FAILURE ANALYSIS OF A DBST ROAD USING MECHANISTIC EMPIRICAL METHOD

W.K. Mampearachchi
Senior Lecturer, Department of Civil Engineering, University of Moratuwa
(e-mail:wasantha@uom.lk)
D.L.Marasinghe
Undergraduate, Department of Civil Engineering, University of Moratuwa
(e-mail:lankilive87@gmail.com)
R.M.T.M.Dahigamuwa
Undergraduate, Department of Civil Engineering, University of Moratuwa
(e-mail:thilanki_d@yahoo.com)
W.D.N.G.Wanniarachchi
Undergraduate, Department of Civil Engineering, University of Moratuwa
(e-mail:nipunawanniarachchi12@yahoo.com)

Abstract: The objective of this research is to analyze a failure of a DBST road section using a Mechanistic - Empirical method. For this analysis, failure of A15- Trincomalee-Batticaloe road was selected.This particular road section was rehabilitated recently by extending the width of the initial road section from both the sides and soon, a large amount pot holes appeared in the newly constructed areas.Empirical methods alone failed to identify the reason behind this failure and therefore a Mechanistic - Empirical approach was used along with the KENLAYER software to analyze the section. Mechanistic approach to pavement design seeks to explain phenomena only by reference to physical causes. Thus it uses stresses, strains and deflections within a pavement structure to analyze the loads and material properties of the pavement. This study would help future engineers to identify the reason behind the failure of road sections. This will promote mechanistic softwares like KENLAYER and increase the usage of it. These softwares will make life easy for road designers and consultants and this may turn a new chapter in road designing of Sri Lanka.

Key Words: KENLAYER, Road Note 31,failure analysis, mechanistic empirical method.

1. Introduction

Road structures may be classified as flexible, composite or rigid. A flexible pavement consists of one or more layers of flexible (bituminous) material supported by a granular subgrade. Composite pavements consist of a flexible surface layer supported by a stiff (concrete) base and rigid road surfaces consist of a layer of concrete on a granular foundation. Rigid pavements may be further classified according to their arrangement of steel reinforcement and joints.

Current practice in pavement designing is to design flexible road structures with resistance to failure by fatigue and rutting. Elastic or viscose-elastic layer theory or finite element methods are used to calculate stresses and strains in the road due to a static, standard wheel load (usually 80 kN). The main two types of failures are [7]

- Rutting: Subgrade compressive stress or strain. Vertical surface deflection
- Fatigue: Horizontal tensile stress or strain, shear strain and shear stress.

Rutting is the irrecoverable vertical deformation in any layer of the pavement structure is possible in the asphalt layer at the early stages of the road when the asphalt layer is malleable. Occurance of rutting is not possible later in the asphalt layer. Saturated clay in subgrade can cause irrecoverable vertical deformation in road structure due to consolidation but it will take a long time.

Although considerable research effort has been concentrated on prediction of pavement failure agreement between theory and experiment is often unsatisfactory. There are numerous complicating factors including "healing" of bituminous materials in rest periods between load pulses the distribution of wheel paths across the road extreme sensitivity of material properties to climatic conditions particularly.[7]
Each of these road types have a number of characteristic failure mechanisms. Most important of these are [1].

- Fatigue cracking for all types of pavements
- Permanent deformation for flexible and composite pavements
- Reduced skid resistance for flexible and composite pavements
- Low temperature cracking for flexible pavements
- Reflection cracking for composite pavements
- Faulting, spalling, low temperature and shrinkage cracking, blow ups.
- Punch outs and steel rupture for rigid pavements.

Each failure mechanism is affected by many factors including the roadway design and construction methods. The material properties of each constituent layer (these are generally discontinuous, nonlinear and anisotropic), the traffic loading and the environmental conditions throughout the service life.
Empirical method of pavement design, such as Roadnote 31 cannot be used effectively to analyse the cause for the failure of road pavements. Therefore, there is a need to develop a mechanistic model to facilitate this analysis. This research focuses on analysis of road failures using the mechanistic tool KENLAYER software. For this analysis, failure of A15 - highway (Batticaloa - Trincomalee), in Sri Lanka was selected as a case study.

2. KENLAYER Software

KENLAYER is a part of KENPAVE software which allows designing of both flexible and rigid pavements. KENLAYER is used for flexible pavements.[1].
KENLAYER is a mechanistic tool for pavement design, which used stresses, strains and deflections within a pavement structure for analysis.

KENLAYER software uses the layer theory when analyzing pavement structures. It can provide nine output parameters, which are

1. vertical stress
2. vertical strain
3. horizontal strain
4. major principal stress
5. major principal strain
6. minor principal stress
7. minor principal strain
8. intermediate principal stress
9. intermediate principal strain

KENLAYER can perform a damage analysis, where the user can calculate the design life of the pavement, which is not available with the empirical methods. The failure condition can be changed according to the design guideline that the user adapts, such as Asphalt Institute Method and Shell Design Guidelines. The method used in this analysis is the Asphalt Institute Method.[1].
Even though the traditional empirical methods assume that the pavement material such as aggregates are linear elastic, it show non linear properties in reality. KENLAYER facilitates the user to perform non linear analysis on non linear layers.
Since the material properties of road pavements such as strength vary according to weather conditions, KENLAYER allows the user to change material properties, depending on the season. This was absent in traditional empirical methods.
In this analysis, damage analysis together with the non linear analysis was carried out. When carried out a damage analysis damage ratio on the road by each load group is separately mentioned. For rutting failure we need to input the layers as "top layer compression" where as for fatigue failure the failed layer has to introduced as "Bottom layer tension"
Top compression analysis can be carried out by giving all the soil layers in Top compression apart from the DBST layer. When carried out damage analysis together with this it gives the damage ratio of each load group per each soil layer. Then it provides a summary of cumulative damage ratio per each layer and the design life is calculated by one over maximum cumulative damage ratio. Therefore the layer which has the maximum damage ratio may govern the design life of the pavement. In the sametime there is no clear definition for failure under empirical methods because sometimes the failure can be taken as the failure in the sub grade but sometimes it can be in any critical layer.

In the Non linear analysis ABC layer is allowed to take certain tension and this improves the load capacity of the road.

3. Failure Investigation

Trincomalee- Batticaloe (A15) road was selected for the case study. The rehabilitation of road section from Ch. 36+400 to 90+000 of Trincomalee - Baticaloa road (A15) was commenced on April 01, 2009.

The road section consists of 6.2m wide carriageway and 1m soft shoulder. The edge widening work has been carried out on either sides of the road to achieve the required width of the road. This road was designed according to ROADNOTE 31 design guide, as a DBST road. Design subgrade strength class was S4 (8% sub grade) and traffic class was T3. Selected road design is as shown below.

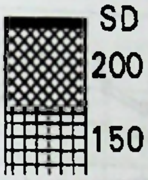

Figure 1 : Charts of the Roadnote 31

The design was modified during the construction stage and the base thickness was reduced to 150mm and constructed using Dense Graded Aggregate Base Course and sub base thickness was increased to 200mm. Then the surfacing has been carried out using DBST. Surface distresses such as cracks, depressions and shoving could be observed in the rehabilitated area. Therefore a requirement for identifying the reason behind the failure was developed.

Figure 2: Failed road section of the Trinco - Batticaloe road

There were no relationship between geometry and the road failure identified. Failures have been observed on both straight and curved sections of the road but most of the failures can be seen at straight locations since the road is in a flat terrain. Failures have been observed on horizontal curves but not at all the curves. It has been observed that failure is mainly in the widened area (from edge of the old pavement to the edge of the new pavement).

Damages were not penetrated beyond the sub grade according to the field investigations. After these observations it was identified as a **"Rutting Failure"**. Failure at location 69+070 was selected for further investigation

4. Methodology

Field DCP tests were conducted on site after removing the DBST and ABC layer as shown below for both the failed and non failed location.

The graphs were plotted and site CBR value of subbase and subgrade soil obtained.

Standard proctor compaction test was carried out in the laboratory according to ASTM standards to identify the amount of water required to reach optimum moisture content. Laboratory CBR tests were conducted on selected soil samples for their respective optimum moisture contents which were taken from both the failed and non failed locations

In order to calculate the Average Daily Traffic (ADT), a traffic survey was conducted on two days, one week day and one weekend on the selected road. Axle load has been calculated based on finding of previous research results[6].

Traffic was divided in to two directions and 10 load groups were obtained with the respective repetitions for Trinco to Batticaloe. The same procedure was repeated for the traffic data of Batticaloe to Trinco.

Traffic load groups, respective number of repetitions and soil data of each location was fed to the KENLAYER software and damage analysis was carried out.

5. Failure Analysis Using Kenlayer Software

The first task under analysis was to identify the type of failure. The alligator cracks were not seen on the surface of the road and thus it was not the fatigue failure.

Wheel path deflection observed on the road drew the attention towards rutting failure. Then all three layers were checked for rutting using "KENLAYER" software. The software is used to analyze the real reason behind the failure of this particular road section.

The possible reasons for the failure were identified as below.

- The initial design had a 200mm ABC layer and a 150 mm Subbase whose CBR is 30% but during the construction stage the relevant design was altered to a 150 mm ABC layer and a 200 mm subbase of CBR value 30%. This alteration might have resulted in a failure.
- Material properties were not up to the required standards. According to the designs, subbase must have a CBR value of 30 % and subgrade must have a CBR value of 8% and the DCP data shows that the subbase CBR is close to 15% on non failed locations and 5% on failed locations. Therefore the weakness in subbase material properties might have resulted in a failure.

All the situations available within the site were summarized to four options as shown in table 1 and were evaluated .

Table 1: Selected four options for analysis

Option No	Description	Base	Subbase	Subgrade
1	Original Design	200mm thickness 80% CBR	150mm thickness 30% CBR	8% CBR
2	Actual Pavement	150mm thickness 80% CBR	200mm thickness 30% CBR	8% CBR
3	Failed Location	150mm thickness 80% CBR	200mm thickness 5% CBR	40% CBR
4	Partially failed location	150mm thickness 80% CBR	200mm thickness 15% CBR	40% CBR

Failed location mentioned above under option 3 demonstrated a subbase CBR of 5% and subgrade CBR of 40% from the DCP tests. Partially failed location had a subbase CBR of 15% and subgrade CBR of 80% according to the DCP tests but for analysis purposes subgrade CBR was taken as 40% for the " Option 4 ". The CBR of subgrade in "Option 4" was reduced due to limitations in KENLAYER model in analysis. Also, a subgrade CBR value greater than 8% was considered as suitable by the designers. Therefore, a subgrade CBR of 40% was selected for the subgrade in "Option 4".

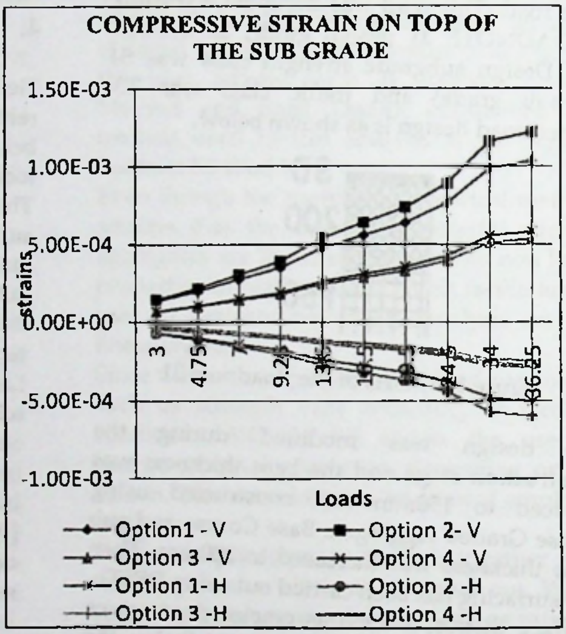

Figure 3 : Compressive Strain on Top of Subgrade

As shown above in figure 3, with the help of KENLAYER vertical compressive strain and horizontal compressive strain on top of the subgrade was plotted and this shows that there is very small vertical compressive strain on the top of the subgrade of the failed location when compared to other stresses (Option 3).

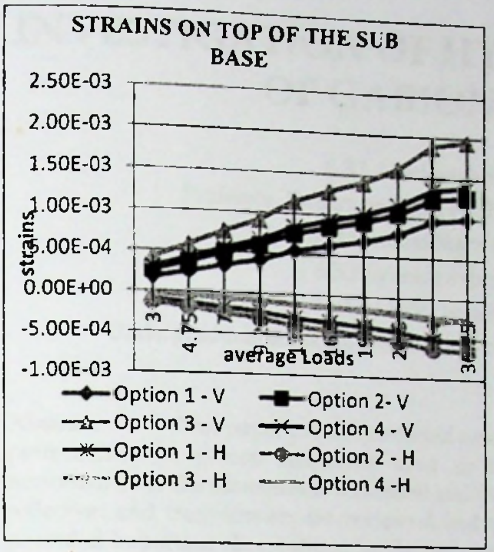

Figure 4 : Strains on Top of Subbase

The same analysis was done for the subbase layer using KENLAYER as shown in figure 4. Higher vertical stresses were shown on the failed location (option 3). Subbase has become critical at the failed location.

KENLAYER has the facility to perform a damage analysis, where it interprets damage ratio for each load group and finally the cumulative damage ratio for each group. A graph was plotted for the cumulative damage ratio verses the four options as shown in figure 5.

Highest cumulative damage ratio is visible in the Option 3 on the subbase and it shows a significant deviation from the rest of the graphs.

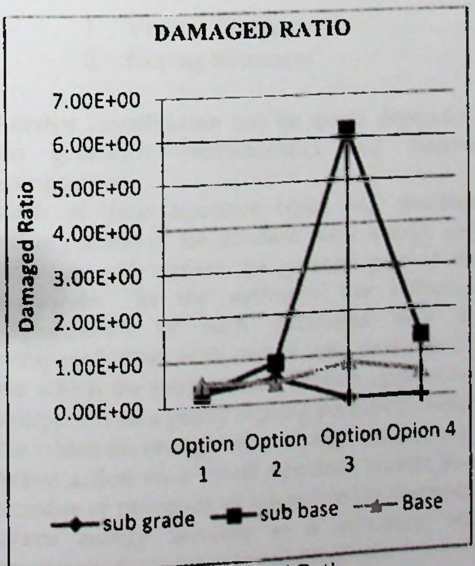

Figure 5 : Damaged Ratio

6. Conclusions

Failure has not penetrated beyond the subgrade. It was proven through the site investigations and it was further confirmed by Figure 3 shown above. Subgrades' vertical compressive strain has not been very significant in the failed location according to it. It can be concluded that failure has taken place above the subgrade and there is no connection between subgrade and the failure. This type of failure can be identified as a "Rutting Failure" Vertical compressive stress plays a higher role in determining design life and damaged ratio in rutting failures.

The subbase has displayed a higher vertical compressive stain at the failed location. A subbase condition at the failed location had been the reason for the failure. Low subbase CBR value of 5% has ended up resulting in higher vertical stress on the subbase which had lead to a failure in the subbase.

Damaged ratio has become very high in option 3 and on the subbase layer. The above statement is further justified by the damaged ratio for each options as plotted in the figure 5.

According to figure 5, subbase damaged ratio for option 4 is little higher than the option 1 and 2 and it concludes that sub base in the partially failed location has also got affected. Subgrade of option 3 and 4 shows very insignificant damaged ratio which tells that the subgrade has not failed and that is due to the high CBR of 40% and subgrade has got failed due to it's poor material properties. Failed locations' subbase has failed severely due subbase properties being worst on the failed location (Option 3) than partially failed location (Option 4).

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