Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019Mumbai 26-31 May 2019

Overlay design of low volume roads using Dynamic Cone Penetrometer - a review in Indian scenario

Wilson.K.C[1], Shindon Baby[2], Teena John[3]

[1]*Scientist, Highway Engineering division, National Transportation Planning and Research Centre (corresponding author: iamwils@gmail.com)*
[2]*M.Tech, Highway Engineering division, National Transportation Planning and Research Centre (corresponding author: shindon89@gmail.com)*
[3]*B.Tech, Highway Engineering division, National Transportation Planning and Research Centre (corresponding author: bcmalhartechno@gmail.com)*

Abstract

India has a road network of over 5,603,293 kilometres (3,481,725 mi) as on 31 March 2016, the second largest road network in the world. The majority of roads in India comes under the category of flexible pavement rather than rigid pavement. Pavements undergo deterioration due to traffic loading, adverse climatic conditions, insufficient drainage or due to inferior pavement layer material. Hence pavements should be maintained periodically to ensure satisfactory performance. In India this is done by providing asphalt overlays on the existing surface. Overlays of existing pavements should be done periodically to increase the load carrying capacity of the pavement or to correct any defective surface condition and thereby maintaining the pavement performance during its design period. A number of methods like equivalent thickness method and deflection-based methods are used for the overlay design of flexible pavements in worldwide. Deflection based methods are mostly used in India. The overlay design using Dynamic Cone Penetrometer (DCP) is relatively an unexplored area and not much studies are reported in this area. The method had its origin in South Africa and is mostly used in countries like South Africa, UK and USA. Instead of other methods, DCP test is a simple test which gives the properties of individual layers like pavement layer strength and layer thickness with comparitively good accuracy and minimum destruction to the pavement, there by one can assess the existing conditions of each layer rather than condition of a pavement as a whole. DCP is best suited for design of Low Volume Roads(LVR) i.e. the roads in which the cumulative traffic loading over the design life does not exceed about 1 million equavalent standard axles or 300 vehicles/day. The paper attempts to review studies previously done by road authority of South Africa on using DCP for the overlay design of low volume roads, points out the advantages and disadvantages of the methods specified in these studies for the purpose of answering the question, is DCP a better method for overlay design compared to other methods in Indian scenario. The study has concluded that DCP outperforms other traditional overlay design methods when it comes to data accuracy, ease of collecting data and is a cheap method and hence better than other traditional methods for usage in India.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: overlay design;dynamic cone penetrometer;low volume roads;flexible pavement

2352-1465
Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY

1. Introduction

Dynamic cone penetrometer is an equipment used to obtain in-situ soil charateristics and conditions beneath the existing pavement surface such that the data can be used for pavement design purposes. Not much background studies has been done in the field of overlay design using DCP. The equipment consists of a steel cone (20 mm diameter with a 60º angle) that is driven into the ground with a constant energy (an 8 kg mass falling through 575 mm). The rate of penetration DN (mm/blow) through the pavement layers is measured which gives a fair indication of the effective in-situ layer properties. In India roads are subjected to seasonal variations in climate resulting in the fluctuations of pavement moisture regime. Traffic volume is also on the rise. Hence an environmentally optimised simpler design methods are suitable for LVRs due to economy taking into account the different environmental factors like moisture content, prevailing traffic, availability of locally available construction material etc as compared to the design of High volume roads. Some of the traditional methods used for overlay design are discussed below.

Nomenclature

A	DCP - Dynamic Cone Penetrometer
B	LVR - Low Volume Road
C	DN - DCP number

1.1 Methods for overlay design

1.1.1. Deflection based methods of Overlay design

Benkelman beam deflection method and falling weight deflectometer method are the deflection based non destructive testing methods(NDT) commonly used in India for overlay design of pavements.
In BBD method overlay thickness is found out from the standard chart provided by IRC 81 using characteristic deflection and traffic volume. The amount of pavement deflection under a design wheel load or its rebound deflection on removal of this load is a measure of the structural stability of the pavement system under the prevailing condition of the test. Larger rebound deflection indicates weaker pavement structure which may require earlier strengthening or higher overlay thickness. The rebound deflection is measured by benkelman beam(source-highway engineering by Khanna and Justo).
A Falling Weight Deflectometer (FWD) is a non destructive pavement loading device used to measure the vertical deflection response of a surface to an impulse load. The existing pavement and subgrade support levels determined from FWD testing, along with traffic data, design loading, and design period, are used as inputs to determine an overlay thickness suiting the design conditions. Additional overlay thickness can be prescribed for localized weak areas identified using FWD data.

1.1.2. Equivalent thickness method of Overlay design

CBR method is an equivalent thickness method. The CBR method of pavement design is developed by California Division of Highways in the U.S.A. in 1928. They developed an empirical design chart correlating the CBR value and the pavement thickness. The basis of the design chart is that a material with a given CBR required a certain thickness of pavement layer as a cover. A higher load needs a thicker pavement layer to protect the subgrade. In order to design a pavement by CBR method, first the soaked CBR value of the soil subgrade is evaluated. Then the appropriate design curve is chosen by taking either the design wheel load or by taking the anticipated traffic into consideration. Thus the total thickness of flexible pavement needed to cover the subgrade of the known CBR value is obtained. Thickness of any pavement layer can be found out by knowing the CBR value of the particular layer. From the design chart the thickness of construction over a particular layer is found out. The layer thickness is nothing but the total thickness minus the thickness over the particular layer(highway engineering by Khanna and Justo).

2. Scope and need of the study

The purpose of this paper is to review the advantages and disadvantages of various alternative methods of DCP design and to come up with the most effective alternative pertaining to Indian conditions. Design of pavements using DCP method is a more optimum, reliable and more easy to perform method when compared to CBR and BBD yet the method is not so popular in our country. This review paper approach each method described in the articles with a set of questions in mind. They are as follows.

- Does the layer strength and thicknesses of LVR obtained through DCP design falls back behind the strength requirement and thicknesses obtained by other methods of design like CBR or specified by experienced engineers?
- Does the variations in specifications is compatible with the Indian conditions?
- Since DCP method of pavement design is empirical in nature does the assumptions and other drawbacks are likely to lead to error in design?
- Does the advantages of each method out weigh any perceived disadvantages?
- What is the future scope of each method?

In India each year huge amount of money is spent by Government on infrastructure development. Road maintanence, rehabilitation and development is a never ending process. The need to evolve intermediate technologies to provide road access to 600,000 villages across India most of which are low volume roads (LVRs) are enormous. One such technology is DCP. DCP method is a simple, cheap and effective tool for obtaining in-situ data which is used for pavement design. Although a number of methods have been described for the use of DCP for the design of low volume roads but no comprehensive methods has been published. This paper is intended to study the suitability of DCP in Indian scenario and tries to approach each method with the above set of questions in mind.

3. Studies on overlay design using DCP

Rolt et al(2016) conducted a study on the design of low volume roads using dynamic cone penetrometer. In the study they discuss two DCP methods. They are DCP-CBR and DCP-DN method.

3.1.1 DCP-CBR method

In the DCP-CBR method pavement layers are identified from the DN value(DCP penetration value in mm/blow).Using correlation equation developed by TRL DN value is converted into CBR value. Moisture correction is done by adjusting the CBR of the pavement layers or by applying a ‘drainage factor’to modify the DN value. Uniform sections along a road are determined by the analysis software to produce a subgrade design class for pavement design purposes. The design of the upgrading of the pavement is based on a CBR catalogue of pavement structures for different traffic levels, subgrade strength values and layer strengths.

Over conventional CBR method the DCP-CBR method has many advantages. Sample collection for conducting undisturbed CBR test is difficult and are rarely attempted. Often samples are extracted from test pits dug along the road and are tested in the laboratory under different densities and moisture content to determine their strength characteristics.

DCP test is conducted on undisturbed samples and hence chances of error on strength determination is minimised. The CBR test exhibits poor repeatability and reproducibility compared with the DCP test.

DCP provides strength profile throughout the pavement layer on the other hand CBR is naturally biased towards material at the top and bottom of the mould.

Since DCP is easy to conduct a large no of data's can be collected providing good statistical distribution of subgrade and layer strength as compared to a test pit-based method like CBR which is more difficult to perform. Hence chances of under or over design is minimised.

The perceived disadvantage is that the accuracy of the method depends on the accuracy of the correlation equation. Many of the DCP-CBR correlation equations are developed by foreign authorities under foreign conditions and the equation will only be accurate for usage in India if used for the evaluation and analysis of pavements similar to those from which they were derived.

3.1.1.1 Subgrade strength

The traditional CBR method incorporates numerous assumptions especially in predicting the likely moisture content and therefore chances of design errors are high. In CBR method subgrade strength is measured based on subgrade moisture content measurement. This involves compaction to different density levels and at different moisture contents plus CBR testing to determine strength at a particular density and moisture content. From these tests and knowledge of the specified compaction level and estimated moisture content, the likely strength of the subgrade could be determined. The disadvantage of this method is that the testing is time consuming and hence the number of tests carried out was usually quite small and statistically unsound. Also the strength of the subgrade is highly variable along the road alignment. Hence large number of tests need to be done along the alignment which is practically impossible with CBR method.

Also in CBR method soaked CBR value is taken to account for the worst subgrade condition. But this may lead to over design of the pavement. In DCP method in-situ subgrade strength is obtained directly which is more accurate than the strength obtained by CBR method.

In CBR method of pavement design the in-situ strength measured involves numerous assumptions compared to DCP method which is a direct method and hence chances of errors are high.

3*.1.1.2 Pavement material specification*

For LVRs the selection of pavement materials that do not meet the traditional specifications has been a body of considerable research. The studies shows that substandard materials can be used effectively for base and sub-base considering the climate and traffic level for LVRs, when it comes to Indian conditions this is an advantage because substandard materials are locally available. Studies shows that when roads fail many of the traditionally controlled properties of the pavement layers (e.g. plasticity index (PI), plasticity modulus (PM) and grading) do not correlate well with the observed performance. Materials that are deemed sub-standard have frequently performed well and some, apparently good materials, have not performed well under comparable environmental conditions (Rolt et al(2016)). There are two main reasons for the lack of apparent correlation between traditional specifications for materials and performance. First of all, the reasons for poor performance are most often associated with the poor performance of the surfacing rather than the individual pavement layers (Paige et al, (2009); Rolt et al(2016). Secondly, if water becomes a serious problem within the pavement (e.g. because the surfacing is allowing water to penetrate) the fact that the soaked CBR of one material is higher than another is no guarantee of sufficiently better performance, especially if positive pore pressures are able to occur, even for a relatively short time(Rolt et al(2016))

3.1.2. DCP-DN method

In the DCP DN method the pavement layers are divided into layers of 150mm thickness and the DCP number(DN) for each 150mm layer is found out by using a weighted average approach. The DCP measurements are then combined to yield the median, 20^{th} and 80^{th} percentile values of 150mm incremental layers along a uniform section of the road. Based on the anticipated moisture conditions (three choices) one of the three values is selected and is compared with the values provided in the design catalogue to see where the structure fails to meet. For those layers failing to meet the strength criteria either mechanical stabilisation is provided or an additional layer with the adequate DN value is provided at the top.

The use of DN method offers many advantages over conventional CBR method. The pavement material selection is solely based on DN measurement on the assumption that it provides a unified measure of material grading, plasticity, moisture and density without conducting any of these tests. Grading and plasticity tests are done to avoid unnecessary materials for eg: materials of poor grading like gravels or very fine particles.

But relying material selection solely on DN value may be risky. But when in doubt conventional grading and plasticity tests can be done to avoid unsuitable materials. For these reasons this disadvantage is outweighed by the advantages by DCP-DN method and is superior to conventional methods.

The study concludes that DCP method of pavement design based on the concept of environmentally optimised design using locally available substandard materials offer many advantages over traditional CBR based method but in the case of LVRs sufficient layer thickness and using materials of adequate strength alone is not sufficient for quality performance. Good drainage system, good surfacing, maintenance and control of heavy vehicles are also equally important and which cannot be compensated with provision of additional pavement thickness with strong materials.

3.2.Paige et al (2012)conducted a study on designing a sealed LVR, upgrading the road from a unsealed to sealed standard, using DCP. The road design is based on a sustainable design approach utilising maximum in-situ materials reducing the need to import large scale virgin materials thereby effecting the economy. They conducted study on different LVRs in South Africa using DCP. DCP is used to assess the in situ conditions including material quality and moisture regimes along the road. Uniform sections along the road alignment is identified, the layer strength diagrams for each of these sections is prepared and based on the in-situ traffic volume the layer thicknesses and material quality required for each layer is found out thereby identifying inferior layers. The unpaved roads in South Africa uses gravel as a wearing course. Unsealed roads offers many disadvantages such as the erosion of gravel, dust problem, need for regular grade maintanence etc. Also avialability of gravel is scarce as well. Hence regular resurfacing is required which adds to the life time cost. The upgrading of unpaved roads to a paved standard by bituminous surfacing using DCP offers many advantages. From an economic point of view the advantages of a paved road will outweighs the disadvantages of unpaved roads only if the construction cost is minimised such that it can compete with the life time cost of an unpaved alternative. This is very much possible with the environmentally optimised design of DCP. Over the years due to traffic loading, alternate wetting and drying cycles the subgrade has undergone a considerable amount of compaction and the localised weak areas is strengthened. Hence locally available materials can be effectively utilised as layer material. The length of unsealed road network exceeds than that of sealed road network in developing countries like India. The importance of a sustainable low cost method of pavement design for Low volume roads is the need of the time and DCP method is the best answer.

The design process involves preparation of standard layer strength diagram from existing pavement design catalogues for different traffic categories. The DCP survey is conducted and data is analysed is a number of ways. One way is to find out the number of blows required to reach a debth of 800mm (DSN_{800}). A cumulative sum plot of DSN_{800} to the kilometer is plotted to identify different road sections based on the difference is subgrade support. Another way is to plot the cumulative sum of DCP penetration rate (DN) to the kilometer. Uniform road sections is identified based on this plot as well. The homogeneity of the top layers is identified based on this plot. The actual strength profile of all the DCP results within a uniform section is plotted by taking the weighted average of the penetration rates (sum of products of DN and thickness of that DN value). The DN value is appropriately chosen based on the actual moisture regime of the test location. The design process then involves superimposing the standard LSD for the traffic with the actual in-situ LSD. The in-situ layers to the right of standard LSD has less strength and will fails under the traffic. Hence such layers require adequate strengthening.

A sustainable approach to optimise the design of LVRs using DCP has got many advantages over conventional design approaches used in India. In India the construction cost and lifetime cost for the maintanence of low volume roads is a major problem. The premature failure of roads is a common occurance in our country. Using this technique, it is possible to upgrade unsealed roads to sealed standard or can be used for rehabilitation of the existing roads using in-situ materials or atmost requiring to import materials for a single layer, without the risk of premature failure. There are many reasons for such a premature failure. Road design using conventional CBR method uses inadequate amount of data. The soaked condition used for CBR test may result in over design of the pavements. In DCP method a large amount of data is used for analysis and design. The road section is divided into uniform sections based on the homogeinity of the top layers or the subgrade. Each of these uniform sections has got different strength profile and hence the design will also be different. The penetration rate(DN value) is suitably manipulated as the site condition during DCP survey is wetter than or drier than or same as the expected in service moisture condition. The method allows the designer to make use of local knowledge and experience in developing the appropriate layer strength diagrams for different traffic classes and environmental condition in order to optimise the pavement layer thicknesses and material strengths(Paige et al(2012)).

The method also has some disadvantages. The standard layer strength diagram prepared for the traffic is based on existing pavement design catalogues based on traditional design methods. This may not be economic. A number of design catalogues is prepared for different in-situ moisture conditions based on the assumption that the drainage facilities are well maintained. In India especially in rural areas the low volume roads lacks appropriate drainage facilities. Hence the design may leads to error.

The provision of proper drainage facilities cannot be overemphasised in any design method. Proper engineering judgement is required in assessing the in-situ moisture regime. Once these are met DCP method is accurate and cost effective. Overall, it can be concluded that the perceived advantages outweighs the disadvantages.

3.3.Paige et al (2011)conducted a study on the application of DCP for designing low volume roads.The method is based on CBR values derived from DCP readings from the DCP-CBR relationship and they illustrate the study using two design examples.Although DCP is a very effective tool to determine in-situ material strength and layer thickness the strength will always varies with density and moisture content. Kleyn and Van Zyl described a method for the material G class classification based on expected moisture regime as a percentage of OMC that will prevail over the road and DCP-CBR readings and design strength, a percentile of in-situ strength, will be based on this.The first step in the design process is the determination of cumulative traffic over the design life of the pavement. The potential of overloading due to short periods of heavy traffic has disproportionate effect on overall traffic of LVRs and this should be taken care of. An idea of the required pavement structure can be obtained from available catalogues for LVRs. This provides an indication of the number and layer thickness of individual pavement layers at the expected worst moisture condition of the road and from this individual Layer Strength Diagram(LSD) in terms of the CBR can be constructed. The plots are for the standard soaked CBR design as well as the required LSDs for different DCP test moisture conditions based on earlier road material G class classification based on expected moisture regime. The next step is to conduct DCP survey, assess the moisture condition of the road based on laboratory observations, finding uniform sections of the road based on DCP results. Each of these sections require a specific pavement design or treatment. The actual pavement design process consists of fitting the in-situ pavement structure to the standard design structure and to identify layers falling short of strength. Such layers should be strengthened.

The study concludes that the DCP test is quick,cheap, non-destructive and very much appropriate for the design of LVRs. However, the designer should have an understanding of the field density and moisture content at the time of DCP testing and understands the relationship between field and laboratory test results for the materials involved.

4. Conclusions

The DCP design technique has been shown to be highly appropriate for the design of low volume roads. Testing is quick, cheap and non-destructive. The overlay design of low volume roads using dynamic cone penetrometer is relatively an unexplored area and not much literatures is available for reference. Three papers focusing on the design of low volume roads using dynamic cone penetrometer is reviewed in this paper. In Indian scenario a sustainable, cost effective and accurate design method is the need of the time and DCP design method is so far the best solution. But proper design standards and specifications should be followed. The performance of LVRs depends on proper drainage, good surfacing and control of heavy vehicle traffic. Ignorance in these areas will leads to design error.

The main conclusion is that the ovelay design of low volume roads using dynamic cone penetrometer, although a partially destructive method, combines the optimal use of in-situ material is suitable for use in India and is superior to traditional design methods.

Acknowledgements

The authors express their sincere gratitude to the Kerala State Council for Science Technology and Environment, Government of Kerala for providing necessary financial assistance for the project.

References

Paige, P., Du Plessis, L., 2009. The Use And Interpretation Of The Dynamic Cone Penetrometer Test

Paige,P., 2011. Applying The Dynamic Cone Penetrometer(DCP) Design Method To Low Volume Roads, Proceedings of the 15th African Regional Conference on Soil Mechanics and Geotechnical Engineering C. Quadros and S.W. Jacobsz (Eds.) IOS Press, 2011

Paige,P., Pinard, M., 2012. Optimum Design Of Sustainable Sealed Low Volume Roads Using The Dynamic Cone Penetrometer. 25th ARRB Conference – Shaping the future: Linking policy, research and outcomes, Perth, Australia 2012

Rolt, J., Pinard, M., 2016. Designing low-volume roads using the dynamic cone penetrometer. Proceedings of the Institution of Civil Engineers Transport 169 June 2016 Issue TR3