Evaluation of Flexible Pavement by Using Dynamic Cone Penetration Test

Rajana Raja Kumar[1], K Vamsi Satyanarayana[2], Dr. N C Anil[3], P Sanyasi Naidu[4]

[1]*PG Student,* [2]*Assistant Professor,* [3]*Associate Professor,* [4]*Assistant Professor,*

[1,2,3,4]*Civil Engineering & Sanketika Institute of Technology and Management, Andhra Pradesh, India*

***Abstract*—Over the past four decades, the share of total rail and road traffic carrying passengers and goods has gradually increased from about 24 percent and 11 percent, respectively, in 1951 to about 80 percent and 58 percent, respectively, in 1990. Road length has increased correspondingly, from 0.4 million km in 1951 to 2 million km, giving a road density of 59 km/100km^2. Because of fast and ever-increasing industrial, commercial, and other socioeconomic development activities, the road transport vehicle population, particularly vehicles population, particularly vehicles carrying goods, has also increased phenomenally during this period.**

Because of economies in road transportation, overloading by truck operators is common. The majority of the arterial road system experiences overloading, as much as 18 to 20-tonne axle loads versus the permissible legal limit of 10.2 tones. The existing road network has shown signs of premature distress because of the unexpected demands of growing traffic volume and heavier axle loads. The network has fallen short of its structural capacity and hence it is greatly overstrained. The majority of allocated funds are utilized for providing M&R measures to the existing network rather than for new construction. The funds being provided for the arterial road network are on the order of 50 to 60 percent of the amount needed.

With this background, in the present study, a road sections were identified in Kurnool district, Andhra Pradesh to carry out the pavement performance study on distresses. For the selected stretch data was collected on rutting, raveling, potholes, edge failures, traffic, etc and soil samples of the subgrade for the determination of laboratory or insitu moisture content. The detailed analysis was performed using NCSS statistical tool and to develop a pavement performance model for the selected stretch. Based on surrounding soil values the California bearing ratio values are taken in to consideration for designs.

Key words: **Dynamic cone penetration test (DCP), Million standard axles (msa), CBR Values, IRC:37-2001, Empirical models, mechanistic empirical models**

I. INTRODUCTION

A. General

The accurate prediction of pavement performance is important for efficient management of road infrastructure. At the network level, pavement performance prediction is essential for rational budget and resource allocation. At programming level, pavement performance prediction is needed for adequate activity planning and project prioritization while at project level it is needed for establishing and designing the necessary corrective actions such as maintenance and rehabilitation.

Several performance prediction models have been proposed over the years. The models vary greatly in their comprehensiveness, their ability to predict performance with reasonable accuracy, and input data requirement. Most of these models are empirical and were developed for use under particular traffic and climatic conditions. Few of the models are of mechanistic – empirical type in which some of the input parameters are calculated using mechanistic models.

This report gives brief review of the existing models, particularly those models that are being used or under development in the local countries. The report forms part of the preparatory work for the present project on deterioration models for flexible pavements.

The main goal of the project is to develop a practical performance model for flexible road constructions based on already existing models

B. Terminology

Some terms and expressions are often interchangeably used, in some cases with slightly different meanings. It is therefore considered necessary to clarify the meaning of the key terms and expressions employed in this report. These terms are defined in the following paragraph.

1. Pavement: The term pavement is used in this report to mean the whole road structure with all of its layers and not just the surfacing layer.

2. Flexible pavement: A pavement type in which bituminous mixtures are used as surfacing materials.

3. Pavement performance: Pavement performance is a measure of the in-service condition of the pavement. Performance is often expressed in two ways; the first is structural performance which is expressed in terms of distresses such as cracking and the second is functional performance expressed in terms of serviceability, which in turn might be function of distresses such as rutting and roughness. The term performance in this report refers to the general condition of the pavement, including its structural and functional condition, unless otherwise specified.

4. Pavement deterioration: Represents a negative change in performance or condition of the pavement, i.e, an increase in distresses or decrease in serviceability.

C. Need for the Study:

The purpose of the review was to find out the strengths and the weaknesses of present model in order to provide basis for more detailed evaluations, selection and improvement of models.

1. Performance prediction models represent a key element of road infrastructure asset management systems or pavement management systems. Thus successful implementation of these systems depends heavily on the performance prediction model used as the accuracy of the predictions determines the reasonableness of the decisions.
2. Several pavement performance prediction models have been proposed over the years. Many of these models are developed for application in a particular region or country under specific traffic and climatic conditions. Therefore they can not be directly applied in other countries or conditions.
3. Although much research has been devoted to performance modeling of pavements, a comprehensive model that can predict pavement performance accurately has yet to be developed network and project levels. The mechanistic-empirical models are often developed in connection to design systems and therefore have not been widely applied in pavement management systems (PMS), but have the potential to be applied at a network level. The subjective models are mostly developed for strategic (investment) planning at the network level.

Thus, the review showed that there is a need to develop improved models for use both at the network level and the project level. In order to develop such improved models, it is recommended to take the following steps in the present study.

D. Objectives

1. To examine the static pavement characteristics included the road type, pavement thickness, composition of different layers, pavement width, and shoulders width and indentify certain deterioration length of pavement.
2. To find dynamic pavement conditions like pavement behavior which includes rutting of pavement, Edge failure raveling, minor path holes
3. To take count of traffic characterizations like traffic volume corresponding time of day daily commercial traffic and classify the different class of vehicle as two wheeler vehicles, single axles, tendam axles like buses, lorry etc…
4. To observe the indentified pavement has its strength is in within limits by using dynamic cone penetration test.

II. LITERATURE REVIEW

An attempt to investigate **Mohammed Taleb Obaidat et.al (1997)[1]** the potential capabilities and accuracy of the stereo vision system in quantification of pavement rut depth was performed. This process was demonstrated using three rutted sections of flexible pavement.

Measurement and Utilization of Rutting Data is provided **J.J. Hajek et.all (1998)[2]** In response to the increased occurrence of rutting, particularly dual rutting, in 1988 the Ontario Ministry of Transportation started a comprehensive program to measure, manage, and utilize rutting data as part of the pavement management system at both project and network levels.

In-situ penetration tests have been widely used in geotechnical and foundation engineering for site investigation in support of analysis and design. The standard penetration test (SPT) and the cone penetration test are two typical in-situ Penetration tests. The field testing includes the DCPT and nuclear density gauge tests. Based on analysis of this testing, the relationships between the DCPT results and the subgrade parameters such as unconfined compression strength and resilient modulus are obtained is theory is given by **Indiana Department of Transportation and Federal Highway Administration (2003)[3]**

Indian standard deals with the design of flexible pavement and recommends the california bearing ratio as an indicator of sub grade soil strength. The sub base/base thickness of pavement is governed by the CBR value of the sub grade soil along with some other parameters such as traffic intensity, climatic conditions etc.

LUU Xuan Le et.al (2016) [7]Defined Rutting of a Asphalt pavement as longitudinal surface depression in the wheel path. This is one of the main deformation problems of asphalt pavement. In recent years in Vietnam, scale and severity of rutting on asphalt pavement keep increasing significantly on national roads, according to reports of Directorate for Roads of Vietnam the central road authority at in Vietnam.

Dynamic Cone Penetrometer Value and California Bearing Ratio Relationship Is Derived **RAJ KUMAR e.t al (2017) [9]**using light of different specialists, it is watched that there exist relationship be Tween's CBR Esteem and DCPT esteem the connection be Tween's CBR esteems have for the most part been resolved under splashed conditions. In light of above writing audit it could be presumed that Coefficient of this direct relationship is rely upon plastic file and dirt substance of soil. The present examination was restricted to fine ground soils. IRC 37 –2012 have given a solitary relationship.$Log_{10}CBR= 2.45-1.12\ Log_{10}\ N$ Where N= mm/blow

Makendran Chandrakasu et.al (2018)[10] Developed a model for Roughness Estimation for low volume roads and the Pavement roughness is one of essential performance indicators that are used in road maintenance. A model was developed in this study to obtain roughness value from easily measurable distress values, namely cracking and potholes, for low-volume roads in India. The data collected at 173 in-service flexible pavements were utilized for model development. Using the model developed in this study, a satisfactory roughness value can indirectly be obtained from the cracking and potholing data, even without the use of a roughness measuring device.

III. STUDY METHODOLOGY

In the past section, a point by point review with respect to the different past examinations on asphalt execution was talked about. Encourage particular extent of the work, touched base at from the writing audit, was likewise exhibited. Insight with respect to the proposed strategy for the present examination is exhibited in this part. With the end goal of Pavement Performance Study (PPS) in Andhra Pradesh the accompanying street extends is chosen for the examination in the Kurnool region in view of the chose parameters and criteria, and distinctive real urban communities between on NH-18 are displayed in Table 1

TABLE 1

DETAILS OF POPULATION, RAINFALL INTENSITY OF CITIES

#	Name of the cities	District	Road length	Population	Rainfall intensity
1	KURNOOL	**KURNOOL**	369KM	4,78,124	704
2	ORVAKALLU			4,866	579
3	NANDYAL			2,11,787	836
4	ALLAGADDA			26,375	800
5	CHAGALAMARI			47,076	798
6	MYDUKUR	**KADAPA**		72,356	719
7	KHAJIPETA			48,784	734
8	CHENNUR			48,654	691
9	KADAPA			3,44,078	725
10	RAYACHOTI			90,814	605
11	PILERU	**CHITOOR**		61824	760
12	CHITTOOR			1,74,640	1048

Kurnool is a locale in Andhra Pradesh, India Kurnool District has a region of 17600 km2, and a populace of 4,78,124 of which having 704mm yearly rain fall. The locale is limited by Mahbubnagar area toward the north, Prakasham region toward the east and Kadapa region toward the southeast, , and Karnataka state toward the west, Anantapur region toward the south . Kandanavolu' which in course of the time came to be known as Kurnool. Kurnool is notable for its sanctuaries. The Kurnool region headquarter is Kurnool city.

Transport at Kurnool: Kurnool is considered as the Gateway of Rayalaseema as one must go through Kurnool to achieve Kadapa or Chittor or Anantapur areas while going from Hyderabad. Kurnool is having the second biggest transport station in Andhra Pradesh after Hyderabad and Vijayawada. Kurnool is associated with most urban communities and towns in Andhra Pradesh and in addition to Bengaluru and Chennai by the Andhra Pradesh State Road Transport Corporation (APSRTC) and the Karnataka State Road Transport Corporation (KSRTC). National Highway 7 associates Kurnool to Hyderabad (210 km,4.hours), Anantapur (140 km, three hours), Hindupur {245 km, 5.5 hours} and Bengaluru (360 km. The State Highway 51 interfaces with Srisailam, Vinukonda, Guntur, Vijayawada. The National Highway 18 Kurnool-Chittoor associates the city to Panyam, Nandyal, Allagadda, Ahobilam(near to the highway),Mahanandi(near to the highway),Maidukuru, Kadapa, Rayachoty Pileru, and Chittoor.

The four railroad stations in Kurnool District are Kurnool Town, Adoni, Nandyal and Dhone intersection. Adoni is on the Chennai-Mumbai Railway Line and a few trains run every day to these urban communities and New Delhi. Nandyal is on the Guntakal - Vijayawada line and has every day trains to Hyderabad, Vijayawada, Bengaluru, Vishakhapatnam and Howrah. Dhone intersection is arranged on the Guntakal - Secunderabad/Vijayawada line. Every one of the trains which go through Nandyal and Kurnool go through this intersection. The closest airplane terminal is Rajiv Gandhi International Airport, at Hyderabad, three and half hours drive from Kurnool City.

A. *Rules for Selection of Road Section.*

The test areas have been chosen in view of the accompanying criteria.

- The length of test area to be 1000m, beginning from a land check thing (like the sign leading body of 273+550 to 274 of the street).
- Test areas are to be chosen to speak to various blends of sub grade soil write, asphalt compose and organization, activity power, yearly precipitation. Areas are to be chosen on straight reaches.
- The test areas are to be chosen to cover beyond what many would consider possible the accompanying three factors.

Fig.1 View of selected stretch in Kurnool (NH-18)

Fig. 2 India Map

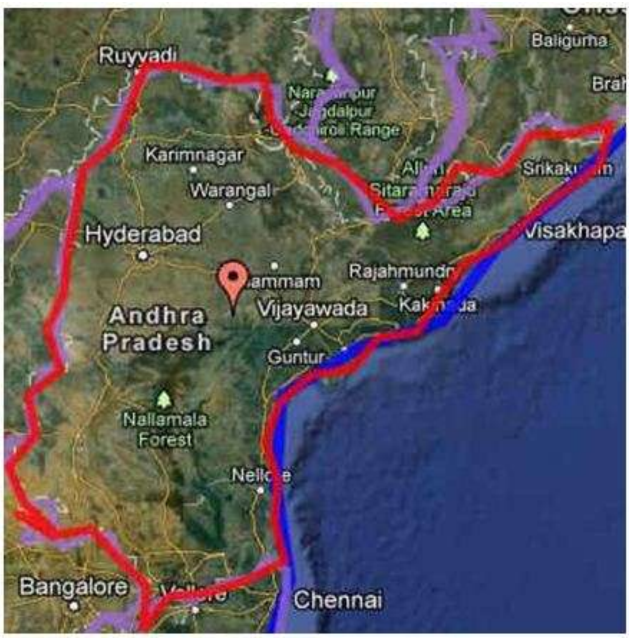


Fig. 3 Andhra Pradesh Map

Fig. 4 Selected stretch

Fig .5 NH-18

In the above map the shows the our selected stretch, these are taken from google earth the second picture represents the India map and the third picture represents the A.P map and fifth picture shows the National Highway-18 and finally the selected stretch by considering above mentioned guide lines are respected stretch is selected.

B. Date of Visits for Data Collection

TABLE 2

DATE OF COUNTS FOR DATA COLLECTION

No of Visits	Date of visit	Data collected
1	25-01-2017	Rutting depth measured
2	20-02-2017	Traffic data collection(24 hours)
3	28-02-2017	Test conducted on soil sample
4	28-02-2017	Observations of different failures
5	21-03-2017	Traffic data collection(24 hours)
6	03-04-2017	Rutting depth & failures observed
7	06-04-2017	Traffic data collection(24 houres)
8	13-04-2017	DCP Test conducted on road

C. Details of Selected Road

Information gathering through the direct of recommended try shapes the most critical part of concentrate as the information acquired structures the reason for investigating the issue attributes. Healing measures prompting appropriate arrangements are to be guaranteed at ground on points of interest accumulation related with the issue which are utilized as a part of definition of start to issues. In this section strategies embraced are depicted and the information so gathered is handled and exhibited

IV. APPLICATION METHODOLOGY

A. Overview of the Methodology

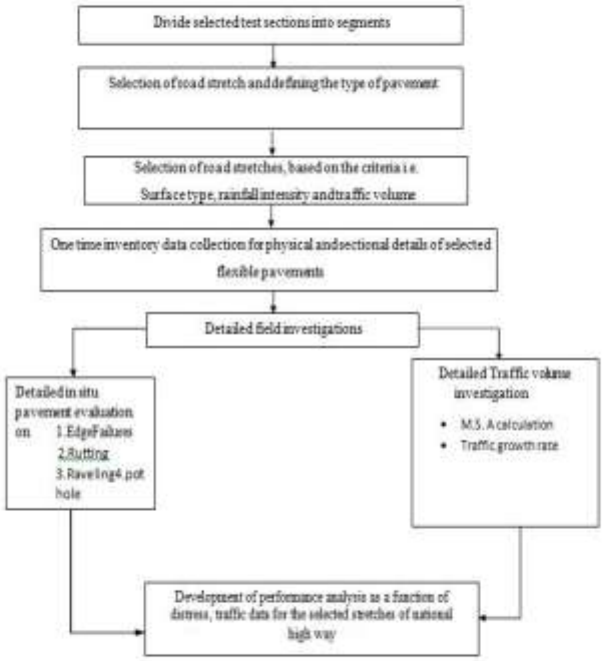


Fig. 6 Study Methodology

B. Description of Rutting Data Collection

Rutting of pavement can represent a major hazard to users as well as being an early indicator of pavement failure. Rut depth measurements are therefore usually included in most of the road monitoring programmers. Rutting is defined as the difference in elevation between the straight edges resting on two high points to the lowest point on the pavement surface. In the present investigation the rut depth was measured using 3 m straight edge positioned at different locations across the profile and the high and low points were determined. From this the rutting was calculated.

C. Description of Traffic Data Collection

Traffic volume counts are needed to determine the traffic using the highway so that planner gets accurate idea of the need for the improving the pavement surface. Traffic counts are carried out on continuous basis or for limited basis. The volume study for selected stretch done for NH-18 at 273+550 to 274+550 have considered 2 days 24hours data, conducted have considered all the slow moving and fast moving vehicles at regular intervals of 1 hour. As far as this report have considered only commercial vehicles such that the gross weight of vehicle is more than 3 tons for calculation of M.S.A. Because the pavement deterioration is directly proportional to the load under repetition.

D. Description of Dynamic Cone Penetration Test (DCPT)

The dynamic cone penetration test (DCPT) was originally developed as an alternative for evaluating the properties of flexible pavement or sub grade soils. The conventional approach to evaluate strength and stiffness properties of asphalt and sub grade soils involves a core sampling procedure and a complicated laboratory testing program such as resilient modulus, Marshall tests and Due to its economy and simplicity, better understanding of the DCPT results can reduce significantly the effort and cost involved in the evaluation of pavement and sub grade soils.the DCP consists of upper and lower shafts. The upper shaft has an. Fig 6 shows a typical configuration of the dynamic cone penetrometer (DCP).

8 kg (17.6 lb) drop hammer with a 575 mm (22.6 in) drop height and is attached to the lower shaft through the anvil. The lower shaft contains an anvil and a cone attached at the end of the shaft. The cone is replaceable and has a 60 degree cone angle. As a reading device, an additional rod is used as an attachment to the lower shaft with marks at every 5.1mm (0.2in).

In order to run the DCPT, two operators are required. One person drops the hammer and the other records measurements. The first step of the test is to put the cone tip on the testing surface. The lower shaft containing the cone moves independently from the5reading rod sitting on the testing surface throughout the test. The initial reading is not usually equal to 0 due to the disturbed loose state of the ground surface and the self-weight of the testing equipment.

The value of the initial reading is counted as initial penetration corresponding to blow 0. the penetration result from the first drop of the hammer. Hammer blows are repeated and the penetration depth is measured for each hammer drop. This process is continued until a desired penetration depth is reached.

DCPT results consist of number of blow counts versus penetration depth. Since the recorded blow counts are cumulative values, results of DCPT in general are given as incremental values defined as follows,

$PI = \Delta DP$

where PI = DCP penetration index in units of length divided by blow count; ΔDp =penetration depth; BC = blow counts corresponding to penetration depth ΔDp. As a result,values of the penetration index (PI) represent DCPT characteristics at certain depths.

V. RESULTS AND DISCUSSION

A. General

This chapter deals with results and discussions of the data collection and tests conducted on selected road on pavement performance the following table are prepared by using of data collection of rutdepth, traffic volume selected street is includes towards Kurnool and toward kadapa during 3visits on traffic data ,2 visits on rut depth and moisture content other failure like revaling, patholes,edge failure and dynamic cone penetration test on single visit on selected road identified on pavement performanace. The traffic data classified as different axle loads as a different wheel loads

To done Tabular Calculations, it can be observed that there is significant variation in rut depth i.e. maximum rut depth is 12 mm towards Nandyal and 11 mm towards Kadapa for january and depth is 12.3 mm towards Nandyal and 11.4mm towards Kadapa for March respectively. This may be due to the many factors such as traffic, sub grade moisture content etc. One can observe from above data that in both instances the rut depth is within the limits (5 and 20 mm) as per IRC:SP:20 and IRC 37-2001 respectively. In some instances for 50 mm subsection, the sample data reported that there was no rutting when the profile indicated significant rutting. The pictorial variation of rut depth and average rut depth of all the selected test stretches are presented in Figure.

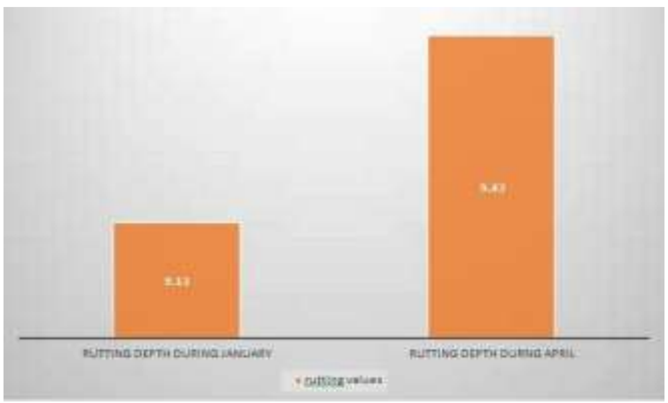


Fig. 7 Rutting Variation towards Kadapa

From the Figure it is clearly seen that the characteristic rut depth has been increased from January 2017 (8.44mm) to April 2017 (8.5 mm) towards nandyal and it has been increased from January 2017 (9.13mm) to April 2017 (9.42 mm) towards kadapa. This may be due to increase in the number of the wheel passes on the pavement.

B. Variation of Traffic Data

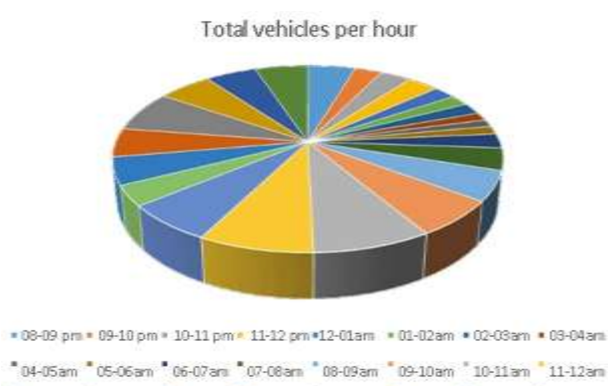
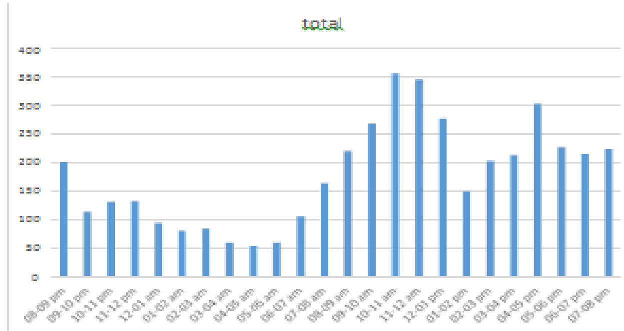


Fig.8 Pie chart on Hourly variation of all vehicles towards kurnool



Graph 1. Hourly variation of all vehicles towards kunool

Same we can also observed that hours variation all vehicles towards kadapa, hours variation of traffic data towards Kurnool during 2ndcount, hours variation of traffic data towards Kadapa during 2ndcount, hourly variation of traffic data towards Kurnool 3rdcount and hourly variation of traffic data towards Kadapa 3rdcount

C. Results of Dynamic Cone Penetration Test

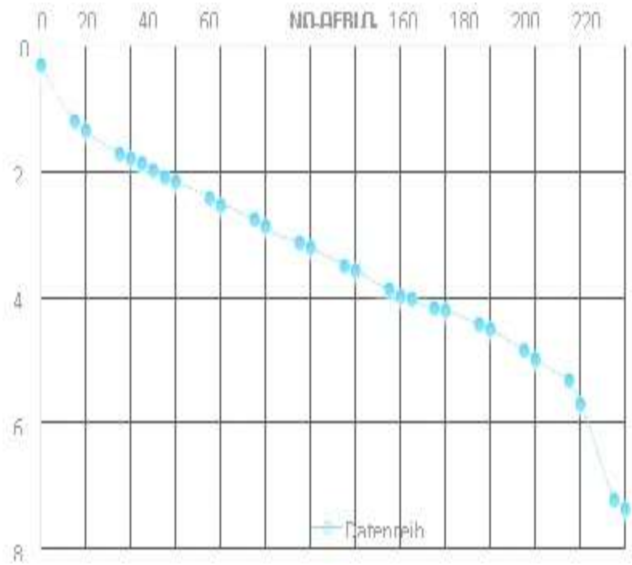
The dynamic cone penetration test conducted on 274+540L

TABLE 3

DCP VALUES AT CHAINAGE 274+540 L

Number of Blows	**Depth of penetration in CMS**			
	Initial	Final		
0	0	11.5	155	48.9
5		14.9	160	49.8
10		17.3	165	50.7
15		18.9	170	51.3
20		20.4	175	52.1
25		21.8	180	53.2
30		23.3	185	54.4
35		24.6	190	55.2
40		25.6	195	56.1
45		26.8	200	57
50		28.1	205	58
55		29.4	210	59.2
60		30.5	215	60.9
65		31.4	220	62.5
70		32.1	225	63.7
75		33.1	230	65.2
80		34.1	235	66.7
85		35.7	240	68.7

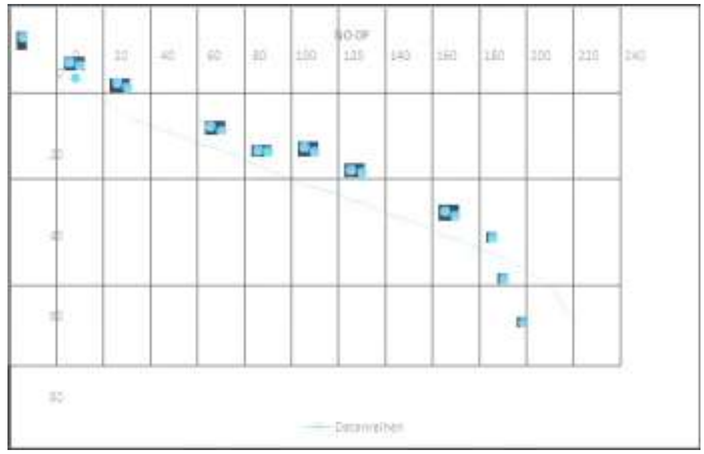
90		36.5	245	71.7
95		37.2	250	76.7
100		38	254	81
105		39.5		
110		40.4		
115		41.4		
120		42.3		
125		43		
130		43.8		
135		44.9		
140		45.8		



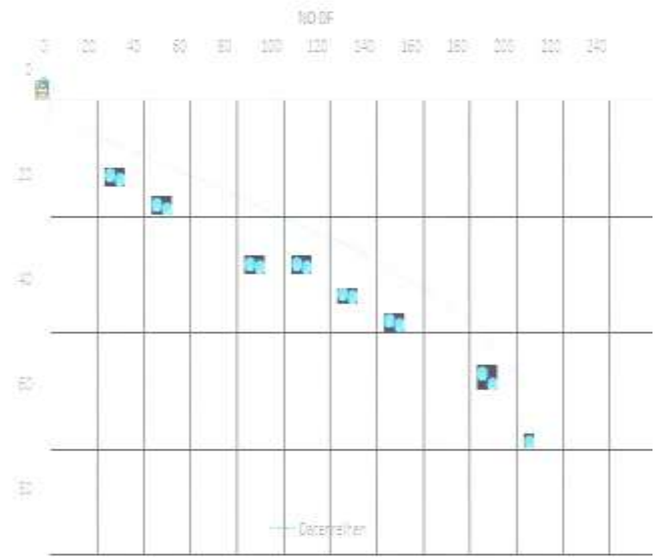
Graph 2 between every five blows and depth of penetration At Chainage274+540L

From the above graph it is observed that, the rate of penetration is uniform up to a depth of 572mm for 240 blows. From there, the rate of penetration increased adversely due to the reason that the cone of the Dynamic Cone Penetrometer entered the subgrade soil. As the subgrade soil is soft compared to the above layers, ie. The granular sub-base (200mm), Wet mix Mecadam (250mm), Dense Bituminous Mecadam with Wearing Coat (140mm), the penetration rate increased (12.3cm) with less number of blows (14 blows) after 572mm depth. Within 572mm depth, the minimum and maximum penetration values for a single blow are 0 mm and 5mm respectively. As per the code provisions the permissible penetration value for a single blow is 5mm.

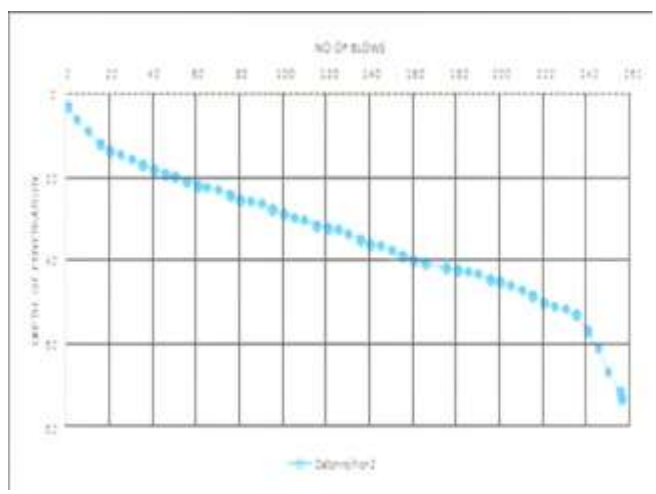
Same tabular forms were studied, Like Table of DCP Values At Chainage274+050 L, Table of DCP values at chainage 273+800R, Table of DCP values at chainage 274+300R, Graphs are shown in below.



Graph. 3 Between every five blows and depth of penetration AT chainage 274+050L



Graph 4. Between every five blows and depth of penetration at chainage 273+800R



Graph 5. Between every five blows and depth of penetration at chainage 274+300R

D. M.S.A Calculations:

Design traffic in terms of million slandered axles has been determined at selected stretch where both volume count surveys were conducted. The traffic loading in terms of cumulative number of standard axles for the given period has been computed using the following relationship.

$$N = 365 \text{ x } [(1+r)^n - 1] \frac{\text{AxDxFxLx } 10^{-6}}{r}$$

N = Cumulative no. of standard axles to be calculated for the design in terms of MSA.

A = Cumulative vehicles per day=5132, $A=P*(1+r)^n$ where p=Average daily traffic(ADT)

D = Directional distribution factor =0.5 L = Lane distribution factor =0.75

n = Design life in years =15

r = Annual growth rate of c.v =7.5% (IRC-58-2002) F = Vehicle damage factor =5.00

24 Hours Traffic count=7601.5

24 Hours Traffic count =7565.

A = 5056

N = 91.03 MSA

VI. CONCLUSIONS

Based on the filled investigation and analysis : In this paper the nominal effects of pavement roughness on vehicle-pavement interaction are demonstrated. Pavement roughness is the primary cause for moving dynamic tyre loads on Pavements. Control and management of pavement roughness can aid in limiting the Magnitude of moving dynamic tyre loads on a pavement.

Although it has been known for long that pavement roughness deteriorates with traffic and time, the effect on moving dynamic tyre loads and structural pavement lives could not easily be quantified. In the paper a simplified and practical method is demonstrated that can be used to obtain an initial quantification of the effects of pavement roughness on these parameters, based on input data from the vehicle population and pavement roughness.

In this investigation it is observed that the maximum characteristic rut depth is 9.42 mm.. This values is well within the limit of permissible value given by IRC 37 -2002.

It is concluded that the rate of rut depth progression is relatively increasing, and it has increased from 5 mm to 9.42 mm since the last 10 months

It is further concluded that the traffic volume on this road is comparatively high compared to the last year traffic data .Specially commercial vehicles per day is very high.

By conducting the DCP test we conclude that the strength of the existing road is good.

Future Scope of Study

In the course of recent decades, the offer of aggregate rail and street movement conveying travelers and products has slowly expanded from around 24 percent and 11 percent, separately, in 1951 to around 80 percent and 58 percent, individually, in 1990. Street length has expanded correspondingly, from 0.4 million km in 1951 to 2 million km, giving a street thickness of 59 km/100km2. On account of quick and regularly expanding modern, business, and other financial advancement exercises, the street transport vehicle populace, especially vehicles populace, especially vehicles conveying merchandise, has likewise expanded wonderfully amid this period

- By conducting DCP test on pavement we can estimate the performance of existing road network whether it works or not
- The funds released for road development in India will decreases drastically so it is not possible to form the entire length of the at that time this type of study will gives good guidelines for cost efficient designs.
- In future the population of vehicles will increases by that time there is a possibility of rapid failure of the roads we don’t know how much road is damaged if we are not conducting DCP test on that particular road we need to remove entire portion of the road.
- If we conduct DCP we will get clear idea how much length of the road is damaged then we will repair only that particular portion of the road. In this way we will reduce the cost.
- From the above discussion it is clear that this kind of study will helps in future how to reduce the cost of the road development

REFERENCES

[1]. Mohammed Taleb obaidat , Turki I. Suleiman (1997) “ Quantification Of Pavement Rut depth Using Stereovision Technology” Article In Journal Of Surveying Engineering, DOI: 10.1061/(ASCE)0733-9453(1997)123:2(55).

[2]. J.J. Hajek, G. Musgrove, and T.J. Kazmierowski (1998) “ Measurement , Management and Utilization Of Rutting Data” Ontario Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario,Canada M3M 1J8.

[3]. “ Dynamic Cone penetration Test (DCPT) For Sub grade Assessment ” TRB Subject Code:62-7 Soil Foundation Subgrades ,February 2003 Publication No.: FHWA/IN/JTRP-2002/30, SPR-2362

[4]. Gill, K.S. Jha, J.N. Choudhary, A.K (2010) “CBR Value Estimation Using Dynamic Cone Penetrometer ” Indian Geotechnical Conference – 2010, GEO trendz December 16–18, 2010 IGS Mumbai Chapter & IIT Bombay

[5]. Patrick Liq Yee Tiong, Mushairry Mustaffar and Mohd Rosli Hainin (2012) “Road Surface Assessment of Pothole Severity by Close Range Digital Photogrammetry Method ” World Applied Sciences Journal 19 (6): 867-873, 2012 ISSN 1818-4952 DOI: 10.5829/idosi.wasj.2012.19.06.3353

[6]. S.Shankar, Y.Ravi (2014) “IN-SITU Strength Evaluation of Pavement Layers of Low Volume Road Using Dynamic Cone Penetrometer (DCP) ” Transactions on Engineering and Sciences ISSN: 2347-1964 (Online) 2347-1875 (Print), Vol.2, Issue 8, August 2014.

[7]. LUU Xuan Le, THAO Dinh Nguyen(2016) "research of asphalt pavement rutting on national roads in vietnam" https://www.researchgate.net/publication/307373551.

[8]. Anthony Quansaha, Tresor Ntaryamiraa, and Daniel Obeng-Atuahb,(2017) "Evaluation of Pavement Structural Life Using Dynamic Cone Penetrometer" https://www.researchgate.net/publication/322357920

[9]. Makendran Chandrakasu, Murugasan Rajiah (2018) "Development of a roughness estimation model for low volume roads" DOI: https://doi.org/10.14256/JCE.1488.2015.

[10]. Sanjiv Aggarwal*, Prof. (Dr.) S.S. Jain** & Dr. M. Parida "Development Of Pavement Management System For Indian National Highway Network"Indian Institute Of Technology, Rookie – 247667 (Uttaranchal) Paper No. 502.

[11]. Prozzi, J. And Madanat, S. (2003)."Incremental Nonlinear Model For Predicting Pavement Serviceability."*J. Transp. Eng.*, 129(6),635–641.

[12]. Chen, P.E., Chih-Hsien Lin., Erwin Stein., and Jurgen Hothan (2004). "Development of a Mechanistic-Empirical Model to Characterize Rutting in Flexible Pavements."*Journal of Transportation Engineering*, 140 (4), 519-525.