APPLICATION OF A NEW MECHANICAL STABILIZATION AND OTHER TECHNIQUES IN REDUCING THE COST AND IMPACT OF RURAL ROAD CONSTRUCTION

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ABSTRACT:

It is indeed a common notion world wide that civil engineering projects cause detrimental damage to the environment. However, concrete analysis of the balance between development oriented projects and nature and environmental conservation have yet to be pragmatically addressed from a civil and geotechnical engineering perspective. The necessity to develop the mechanical stabilization based Optimum Batching Ratio Method (OBRM) was first prompted by the lack of suitable materials for the construction of a 330km trunk road traversing mainly through lowland rural areas where the alignment soils were mostly of an expansive nature. Conventional engineering solutions would have necessitated deeper excavations of borrow pits to ensure the extrusion of quality materials. Furthermore, during the construction of this road, the 1998 El-Nino floods caused colossal damage to the pavement and hydraulic structures. The road works operations would therefore have been forced to expand requiring more land for realignment and material use. Two project case studies of trunk roads where the OBRM and other recently developed comprehensive design and construction procedures were adopted in solving issues that would have otherwise been detrimental to road users and land owners are presented from an engineering perspective. It is demonstrated that these methods effectively reduced the cost of construction and minimized negative environmental impacts mainly in terms of dust reduction, disturbance of the local habitat, contributed to the preservation of the adjacent national park and displacement of the inhabitants.

1. INTRODUCTION

1.1. Rural Road Development Aspects in The Eastern African Region

Roads facilitate the movement of people and goods and play a central role in economic development whilst enhancing countless social interactions. On the other hand, more than 3 billion or two thirds of the population in developing countries live in rural areas where their lives are predominantly characterized by isolation, exclusion and highly unreliable access even to the most basic economic activities and social services. Consequently, in recent years, renewed emphasis on assisting very poor populations through sustained rural development has led governments and development partners to accelerate resource flows to rural infrastructure. This has made rural road development rampant particularly in the developing countries. The construction of major civil engineering and geotechnical structures, however, is known to destroy the environment in various respects. Nevertheless, such road construction and development in Kenya, Ethiopia, Southern Sudan and other countries in the eastern Africa region have a common goal of achieving industrialization by the year 2030 similar to that of the Asian Tigers. Figure 1 is a schematic depiction of the transport sector contribution to industrialization activities in Kenya based on the Governments Development Plans. While a cross-sector orientation in such projects is desirable, there is a serious need for sound technical advice on the design of sub-components and in particular, on appropriate design and appraisal methods for rural transport infrastructure. It is also imperative to consider the fact that rural transport networks in most developing countries is usually under-developed and of poor quality, being mainly characterized by earth of gravel roads and paths as opposed to asphalt or concrete roads in developed countries.

In most cases, these type of roads have negative environmental and social impacts such as: 1) dust from vehicles polluting the air thus affecting human beings and animals living along Road Transport Infrastructure (RTI), which can be blinding and coughing culminating in respiratory problems such as lung related diseases (bronchitis), 2) Improved access requires acquisition of productive agricultural land and housing which necessitates resettlement. This implies that wildlife habitats are affected for (a) the Route of the roads and (b) the resettled communities.

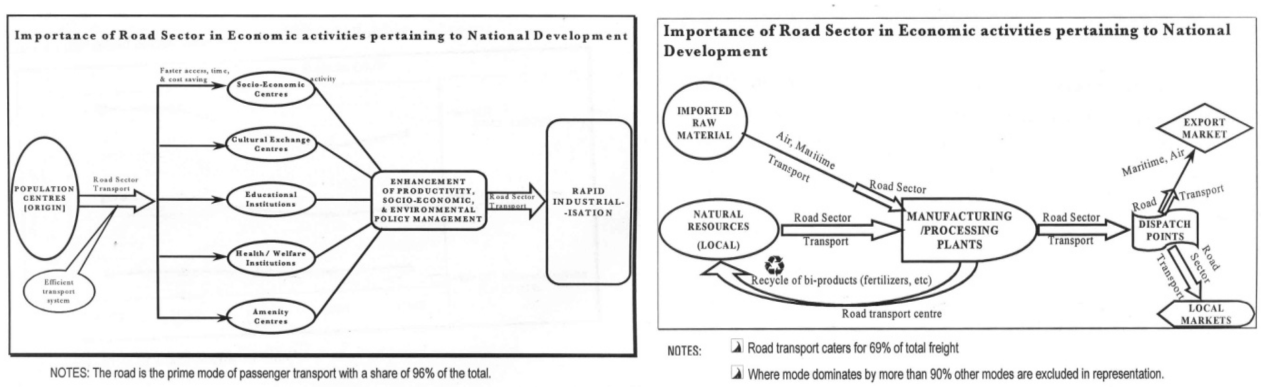


Figure 1 – Transport sector in industrialization and economic activities

1.2. Example of Negative Impacts of Rural Road Transport Infrastructure on Ecology and Wildlife In Eastern Africa

From the various studies carried out in the Eastern Africa region, it has been determined that road transport infrastructure development causes the following problems.

1. Improved access requires acquisition of productive agricultural land and housing which necessitates resettlement. This implies that wildlife habitats are affected for (1) the Route of the roads and (2) the resettled communities.
2. Dust from the vehicles and erosion of RTI surfaces causes siltation to their watering areas i.e. water pollution and soil contamination.
3. Noise pollution and vibrations from the traffic and activities along the RTI limits the mobility of wildlife.
4. Death due to accidents along the RTI i.e. collision cases between vehicles and wildlife increased.
5. Air pollution generated by the operation of facilitates and exhaust fumes.
6. Interference with migratory routes.
7. Interference with original water bodies.
8. Chemical dust levels during construction increased.
9. Animal – driver conflicts for example animals want cover, escape cover (in case of danger), visibility and the ability to cross a road, while drivers want efficient travel without hitting wildlife.
10. Mowing and vegetation control alongside roads contributes to safety; grass, weeds, bush and trees can limit a drivers' view of approaching vehicles and signs. This affects the survival of certain species.

Generally roads can cause a direct loss of habitat, alter the quality of adjacent habitat, lead to road-kills, and impede animal movements. As roads are upgraded to accommodate greater traffic volume the rate of successful wildlife crossing decreases significantly. Thus roads may effectively fragment habitats and alternate continuous population distributions. Smaller populations typically result, with a greater potential of genetic problems and an increased chance of local extinction.

1.3. Example of Positive Impacts of Rural Road Transport Infrastructure on Socio-economic Development In Eastern Africa

One of the most comprehensive Feasibility Studies undertaken in East Africa showed that the highest income generation along the project roads studied, i.e. Homabay~Mbita (C20), Rongo~Ogembo (C19) and Bumala~Port Victoria (D250/251/C30) indicated in Figure 2 was from activities such as fisheries, trade, commerce and agriculture, the level of income of which directly depends on the standard of rural road development. Along some project roads, fishing is the most important activity and takes place in the lake, rivers and swamps where a variety of fish species are caught and exported to Europe via rural roads in the region. These include, but are not limited to, Nile perch (Lates niloticus), Tilapia (Oreochromis niloticus) and Omena (Rastrineobola argentea). Eels and mud fish are caught in the rivers and swamps. The transportation to markets for example, in Busia District of Kenya in 1995 over 10,000 tonnes and, due to rural road development this figure increased tremendously in 1998, by 1.5 times to 15,000 tonnes of fish products valued at approximately Kshs. 274 and 400 million in the respective years. Clearly these figures reflect the importance of fishing in the area of influence of the project road. Moreover the project road provides the quickest access routes to markets for fish and agricultural produce. Therefore the impact on economic activities might be positive rather than negative. Ecology, on the other hand, in relation to rural roads development, seeks to maintain the diverse characteristics and services of plants and animals infact, or undegraded and to maintain or re-establish relatively natural ecological systems in human being-imprinted areas. Meshing this goal with the economic and social activities of our rural road development infrastructure still remains a daunting challenge.

1.4. Social benefit in the case of TANA BASIN ROAD PROJECT in the Republic of Kenya

The road project generated numerous socio-economic and cultural activities in terms of opening possibilities of reaching new markets, distributing services and exchanging ideas. Better roads led to:

1. Improved marketing of agricultural products – mangoes, bananas, tomatoes, rice, and paw paws.
2. Coastline fishing, mangrove exploitation and farming of crops such as cotton, cashew nuts, bananas, cassava etc benefited greatly from increased accessibility to the wider external market.
3. Transportation of industrial products and raw materials was greatly enhanced.
4. Tourism was also boosted in the region.
5. Jua kali and the business sector were able to sell their products easily and at more competitive prices due to the reduced cost of transport relative efficiency and safety of transport safety.
6. Accessibility of basic welfare services such as health centres and schools also improved.

1.5. Important Geotechnical Concepts That Contribute To Reduction of Impacts of Road Works

In geotechnical engineering, composite materials are considered such that the particle size distribution tends towards a correctly proportioned ratio that would yield optimum density and shear strength to resist stress-induced deformation. On the other hand, most geomaterials in their natural state are usually deficient in one or more of the particle fractions required, hence the necessity of mechanical stabilization and comprehensive geotechnical study and investigation. Various experimental regimes, aimed at achieving enhanced strength, better compaction characteristics, greater durability and sound resilience, were designed. In designing the experimental and developing the analytical methods, consideration was made of soil as an assembly of particles whose integrated motion can be characterized theoretically by concepts and fundamental principles of continuum mechanics and models that take into account, probabilistic perspectives of microscopic state combined with multi-dimensional analysis within defined boundary conditions but with infinite scales of movement. The particle motion was integrated, limited along defined vectors, confined to relativity. Consequently, the mode and proportion of mixing two geomaterials influences the compaction and stress-strain energy characteristics resulting in improved mechanical, shear, elastic and work hardening properties. The construction cost savings were realized mainly from the reduction of volumes of imported (borrow) materials, haulage costs, and reinforcement materials required for reinforced earth structures for abutments. Environmentally, this was achieved by controlled land use based on the reduction in the number of borrow pits, shortening access road distances which would interfere and affect the natural surroundings and habitat of both humans and animals within the adjacent largest national park of Tsavo in Kenya, minimizing the amount of material dumping sites and dust reduction in the dry season.

2. BRIEF BACKGROUND OF PRAGMATIC ENGINEERING METHODS APPLIED

2.1 Theoretical and Engineering Basis

In order to achieve the objectives of this Study, the theoretical point of departure in establishing these methods is that soil is regarded as an assembly of particles whose integrated motion can be characterized theoretically by basic concepts and fundamental principles of continuum mechanics and models that consider probabilistic perspectives of microscopic state and multi-dimensional analysis. A summary of the theoretical and empirical basis for this method is presented in Figs. 2 (a) ~ (h), in the form in which the paper was presented at the World Road Congress (IRF 2001) in Paris, Mukabi (2001a) and Mukabi and Shimizu (2001b). Since then the method has been developed to versatile scales as is demonstrated in this paper.

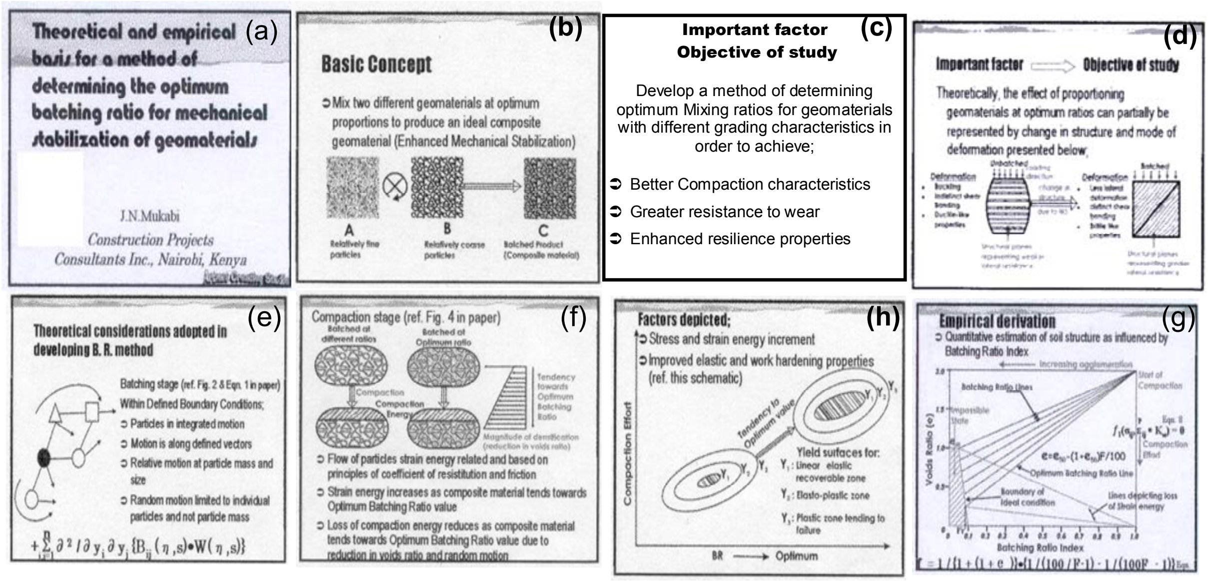


Figure 2 - Theoretical Background of OBRM

In developing the Optimum Batching Ratio Method (OBRM), Mukabi (2001a) considered that; such geomaterials would have a particle size distribution that tends towards correctly proportioned ratio that would yield optimum density and adequate strength to resist stress-induced deformation. This concept is demonstrated in Figures 3~5.

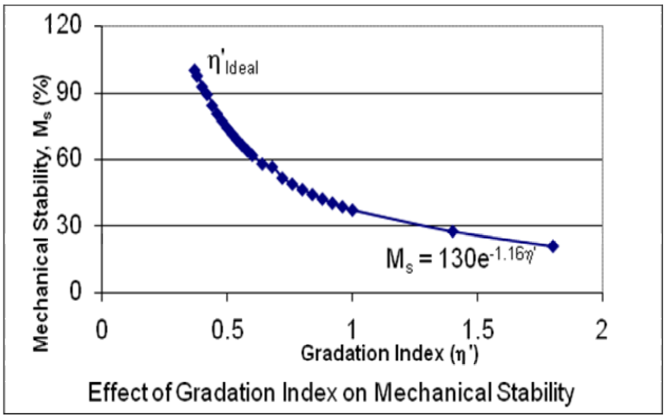


Figure 3 – Mechanical Stability

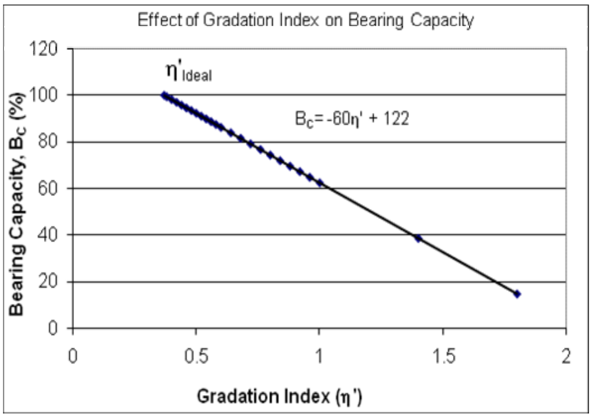


Figure 4 – Bearing capacity

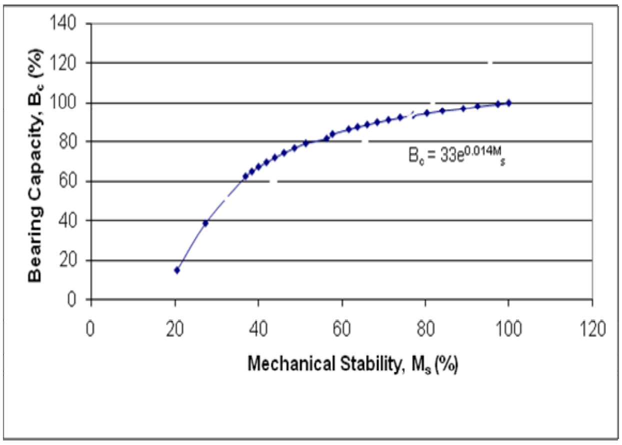


Figure 5 – Correlation B_C and M_S

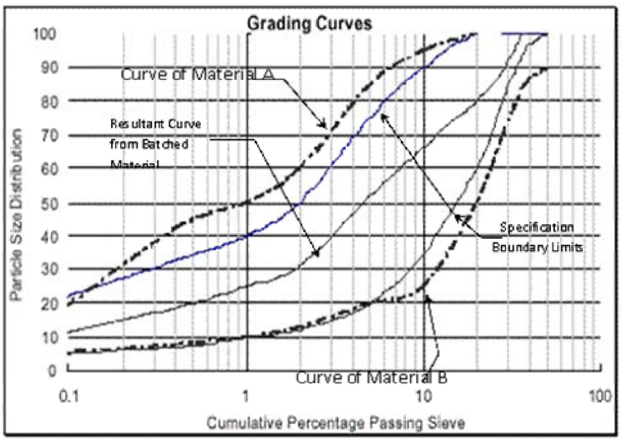


Figure 6 – Grading curves

2.2 Proposed Method of Determining Optimum Batching Ratio

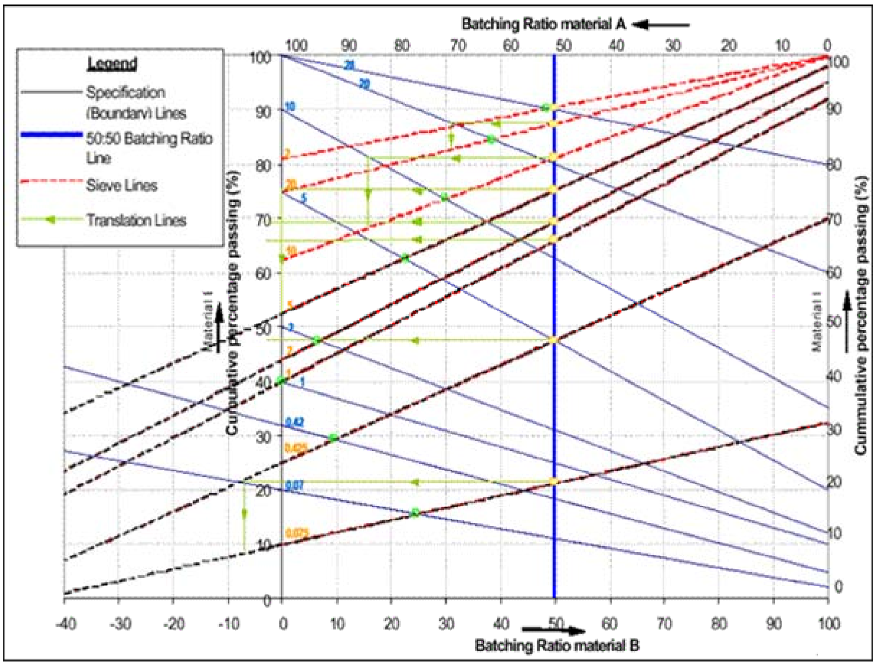


Figure 7 - New Batching Ratio Method

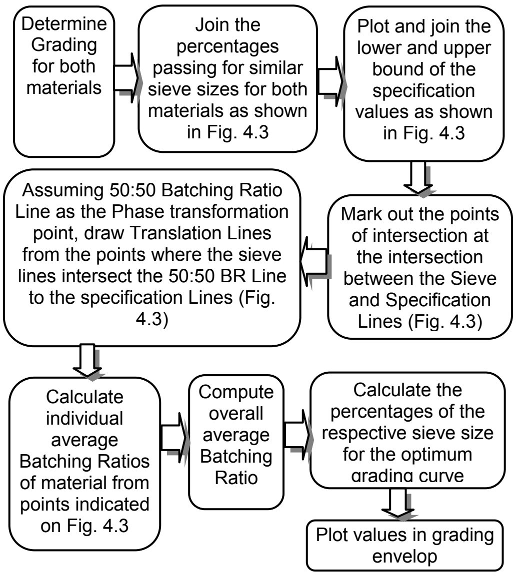


Figure 8 - Proposed BR Method

The mechanical stabilization method, developed on the foregoing theory, is represented graphically in Figures 6 and 7 as well as Figure 8.

3. APPLICATION IN DESIGN, CONSTRUCTION, LAND USE AND DUST CONTROL

3.1 Controlling Land Use

This Study has given serious consideration, from an engineering perspective, to the control of the reduction in land use, road construction noise, safety, air and ground pollution including dynamically propagated vibrational ground movement that can cause damage to minor housing structures in the rural areas. Originally, the concept of reinforcing earth to mainly enhance its strength properties was initially construed in the early sixties. The oldest amongst the Reinforced Earth methods is the Terre Armee. It's innovation was prompted mainly by the fact that, although earth soil is obviously the cheapest construction material for civil works and is easily available in large quantities, it is usually highly inferior in strength and resistance to deformation. In order to counter this weakness therefore, it was deemed necessary to apply a reinforcing interface that would enhance the ability of the soil-inter particle resistance to deformation and shear stresses. Since the use of the Terre Armee method alone proved to be costly, a design employing a combination of this method and the method of achieving optimum mechanical stabilization proposed by Mukabi (2001a), was devised. It was noted that, by employing an equal amount of reinforcement strips, the performance of the optimumly mechanically stabilized embankment was superior by about 40% in comparison to the one stabilized using an arbitrarily selected batching ratio.

3.1.1 Highway pavements

As can be derived from Figures 9 to 20, the method developed was found to be effective in enhancing the structural capacity of a structure in terms of mechanical stabilization, physical strength, deformation resistance and reduction in the rate of subgrade fines intrusion to upper pavement layers. In other words, enhanced engineering properties results in the reduction in quantities of the natural materials required contributing to controlled land use and as one of the mitigation measures to negative environmental impacts.

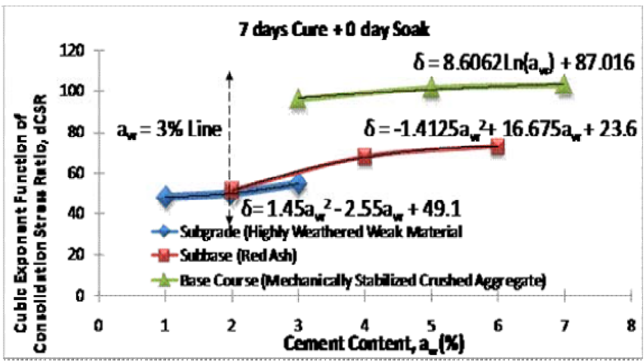


Figure 9 – OPMC unsoaked

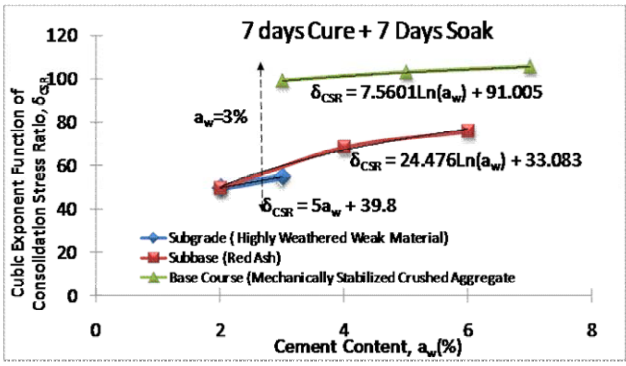


Figure 10 – 7 days soak OPMC

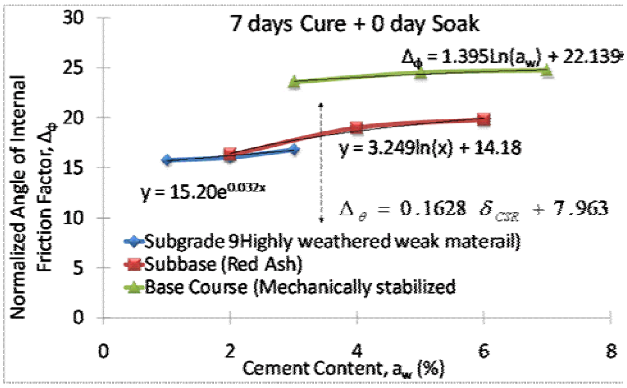


Figure 11 – Friction factor unsoaked

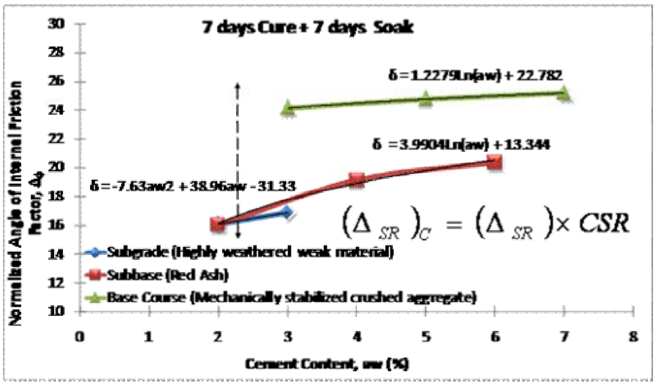


Figure 12 – Soaked friction factor

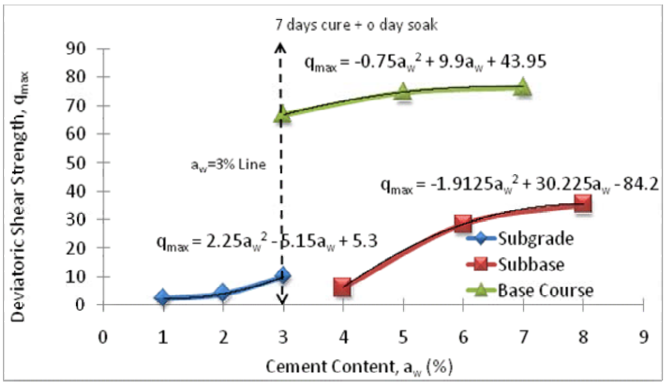


Figure 13 – Shear strength

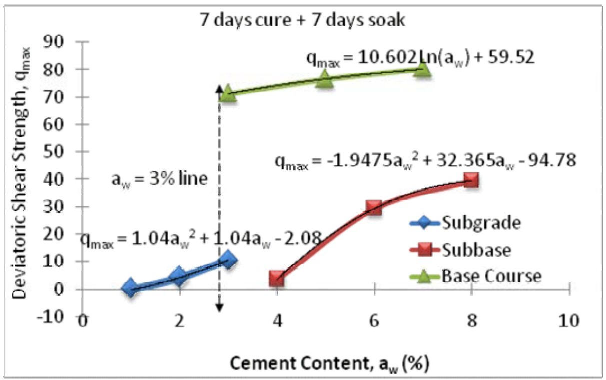


Figure 14 – 7 days soak

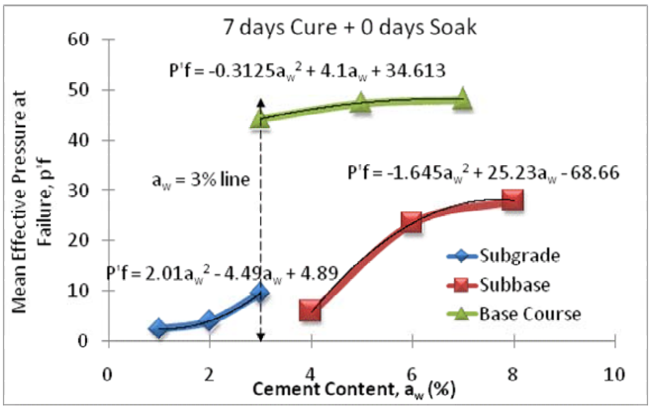


Figure 15 – Mean effective pressure

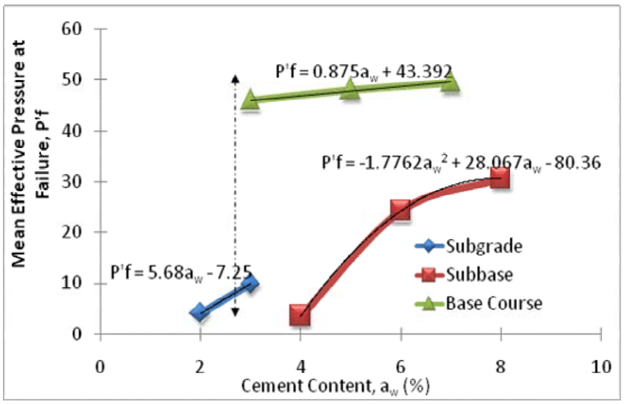
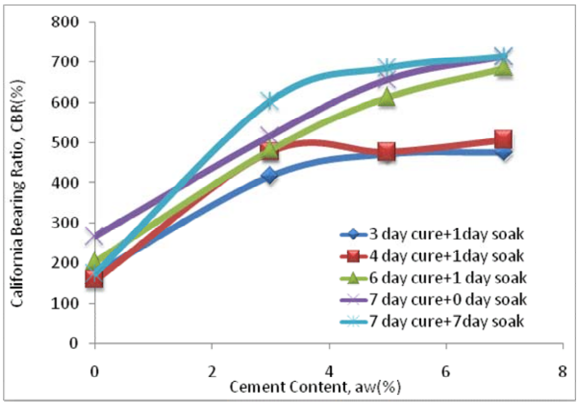


Figure 16 – 7 days soak



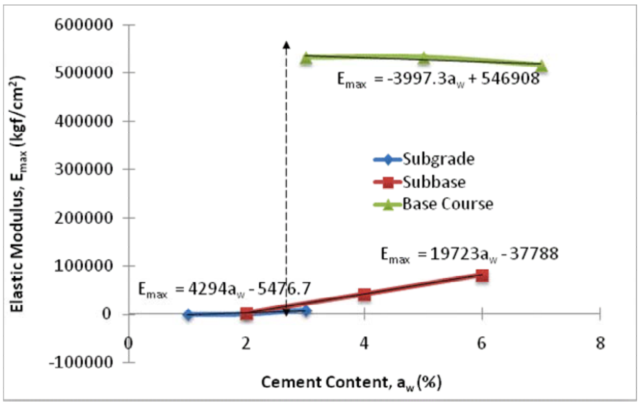
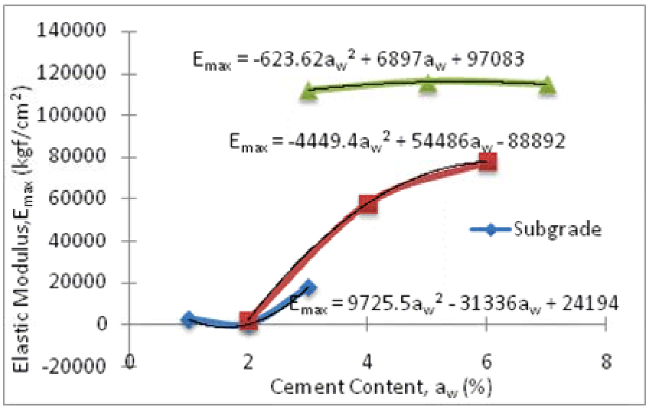


Figure 17 – California Bearing Ratio

Figure 18 – Elastic modulus



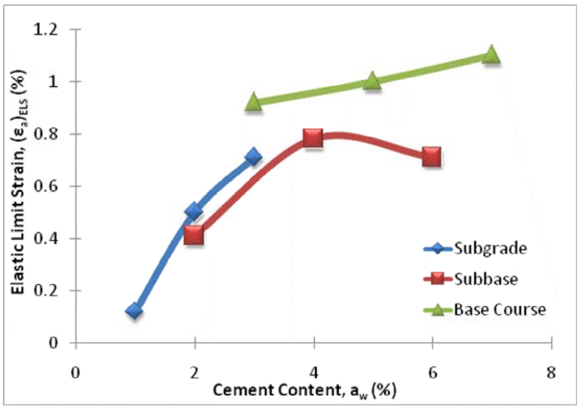


Figure 19 – Elastic modulus

Figure 20 – Elastic limit strain

3.1.2 Slope Stability

Land slides and slope failure are considered amongst the most menacing environmental hazards and disaster which usually result in the loss of lives and property, displacement of persons and devastation large masses of land. Innovative methods of enabling the recycling of the devastated natural geomaterials in the reconstruction of the necessary geotechnical engineering structures should therefore be greatly encouraged.

The innovative methods developed in this Study were successfully applied in various parts of the eastern Africa region in fostering the recycling concepts and either sustaining or enhancing slope stability.

Figure 21 is an example of how this technique was applied in mainly utilizing the in-situ geomaterials in the reconstruction of a pavement and embankment structure due to slope failure that occurred along the integral Addis Ababa~Debre Markos International Trunk Road which connects Ethiopia to Sudan to the west mainly facilitating the transportation of oil while linking Ethiopia to Eriteria to the west. The road works had to be undertaken as a matter of urgency since there was no alternative route. Savings of approximately 50% in construction costs and a reduction of about 60% in construction time were also realized.

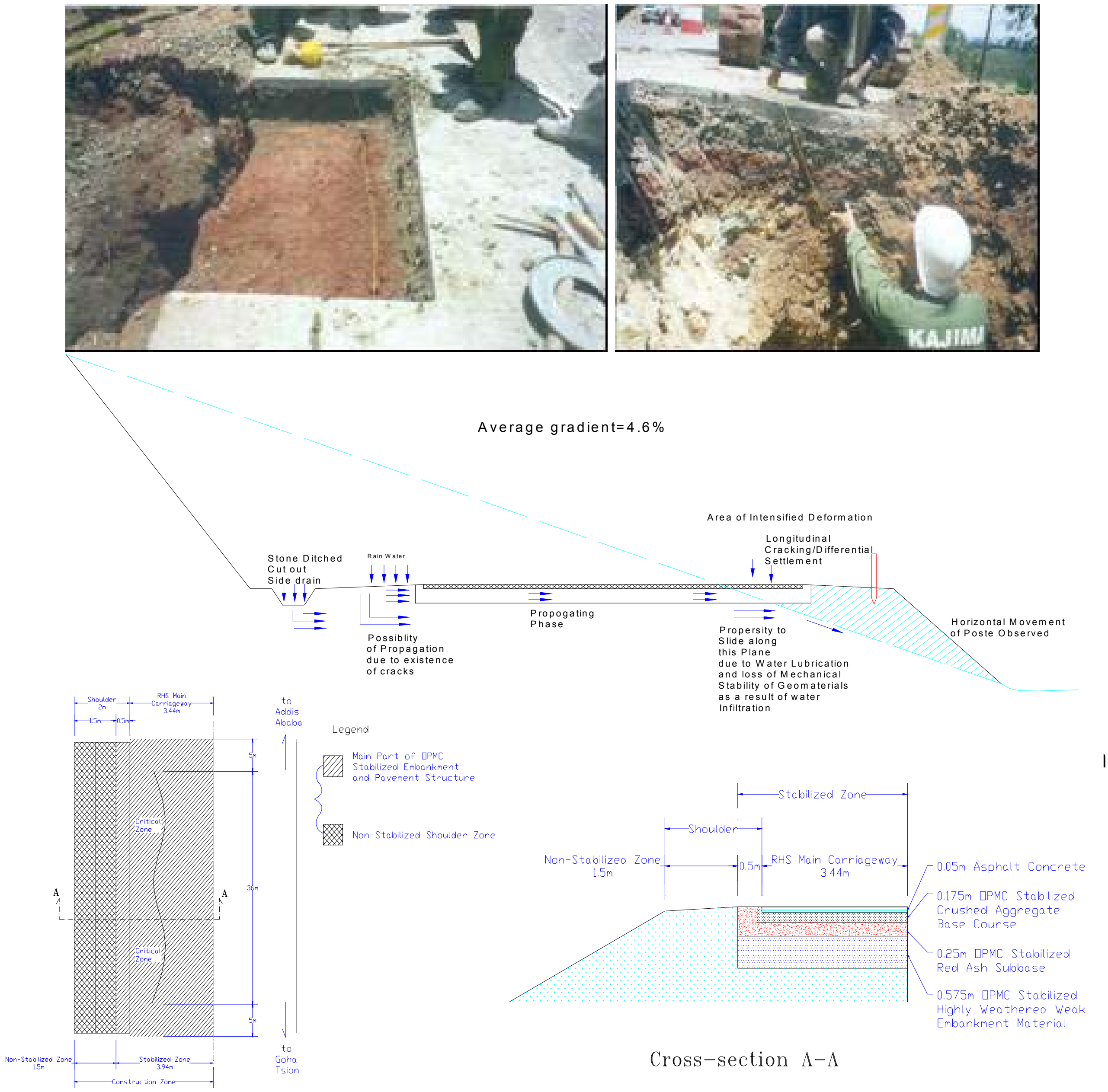


Fig. 21 Example of Application of Innovative Techniques in Recycling In-situ Material for Slope Stability, Pavement Structure and Embankment Construction

3.2 Preserving Natural Habitat for Human and Wildlife

The Tana Basin Development consisted of development of a large scale irrigation scheme and the construction of a 330km International Trunk Road between Malindi and Garrisa linking Kenya to Ethiopia to the north and Somalia to the east. This road traverses trough the rural lowlands of the coastal area of Kenya alongside the Tsavo National Park, one of the largest animal habitats in the country. Consequently, during the design and construction of this road, particularly after the devastation caused by the 1997~1998 El Nino Floods (ref. to Figure 22), care had to be taken to ensure as minimal realignment as possible in order to avoid interfering with the natural habitat for both human and wildlife.

In view of this therefore, the innovatively developed methods were applied in the utilization of in-situ materials as much as possible through the enhancement of their engineering properties.

Fig. 22 El Nino Damaged Tana Basin Road Project

4. CONCLUSIONS

This Study has demonstrated that the developed innovative geotechnical engineering techniques were effectively applied in reducing the cost and impact of road construction.

The methods developed achieved enhanced strength, better compaction characteristics, greater durability and sound resilience resulting in the reduction in the quantities of the natural materials required contributing to controlled land use and reducing negative environmental and social impacts.

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MAIN REFERENCES

1. Construction Project Consultant (1995). Tana Basin Road Development Project, Phase II Materials Report Vo. 3
2. Construction Project Consultant Inc., May, 2000, Hydrological Review and Annalyses for Hydraulic Design of Bridge and Major Culvert Structures and Determination of Areas of Protection, Volume I & II, Tana Basin Road Project Phase II
3. Construction Project Consultant Inc., July, 2000 Engineering Report on the Design and Construction of Reinforced Earth Embankments (The Terre Armee Method), Tana Basin Road Project Phase II.
4. Construction Project Consultant, 2001a. A Brief Report on the Computation of Capping Layer Thickness with Reference to Native Subgrade Bearing Capacity, *CPC Internal Report*
5. Construction Project Consultants, 2001b. Analysis And Evaluation of the Structural Capacity and Serviceability Level of the Existing Road Pavement (Phase III), *CPC Internal Report*
6. Construction Project Consultants, 2001c. Characterization of Black Cotton Soil as a Pavement Foundation Material Based On Comprehensive Analysis (Stage 1), *CPC Internal Report*
7. Construction Project Consultant Inc., Tana Basin Road Development Project, Phase II. Materials Report Vol. 3.
8. Gidigasu. M.D. 1974a. Review of Identification of Problem Laterite Soils in Highway engineering, Transport Research Board, *Washington Recording, I, 497:96~111*
9. Gidigasu. M.D. 1988. Potential application of engineering pedology in shallow foundation engineering on tropical residual soils. *In Geomechanics in Tropical Coils. Proc. of the II Int'l Conference on Geomechanics in Tropical Soils, Singapore, 1,17~24.*
10. Gono, K., Mukabi, J.N., Koishikawa, K., Hatekayama, R., Feleke G., Demoze W., Zelalem A., (2003a). Characterization of Some Engineering Aspects of Black Cotton Soils as Pavement Foundation Materials, to be published in the proceedings of the International Civil Engineering Conference on Sustainable development in the 21st Century.
11. Jardine, R.J. (1995): One perspective of the pre-failure deformation characteristics of some geomaterials, IS Hokkaido' 94,2,pp.855-885.
12. JICA Study Team, 1999. The Study on Rural *Roads* Improvement In Western Kenya-Materials Testing Analyses and Countermeasures for Design Purposes, *Feasilibility Study by The Government of Japan And The Government of Kenya.*
13. Konagai[1] Kazuo and Sato[2] Takeshi. Dependence on Frequency of the Failure Process of Slope Made up of coarse Particles. pp. 33~39
14. K.J. McManus, G. Lu and D. Ruan, The Effects on a Bridge Superstructure of Dynamic Loads Generated by Long Wavelength Roughness in Road Surfaces. *IRF Road World Congress, Paris, June 2001.*
15. Ministry of Transport & Public Works, Kenya, 1981. Materials and Pavement Design for New Roads. *In Road Design Manual Part III.*
16. Ministry of public works & Housing Republic of Kenya, March 1999. Report to OECF Appraisal Mission for the Additional Loan to "Tana Basin Road Project" in the Republic of Kenya, Volume II & I.
17. Mukabi J.N & Tatsuoka, F. (1995b). Effects of swelling and saturation of Unsaturated Soil Behaviour and Applications, Int. Symposium on the Behaviour of Unsaturated Soils, University of Nairobi, Nairobi, Kenya.
18. Mukabi, J.N & Tatsuoka, F. (1999b) Influence of reconsolidation stress history and strain rate on the behaviour of kaolin over a wide range of strain. In Wardle, Blight & fourie (eds), Geotechniques for Developing Africa: Proc. 12th African regional Conf. ISSMGE Durban, 1999. Balkema, Rotterdam.
19. Mukabi, J.N., Murunga P.A, Wambura J.H. & Maina J.N., (1999a) Behavior of con-Aid treated fine grained Kenyan soils. Geotechnics for Developing Africa, Wardle, Blight & Fourie (eds) Balkema, Rotterdam, ISBN 90 809 082 5.pp.583~519.
20. Mukabi J.N & Tatsuoka, F. (1999c). Effects of stress path and ageing in reconsolidation on deformation characteristics of stiff natural clays. *Proc. 2nd I.S on pre-failure characteristic of geomaterials, Torino.*
21. Mukabi, J.N (1999). The Study on Rural Roads Improvement in Western Kenya – Materials Testing Analyses and Countermeasures for Design Purposes. In *Internal Reports and Correspondence*, Japan International Cooperation Agency (JICA) & Ministry of Roads & Public Works, Kenya.
22. Mukabi, J.N. (2000). The design and construction of Reinforced Earth Embankments. *In Internal Reports and Correspondence,* The Terre Armee Method, 2000. CPC, Nairobi.

23. Mukabi, J.N. (2001a). Theoretical and empirical basis for a method of determining the optimum batching ratio for mechanical stabilization of geomaterials. *In Proc. 14th IRF road World Congress, Paris, June 2001.*
24. Mukabi, J.N & Shimizu, N. (2001b). Strength and deformation characteristics of mechanically stabilized road construction materials based on a new batching ratio method. *In Proc. 14th IRF Road World Congress, paris, June 2001.*
25. Mukabi, J.N. Njoroge, B.N. & Toda, T. (2001c). pragmatic method of evaluating design parameters adopting Kenyan tropical soils for pavement structure, *In Procl 4th IRF Road World Congress, Paris, June 2000.*
26. Mukabi, J.N, (2001d). Derivation and application of consolidation and shear stress ratio functions with reference to Critical State analysis of N.C clays. *In Proc. ISSMGE Istabul International Conference. August 2001.*
27. Mukabi, J.N., (2002c). Some Recent Advances in highway and bridge foundation engineering, *Seminar for Ethiopian Roads Authority and Japan Overseas Development Assistance Ethiopia.*
28. Newill, R.J. (1961). A Laboratory Investigation of Two Red Clays from Kenya, Geotechnique, 11(4) 302~318.Pandian, N.S., Nagaraj, T.S. & Sivakumar Banu, G.L (1993). Tropical Clays, Part II. *Engineering behaviour. J.* Geotech. Engrag., ASCE.
29. Peck, R.B., Hanson, W.E. & Thornburn, T.H (1967). (2nd ed) *Foundation Engineering, 271-276.* New York, John Wiley.
30. Richart, Jr., F.E. (1977); Dynamic stress-strain relationships for soils, S-SO-A {a[er,Proc. Of 9th ICSMFE, Tokyo, 3, pp.189-195.
31. Road Research. Catalogue of road surface deficiencies. (1978) Organization for economic cooperation and development. Road Research Institute. MOC, Japan. 1990 Specifications for road and bridge design, Vol. IV & I. (in Japanese)
32. Road Research Laboratory, (1970). A guide to the structural design of pavements for new road. *Road Note No. 29.*
33. Road Transport Research. Pavement Management Systems. Paris, (1987) Organization for economic cooperation and development.
34. Tatsuoka, F. & Shibuya, S. Report of the institute of industrial science the University of Tokyo Vol. 37 No. (serial No. 235) (1992) Deformation Characteristics of soils and Rocks from Field and Labortory Tests.
35. Tatsuoka, F. and Kohata, Y. (1995): Stiffness of hard soils and soft rocks in engineering applications, Keynote Lecture, IS-Hokkaido ’94,Vol.