A Review of Finite Element Method Applications in Flexible Pavement Design

Velagapalli Chiranjeevi[1*], Kamal Singh[2]
[1,2]Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, India

Corresponding Author: **V.Chiranjeevi**

Abstract: Recently, the Finite Element Method (FEM) has found widespread use acrossvarious engineering disciplines, particularly in structural analysis. Its application in pavement structure analysis has become increasinglyprevalent. As mechanical investigation becomesintegral to pavement construction, FEM has emerged as a crucial tool for precise structural assessment. This paperprovides a brief overview of FEM-adapted flexible pavement design, focusing on the utilization of in finiteelement modeling to design different layers of pavement structures. The objective is to explore various FEM applications in flexible pavement design, high lighting its potential capabilities. Additionally, the strengths and weaknesses of FEM in this context will be discussed, along with an examination of current trends.

Keywords: Finite Element Method, Visco-elasticity, Asphalt Design, Materials.

Introduction

For quite a long time, the complex elasticity model is broadly utilized in pavement structure examination. Programming dependent on a complex elastic model, for example, ILLIPAVE, MICHPAVE, and ever stress is simple to utilize, notwithstanding, granular material of asphalt structure depicts nonlinear system behaviour which tells that there is a requirement for mechanical examinations which can manage this problem. Finite element method can be incredible tool because of its beautiful user changeable

element command. Not only the estimation of critical reaction becomes possibly effective by FE program, but it also assists examiners with building a stress dependent material model by altering a few pieces of the codes so FEM can be recognized from existing multi-facet versatile examination.
With the plan idea of empirical based Mechanical design on asphalt structure was presented, those different apparatus for asphalt structure development likewise becomes widely spread. Representatively, the finite element (FE) technique becomes the wonderful tools for mechanical development. Because the commercially available FE based analysis solution has constitutive conditions, the finite element strategy will be utilized in asphalt structure to demonstrate the viscoelastic or anisotropic properties. But many, commercially available FE solutions don't completely uphold nonlinear investigation of asphalt design like pressure subordinate capacity in different stack-up layers, and not appropriate to examine a material property. Hence as of late scientists are attempting to include this nonlinearity into examination in their own codes. Some of these codes are based on time series model. Attempted to present fundamental interaction during improvement of the mathematical modelling and the foundation of FE examination in asphalt design. The broad conceptual framework is shown in Fig. 1 below.

Literature Review

Asphalt is composite of different layers, which are having diverse material properties from one another but cooperate to work as one complete structure which makes examination inside the structure troublesome. The main reason of investigation is that there is need to confirm different layer's reaction to portray the nature of the entire pavement design. FE is the instrument used for the examination or validation. Below are the most notable consequent conditions for different layer–

2.1 Surface Layer of Asphalt Concrete

Dynamic modulus estimated for different temperature values and loading conditions could be changed over the master curves that address the actual mechanical characteristics of the pavement cement for design of asphalt width and for the quality investigation. Most of the time binder material of asphalt and its blend is influenced by heat and stacking recurrence. These material characteristics change that bituminous layering to show viscoelasticity behavior.

Dynamic modulus computed with the help of below equation –

$$E(t)= \sigma_o/\varepsilon_o \ e^{(-i\emptyset)}= Ee^{(i\emptyset)}$$

This is the function of mechanical parameters like stress& strain, phasor angle, frequency, and some non-real portion. Bituminous material such as asphalt blend show timely variation mechanical nature. A model Huet-Sayegh depicts the reaction of bituminous material [1]

2.2 Subgrade

Subgrade modulus depicts a pressure reliance on the modulus, along these lines its displaying incorporates the modulus esteems appointed to any component are identified with recently registered upsides of stress for the component [2], [4]. It have been realized that subgrade modulus is the important factor that changes the deflection of the surface and the flexibility of pavement because modulus of base layer and surface modulus of asphalt minorly affect surface deflection contrast with the impact of subgrade modulus [22].

2.3 Finite element modelling

The pavement design contains number of layers, theapplied loading condition is acted on the AC plane inside the beneath layers. Subsequently the modelling of asphalt system is to provide component information for different layer and take all layers together make a complete whole structure. Fig. 2 depicts the sectional view of the mathematical analytical model and situating the critical points at the location where plastic distress of material occurs.

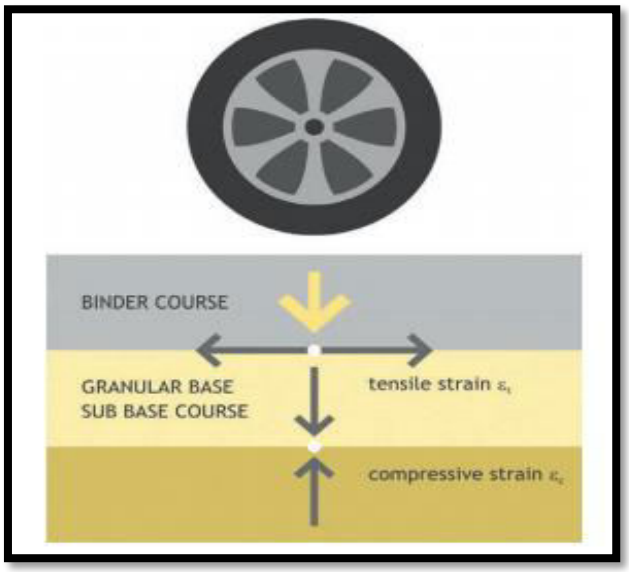

Fig 2. the typical cross-section of asphalt with critical sections [19]

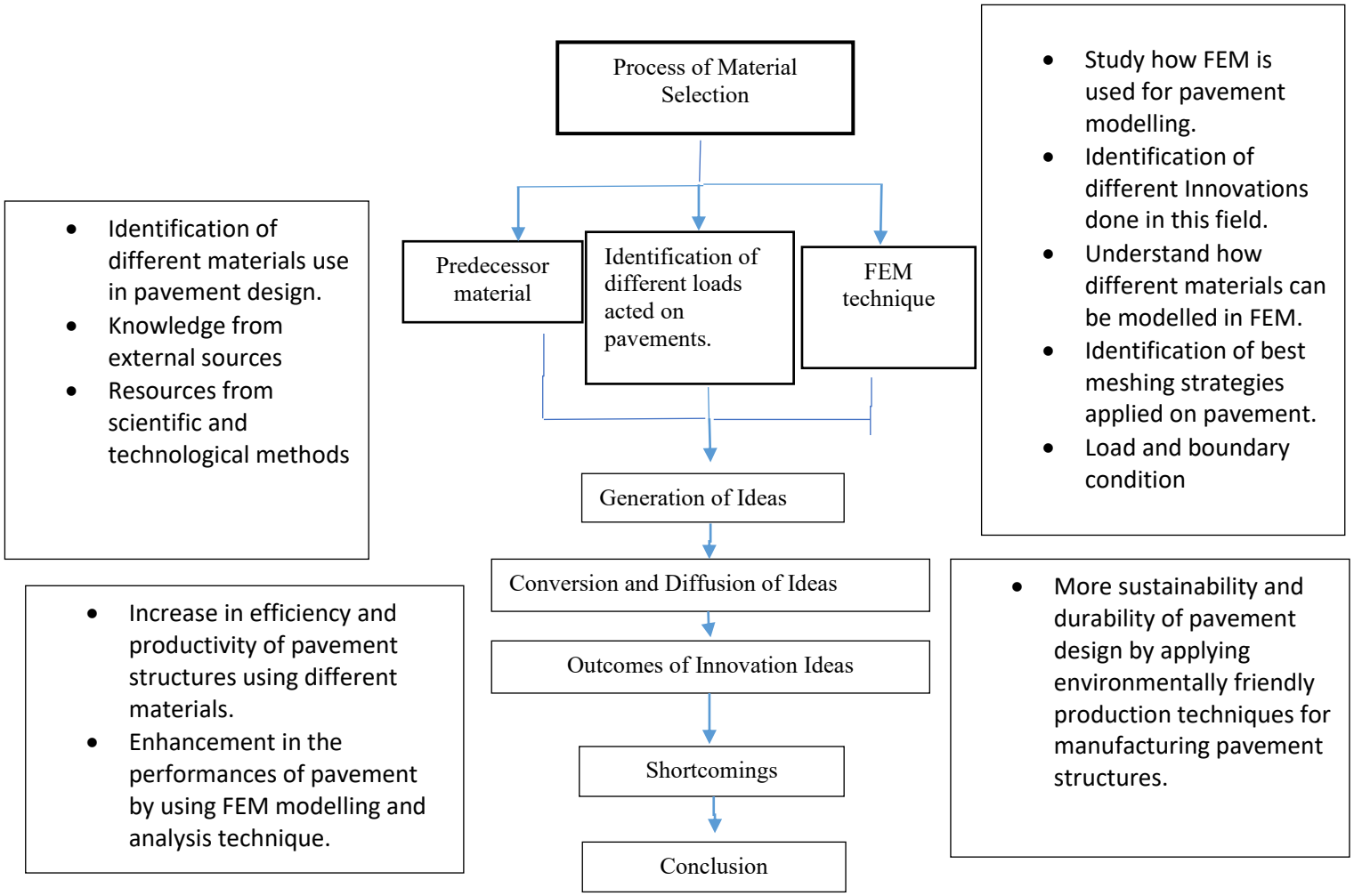

Fig.1 Conceptual Framework of review

Modelling& loading configuration look easy to demonstrate, however lot of intricacy is there on demonstrating real behavior of computing the analysis. From the examinations, specialists tracked down those granular materials of pavement structure showing dependency on stress which is versatile in nature. FE software which breaks down pavement structures need to consider this nonlinear behavior division to make important sensible investigation.

The variation in nature among a homogeneous (flexible framework) and a layering framework demonstrated using finite element technique, where the factors to deflection of surface are elements of width underneath the surface [6], [12] It shows that the role of the material in the depth part plays a significant part in the diversion in the multi-facet framework than the half-space. This investigation depicts the attention with the impact on deflection of sub-layer is significant and needs to ensure sufficient profundity yet does not surpass length-to-width proportion that is five to one.In terms of advantageous and precise examination, the previous ones are appropriate with generally straightforward data sources. The last ones are for reasonable investigation however requires experts a time to get skilled. The result got vary from the experts due to the suppositions on input values at the time of modelling process which is mainly dependent on examiners or experts. Therefore, some rules need to be established to avoid from different experts mistake and set a prepared to-utilize input guide for the analysis [1].

Recent year researcher [24] depicts the Group Index Methodology and California Bearing Ratio Methodology for plan of adaptable asphalts design. In Group Index Methodology the width of pavement width is gotten by initially deciding the Group Index of material soil. The graphs are formed between Group Index of material subgrade and different width at different values. In California Bearing Ratio Methodology, the graphs are formed among California Bearing Ratio Percentage and construction thickness. However [25] revealed different techniques for development of adaptable asphalts. These different strategies are Group Index technique, CBR technique, California Resistance Value technique and McLeod technique. In the Group Index Methodology, the width of plane and surface is calculated with the help of volume of traffic. Under CBR technique the graphs are formed among CBR and asphalt width for little, medium, and substantial traffic. California Resistance Value Methodology utilizes California Resistance values, known as R-values. In Mcleod Method curves are formed among profundity of construction and CBR dependent on traffic values. [26] detailed about stresses in homogeneous weight, versatile distortion under

variable loading conditions and Bur mister examination for adaptable asphalt. Diagrams in vertical redirections are created. The graphs by Group Index Methodology and California Bearing Ratio Methodology are created. In Gathering Index technique, the graphs are formed in between Group Index and width. In California Bearing Ration Methodology graphs are formed among width of construction and California Bearing Ratio. [27] examines a contextual investigation for multi-facet asphalt design examination utilizing techniques for identical thickness. A rough technique has been created to ascertain stresses and strains in multi-facet asphalt frameworks by changing this design to an identical single layer framework with identical width of single elastic modulus. This idea is called as the strategy for same width which expects that the anxieties and strains under a layer rely upon the stiffness of the layer. [28] talks about the reliability variances in bituminous asphalt configuration, considering mechanistic empirical approach. Fluctuations of asphalt configuration input boundaries are examined and issues of reliability, for different proposed failures, of a given asphalt is assessed by both simulation and analytical technique. A philosophy had been proposed for planning bituminous asphalts for guaranteed value of reliability by mechanistic empirical approach. [29] shows that quality and reliability is a significant factor in adaptable asphalt development to calculate the inconstancy related because of the input's parameters in design. In this research, subgrade strength fluctuation and adaptable asphalt design are assessed for checking reliability. Boundaries like mean, greatest probability, median, coefficient of variation, distribution of density, capacity of subgrade strength are examined. Outputs of development are looked to check reliable quality and thickness utilizing this design methodology. It is observed that the AASHTO gives more reliability calculations contrasted with the probabilistic method. Reliability of the adaptable asphalt configuration is assessed by fluctuating hot blend asphalt properties. Elective plans are suggested for the current asphalt width by changing material and subgrade properties to decrease various issues.

As indicated by [30], design of adaptable asphalt is to a great extent dependent on empirical techniques utilizing elastic layer and two-dimensional FEA investigation. Right now, a shift in progress in much more mechanical development procedures to decrease the limits in calculating stress, strain and movement or changes in asphalt examination. In the investigation, adaptable asphalt demonstrating is performed utilizing ABAQUS programming in that model measurements, component types and meshing systems are achieved using progressive trial and error method to

accomplish required precision and converge of the examination. Authors [31] have utilized finite element methodology strategy to examine and develop asphalts. Finite element methodology strategy can examine stableness, time variation issues and issues with material nonlinear. In there search, an incredible quantity of the predominant asphalts has been examined through two procedures: Finite element method strategy and hypothesis of multi-layer framework. Ultimately, from measurable perspective, the outcomes of examination on the two procedures are analyzed by using parameters basis and correlation coefficient. The consequences of the investigation show that output of examination on small size elements are properly arranged, and outputs achieved using hypothesis of multi-layer framework and there is no huge contrast between the mean values in the two procedures. Authors [32] talk about the development strategies which generally being instructed and inspect the "Design of inflexible and adaptable asphalts by different strategies and their expense investigation by every technique". Adaptable asphalts are popular over cement concrete streets as they enjoy an incredible benefit which can be reinforced, and quality can be changes under stages on the increase of traffic and furthermore their planes could be processed and reused for restoration. The adaptable asphalt is lesser costly in respect to beginning investigation and maintenance activities. Though inflexible asphalt is more costly, but little maintenance is required and have great design life. It is observed that adaptable asphalts are more practically valuable for small traffic. The life cycle of adaptable asphalt is near to 15 years whose underlying expense is little necessities periodic maintenance support after a specific period and upkeep costs are more. The existence of inflexible asphalt is significantly more than the adaptable asphalt of around 40 years, roughly 2.5 occasions life of adaptable asphalt which underlying expense is considerably greater than adaptable asphalt, yet maintenance cost is little. Authors [33] talk about the vulnerability in material behavior and traffic characterization in the development of adaptable asphalts. That had prompted huge endeavors recently to consolidate dependability techniques and probabilistic plan systems for the development, restoration, and upkeep of asphalts. This study does the dependability examination for an adaptable asphalt segment dependent on the 1 order reliability strategy and 2-order reliability technique strategies and unrefined Monte Carlo Simulation. Examination additionally tells about the utilization of narrow bound to the likelihood of failure, which gives a superior gauge of the likelihood of failure as approved from the outcomes acquired from Monte Carlo Simulation. Authors [34] use the axisymmetric finite element investigation by

fluctuating various boundaries to foster development diagrams. The boundaries differed are width of asphalt, pressing factor and flexible subgrade modulus. The asphalt and base course have been admired as linearly versatile material but the subgrade has been admired as nonlinearly behavior material using Drucker-Prager rule. The asphalt, base course and soil material are bifurcated by 4noddedisoperimetric finite components.4 sorts of development diagrams are created. Every one of the plan graphs has three boundaries. For 2 known boundaries, the 3 boundaries can be achieved.

Followingare the acquaintance of studies which is done by different researchers in different parts of FEA analysis.

2.4 Modelling of material

Material choice in FE analysis is the pivotal cycle. To fabricate more reasonable mathematical model, the appropriate material choice must be taken care. Different isotropic and anisotropic properties-based models that could be demonstrated by vary the horizontal plane and vertical plane modulus of elasticity. Because the soil molecule is certainly not formed ordinary, thinking about the anisotropic properties of during demonstrating which canat times required. Anisotropic properties-based materials have no huge impact on the extent of pavement uprooting under dynamic loading conditions, which huge impact on the extent of elastic strain. In any case, as far as servicing life is considered there is no huge contrast among isotropic and anisotropic based models as shown in Fig. 3 [18].

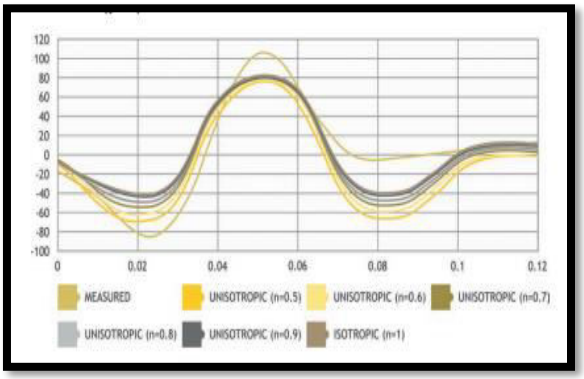

Fig 3. showing the variations of the thermal strain in the bottom of pavement layer among isotropic and anisotropic material [18]

Another modelling of material to conclude is to decide if the part can be linear in nature or nonlinear in nature. An understanding needs to be taken into mind which is gratitude for tough nature of asphalt, it should be sufficient to start up the model framework using a flexible constitutive

relation. The reality that notable is that granular based materials and subgrade layer soils shows non-linear tough nature which is differed by amount of pressure. A large portion of time the development of pavement stress depends on complex versatility hypothesis, but this hypothesis develops using its presumption; every layer is homogeneous all through the layers. Under molecule level, material acts in nonlinear manner and if the disregards this nonlinearity nature, it could not require a lot of reasonable outcomes. Fnite element programs are utilized to settle this inadequacy by consolidating the material nature; up to this point K – θ model and bilinear model is utilized for granular phase to mirror this nonlinear variation. The impact of nonlinearity of starting base course is diminished as the flexible modulus of surface layer enhances [10], [23].

The 3D model using thought of dynamic examination, viscoelasticity and nonlinearity behavior, and temperature slope lies in the direction of field information though straightforward model supposition produces lot of blunders particularly at the time when the viscoelasticity behavior of asphalt blend was not taken care [10].Under I of the incredible components of finite element program is that experts could utilize user dependent characterize subroutines of material. Because of this subroutine nature, assessment of interlayer is accessible that makes finite element model substantially much practical. One of investigation utilizes spring component (partial bonded) and used distinctive spring constants in various axes direction [11]. The entire pavement structure is made in the form of layers, and the layers are uncompleted (layers of pavement), or unreinforced by any means (granular layers).Using user characterize models of material, modelling of such sort of fractional boding variation is conceivable [5].

Under the notice that an extensive investigation of flexible asphalts ought to incorporate the stress values dependent nature of granular course at base and the subgrades that is coherent in nature, limited width of the AC asphalt structure, numerous loading condition on any part of the provided area is dissected, and partial bonding among the AC and the granular [5]. The problem for the designing using blend of asphalt having the exceptionally heterogeneous behavior containing total inner structure and circulation of air void, the time, temperature and variation nature of the lattice and the restricted calculation limit with respect to exceptionally exact forecast [23]. A non-linear nature and time variation investigation by FE strategy, literary works proposes to utilize a period dependent material. By taking steeply investigation the time dependent issue is addressed. In this interval of time stress must be steady and this span must be sufficiently

little. The viscoelastic asphalt model uses the idea of recreating the fractional bond condition among the asphalt material and the base layer [11]. Time accounts of strains or creep stiffness of creep tests are expected to mimic viscoelastic reactions of pavement material [14].

2.5 Mesh

Largest time and effort requiring part is development of mesh in finite element investigation. The shape and size of mesh is straightforwardly identified with the exactness of the outcomes, and the expense of investigation. Fine size of mesh creates substantially greater exact outcome contrasted with coarse size mesh yet not generally the fine size of mesh is satisfactory because a significant amount of level that suits the exactness and economy simultaneously. Originators are seriously attempting to discover required level and construct rules for it.

Computed exactness of stress is identified with mesh at vertical direction and deflected is connected by mesh in horizontal fashion. Vertical direction of finite size mesh overwhelms stress convergence [11]. The determination for the mesh size depends on the convergence of mesh. The level of mesh refinement is a significant factor in assessing an exact stress recorded inside the asphalt. The mesh development, refinement of mesh, component aspect ratio and material non-linear nature influence the total time productivity. Using the 3-dimensional issues, a cautious equilibrium is needed to fulfill the requirements of time and space of memory without forfeiting precision [13]. For the asphalt investigation, determination of mesh size is a significant matter of fatigue crack examination. Flow of traffic is generally designed as a axial fatigue load with identical fatigue failure. FE technique found helpful to deciding required stress for fatiguefailureo assessment and simultaneously examination of connection among asphalt and bridge deck [3]. With the goal that it assists with choosing the allowable stress values of asphalt structure.

2.6 Boundary and loading condition.

Boundary and loading conditions are demonstrated in the form of consistently distributed load in the form of circular or rectangular region. The determination of examination model is likewise one of the factors that impacts on examination result. Simulator can pick between factual static simulation or dynamic simulation. Static investigation is financially effective and more reliable but dynamic examination reflects a lot more sensible impact on model as demonstrated in Fig. 4.

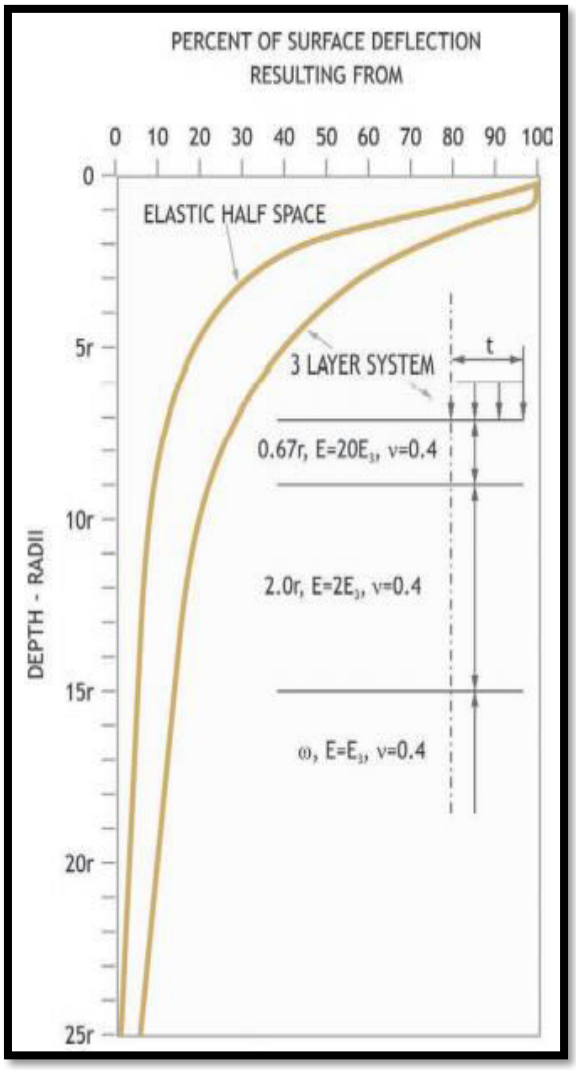

Fig 4. Comparison deflections of elastic half space surface and layered system [6].

Most of cases boundary loading condition is demonstrated as a contact stress in the region at the location where load is remaining on asphalt layer and needs to be a disseminated load on a contacted region. The contacted region could be displayed in the form of round shape or rectangular shape, and under the situation when contact part is designed as a rectangle shape it needs to be directed to have a measurement of BX0.7B. The variable load could be exemplified in the form of engraving region to show a smooth asphalt plane shown in Fig. 5, [8-9].

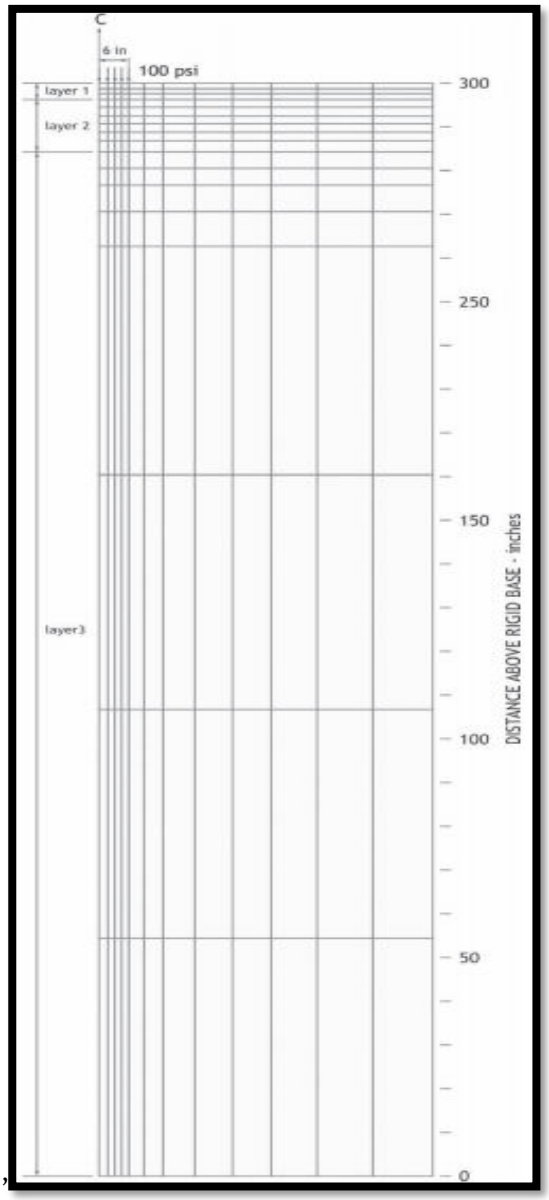

Fig 5. Finite element configuration of layered system deep bottom boundary condition [6]

Mainly two kinds of thermal strains that is intriguing in development of mechanical. First is gradient of thermal and the second one is uniform strains of thermal. First one occurs due tothe temperature gradients in one day, and the last one happens on the grounds that temperature changes because of seasons. In the finite element designing, the load of thermal could be displayed by acting gravity action in different steps of time and gravity action is propagated to achieve at hermal slope profile [18], [17], [7], [16]. Hooke's linear flexible model is utilized for mechanical examination and modelling of asphalt part. It is reasoned to give good reaction for assurance of reaction of pavement layers at lesser temperatures [19].

Rheological conduct straightforwardly associated with disintegration and decides the thickness of layers. Bituminous materials such as asphalt combination show time variation mechanical nature. A Huet-Sayegh model portrays reaction of bituminous material. Numerical investigation could mimic nature of asphalt blends in cycling tests in wide range of frequency [1]. This model mirrors the delay among stress and reaction because of the viscoelastic nature of bituminous asphaltic type of material in asphalt structure. Burger, Maxwell, and Kelvin models are remembered for structure part for liquid material too, notwithstanding it has the obstruction because of which they do not completely draw critical nature of asphalt cement. Though Huet-Sayegh model has inadequacy that does not show irreversible deformity appropriately contrast with bituminous models shown in Fig. 6.

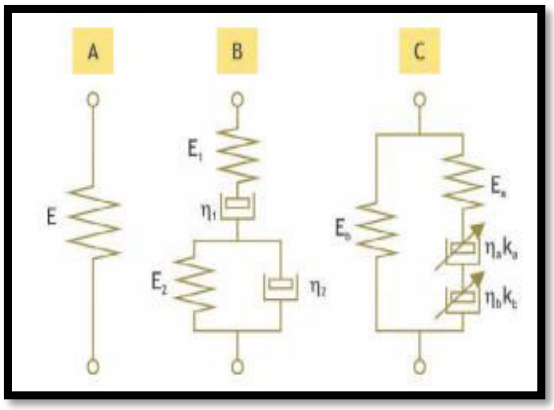

Fig 6. A shows Hooke'selastic model, B shows Burgers' viscoelastic model and C shows Huet-Sayegh'sviscoelastic model.

To represent the variety in the elasticity modulus with increase in depth inside a layer, in which the layer ought to be partitioned under a few sublayers and the modulus ought to be steadily changed among the layers. For mathematically tackle a limit esteem issue that includes limits reaching out to limitlessness (for example subgrade), the space should be shortened at a sensible separation from the loads. Therefore, the amount of the computational space and the impacts of the limit conditions under the shortened remote limits must be painstakingly considered [20], [11].Subgrade layer is designed for the limit less dimension in the vertical fashion. Considering the calculation time and cost, the amount of area must be resolved. For the investigation of construction, setting the legitimate limit amount is pivotal part in modelling process. In 1968 there was an examination which confirmed limit condition that provides exact results that defined fixed limit at a profundity around 50 radii and obliged from moving spiral way around 12 radii from the middle when the FE model is acted under distributed load in circular manner [2]. Apart that is big

enough can stay away from the out side boundary impact. To decide the outer boundary size varies from simulators and this progression is examination of primary reactions when limit condition is 10 to multiple times from the focal point of symmetry. An examination recommends an overall measure for circular disseminated load, planners to utilize a space150 times greater than stacking radius [21].

3 Conclusion

This is a review paper analysis about the worries and decisions when to do the development of pavement design with FE programming. There is much and more interest for exact investigation to decrease development cost and guarantee mechanical uprightness during its design life. Presently the development pattern is varying observational strategy into Mechanistic-Empirical technique because of that reason. Alongside mechanistic experimental investigation, different mechanical part is confirmed and acted in the FE strategy in a user characterize command for the element. Because the decision of appropriate material model to provide legitimate mesh size and limits are totally selected by expert in FE investigation. Under all the stages in the process of modelling a progression of determination is proceeded and it creates entire process of design to be reliant upon experts. The choice issues cause modelling and FEA process to be troublesome and confounded. To overcome, numerous scientists do sensitivity tests to confirm and pick which boundary condition is essential and affects the reaction. In conclusion, there is a requirement to remove the hole among the mathematical models that can beat the intricacy in real conduct due to structure connection in different layer.

Acknowledgement: Authors are grateful to anonymousre viewer for their suggestion through out manuscript content improvement.

References

1. AASHTO, Mechanistic-Empirical Pavement Design Guide.WashingtonDC: American Association of State Highway and Transportation Officials.2008 ISBN; 978-1-56051-597-5
2. ABAQUS, Standard user's guide. RI, USA.: The Abaqus Software is a product of Dassault SystèmesSimulia Corp.(2014).
3. J. Bohai, L. Rong, C. Ce,M.Hirofumi,C. Xiongfei, Evaluation on root-deck fatigue of orthotropicsteel bridge deck. J. Constr. Steel Res. 90 (2013) 174-183.
4. D. H. Chen, M. Zaman, J. Laburos, A. Soltani, Assessment of ComputerPrograms for Analysis of Flexible Pavement

Structure,Washington D.C.: Transportation ResearchBoard of the National Academy of Sciences(1995).

5. S. Chun, K.Kim, J. Greene, B. Choubane, Evaluation of interlayerbondingcondition on structural responsecharacteristics of asphalt pavement usingfiniteelementanalysis and full-scalefieldtests.Constr. Build. Mater. 96 (2015) 307-318.
6. M. J. Duncan, C. L. Monismith, E. L. Wilson, FiniteElementAnalyses of Pavements. Highw. Res. Rec. 228 (1968) 18-33.
7. A. E. A. El-Maaty, G. M. Hekal, E. M. El-Din, Modelling of DowelJointedRigidAirfield Pavement user Thermal Gradients and Dynamic Loads. Civ. Eng. J. 2(2) (2016) 38-51.
8. H. Faheem, M. Hassan, 2D plaxisfiniteelement modeling of asphlaltconcrete pavement reinforcedwithgeogrid. J. Eng. Sci. 42(6) (2014) 1336-1348.
9. A. Gupta, A. Kumar, Comparative structural analysis of flexible pavements usingfiniteelementmethod. Int. J. Pavement Eng.Asph. Technol.15(1) (2014) 11-19.
10. R. G. Hicks, C. L. Monismith, Factorsinfluencing the resilientresponse of granularmaterials. Highw. Res. Rec. 345 (1971) 15-31.Record URL: onlinepubs.trb.org
11. D. K. Hjelmstad,J.Kim, H. Q. Zuo, Finite Element Procedures for Three-dimensional Pavement Analysis,(1997)Seatttle: ASCE.
12. K. D. Hjelmstad,E.Taciroglu, Coupledhyperelastic constitutive model for resilientresponse of granularmaterials. (1997)N.Y., Proceedings of the Airfield Pavement Conference.
13. C.-M. Kuo, F.-J. Chou, Development of 3-D Finite Element model for flexible pavements. J. Chin. Inst. Eng. 27(5) (2004) 707-717.
14. M. Li, H. Wang, G. Xu, P. Xie, Finiteelement modeling and parametricanalysis of viscoelastic and nonlinear pavement responsesunderdynamic FWD loading. Constr. Build. Mater. 141(2017) 23-35.
15. Ł. Mejłun, J.Judycki, B. Dołżycki, Comparison of elastic and viscoelasticanalysis of asphalt pavement at high temperature. Procedia Eng. 172 (2016) 746-753.
16. A. C. Pronk, (2005): The Huet-Sayegh model; A simple and excellent rheological model for master curves of asphalt mixes. Louisiana, American Society of Civil Engineers.
17. B. H. Seed, G. F. Mitry, C. L. Monismith, K. C. Chan, Prediction of flexible pavement deflectionsfromlaboratoryrepeatedload tests,

(1967)WashingtonD.C.: Transportation ResearchBoard. OrderURL: worldcat.org

18. A. Shayesteh, E.Ghasemisalehabadi, M. W. Khordehbinan, T. Roastmi, Finite Element Method in StatisticalAnalysis of Flexible pavement. J. Marine Sci. Technol. 25(2)(2017) 142-152.
19. R. M. Srikanth, Study on Analysis of Flexible Pavement usingFinite Element based Software Tool. Int. J. Eng. Res. Technol. 4(9) (2015) 912-916.
20. [B. Sukumaran, N.Chamala,M. Willis,J. Davis, ThreedimensionalFinite Element modeling of flexible pavements. (2004) Atlantic city, FAA Worldwide airporttechnologytransfer.
21. C.Szydłowski, J.Górski, M. Stienss, Ł. Smakosz, (2018): Numerical simulation of asphalt mixtures fracture using continuum models. s.l., AIP ConferenceProceedings 1922.
22. J.Uzan, Characterization of GranularMaterial, Washington D.C.: Transportation Research Record (1985).
23. J. Zhang, J. Yang, Advances in micromechanical constitutive theories and modeling. China, Procedia-Soc.Behav. Sci. 96(2013) 1304-1314.
24. I.H. Khan, A Textbook of Geotechnical Engineering, Pentice Hall of IndiaPrivate Limited (1998), New Delhi.
25. K.R. Arora, Soilmechanics and Foundation Engineering, Standard Publishers Distributors(2003), Delhi
26. B.C.Punmia, A.K. Jain, A. K.JainSoilMechanics and Foundations, Lakshmi Publications(2005), New Delhi.
27. B.Subagio, H. Cahyanto, A.Rahman, S.Mardiyah, Multilayer Pavement Structural AnalysisUsing Method of Equivalent Thickness, Case Study: Jakarta-CikampeckToll Road. J. Eastern Asia Soc.Transp. Stud. 6 (2005) 55-65.
28. A.Das, ReliabilityConsiderations of Bituminous Pavement Design by Mechanistic-EmpiricalApproach. Int. J. Pavement Eng. 9(1) (2008) 19-31.
29. R. Tarefder, N.Saha, J. Stormont, Evaluation of SubgradeStrength and Pavement Designs for Reliability.J.Transp. Eng. 136(4) (2010) 379-391.
30. M.T. Rahman, K. Mahmud, K. Ahsan, Stress-StrainCharacteristics of Flexible Pavement UsingFinite Element Analysis. Int. J. Civ. Struct. Eng. 2(1)(2011) 233-240.
31. M. Ameri, E.G. Salehabadi, F.M. Nejad, T. Rostami, Assessment of Analytical Techniques of Flexible Pavements by Finite Element Method and Theory of Multi-Layer System. J. Basic Appl. Sci. Res. 2(11)(2012) 11743-11748.

32. S. Jain, Y.P. Joshi, S.S. Golia, Design of Rigid and Flexible Pavements by Various Methods and TheirCostAnalysis of EachMethod.Int.J. Eng. Res. Appl. 3(5)(2013) 119-123.
33. D. Dilip, P. Ravi,G. Babu, System ReliabilityAnalysis of Flexible Pavements. J. Transp. Eng. 139(10) (2013) 1001-1009.
34. D.K. Maharaj, S. Gill, Development of Design Chart for Flexible Pavement by Finite Element Method. Int. J. LatestRes.Eng. Comput. 2(2)(2014) 8-23..