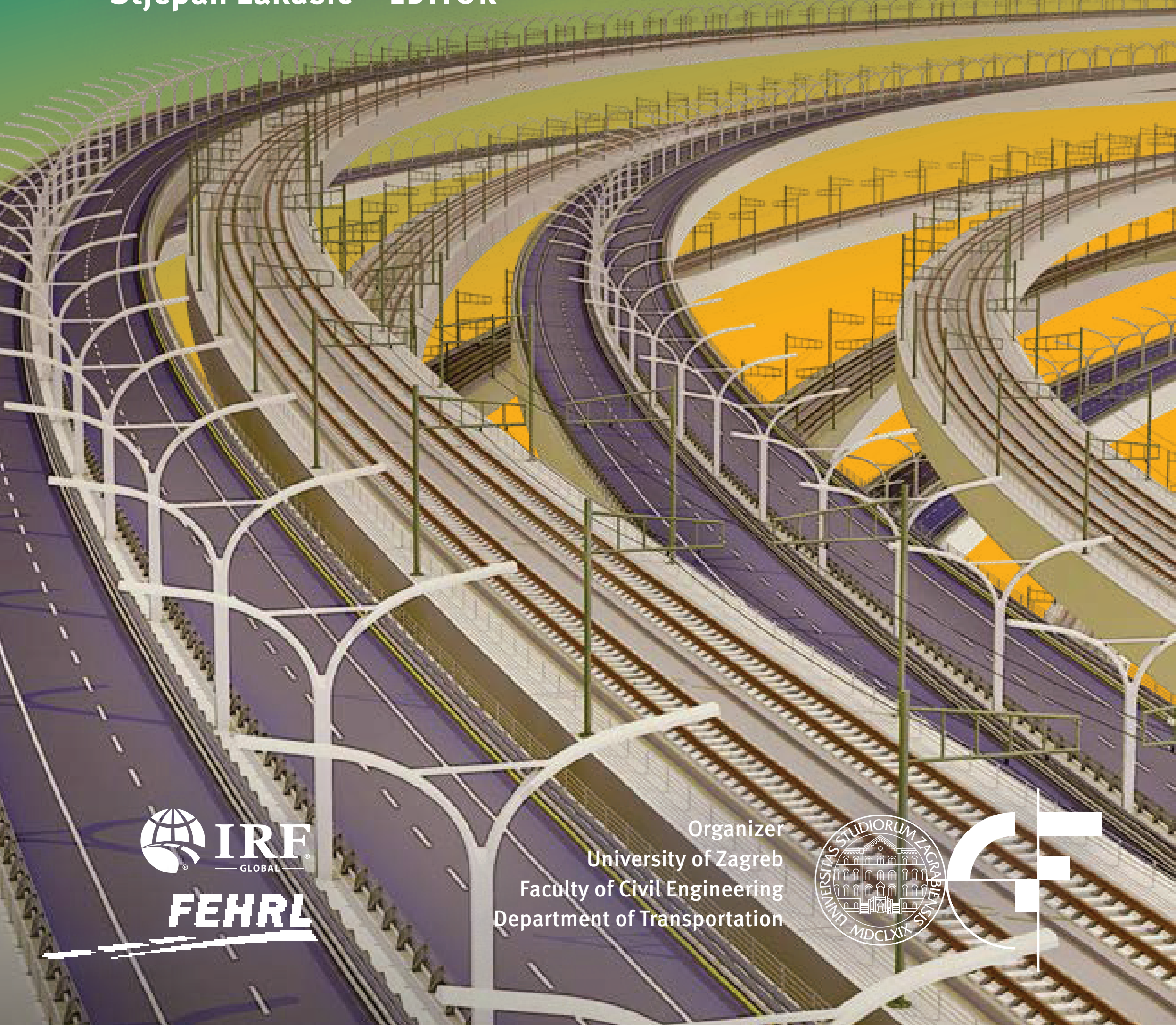
CETRA[2020*]

6th International Conference on Road and Rail Infrastructure
20–21 May 2021, Zagreb, Croatia

Road and Rail Infrastructure VI

Stjepan Lakušić – EDITOR



IRF GLOBAL
FEHRL

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA2020*

6th International Conference on Road and Rail Infrastructure
20–21 May 2021, Zagreb, Croatia

TITLE
Road and Rail Infrastructure VI, Proceedings of the Conference CETRA 2020*

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-48-2

DOI
https://doi.org/10.5592/CO/CETRA.2020

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN & COVER PAGE
Trpimir Ježić

LAYOUT
Tanja Vrančić

PRINTED IN CROATIA, ZAGREB BY
“Tiskara Zelina”, May 2021

COPIES
200

Zagreb, May 2021.

Proceedings of the
6th International Conference on Road and Rail Infrastructures – CETRA 2020*
20–21 May 2021, Zagreb, Croatia

Road and Rail Infrastructure VI

EDITOR
Stjepan Lakušić
University of Zagreb
Faculty of Civil Engineering
Department of Transportation
Zagreb, Croatia

CETRA2020*

6th International Conference on Road and Rail Infrastructure
20–21 May 2021, Zagreb, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. emer. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. **Stjepan Lakušić**
Prof.emer. **Željko Korlaet**
Prof. **Vesna Dragčević**
Prof. **Tatjana Rukavina**
Assist.Prof. **Ivica Stančerić**
Assist.Prof. **Maja Ahac**
Assist.Prof. **Saša Ahac**
Assist.Prof. **Josipa Domitrović**
Assist.Prof. **Ivo Haladin**
Dr. **Tamara Džambas**
Šime Bezina
Katarina Vranešić
Krešimir Burnać
Mate Ivančev
Željko Stepan
Prof. **Kenneth Gavin**
Prof. **Janusz Madejski**
Prof. **Andrei Petriaev**
Prof. **Otto Plašek**
Assist.Prof. **Andreas Schoebel**
Prof. **Adam Szelag**
Dr. **Thierry Goger**
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Mario Bačić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, Josip Juraj Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Said Easa, Ryerson University Toronto
Rudolf Eger, RheinMain University
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Piotr Jaskuła, Gdansk University of Technology
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics
Vaclav Kolar, Technical University of Ostrava
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius University in Skopje
Ivan Lovrić, University of Mostar
Elżbieta Macioszek, Silesian Univ. of Technology
Janusz Madejski, Silesian Univ. of Technology
Stergios Mavromatis, National Tech. University of Athens
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Irina Stipanović, University of Twente
Adam Szeląg, Warsaw University of Technology
Andrej Tibaut, University of Maribor
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Anđelko Vlašić, University of Zagreb
Aleš Žnidarič, Slovenian National Build. and Civil Eng. Institute

FOREWORD

The 6th International Conference on Road and Rail Infrastructure – CETRA 2020* was organized by the University of Zagreb - Faculty of Civil Engineering, Department of Transportation Engineering. The Conference was held in Zagreb, capital of Croatia. Zagreb's history dates back to Roman times when the urban settlement of Andautonia existed at the location of the modern-day Ščitarjevo. In 1945, Zagreb was declared the capital of Croatia and today it is the cultural, scientific, economic, political and administrative centre of the Republic of Croatia, and a home to the Croatian Parliament, Government and President. It is located on the southern foothills of Medvednica Mountain and spreads along the banks of the Sava River. Culturally, it is a European city well worth visiting, with its numerous historical monuments, parks and medieval architecture. Everything is accessible by foot - from your hotel to the theatre, and for wandering around the old Upper Town or through the bustling streets of the more modern Lower Town, which has not lost an ounce of its charm despite the eternal march of time. The streets and monuments of Zagreb proudly testify to its hundreds of years of history.

The 1st International Conference on Road and Rail Infrastructure – CETRA 2010 was held on 17-18 May 2010 in Opatija. The 2nd International Conference on Road and Rail Infrastructure – CETRA 2012 was held on 7-9 May 2012 in Dubrovnik. The 3rd International Conference on Road and Rail Infrastructure – CETRA 2014 was held on 28-30 April 2014 in Split. The 4th International Conference on Road and Rail Infrastructure – CETRA 2016 was held on 23-25 May 2016 in Šibenik. The 5th International Conference on Road and Rail Infrastructure – CETRA 2018 was held on 17-19 May 2018 in Zadar. Great interest of participants in topics from the field of road and rail infrastructure, as expressed during previous CETRA conferences, confirms the adequacy of the Department for Transportation Engineering's decision to keep organising this international event. Positive comments given by participants in past conferences motivated the Department for Transportation Engineering of the Faculty of Civil Engineering at the University of Zagreb, to organise a new CETRA conference (CETRA 2020) on 20-21 May 2020 in Pula. However, due to the circumstances arising from the ongoing spread of COVID-19 - the continuing danger it still poses to public health and safety, together with an increase in travel restrictions - CETRA 2020 Organizing Committee has decided to further postpone the Conference. We held on for as long as we could, wishing that things would return to some semblance of normality. We were very optimistic, hoping that the situation with COVID-19 will be much better in October, trying our best to organize CETRA 2020 and to bring our professional and scientific community together one more time. However, the safety of the participants is our priority, and we decided it would be prudent to postpone the CETRA 2020 Conference to the spring of 2021. At the same time, postponing the Conference to the following year provided the members of our Committees valuable time to completely dedicate themselves to the determination of damage caused by the disastrous earthquake that hit Zagreb in March last year. Although we wished to organise the conference in 2020, even in the autumn of that year, we had to postpone the conference so as to be held in May 2021 on the same dates on which it was supposed to take place in 2020. We also partly kept the identity of the conference so that in 2021 the conference will be organized under the name of CETRA 2020*.

The CETRA conference has established itself as a venue where scientific and professional information from the field of road and rail infrastructure is exchanged. The idea on linking research organisations with economic sector has been the guiding concept for the realisation of this conference. Conferences of this kind are undoubtedly a proper place for establishing closer ties between the economy and university operators, and for facilitating communication and inspiring greater confidence, which might result in cooperation on new projects, especially those that contribute to greater competition. Lectures organized in the scope of the conference are based on interesting technical solutions and new knowledge from the field of transport infrastructure as gained on the projects already realised, projects currently at the planning stage, and those that are now being realized, in all parts of the world. In addition to presentations given by authors from the academic community, lectures are also presented by authors from engineering practice, the idea being to ensure the best possible synergy between the theory and practice. Because of great interest for the themes relating to the field of road and rail infrastructure, as shown during the past fourth conferences (CETRA 2010, CETRA 2012, CETRA 2014, CETRA 2016 and CETRA 2018), the Department for Transportation Engineering of the Faculty of Civil Engineering – Zagreb has assumed the responsibility to organise the new CETRA Conference in 2020 as well but, as already mentioned, the COVID-19 pandemic is the reason why the conference has been rescheduled for 2021 (but keeping the identity in the form of the name CETRA 2020*). However, due to the pandemic, the form in which the conference will be organised was also changed so that it will be held via an on-line platform.

This year, the 6th International Conference on Road and Rail Infrastructure – CETRA 2020* is organized with the intention of bringing together scientists and experts in the fields of road and railway engineering, so that they can present the results of their research, their findings and innovations, and analyse problems encountered in everyday engineering practice and, finally, offer solutions that will undoubtedly contribute to a more efficient planning, design, construction, and maintenance of transport infrastructure. The CETRA 2020* Conference serves as a platform for presenting a broad blend of scientific and technical papers in the fields of civil, transport, geotechnical, environmental, traffic and electrical engineering, with practical application in the road and rail infrastructure. Papers considered for publication are original papers that adequately contribute to the theory or practice of infrastructure engineering, and present either state-of-the-art work on topics related to infrastructure, or case studies in which theory is applied to solve significant infrastructure problems.

This year's CETRA Conference attracted a large number of papers and presentations from 32 countries. More than 140 papers were presented at the Conference and are contained in these proceedings **Road and Rail Infrastructure VI**. We believe that these CETRA 2020* proceedings will prove to be, just like the preceding five proceedings from the CETRA cycle, highly interesting and useful to all experts exhibiting a scientific and professional interest in road and rail infrastructure. The organizers of the Conference express their thanks to all Businesses and Institutions that provided support to this Conference. Special thanks are extended to the IRF - International Road Federation, and FEHRL – the Forum of European National Highway Research Laboratories, for their assistance and support in organizing very important conference sessions relating to innovations in roads maintenance and innovative transport infrastructure development. These operators have contributed, each in its own way, to the success of this conference. Great thanks are also extended to the following institutions that have supported the CETRA conference over the past ten years: University of Zagreb, Ministry of Sea, Transport, and Infrastructure, Ministry of Science and Education, and Croatian Academy of Engineering.

The Editor commends all authors for excellent papers contributed to these proceedings and wishes to thank members of the Organizing Committee and International Academic Scientific Committee, and numerous experts who participated in the review process. The gratitude is also extended to all participants for taking part in the CETRA 2020* Conference. The quality of the papers presented and the CETRA Conference is best demonstrated by the fact that a considerable interest is being expressed for most of these papers by researchers and industry operators from all parts of the world. This is not only due to the high visibility of the conference thanks to its presence in relevant databases, but is also a logical consequence of the quality of papers published in the scope of this conference series. Lectures that are organised at the conference are based on interesting technical solutions and latest findings in the field of transport infrastructure from the projects already realised, those that are at the design stage, or projects that are currently being realised in all parts of the world. In addition to representatives from the academic community, conference lectures are also given by industry operators, which constitutes the best possibly synergy of theoretical and practical achievements. Problems encountered in everyday engineering practice are analysed through papers presented at the conference, where practical solutions are offered in order to enable a more efficient planing, design, construction, and maintenance of transport infrastructure.

The organization of the CETRA 2020* Conference has proven to be a greater challenge compared to the organisation of the first CETRA 2010 Conference. The persistence of organisers and great perseverance of the authors who have accepted that their valuable scientific achievements and interesting professional projects are published not in 2020 but in 2021, i.e. in the year to which the conference has been rescheduled, are the proof that only by acting together we will be able to overcome challenges that inevitably occur in the society. High quality papers published in the Conference Proceedings are the result of great efforts of the authors and reviewers as they have worked in close synergy to achieve outstanding papers included in the proceedings and presented at the conference. All those who took part in the preparation of the proceedings (authors, reviewers, members of the Organizing Committee, technical editor, and the editor-in-chief) have worked hard to enable timely publication of the proceedings. We believe that the papers published in the proceedings will be interesting not only to our colleagues in the everyday engineering practice but also to students of technical faculties where disciplines from the field of road and rail infrastructure are studied.

Zagreb, May, 2021

THE EDITOR

Prof. Stjepan Lakušić

CONFERENCE SUPPORT

Co-organizer and Support of the Conference

University of Zagreb
Trg Republike Hrvatske 14, 10000 ZAGREB, Croatia
www.unizg.hr

University of Zagreb
Faculty of Civil Engineering
Kačićeva 26, 10000 Zagreb, Croatia
www.grad.unizg.hr

Ministry of the Sea, Transport and Infrastructure
Prisavlje 14, 10000 Zagreb, Croatia
https://mmpi.gov.hr/

Ministry of Science and Education
Donje Svetice 38, 10000 Zagreb, Croatia
https://mzo.gov.hr

International Road Federation
www.irf.global

FEHRL - the Forum of European
National Highway Research Laboratories
www.fehrl.org

General Sponsor

MONTERRA
Vukovarska ulica 76
51000 Rijeka
www.monterra.hr

Silver Sponsor

University of Zagreb
Faculty of Civil Engineering
Kačićeva 26, 10000 Zagreb, Croatia
www.grad.unizg.hr

Bronze Sponsors

Bentley Systems International Limited
Charlemont Exchange
Charlemont Street
DUBLIN 2
Ireland

Centar za vozila Hrvatske
Capraška 6
10000 Zagreb

DIV GROUP Ltd.
Bobovica 10/A,
10430 HR-Samobor

Media Partner

Journal of Croatian Association of Civil Engineers
Berislavićeva 6, 10000 Zagreb, Croatia
www.casopis-gradjevinar.hr · gradjevinar@hsgi.org

CETRA2020* 20-21 May 2021, Zagreb, Croatia
6th International Conferenceon Road and Rail Infrastructure

COMPARATIVE STUDY ON THE DESIGN METHODS FOR FLY ASH-FLEXIBLE PAVEMENT

Jacob A. Adedeji[1], Samuel O. Abejide[2], Mohamed M. Hassan Mostafa[3]
[1] *Durban University of Technology, Civil Engineering Department Midlands, Kwazulu-Natal Province, South Africa*
[2] *Walter Sisulu University, Faculty of Engineering Technology, Civil Engineering Department, Eastern Cape Province, South Africa*
[3] *University of KwaZulu-Natal, School of Engineering, Sustianble Transportation Research Group (STRg), Civil Engineering, Kwazulu-Natal Province, South Africa*

Abstract

Advancement in the design of pavement structures in the recent decade has brought about the use of finite element modelling (FEM) tools. Numerical simulation of flexible pavement through these models are yielding positive results and enhancing pavement design year after year. Various factors contribute to this success; yet, material characterization model in FEM is a major/critical factor. However, in using FEM, there are various material characterization input methods which are; input through laboratory testing; secondly, through correlation and lastly a backward calculation from deflection measurements. Overall, input methods are more realistic and give a better understanding of the mechanical behaviour of the material, nevertheless quite difficult to obtain. Although, the use of fly-ash stabilizer in pavement structure is not new yet its use has not been fully implemented in FEM design. As a result, a comparative study is considered based on input and correlation parameters on fly ash stabilized flexible pavement using Abaqus. Furthermore, the results show that the material input method provides better results and gives some amount of certainty on the design life of the pavement.

Keywords: flexible pavement; finite element modelling; empirical design methods; material characterization; Non-linear model; fly ash

1 Introduction

Flexible pavement design is based on load distributing characteristic of the component layers. The asphalt surface depending on time and temperature behaves as a viscous material and the pavement foundation matrix (coarse-grained unbound granular materials in base / sub-base course and fine-grained soils in the sub-grade) exhibit stress-dependent non-linear behaviour [1]. Furthermore, with the introduction of soil stabilization resulting in alternative materials, the design of flexible pavement has become more complex. Thou the analysis of pavement via empirical methods sometimes result in errors [2]. Therefore, this study presents a comparative analysis of material characterization input methods for fly ash stabilized flexible pavement using FEM. FEM has been applied extensively in road engineering over the years [3]. So far, it is the most versatile of all analysis techniques, with capabilities for 2D and 3D geometric modelling, able to analyze stable (static), time-dependent problems, non-linear material characterization, large strains/deformations, dynamics analysis and other sophisticated features [4]. However, the application of FEM to solve any problem consists of three separate stages; pre-processing (Modelling), processing (Evaluation) and post-processing (Simulation). Yet, the use of 3D appears to be the best approach [5]. FEM has been successfully used in the analysis of the major forms of failure in pavement structure such as rutting and fatigue cracking at different layers [6] and also used to determine the accurate positioning of geogrid materials [6], the thickness of each layer [7] and the interaction between pavement and its instrumentation.

2 Critical factors in finite element analysis of flexible pavement

In general, creating an FE model for flexible pavement analysis involves the consideration of all the steps in the pre-processing (Modelling), which are; the geometry of pavement (dimensions), material characterization, the relationship between parts (assembling and interactions), loading and boundary conditions (constraints), and analysis type. Although critical considerations need to be given to the aforementioned, any FEM simulation's success depends greatly on them. If these factors are not properly considered, it can result in errors in the design. However, based on the scope of this study, material characterization would be discussed.

2.1 Material characterization

Proper material characterization is a critical/major aspect of FEM based design of pavement, as it determines the reliability of response prediction in pavement design. However, accurate material characterization, selection and formulation of proper constitutive equations to represent the behaviour of the materials under loading is considered [1]. Qualitative choice is needed in material characterization and the model must capture the major features of material behaviour while minor features may be ignored in the model [8]. Furthermore, resilient modulus (MR) alongside Poisson's Ratio as input material property for characterizing all unbounded layers and soils in any FEM model for flexible pavement design is considered [9]. MR values although estimated directly from laboratory testing such as; Triaxial, Oedometer and Shear test; indirectly through correlation with other laboratories/field tests which are CBR, Isotropic compression test, Uniaxial strain test, Indirect tensile strength and unconfined compression strength (UCS) or back-calculated from deflection measurements [9], [10]. On this note, correlation is selected due to the difficulty in laboratory testing of input parameters.

2.2 Material characterization via correlation equations

AASHTO recommends MR from repeated Triaxial test. Due to the complexity of the test and time required, results are not readily available. In view of this, Sas et al. [11] and Rao et al. in the Technical Report [12] improvised the use of correlation equations for readily available test results. Thus, it is necessary to evaluate design MR of a stabilized base layer available data of UCS. Table 1, amongst others, suggests equations to estimate MR considering UCS test.

Table 1 Summary of correlations between the unconfined compressive strength and resilient modulus of underlying pavement layers [13]

Correlation	Source of the correlation	Application area
MR (ksi) = 500 + UCS (psi)	American Coal Ash Pavement Manual (1990)	Lime-cement-fly ash stabilized soils
MR (psi) = 1200 UCS (psi)	Barenberg (1977)	Cement stabilized coarse-grained sandy soils
MR (psi) = 440 UCS (psi) + 0.28 UCS2 (psi)	Barenberg (1977)	Cement stabilized fine-grained soils
MR (ksi) = 0.124 UCS (psi) + 9.98	Thompson (1966)	Lime stabilized soils
MR (psi) = 0.25 UCS2 (psi)	McClelland Engineers (unpublished)	Lime-cement-fly ash mixtures
MR (MPa) = 2240 UCS0.88 (MPa) + 110	Australian Road Research Laboratory (1998)	Cemented natural gravel

2.3 Material characterization using resilient modulus model

The use of Triaxial, Oedometer and Shear test results as material characterization is considered more accurate. Using any of the aforementioned test results requires at least one to two laboratory tests for calibration in the FE model. Over the years, various models have been developed for obtaining MR through Triaxial laboratory results. In NCHRP [14], few of the several models available were suggested. Overall, amongst the models in that study, the LTTP model (equation 1), – a modification of the Universal model – is adopted in the Design Guide (United States Department of Transportation – Federal Highway Administration [15], this will be considered in this study based on its general acceptance. The result in terms of MR obtained is inputted in constitutive material models in the FE Model.

$$M_R = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left[\left(\frac{\tau_{oct}}{P_a}\right) + 1\right]^{k_3} \quad (1)$$

Where
M_R - Resilient modulus,
θ - Bulk stress (σ1 +σ2 +σ3),
P_a - Atmospheric pressure,
σd - Deviator stress,
σ3 - Confining stress,
k_i - Regression coefficient,
τ_{oct} - Octahedral stress ($\sqrt{\frac{2}{3}}\sigma_d$).

2.4 Failure criteria in numerical simulation

This is the empirical portions of the M-E design, known as the damage models, and it is developed to provide the resistance of pavement to failure [16]. These models require results from FEM such as stress, strain or deflection to give the behaviour of pavement in terms of performance, cracking, rutting, roughness and life span with equations derived from observation and performance of pavement to observed failure and initial strain under various loads. Various types of failure criteria exist depending on the type of pavement layer in question; Asphalt surface – (Fatigue cracking); Unbound granular base and sub-base layer – (Permanent deformation); Cemented base and sub-base layers – (Crushing failure, Effective fatigue and Permanent deformation); Subgrade – (permanent deformation or rutting), nonetheless two are widely recognized; fatigue cracking in asphalt and deformation in the subgrade [17]. Permanent deformation is induced in any layer of the structure, making it more difficult to predict than fatigue cracking. Yet, critical rutting can be attributed mostly to a weak pavement layer (subgrade). This is typically expressed in terms of the vertical compressive strain at the top of the subgrade layer and is given by Asphalt Institute by equation (3).

$$N_f = 0.0796\left(\varepsilon_t\right)^{-3.291}\left(E\right)^{-0.854} \tag{2}$$

Where
N_f - Number of repetitions for fatigue cracking;
ε_t - Tensile strain at the bottom of the asphalt surface in microstrain;
E - resilient modulus of asphalt in psi.

$$N_r = 1.365 \cdot 10^{-9}\left(E_c\right)^{-4.477} \tag{3}$$

Where
Nr - Number of repetitions for subgrade rutting failure;
Ec - Compressive strain on top of the subgrade.

Overall, the failure analysis models define the point at which failure occurs in pavement by determining the incremental damage.

3 Methodology

The research design adopted for this study incorporates Finite Element analysis of pavement layers subjected to traffic loading conditions. The design principle also allows for the response analysis to be analysed based on the pavement's characteristic input values; the analysis result is developed in form of failure deformation patterns considering resilient modulus of the underlying asphalt base layers down to the subgrade layer. A scenario of a paved flexible pavement is developed for a three-layered system of the pavement structure which is; asphalt surface, 18 % fly ash with 1 % cement stabilized base and subgrade layer. 3D FEM was used in the development of these models. The thicknesses of the asphalt layer ranges (25mm – 100mm) while that of base and subgrade layer were kept constant at a specific depth (300 mm and 2000 mm respectively).
Additionally, the 3D model is 3000 mm in length by 3000 mm breadth and the total depth of 2350 mm. This geometry is also similar to that used by Tiliouine and Sandjak [18], intending to avoid edge error when loaded. Furthermore, 8-node solid continuum elements (C3D8R) with reduction integration were used. The asphalt, stabilized base and subgrade layer was seed at 0.025 m at the loading area, while other areas were seed at 0.1 m; as a result, meshes are fine in/near loading area and coarse at distances away from the applied load for an efficient model as suggested by Peng and He [3].

3.1 Material input classification for analysis

Material properties of the stabilized base layers were obtained from laboratory test (UCS) and by correlation formula [13]. Although, other material properties are selected from research reported in [17] represented by the linear elastic model. Parameters such as (bulk stress = 1854kPa) are obtained from Heyns and Mostafa Hassan [19] and regression coefficients (k1 = 3000psi and k2 = 0.5) suggested by AASHTO [13]. A Drucker-Prager, (D-P) elasto-plastic model and plasticity model in Abaqus was used for the material characterization

to be non-linear. The D-P shear criterion is assumed ‘exponent form’ to allow for the use of sub-option (Triaxial test data), and the dilation angle is assumed to be 15^{o}.
Furthermore, the non-linear material characterization for the stabilized base layer is analyzed in a static-general analysis procedure, to consider the non-linear effect. All laboratory test result were conducted by [19]. Tables 2-3 presents the material properties used in this study.
3.2 Boundary Conditions and load parameters
The pavement layers are assumed to be perfectly bond together, and the model is fixed at the bottom of the subgrade and roller constraints on the vertical boundaries. A static standard equivalent single axle load with dual tires is used. TRH4 [20] specified that the maximum stress at a specific point in the pavement occurs when the wheel load is directly above it, while the stress can be assumed zero when the load is quite far from that point. The contact area of 72557 mm^2 with a rectangular area of contact was placed above the asphalt layer [2]. These loads were standard equivalent single axle load (80 kN) with dual tires and applied uniformly with a pressure of 0.65 MPa following South African standard.

Table 2 Material properties of conventional pavement interlayers profile

Layer	Material code (Colto 2008)	Modulus of Elasticity [MPa]	Poisson’s Ratio
Surface	AG	3000	0.44
Granular Base	G5	200	0.35
Subgrade	G10	45	0.35

Table 3 Material properties of the stabilized base layer

Stabilized Base (%18Flyash+1%Cement)	Material code (Colto 2008)	USC [kPa]	Modulus of Elasticity [MPa] (Level 1)	Modulus of Elasticity [MPa] (Level 2)	Poisson’s Ratio
18	C3	2133	1301	2560	0.35

4 Result and discussion

4.1 Finite Element Deformation Models

The non-linear material characterization over linear gives a close field measurement; thus, a comparative analysis of non-linear and linear material characterization was undertaken in this study. Figures 1 – 3 show the contour plots for displacements, strains and stresses in the 25 mm asphalt thickness layer. From Figure 1, it was observed that the maximum magnitude of deflection (rutting - 4.544×10^{-4} m) was higher in Figure 1B, which is for the non-linear model, implying the material acts like an elasto-plastic membrane; thus did not return to the original state. Similarly, from Figure 2, the maximum strain (1.838×10^{-4} m) was higher in the non-linear model but also worth to noting that the minimum strain (-5.076×10^{-6} m) was higher in the linear model, thus implying that strain in the linear model extended to the lower part of the sub-grade which will overall fail.
In Figure 3, the maximum stress transfer (tyre load) through the linear model was high, implying that more stress is transferred to the rest of the layers. Overall, there are not many differences in the results obtained, despite the MR (1301 MPa) used in the non-linear model is smaller when compared with that of the linear model (2560 MPa).

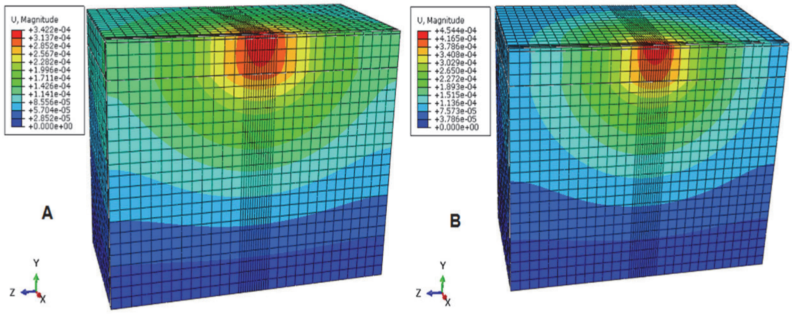


Figure 1 Displacement Failure Mode 25mm Asphalt Layer Thickness (A – Linear Model; B – Non-Linear Model)

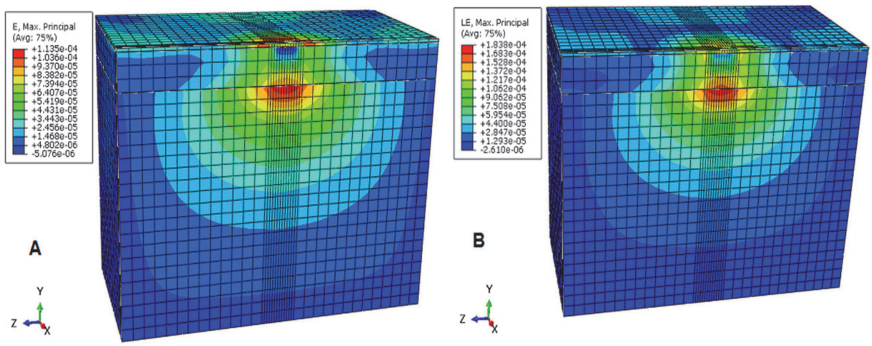


Figure 2 Strain failure Mode 25mm Asphalt Layer Thickness (A – Linear Model; B – Non-Linear Model)

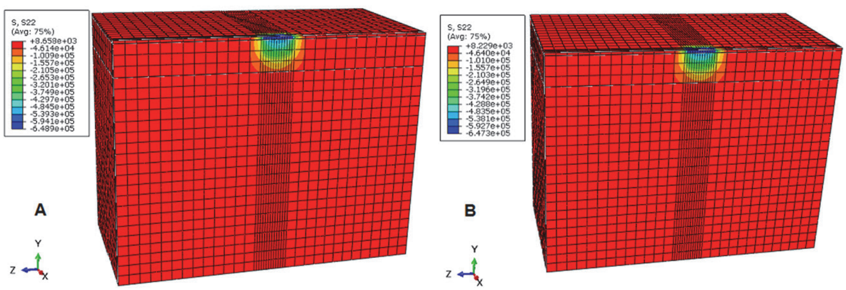


Figure 3 Stress Failure Mode 25mm Asphalt Layer Thickness (A – Linear Model; B – Non-Linear Model)

The non-linear model [Table 4] experienced an increase in the compressive strain for the stabilized base in 50 mm thickness asphalt layer and after that a decrease. Conversely, the horizontal strain in asphalt layer decreases in the 50 mm thickness and thereafter increases for subsequent thickness, thus, implying that the thickness of asphalt layer beyond 50 mm may result in bottom-up fatigue cracking. Overall, it is worth noting that the use of 50 mm thickness of asphalt layer over the stabilized base layer by developing countries, is not only justifiable by economic reasons, but also on its effectiveness to prevent failure such as bottom-up fatigue cracking which can be experienced in thicknesses beyond 50 mm.

Table 4 Asphalt Layer Response (Linear and Non-Linear Model)

Asphalt Layer Thickness (mm)	Linear Model		Non-linear Model	
	Vertical Strain εc (10^{-6}) in Stabilized Base Layer	Tensile Strain εt (10^{-6}) bottom of Asphalt Layer	Vertical Strain εc (10^{-6}) in Stabilized Base Layer	Tensile Strain εt (10^{-6}) bottom of Asphalt Layer
25	120.0	31.94	259.1	38.57
50	131.9	27.53	285.7	30.92
75	135.2	23.08	273.9	41.46
100	129.8	35.60	247.5	61.55

4.2 Structural Capacity Comparative Analysis

Table 5 presents the pavement structural capacity results obtained from the use of mechanistic-empirical structural capacity estimation (mePADS), 3D FEM Linear and Non-Linear Material with the Asphalt Institute model. The mePADS; which serves as a check for 3D FEM models' performance, although within a close range yet, tend to be higher than those of 3D FEM models. This is so because the South African Pavement Design Method (SAPDM) damage model used in software in question is outdated and currently under review [13]. Furthermore, results from linear models are higher than those of non-linear, which show that the linear model is over-designed as a result of the MR of the stabilized base layer considered. Thus it can be concluded that MR has a significant effect on the design of pavement through FEM.

Table 5 Effect of Asphalt layer thickness (linear and non-linear material model)

Asphalt Layer Thickness (mm)	Sub-grade Bearing Capacity (mePADS Results)	No. of Load Repetitions to Failure Nr (Linear Model)	No. of Load Repetitions to Failure Nr (Non-Linear Model)
25	30.70×10^{12}	2.92×10^{6}	5.41×10^{5}
50	12.70×10^{14}	5.60×10^{6}	1.13×10^{6}
75	43.11×10^{14}	9.89×10^{6}	2.13×10^{6}
100	10.00×10^{15}	17.04×10^{6}	3.91×10^{6}

5 Conclusion

In this study, a comparative analysis of material characterization inputs methods was undertaken. According to literature reviews, material characterization is one of the major factors contributing to the success in pavement design through FEM. Firstly, this study's results showed that an increase in the asphalt layer's thickness increases pavement resistivity to failure; yet, an increase in thickness beyond minimum allowance based on the design requirement may result in bottom-up fatigue cracking. Secondly, results showed that the use of non-linear (level 1) material characterization model is more efficient than linear material characterization. However, as a result of the Triaxial test results' unavailability, the linear material characterization model can be used as a preliminary study. Overall, the non-linear material characterization model stands a chance to provide better results and gives some certainty on the pavement's design life.

References

[1] Kim, M.: Three-dimensional finite element analysis of flexible pavements considering nonlinear pavement foundation behavior, University of Illinois at Urbana-Champaign, 2007.

[2] Huang, Y.H.: Pavement Analysis and Design, 2nd Edition, Pearson Education Inc, NJ., 2004.

[3] Peng, Y., He, Y.: Structural characteristic of cement-stabilized soil bases with 3D finite element method, Frontiers of Architecture and Civil Engineering in China, 3 (2009) 4, pp. 428-434

[4] NCHRP: Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures: Appendix RR-Finite Element Procedures for Flexible Pavement Analysis, Transportation Research Board, National Research Council, Washington D.C., 2004.

[5] Shafabakhsh, G.A., Motamedi, M., Family, A.: Influence of Asphalt Concrete Thickness on Settlement of Flexible Pavements, Electronic Journal of Geotechnical Engineering, 18 (2013), pp. 473-483

[6] Abed, A.H., Al-Azzawi, A.A.: Evaluation of Rutting Depth in Flexible Pavements by Using Finite Element Analysis and Local Empirical Model, American Journal of Engineering and Applied Sciences, 5 (2012) 2, pp. 163-169

[7] Sinha, A.K., Chandra, S. Kumar, P.: Finite Element Analysis of Flexible Pavement with Different Subbase Materials, Technical Paper, Indian Highway. 42 (2014) 2, pp. 53-63

[8] Abaqus, Inc.: Analysis of geotechnical problems with ABAQUS. 2003. ABAQUS, Inc.

[9] Ji, R., Siddiki, N., Nantung, T., Kim, D.: Evaluation of Resilient Modulus of Subgrade and Base Materials in Indiana and Its Implementation in MEPDG, The Scientific World Journal, 2014., pp.1-14, doi: https://doi.org/10.1155/2014/372838

[10] Al-Jhayyish, A.K.: Incorporating Chemical Stabilization of the Subgrade in Pavement Design and Construction Practices, PhD Thesis, Ohio University, 2014.

[11] Sas, W., Głuchowski, A., Szymański, A.: Determination of the resilient modulus MR for the lime stabilized clay obtained from the repeated loading CBR tests, Annals of Warsaw University of Life Sciences-SGGW, Land Reclamation, 44 (2012) 2, pp. 143-153

[12] Rao, C., Titus-Glover, L., Bhattacharya, B., Darter, M.I.: User's Guide: Estimation of Key PCC, Base, Subbase, and Pavement Engineering Properties from Routine Tests and Physical Characteristics, technical Report, FHWA-HRT-12-03, Federal Highway Administration, Washington, DC, 2012.

[13] Adedeji, J.A.: Simulation of flexible pavement utilizing fly ash as alternative stabilizer. Master's thesis, Department of Civil Engineering, Central University of Technology, Free State, South Africa, 2015.

[14] NCHRP, National Cooperative Highway Research Program. Mechanistic-Empirical Pavement Design Guide, Transportation Research Board, Washington, DC, http://onlinepubs. trb.org/onlinepubs/archive/mepdg/home.htm, 14.04.2010.

[15] United States Department of Transportation - Federal Highway Administration (USDT-FHA), Geotechnical Aspects of Pavements Reference Manual, http://www.fhwa.dot.gov/engineering/geotech/pubs/05037/05b.cfm, 3.1.2020.

[16] South African National Road Agency, Pavement Design: South African Pavement Engineering Manual, An initiative of the South African national roads agency ltd, South Africa, 2013.

[17] Ekwulo, E.O., Eme, D.B.: Fatigue and rutting strain analysis of flexible pavements designed using CBR methods, African Journal of Environmental Science and Technology, 3 (2009) 12, pp. 412-421

[18] Tiliouine, B., Sandjak, K.: Numerical simulation of granular materials behaviour for unbound base layers used in Algerian pavement structures, International Journal of Civil and Structural Engineering, 4 (2014) 3, pp. 419-429

[19] Heyns, M.W., Mostafa Hassan, M.: South Africa Class F Fly Ash for roads: physical and chemical analysis, Interim: Interdisciplinary Journal, 12 (2013) 3, pp. 28-41

[20] TRH 4: Structural Design of flexible pavements for interurban and rural roads. Pretoria: Committee of Land Transport Officials (COLTO), Department of Transport (DoT). (DoT Technical Recommendations for Highways; Draft TRH 4, 1996.