime could be used as binder instead of the imported blast-furnace slag. In 1999-2000, COWI carried out a preliminary investigation on the properties of natural volcanic pozzolans in Tanzania with the objective of verifying the material's viability as a stabilising agent for road building. Pozzolanic materials are abundant in a number of countries, including Tanzania, and the binding mechanisms formed are similar to those using Portland cement.

The testing of 11 different sources of natural pozzolan was based on a direct comparison with the sand-slag mixture used in the construction of the Dar-Mlandizi Road. Further, other conditions considered important for utilisation of the pozzolan deposits were discussed during the project [Ref. 1].

The Pozzolan Pilot Study showed that:

- Deposits of various types of pozzolan are plentiful in Tanzania.
- The major part demonstrates good strength properties.
- Many of the pozzolan samples investigated show a high glass content and they are suitable as sources for pozzolan based innovative cement binder production.
- Utilisation of the resources is considered highly viable, economically and environmentally friendly.
- Development of a mining industry and an innovative binder technology offers the unique opportunity to address two major challenges of the donor organisations - sustainable development and climate change.
- Pozzolan resources can be utilised in several sectors - road, housing and cement industry - as a substitute for high-energy consuming, ordinary binder materials as well as for other purposes in the building sector.
- Detailed geological investigations and material testing is required for development of a local mining industry.
- Development of new strategies and technical assistance programmes are essential for utilisation of the new technology.
- Utilisation of pozzolan will typically require 15-30% hydrated lime (by weight of the pozzolan).
- Several natural pozzolans investigated in the pilot study show higher strength results for similar binder dosages than in blast-furnace slag-sand mixtures, e.g. the binder dosage of pozzolan-lime compared with slag can be reduced for similar strength properties.

It was further recommended that a Pozzolan Pavement Stabilisation Development Programme should include the following:

- Develop new strategies for road works to promote innovative and appropriate road construction technology.
- Planning of pozzolan stabilisation demonstration projects to develop appropriate construction technology and guidelines for utilisation of the new technology.
- Develop design guidelines and technical specifications.
- Develop maintenance guidelines for repair of pozzolan bases in the case of possible failures or repair after excavations for e.g. pipes.
- Seminars to promote the new technology and to improve local competence by dissemination of project results to representatives from relevant ministries, donors and the road construction and pozzolan mining industry.

4. NEW TEST SECTION AT THE CHALINZE - MELELA ROAD, TANZANIA

In connection with the reconstruction starting 2001 of the Chalinze - Melela section of the TANZAM highway in Tanzania, a test section is being considered in line with the above recommendations, where the base course will be stabilised using a natural pozzolan.

In connection with this test section, theoretical tests are planned to be carried out at the Technical University of Denmark (DTU) using their unique Road Testing Machine (RTM). The aim is to establish a theoretical model for the structural and functional deterioration of pavements with a base course stabilised with a natural pozzolanic material.

5. DANISH ROAD TESTING MACHINE

The Danish Road Testing Machine is a pavement testing facility, with a width of 2.5 m and a length of 27.0 m. The central 9.0 m is the actual instrumented test section, which is 2.0 m deep. A view of the RTM is shown in Figure 2.

The RTM is enclosed in a climate chamber, 4.0 m wide and 3.8 m in height. Heating and cooling machinery make it possible to maintain a temperature range of -10 °C to +40 °C. The ground water level is automatically controlled and may be raised or lowered by making appropriate adjustments to the water supply to maintain the water surface level in the well alongside the RTM test pit.

The wheel load is hydraulically applied by a single or a dual wheel. In practice, the Danish RTM is capable of applying a maximum dual wheel load of 60 kN at a maximum speed of approximately 25 km/h. At this dual wheel load, and with an operational speed range of 15 to 20 km/h, roughly 5,000 to 10,000 load repetitions may be applied during a working day. The lateral position of the wheel can be automatically controlled during testing to give a desired transverse wheel load distribution (wander).

The pavement to be tested in the RTM can be instrumented with the following sensors, which have been developed through previous research projects:

- Asphalt Strain Gauges (ASGs) measure the horizontal strains in a bound material such as an Asphalt Concrete or a Portland cement stabilised pavement material.
- Soil Deformation Transducers (SDTs) measure the dynamic strains and permanent deformations in unbound materials.
- Soil Pressure Cells (SPCs) measure the vertical and horizontal stresses induced by dynamic loading in unbound materials.
- Soil Pore Pressure Sensors (PPSs or Tensiometers) measure the negative porewater pressures in the soil, giving an indication of the fluctuations of moisture contents in the subgrade.
- Thermocouple probes (TMs) monitor the temperatures in the pavement layers. The TMs in the subgrade are normal temperature range sensors, whilst the TMs in the Asphalt Concrete surfacing (AC) are temperature-resistant sensors capable of withstanding high AC laying temperatures.

The surface profiles of the test pavement are measured with a Profilometer that is specifically constructed for profile measurements in the RTM. In principle, the Profilometer runs on the loading cart rails (see Figure 2) and measures the vertical distances from a fixed reference point (the Profilometer beam) to the pavement surface with a high precision digital transducer. Longitudinal profiles and transverse profiles are recorded for each measurement. From the measured longitudinal profiles, Slope Variance (SV) and International Roughness Index (IRI) are computed. From the measured transverse profiles, Rut Depth (RD) is calculated by applying a 4-foot (1.2 m) straightedge in a spreadsheet-based analysis.

Figure 2: Interior View of the Road Testing Machine

Since 1973, seven major projects have been conducted with the RTM. The findings from the projects have provided a solid base for the development of the "analytical-empirical" method used in pavement design. The most recent projects have aimed at extending this to incremental-recursive models that may predict the gradual deterioration of pavement structures as a function of loading and climatic conditions. These have been used in stochastic simulation models like MMOPP (Mathematical Model of Pavement Performance) which will be part of the newest Danish Design Standard for flexible pavements. Similar models for rigid or semi-rigid pavements, e.g., pavements with a pozzolan-stabilised base, are presently not available.

A very important aspect of the research in the RTM is the instrumentation. The instrumentation developed through the research projects in the RTM are both reliable and durable, i.e., the measured stresses and strains are correct and the instruments are guaranteed to last for the entire test period. Reliable instrumentation is a prerequisite for both the verification of response models and for the development of performance models. The combination of full-scale testing under controlled climatic conditions with reliable instrumentation makes the RTM unique.

6. PROJECT CONTENTS

The overall development objective of the study is to verify the method of use and feasibility of using naturally occurring pozzolan - volcanic ash - as a stabiliser for all-weather roads in developing countries. More specifically, the immediate objective is to establish a theoretical model for the structural and functional deterioration of rural road pavements with a base course stabilised with natural pozzolan. A secondary objective is the technology transfer of the project findings to Tanzanian professionals, politicians, and contractors.
The research project will be based on existing laboratory tests and in situ tests carried out by COWI in Tanzania. These will be supplemented by laboratory tests on stabilised materials, done by the Danish Road Institute. Most of the research effort, however, will be concentrated on the research in the Danish Road Testing Machine.

The RTM may be considered as a large scale laboratory equipment, where it is possible to test full-scale instrumented pavements under controlled conditions of climate and loading. The RTM cannot be used for empirical testing. Only one (or possibly two) material(s) can be tested at any one time and the duration of a test can be up to one year. The test is still accelerated compared to actual road pavements, with much longer life expectancies, and certain environmental effects (such as sunlight and heavy rain) are not simulated. The RTM, therefore, requires a theoretical model based on the mechanical properties of the materials, in order to extrapolate the results to real-life in situ conditions. The results of the RTM must also be followed up by observations on in situ pavements, preferably on under-designed trial sections. Using an incremental-recursive model enables calibration to in situ conditions, because the model can describe the gradual deterioration of the pavement.

A full-scale test pavement will be constructed, instrumented and tested under varying conditions of load and environment in the RTM. Selection of the base course material will be based on the existing laboratory and in situ tests, as well as on the supplementary tests carried out by the Danish Road Institute.

The subgrade currently in the RTM test pavement will remain in the pit for the testing, and all the installed instruments in these layers will be reused for the pozzolan study. The soil used in the subgrade is a Danish "moraine clay", and from the laboratory tests that have been conducted, the subgrade has been classified as a clayey silty sand (AASHTO (M145-87) classification A-4 (0)). The instruments installed in the subgrade are SDTs to measure vertical and horizontal strains, and SPCs to record vertical and horizontal stresses.

The planning of the research project is not yet completed, but it is expected that the pozzolan stabilised base layer to be tested will have a thickness of approximately 150-200 mm. Instruments installed in the pozzolan stabilised base course will be ASGs to measure the horizontal strains in the bottom of the stabilised layer.

To limit the transportation of material, it is intended to use a Danish quartz sand stabilised with pozzolan from Tanzania, mixed with hydrated lime. By developing a theoretical basis for the model development, it should also be possible to use the model for different materials, as long as the mechanical characteristics of these materials are known.

Stresses and strains in the pavement layers will be measured under rolling wheel loads at specific numbers of load repetitions. The surface deflections, and the strains and stresses in the pavement materials will also be measured under Falling Weight Deflectometer (FWD) loading. Frequent FWD measurements will be done to monitor the structural deterioration. The measured pavement responses will be used to verify the theoretical model for pavement response. The outcome of the project will also make it possible to use the FWD to evaluate the structural condition of in situ pavements in Tanzania (or elsewhere). Pavement profiles will be measured both longitudinally and transversely, for precise determination of the development of roughness and rutting (i.e., functional deterioration). Moisture contents and temperatures in the pavement layers will be varied and recorded. Performance models for structural and functional deterioration will be developed based on the measured data.

The research is planned to commence in the spring 2001 and will be conducted over a period of 11 months. The first three months will include the planning of the test, importing the pozzolanic material to Denmark and construction of the test pavement. The next seven months will include the actual testing, and the final month will conclude the project through analysis of the results, reporting and dissemination of the project conclusions and recommendations.

7. EXPECTED OUTCOME

The results from the project will hopefully provide a significant contribution to the current pavement design method in developing countries, which is mostly based on the empirical models for the deterioration of roads. Due to the general and theoretical approach taken in the research at the Technical University of Denmark, the findings will be valid for similar types of roads in developing countries worldwide. As the results of the research mainly apply to rural roads, the derived project benefits, such as cost savings, improved passability, and reduction in the use of imported materials will have a major impact on the economy in the rural areas of many developing countries.

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REFERENCE

1. "Pilot Study for Possible Use of Locally Available Pozzolan in Tanzania." Summary Report prepared by COWI for the Ministry of Works, The United Republic of Tanzania, August 2000.