

**SIMPLIFIED APPROACH TO ESTIMATE OVERLAY
THICKNESS FOR PRELIMINARY PAVEMENT DESIGN USING
AASHTO (1993) METHOD**

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Degree of Master of Engineering

Department of Civil Engineering

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Thesis submitted in partial fulfillment of the requirement for the degree
of Master of Engineering in Highway & Traffic Engineering

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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ABSTRACT

In the past, Benkelman beam test is used as a nondestructive test (NDT) to investigate pavements and to do overlay designs. The main advantage of the Benkelman beam method is that using this method, an overlay design can be done without carrying out detailed investigation of the existing pavement. This is possible because, design deflections obtained from Benkelman beam test are empirically related to the overlay thickness in the Benkelman beam overlay design guideline. However, this design method has become obsolete and the field work of this test is very time consuming and labour-intensive. Thus the Benkelman beam test is not widely used at present.

At present, Falling Weight Deflectometer (FWD) test is considered as the modern nondestructive testing (NDT) method for road pavements. To do a pavement overlay design with FWD data, it is required to follow AASHTO (1993) method. To do an overlay design according to AASHTO (1993) method, resilient modulus (M_R) of subgrade and effective structural number of the pavement (SN_{eff}) is required. Information of subgrade conditions is required to determine the resilient modulus of subgrade (M_R). Also thickness of the pavement layers is required to determine the effective structural number of the pavement (SN_{eff}). This means, to do an overlay design with FWD data, using AASHTO (1993) method, a detailed pavement investigation is required. During the pavement investigations, existing pavement will be damaged to some extent.

Since pavement overlay designs can be done without a detailed pavement investigation using the Benkelman beam test, there is a motivation to do pavement overlay designs also using FWD test without a detailed pavement investigation. Hence, this research is conducted to formulate a simplified approach to estimate overlay thickness for preliminary overlay designs using AASHTO (1993) method using FWD data only. The developed method is called "Simplified Method" to distinguish it from AASHTO (1993) method.

FWD data from four road sections are used to develop the Simplified method. In this method, M_R of subgrade is determined from Surface Modulus and SN_{eff} of existing pavement is determined from Hoffman's method. The overlay thickness calculated from the Simplified method and the AASHTO (1993) method is compared with the overlay thicknesses given in the design reports.

The outcome of the research enables the Engineer to do a preliminary pavement design during the feasibility stage of a project by using only FWD data, without carrying out a detailed pavement investigation. Thus this method will help to avoid damaging the existing pavements and save time and money for pavement investigations.

Keywords: FWD-AASHTO-Resilient Modulus-Effective Structural Number

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LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---------------------|--|
| A001 | Colombo-Kandy road |
| A011 | Maradankadawela Habarana Tirikkondiadamadu road |
| B133 | Ganewalpola – Dachchahalmillewa road |
| B212 | Kekirawa – Ganewalpola road |
| AASHTO | American Association of State Highway and Transportation Officials |
| AC | Asphalt Concrete |
| CBR | California Bearing Ratio test |
| COV | Coefficient of variation |
| FWD | Falling Weight Deflectometer |
| iRoad | Integrated Road Investment Program |
| M_R | Subgrade resilient modulus |
| psi | pounds per square inch |
| RDA | Road Development Authority |
| SM | Surface Modulus |
| SN_{eff} | Effective structural number of the pavement |
| SN_f | Required structural number to carry future traffic |
| SSV | Soil Support Value |
| ORN 31 | Overseas Road Note 31 |

Chapter 1. INTRODUCTION

1.1 Background

Pavement overlays are required to rehabilitate the existing pavements. They are designed to provide an economical combination of pavement layers over the existing pavement to serve the estimated future traffic volume for a specified design period. Existing pavement strength, subgrade strength, Traffic volume and climatic conditions are the main parameters that will determine the structural requirements of a pavement. If these parameters are not characterized properly, it will adversely affect the pavement performance.

Existing pavement strength can be evaluated by conducting field investigations. Subgrade strength can be characterized by conducting laboratory tests or field tests. Traffic is estimated from average daily traffic (ADT) and vehicle growth rates. Climatic conditions are incorporated in the design by accounting for their effects on pavement material properties.

A typical asphalt pavement structure is made up with bitumen, aggregate and soil. The properties of these materials determine the structural integrity of the pavement system. Although material properties can be obtained from laboratory testing, a pavement investigation is required to obtain material samples. However, there are limitation in the pavement investigations for taking material samples. First, it disturbs the existing pavement and will affect the accuracy of subsequent laboratory testing. In addition, pavement materials are not homogeneous (particularly in subgrade and base), and therefore, the properties of these samples will not be representative of the pavement system as a whole.

In order to overcome the above shortcomings of a pavement investigation, Falling Weight Deflectometer (FWD) test can be used to assess pavement condition in situ. FWD test falls under the category of nondestructive testing (NDT). Unlike the sampling process during pavement investigations, FWD test does not disturb the existing pavement structure and also test results of FWD represent the properties of

the pavement structure over a wide range. In fact, FWD test can simulate the actual vehicle dynamic load during the testing.

1.2 Problem Statement

Investigation of the existing pavement is an important aspect in any pavement rehabilitation project. However, during the feasibility stage of a project, detailed pavement investigation is not required. Since only tentative cost estimates are prepared during the feasibility stage of a project, preliminary designs are sufficient without detailed investigations.

Using the Benkelman beam test, the pavement overlay design can be done without conducting a detailed pavement investigation. However, for the FWD test, a detailed pavement investigation is required to do an overlay design with AASHTO (1993) method. The Pavement investigation is required in AASHTO (1993) method to estimate subgrade resilient modulus (M_R) and effective structural number of the pavement (SN_{eff}). However, at present, Benkelman beam test is not widely used for overlay designs, since its design methodology has become obsolete.

Since pavement overlay designs can be done without a detailed pavement investigation using the Benkelman beam test, there is a motivation to study the possibility of carrying out pavement overlay design using FWD test without a detailed pavement investigation. Thus, this research is conducted to answer the research problem of finding a simple method to estimate pavement overlay thickness for preliminary designs with AASHTO (1993) method, using only FWD data, without a carrying out a detailed pavement investigation.

1.3 Objectives

There are three specific objectives in this research:

1. To formulate a method to estimate the subgrade resilient modulus (M_R) using only FWD data without any additional information, like pavement thicknesses or material types of pavement layers.

2. To formulate a method to estimate the effective structural number (SN_{eff}) of the pavement using only FWD data without any additional information, like thicknesses or material types of pavement layers
3. To develop a method to estimate pavement overlay thickness for preliminary designs using the estimated subgrade resilient modulus (M_R) and effective structural number (SN_{eff}) of the pavement according to AASHTO (1993) pavement design guideline.

The method developed, in this research, to estimate pavement overlay thickness is called “Simplified Method”, to distinguish it from AASHTO (1993) method.

1.4 Research Approach

In order to achieve the objectives of this research the following approach is followed:

- A literature review is done to study the previous research efforts in the area of determination of subgrade resilient modulus (M_R) and existing structural number (SN_{eff}) of the pavement only from FWD data.
- During the data collection, FWD data and pavement design reports of A001, A011, B212 and B133 roads are obtained.
- FWD data of four road sections are analyzed to develop a method to estimate the subgrade resilient modulus (M_R) for Simplified method.
- FWD data of four road sections are analyzed to develop a method to estimate the effective structural number (SN_{eff}) of the pavement for Simplified method.
- Using AASHTO (1993) method and Simplified method, overlay thicknesses are determined for the four road sections.
- Finally, overlay thickness obtained from Simplified method and AASHTO (1993) method is compared with the overlay thicknesses given in the design reports.

Chapter 2. LITERATURE REVIEW

2.1 Pavement Overlay Design Methods

2.1.1 Benkelman beam method

Benkelman beam was developed in 1952 at the Western Association of State Highway Organizations (WASHO) Road Test. It uses lever arm principle to take deflection measurements. To do a Benkelman beam test, it must be used with an 80kN loaded truck on a single axle with dual tires. To take measurements during a test, tip of the Benkelman beam is placed between the rear tires of the truck. Then, as the truck moved away, the deflections of the pavement surface is measured from the dial gauge of the beam and it is recorded manually. Benkelman Beam is a slow and labor intensive test and also its deflection measurements do not provide the deflection basin. Schematic diagram of Benkelman Beam is shown in Figure 2-1

Benkelman Beam overlay design can be done based on the TRRL Laboratory Report 833. The characteristic deflection obtained from Benkelman Beam test is related to the overlay thickness through empirically developed design charts given in TRRL 833.

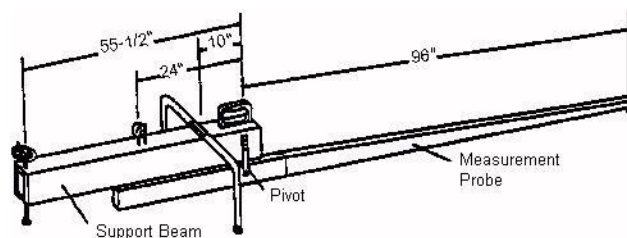


Figure 2-1 Schematic diagram of Benkelman Beam

2.1.2 Road Note 31 Method

The 4th edition of Road Note 31, “A guide to the structural design of bitumen surfaced roads in tropical and subtropical countries” was published in 1993 by Transport Research Laboratory (TRL), UK. After gathering some local experience, a committee consists of senior RDA engineers modified the 4th edition of Road Note 31 in 1999, to suit the local conditions of road pavements. The modified guideline is called “A Guide

to the Structural Design of Roads under Sri Lankan Conditions”. In Sri Lanka, overlay designs are sometimes carried out using this modified Road Note 31 guideline.

To do an overlay design with modified Road Note 31 guideline, three parameters, structural number of the existing pavement, subgrade strength and traffic data are required. To obtain structural number of the existing pavement and subgrade strength, it is required to do a pavement investigation. During a pavement investigation, soil samples of subgrade is collected and also thickness and the condition of the pavement layers are recorded manually. Structural number of the existing pavement is obtained by multiplying appropriate layer coefficients with layer thicknesses. The Subgrade strength is obtained by conducting CBR test for the collected soil samples. Using CBR data and traffic data, structural number of the new pavement can be obtained using modified Road Note 31. Required overlay thickness can be obtained by deducting structural number of the existing pavement from structural number of the new pavement.

2.2 AASHTO Method

Overlay design with AASHTO 1993 method is discussed in detail in section 3.1 of this report.

2.3 Falling Weight Deflectometer (FWD)

Since 1980s, there were significant improvement in nondestructive deflection testing (NDT) devices (Horak, 1988). NDT devices became popular because of their ability to assess the structural condition of pavements in situ. At present, Falling Weight Deflectometer (FWD) is the most widely used nondestructive pavement deflection testing device. FWD can measure several pavement deflections at once. These measured deflections can be used to create an accurate deflection bowl of the pavement. Using the deflection bowl, various structural condition of the pavement layers can be evaluated. Also FWD can simulate the actual pavement deflection bowl created by dynamic loading due to moving vehicles (Ali and Khosla, 1985).

Road development Authority (RDA) has a FWD device. It is called KUAB FWD 50. It is brought from Sweden to Planning Division of RDA in 2010. FWD device is contained within a trailer and it has to be towed to the test site by another vehicle.



Figure 2-2 KUAB FWD 50

2.3.1 Deflection basin of a pavement

Figure 2-3 shows the deflection basin of a pavement generated from the FWD test. Deflection basin is a profile obtained from the deflection data of FWD test. From the above figure, it can be observed that the maximum deflection (D_0) occurs at the center of the loading plate. Maximum deflection (D_0) is the most important parameter for the pavement condition evaluation. It can be related to the structural condition of pavement layers as well as the subgrade condition underneath the pavement. (Dasari, K.V. 2013)

During the FWD testing, an impulse load is applied to the pavement via a circular load plate. The load is applied by dropping a standard weight from a standard height. The resulting deflection is measured from seven deflection sensors. The center deflection (D_0) has been placed directly under the load. The other six deflection sensors are placed at 200mm, 300mm, 450mm, 600mm, 900mm and 1200mm offsets from the center of the loading plate. The deflections obtained from these six deflection sensors are termed as D_{200} , D_{300} , D_{450} , D_{600} , D_{900} and D_{1200} .

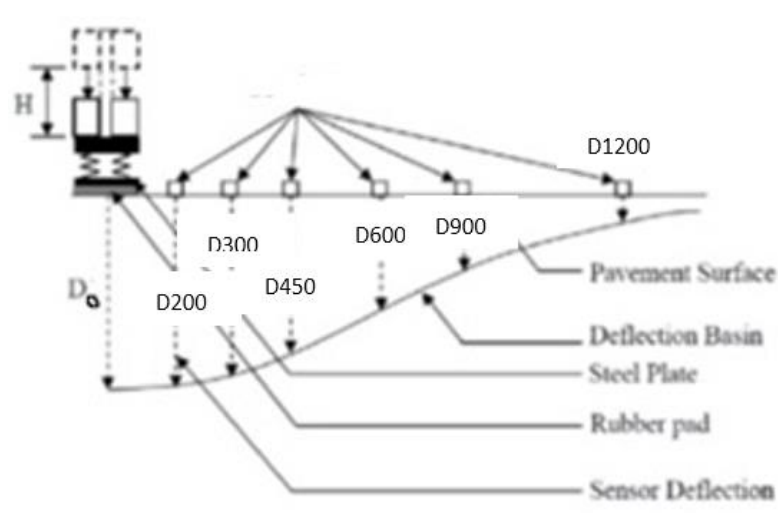


Figure 2-3 Pavement Deflection basin obtained from FWD test

2.4 Subgrade Resilient Modulus (M_R)

2.4.1 Definition of Resilient Modulus

Resilient modulus (M_R) is a fundamental material property that is similar to modulus of elasticity. However, the concept of resilient modulus is different from modulus of elasticity. Modulus of elasticity is calculated based on total strain but, resilient modulus is calculated based on the resilient (or recoverable) portion of the strain (Figure 2-4). At present, resilient modulus is widely used to characterize unbound pavement materials. This is because, the resilient pavement deflection has a better correlation to pavement performance than the total pavement deflection (George, K.P., 2003). Resilient modulus is defined as the ratio of deviator stress, σ_d , to the recoverable strain, ϵ_r ,

$$M_R = \frac{\sigma_d}{\epsilon_r} \quad (1)$$

Where,

σ_d - applied deviator stress
 ϵ_r - resilient strain

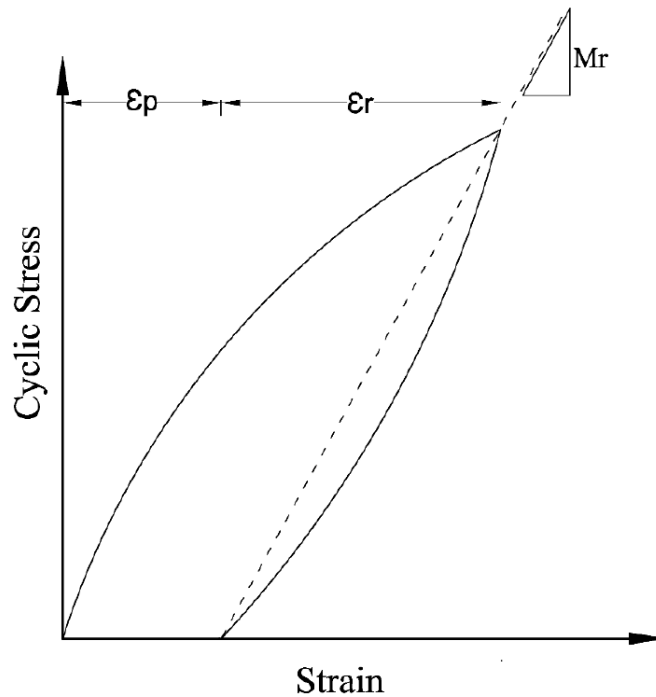


Figure 2-4 Definition of resilient modulus

2.4.2 Use of Resilient Modulus in AASHTO (1993) method

In the earlier versions of the AASHTO guide (1961 and 1972), subgrade is characterized through a parameter called soil support value (SSV). The soil support value (SSV) had a scale ranging from 1 to 10. The value 3 represented the natural soil used in the test bed at the AASHTO Road Test (George, K.P., 2003).

In the AASHTO (1993) flexible pavement design guide, resilient modulus (M_R) is used to characterize the unbound pavement materials (base, subbase and subgrade). Since resilient modulus (M_R) is a basic material property, it is preferred over the empirical soil support value (SSV). Using the resilient modulus (M_R), stresses and strains can be calculated in a multilayered pavement system. Also, the standard method of determining the resilient modulus (M_R) is prescribed in the AASHTO T-274 standard.

2.4.3 Correlation Equations of Resilient Modulus

AASHTO (1993) flexible pavement design guide has listed three different methods to determine the resilient modulus (M_R) value. The first method is to conduct laboratory testing. Second method is to back-calculate using FWD data. Third method is to

estimate subgrade resilient modulus (M_R) from correlations with other soil properties such as CBR.

In the laboratory, resilient modulus (M_R) can be obtained by conducting repeated load triaxial tests on undisturbed samples, according to harmonized test protocol, described in NCHRP1-28A standard (2).

Heukelom, W. & Klomp, A. (1962) developed the following correlation equation (2) to obtain resilient modulus (M_R) from standard California Bearing Ratio (CBR).

$$M_R(\text{psi}) = 1500 \text{ CBR} \quad (2)$$

Still, this correlation equation (2) has been widely used by many road agencies to obtain resilient modulus (M_R) from CBR value. This correlation is applicable for fine grained soils with a soaked CBR of 10 or less. AASHTO (1993) guide also recommends using this correlation equation (2) to estimate M_R , when the road agencies do not have the necessary equipment for performing triaxial test to obtain resilient modulus in the laboratory.

The Georgia Department of Transportation developed the following correlation (3) to estimate M_R value form CBR as long as soil used for CBR tests are within ± 1.5 % of optimum moisture condition. (George, K.P., 2003)

$$M_R(\text{psi}) = 3116 \text{ CBR}^a \quad (3)$$

where $a = 0.4779707$

2.5 Surface Modulus

Surface modulus is the weighted mean modulus of all the pavement layers including the subgrade. Surface modulus is calculated from surface deflections assuming an equivalent elastic half space using Boussinesq's equations. (Ullidtz 1987). The formula to calculate surface modulus directly under the point of loading using the maximum deflection D_0 is as follows:

$$SM_0 = \frac{2 * \sigma_0 * (1 - \mu^2) * a}{D_0} \quad (4)$$

Where,

- SM₀ - surface modulus of the total pavement response at the point of maximum deflection (D₀) (MPa)
- σ₀ - contact stress under the FWD loading plate (MPa)
- ν - Poisson's ratio (usually set at 0.35)
- a - radius of the loading plate (mm)
- D₀ - maximum deflection measured at center of loading plate (micron)

The general formula for surface modulus (SM_r) determined for any deflection (D_r) at any point r (in mm) away from the point of maximum deflection (D₀) is as follows.

$$SM_r = \frac{\sigma_0 * (1 - \mu^2) * a^2}{r * D_r} \quad (5)$$

Where,

- SM_r - surface modulus at a distance r (mm) from the center of the loading plate (Mpa)
- r - radial distance from the center of loading (mm)
- ν - Poisson's ratio (usually set at 0.35)
- a - radius of the loading plate (mm)
- D_r - deflection at distance r (mm)

2.5.1 Obtaining Subgrade Resilient Modulus from Surface Modulus

Surface modulus can be used to obtain subgrade resilient modulus (M_R) analytically using the surface deflections obtained from FWD test. When a load (P) is applied to the pavement, stresses are transferred from the top layers to the subgrade across the pavement layers (Figure 2-5). The zone of influence of stress due this load transfer can be assumed as a shape of cone of about 45 degrees. (Horak, E. ,2008).

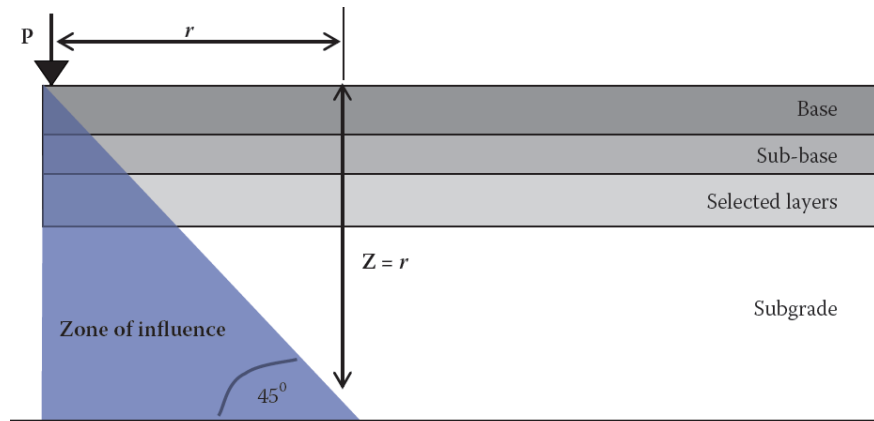


Figure 2-5 Influence zone due to pavement load (P)

The surface modulus, calculated at horizontal distance “r” away from the center of the load, is a representative of the compressed material, in the zone of influence below depth “z”. (Horak, E. ,2008). From the Figure 2-5, it can be seen that, at a distance “r” away from the center of the load, the zone of influence consists compressed materials only from subgrade. This means, “surface modulus” calculated at a sufficient distance “r” away from the center of the load, represents the influence of stresses, from subgrade only. Therefore, according to the above concept, “surface modulus” calculated at a sufficient distance away from the center of the load can be taken as the “Resilient Modulus of Subgrade”.

2.6 Deflection Bowl Parameters

One of the main advantage of the FWD device is that, its ability to measure the entire deflection bowl of a pavement, at various critical points up to 2m away from the center of loading point (Coetzee et al, 1989). (FWD device used in RDA (KUAB 50) can measure surface deflections up to 1.2m away from the center of loading point). The measurements of pavement deflection bowl using FWD data, lead researchers to define various deflection bowl parameters. Some of these deflection bowl parameters and their formula are summarized in Table 2-1.

Table 2-1 Deflection Bowl Parameters (Hoak et al,1989)

| Parameter | Formula | Structural indicator |
|------------------------------|---|---|
| 1 .Maximum deflection | D_0 as measured | Gives an indication of all structural layers with about 70% contribution by the subgrade |
| 2. Radius of Curvature (RoC) | $RoC = \frac{(L)^2}{2D_0(1-D_0/D_{200})}$ Where L=127mm in the Dehlen curvature meter and 200mm for the FWD | Gives an indication of the structural condition of the surfacing and base condition |
| 3.Base Layer Index (BLI) | $BLI = D_0 - D_{300}$ | Gives an indication of primarily the base layer structural condition |
| 4.Middle Layer Index (MLI) | $MLI = D_{300} - D_{600}$ | Gives an indication of the subbase and probably selected layer structural condition |
| 5. Lower Layer Index (LLI) | $LLI = D_{600} - D_{900}$ | Gives an indication of the lower structural layers like the selected and the subgrade layers |
| 6.Spreadability, S | $S = \frac{[(D_0 + D_1 + D_2 + D_3)/5]100}{D_0}$ Where D1, D2, D3 spaced at 300mm | Supposed to reflect the structural response of the whole pavement structure, but with weak correlations |
| 7. Area, A | $A = 6[1 + 2(D_1/D_0) + 2(D_2/D_0) + D_3/D_0]$ | The same as above |
| 8.Shape factors | $F_1 = (D_0 - D_2)/D_1$ $F_2 = (D_1 - D_3)/D_2$ | The F2 shape factor seemed to give better correlations with subgrade moduli while F1 gave weak correlations |
| 9. Slope of Deflection | $SD = \tan^{-1}(D_0 - D_{600})/600$ | Weak correlations observed |

2.7 AREA Parameter

AREA is one of the deflection bowl parameters that can be obtained using FWD data. It is used as an indicator of the stiffness of the whole pavement structure. It is obtained from the area under the deflection basin curve normalized with respect to the maximum deflection, D_0 . The AREA parameter was initially proposed by Hoffman and Thompson (1982) (Kasthurirangan et al., 2010). The AREA parameter is defined as:

$$\text{AREA} = 6 \left(1 + 2 \frac{D_{300}}{D_0} + 2 \frac{D_{600}}{D_0} + \frac{D_{900}}{D_0} \right) \quad (6)$$

Where,

AREA - Deflection Basin Area (in inches)
 $D_0, D_{300}, D_{600}, D_{900}$ - FWD deflections at $r=0, 300\text{mm}, 600\text{mm}$ and 900mm respectively.

The maximum AREA value cannot be greater than 36 inches (914 mm). It occurs when all four deflection measurements (D_0, D_{300}, D_{600} & D_{900}) are equal (“pavement interactive”, n.d.). To have all four deflection measurements equal, the pavement structure must be extremely stiff (like rigid pavement or full-depth HMA pavement).

The minimum AREA values occur when all the pavement layers have the same elastic modulus. (“pavement interactive”, n.d.). When the pavement structure above subgrade does not contribute any additional stiffness to the underlying subgrade, low AREA values can occur. This situation occurs very rarely for an actual pavement structures unless the pavement structure is highly cracked. Also, low AREA values indicate that the stiffness of the pavement structure is more or less same as the underlying subgrade material.

2.8 Effective structural number (SN_{eff}) of existing pavements

Evaluating the structural strength of an existing pavement is an essential part of overlay design, since, it helps to identify structural deficiency of the existing pavement. Structural deficiency is defined as any condition that reduces the load-carrying capacity of the pavement. The flexible pavement overlay design procedure presented in AASHTO (1993) guide has identified traffic loading and climatic conditions as the main factors that reduce the load-carrying capacity of a pavement. Thus, an overlay need to be designed in such a way that it increases the structural capacity of the existing pavement to withstand the estimated future traffic and climatic conditions over the design period.

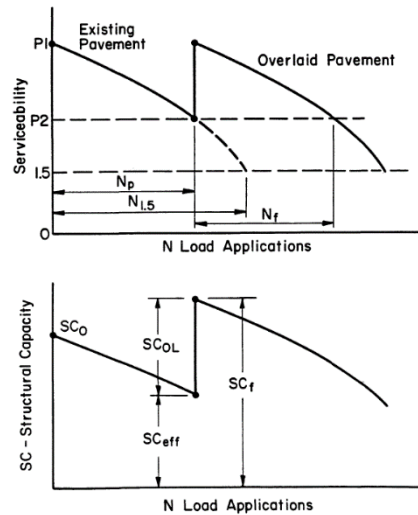


Figure 2-6 Structural Capacity Loss over time with Traffic

Figure 2-6 illustrates the concepts of structural capacity of a pavement at the various stages of its life time. The initial structural capacity of a new pavement is denoted as SC_0 . When the new pavement is opened to traffic its initial structural capacity (SC_0) declines over time. After some load applications (N_p), the initial structural capacity will decrease to SC_{eff} . SC_{eff} is the existing structural capacity of the pavement. At this stage, a total structural capacity of SC_f is required to restore the pavement to carry expected future traffic (N_f). Thus, the structural capacity an overlay (SC_{OL}) can be obtained by deducting SC_{eff} from SC_f ($SC_{OL} = SC_f - SC_{eff}$). This approach to overlay design is known as the structural deficiency approach. In AASHTO (1993) design guide, the existing structural capacity (SC_{eff}) of a flexible pavement is obtained from effective structural number (SN_{eff}). Thus, one of the objectives of overlay design using AASHTO 1993 guide with FWD testing is, to determine the effective structural number (SN_{eff}) of the existing pavement.

It should be noted that a low effective structural number (SN_{eff}) does not necessarily mean the pavement section requires a high overlay thickness, because if the pavement section has a good subgrade support and low traffic demand, it does not always require a high overlay thickness.

Chapter 3. METHODOLOGY OF STUDY

3.1 Methodology of AASHTO (1993) method

3.1.1 Overview of AASHTO (1993) Method

In the AASHTO (1993) method, resilient modulus (M_R) of subgrade and effective structural number (SN_{eff}) of the pavement are required to determine the overlay thickness. To determine resilient modulus (M_R) of subgrade and effective structural number (SN_{eff}) of the pavement, total pavement thickness and FWD data are required.

3.1.2 Determination of resilient modulus of subgrade (M_R) from AASHTO (1993) method

AASHTO (1993) guide states that, at sufficiently large distances away from the center of the load, FWD deflections measured at the pavement surface are due to subgrade deformation only. This concept permits back-calculation of the subgrade resilient modulus (M_R) from a single surface FWD deflection measurement, using the following equation given in AASHTO (1993) guide.

$$M_R = \frac{0.24p}{d_r r} \quad (7)$$

Where

- M_R - back-calculated subgrade resilient modulus, psi
- P - applied load, pounds
- d_r - deflection at a distance r from the center of the load, inches
- r - distance from center of load, inches

AASHTO (1993) guide states that no temperature correction is required for the deflection (d_r) in determining M_R since the deflection (d_r) occurs only due to subgrade deformation.

AASHTO (1993) guide specifies two criteria for the deflection (d_r) used to back-calculate subgrade resilient modulus (M_R). The first criteria is that, the deflection (d_r) must be measured far away from the load center so that it provides a good estimate of the subgrade modulus, independent of effects of any pavement layers above the subgrade. The second criteria is that, the deflection (d_r) must also be measured close

enough to load center so that the deflection (d_r) will not be too small to measure accurately. This means that, there should be a minimum distance from the center of the load to satisfy both criteria. AASHTO (1993) guide has specified this minimum distance from center of load (r), which can be determined from the following relationship (8) given in AASHTO (1993) guide.

$$r \geq 0.7a_e \quad (8)$$

where

$$a_e = \sqrt{\left[a^2 + \left(D \sqrt[3]{\frac{E_p}{M_R}} \right)^2 \right]}$$

- a_e - radius of the stress bulb at the subgrade-pavement interface, inches
- a - NDT load plate radius, inches
- D - total thickness of pavement layers above the subgrade, inches
- E_p - effective modulus of all pavement layers above the subgrade, psi
(refer equation (11))
- M_R - back-calculated subgrade resilient modulus, psi
- r - distance from center of load, inches

3.1.2.1 Determination of design subgrade resilient modulus (Design M_R) from AASHTO (1993) Method

To obtain design subgrade resilient modulus (design M_R), AASHTO (1993) guide recommends using a correction factor, ($C = 0.33$) for the back-calculated resilient modulus (M_R) value obtained from equation (7). The design subgrade resilient modulus (design M_R) can be obtained from the following relationship (9) given in the AASHTO (1993) guide.

$$\text{Design } M_R = C * \text{Backcalculated } M_R \quad (9)$$

Where,

- Design M_R - design subgrade resilient modulus, psi
- C - adjustment factor given in AASHTO (1993) guide (0.33)
- Back-calculated M_R - back-calculated subgrade resilient modulus, psi
(calculated from equation (7))

According to AASHTO (1993) guide, design subgrade resilient modulus (Design M_R) calculated from equation (9) should be used in the equation (12), to calculate structural number for future traffic (SN_f).

To account for outliers in field data, design subgrade resilient modulus (Design M_R) calculated from equation (9), is limited between a maximum value of 15,000 psi (CBR=10) and minimum value of 3000 psi (CBR=2). Accordingly, if the calculated design M_R is more than 15,000 psi for a particular chainage, the design M_R of that chainage should be taken as 15,000 psi. Also, if the calculated design M_R is less than 3000 psi, that value should be omitted from calculations and the location should be identified as a potential reconstruction section.

After treating the outliers in data as mentioned above, the design subgrade resilient modulus of a pavement, should be obtained from the average design subgrade resilient modulus value of that section.

3.1.3 Determination of effective structural number (SN_{eff}) from AASHTO (1993) method

AASHTO (1993) guide presents the following equation (10) to obtain effective structural number (SN_{eff}) of a pavement from the Nondestructive Testing (NDT) method. According to the equation (10), the existing structural capacity of a pavement is related to a number called effective structural number (SN_{eff}) and it is a function of total pavement thickness (D) and overall stiffness (E_p) of the pavement.

$$SN_{eff} = 0.0045 h_p \sqrt[3]{E_p} \quad (10)$$

Where,

SN_{eff} -effective structural number of the pavement

h_p -total thickness of pavement layers above the subgrade (inches)

E_p -effective modulus of pavement layers above subgrade (psi)

The total thickness of pavement layers above subgrade (h_p) can be obtained from a pavement investigation. Effective modulus of pavement layers above subgrade (E_p) can be obtained from the equation (11) given in the AASHTO (1993) guide.

$$d_0 = 1.5pa \left\{ \frac{1}{M_R \sqrt{1 + \left(\frac{h_p}{a} \sqrt[3]{\frac{E_p}{M_R}} \right)^2}} + \frac{\left[1 - \frac{1}{\sqrt{1 + \left(\frac{h_p}{a} \right)^2}} \right]}{E_p} \right\} \quad (11)$$

Where,

d_0 - deflection measured at the center of the load plate (adjusted to a standard temperature of 68°F) (inches)

h_p - total thickness of pavement layers above the subgrade (inches)

a - load plate radius, inches

M_R - subgrade resilient modulus

E_p - effective modulus of pavement layers above subgrade (psi)

3.1.3.1 Temperature Correction for AASHTO (1993) method

Although, AASHTO (1993) guide states that no temperature correction is required for determination of resilient modulus (M_R) value, temperature correction is required for determination of effective structural number (SN_{eff}).

The temperature correction procedure described in AASHTO (1993) guide is only applicable for the pavements with asphalt concrete (AC) surfaces more than 50 mm. Temperature correction is applied for the maximum FWD deflection (d_0). The corrected maximum FWD deflection (d_0) is used in equation (11) to obtain the effective modulus of pavement layers (E_p). Effective modulus of pavement layers (E_p) is used in equation (10) to determine the effective structural number (SN_{eff}) of pavement.

A set of curves, (Figure 3-1), is presented in the AASHTO (1993) guide to obtain an adjustment factor to correct the maximum deflection (d_0) measured at the test temperature to a standard temperature of 20°C (68°F).

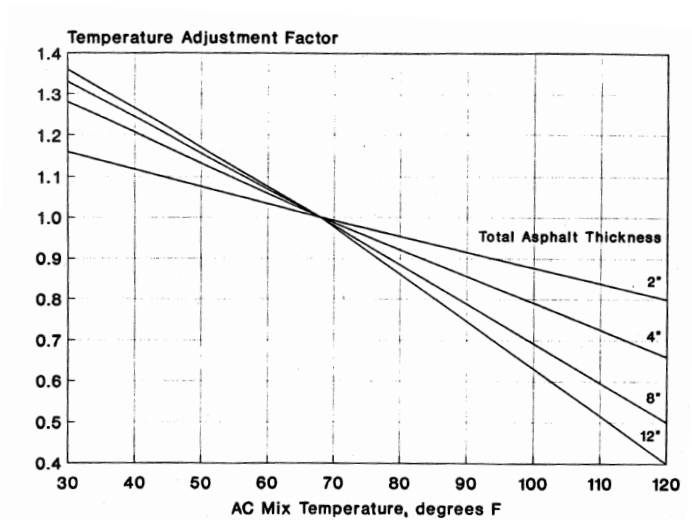


Figure 5.6. Adjustment to d_0 for AC Mix Temperature for Pavement with Granular or Asphalt-Treated Base

Figure 3-1 Temperature correction chart for d_0 given in AASHTO Guide

To obtain adjustment factor from the chart given in Figure 3-1, the total thickness of asphalt layer and its mid-depth temperature is required. Total thickness of the asphalt layer can be obtained from the pavement investigations and the mid-depth temperature of asphalt pavements are measured during the FWD testing. Using these two parameters, the temperature correction factor for the maximum FWD deflection (d_0) can be obtained from Figure 3-1.

3.1.4 Determination of required structural number for future traffic (SN_f) for AASHTO (1993) method

The required structural number for future traffic (SN_f) can be obtained from the following equation (12) presented in the AASHTO (1993) guide.

$$\log_{10} W_{18} = Z_R * S_0 + 9.36 * \log_{10}(SN + 1) - 0.20 + \frac{\log_{10} \left[\frac{\Delta PSI}{4.2 - 1.5} \right]}{0.40 + \frac{1094}{(SN + 1)^{5.19}}} + \log_{10} M_R - 8.07 \quad (12)$$

Where,

- SN - structural number required to carry future traffic (SN_f)
- W_{18} - estimated future traffic
- Z_R - based on reliability, Z_R can be obtained from section 4.2.3 of AASHTO (1993) guide
- R - reliability (section 2.1.3 of AASHTO (1993) guide)
- S_0 - overall standard deviation (section 2.1.3 of AASHTO (1993) guide)
- M_R - design subgrade resilient modulus
- ΔPSI - design serviceability loss (section 2.2.1 of AASHTO (1993) guide)

Of the above parameters, design subgrade resilient modulus (design M_R) can be obtained from the equation (7) using the deflection data from the FWD test. Future traffic for the design period (W_{18}) can be estimated from the traffic data. Other parameter can be obtained from referring to the relevant sections of the AASHTO (1993) guide, as mentioned in the description of terms of the equation (12).

3.1.5 Determination of overlay thickness from AASHTO (1993) method

After calculating, effective structural number (SN_{eff}) of the pavement as described in section 3.1.3 and structural number required to carry future traffic (SN_f) as described in section 3.1.4, the required asphalt overlay thickness to increase the structural capacity of existing pavement can be calculated from the following equation (13) given in the AASHTO (1993) guide.

$$T_{OL} = \frac{SN_{OL}}{a_{OL}} = \frac{SN_f - SN_{eff}}{a_{OL}} \quad (13)$$

Where,

T_{OL} -required thickness of asphalt overlay (inches)

SN_{OL} -required structural number of asphalt overlay

a_{OL} -structural layer coefficient of asphalt overlay (usually taken as 0.4)

SN_f -required structural number to carry future traffic

SN_{eff} -effective structural number of the existing pavement

3.2 Methodology of Simplified method

3.2.1 Overview of Simplified method

Although, the Simplified method has been developed based on AASHTO (1933) method, the methodology of Simplified method does not require the thickness of pavement layers to determine the overlay thickness as in AASHTO (1993) method. In the Simplified method, overlay thickness can be estimated using only FWD data.

In the Simplified method, resilient modulus (M_R) of subgrade is determined, from surface modulus (SM) method and effective structural number (SN_{eff}) of the pavement is determined using the method developed by Hoffman, M. S. (2003). However, to

obtain the corrected effective structural number (Corrected SN_{eff}) for Simplified method, a modification is done to Hoffman's method based on stiffness of the pavement.

3.2.2 Determination of resilient modulus (M_R) for Simplified method

The Simplified method proposed in this research, determines resilient modulus (M_R) of subgrade from surface modulus (SM) method. In surface modulus method, resilient modulus (M_R) of subgrade is determined from calculating surface modulus (SM) using equation (5) with FWD data.

Simplified method does not require the thickness of pavement layers to calculate resilient modulus (M_R) of subgrade as in AASHTO (1993) method. Also, in Simplified method, it is not required to check the minimum distance criteria (8) for the distance from center of load as specified in AASHTO (1993) method.

To obtain resilient modulus (M_R) of subgrade for the Simplified method, first, it is required to calculate the surface modulus (SM) using equation (5), for the sensor locations 300mm, 450mm, 600mm and 900mm with FWD data. The minimum surface modulus calculated from these sensor locations, is taken as the resilient modulus (M_R) of subgrade for the Simplified method. The reason for selecting the minimum surface modulus as the resilient modulus (M_R) of subgrade is, to follow a conservative approach for Simplified method.

It should be noted that, in the Simplified method, when calculating the resilient modulus (M_R) of subgrade, 200 mm and 1200 mm sensor locations are omitted, based on the recommendations given in AASHTO (1993) guide.

One of the recommendation in AASHTO (1993) guide states that the deflection used to back-calculate the resilient modulus (M_R), should be measured far away from center of the load so that it provides a good estimate of the subgrade modulus, independent of the effects of pavement layers above the subgrade. Since deflection sensor at

200mm is positioned too close to the load center, resilient modulus calculated at 200 mm will have the effects on upper pavement layers. Therefore, 200 mm deflection sensor is omitted, when calculating the resilient modulus (M_R) of subgrade for Simplified method.

Another recommendation in AASHTO (1993) guide states that the measured deflections used to back-calculate the resilient modulus (M_R), should not be too far away from center of the load so that deflections are not too small to measure accurately. Since, deflection sensor at 1200 mm is positioned too far away from center of the load, resilient modulus calculated at 1200 mm will have some estimation errors due to low deflection values measured at 1200 mm deflection sensor. Therefore, 1200 mm deflection sensor is also omitted, when calculating the resilient modulus (M_R) of subgrade for Simplified method.

3.2.2.1 Applicability of Surface Modulus method for calculating M_R in Simplified method

Before adopting the surface modulus method for calculating the resilient modulus (M_R) of subgrade for simplified method, it is required to check whether, the resilient modulus (M_R) value calculated from surface modulus method is reasonably match with resilient modulus values obtained from AASHTO (1993) method.

To compare the resilient modulus (M_R) values obtained from AASHTO (1993) method and surface modulus method, a data analysis is carried out for A001, A011, B133 and B212 road sections used in this research. Table 3-1 shows the four road sections used in the research.

Table 3-1 Road sections used in the research

| Road No | Road Name | Section | | Surface Type |
|---------|--|-----------|---------|------------------|
| | | From (km) | To (km) | |
| A001 | Colombo-Kandy | 59 | 100 | Asphalt concrete |
| A011 | Maradankadawela Habarana Tirikkondiadamadu | 0 | 5.3 | Asphalt concrete |
| B133 | Ganewalpola – Dachchahalmillewa | 0 | 45 | macadam |
| B212 | Kekirawa – Ganewalpola | 0 | 6.3 | macadam |

To do the data analysis for the comparison of resilient modulus (M_R) values obtained from AASHTO method and surface modulus method, first, 11 number of analysis sections are selected from the four road sections in Table 3-1. In the data analysis, average resilient modulus (M_R) value is calculated from AASHTO method and surface modulus method for each analysis section. After calculating the average resilient modulus (M_R) value from both methods, percentage difference of average resilient modulus (M_R) is calculated for each analysis section. Table 3-2 shows the 11 analysis sections and the percentage difference of average resilient modulus (M_R) values between AASHTO method and surface modulus method.

Table 3-2 Percentage difference of average M_R values between AASHTO method and Surface Modulus method

| Analysis Section | Road No | From (km) | To (km) | Average M_R (psi) | | Percentage Difference |
|------------------|---------|-----------|---------|---------------------|------------------------|-----------------------|
| | | | | AASHTO Method | Surface Modulus Method | |
| 1 | A001 | 59 | 69 | 24,463 | 26,449 | 8% |
| 2 | A001 | 69 | 79 | 21,577 | 23,852 | 11% |
| 3 | A001 | 79 | 89 | 23,016 | 25,249 | 10% |
| 4 | A001 | 89 | 100 | 23,444 | 24,335 | 4% |
| 5 | A011 | 0 | 5.3 | 22,459 | 24,413 | 9% |
| 6 | B133 | 0 | 10 | 30,201 | 33,077 | 10% |
| 7 | B133 | 10 | 20 | 26,634 | 29,437 | 11% |
| 8 | B133 | 20 | 30 | 17,232 | 19,415 | 13% |
| 9 | B133 | 30 | 40 | 18,074 | 20,755 | 15% |
| 10 | B133 | 40 | 45 | 13,705 | 15,989 | 17% |
| 11 | B212 | 0 | 6.3 | 29,173 | 27,532 | -6% |

From Table 3-2, it can be observed that percentage difference of average subgrade resilient modulus (M_R) values between AASHTO method and Surface Modulus method is less than 15% for all the analysis sections except for the analysis section-9. Therefore, it is decided to adopt the surface modulus method for calculating subgrade resilient modulus (M_R) for simplified method.

3.2.2.2 Determination of design subgrade resilient modulus (Design M_R) for Simplified method

After obtaining subgrade resilient modulus for Simplified method as described in section 3.2.2, to obtain design subgrade resilient modulus (design M_R), the equation (9) given in AASHTO (1993) guide is used. The method of obtaining design subgrade resilient modulus (design M_R) from AASHTO (1993) guide is described in section 3.1.2.1.

3.2.3 Determination of effective structural number (SN_{eff}) for Simplified method

The simplified method proposed in this research, determines the effective structural number (SN_{eff}) of pavement based on the method proposed by Hoffman, M. S. (2003).

3.2.3.1 Determination of effective structural number (SN_{eff}) from Hoffman's Method

In his research, Hoffman, M. S. (2003) proposed a method to calculate effective structural number (SN_{eff}) of the pavement, defined in the AASHTO (1993) guide, without using thickness of the pavement layers. Hoffman, M. S. (2003) developed his methodology based on Hogg model. There are two parameters defined in the Hogg model called, pavement rigidity (D) and characteristic length (l_0). These parameters are defined in the Hogg model based on the following assumptions,

1. In the Hogg model, pavement structure is modelled as a thin slab resting on a subgrade with a stiff bottom located at certain distance.
2. It is assumed that no deflection will take part in the slab due to loading.

Figure 3-2 shows the Hogg model geometry used to define Hogg model parameters.

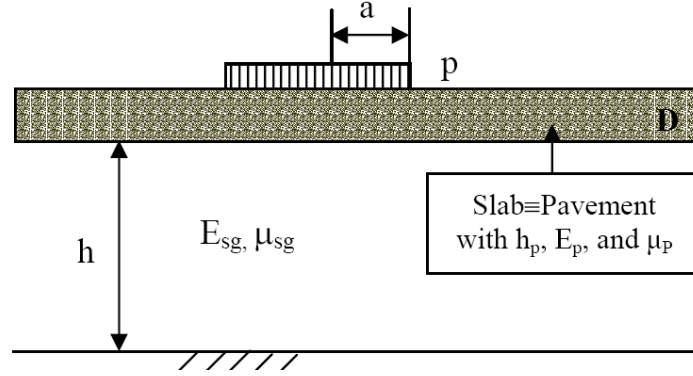


Figure 3-2 Hog model geometry

Hogg model parameter, pavement rigidity (D) is defined as follows.

$$D = \frac{E_p h_p^3}{12(1 - \mu_p^2)} \quad (14)$$

Where

- D - pavement rigidity (flexural stiffness of the pavement)
- h_p - total thickness of pavement layers above the subgrade
- E_p - effective modulus of pavement layers above subgrade
- μ_p - Poisson's ratio of pavement

Hogg model parameter, characteristic length (l_0) is defined as follows.

$$l_0 = \sqrt[3]{\frac{D}{M_R} * \frac{(1 + \mu_{sg})(3 - 4\mu_{sg})}{2(1 - \mu_{sg})}} \quad (15)$$

Where

- l_0 - characteristic length
- D - pavement rigidity
- M_R - resilient modulus of subgrade
- μ_p - Poisson's ratio of pavement
- μ_{sg} - Poisson's ratio of subgrade

Hoffman modified the AASHTO SN_{eff} equation (10) using the Hogg model parameters. After incorporating the values of $\mu_p=0.25$ and $\mu_{sg}=0.5$ in Hogg model parameter equations (14) and (15) and making proper substitutions in AASHTO SN_{eff} equation (10), Hoffman modified the AASHTO SN_{eff} equation as follows:

$$SN_{eff} = 0.182 l_0 \sqrt[3]{M_R} \quad (16)$$

Where

SN_{eff} - effective structural number of the pavement

l_0 - characteristic length (in cm)

M_R - resilient modulus of subgrade (in Mpa)

From the equation (16), it can be understood that, effective structural number of the pavement (SN_{eff}) is not a direct function of total pavement thickness anymore. Using the equation (16), effective structural number of the pavement (SN_{eff}) can be determined using characteristic length (l_0) and subgrade resilient modulus (M_R).

Resilient modulus (M_R) of subgrade required in equation (16) can be obtained using the method discussed in section 3.2.2 of this report. To obtain characteristic length (l_0) for the equation (16), Hoffman, M. S. (2003) developed the following relationship (17) using FWD AREA parameter from curve fitting techniques,

$$l_0 = A \times e^{B \times AREA} \quad (17)$$

Where

l_0 - characteristic length (in cm)

AREA - FWD area parameter as defined in following equation (6)

$$AREA = 6 \left(1 + 2 \frac{D_{300}}{D_0} + 2 \frac{D_{600}}{D_0} + \frac{D_{900}}{D_0} \right)$$

A,B - Regression coefficients given in Table 3-3

AREA values, required for equation (17) can be calculated using the equation (6) with FWD data. Using the calculated AREA values, regression coefficients A and B can be obtained from the Table 3-3, proposed by Hoffman, M. S. (2003).

Table 3-3 Regression coefficients for calculation of l_o

| Range of Area Values (inches) | A | B |
|-------------------------------|-------|--------|
| AREA \geq 23.0 | 3.275 | 0.1039 |
| 21.0 \leq AREA < 23.0 | 3.691 | 0.0948 |
| 19.0 \leq AREA < 21.0 | 2.800 | 0.1044 |
| AREA < 19.0 | 2.371 | 0.1096 |

3.2.3.2 Temperature correction for Hoffman's Method

In his research paper, Hoffman, M. S. (2003) has proposed applying a temperature correction for SN_{eff} values calculated using the equation (16), to a standard temperature $30^{\circ}C$, using the following equation (18),

$$\frac{SN_T}{SN_{30}} = 1.33 - 0.011 \times T \quad (18)$$

Where

SN_T - effective structural number calculated at any AC temperature (from equation (16))

SN_{30} - effective structural number corrected at AC base temperature of $30^{\circ}C$

T - asphalt concrete temperature in $^{\circ}C$ at a depth of 5 cm

Temperature correction in Hoffman method is only applicable for asphalt pavements.

3.2.3.3 Corrected effective structural number (Corrected SN_{eff}) in Hoffman's Method

After obtaining effective structural number (SN_{eff}) from equation (16) and applying the temperature correction using equation (18), Hoffman compared the SN_{eff} values obtaining from his method with the SN_{eff} values obtaining from AASHTO (1993) method. He observed that SN_{eff} values obtaining from his method under-estimates the SN_{eff} values obtaining from AASHTO (1993) method. This happened because of the assumptions of the Hogg model (refer section 3.2.3.1) used to derive the SN_{eff} equation (16) in Hoffman's method. Therefore, to match with SN_{eff} vales obtained from AASHTO (1993) method, Hoffman introduced a correction for his SN_{eff} equation ((16) as follows:

$$\text{Corrected } SN_{eff} = 2 SN_{30} - 0.5 \quad (19)$$

Where

Corrected SN_{eff} - Corrected effective structural number
 SN_{30} - Effective structural number corrected for AC base temperature of 30⁰C (obtained from equation (18))

3.2.3.4 Applicability of Hoffman’s Method to calculate SN_{eff} in Simplified

Method

Before adopting the Hoffman’s method for calculating the effective structural number of pavement (SN_{eff}) for simplified method, it is required to check whether, the effective structural number (SN_{eff}) value, calculated from Hoffman’s method is reasonably agree with effective structural number (SN_{eff}) values obtained from AASHTO (1993) method.

In order to fulfil the above requirement, a data analysis is carried out to compare the effective structural number (SN_{eff}) obtained from Hoffman’s method with AASHTO (1993) method. First, 18 number of analysis sections are selected from the four road sections in Table 3-1. Then, effective structural number (SN_{eff}) is calculated from Hoffman’s method and AASHTO method for each analysis section. The effective structural number (SN_{eff}) of an analysis section is calculated from the 15th percentile SN_{eff} value. After calculating the 15th percentile SN_{eff} value from both methods, percentage difference of 15th percentile SN_{eff} value is calculated for each analysis section. Table 3-4 shows the 18 analysis sections and the percentage difference of 15th percentile SN_{eff} values between AASHTO Method and Hoffman’s Method.

Table 3-4 Percentage difference of SN_{eff} values between AASHTO (1993) Method and Hoffman's Method

| Analysis Section | Road No | From (km) | To (km) | 15 th percentile SN_{eff} | | Percentage Difference |
|------------------|---------|-----------|---------|--|------------------|-----------------------|
| | | | | AASHTO Method | Hoffman's Method | |
| 1 | A001 | 59 | 65.5 | 3.53 | 3.11 | -12% |
| 2 | A001 | 65.5 | 69 | 3.46 | 2.75 | -21% |
| 3 | A001 | 69 | 79 | 3.91 | 3.15 | -19% |
| 4 | A001 | 79 | 79.6 | 4.66 | 3.73 | -20% |
| 5 | A001 | 79.6 | 85.4 | 4.47 | 3.63 | -19% |
| 6 | A001 | 85.4 | 85.8 | 4.91 | 4.39 | -11% |
| 7 | A001 | 85.8 | 88.2 | 4.37 | 3.54 | -19% |
| 8 | A001 | 88.2 | 88.6 | 5.35 | 5.38 | 1% |
| 9 | A001 | 89 | 91.7 | 4.10 | 3.18 | -22% |
| 10 | A001 | 91.7 | 92.3 | 4.81 | 4.99 | 4% |
| 11 | A001 | 92.3 | 100 | 4.38 | 3.34 | -24% |
| 12 | A011 | 0 | 5.3 | 2.71 | 3.22 | 19% |
| 13 | B133 | 0 | 10 | 1.23 | 1.85 | 50% |
| 14 | B133 | 10 | 20 | 1.17 | 1.61 | 38% |
| 15 | B133 | 20 | 30 | 0.97 | 1.33 | 37% |
| 16 | B133 | 30 | 40 | 0.90 | 1.49 | 66% |
| 17 | B133 | 40 | 45 | 0.84 | 1.46 | 74% |
| 18 | B212 | 0 | 6.3 | 1.03 | 1.30 | 26% |

From Table 3-4, it can be observed that, for most of the analysis sections, percentage difference of 15th percentile SN_{eff} value between AASHTO method and Hoffman's method is more than 15%. Therefore, it is decided to do a modification for Hoffman's method to reduce the percentage difference within 15% of AASHTO method.

3.2.3.5 Modification of Hoffman's Method

The basis for modification of Hoffman's method is the stiffness of pavement. Therefore, as the first step in modification of Hoffman's method, it is required to identify a method to characterize the stiffness of a pavement. In the section 2.7 of this report, it is mentioned that AREA parameter, calculated using FWD data, can be used to characterize the stiffness of a pavement. Therefore, it is decided to use the AREA parameter method to characterize the stiffness of a pavement.

After characterizing the stiffness of a pavement with AREA parameter, the next step is to define the stiffness categories of a pavement based on range of AREA parameter values. In his research, Hoffman, M. S. (2003) developed a regression coefficient table (Table 3-3) based on range of AREA parameter values. Consequently, in this research,

it is decided to use the same range of AREA parameter values given in Hoffman's regression coefficients table (Table 3-3) to define four stiffness categories for a pavement. Table 3-5 shows the Hoffman's regression coefficient table with new four pavement stiffness categories (defined in this research) added to it as a new additional column.

Table 3-5 Pavement stiffness categories added to Hoffman's regression coefficient table as a new additional column

| Range of Area Values (inches) | A | B | Pavement Stiffness Category |
|-------------------------------|-------|--------|-----------------------------|
| AREA \geq 23.0 | 3.275 | 0.1039 | Very High |
| 21.0 \leq AREA < 23.0 | 3.691 | 0.0948 | High |
| 19.0 \leq AREA < 21.0 | 2.800 | 0.1044 | Low |
| AREA < 19.0 | 2.371 | 0.1096 | Very Low |

To obtain the stiffness category of a pavement section, first, the average AREA value of the pavement section should be calculated using equation (6). Based on the average AREA value of the pavement section, the relevant stiffness category of the pavement section can be identified from Table 3-5.

3.2.3.6 Method used for modification of Hoffman's Method

In his research, Hoffman M.S. (2006) introduced the corrected SN_{eff} equation (19) to correct the effective structural number obtained from his method to match with effective structural number obtained from AASHTO (1993) method. Table 3-6 shows the pavement stiffness categories and the Hoffman's corrected SN_{eff} equation. However, from Table 3-6, it can be observed that the Hoffman's corrected SN_{eff} equation (19), is same for all the stiffness categories of the pavement. Therefore, it is decided to change the Hoffman's corrected SN_{eff} equation (19) based on the stiffness categories of the pavement, as the method for modification of Hoffman's method.

Table 3-6 Stiffness categories and Hoffman's corrected SN_{eff} equation

| Range of Area Values (inches) | Pavement Stiffness Category | Hoffman's corrected SN_{eff} Equation |
|-------------------------------|-----------------------------|---|
| $AREA \geq 23.0$ | Very High | $2 SN_{30}^{-0.5}$ |
| $21.0 \leq AREA < 23.0$ | High | $2 SN_{30}^{-0.5}$ |
| $19.0 \leq AREA < 21.0$ | Low | $2 SN_{30}^{-0.5}$ |
| $AREA < 19.0$ | Very Low | $2 SN_{30}^{-0.5}$ |

3.2.3.7 Data analysis for modification of Hoffman's method

To perform the data analysis for modification of Hoffman's corrected SN_{eff} equation (19), first, the average AREA value is calculated for each analysis section in Table 3-4, using equation (6). The average AREA values is used to define the stiffness category of each analysis section. Table 3-7 shows the stiffness category, assigned for each analysis section and the percentage difference between 15th percentile SN_{eff} values obtained from AASHTO (1993) method and Hoffman's method for each analysis section.

Table 3-7 Percentage difference of SN_{eff} values between AASHTO (1993) method and Hoffman's method

| Analysis Section | Road No | From (km) | To (km) | Average AREA Value | Pavement Stiffness Category | 15 th percentile SN_{eff} | | Percentage Difference | Hoffman's corrected SN_{eff} equation |
|------------------|---------|-----------|---------|--------------------|-----------------------------|--|------------------|-----------------------|---|
| | | | | | | AASHTO Method | Hoffman's Method | | |
| 6 | A001 | 85.4 | 85.8 | 23.4 | very high | 4.91 | 4.39 | -11% | $2 SN_{30}^{-0.5}$ |
| 8 | A001 | 88.2 | 88.6 | 23.3 | very high | 5.35 | 5.38 | 1% | $2 SN_{30}^{-0.5}$ |
| 10 | A001 | 91.7 | 92.3 | 23.2 | very high | 4.81 | 4.99 | 4% | $2 SN_{30}^{-0.5}$ |
| | | | | | | | | | |
| 3 | A001 | 69 | 79 | 21.0 | high | 3.91 | 3.15 | -19% | $2 SN_{30}^{-0.5}$ |
| 5 | A001 | 79.6 | 85.4 | 21.8 | high | 4.47 | 3.63 | -19% | $2 SN_{30}^{-0.5}$ |
| 7 | A001 | 85.8 | 88.2 | 21.1 | high | 4.37 | 3.54 | -19% | $2 SN_{30}^{-0.5}$ |
| 9 | A001 | 89 | 91.7 | 21.1 | high | 4.10 | 3.18 | -22% | $2 SN_{30}^{-0.5}$ |
| 11 | A001 | 92.3 | 100 | 21.3 | high | 4.38 | 3.34 | -24% | $2 SN_{30}^{-0.5}$ |
| | | | | | | | | | |
| 1 | A001 | 59 | 65.5 | 20.5 | low | 3.53 | 3.11 | -12% | $2 SN_{30}^{-0.5}$ |
| 2 | A001 | 65.5 | 69 | 20.1 | low | 3.46 | 2.75 | -21% | $2 SN_{30}^{-0.5}$ |
| 4 | A001 | 79 | 79.6 | 20.4 | low | 4.66 | 3.73 | -20% | $2 SN_{30}^{-0.5}$ |
| | | | | | | | | | |
| 12 | A011 | 0 | 5.3 | 18.9 | very low | 2.71 | 3.22 | 19% | $2 SN_{30}^{-0.5}$ |
| 13 | B133 | 0 | 10 | 13.7 | very low | 1.23 | 1.85 | 50% | $2 SN_{30}^{-0.5}$ |
| 14 | B133 | 10 | 20 | 15.7 | very low | 1.17 | 1.61 | 38% | $2 SN_{30}^{-0.5}$ |
| 15 | B133 | 20 | 30 | 15.2 | very low | 0.97 | 1.33 | 37% | $2 SN_{30}^{-0.5}$ |
| 16 | B133 | 30 | 40 | 14.9 | very low | 0.90 | 1.49 | 66% | $2 SN_{30}^{-0.5}$ |
| 17 | B133 | 40 | 45 | 12.2 | very low | 0.84 | 1.46 | 74% | $2 SN_{30}^{-0.5}$ |
| 18 | B212 | 0 | 6.3 | 13.0 | very low | 1.03 | 1.30 | 26% | $2 SN_{30}^{-0.5}$ |

From Table 3-7, it can be observed that the percentage difference is less than 15% for all the analysis sections tabulated under “very high” pavement stiffness category. Therefore, it is decided not to modify Hoffman's corrected SN_{eff} equation (19) for “very high” pavement stiffness category

However, for “high”, “low” and “very low” stiffness categories, percentage difference is more than 15% for all the analysis sections except for one analysis section in A001 road. Therefore, it is decided to modify Hoffman's corrected SN_{eff} equation (19) for “high”, “low” and “very low” stiffness categories.

Table 3-8 Modified corrected SN_{eff} equations used in Simplified method

| Range of Area Values (inches) | Pavement Stiffness Category | Modified corrected SN_{eff} Equation |
|-------------------------------|-----------------------------|--|
| $21.0 \leq AREA < 23.0$ | High | $2 SN_{30}$ |
| $19.0 \leq AREA < 21.0$ | Low | $2 SN_{30}$ |
| $AREA < 19.0$ | Very Low | $2 SN_{30} - 1.0$ |

Table 3-8 shows the modified SN_{eff} equations obtained for “high”, “low” and “very low” stiffness categories using trial and error method with Excel data analysis. These modified corrected SN_{eff} equations are used to obtain corrected SN_{eff} for Simplified method based on stiffness category of the pavement section.

Table 3-9 Percentage difference of SN_{eff} values between AASHTO (1993) method and Hoffman’s method with modified corrected SN_{eff} equations

| Analysis Section | Road No | From (km) | To (km) | Average AREA Value | Pavement Stiffness Category | 15 th percentile SN_{eff} | | Percentage Difference | Modified corrected SN_{eff} equation |
|------------------|---------|-----------|---------|--------------------|-----------------------------|--|---|-----------------------|--|
| | | | | | | AASHTO Method | Hoffman's Method with modified corrected SN_{eff} equations | | |
| 3 | A001 | 69 | 79 | 21.0 | high | 3.91 | 3.65 | -6.6% | $2 SN_{30}$ |
| 5 | A001 | 79.6 | 85.4 | 21.8 | high | 4.47 | 4.13 | -7.6% | $2 SN_{30}$ |
| 7 | A001 | 85.8 | 88.2 | 21.1 | high | 4.37 | 4.04 | -7.6% | $2 SN_{30}$ |
| 9 | A001 | 89 | 91.7 | 21.1 | high | 4.10 | 3.68 | -10.2% | $2 SN_{30}$ |
| 11 | A001 | 92.3 | 100 | 21.3 | high | 4.38 | 3.84 | -12.3% | $2 SN_{30}$ |
| 1 | A001 | 59 | 65.5 | 20.5 | low | 3.53 | 3.61 | 2.3% | $2 SN_{30}$ |
| 2 | A001 | 65.5 | 69 | 20.1 | low | 3.46 | 3.25 | -6.1% | $2 SN_{30}$ |
| 4 | A001 | 79 | 79.6 | 20.4 | low | 4.66 | 4.23 | -9.2% | $2 SN_{30}$ |
| 12 | A011 | 0 | 5.3 | 18.9 | very low | 2.71 | 2.72 | 0.4% | $2 SN_{30} - 1.0$ |
| 13 | B133 | 0 | 10 | 13.7 | very low | 1.23 | 1.35 | 9.8% | $2 SN_{30} - 1.0$ |
| 14 | B133 | 10 | 20 | 15.7 | very low | 1.17 | 1.11 | -5.1% | $2 SN_{30} - 1.0$ |
| 15 | B133 | 20 | 30 | 15.2 | very low | 0.97 | 0.83 | -14.4% | $2 SN_{30} - 1.0$ |
| 16 | B133 | 30 | 40 | 14.9 | very low | 0.90 | 0.99 | 10.0% | $2 SN_{30} - 1.0$ |
| 17 | B133 | 40 | 45 | 12.2 | very low | 0.84 | 0.96 | 14.3% | $2 SN_{30} - 1.0$ |
| 18 | B212 | 0 | 6.3 | 13.0 | very low | 1.03 | 0.80 | -22.3% | $2 SN_{30} - 1.0$ |

Table 3-9 shows the percentage difference between 15th percentile SN_{eff} values obtained from AASHTO method and Hoffman’s method (using modified corrected SN_{eff} equations in Table 3-8) for analysis sections in “high”, “low” and “very low” stiffness categories.

From Table 3-9, it can be observed that percentage difference of 15th percentile SN_{eff} values is less than 15% for all the analysis sections except for one analysis section in B212 road. Therefore, it is decided to adopt the equations given in Table 3-8 as the corrected SN_{eff} equation for Simplified method. Table 3-10 summarizes the Hoffman's corrected SN_{eff} equations and modified corrected SN_{eff} equations (used in Simplified method).

Table 3-10 Hoffman's corrected SN_{eff} equations and modified corrected SN_{eff} equations

| Range of Area Values (inches) | Pavement Stiffness Category | Hoffman's corrected SN_{eff} Equations | Modified corrected SN_{eff} Equations (used in Simplified method) |
|-------------------------------|-----------------------------|--|---|
| $AREA \geq 23.0$ | Very High | $2 SN_{30-0.5}$ | $2 SN_{30-0.5}$ |
| $21.0 \leq AREA < 23.0$ | High | $2 SN_{30-0.5}$ | $2 SN_{30}$ |
| $19.0 \leq AREA < 21.0$ | Low | $2 SN_{30-0.5}$ | $2 SN_{30}$ |
| $AREA < 19.0$ | Very Low | $2 SN_{30-0.5}$ | $2 SN_{30-1.0}$ |

3.2.4 Determination of required structural number for future traffic (SN_f) for Simplified method

The equation (12) presented in AASHTO (1993) guide is used in Simplified method also to obtain the required structural number for future traffic (SN_f). All the parameters used in the equation (12) are same, except the design subgrade resilient modulus (design M_R) is obtained from the method specified in section 3.2.2.

3.2.5 Determination of overlay thickness for Simplified method

After calculating, effective structural number (SN_{eff}) of the pavement as described in section 3.2.3 and structural number required to carry future traffic (SN_f) as described in section 3.2.4, the required asphalt overlay thickness for Simplified method can be obtained following the AASHTO (1993) method, described in section 3.1.5.

Chapter 4. DATA ANALYSIS

4.1 Introduction

Data analysis is carried out to obtain overlay thickness for the four road sections, (A001, A011, B133 and B212) from AASHTO (1993) method and Simplified method. The overlay thickness calculated from the two methods are compared with the overlay thickness given in the design reports. To compare the results easily with the design report, same road sections given in the design reports are used to calculate overlay thickness from AASHTO (1993) method and Simplified method. The road sections used in the design reports are given in Table 4-1.

Table 4-1 Road sections used in the design reports

| Road No | Road Name | Section | | Surface Type |
|---------|--|-----------|---------|------------------|
| | | From (km) | To (km) | |
| A001 | Colombo-Kandy | 59 | 100 | Asphalt concrete |
| A011 | Maradankadawela Habarana Tirikkondiadimadu | 0 | 1.5 | Asphalt concrete |
| A011 | Maradankadawela Habarana Tirikkondiadimadu | 1.5 | 5.3 | Asphalt concrete |
| B133 | Ganewalpola – Dachchahalmillewa | 0 | 21 | macadam |
| B133 | Ganewalpola – Dachchahalmillewa | 21 | 45.8 | macadam |
| B212 | Kekirawa – Ganewalpola | 0 | 6.95 | macadam |

Stiffness category of the road sections are obtained from Table 3-5, after calculating the average AREA value of the road section. Stiffness category of the road sections are given in Table 4-2.

Table 4-2 Stiffness category of road sections

| Road No | Section | Average AREA value | Stiffness Category |
|---------|------------------|--------------------|--------------------|
| A001 | 59 km to 100 km | 21.1 | High |
| A011 | 0 to 1.5 km | 18.1 | Very Low |
| A011 | 1.5 km to 5.3 km | 19.2 | Low |
| B133 | 0 to 21 km | 16.0 | Very Low |
| B133 | 21 km to 45.8 km | 14.0 | Very Low |
| B212 | 0 to 6.95 km | 13.7 | Very Low |

4.2 Calculation of overlay thickness for A001 Road

The road section selected for the overlay design of Colombo-Kandy (A001) road is from 59 km to 100 km. FWD test has been carried out at 50 m interval. The pavement section consists of asphalt surface about 120 mm average thickness and the average total pavement thickness is about 500 mm.

The overlay thickness calculated using AASHTO (1993) method and Simplified method is compared with the overlay thickness given in the design report. In the design report, overlay design has been carried out according to AASHTO (1993) method for a one road section from 59 km to 100 km. Also, in the design report, design subgrade resilient modulus (Design M_R) for AASHTO (1993) method has been obtained from field CBR data.

FWD data, extracts of pavement design report of A001 road, parameters of AASHTO (1993) guide and calculation sheets used for determination of overlay thickness from AASHTO (1993) method and Simplified method for A001 road, is attached in annex-1.

Table 4-3 shows the results of design subgrade resilient modulus (Design M_R), effective structural number of pavement (SN_{eff}) and overlay thickness obtained from AASHTO (1993) method, Simplified method and design report.

Table 4-3 M_R , SN_{eff} and overlay thickness results of A001 road

| Analysis Method | Section | M_R (psi) | SN_{eff} | SN_f | Required overlay thickness (mm) | Design overlay thickness (mm) |
|----------------------|--------------|----------------|------------|--------|------------------------------------|----------------------------------|
| Design report | 59 km-100 km | 9,000 | 3.75 | 5.08 | 84 | 100 |
| AASHTO (1993) method | 59 km-100 km | 7,715 | 4.00 | 5.34 | 85 | 100 |
| Simplified method | 59 km-100 km | 8,318 | 3.66 | 5.21 | 98 | 100 |

4.3 Calculation of overlay thickness for A011 Road

The road section selected for the overlay design of Maradankadawela-Habarana-Tirikkondiadimadu (A011) road is from 0 to 5.3 km. FWD test has been carried out at

50 m interval. The pavement section consists of asphalt surface about 160 mm average thickness and the average total pavement thickness is about 210 mm.

The overlay thickness calculated using AASHTO (1993) method and Simplified method is compared with the overlay thickness given in the design report. In the design report, overlay design has been carried out according to AASHTO (1993) method for two road section from 0 to 1.5 km and 1.5 km to 5.3 km. Also, in the design report, design subgrade resilient modulus (Design M_R) for AASHTO (1993) method has been obtained from field CBR data.

FWD data, extracts of pavement design report of A011 road, parameters of AASHTO (1993) guide and calculation sheets used for determination of overlay thickness from AASHTO (1993) method and Simplified method for A011 road, is attached in annex-2.

Table 4-4 shows the results of design subgrade resilient modulus (Design M_R), effective structural number of pavement (SN_{eff}) and overlay thickness obtained from AASHTO (1993) method, Simplified method and design report.

Table 4-4 M_R , SN_{eff} and overlay thickness results of A011 road

| Analysis Method | Section | M_R (psi) | SN_{eff} | SN_f | Required overlay thickness (mm) | Design overlay thickness (mm) |
|----------------------|---------------|----------------|------------|--------|------------------------------------|----------------------------------|
| Design report | 0 km-1.5 km | 10,500 | 2.40 | 4.04 | 104 | 105 |
| | 1.5 km-5.3 km | 12,000 | 2.40 | 3.85 | 92 | 100 |
| AASHTO (1993) method | 0 km-1.5 km | 8,091 | 2.65 | 4.44 | 114 | 115 |
| | 1.5 km-5.3 km | 7,236 | 2.74 | 4.61 | 119 | 120 |
| Simplified method | 0 km-1.5 km | 8,928 | 2.58 | 4.29 | 109 | 110 |
| | 1.5 km-5.3 km | 7,811 | 3.73 | 4.49 | 48 | 100 |

4.4 Calculation of overlay thickness for B133 Road

The road section selected for the overlay design of Ganewalpola-Dachchahalmillewa (B133) road is from 0 to 45.8 km. FWD test has been carried out at 250 m interval. The pavement section consists of macadam surface about 150 mm average thickness and the average total pavement thickness is about 150 mm.

The overlay thickness calculated using AASHTO (1993) method and Simplified method is compared with the overlay thickness given in the design report. In the design report, overlay design has been carried out according to Road Note 31 (RN31) method, for two road section from 0 to 21 km and 21 km to 45.8 km. Also, in the design report, existing strength of the pavement has been evaluated using the SN_{eff} method given in AASHTO (1993) guide with FWD data.

FWD data, extracts of pavement design report of B133 road, parameters of AASHTO (1993) guide and calculation sheets used for determination of overlay thickness from AASHTO (1993) method and Simplified method for B133 road, is attached in annex-3.

Table 4-5 shows the results of design subgrade resilient modulus (Design M_R), effective structural number of pavement (SN_{eff}) and overlay thickness obtained from AASHTO (1993) method, Simplified method and design report.

Table 4-5 M_R , SN_{eff} and overlay thickness results of B133 road

| Analysis Method | Chainage | M_R (psi) | SN_{eff} | SN_f | Required overlay thickness (mm) | Design overlay thickness | |
|----------------------|---------------|----------------|------------|--------|------------------------------------|--------------------------|----------|
| | | | | | | AC (mm) | ABC (mm) |
| Design report | 0-21 km | 10,500 | 1.16 | 3.76 | 165 | 50 | 200 |
| | 21 km-45.8 km | 12,000 | 0.92 | 3.57 | 168 | 50 | 180 |
| AASHTO (1993) method | 0-21 km | 9,454 | 1.54 | 3.91 | 150 | 100 | 150 |
| | 21 km-45.8 km | 5,430 | 1.19 | 4.75 | 226 | 100 | 375 |
| Simplified method | 0-21 km | 10,268 | 1.55 | 3.79 | 142 | 100 | 150 |
| | 21 km-45.8 km | 6,135 | 1.13 | 4.56 | 218 | 100 | 350 |

4.5 Calculation of overlay thickness for B212 Road

The road section selected for the overlay design of Kekirawa-Ganewalpole (B212) is from 0 to 6.95 km. FWD test has been carried out at 50 m interval. The pavement section consists of macadam surface about 150 mm average thickness and the average total pavement thickness is about 150 mm.

The overlay thickness calculated using AASHTO (1993) method and Simplified method is compared with the overlay thickness given in the design report. In the design report, overlay design has been carried out according to Road Note 31 (RN31) method,

for one road section from 0 to 6.95 km. Also, in the design report, existing strength of the pavement has been evaluated using the SN_{eff} method given in AASHTO (1993) guide with FWD data.

FWD data, extracts of pavement design report of B212 road, parameters of AASHTO (1993) guide and calculation sheets used for determination of overlay thickness from AASHTO (1993) method and Simplified method for B212 road, is attached in annex-4.

Table 4-6 shows the results of design subgrade resilient modulus (Design M_R), effective structural number of pavement (SN_{eff}) and overlay thickness obtained from AASHTO (1993) method, Simplified method and design report.

Table 4-6 M_R , SN_{eff} and overlay thickness results of B212 road

| Analysis Method | Chainage | M_R (psi) | SN_{eff} | SN_f | Required overlay thickness (mm) | Design overlay thickness | |
|----------------------|-------------|----------------|------------|--------|------------------------------------|--------------------------|----------|
| | | | | | | AC (mm) | ABC (mm) |
| Design report | 0 - 6.95 Km | 22,500 | 1.05 | 3.08 | 129 | 50 | 125 |
| AASHTO (1993) method | 0 - 6.95 Km | 8,548 | 1.03 | 4.42 | 215 | 100 | 325 |
| Simplified method | 0 - 6.95 Km | 9,171 | 0.80 | 4.31 | 223 | 100 | 350 |

4.6 Comparison of results

Comparison of design subgrade resilient modulus (Design M_R) obtained from design report, AASHTO (1993) method and simplified method is given in Table 4-7.

Table 4-7 Comparison of Design M_R

| Road Number | Section | Design M_R (psi) | | |
|----------------|---------------|--------------------|------------------|----------------------|
| | | Design Report | AASHTO Method | Simplified Method |
| A001 | 59 km-100 km | 9,000 | 7,715 | 8,318 |
| A011 | 0 -1.5 km | 10,500 | 8,091 | 8,928 |
| | 1.5 km-5.3 km | 12,000 | 7,236 | 7,811 |
| B133 | 0 -21 km | 10,500 | 9,454 | 10,268 |
| | 21 km-45.8 km | 12,000 | 5,430 | 6,135 |
| B212 | 0 -6.95 Km | 22,500 | 8,548 | 9,171 |

Comparison of effective structural number of pavement (SN_{eff}) obtained from design report, AASHTO (1993) method and simplified method is given in Table 4-8.

Table 4-8 Comparison of SN_{eff}

| Road Number | Section | SN _{eff} | | |
|-------------|---------------|-------------------|---------------|-------------------|
| | | Design Report | AASHTO Method | Simplified Method |
| A001 | 59 km-100 km | 3.75 | 4.00 | 3.66 |
| A011 | 0 -1.5 km | 2.40 | 2.65 | 2.58 |
| | 1.5 km-5.3 km | 2.40 | 2.74 | 3.73 |
| B133 | 0 -21 km | 1.16 | 1.54 | 1.55 |
| | 21 km-45.8 km | 0.92 | 1.19 | 1.13 |
| B212 | 0 -6.95 Km | 1.05 | 1.03 | 0.80 |

Comparison of overlay thickness obtained from design report, AASHTO (1993) method and simplified method is given in Table 4-9.

Table 4-9 Comparison of overlay thickness

| Road Number | Section | Design Report | | AASHTO method | | Simplified method | |
|----------------|---------------|-----------------------------------|-------------------------------|-----------------------------------|-------------------------------|-----------------------------------|-------------------------------|
| | | Calculated Overlay Thickness (mm) | Design Overlay Thickness (mm) | Calculated Overlay Thickness (mm) | Design Overlay Thickness (mm) | Calculated Overlay Thickness (mm) | Design Overlay Thickness (mm) |
| A001 | 59 km-100 km | 84 | 100 | 85 | 100 | 98 | 100 |
| A011 | 0 -1.5 km | 104 | 105 | 114 | 115 | 109 | 110 |
| A011 | 1.5 km-5.3 km | 92 | 100 | 119 | 120 | 48 | 100 |
| B133 | 0 -21 km | 165 | 50/125* | 150 | 100/150* | 142 | 100/150* |
| B133 | 21 km-45.8 km | 168 | 50/180* | 226 | 100/375* | 218 | 100/350* |
| B212 | 0 -6.95 Km | 129 | 50/200* | 215 | 100/325* | 223 | 100/350* |
| *ABC thickness | | | | | | | |

Chapter 5. DISCUSSION

5.1 Design Subgrade Resilient Modulus (Design M_R)

The variation of design subgrade resilient modulus (Design M_R) for the road sections used to calculate overlay thickness in design report, AASHTO (1993) method and simplified method is given in Table 5-1. In the design report, Design M_R is determined from field CBR data using the correlation equation (2).

Table 5-1 Variation of Design M_R

| Road Number | Section | Design M_R (psi) | | | Coefficient of Variation (COV) | | |
|-------------|---------------|--------------------|---------------|-------------------|--------------------------------|---------------|---------------|
| | | Design Report | AASHTO method | Simplified method | between 1 & 2 | between 1 & 3 | between 2 & 3 |
| | | (1) | (2) | (3) | | | |
| A001 | 59 km-100 km | 9000 | 7715 | 8318 | 11 | 6 | 5 |
| A011 | 0 -1.5 km | 10500 | 8091 | 8928 | 18 | 11 | 7 |
| | 1.5 km-5.3 km | 12000 | 7236 | 7811 | 35 | 30 | 5 |
| B133 | 0 -21 km | 10500 | 9454 | 10268 | 7 | 2 | 6 |
| | 21 km-45.8 km | 12000 | 5430 | 6135 | 53 | 46 | 9 |
| B212 | 0 -6.95 Km | 22500 | 8548 | 9171 | 64 | 60 | 5 |

From Table 5-1 , it can be observed that coefficient of variation (COV) of design M_R values determined from AASHTO (1993) and Simplified method does not differ much (less than 10%). However, design M_R values obtained from CBR data, is always higher than that of AASHTO (1993) and Simplified method. One reason for having higher design M_R values from CBR data is that the difference in testing conditions. CBR test is done at a laboratory in a confined space and FWD test is done in the field. Another reason is that, CBR test is carried out for few soil samples obtained from the site but FWD test is carried out over the entire pavement section.

For comparison purpose, it is convenient to convert M_R values to equivalent CBR values using the correlation equation (2). In the A001, A011 and B133 design reports, the equivalent CBR values are between 6 and 8. For AASHTO (1993) method and Simplified method, corresponding CBR values are between 5 and 7. Since it is customary to adapt a design subgrade CBR value of less than 10 (15,000 psi) for the

pavement designs in Sri Lanka, it can be concluded that Simplified method and AASHTO (1993) methods presents M_R values within the acceptable range.

However, in the B212 design report, design subgrade CBR value of 15 (22,500 psi) is adapted for design subgrade resilient modulus. However, it should be noted that adopting a design subgrade CBR value of 15 requires a very careful consideration, since it will represent a very strong subgrade. This will result in thin pavement layer in the design and subsequently it may lead to premature structural failures in the pavement.

5.2 Effective structural number (SN_{eff})

The variation of effective structural number (SN_{eff}) obtained from data analysis is given in Table 5-2 .

Table 5-2 Variation of SN_{eff}

| Road Number | Section | SN_{eff} | | | Coefficient of Variation (COV) | | |
|-------------|---------------|---------------|---------------|-------------------|--------------------------------|---------------|---------------|
| | | Design Report | AASHTO method | Simplified method | between 1 & 2 | between 1 & 3 | between 2 & 3 |
| | | (1) | (2) | (3) | | | |
| A001 | 59 km-100 km | 3.75 | 4.00 | 3.66 | 5 | 2 | 6 |
| A011 | 0 -1.5 km | 2.40 | 2.65 | 2.58 | 7 | 5 | 2 |
| | 1.5 km-5.3 km | 2.40 | 2.74 | 3.73 | 9 | 31 | 22 |
| B133 | 0 -21 km | 1.16 | 1.54 | 1.55 | 20 | 20 | 0 |
| | 21 km-45.8 km | 0.92 | 1.19 | 1.13 | 18 | 14 | 4 |
| B212 | 0 -6.95 Km | 1.05 | 1.03 | 0.80 | 1 | 19 | 18 |

From Table 5-2, it can be observed that coefficient of variation (COV) of SN_{eff} values are less than 10% for A001 road section. Higher SN_{eff} value has been obtained from Simplified method for A011 road. For B133 road SN_{eff} values are nearly identical for AASHTO (1993) method and Simplified method. However, for B212 road, Simplified method gives a lower SN_{eff} value.

5.3 Overlay Thickness

The summary of design overlay thicknesses are given in Table 5-3. For the A001 and A011 road sections, AASHTO (1993) method has been adopted in the design reports. For the B133 and B212 road sections, Road Note 31 method has been adopted in the design reports because of estimated low future traffic.

Table 5-3 Variation of Overlay Thickness

| Road Number | Section | Design Report | | AASHTO method | | Simplified method | |
|-------------|---------------|-----------------------------------|-------------------------------|-----------------------------------|-------------------------------|-----------------------------------|-------------------------------|
| | | Calculated Overlay Thickness (mm) | Design Overlay Thickness (mm) | Calculated Overlay Thickness (mm) | Design Overlay Thickness (mm) | Calculated Overlay Thickness (mm) | Design Overlay Thickness (mm) |
| A001 | 59 km-100 km | 84 | 100 | 85 | 100 | 98 | 100 |
| A011 | 0 -1.5 km | 104 | 105 | 114 | 115 | 109 | 110 |
| A011 | 1.5 km-5.3 km | 92 | 100 | 119 | 120 | 48 | 100 |
| B133 | 0 -21 km | 165 | 50/125* | 150 | 100/150* | 142 | 100/150* |
| B133 | 21 km-45.8 km | 168 | 50/180* | 226 | 100/375* | 218 | 100/350* |
| B212 | 0 -6.95 Km | 129 | 50/200* | 215 | 100/325* | 223 | 100/350* |

*ABC thickness

The following graphs are used to study the variation of overlay thickness with design subgrade resilient modulus (Design M_R) and effective structural number of pavement (SN_{eff}) more effectively.

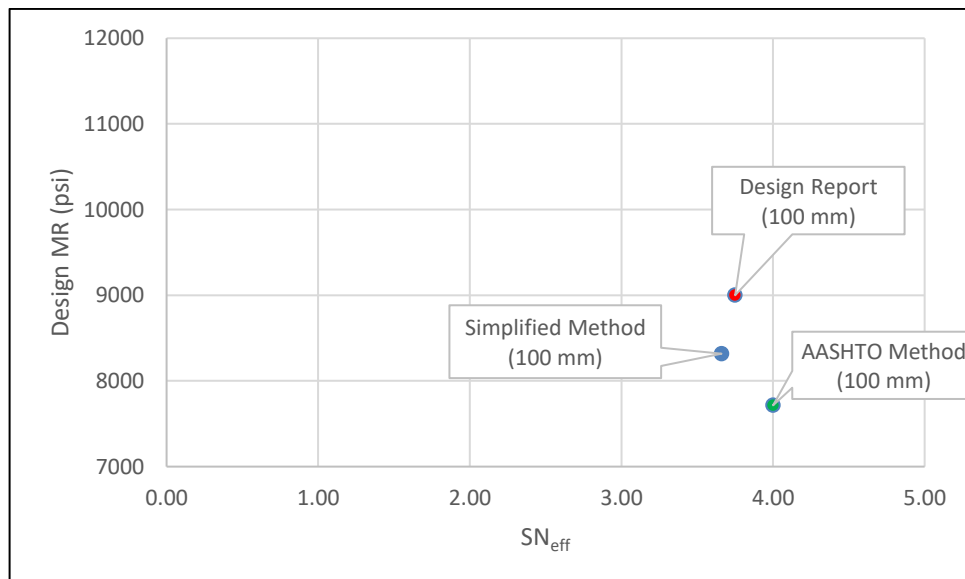


Figure 5-1 Variation of design overlay thickness with design M_R and SN_{eff} for A001 road

Figure 5-1 shows the variation of design overlay thickness with design M_R and SN_{eff} for A001 road. From Figure 5-1, it can be observed that design overlay thickness is same for A001 road in all three methods. The reason for this is that, the calculated overlay thickness is less than 100 mm for all three methods. Therefore, in order to comply with minimum thickness requirement specified in AASHTO (1993) guide, a 100 mm thick asphalt surface is required by all three methods.

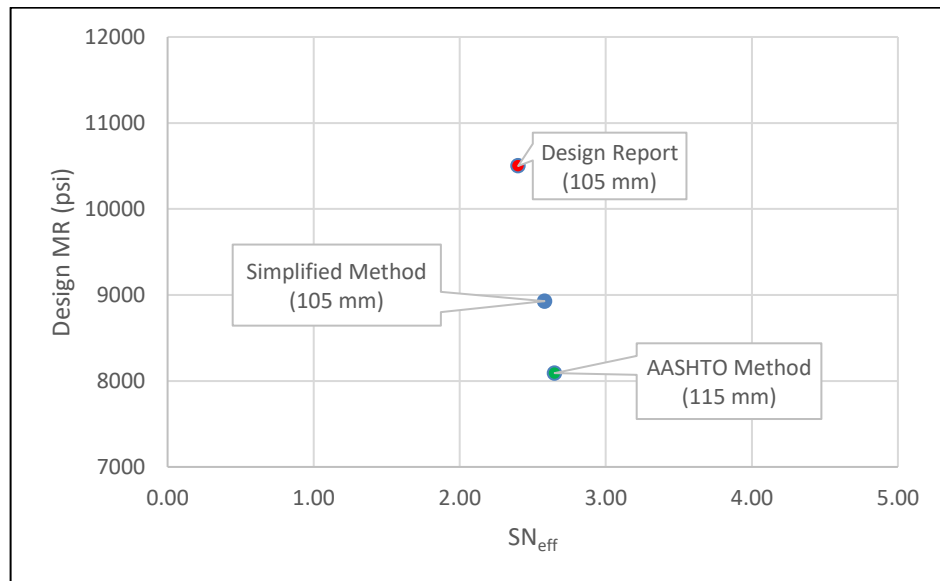


Figure 5-2 Variation of design overlay thickness with design M_R and SN_{eff} for A011 road (section-1)

Figure 5-2 shows the variation of design overlay thickness with design M_R and SN_{eff} for A011 road (section-1). From Figure 5-2, it can be observed that, AASHTO (1993) method gives the highest overlay thickness (115 mm) for A011 (section-1), since it has the lowest design M_R . Design M_R is higher in the design report than that in Simplified method, however, Simplified method gives higher SN_{eff} . Therefore, overlay thickness (105 mm) is same for both methods.

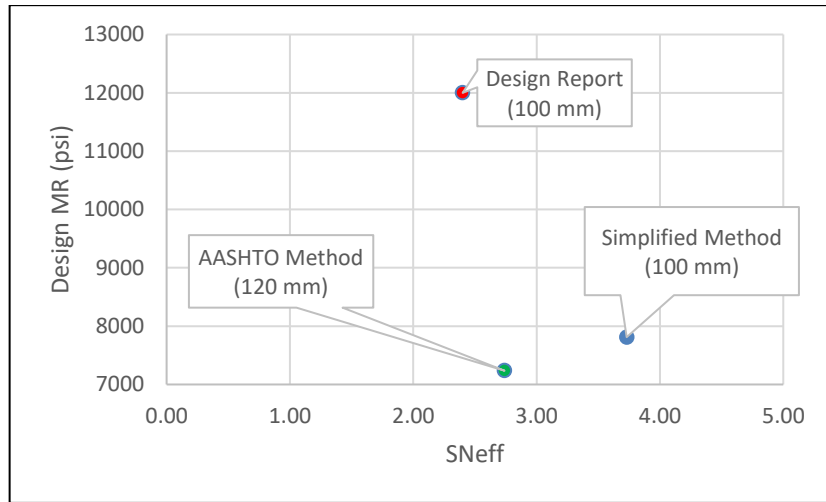


Figure 5-3 Variation of design overlay thickness with design M_R and S_{Neff} for A011 road (section-2)

Figure 5-3 shows the variation of design overlay thickness with design M_R and S_{Neff} for A011 road (section-2). From Figure 5-3, it can be observed that, AASHTO (1993) method gives the highest overlay thickness (120 mm) for A011 (section-2) since it has the lowest design M_R . CBR presented in the Design report gives a higher design M_R value (12000 psi) than the other two methods, and therefore it has the lowest overlay thickness (100 mm).

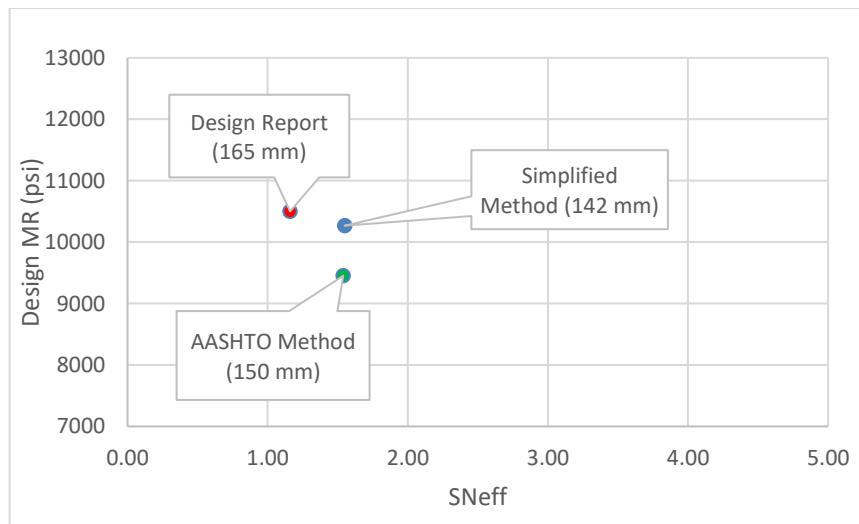


Figure 5-4 Variation of design overlay thickness with design M_R and S_{Neff} for B133 road (section-1)

Figure 5-4 shows the variation of design overlay thickness with design M_R and SN_{eff} for B133 road (section-1). From Figure 5-4, it can be observed that, for B133 road (section-1), Simplified method presents the lowest overlay thickness (142 mm) since it gives a highest SN_{eff} value from the three methods. However, since B133 has a low traffic volume, the consultant has recommended an overlay design with a 50 mm asphalt surface on top of an aggregate base course (ABC). (Refer Table 5-3 for comparison of design overlay thickness for B133 road.)

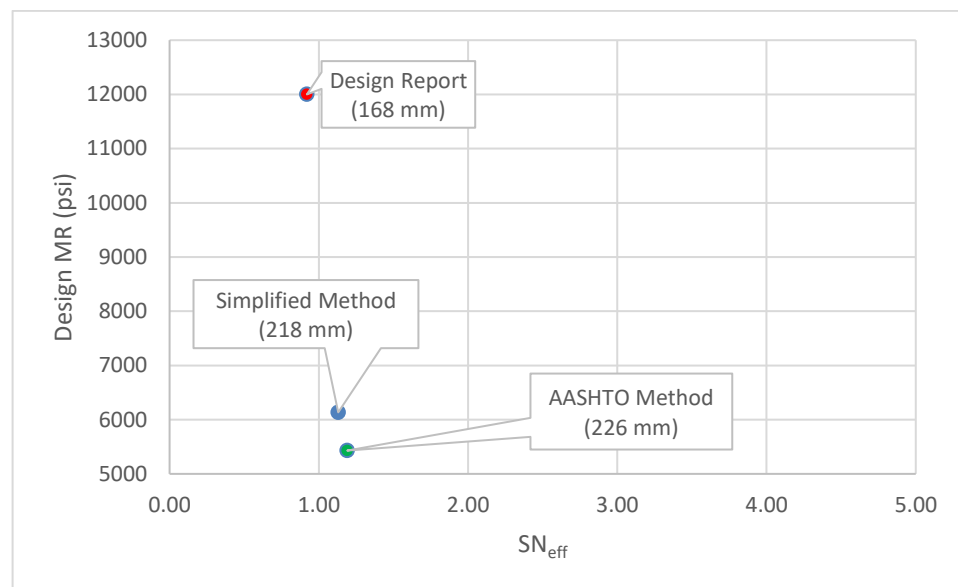


Figure 5-5 Variation of design overlay thickness with design M_R and SN_{eff} for B133 road (section-2)

Figure 5-5 shows the variation of design overlay thickness with design M_R and SN_{eff} for B133 road (section-2). From Figure 5-5, it can be observed that, the design report has the lowest overlay thickness, since it has the highest design M_R value for B133 road (section-2) than other two methods. Although, Simplified method and AASHTO (1993) method give higher overlay thickness, both methods present nearly identical design M_R values. (Refer Table 4-7 Comparison of Design MR values)

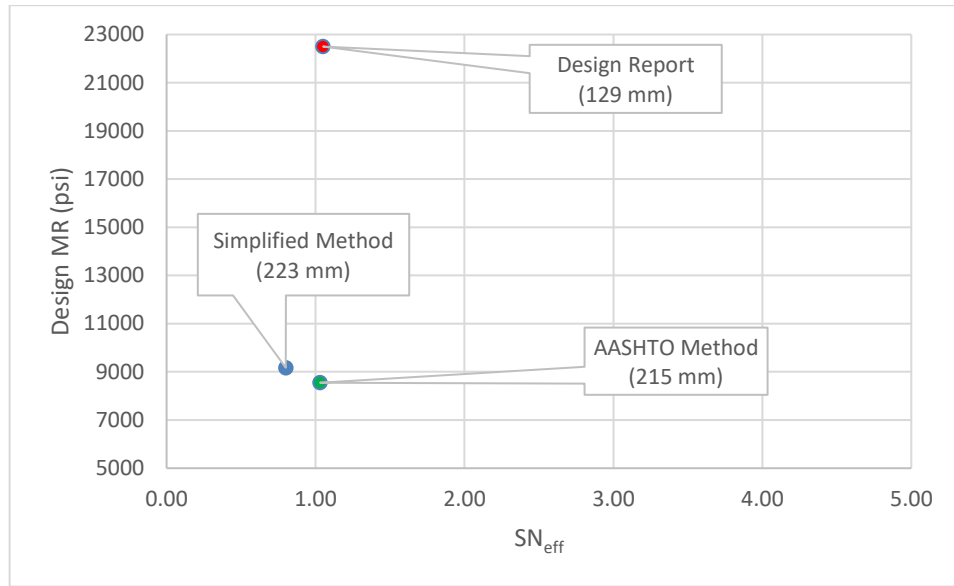


Figure 5-6 Variation of design overlay thickness with design M_R and SN_{eff} for B212 road

Figure 5-6 shows the variation of design overlay thickness with design M_R and SN_{eff} for B212 road. From Figure 5-6, it can be observed that the design report gives a very high design M_R value for B212 road than other two methods. Therefore it obviously has the lowest overlay thickness. However, in this instance also, Simplified method and AASHTO method present nearly identical design M_R values. (Refer Table 4-7 Comparison of Design MR values)

Chapter 6. CONCLUSION & RECOMMENDATIONS

In this research, a Simplified method is developed to estimate overlay thickness based on AASHTO (1993) method. Four road sections with different design requirements are selected in this research study to develop this method. The following are the recommendations obtained from this research study.

- The Simplified method can be used to determine the overlay thickness from FWD data files only. It does not require any pavement investigations.
- The Simplified method is recommended for carrying out a preliminary pavement design during the feasibility stage of a project.
- A detailed pavement design should be carried out to finalize the final overlay thickness. To do a detailed pavement design, it is recommended conducting a new FWD test and a detailed pavement investigation.
- In the Simplified method, surface modulus method (described in section 3.2.2) should be used to obtain design subgrade resilient modulus (Design M_R).
- In the Simplified method, if the design subgrade resilient modulus value (Design M_R) is less than 3000 psi (CBR=2) in a section, then, that section should be considered as a potential reconstruction section and the value should be omitted from calculations.
- In the Simplified method, Hoffman's method (described in section 3.2.3.1) should be used to obtain effective structural number (SN_{eff}) of pavement.
- However, to obtain corrected effective structural number of pavement (Corrected SN_{eff}), the following modified equations should be used based on the stiffness category of the pavement section (described in section 3.2.3.7).

| Range of Area Values (inches) | Pavement Stiffness Category | Modified corrected SN_{eff} Equations (used in Simplified method) |
|-------------------------------|-----------------------------|---|
| AREA \geq 23.0 | Very High | 2 $SN_{30}^{-0.5}$ |
| 21.0 \leq AREA < 23.0 | High | 2 SN_{30} |
| 19.0 \leq AREA < 21.0 | Low | 2 SN_{30} |
| AREA < 19.0 | Very Low | 2 $SN_{30}^{-1.0}$ |

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Annex-01-A001 Road

Annex-01-A001 Road

FWD Data

IKUAB FWD FILE : A001 From 59kmp.fwd
HOperator : MRM
HRoad : A001
HWeather : Sunny

IDate Created : 19/01/2019
IVersion : 2.4.75
ILoad Mode : 1 (2 + 2 buffers)
IPlate Radius : 15.0 (cm)
IExtra Field Set : KUAB
IDrop Sequence : 33
INo of drops : 11
IRecord Drop? : NY
IDrop Height : 1 2 3 4
IImpact Load : 15.0 25.0 40.0 50.0 kN
ISensor Number : 0 1 2 3 4 5 6
ISensor Distance : 0.0 20.0 30.0 45.0 60.0 90.0 120.0 (cm)
ISensor Position : CENTER BEHIND BEHIND BEHIND BEHIND BEHIND BEHIND

IReference Offset : 0 m
ITestpoint spacing: 100 m

| J | Distance | Imp | Load | D0 | D1 | D2 | D3 | D4 | D5 | D6 | Air | Pave | Emod | Lat | Long | Time |
|---|---|-----|------|-----|-----|-----|-----|-----|-----|----|------|------|------|------------|-------------|----------|
| J | m | Num | kN | µm | µm | µm | µm | µm | µm | µm | °C | °C | MPa | | | |
| D | 59000 | 2 | 41.9 | 191 | 158 | 136 | 114 | 95 | 70 | 51 | 23.6 | 28.5 | 816 | 0714.45118 | 08012.53289 | 20:36:29 |
| D | 59100 | 2 | 41.0 | 395 | 297 | 242 | 183 | 140 | 89 | 61 | 23.3 | 28.7 | 387 | 0714.47680 | 08012.58079 | 20:37:49 |
| D | 59300 | 2 | 41.6 | 170 | 129 | 108 | 89 | 75 | 59 | 48 | 23.4 | 28.8 | 910 | 0714.48162 | 08012.68414 | 20:39:02 |
| D | 59400 | 2 | 41.4 | 144 | 107 | 86 | 66 | 52 | 36 | 27 | 23.2 | 27.9 | 1070 | 0714.45750 | 08012.73256 | 20:39:57 |
| T | Mix temperature at 59501 m, depth 5 cm :35.0 Time: 20:51:51 | | | | | | | | | | | | | | | |
| D | 59501 | 2 | 41.1 | 143 | 98 | 80 | 65 | 53 | 38 | 29 | 23.2 | 27.1 | 1070 | 0714.42262 | 08012.77562 | 20:52:22 |
| D | 59600 | 2 | 41.2 | 313 | 256 | 219 | 183 | 147 | 101 | 72 | 23.0 | 27.1 | 491 | 0714.37442 | 08012.79852 | 20:53:18 |
| D | 59700 | 2 | 41.2 | 278 | 222 | 191 | 159 | 131 | 97 | 73 | 22.8 | 26.6 | 552 | 0714.32683 | 08012.82112 | 20:54:10 |
| D | 59800 | 2 | 41.2 | 111 | 84 | 70 | 55 | 43 | 29 | 20 | 22.9 | 26.1 | 1382 | 0714.28435 | 08012.85463 | 20:55:03 |
| D | 59900 | 2 | 40.9 | 217 | 163 | 133 | 99 | 73 | 44 | 27 | 23.2 | 26.9 | 701 | 0714.23721 | 08012.88196 | 20:56:06 |
| D | 60000 | 2 | 41.2 | 285 | 234 | 199 | 161 | 131 | 94 | 69 | 23.2 | 27.4 | 537 | 0714.19142 | 08012.91118 | 20:57:37 |
| D | 60100 | 2 | 41.3 | 198 | 149 | 119 | 91 | 70 | 44 | 29 | 21.8 | 25.9 | 777 | 0714.14326 | 08012.93471 | 21:23:23 |
| D | 60200 | 2 | 40.9 | 297 | 221 | 175 | 133 | 103 | 69 | 47 | 21.8 | 25.8 | 513 | 0714.09492 | 08012.95904 | 21:24:19 |
| D | 60300 | 2 | 41.6 | 150 | 115 | 95 | 73 | 55 | 33 | 22 | 21.8 | 26.1 | 1033 | 0714.04177 | 08012.97413 | 21:25:12 |
| D | 60400 | 2 | 41.4 | 161 | 138 | 123 | 106 | 90 | 67 | 51 | 21.6 | 26.0 | 957 | 0714.01258 | 08013.01379 | 21:26:03 |
| D | 60500 | 2 | 41.1 | 250 | 212 | 184 | 154 | 126 | 87 | 62 | 21.6 | 26.2 | 613 | 0713.96573 | 08013.03004 | 21:26:45 |
| D | 60600 | 2 | 41.1 | 218 | 158 | 123 | 88 | 64 | 38 | 24 | 21.6 | 25.9 | 702 | 0713.91655 | 08013.04472 | 21:27:26 |
| D | 60700 | 2 | 41.3 | 96 | 63 | 47 | 36 | 28 | 19 | 13 | 21.7 | 26.2 | 1600 | 0713.86473 | 08013.05979 | 21:28:20 |
| D | 60800 | 2 | 41.6 | 233 | 193 | 160 | 122 | 91 | 51 | 29 | 21.5 | 26.7 | 664 | 0713.85255 | 08013.09782 | 21:32:53 |
| D | 60900 | 2 | 41.2 | 125 | 96 | 79 | 61 | 47 | 30 | 20 | 21.7 | 25.4 | 1232 | 0713.88942 | 08013.13521 | 21:33:33 |
| D | 61000 | 2 | 41.0 | 311 | 236 | 197 | 157 | 125 | 86 | 62 | 21.7 | 26.2 | 491 | 0713.92819 | 08013.16774 | 21:34:37 |
| D | 61100 | 2 | 40.9 | 455 | 348 | 269 | 192 | 133 | 54 | 22 | 21.8 | 26.1 | 334 | 0713.95357 | 08013.21624 | 21:35:19 |
| D | 61200 | 2 | 41.5 | 171 | 131 | 110 | 86 | 68 | 47 | 34 | 21.8 | 25.8 | 904 | 0713.98910 | 08013.25507 | 21:36:12 |
| D | 61300 | 2 | 41.4 | 145 | 118 | 100 | 78 | 60 | 39 | 28 | 21.7 | 25.3 | 1059 | 0714.01196 | 08013.30513 | 21:37:06 |
| D | 61400 | 2 | 41.1 | 212 | 181 | 161 | 139 | 120 | 94 | 73 | 21.8 | 26.4 | 721 | 0714.03472 | 08013.35366 | 21:38:01 |
| D | 61500 | 2 | 41.6 | 145 | 115 | 95 | 74 | 58 | 40 | 30 | 21.8 | 26.0 | 1067 | 0714.07441 | 08013.38947 | 21:39:01 |
| D | 61600 | 2 | 41.3 | 127 | 100 | 83 | 64 | 47 | 26 | 14 | 21.9 | 26.2 | 1208 | 0714.11646 | 08013.42287 | 21:39:53 |

D 61700 2 41.6 404 338 292 187 108 55 25 21.8 26.1 384 0714.16401 08013.44844 21:40:44
D 61800 2 42.0 179 156 140 120 101 77 59 22.1 25.5 875 0714.20276 08013.48806 21:41:38
D 61900 2 41.6 268 219 185 150 121 86 66 22.1 25.8 578 0714.21544 08013.53923 21:42:30
D 62000 2 41.4 334 221 160 108 75 50 34 22.1 26.0 462 0714.22955 08013.58779 21:43:24

D 62100 2 41.4 224 193 169 141 114 78 54 22.1 26.3 688 0714.24967 08013.63747 21:44:17
D 62200 2 41.0 288 223 187 146 114 76 53 22.1 25.5 529 0714.28190 08013.68140 21:45:12
D 62300 2 41.5 406 322 261 205 156 105 73 22.0 26.1 380 0714.29768 08013.73335 21:46:06
D 62400 2 41.5 444 347 279 199 144 85 52 22.6 26.1 348 0714.31255 08013.78834 21:46:58
D 62500 2 41.4 324 258 219 175 134 89 65 22.8 26.6 476 0714.33258 08013.83488 21:47:51
D 62600 2 41.3 194 159 135 109 87 61 46 23.2 26.3 791 0714.34578 08013.88873 21:48:42
D 62700 2 41.0 367 270 216 166 128 86 60 23.3 26.1 416 0714.35635 08013.94265 21:49:33
D 62800 2 41.2 196 142 117 94 77 58 45 23.5 27.0 782 0714.35682 08013.99453 21:50:26
D 62900 2 41.3 356 274 216 159 116 62 33 23.7 26.5 432 0714.31868 08014.02914 21:51:19
D 63000 2 40.8 572 515 407 321 238 141 93 23.6 26.7 265 0714.27433 08014.06195 21:52:13

D 63100 2 41.2 209 180 163 144 125 99 78 23.7 26.2 734 0714.23081 08014.09422 21:53:06
D 63200 2 40.9 494 429 371 314 240 167 115 23.7 25.5 308 0714.18826 08014.12643 21:53:59
D 63300 2 41.1 360 293 241 190 151 105 75 23.6 26.3 425 0714.14345 08014.15800 21:54:52
D 63400 2 41.1 450 346 278 212 163 108 77 23.5 25.9 340 0714.09730 08014.19073 21:55:44
D 63500 2 41.3 282 225 193 160 132 99 74 23.7 26.1 545 0714.05450 08014.21896 21:56:38
D 63600 2 41.0 225 183 153 116 87 53 34 23.6 26.0 678 0714.01906 08014.25764 21:57:34
D 63700 2 41.3 115 92 79 66 54 39 28 23.8 25.4 1335 0714.01795 08014.31117 21:58:31
D 63800 2 41.4 108 89 80 70 60 46 34 23.8 24.7 1430 0714.02816 08014.36466 21:59:29
D 63900 2 40.7 177 131 111 90 73 51 37 23.8 26.2 856 0714.03141 08014.41561 22:00:23
T Mix temperature at 64001 m, depth 5 cm :34.0 Time: 22:12:37
D 64001 2 41.2 174 133 109 85 68 49 37 23.9 26.2 883 0714.00746 08014.46125 22:13:07

D 64100 2 41.2 297 204 155 103 68 33 19 23.8 26.2 516 0713.97841 08014.50700 22:14:09
D 64200 2 40.9 291 229 184 129 88 52 32 23.5 26.1 523 0713.94703 08014.55051 22:15:08
D 64300 2 41.2 265 195 153 111 78 49 33 23.2 25.7 579 0713.91421 08014.59684 22:19:29
D 64400 2 41.2 353 274 223 170 125 75 50 23.3 26.8 434 0713.88166 08014.63880 22:20:21
D 64500 2 41.4 445 315 231 156 113 78 58 23.1 26.4 347 0713.86678 08014.69195 22:21:14
D 64600 2 41.1 95 56 43 32 24 16 11 23.0 26.2 1608 0713.88821 08014.74547 22:22:05
D 64700 2 41.1 296 211 159 107 61 32 17 22.9 26.5 518 0713.91331 08014.78994 22:22:52
D 64800 2 41.7 146 105 82 60 45 29 22 22.9 26.1 1059 0713.93863 08014.83628 22:23:40
D 64900 2 41.6 175 136 113 87 66 41 27 22.8 25.4 886 0713.94818 08014.88946 22:24:29
D 65000 2 41.5 126 95 80 64 52 37 26 22.4 25.6 1226 0713.94610 08014.94227 22:25:17

D 65100 2 41.3 171 136 111 82 59 31 18 22.5 24.1 899 0713.95802 08014.99587 22:26:08

D 65200 2 41.2 180 141 120 99 81 58 41 22.3 25.9 854 0713.96992 08015.05076 22:27:22
D 65300 2 41.6 174 148 129 108 88 60 41 22.5 25.1 890 0713.98102 08015.10061 22:27:59
D 65400 2 41.3 300 222 184 141 104 61 35 22.4 24.5 512 0713.98573 08015.15692 22:28:41
D 65500 2 40.8 362 280 230 186 151 106 76 22.2 25.4 419 0713.99635 08015.20811 22:29:30
D 65600 2 41.3 245 198 168 136 108 73 48 22.2 24.9 629 0714.01301 08015.25807 22:30:25
D 65700 2 41.4 285 217 169 120 86 55 40 22.1 25.5 541 0714.02509 08015.31011 22:34:57
D 65800 2 41.3 151 103 80 60 47 32 24 22.4 25.9 1020 0714.02546 08015.36295 22:35:49
D 65900 2 41.6 190 135 108 83 64 43 30 22.4 25.6 816 0714.02707 08015.41771 22:36:39
D 66000 2 41.4 175 144 128 111 96 75 57 22.2 25.6 882 0714.02966 08015.47218 22:37:33

D 66100 2 41.3 234 184 156 128 104 77 58 22.3 25.6 657 0714.03994 08015.52270 22:38:24
D 66200 2 41.3 216 143 110 87 72 56 45 22.4 26.3 711 0714.04994 08015.57445 22:42:15
D 66300 2 41.1 220 173 146 120 99 75 57 22.5 26.1 695 0714.05718 08015.62842 22:42:58
D 66400 2 41.3 272 214 175 132 100 66 47 22.6 25.6 565 0714.06377 08015.68557 22:43:52
D 66500 2 41.3 258 206 164 126 100 73 55 22.6 26.3 596 0714.07826 08015.73578 22:44:44

Annex-01-A001 Road

Pavement Design Report

1. Introduction

A01- Colombo- Kandy Road is a major arterial road in the road network of Sri Lanka. This report contains the pavement design of A01- Colombo - Kandy road from 59+000 km to 100+000 km, proposed to rehabilitate under the ADB Funded Intergraded Road Investment Program (I Road Project). Surface of the road is Asphalt with ABC base. The road consists of two lanes with 3.5-3.7m carriageway and asphalt hard shoulder of 1.0 - 1.5m. RDA has proposed two lane road with 3.5m carriageway and 3.5m passing lane at possible locations and 1.0-1.5m hard shoulder.

2. Investigation

Non-destructive Testing

Load-Deflection measurement test was carried out by Falling Weight Deflectometer (FWD) in 50 m interval and summary of deflections are given in Annex 5. FWD was conducted by Road Development Authority (RDA).

Material Sampling and Testing

Test pit investigations were conducted at 1000 m interval on the existing pavement of the road and widening area separately. Following tests have been carried out at the test site and the laboratory.

Field tests:

- A log of existing layer profile
- Field Density

Laboratory tests:

- CBR (4 days soaked at Field Density)
- Modified Proctor Compaction Test
- Atterberg Limits Test

Furthermore, Dynamic Cone Penetrometer (DCP) Test was conducted in 1000 m intervals at test pit locations.

An Equivalent DCP CBR value of subgrade soil layers were calculated using the following Japanese formula, introduced by Japan Road Association in 1989 (Refer Ausroad-2010).

$$\text{Equivalent DCP CBR} = \left[\frac{\sum (\text{Layer thickness} \times \text{DCP CBR}^{1/3})}{\sum \text{Layer thickness}} \right]^3$$

Summary of test results at existing pavement and widening areas are given under Annex 2 and summary of existing pavement layer details are given under Annex 3.

4 day soaked Lab CBR at Field Density under modified conditions of compaction for overlaying section is considered for design calculations. 4 day soaked CBR at 95% of MDD is considered for widening areas.

Both an Equivalent DCP CBR and Lab CBR are used to determine the design Subgrade strength (Design CBR)

Summary of Design CBR values of subgrade are given in Table 01.

Table 01: Design CBR Values

| | Chainage | Design CBR/ (%) |
|------------|-------------------------|-----------------|
| Overlaying | Ch 59+000 to Ch 100+000 | 6 |
| Widening | Ch 59+000 to Ch 100+000 | 7 |

Pavement Condition Survey

The pavement condition survey was carried out. According to condition survey more than 20% of road surface cracked and more than 9% of road surface has been patched. Formation of waves and corrugation at sharp curves and stop and go location were observed in the existing pavement. Significant surface rutting or settlement were not observed in the road surface. Details of distresses are given in the Detailed Condition Survey Reports.

3. Traffic Forecast

Traffic data were provided by Planning Division of Road Development Authority and attached under Annex 6A. The Design Cumulative Number of Standard Axles (CNSA) for 15-year design traffic are summarized in Table 2. Since lane width is 3.5 m, Directional factor is considered as 0.50 and Lane Distribution Factor is taken as 1.0.

Further in this calculation growth rate has been not considered because RDA has already provided, predicted vehicles per day in 2020, 2025, 2030 and 2035 (Refer annexure 6A). Equivalent Standard Axle values extracted from letter No. RDA/PI/TRS -19.12.2016 (refer Annexure 06B).

Table 02: CNSA Value - 15 years

| Road Section | CNSA/msa | Design CNSA/msa |
|-------------------------|----------|-----------------|
| Ch 59+000 to Ch 100+000 | 52.5 | 26.25 |

4. Pavement Distresses

According to the pavement condition survey, alligator (or map) crack and formation of waves and corrugation are observed on asphalt surfaces. Since more than 20% of road surface has cracked and 9% of road surface has been patched. More attention should be provided for rectification and prevent reflection of crack in future. Some photos are shown in below Figure 1. Summary of cracks and patches are given in Annex 4. Significant surface rutting or settlement was not observed in the road surface.



Ch. 65+600



Ch. 69+300



Ch. 72+700



Ch. 75+200



Ch. 87+100



Ch. 95+500

Figure 1: Surface condition of the road

5. Pavement Structural Evaluation

The Falling Weight Deflectometer (FWD) is an excellent device for evaluating the structural capacity of pavements for overlay designs. AASHTO Guide was used to estimate Effective Structural Number of existing top hard layers. FWD data along with the computed Effective Structural Numbers of the existing pavement are presented in Annex 5. Details of the calculations are described below.

- Based on test pit investigation, top hard layer thickness (D) is taken.
- Overall Subgrade Resilient Modulus (M_R) below the depth was estimated from Eq.02.

$$M_R = \frac{0.24P}{d_r} \text{-----Eq. 02}$$

where

- M_R = backcalculated subgrade resilient modulus, psi
- P = applied load, pounds
- d_r = deflection at a distance r from the center of the load, inches
- r = distance from center of load, inches

- However, since CBR data of the exiting pavement is available Design Subgrade Modulus is computed from the CBR figures (Refer Annex 7 for further details)
- Minimum distance (r) was determined by following relationship given by Eq03.

$$r \geq 0.7a_e \text{-----Eq. 03}$$

where

$$a_e = \sqrt{\left[a^2 + \left(D \sqrt[3]{\frac{E_p}{M_R}} \right)^2 \right]}$$

- a_e = radius of the stress bulb at the subgrade-pavement interface, inches
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- E_p = effective modulus of all pavement layers above the subgrade, psi (described below)

- Effective modulus (Ep) of all existing pavement layers above the subgrade is calculated from Eq.04. and presented under Annex 5

$$\frac{M_R d_0}{qa} = 1.5 \left\{ \frac{1}{\sqrt{1 + \left[\left(\frac{D}{a} \right)^3 \frac{E_p}{M_R} \right]^2}} + \frac{1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a} \right)^2}}}{\left(\frac{E_p}{M_R} \right)} \right\} \text{-----Eq. 04}$$

where

- d₀ = deflection measured at the center of the load plate, inches
- p = NDT load plate pressure, psi
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- M_R = subgrade resilient modulus, psi
- E_p = effective modulus of all pavement layers above the subgrade, psi

- Effective Structural Number of existing pavement layers are computed from Eq.05 and presented under Annex 5.

$$SN_{\text{eff}} = 0.0045 D \sqrt[3]{E_p} \text{-----Eq. 05}$$

- Summary of Effective Structural Number is presented under Table 3 as given below.

Table 03: Summary of Effective Structural Number of the Existing Pavement

| Section | SN _{eff} |
|-------------------------|-------------------|
| Ch 59+000 to Ch 100+000 | 3.75 |

According to pavement structural capacity calculation, existing pavement has excellent structural capacity.

6. Pavement Thickness Calculation

As there are strong structural capacity in the existing pavement, it was decided to overlay with asphalt concrete. Pavement overlay thickness was calculated according to AASHTO Guide for Design of Pavement Structures 1993 considering Design Traffic, Subgrade Modulus and Effective Structural Number.

- Design Subgrade Resilient Modulus (M_R) is estimated from Design Subgrade CBR using the following equation.

$$M_R = 1500 \times CBR \% \dots\dots\dots \text{Eq.06}$$

- Required Structural Number (SN_f) for different traffic and Subgrade Resilient Modulus are calculated from equation 08. Considered parameters are as follows.

$$\log W_{18} = Z_R S_0 + 9.36 \log(SN + 1) - 0.20 + \frac{\log[\Delta PSI / (4.2 - 1.5)]}{0.4 + 1094 / (SN + 1)^{5.19}} + 2.32 \log M_R - 8.07 \quad (11.37)$$

\dots\dots\dots \text{Eq. 07}

Table 04 - Design Parameters

| Item | Reference |
|----------------------------------|------------------|
| Reliability = 85% (Urban) | Table 2.2 AASHTO |
| Reliability = 80% (Rural) | Table 2.2 AASHTO |
| Standard Deviation = -1.037 | Cl 2.1.3 AASHTO |
| Standard Deviation = -0.841 | Cl 2.1.3 AASHTO |
| Design Serviceability Loss = 1.7 | Cl 2.2.1 AASHTO |

- Overlay thicknesses are calculated from Eq.09 and summary of design pavement thicknesses are presented in Table 05.

$$D_{ol} = \frac{SN_{ol}}{a_{ol}} = \frac{(SN_f - SN_{eff})}{a_{ol}} \quad \text{-----Eq. 09.}$$

where

- SN_{ol} = Required overlay structural number
- a_{ol} = Structural coefficient for the AC overlay
- D_{ol} = Required AC overlay thickness, inches
- SN_f = Structural number determined in Step 6
- SN_{eff} = Effective structural number of the existing pavement, from Step 7

- Pavement layer thicknesses of widening and reconstruction sections are calculated using Layered Analysis Approach as per AASHTO 1993 clause 3.1.5. Pavement thickness of widening and reconstruction sections are shown under Table 06.

Table 05- Design Layer Thicknesses for Existing Pavement

| Section (Chainage) | SN_{eff} | Sub grade CBR % | Condition | Traffic CNESA /(msa) | Asphalt Wearing Course (in mm) | Asphalt Binder Course (in mm) |
|--------------------|------------|-----------------|--------------|----------------------|--------------------------------|-------------------------------|
| 59+000-100+000 | 3.75 | 6 | Urban/ Rural | 26.25 | 50 | 50 |

Table 06- Design Layer Thicknesses for Widening and Reconstruction Sections.

| Section (Chainage) | Sub grade CBR % | Traffic CNESA /(msa) | Asphalt Wearing Course (in mm) | Asphalt Binder Course (in mm) | Dense Graded Aggregate Base (in mm) | Sub Base (in mm) |
|--------------------|-----------------|----------------------|--------------------------------|-------------------------------|-------------------------------------|------------------|
| 59+000-100+000 | 7 | 26.25 | 50 | 125 | 300 | 150 |

7. Summary and Conclusion

Summary of pavement evaluation are shown in Table 08. As per the pavement evaluation, Average Percentage of Cracked and Patch Areas are 22.0% and 9.5%. Therefore, the road pavement has reached to its terminal condition. Structural capacity of the pavement is good, but it is not sufficient for cater next 15 year design traffic. Hence road should rehabilitate immediately with layer thicknesses given in Table 05 and Table 06. All cracked areas should be sealed and other distresses should be rectified before overlaying. Additional thicknesses resulting on vertical correction and camber correction might be substituted with a Bitumen Bound Base (BBB) layer of minimum thickness of 75mm and a minimum width of 2m. Considering proposed overlay thickness, percentage of crack, climate and future traffic demand, all cracked area should be sealed with suitable sealant to prevent reflection of cracks. According to our estimation, 60/70 bitumen is not suitable for this climate and traffic demand. Use of 60/70 bitumen will lead to form alligator crack,

waves and corrugate at early stage. Therefore, polymer modified bitumen is recommended according to Austroads Guide to Pavement Technology.

Table 08: Summary of Pavement Evaluation

| Item | Description |
|------------------------------|---|
| Pavement Distresses | Average Percentage of Cracked Area is 21.3% and 22.3% in LHS and RHS respectively. Percentage of Patched Area 9.3% and 9.6% in LHS and RHS respectively. |
| Structural Evaluation | Structural Capacity of the existing pavement has 3.75, which provide 0.15% percentile value. |
| Overlay Pavement Thicknesses | Structural capacity of the pavement is not sufficient for cater next 15year design traffic. Hence, 50mm Asphalt Wearing Course with 50mm Asphalt Binder Course over layer are proposed. |

Material and method of construction has to be selected according to Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009) and the Employer Requirement.

8. References

- AASHTO Guide for Design of Pavement Structures, 1993
- Transport & Road Research Laboratory, United Kingdom Road Note 18, 1999
- Transport & Road Research Laboratory, United Kingdom Road Note 31, 1977
- “Pavement Analysis and Design”, Yang H. Huang ,2nd Edition
- Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009)
- RDA Pavement Design Guide, 1999
- Guide to Pavement Technology Part 2: Pavement Structural Design, Austroads 2012.
- Bandara, W.W & Premathilaka, R.P.M.M, 2017. Dense Graded Asphalt for Sri Lanka: Considerations related to Climate and Different Traffic Conditions. Annual Sessions of IESL 2017, Transactions Part B, pp. 617-22

Annex-01-A001 Road

Calculation of Design M_R and SN_{eff} -AASHTO (1993) method

Calculation of Design M_R and SN_{eff} -A001-AASHTO (1993) method

| Chainage | M_R (psi) | Design M_R (psi) | SN_{eff} |
|-----------------|-------------------------------|--------------------------------------|------------------------------|
| 59000 | 19,292 | 6,431 | 4.66 |
| 59050 | 12,413 | 4,138 | 4.87 |
| 59100 | 13,910 | 4,637 | 3.35 |
| 59150 | 12,253 | 4,084 | 3.73 |
| 59250 | 11,327 | 3,776 | 3.23 |
| 59300 | 22,661 | 7,554 | 4.75 |
| 59350 | 24,153 | 8,051 | 4.08 |
| 59400 | 38,124 | 12,708 | 4.58 |
| 59450 | 45,408 | 15,136 | 4.52 |
| 59501 | 37,257 | 12,419 | 4.76 |
| 59550 | 19,720 | 6,573 | 6.25 |
| 59600 | 12,955 | 4,318 | 4.22 |
| 59649 | 16,911 | 5,637 | 4.78 |
| 59700 | 13,504 | 4,501 | 4.47 |
| 59750 | 21,888 | 7,296 | 3.76 |
| 59800 | 45,528 | 15,176 | 5.45 |
| 59850 | 10,253 | 3,418 | 3.22 |
| 59900 | 26,661 | 8,887 | 4.31 |
| 59950 | 17,553 | 5,851 | 5.89 |
| 60000 | 13,978 | 4,659 | 4.44 |
| 60050 | 34,893 | 11,631 | 4.47 |
| 60100 | 28,189 | 9,396 | 4.34 |
| 60150 | 30,023 | 10,008 | 4.61 |
| 60200 | 18,832 | 6,277 | 3.73 |
| 60250 | 17,657 | 5,886 | 4.62 |
| 60300 | 36,567 | 12,189 | 4.67 |
| 60350 | 46,301 | 15,434 | 4.63 |
| 60400 | 19,768 | 6,589 | 5.14 |
| 60450 | 21,324 | 7,108 | 6.70 |
| 60500 | 14,996 | 4,999 | 4.46 |
| 60550 | 37,710 | 12,570 | 4.85 |
| 60600 | 30,569 | 10,190 | 4.07 |
| 60650 | 32,102 | 10,701 | 4.02 |
| 60700 | 70,471 | 23,490 | 4.87 |
| 60750 | 60,990 | 20,330 | 4.75 |
| 60800 | 26,376 | 8,792 | 4.07 |
| 60850 | 42,683 | 14,228 | 4.89 |
| 60900 | 41,934 | 13,978 | 4.80 |
| 60950 | 15,248 | 5,083 | 4.10 |
| 61000 | 15,102 | 5,034 | 3.80 |
| 61050 | 33,278 | 11,093 | 5.76 |
| 61100 | 14,557 | 4,852 | 3.19 |
| 61150 | 32,024 | 10,675 | 5.68 |
| 61200 | 29,361 | 9,787 | 4.57 |
| 61250 | 34,229 | 11,410 | 3.80 |

Annex-01-A001 Road

Calculation of Design M_R and SN_{eff} -Simplified method

Calculation of Design M_R -A001-Simplified method

| Chainage (m) | SM calculated at sensor locations | | | | Min SM (psi) | Design M_R (psi) (with correction factor 0.33) |
|-----------------|-----------------------------------|----------|----------|----------|-----------------|--|
| | 300 (mm) | 450 (mm) | 600 (mm) | 900 (mm) | | |
| 59000 | 35,012 | 27,804 | 25,097 | 22,508 | 22,508 | 7,503 |
| 59050 | 27,607 | 20,642 | 17,623 | 14,481 | 14,481 | 4,827 |
| 59100 | 18,814 | 16,592 | 16,228 | 16,973 | 16,228 | 5,409 |
| 59150 | 17,447 | 14,803 | 14,115 | 14,295 | 14,115 | 4,705 |
| 59250 | 14,960 | 13,121 | 13,215 | 13,704 | 13,121 | 4,374 |
| 59300 | 43,318 | 35,086 | 31,285 | 26,438 | 26,438 | 8,813 |
| 59350 | 33,677 | 29,456 | 28,179 | 25,570 | 25,570 | 8,523 |
| 59400 | 53,887 | 46,702 | 44,478 | 43,444 | 43,444 | 14,481 |
| 59450 | 62,608 | 56,508 | 52,976 | 44,793 | 44,793 | 14,931 |
| 59501 | 57,357 | 46,951 | 43,466 | 40,316 | 40,316 | 13,439 |
| 59550 | 46,204 | 33,883 | 28,524 | 23,007 | 23,007 | 7,669 |
| 59600 | 20,967 | 16,748 | 15,666 | 15,114 | 15,114 | 5,038 |
| 59649 | 30,570 | 24,243 | 21,733 | 19,729 | 19,729 | 6,576 |
| 59700 | 24,040 | 19,265 | 17,538 | 15,755 | 15,755 | 5,252 |
| 59750 | 27,811 | 25,136 | 25,535 | 27,139 | 25,136 | 8,379 |
| 59800 | 65,614 | 55,494 | 53,627 | 53,116 | 53,116 | 17,705 |
| 59850 | 13,342 | 11,897 | 11,961 | 14,231 | 11,897 | 3,966 |
| 59900 | 33,967 | 30,505 | 31,104 | 34,176 | 30,505 | 10,168 |
| 59950 | 38,557 | 28,452 | 24,308 | 20,479 | 20,479 | 6,826 |
| 60000 | 23,046 | 19,067 | 17,538 | 16,308 | 16,308 | 5,436 |
| 60050 | 50,611 | 43,549 | 40,709 | 40,709 | 40,709 | 13,570 |
| 60100 | 38,825 | 33,883 | 32,887 | 35,162 | 32,887 | 10,962 |
| 60150 | 45,196 | 37,739 | 35,027 | 31,663 | 31,663 | 10,554 |
| 60200 | 25,872 | 22,645 | 21,971 | 21,971 | 21,971 | 7,324 |
| 60250 | 30,567 | 24,613 | 22,742 | 20,600 | 20,600 | 6,867 |
| 60300 | 49,398 | 42,662 | 42,662 | 46,928 | 42,662 | 14,221 |
| 60350 | 67,684 | 56,746 | 54,017 | 53,503 | 53,503 | 17,834 |
| 60400 | 37,613 | 29,189 | 25,708 | 23,063 | 23,063 | 7,688 |
| 60450 | 55,230 | 39,592 | 32,111 | 24,879 | 24,879 | 8,293 |
| 60500 | 24,838 | 19,835 | 18,182 | 17,496 | 17,496 | 5,832 |
| 60550 | 53,126 | 45,232 | 43,995 | 44,693 | 43,995 | 14,665 |
| 60600 | 37,091 | 34,665 | 35,664 | 40,316 | 34,665 | 11,555 |
| 60650 | 36,959 | 35,002 | 37,452 | 46,815 | 35,002 | 11,667 |
| 60700 | 98,083 | 84,708 | 82,217 | 81,025 | 81,025 | 27,008 |
| 60750 | 77,085 | 71,155 | 71,155 | 80,437 | 71,155 | 23,718 |
| 60800 | 29,330 | 25,539 | 25,832 | 30,772 | 25,539 | 8,513 |
| 60850 | 61,288 | 53,116 | 49,796 | 46,477 | 46,477 | 15,492 |
| 60900 | 58,096 | 50,245 | 48,923 | 51,641 | 48,923 | 16,308 |
| 60950 | 23,618 | 19,474 | 18,378 | 17,789 | 17,789 | 5,930 |
| 61000 | 23,126 | 19,372 | 18,257 | 17,619 | 17,619 | 5,873 |
| 61050 | 63,531 | 49,695 | 44,371 | 38,825 | 38,825 | 12,942 |
| 61100 | 16,829 | 15,707 | 16,983 | 27,963 | 15,707 | 5,236 |
| 61150 | 56,043 | 43,955 | 40,030 | 37,362 | 37,362 | 12,454 |
| 61200 | 42,239 | 36,012 | 34,255 | 32,853 | 32,853 | 10,951 |
| 61250 | 40,808 | 38,825 | 39,934 | 39,651 | 38,825 | 12,942 |
| 61300 | 46,316 | 39,747 | 38,919 | 39,747 | 38,919 | 12,973 |

Calculation of SN_{eff} -A001-Simplified method

| Chainage | 0 | 200 | 300 | 450 | 600 | 900 | 1200 | Temp |
|----------|-----|-----|-----|-----|-----|-----|------|------|
| 59000 | 228 | 189 | 162 | 136 | 113 | 84 | 61 | 27.5 |
| 59050 | 268 | 228 | 203 | 181 | 159 | 129 | 101 | 29 |
| 59100 | 482 | 362 | 295 | 223 | 171 | 109 | 74 | 28.1 |
| 59150 | 454 | 378 | 322 | 253 | 199 | 131 | 89 | 33.6 |
| 59250 | 617 | 460 | 371 | 282 | 210 | 135 | 95 | 33.4 |
| 59300 | 204 | 155 | 130 | 107 | 90 | 71 | 58 | 28.7 |
| 59350 | 292 | 207 | 164 | 125 | 98 | 72 | 56 | 33.4 |
| 59400 | 174 | 129 | 104 | 80 | 63 | 43 | 33 | 29.2 |
| 59450 | 173 | 118 | 88 | 65 | 52 | 41 | 32 | 32.3 |
| 59501 | 174 | 119 | 97 | 79 | 64 | 46 | 35 | 35.3 |
| 59550 | 149 | 132 | 121 | 110 | 98 | 81 | 64 | 32.6 |
| 59600 | 380 | 311 | 266 | 222 | 178 | 123 | 87 | 35.7 |
| 59649 | 247 | 206 | 182 | 153 | 128 | 94 | 68 | 32.7 |
| 59700 | 337 | 269 | 232 | 193 | 159 | 118 | 89 | 36.1 |
| 59750 | 340 | 254 | 202 | 149 | 110 | 69 | 48 | 32.9 |
| 59800 | 135 | 102 | 85 | 67 | 52 | 35 | 24 | 36.6 |
| 59850 | 629 | 518 | 416 | 311 | 232 | 130 | 87 | 31.8 |
| 59900 | 265 | 199 | 163 | 121 | 89 | 54 | 33 | 37.1 |
| 59950 | 180 | 160 | 145 | 131 | 115 | 91 | 69 | 32.6 |
| 60000 | 346 | 284 | 242 | 195 | 159 | 114 | 84 | 37.8 |
| 60050 | 204 | 143 | 111 | 86 | 69 | 46 | 34 | 32.8 |
| 60100 | 240 | 180 | 144 | 110 | 85 | 53 | 35 | 33 |
| 60150 | 190 | 150 | 124 | 99 | 80 | 59 | 45 | 28.9 |
| 60200 | 363 | 270 | 214 | 163 | 126 | 84 | 57 | 32.9 |
| 60250 | 257 | 214 | 186 | 154 | 125 | 92 | 71 | 30.9 |
| 60300 | 180 | 138 | 114 | 88 | 66 | 40 | 26 | 32.9 |
| 60350 | 164 | 107 | 83 | 66 | 52 | 35 | 25 | 32.4 |
| 60400 | 194 | 167 | 149 | 128 | 109 | 81 | 62 | 32.8 |
| 60450 | 120 | 108 | 100 | 93 | 86 | 74 | 60 | 32.6 |
| 60500 | 304 | 258 | 224 | 187 | 153 | 106 | 75 | 32.8 |
| 60550 | 159 | 126 | 106 | 83 | 64 | 42 | 30 | 32.6 |
| 60600 | 265 | 192 | 150 | 107 | 78 | 46 | 29 | 32.7 |
| 60650 | 269 | 196 | 152 | 107 | 75 | 40 | 24 | 32.5 |
| 60700 | 116 | 76 | 57 | 44 | 34 | 23 | 16 | 32.7 |
| 60750 | 134 | 95 | 72 | 52 | 39 | 23 | 16 | 32.7 |
| 60800 | 280 | 232 | 192 | 147 | 109 | 61 | 35 | 31.6 |
| 60850 | 144 | 112 | 91 | 70 | 56 | 40 | 29 | 32.4 |
| 60900 | 152 | 117 | 96 | 74 | 57 | 36 | 24 | 31.7 |
| 60950 | 338 | 278 | 235 | 190 | 151 | 104 | 72 | 30.2 |
| 61000 | 379 | 288 | 240 | 191 | 152 | 105 | 76 | 31.8 |
| 61050 | 128 | 103 | 88 | 75 | 63 | 48 | 36 | 31.3 |
| 61100 | 556 | 425 | 329 | 235 | 163 | 66 | 27 | 31.8 |
| 61150 | 134 | 114 | 100 | 85 | 70 | 50 | 35 | 30.7 |
| 61200 | 206 | 158 | 133 | 104 | 82 | 57 | 41 | 31.8 |
| 61250 | 249 | 179 | 137 | 96 | 70 | 47 | 35 | 27.3 |

| Area | A | B | l_0 (cm) |
|------|-------|--------|------------|
| 22.7 | 3.691 | 0.0948 | 31.70139 |
| 25.1 | 3.275 | 0.1039 | 44.42924 |
| 19.0 | 2.371 | 0.1096 | 18.93788 |
| 21.5 | 3.691 | 0.0948 | 28.34091 |
| 18.6 | 2.371 | 0.1096 | 18.23344 |
| 21.0 | 3.691 | 0.0948 | 27.0987 |
| 18.2 | 2.371 | 0.1096 | 17.51638 |
| 19.0 | 2.8 | 0.1044 | 20.35282 |
| 17.1 | 2.371 | 0.1096 | 15.50377 |
| 18.7 | 2.371 | 0.1096 | 18.388 |
| 26.9 | 3.275 | 0.1039 | 53.57905 |
| 22.0 | 3.691 | 0.0948 | 29.60682 |
| 23.3 | 3.275 | 0.1039 | 37.03165 |
| 22.0 | 3.691 | 0.0948 | 29.77734 |
| 18.2 | 2.371 | 0.1096 | 17.48346 |
| 19.7 | 2.8 | 0.1044 | 21.97223 |
| 19.6 | 2.8 | 0.1044 | 21.67425 |
| 18.6 | 2.371 | 0.1096 | 18.2761 |
| 26.4 | 3.275 | 0.1039 | 50.69435 |
| 21.9 | 3.691 | 0.0948 | 29.38657 |
| 17.9 | 2.371 | 0.1096 | 16.93978 |
| 18.8 | 2.371 | 0.1096 | 18.5608 |
| 20.7 | 2.8 | 0.1044 | 24.42592 |
| 18.6 | 2.371 | 0.1096 | 18.26436 |
| 22.7 | 3.691 | 0.0948 | 31.65649 |
| 19.3 | 2.8 | 0.1044 | 21.07357 |
| 17.2 | 2.371 | 0.1096 | 15.54731 |
| 24.5 | 3.275 | 0.1039 | 41.60078 |
| 28.3 | 3.275 | 0.1039 | 61.97232 |
| 23.0 | 3.691 | 0.0948 | 32.58339 |
| 20.4 | 2.8 | 0.1044 | 23.59312 |
| 17.4 | 2.371 | 0.1096 | 15.90494 |
| 17.0 | 2.371 | 0.1096 | 15.31065 |
| 16.6 | 2.371 | 0.1096 | 14.62964 |
| 17.0 | 2.371 | 0.1096 | 15.22959 |
| 20.2 | 2.8 | 0.1044 | 23.08643 |
| 19.9 | 2.8 | 0.1044 | 22.39683 |
| 19.5 | 2.8 | 0.1044 | 21.44345 |
| 21.6 | 3.691 | 0.0948 | 28.47041 |
| 20.1 | 2.8 | 0.1044 | 22.76746 |
| 22.4 | 3.691 | 0.0948 | 30.87695 |
| 17.3 | 2.371 | 0.1096 | 15.84386 |
| 23.5 | 3.275 | 0.1039 | 37.49063 |
| 20.2 | 2.8 | 0.1044 | 23.03184 |
| 17.1 | 2.371 | 0.1096 | 15.46217 |

| E_{sg} (Mpa) | SN_{eff} | Tem. Cor.Factor | SN_{eff} Temp.Corrected |
|----------------|------------|-----------------|---------------------------|
| 155.19 | 3.10 | 1.03 | 3.02 |
| 99.84 | 3.75 | 1.01 | 3.71 |
| 111.89 | 1.66 | 1.02 | 1.63 |
| 97.32 | 2.37 | 0.96 | 2.47 |
| 90.46 | 1.49 | 0.96 | 1.55 |
| 182.28 | 2.80 | 1.01 | 2.76 |
| 176.30 | 1.79 | 0.96 | 1.86 |
| 299.53 | 2.48 | 1.01 | 2.46 |
| 308.83 | 1.91 | 0.97 | 1.96 |
| 277.97 | 2.18 | 0.94 | 2.32 |
| 158.63 | 5.28 | 0.97 | 5.43 |
| 104.21 | 2.54 | 0.94 | 2.71 |
| 136.03 | 3.47 | 0.97 | 3.57 |
| 108.63 | 2.59 | 0.93 | 2.77 |
| 173.30 | 1.77 | 0.97 | 1.83 |
| 366.22 | 2.86 | 0.93 | 3.09 |
| 82.03 | 1.71 | 0.98 | 1.75 |
| 210.32 | 1.98 | 0.92 | 2.15 |
| 141.20 | 4.80 | 0.97 | 4.95 |
| 112.44 | 2.58 | 0.91 | 2.82 |
| 280.68 | 2.02 | 0.97 | 2.08 |
| 226.75 | 2.06 | 0.97 | 2.13 |
| 218.31 | 2.68 | 1.01 | 2.64 |
| 151.48 | 1.77 | 0.97 | 1.83 |
| 142.03 | 3.01 | 0.99 | 3.04 |
| 294.14 | 2.55 | 0.97 | 2.63 |
| 368.89 | 2.03 | 0.97 | 2.08 |
| 159.01 | 4.10 | 0.97 | 4.23 |
| 171.53 | 6.27 | 0.97 | 6.45 |
| 120.63 | 2.93 | 0.97 | 3.02 |
| 303.33 | 2.89 | 0.97 | 2.97 |
| 239.00 | 1.80 | 0.97 | 1.85 |
| 241.33 | 1.73 | 0.97 | 1.78 |
| 558.65 | 2.19 | 0.97 | 2.26 |
| 490.60 | 2.19 | 0.97 | 2.25 |
| 176.08 | 2.36 | 0.98 | 2.40 |
| 320.44 | 2.79 | 0.97 | 2.87 |
| 337.31 | 2.72 | 0.98 | 2.77 |
| 122.65 | 2.57 | 1.00 | 2.58 |
| 121.48 | 2.05 | 0.98 | 2.09 |
| 267.69 | 3.62 | 0.99 | 3.67 |
| 108.29 | 1.37 | 0.98 | 1.40 |
| 257.60 | 4.34 | 0.99 | 4.38 |
| 226.51 | 2.56 | 0.98 | 2.61 |
| 267.69 | 1.81 | 1.03 | 1.76 |

Annex-01-A001 Road

Overlay Design with AASHTO (1993) method and Simplified method

Overlay Design-A001 Road-AASHTO (1993) method

Calculation of SN_f for A011 road (0 to 1.5 km)

| | | | |
|--------------|-----------------------------------|------------------|---|
| M_R | design subgrade resilient modulus | 7,715 psi | (from calculation) |
| W_{18} | estimated future traffic | 26.25 msa | (from design report) |
| R | reliability | 0.85 | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) |
| S_0 | standard deviation | 0.4 | (cl.4.3 AASHTO (1993)-Part I) |
| ΔPSI | serviceability loss | 1.5 | (cl.2.2.1 AASHTO (1993)-Part II) |
| | SN_f | 5.34 | (cl.3.1.1 AASHTO (1993)-Part II) |

Calculation of design overlay thickness for A001 road 59 km to 100 km)

| | | | |
|------------|--|---|--|
| SN_f | - required structural number to carry future traffic | = | 5.34 |
| SN_{eff} | - effective structural number of the existing pavement | = | 4.00 |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 1.34$ |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 1.34/0.4 = 85.09$ mm |
| T_{pro} | - overlay thickness provided | = | 100 mm |

Overlay Design-A001 Road-Simplified method

Calculation of SN_f for A011 road (0 to 1.5 km)

| | | | |
|--------------|-----------------------------------|------------------|---|
| M_R | design subgrade resilient modulus | 8,315 psi | (from calculation) |
| W_{18} | estimated future traffic | 26.25 msa | (from design report) |
| R | reliability | 0.85 | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) |
| S_0 | standard deviation | 0.4 | (cl.4.3 AASHTO (1993)-Part I) |
| ΔPSI | serviceability loss | 1.5 | (cl.2.2.1 AASHTO (1993)-Part II) |
| | SN_f | 5.21 | (cl.3.1.1 AASHTO (1993)-Part II) |

Calculation of design overlay thickness for A001 road 59 km to 100 km)

| | | | |
|------------|--|---|--|
| SN_f | - required structural number to carry future traffic | = | 5.21 |
| SN_{eff} | - effective structural number of the existing pavement | = | 3.66 |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.21 - 3.66 = 1.55$ |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 1.55/0.4 = 98.43$ mm |
| T_{pro} | - overlay thickness provided | = | 100 mm |

Annex-02-A011 Road

Annex-02-A011 Road

FWD Data

IKUAB FWD FILE : A11 MHT Rd.fwd

HOperator : MRM

HRoad : A011

HWeather : Sunny

IDate Created : 02/04/2019

IVersion : 2.4.75

ILoad Mode : 1 (2 + 2 buffers)

IPlate Radius : 15.0 (cm)

IExtra Field Set : KUAB

IDrop Sequence : 33

INo of drops : 11

IRecord Drop? : NY

IDrop Height : 1 2 3 4

IImpact Load : 15.0 25.0 40.0 50.0 kN

ISensor Number : 0 1 2 3 4 5 6

ISensor Distance : 0.0 20.0 30.0 45.0 60.0 90.0 120.0 (cm)

ISensor Position : CENTER BEHIND BEHIND BEHIND BEHIND BEHIND

IReference Offset : 0 m

ITestpoint spacing: 100 m

JDistance Imp Load D0 D1 D2 D3 D4 D5 D6 Air Pavement Emod Lat Long Time

J m Num kN μm μm μm μm μm μm °C °C MPa

J-----

D 0 2 40.2 559 447 369 265 182 98 58 33.7 47.9 268 0807.64668 08033.77061 10:40:55

C Comment at 0 m Time: 10:41:02 :start on Maradankadawala Jn on A9

D 100 2 40.5 612 451 359 256 176 91 53 33.6 46.1 247 0807.61390 08033.81346 10:41:40

T Mix temperature at 207 m, depth 5 cm :48.0 Time: 10:55:58

D 200 2 41.0 389 284 215 144 96 53 33 33.5 44.9 392 0807.58005 08033.85901 10:56:18

D 300 2 40.9 240 184 147 103 73 45 31 33.6 42.2 636 0807.55068 08033.89750 10:56:59

D 400 2 41.0 245 190 157 118 85 50 32 33.4 41.4 623 0807.51331 08033.94911 10:57:40

D 500 2 40.9 425 335 269 196 138 77 48 33.7 45.8 358 0807.48870 08033.98581 10:58:19

D 602 2 41.1 226 175 152 129 103 71 48 33.7 46.6 675 0807.45488 08034.02975 10:58:58

D 700 2 41.0 346 267 212 153 106 58 37 33.7 41.6 442 0807.41988 08034.07343 10:59:42

D 800 2 40.9 321 234 187 141 105 67 47 33.8 43.0 476 0807.39131 08034.11798 11:00:23

D 900 2 40.9 244 172 130 91 67 46 35 34.0 44.5 625 0807.35764 08034.16467 11:04:44

C Comment at 993 m Time: 11:05:05 :1kmp

D 1000 2 40.9 278 208 166 125 93 58 39 33.9 41.6 548 0807.32835 08034.20736 11:05:24

D 1100 2 40.9 417 338 278 211 151 83 48 33.7 37.7 365 0807.29961 08034.25556 11:06:06

D 1200 2 40.7 653 504 405 299 210 116 71 33.6 45.3 232 0807.26592 08034.30046 11:09:27

D 1300 2 41.2 285 193 151 109 82 53 38 33.5 42.9 538 0807.23678 08034.34290 11:10:06

D 1400 2 41.2 197 154 124 91 66 40 26 33.6 41.0 777 0807.21038 08034.38590 11:13:34

D 1500 2 41.3 223 151 112 75 54 34 24 33.5 35.1 689 0807.17591 08034.43819 11:14:17

D 1600 2 41.2 201 129 93 66 48 33 25 33.6 37.7 765 0807.14800 08034.47388 11:14:57

D 1700 2 41.0 381 259 185 114 68 27 12 33.6 46.3 400 0807.11584 08034.51893 11:18:18

D 1900 2 41.2 163 134 120 106 90 65 45 33.5 44.8 941 0807.05782 08034.61327 11:21:48

C Comment at 1992 m Time: 11:25:07 :2kmp

D 2000 2 40.5 382 295 243 180 126 58 25 33.6 47.2 395 0807.02019 08034.64862 11:25:30

D 2100 2 41.2 237 183 152 120 94 63 45 33.8 46.4 648 0806.98585 08034.69391 11:26:12

D 2200 2 40.9 461 362 297 226 163 94 59 33.6 46.0 331 0806.94934 08034.73729 11:29:31

D 2300 2 41.0 425 352 292 223 165 96 59 33.8 48.2 359 0806.91704 08034.77751 11:30:09
D 2400 2 41.1 397 279 204 132 86 51 36 33.8 48.8 386 0806.88324 08034.82170 11:33:47
D 2500 2 40.8 404 296 226 158 112 72 53 34.2 52.0 376 0806.84581 08034.86544 11:36:26
D 2600 2 40.9 348 270 220 164 120 77 55 34.7 53.9 438 0806.81078 08034.89985 11:37:09
D 2700 2 41.1 404 290 211 143 98 62 44 35.0 52.4 379 0806.77070 08034.93326 11:39:48
D 2800 2 41.1 398 278 205 131 85 52 38 35.0 52.9 385 0806.72661 08034.96416 11:40:33
D 2900 2 41.1 340 283 239 189 143 90 60 35.5 45.5 451 0806.68181 08034.99725 11:41:16
C Comment at 2998 m Time: 11:41:40 :3kmp
D 3000 2 41.0 430 353 304 244 188 118 74 35.6 52.2 355 0806.63902 08035.03038 11:41:59
D 3100 2 41.1 434 353 295 229 170 105 69 35.7 41.6 353 0806.59488 08035.06718 11:42:47
C Comment at 3112 m Time: 11:42:54 :culvert
T Mix temperature at 3200 m, depth 5 cm :45.0 Time: 11:54:53
D 3200 2 40.5 585 470 395 310 233 138 84 35.8 50.4 258 0806.55709 08035.09594 11:55:22
D 3300 2 40.8 594 474 397 308 233 148 97 35.6 50.6 256 0806.52580 08035.14008 11:56:07
D 3400 2 40.8 497 409 341 268 204 128 85 36.2 50.3 306 0806.49332 08035.18878 11:56:52
D 3500 2 40.8 590 482 400 297 208 109 62 36.4 50.3 258 0806.46482 08035.23053 11:57:36
D 3600 2 40.8 527 409 329 243 174 100 63 36.3 50.1 288 0806.43848 08035.27539 11:58:19
D 3700 2 41.0 459 368 307 236 174 102 63 36.2 50.3 333 0806.40875 08035.32407 11:59:08
D 3800 2 41.3 276 207 171 135 103 68 47 36.3 50.8 558 0806.38023 08035.37228 11:59:52
D 3900 2 40.9 525 414 335 248 173 92 54 36.2 51.1 290 0806.35288 08035.41685 12:03:33
D 4000 2 41.4 210 146 111 81 62 43 32 36.4 52.6 734 0806.32526 08035.46584 12:04:17
C Comment at 4002 m Time: 12:04:24 :4kmp
D 4100 2 41.3 242 175 133 94 67 42 30 36.5 43.1 634 0806.29490 08035.51069 12:07:45
D 4200 2 40.6 787 602 470 326 209 106 60 36.5 53.3 192 0806.26798 08035.55855 12:08:25
D 4300 2 40.7 861 690 564 415 291 153 86 36.6 53.1 176 0806.24142 08035.60388 12:11:47
D 4400 2 41.2 414 321 256 183 124 65 40 37.1 49.8 370 0806.21201 08035.65203 12:15:23
D 4500 2 41.3 290 218 178 140 109 75 51 37.0 51.6 531 0806.18527 08035.69706 12:16:02
D 4600 2 41.1 317 216 161 110 76 48 34 36.9 51.1 484 0806.15569 08035.74530 12:16:42
D 4700 2 41.3 406 336 269 202 146 87 56 37.0 48.9 379 0806.12888 08035.78698 12:20:04
D 4800 2 41.0 490 413 353 283 215 128 75 37.1 52.2 312 0806.09651 08035.84250 12:20:44
D 4900 2 41.3 250 209 190 166 139 100 70 37.3 50.7 616 0806.06773 08035.87424 12:21:23
D 5000 2 41.0 476 374 312 239 174 103 63 37.4 52.7 321 0806.02847 08035.91245 12:22:06
C Comment at 5012 m Time: 12:22:19 :5kmp
D 5100 2 41.1 327 260 212 159 116 70 47 37.4 52.5 469 0805.99073 08035.94903 12:22:47
D 5200 2 41.1 405 324 263 194 139 77 47 37.4 51.3 378 0805.94357 08035.97622 12:23:30
D 5300 2 41.3 241 197 172 143 114 77 51 37.0 40.9 639 0805.89631 08036.00513 12:27:46
D 5400 2 41.1 444 343 271 196 133 67 37 37.0 53.0 344 0805.85813 08036.03516 12:31:23
D 5500 2 40.6 470 354 277 203 150 94 64 37.4 52.6 322 0805.81400 08036.07142 12:32:01
D 5600 2 40.9 489 365 293 219 164 107 74 37.7 52.3 312 0805.77703 08036.11320 12:36:28
D 5700 2 41.2 328 273 235 190 150 102 72 37.8 52.7 468 0805.76384 08036.16214 12:40:07
D 5800 2 41.1 429 333 268 201 149 98 69 37.8 52.4 356 0805.75722 08036.21866 12:40:48
D 5900 2 41.2 447 342 272 200 144 91 64 38.1 52.5 343 0805.75840 08036.27389 12:41:28
D 6000 2 41.1 369 282 229 174 131 89 65 38.3 52.8 415 0805.76394 08036.32765 12:42:07
C Comment at 6017 m Time: 12:42:19 :6kmp
D 6100 2 41.0 687 497 390 273 187 99 57 38.2 52.3 222 0805.76420 08036.38423 12:42:46
D 6200 2 41.2 337 255 212 166 127 83 56 38.1 54.0 456 0805.75568 08036.43340 12:43:26
D 6300 2 40.9 531 393 303 216 148 79 46 38.2 54.1 287 0805.74413 08036.48497 12:44:09
D 6400 2 41.1 485 355 277 189 123 62 40 38.1 40.7 316 0805.73145 08036.53789 12:44:57
T Mix temperature at 6400 m, depth 5 cm :45.0 Time: 13:05:33
D 6500 2 40.5 621 482 392 291 208 120 75 36.9 55.6 243 0805.73128 08036.53826 13:06:05
D 6600 2 40.5 895 678 518 352 234 121 70 37.3 54.3 169 0805.71088 08036.64606 13:06:47

Annex-02-A011 Road

Pavement Design Report

1. Introduction

A011- Maradankadawala- Trikandimadu Road is a major arterial road in the road network of Sri Lanka. Pavement enhancement and widening of A011- Maradankadawala- Habarana Road from 00+000 km to 25+000 km, proposed to rehabilitate under the ADB Funded Intergraded Road Investment Program (I Road Project).

Surface of the existing pavement is Asphalt Concrete which is having average thickness of 150mm over old Macadam or ABC base. The existing road consists of two lanes with 3.2m carriageway and 1.0-2.0 m soft shoulder. There is no hard shoulder.

RDA has proposed two lane road with 3.5m carriageway and 1.0m hard and 2.0 soft shoulder for asphalt pavement, 3.5m carriage way and 3.0m hard shoulder for concrete pavement in inundation road sections.

This report contains feasible pavement design with asphalt surface from Ch. 0+000 to Ch. 5+300 as there is no inundation road sections for rigid pavement with concrete surface.

2. Surface Condition

Surface condition survey was carried out on 23rd and 24th of March 2019. Condition of existing pavement is visually good. However, Longitudinal, Transverse and Crocodile Cracks can be observed in loaded areas. This shows the requirement of rehabilitation with asphalt overlay. Detail of surface condition survey is attached in Annex 10. All cracked areas shall be sealed. Geo-Composite shall be used to mitigate reflection of cracks.

3. Investigation

Non-destructive Testing

In order to calculate the strength of existing pavement and its subgrade strength, Load-Deflection measurement test was carried out by Falling Weight Deflectometer (FWD) in 50m interval and summary of deflections are given in Annex 6. FWD was conducted by Road Development Authority (RDA) on 2nd April 2019.

Since high deflections were observed at Ch. 1+150 and Ch. 1+250, addition test pits will be carried out in this locations and suitable improvement will be provided where required.

Material Sampling and Testing

To determine subgrade strength (at soaked condition & deferent compaction levels) and other properties of subgrade. Test pits were conducted at 500 m interval for collecting subgrade sample and field tests on the existing pavement of the road and widening area separately. Following tests have been carried out at the test site locations and the laboratory for collected samples.

Field tests:

- A log of existing layer profile
- Dynamic Cone Penetrometer (DCP) Test
- Field Density

Laboratory tests:

- CBR (4 days soaked)
- Modified Proctor Compaction Test
- Atterberg Limits Test
- Sieve Analysis
- Optimum Moisture Content

An Equivalent DCP CBR value of subgrade soil layers were calculated using the following Japanese formula, introduced by Japan Road Association in 1989 (Refer Ausroad-2010).

$$\text{Equivalent DCP CBR} = \left[\frac{\sum (\text{Layer thickness} \times \text{DCP CBR}^{1/3})}{\sum \text{Layer thickness}} \right]^3$$

Summary of test results at existing pavement and widening areas are given under Annex 1, DCP summary is under Annex 2 and summary of existing pavement layer details are given under Annex 3.

Since subgrade under existing pavement cannot be further compacted, Subgrade strength of overlay areas is considered as 4 day soaked lab CBR at Field Density. Subgrade strength of widening and reconstruction areas are considered as 4 day soaked CBR at 95% of MDD (i.e. subgrade strength after compaction of subgrade). According to Sri Lankan condition, 4 days soaked strength is considered in the design.

Further in soil classification (AASHTO Materials, Part 1, Specification, Washington D.C.), A-6 type clay soil is encountered at 0+742, 05+759 (refer annex 1A) and 05+001 (refer annex 1B). Therefore attention should be provided at those locations when preparing sub grade.

Both an Equivalent DCP CBR and Lab CBR are used to determine the design Subgrade strength (Design CBR). Here lower 15 percentile value is considered for overlaying design as reliability is 85% according to AASHTO (Table 2.2 AASHTO). Lower 10 percentile value is considered for widening and reconstruction design according to Road Note 31 (cl. 3.2). For more safe design, minimum of DCP and 4 days soak CBR is considered. Summary of Design CBR values of subgrade are given in Table 01.

Table 01: Design CBR Values

| | Chainage | DCP CBR lower 15 Percentile Value (%) | DCP CBR lower 10 Percentile Value (%) | Lab CBR lower 15 Percentile Value(%) | Lab CBR lower 10 Percentile Value (%) | Minimum CBR (%) | Design CBR/ (%) |
|-----------------------------|----------------------|---------------------------------------|---------------------------------------|--------------------------------------|---------------------------------------|-----------------|-----------------|
| Overlaying | Ch 0+000 to Ch 1+500 | 11.5 | - | 8.5 | - | 7.0 | 7 |
| | Ch 1+500 to Ch 5+300 | 8.5 | - | 11.0 | - | 8.0 | 8 |
| Widening and Reconstruction | Ch 0+000 to Ch 3+256 | - | 9.5 | - | 12.0 | 8.8 | 8 |
| | Ch 3+256 to Ch 4+300 | - | 6.4 | - | 14.4 | 6.2 | 5 |
| | Ch 4+300 to Ch 5+300 | - | 8.3 | - | 23 | 8.1 | 8 |

Sample of trial pit at chainage 0+006 (HM-CL-14) is shown low CBR than design CBR. This area will be retested and provide improvement where required.

4. Traffic Forecast

Three days 24 hours traffic count were conducted on 20th March 2019. Traffic was observed by using CCTV camera. Summary of traffic count is attached in Annex 8B. Axial Load data provided by Planning Division of RDA for initial designs (attached under Annex 8A), are used for Traffic Load Calculation. Growth rates proposed in contract document are used to calculate the Cumulative Number of Standard Axles (CNSA) for 10-year and are summarized in Table 2. Traffic calculations are shown in Annex 8C. Since lane width is 3.5 m, Directional factor is considered as 0.50 according to AASHTO guide for design of pavement 1993, cl.2.1.2

Table 02: CNSA Value - 10 years

| Road Section | CNSA/msa | Design CNSA/msa |
|----------------------|----------|-----------------|
| Ch 0+000 to Ch 5+300 | 16.3 | 8.15 |

5. Pavement Structural Evaluation

The Falling Weight Deflectometer (FWD) is an excellent device for evaluating the structural capacity of pavements for overlay designs. AASHTO Guide was used to estimate Effective Structural Number of existing top hard layers. FWD data along with the computed Effective Structural Numbers of the existing pavement are presented in Annex 6. Details of the calculations are described below.

- Deflection of loading point (D_0) is corrected for standard temperature according to asphalt thickness. Here Average asphalt thickness taken from test pit investigation. Variation of thickness shown in Annexure 04. Average asphalt thickness is 150 mm.
- Based on test pit investigation, top hard layer thickness is taken. Here Asphalt, Macadam and ABC layers are considered as hard layers. 85% value of top hard layer thickness (D) are considered for the design. Calculated D is 210mm and presented in Annex 5.
- Overall Subgrade Resilient Modulus (M_R) below the depth was estimated from Eq.02.

$$M_R = \frac{0.24P}{d_r r} \text{-----Eq. 02}$$

where

- M_R = backcalculated subgrade resilient modulus, psi
- P = applied load, pounds
- d_r = deflection at a distance r from the center of the load, inches
- r = distance from center of load, inches

- Minimum distance (r) was determined by following relationship given by Eq03.

$$r \geq 0.7a_e \text{-----Eq. 03}$$

where

$$a_c = \sqrt{a^2 + \left(D \sqrt[3]{\frac{E_p}{M_R}} \right)^2}$$

- a_c = radius of the stress bulb at the subgrade-pavement interface, inches
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- E_p = effective modulus of all pavement layers above the subgrade, psi (described below)

- Effective modulus (E_p) of all existing pavement layers above the subgrade is calculated from Eq.04. and presented under Annex 3

$$\frac{M_R d_0}{q a} = 1.5 \left\{ \frac{1}{\sqrt{1 + \left[\left(\frac{D}{a} \right)^3 \frac{E_p}{M_R} \right]^2}} + \frac{1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a} \right)^2}}}{\left(\frac{E_p}{M_R} \right)} \right\} \text{-----Eq. 04}$$

where

- d_0 = deflection measured at the center of the load plate, inches
- p = NDT load plate pressure, psi
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- M_R = subgrade resilient modulus, psi
- E_p = effective modulus of all pavement layers above the subgrade, psi

- Effective Structural Number of existing pavement layers are computed from Eq.05 and presented under Annex 6.

$$SN_{eff} = 0.0045 D \sqrt[3]{E_p} \text{-----Eq. 05}$$

- Summary of Effective Structural Number is presented under Table 3 as given below.

Table 03: Summary of Effective Structural Number of the Existing Pavement

| Section | SN_{eff} - Lower 15 percentile value |
|----------------------|---|
| Ch 0+000 to Ch 5+300 | 2.4 |

6. Pavement Thickness Calculation

Pavement Overlay Design

As there are sufficient structural capacity in the existing pavement, it was decided to overlay with asphalt concrete. Pavement overlay thickness was calculated according to AASHTO Guide for Design of Pavement Structures 1993 considering Design Traffic, Design Subgrade Strength and Effective Structural Number of Existing Pavement. Here, Design Subgrade Strength is measured in term of Resilient Modulus (M_R).

- Design Subgrade Resilient Modulus (M_R) is estimated from Design Subgrade CBR using the following equation (Pavement Analysis and Design, Yang H. Huang ,2nd Edition, eq. 7.6) .

$$M_R = 1500 \times CBR \% \dots\dots\dots \text{Eq.06}$$

- Required Structural Number (SN_f) for Design Traffic and Design Subgrade Resilient Modulus are calculated from equation 06. Considered parameters are as follows.

$$\log W_{18} = Z_R S_0 + 9.36 \log(SN + 1) - 0.20 + \frac{\log[\Delta PSI/(4.2 - 1.5)]}{0.4 + 1094/(SN + 1)^{5.19}} + 2.32 \log M_R - 8.07 \quad (11.37)$$

\dots\dots\dots \text{Eq. 07}

Table 04 - Design Parameters

| Item | Reference |
|-----------------------------------|------------------|
| Reliability = 85% | Table 2.2 AASHTO |
| Standard Normal Deviate = -1.037 | Cl 2.1.3 AASHTO |
| Overall Standard Deviation = 0.35 | Cl 2.1.3 AASHTO |
| Design Serviceability Loss = 1.7 | Cl 2.2.1 AASHTO |

- Overlay thicknesses are calculated from Eq.07 and summary of design pavement thicknesses are presented in Table 05.

$$D_{ol} = \frac{SN_{ol}}{a_{ol}} = \frac{(SN_f - SN_{eff})}{a_{ol}} \quad \text{-----Eq. 08.}$$

where

- SN_{ol} = Required overlay structural number
- a_{ol} = Structural coefficient for the AC overlay
- D_{ol} = Required AC overlay thickness, inches
- SN_f = Structural number determined in Step 6
- SN_{eff} = Effective structural number of the existing pavement, from Step 7

Table 05– Design Layer Thicknesses for Existing Pavement

| Section (Chainage) | SN_{eff} | Sub grade CBR % | Traffic CNESA / (msa) | Asphalt Wearing Course (in mm) | Asphalt Binder Course (in mm) |
|--------------------|------------|-----------------|-----------------------|--------------------------------|-------------------------------|
| 0+000-1+500 | 2.4 | 7 | 8.15 | 50 | 50 |
| 1+500-5+300 | 2.4 | 8 | 8.15 | 50 | 40 |

- Refer annex 11 for typical cross section

Pavement Widening and Reconstruction Design

The design thicknesses of the road pavement widening and reconstruction sections for the next 10 years (2019 – 2029) are calculated referring to Road Note 31 and presented in the table 5 based on the design subgrade CBR, and the design traffic. Design calculations are shown in *Annex 5B*.

Table 06– Design Layer Thicknesses for Widening and Reconstruction Sections.

| Section (Chainage) | Sub grade CBR / (Subgrade Strength Class) | Traffic CNESA / (Traffic Class) | Asphalt Wearing Course (in mm) | Asphalt Binder Course (in mm) | Dense Graded Aggregate Base (in mm) | Sub Base (in mm) |
|--------------------|---|---------------------------------|--------------------------------|-------------------------------|-------------------------------------|------------------|
| 0+000-3+250 | 8%/(S4) | 8.15 msa/(T6) | 50 | - | 200 | 275 |
| 3+250-4+300 | 5%/(S3) | 8.15 msa/(T6) | 50 | - | 200 | 350 |
| 4+300-5+300 | 8%/(S4) | 8.15 msa/(T6) | 50 | - | 200 | 275 |

- Refer annex 11 for typical cross section

7. Conclusion

Structural capacity of the pavement is good, but it is not sufficient for cater next 10-year design traffic. Hence, road will rehabilitate immediately with layer thicknesses given in Table 05 and Table 06.

All cracked areas will be sealed and other distresses will be rectified before overlaying. Geo-Composite will be used to mitigate reflection of cracks. Additional thicknesses resulting on vertical correction and camber correction may be substituted with a Bitumen Bound Base (BBB) layer of minimum thickness of 50mm.

Widening section is strengthen to prevent crack along joint between existing road and widening. Appropriate method will be provided in construction stage before asphalt laying.

Material and method of construction has to be used according to Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009) and the Employer Requirement.

References

- AASHTO Guide for Design of Pavement Structures, 1993
- Transport & Road Research Laboratory, United Kingdom Road Note 31, 1977
- "Pavement Analysis and Design", Yang H. Huang ,2nd Edition
- Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009)
- RDA Pavement Design Guide, 1999
- Guide to Pavement Technology Part 2: Pavement Structural Design, Austroads 2012.

Annex-02-A011 Road

Calculation of Design M_R and SN_{eff} -AASHTO (1993) method

AASHTO (1993) method
Calculation of Design M_R and SN_{eff} -A011 Road

| Chainage | M_R (psi) | Design M_R (psi) | SN_{eff} |
|----------|-------------|--------------------|------------|
| 0 | 12,814 | 4,271 | 2.70 |
| 50 | 13,795 | 4,598 | 2.68 |
| 100 | 13,350 | 4,450 | 2.57 |
| 150 | 15,383 | 5,128 | 2.91 |
| 200 | 24,777 | 8,259 | 2.63 |
| 250 | 31,117 | 10,372 | 3.55 |
| 300 | 32,504 | 10,835 | 3.43 |
| 350 | 52,592 | 17,531 | 3.28 |
| 400 | 27,984 | 9,328 | 3.65 |
| 450 | 32,981 | 10,994 | 3.81 |
| 500 | 17,194 | 5,731 | 2.95 |
| 550 | 21,638 | 7,213 | 3.62 |
| 602 | 23,150 | 7,717 | 4.23 |
| 650 | 16,484 | 5,495 | 3.70 |
| 700 | 22,440 | 7,480 | 2.97 |
| 750 | 14,193 | 4,731 | 2.91 |
| 800 | 22,598 | 7,533 | 3.10 |
| 850 | 32,457 | 10,819 | 3.49 |
| 900 | 35,415 | 11,805 | 2.97 |
| 950 | 14,683 | 4,894 | 2.49 |
| 1000 | 25,514 | 8,505 | 3.47 |
| 1050 | 16,411 | 5,470 | 2.97 |
| 1100 | 15,714 | 5,238 | 3.10 |
| 1150 | 11,518 | 3,839 | 1.78 |
| 1200 | 11,244 | 3,748 | 2.62 |
| 1250 | 14,294 | 4,765 | 1.79 |
| 1300 | 29,149 | 9,716 | 2.96 |
| 1350 | 39,659 | 13,220 | 3.52 |
| 1400 | 36,215 | 12,072 | 3.68 |
| 1450 | 44,586 | 14,862 | 3.68 |
| 1500 | 44,371 | 14,790 | 2.83 |
| 1550 | 45,536 | 15,179 | 3.83 |
| 1600 | 49,796 | 16,599 | 2.84 |
| 1650 | 17,320 | 5,773 | 3.77 |
| 1700 | 34,980 | 11,660 | 2.10 |
| 1750 | 36,215 | 12,072 | 2.98 |
| 1850 | 15,106 | 5,035 | 3.94 |
| 1900 | 26,558 | 8,853 | 5.28 |
| 1950 | 12,726 | 4,242 | 2.82 |
| 2000 | 18,648 | 6,216 | 2.96 |
| 2050 | 186,095 | 62,032 | 2.38 |
| 2100 | 25,428 | 8,476 | 3.85 |
| 2150 | 16,081 | 5,360 | 3.22 |
| 2200 | 14,557 | 4,852 | 2.95 |

Annex-02-A011 Road

Calculation of Design M_R and SN_{eff} -Simplified method

Calculation of Design M_R -A011-Simplified method

| Chainage (m) | SM calculated at sensor locations | | | | Min SM (psi) | Design M_R (psi) (with correction factor 0.33) |
|-----------------|-----------------------------------|----------|----------|----------|-----------------|--|
| | 300 (mm) | 450 (mm) | 600 (mm) | 900 (mm) | | |
| 0 | 14,747 | 13,690 | 14,950 | 18,510 | 13,690 | 4,518 |
| 50 | 16,577 | 15,066 | 16,095 | 19,844 | 15,066 | 4,972 |
| 100 | 15,271 | 14,277 | 15,575 | 20,082 | 14,277 | 4,711 |
| 150 | 18,423 | 16,783 | 17,947 | 21,074 | 16,783 | 5,538 |
| 200 | 25,815 | 25,695 | 28,907 | 34,906 | 25,695 | 8,479 |
| 250 | 40,513 | 36,186 | 36,303 | 38,032 | 36,186 | 11,941 |
| 300 | 37,664 | 35,835 | 37,922 | 41,012 | 35,835 | 11,826 |
| 350 | 58,195 | 56,168 | 61,357 | 69,690 | 56,168 | 18,535 |
| 400 | 35,351 | 31,357 | 32,648 | 37,001 | 31,357 | 10,348 |
| 450 | 46,815 | 39,843 | 38,478 | 37,452 | 37,452 | 12,359 |
| 500 | 20,582 | 18,832 | 20,060 | 23,968 | 18,832 | 6,215 |
| 550 | 29,496 | 25,416 | 25,244 | 26,311 | 25,244 | 8,331 |
| 602 | 36,603 | 28,753 | 27,008 | 26,120 | 26,120 | 8,620 |
| 650 | 23,142 | 19,569 | 19,232 | 20,207 | 19,232 | 6,346 |
| 700 | 26,180 | 24,184 | 26,180 | 31,897 | 24,184 | 7,981 |
| 750 | 17,662 | 15,717 | 16,559 | 19,729 | 15,717 | 5,186 |
| 800 | 29,607 | 26,178 | 26,365 | 27,545 | 26,178 | 8,639 |
| 850 | 41,208 | 37,362 | 37,867 | 38,919 | 37,362 | 12,329 |
| 900 | 42,589 | 40,561 | 41,318 | 40,120 | 40,120 | 13,240 |
| 950 | 16,134 | 15,482 | 17,130 | 21,765 | 15,482 | 5,109 |
| 1000 | 33,353 | 29,528 | 29,767 | 31,819 | 29,528 | 9,744 |
| 1050 | 20,479 | 18,451 | 19,146 | 21,924 | 18,451 | 6,089 |
| 1100 | 19,916 | 17,493 | 18,333 | 22,235 | 17,493 | 5,773 |
| 1150 | 10,463 | 10,813 | 13,437 | 20,305 | 10,463 | 3,453 |
| 1200 | 13,604 | 12,284 | 13,118 | 15,832 | 12,284 | 4,054 |
| 1250 | 13,637 | 14,306 | 16,676 | 20,281 | 13,637 | 4,500 |
| 1300 | 36,935 | 34,111 | 34,007 | 35,077 | 34,007 | 11,222 |
| 1350 | 51,317 | 47,041 | 46,269 | 43,759 | 43,759 | 14,440 |
| 1400 | 44,977 | 40,859 | 42,251 | 46,477 | 40,859 | 13,483 |
| 1450 | 58,519 | 52,017 | 52,017 | 52,017 | 52,017 | 17,166 |
| 1500 | 49,917 | 49,695 | 51,766 | 54,811 | 49,695 | 16,399 |
| 1550 | 63,274 | 55,209 | 53,126 | 49,398 | 49,398 | 16,301 |
| 1600 | 59,970 | 56,335 | 58,096 | 56,335 | 56,335 | 18,591 |
| 1650 | 24,461 | 20,542 | 20,207 | 21,871 | 20,207 | 6,668 |
| 1700 | 30,001 | 32,457 | 40,810 | 68,520 | 30,001 | 9,900 |
| 1750 | 41,934 | 39,555 | 42,251 | 54,678 | 39,555 | 13,053 |
| 1850 | 23,351 | 18,775 | 17,623 | 17,791 | 17,623 | 5,816 |
| 1900 | 46,477 | 35,077 | 30,984 | 28,601 | 28,601 | 9,438 |
| 1950 | 15,963 | 14,327 | 14,847 | 17,368 | 14,327 | 4,728 |
| 2000 | 22,561 | 20,305 | 21,756 | 31,508 | 20,305 | 6,701 |
| 2050 | 117,602 | 139,380 | 217,111 | 627,209 | 117,602 | 38,809 |
| 2100 | 36,692 | 30,984 | 29,666 | 29,509 | 29,509 | 9,738 |
| 2150 | 22,274 | 19,114 | 18,761 | 20,706 | 18,761 | 6,191 |
| 2200 | 18,642 | 16,332 | 16,983 | 19,633 | 16,332 | 5,390 |
| 2250 | 21,503 | 18,181 | 17,805 | 19,016 | 17,805 | 5,876 |
| 2300 | 19,007 | 16,592 | 16,819 | 19,271 | 16,592 | 5,475 |

Calculation of SN_{eff} -A011-Simplified method

| Chainage | 0 | 200 | 300 | 450 | 600 | 900 | 1200 | Temp |
|----------|-----|-----|-----|-----|-----|-----|------|------|
| 0 | 559 | 447 | 369 | 265 | 182 | 98 | 58 | 48.8 |
| 50 | 533 | 419 | 334 | 245 | 172 | 93 | 55 | 47.0 |
| 100 | 612 | 451 | 359 | 256 | 176 | 91 | 53 | 48.7 |
| 150 | 461 | 371 | 302 | 221 | 155 | 88 | 53 | 47.0 |
| 200 | 389 | 284 | 215 | 144 | 96 | 53 | 33 | 48.0 |
| 250 | 233 | 173 | 138 | 103 | 77 | 49 | 33 | 47.0 |
| 300 | 240 | 184 | 147 | 103 | 73 | 45 | 31 | 47.9 |
| 350 | 181 | 129 | 97 | 67 | 46 | 27 | 17 | 47.0 |
| 400 | 245 | 190 | 157 | 118 | 85 | 50 | 32 | 47.9 |
| 450 | 201 | 147 | 120 | 94 | 73 | 50 | 35 | 47.0 |
| 500 | 425 | 335 | 269 | 196 | 138 | 77 | 48 | 47.9 |
| 550 | 295 | 229 | 190 | 147 | 111 | 71 | 48 | 47.0 |
| 602 | 226 | 175 | 152 | 129 | 103 | 71 | 48 | 47.8 |
| 650 | 346 | 285 | 241 | 190 | 145 | 92 | 61 | 47.0 |
| 700 | 346 | 267 | 212 | 153 | 106 | 58 | 37 | 47.8 |
| 750 | 487 | 386 | 315 | 236 | 168 | 94 | 57 | 47.0 |
| 800 | 321 | 234 | 187 | 141 | 105 | 67 | 47 | 47.8 |
| 850 | 232 | 173 | 136 | 100 | 74 | 48 | 34 | 47.0 |
| 900 | 244 | 172 | 130 | 91 | 67 | 46 | 35 | 47.6 |
| 950 | 582 | 440 | 344 | 239 | 162 | 85 | 53 | 47.0 |
| 1000 | 278 | 208 | 166 | 125 | 93 | 58 | 39 | 47.5 |
| 1050 | 428 | 335 | 273 | 202 | 146 | 85 | 55 | 46.9 |
| 1100 | 417 | 338 | 278 | 211 | 151 | 83 | 48 | 47.5 |
| 1150 | 983 | 706 | 524 | 338 | 204 | 90 | 52 | 46.9 |
| 1200 | 653 | 504 | 405 | 299 | 210 | 116 | 71 | 47.3 |
| 1250 | 865 | 575 | 406 | 258 | 166 | 91 | 57 | 46.9 |
| 1300 | 285 | 193 | 151 | 109 | 82 | 53 | 38 | 47.3 |
| 1350 | 199 | 140 | 110 | 80 | 61 | 43 | 30 | 46.9 |
| 1400 | 197 | 154 | 124 | 91 | 66 | 40 | 26 | 47.1 |
| 1450 | 168 | 121 | 96 | 72 | 54 | 36 | 26 | 46.9 |
| 1500 | 223 | 151 | 112 | 75 | 54 | 34 | 24 | 47.1 |
| 1550 | 154 | 111 | 89 | 68 | 53 | 38 | 28 | 46.9 |
| 1600 | 201 | 129 | 93 | 66 | 48 | 33 | 25 | 47.0 |
| 1650 | 326 | 267 | 228 | 181 | 138 | 85 | 52 | 46.9 |
| 1700 | 381 | 259 | 185 | 114 | 68 | 27 | 12 | 46.9 |
| 1750 | 235 | 171 | 133 | 94 | 66 | 34 | 19 | 46.8 |
| 1850 | 339 | 276 | 240 | 199 | 159 | 105 | 67 | 46.8 |
| 1900 | 163 | 134 | 120 | 106 | 90 | 65 | 45 | 46.7 |
| 1950 | 542 | 425 | 346 | 257 | 186 | 106 | 64 | 46.8 |
| 2000 | 382 | 295 | 243 | 180 | 126 | 58 | 25 | 46.5 |
| 2050 | 116 | 71 | 48 | 27 | 13 | 3 | 0 | 46.8 |
| 2100 | 237 | 183 | 152 | 120 | 94 | 63 | 45 | 46.5 |
| 2150 | 386 | 301 | 251 | 195 | 149 | 90 | 56 | 46.8 |
| 2200 | 461 | 362 | 297 | 226 | 163 | 94 | 59 | 46.3 |
| 2250 | 384 | 311 | 260 | 205 | 157 | 98 | 63 | 46.8 |

| Area | A | B | l_0 (cm) |
|------|-------|--------|------------|
| 18.9 | 2.371 | 0.1096 | 18.77593 |
| 18.4 | 2.371 | 0.1096 | 17.88977 |
| 17.4 | 2.371 | 0.1096 | 15.9334 |
| 19.0 | 2.800 | 0.1044 | 20.44058 |
| 16.4 | 2.371 | 0.1096 | 14.32479 |
| 18.3 | 2.371 | 0.1096 | 17.68651 |
| 18.1 | 2.371 | 0.1096 | 17.28453 |
| 16.4 | 2.371 | 0.1096 | 14.26897 |
| 19.1 | 2.800 | 0.1044 | 20.51827 |
| 19.0 | 2.800 | 0.1044 | 20.38456 |
| 18.6 | 2.371 | 0.1096 | 18.16598 |
| 19.7 | 2.800 | 0.1044 | 21.8688 |
| 21.4 | 3.691 | 0.0948 | 28.13365 |
| 21.0 | 2.800 | 0.1044 | 25.03335 |
| 18.0 | 2.371 | 0.1096 | 17.11428 |
| 19.1 | 2.800 | 0.1044 | 20.47974 |
| 18.2 | 2.371 | 0.1096 | 17.36661 |
| 18.1 | 2.371 | 0.1096 | 17.24375 |
| 16.8 | 2.371 | 0.1096 | 14.98048 |
| 17.3 | 2.371 | 0.1096 | 15.8063 |
| 18.4 | 2.371 | 0.1096 | 17.87532 |
| 18.9 | 2.371 | 0.1096 | 18.89796 |
| 19.5 | 2.800 | 0.1044 | 21.53222 |
| 15.4 | 2.371 | 0.1096 | 12.87314 |
| 18.4 | 2.371 | 0.1096 | 17.75014 |
| 14.6 | 2.371 | 0.1096 | 11.70244 |
| 16.9 | 2.371 | 0.1096 | 15.1566 |
| 17.6 | 2.371 | 0.1096 | 16.33244 |
| 18.8 | 2.371 | 0.1096 | 18.59517 |
| 18.0 | 2.371 | 0.1096 | 17.04935 |
| 15.8 | 2.371 | 0.1096 | 13.46645 |
| 18.5 | 2.371 | 0.1096 | 18.09967 |
| 15.4 | 2.371 | 0.1096 | 12.82606 |
| 21.0 | 3.691 | 0.0948 | 27.11771 |
| 14.4 | 2.371 | 0.1096 | 11.48293 |
| 17.0 | 2.371 | 0.1096 | 15.32946 |
| 22.0 | 3.691 | 0.0948 | 29.6606 |
| 23.9 | 3.275 | 0.1039 | 39.04129 |
| 19.0 | 2.371 | 0.1096 | 18.92444 |
| 18.5 | 2.371 | 0.1096 | 18.01489 |
| 12.5 | 2.371 | 0.1096 | 9.295519 |
| 20.1 | 2.800 | 0.1044 | 22.71227 |
| 19.8 | 2.800 | 0.1044 | 22.20482 |
| 19.2 | 2.800 | 0.1044 | 20.77661 |
| 20.6 | 2.800 | 0.1044 | 23.95901 |

| E_{sg} (Mpa) | SN_{eff} | Tem. Cor.Factor | SN_{eff} Temp.Corrected |
|----------------|------------|-----------------|---------------------------|
| 94.39 | 1.56 | 0.79 | 1.96 |
| 103.87 | 1.53 | 0.81 | 1.88 |
| 98.44 | 1.34 | 0.79 | 1.69 |
| 115.72 | 1.81 | 0.81 | 2.23 |
| 177.16 | 1.46 | 0.80 | 1.83 |
| 249.49 | 2.03 | 0.81 | 2.49 |
| 247.08 | 1.97 | 0.80 | 2.46 |
| 387.26 | 1.89 | 0.81 | 2.33 |
| 216.20 | 2.24 | 0.80 | 2.79 |
| 258.22 | 2.36 | 0.81 | 2.91 |
| 129.84 | 1.67 | 0.80 | 2.08 |
| 174.05 | 2.22 | 0.81 | 2.73 |
| 180.09 | 2.89 | 0.80 | 3.60 |
| 132.60 | 2.32 | 0.81 | 2.86 |
| 166.74 | 1.71 | 0.80 | 2.13 |
| 108.36 | 1.78 | 0.81 | 2.19 |
| 180.49 | 1.79 | 0.80 | 2.22 |
| 257.60 | 2.00 | 0.81 | 2.46 |
| 276.62 | 1.78 | 0.81 | 2.20 |
| 106.74 | 1.36 | 0.81 | 1.68 |
| 203.59 | 1.91 | 0.81 | 2.37 |
| 127.22 | 1.73 | 0.81 | 2.12 |
| 120.61 | 1.94 | 0.81 | 2.40 |
| 72.14 | 0.98 | 0.81 | 1.20 |
| 84.70 | 1.42 | 0.81 | 1.75 |
| 94.02 | 0.97 | 0.81 | 1.19 |
| 234.47 | 1.70 | 0.81 | 2.10 |
| 301.71 | 1.99 | 0.81 | 2.45 |
| 281.71 | 2.22 | 0.81 | 2.73 |
| 358.64 | 2.20 | 0.81 | 2.71 |
| 342.64 | 1.72 | 0.81 | 2.11 |
| 340.58 | 2.30 | 0.81 | 2.83 |
| 388.42 | 1.70 | 0.81 | 2.09 |
| 139.32 | 2.56 | 0.81 | 3.14 |
| 206.85 | 1.24 | 0.81 | 1.52 |
| 272.72 | 1.81 | 0.82 | 2.22 |
| 121.51 | 2.67 | 0.82 | 3.28 |
| 197.20 | 4.14 | 0.82 | 5.07 |
| 98.78 | 1.59 | 0.82 | 1.95 |
| 140.00 | 1.70 | 0.82 | 2.08 |
| 810.83 | 1.58 | 0.82 | 1.94 |
| 203.46 | 2.43 | 0.82 | 2.97 |
| 129.35 | 2.04 | 0.82 | 2.51 |
| 112.61 | 1.83 | 0.82 | 2.22 |
| 122.76 | 2.17 | 0.82 | 2.66 |

Annex-02-A011 Road

Overlay Design with AASHTO (1993) method and Simplified method

Overlay Design-A011 Road-AASHTO (1993) methodCalculation of SN_f for A011 road (0 to 1.5 km)

| | | | | | | | | | |
|--------------|-----------------------------------|------------------|---|----------------------------------|--|--|--|--|--|
| M_R | design subgrade resilient modulus | 8,091 psi | (from calculation) | | | | | | |
| W_{18} | estimated future traffic | 8.15 | msa (from design report) | | | | | | |
| R | reliability | 0.85 | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) | | | | | | |
| S_0 | standard deviation | 0.4 | (cl.4.3 AASHTO (1993)-Part I) | | | | | | |
| ΔPSI | serviceability loss | 1.5 | (cl.2.2.1 AASHTO (1993)-Part II) | | | | | | |
| | | SN_f | 4.44 | (cl.3.1.1 AASHTO (1993)-Part II) | | | | | |

Calculation of design overlay thickness for A011 road (0 to 1.5 km)

| | | | | | | | | | |
|------------|--|---|--|----|--|--|--|--|--|
| SN_f | - required structural number to carry future traffic | = | 4.44 | | | | | | |
| SN_{eff} | - effective structural number of the existing pavement | = | 2.65 | | | | | | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 1.79$ | | | | | | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | | | | | | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 1.79/0.4 = 113.7$ | mm | | | | | |
| T_{pro} | - overlay thickness provided | = | 115 | mm | | | | | |

Calculation of SN_f for A011 road (1.5 km to 5.3 km)

| | | | | | | | | | |
|--------------|-----------------------------------|------------------|---|----------------------------------|--|--|--|--|--|
| M_R | design subgrade resilient modulus | 7,236 psi | (from calculation) | | | | | | |
| W_{18} | estimated future traffic | 8.15 | msa (from design report) | | | | | | |
| R | reliability | 0.85 | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) | | | | | | |
| S_0 | standard deviation | 0.4 | (cl.4.3 AASHTO (1993)-Part I) | | | | | | |
| ΔPSI | serviceability loss | 1.5 | (cl.2.2.1 AASHTO (1993)-Part II) | | | | | | |
| | | SN_f | 4.61 | (cl.3.1.1 AASHTO (1993)-Part II) | | | | | |

Calculation of design overlay thickness for A011 road (1.5 km to 5.3 km)

| | | | | | | | | | |
|------------|--|---|--|----|--|--|--|--|--|
| SN_f | - required structural number to carry future traffic | = | 4.61 | | | | | | |
| SN_{eff} | - effective structural number of the existing pavement | = | 2.74 | | | | | | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 1.87$ | | | | | | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | | | | | | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 1.87/0.4 = 118.7$ | mm | | | | | |
| T_{pro} | - overlay thickness provided | = | 120 | mm | | | | | |

Overlay Design-A011 Road-Simplified methodCalculation of SN_f for A011 road (0 to 1.5 km)

| | | | | | | | | | |
|--------------|-----------------------------------|--------------|-------------|---|--|--|--|--|--|
| M_R | design subgrade resilient modulus | 8,928 | psi | (from calculation) | | | | | |
| W_{18} | estimated future traffic | 8.15 | msa | (from design report) | | | | | |
| R | reliability | 0.85 | | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) | | | | | |
| S_0 | standard deviation | 0.4 | | (cl.4.3 AASHTO (1993)-Part I) | | | | | |
| ΔPSI | serviceability loss | 1.5 | | (cl.2.2.1 AASHTO (1993)-Part II) | | | | | |
| | | SN_f | 4.29 | (cl.3.1.1 AASHTO (1993)-Part II) | | | | | |

Calculation of design overlay thickness for A011 road (0 to 1.5 km)

| | | | | | | | |
|------------|--|---|--|----|--|--|--|
| SN_f | - required structural number to carry future traffic | = | 4.29 | | | | |
| SN_{eff} | - effective structural number of the existing pavement | = | 2.58 | | | | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 1.71$ | | | | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | | | | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 1.71/0.4 = 108.6$ | mm | | | |
| T_{pro} | - overlay thickness provided | = | 110 | mm | | | |

Calculation of SN_f for A011 road (1.5 km to 5.3 km)

| | | | | | | | | | |
|--------------|-----------------------------------|--------------|-------------|---|--|--|--|--|--|
| M_R | design subgrade resilient modulus | 7,811 | psi | (from calculation) | | | | | |
| W_{18} | estimated future traffic | 8.15 | msa | (from design report) | | | | | |
| R | reliability | 0.85 | | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) | | | | | |
| S_0 | standard deviation | 0.4 | | (cl.4.3 AASHTO (1993)-Part I) | | | | | |
| ΔPSI | serviceability loss | 1.5 | | (cl.2.2.1 AASHTO (1993)-Part II) | | | | | |
| | | SN_f | 4.49 | (cl.3.1.1 AASHTO (1993)-Part II) | | | | | |

Calculation of design overlay thickness for A011 road (1.5 km to 5.3 km)

| | | | | | | | |
|------------|--|---|--|----|--|--|--|
| SN_f | - required structural number to carry future traffic | = | 4.49 | | | | |
| SN_{eff} | - effective structural number of the existing pavement | = | 3.73 | | | | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 0.76$ | | | | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | | | | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 0.76/0.4 = 48.26$ | mm | | | |
| T_{pro} | - overlay thickness provided | = | 100 | mm | | | |

Annex-03-B133 Road

Annex-03-B133 Road

FWD Data

IKUAB FWD FILE : B133 Ganewelpola - Dachchahalmillewa.fwd

HOperator : MRM

HRoad : B133

HWeather : Sunny

IDate Created : 12/07/2017

IVersion : 2.4.75

ILoad Mode : 1 (2 + 2 buffers)

IPlate Radius : 15.0 (cm)

IExtra Field Set : KUAB

IDrop Sequence : 33

INo of drops : 11

IRecord Drop? : NY

IDrop Height : 1 2 3 4

IImpact Load : 15.0 25.0 40.0 50.0 kN

ISensor Number : 0 1 2 3 4 5 6

ISensor Distance : 0.0 20.0 30.0 45.0 60.0 90.0 120.0 (cm)

ISensor Position : CENTER BEHIND BEHIND BEHIND BEHIND BEHIND BEHIND

IReference Offset : 0 m

ITestpoint spacing: 500 m

JDistance Imp Load D0 D1 D2 D3 D4 D5 D6 Air Pave Emod Time

J m Num kN μm μm μm μm μm μm μm $^{\circ}\text{C}$ $^{\circ}\text{C}$ MPa

J-----

D 0 2 41.8 493 323 220 148 104 60 35 35.3 42.0 270 10:03:49

C Comment at 0 m Time: 10:03:55 :Ganewelpola Jn 2 on A011

T Mix temperature at 12 m, depth 4 cm :40.2 Time: 10:20:50

D 500 2 42.1 570 374 243 153 107 71 50 36.0 44.3 235 10:21:37

C Comment at 952 m Time: 10:22:16 :1 kmp

D 1000 2 41.9 452 312 225 153 111 74 53 36.5 43.2 295 10:22:44

D 1500 2 41.9 417 263 175 110 79 54 39 36.8 43.0 319 10:23:46

D 2000 2 42.2 472 330 236 158 111 68 47 37.5 42.2 285 10:24:48

C Comment at 2169 m Time: 10:26:19 :dbst

D 2494 2 41.5 353 249 168 94 56 31 22 28.5 28.3 374 10:29:39

D 3000 2 41.7 226 159 109 72 53 46 41 28.6 28.6 587 10:31:42

C Comment at 3053 m Time: 10:32:05 :3 kmp

D 3500 2 41.7 202 146 106 72 53 39 30 28.9 28.2 659 10:33:31

D 4000 2 40.7 286 209 151 107 78 50 35 29.0 28.2 453 10:35:08

T Mix temperature at 4388 m, depth 4 cm :29.1 Time: 10:53:22

D 4500 2 41.3 411 329 268 210 164 116 87 29.0 28.2 320 10:54:07

D 5000 2 41.2 288 199 141 90 61 39 28 29.2 27.9 456 10:55:58

C Comment at 5051 m Time: 10:56:15 :5 kmp

C Comment at 5249 m Time: 10:58:25 :road in bad condition

D 5500 2 41.6 302 224 162 109 77 52 36 29.2 29.3 439 11:06:03

D 6001 2 41.7 330 219 147 87 58 43 34 29.1 28.8 403 11:07:55

C Comment at 6047 m Time: 11:08:21 :6 kmp

D 6506 2 41.4 238 157 108 65 41 21 12 29.2 28.8 554 11:09:44

D 7000 2 41.7 294 224 170 126 96 67 49 28.8 29.8 451 11:13:10

C Comment at 7042 m Time: 11:13:39 :7 kmp

D 7502 2 41.4 382 269 189 120 80 50 36 28.8 29.7 346 11:30:52

D 8002 2 41.8 160 142 128 113 96 72 54 28.8 29.9 833 11:32:22
C Comment at 8047 m Time: 11:32:40 :8 kmp
D 8500 2 41.4 279 237 205 175 143 98 69 28.8 30.6 472 11:36:57
D 9000 2 41.7 479 322 227 153 106 62 41 32.2 35.8 277 13:34:21
T Mix temperature at 9113 m, depth 4 cm :38.3 Time: 13:34:57
D 9501 2 41.7 162 136 120 100 79 49 30 32.7 37.0 817 13:36:10
D 10000 2 41.8 370 211 135 81 53 29 20 32.9 36.1 360 13:37:50
C Comment at 10043 m Time: 13:38:10 :10 kmp
D 10500 2 41.6 207 179 156 125 95 60 41 33.0 37.1 638 13:39:11
D 11003 2 41.2 428 301 231 162 112 64 42 33.0 36.2 306 13:40:50
C Comment at 11053 m Time: 13:41:07 :11 kmp
D 11504 2 41.3 585 374 238 149 103 69 53 32.7 36.8 225 13:42:15
D 12000 2 41.0 402 301 225 162 118 76 52 32.7 36.1 325 13:43:48
C Comment at 12072 m Time: 13:44:17 :12 kmp
D 12500 2 41.7 359 265 214 158 108 56 33 32.6 35.8 369 13:45:19
D 13000 2 41.4 160 131 110 87 67 43 29 32.8 36.5 825 13:46:49
C Comment at 13056 m Time: 13:47:10 :13 kmp
D 13500 2 41.6 343 226 159 99 61 27 15 33.2 36.7 386 13:48:19
D 14000 2 41.6 300 195 139 90 57 29 17 33.3 36.5 441 13:49:45
C Comment at 14053 m Time: 13:50:04 :14 kmp
D 14500 2 41.3 449 249 143 75 45 26 18 33.7 33.2 293 13:51:20
D 15004 2 41.7 531 286 169 92 56 30 20 34.0 37.9 250 13:52:50
C Comment at 15055 m Time: 13:53:10 :15 kmp
D 15503 2 41.5 566 329 204 131 94 63 46 33.6 37.7 233 13:54:13
D 16003 2 42.0 371 249 190 142 103 63 43 33.2 32.5 360 13:55:39
C Comment at 16058 m Time: 13:55:57 :16 kmp
D 16501 2 42.1 309 230 180 138 100 60 40 33.2 37.3 434 13:57:01
D 17000 2 42.1 178 153 135 116 95 67 45 33.3 38.0 755 13:58:23
C Comment at 17057 m Time: 13:58:42 :17 kmp
D 17507 2 41.4 574 346 216 132 87 49 33 33.2 37.3 230 13:59:46
D 18008 2 41.8 434 241 142 77 46 23 14 33.0 36.9 306 14:01:08
C Comment at 18060 m Time: 14:01:28 :18 kmp
D 18501 2 41.0 319 197 142 97 65 33 21 33.4 36.7 409 14:02:29
D 19006 2 41.3 362 242 172 114 77 36 19 33.6 35.5 364 14:03:52
C Comment at 19057 m Time: 14:04:12 :19 kmp
D 19500 2 41.6 472 286 174 94 54 26 17 73.2 38.1 280 14:05:13
D 20001 2 41.9 409 280 199 120 70 31 18 33.9 37.5 326 14:06:42
C Comment at 20062 m Time: 14:07:01 :20 kmp
D 20500 2 41.3 349 238 162 99 64 37 25 33.7 39.2 377 14:08:18
D 21004 2 41.7 340 217 135 68 39 22 17 32.8 39.2 390 14:10:18
C Comment at 21060 m Time: 14:10:39 :21 kmp
D 21501 2 40.9 653 428 290 162 85 27 13 33.1 37.5 199 14:11:43
D 22000 2 41.3 510 326 216 119 66 25 14 33.1 36.9 257 14:13:04
D 22500 2 41.3 760 496 327 171 84 26 14 33.2 39.3 173 14:14:26
D 23001 2 40.9 855 505 306 148 71 22 14 33.4 37.6 152 14:16:05
C Comment at 23096 m Time: 14:16:29 :23 kmp
D 23500 2 41.0 672 472 324 186 98 32 15 32.9 37.6 194 14:17:42
D 24006 2 41.0 983 634 406 210 102 28 13 33.2 38.4 133 14:19:02
C Comment at 24075 m Time: 14:19:33 :24 kmp
D 24500 2 41.4 549 411 319 216 135 53 29 32.9 37.4 240 14:20:43
D 25000 2 41.4 765 532 362 219 132 59 36 32.8 34.9 172 14:22:12

Annex-03-B133 Road

Pavement Design Report

1. Introduction

B133- Ganewalpola – Dachchahalmillewa Road is situated at North Central Province in Sri Lanka. Pavement enhancement and widening of B133- Ganewalpola – Dachchahalmillewa road from 00+000 km to 45+860 km, proposed to rehabilitate under the ADB Funded Intergraded Road Investment Program (I Road Project). Existing road is Macadam base road and consists of 5.0 m carriageway and soft shoulder of 0.5m. RDA has proposed two lane road with 3.3m carriageway and 0.5m hard and 1m soft shoulder. In this report asphalt pavement design is presented.

2. Investigation

Non-destructive Testing

Load-Deflection measurement test was carried out by Falling Weight Deflectometer (FWD) in 250 m interval and summary of deflections are given in Annex 3. FWD was conducted by Road Development Authority (RDA).

Material Sampling and Testing

Test pit investigations were conducted at 2 km interval on the existing pavement of the road and widening area at 5km intervals. Following tests have been carried out at the test site and the laboratory.

Field tests:

- A log of existing layer profile
- Field Density

Laboratory tests:

- CBR (4 days soaked)
- Modified Proctor Compaction Test
- Atterberg Limits Test
- Sieve Analysis

Furthermore, Dynamic Cone Penetrometer (DCP) Test was conducted in test pit locations. (refer annex 1).

Summary of test results at existing pavement and widening areas are given under Annex 2 and top hard pavement layer thickness is assumed as 150 mm macadam.

4 day soaked Lab CBR at Field Density under modified conditions of compaction for overlaying section is considered for design calculations. 4 day soaked CBR at 95%of MDD is considered for widening areas.

Lab CBR are used to determine the design Subgrade strength (Design CBR)

Summary of Design CBR values of subgrade are given in Table 01. Refer Annex 2

Table 01: Design CBR Values

| | Chainage | Design CBR/ (%) |
|------------|------------------------|-----------------|
| Overlaying | Ch 00+000 to Ch 21+000 | 5 |
| | Ch 21+000 to Ch 45+860 | 8 |
| Widening | Ch 00+000 to Ch 06+000 | 3 |
| | Ch 06+000 to Ch 14+000 | 5 |
| | Ch 14+000 to Ch 22+000 | 3 |
| | Ch 22+000 to Ch 34+000 | 5 |
| | Ch 34+000 to Ch 42+000 | 2 |
| | Ch 42+000 to Ch 45+860 | 5 |

3. Traffic Forecast

Equivalent Standard Axle (ESA) extract from document which provided for B213 by Planning Division of Road Development Authority and attached under Annex 4A. Average Daily Traffic growth rate taken from traffic study report for b133 road (Annex 4B). Design traffic can be predicted between 10- 20 years according to “Guide to Structural Design of Road Under Sri Lankan Condition” and 15 years design traffic is predicted. The Design Cumulative Number of Standard Axles (CNSA) for 15-year design traffic are summarized in Table 2. Traffic calculation can be extracted from Annex 4C. Since lane width is 3.3 m, Directional factor is considered as 0.60 and Lane Distribution Factor is taken as 1.0.

Table 02: CNSA Value - 15 years

| Road Section | CNSA/msa | Design CNSA/msa |
|-----------------------|----------|-----------------|
| Ch 0+000 to Ch 45+860 | 8.55 | 5.13 |

4. Pavement Structural Evaluation

The Falling Weight Deflectometer (FWD) is an excellent device for evaluating the structural capacity of pavements for overlay designs. AASHTO Guide was used to estimate Effective Structural Number of existing top hard layers. FWD data along with the computed Effective Structural Numbers of the existing pavement are presented in Annex 3. Details of the calculations are described below.

- Based on test pit investigation, top hard layer thickness (D) is taken. Top hard layer (D) is assumed 150 mm thickness macadam.
- Overall Subgrade Resilient Modulus (M_R) below the depth was estimated from Eq.02.

$$M_R = \frac{0.24P}{d_r r} \text{-----Eq. 02}$$

where

- M_R = backcalculated subgrade resilient modulus, psi
- P = applied load, pounds
- d_r = deflection at a distance r from the center of the load, inches
- r = distance from center of load, inches

- Minimum distance (r) was determined by following relationship given by Eq03.

$$r \geq 0.7 a_e \text{-----Eq. 03}$$

where

$$a_e = \sqrt{\left[a^2 + \left(D \sqrt[3]{\frac{E_p}{M_R}} \right)^2 \right]}$$

- a_e = radius of the stress bulb at the subgrade-pavement interface, inches
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- E_p = effective modulus of all pavement layers above the subgrade, psi (described below)

- Effective modulus (E_p) of all existing pavement layers above the subgrade is calculated from Eq.04.

$$\frac{M_R d_0}{qa} = 1.5 \left\{ \frac{1}{\sqrt{1 + \left[\left(\frac{D}{a} \right)^3 \frac{E_p}{M_R} \right]^2}} + \frac{1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a} \right)^2}}}{\left(\frac{E_p}{M_R} \right)} \right\} \text{-----Eq. 04}$$

where

- d_0 = deflection measured at the center of the load plate, inches
- p = NDT load plate pressure, psi
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- M_R = subgrade resilient modulus, psi
- E_p = effective modulus of all pavement layers above the subgrade, psi

- Effective Structural Number of existing pavement layers are computed from Eq.05 and presented under Annex 3.

$$SN_{eff} = 0.0045 D \sqrt[3]{E_p} \text{-----Eq. 05}$$

- Summary of Effective Structural Number is presented under Table 3 as given below.

Table 03: Summary of Effective Structural Number of the Existing Pavement

| Section | SN_{eff} - lower 10 percentile value |
|------------------------|--|
| Ch 00+000 to Ch 21+000 | 1.16 |
| Ch 21+000 to Ch 45+860 | 0.92 |

5. Pavement Thickness Calculation

The design thicknesses of the road pavement for the next 15 years (2020 – 2034) are calculated and presented in the Table 4 and 5 for both Overlaying and widening based on Road Note 31. The design sub-grade CBR value, Remaining Structure number, condition of existing pavement and the Traffic class are considered when designing pavement thickness. Design calculations are shown in *Annex 5*.

Table 04– Design Layer Thicknesses for Existing Pavement

| Section (Chainage) | SN _{eff} | Sub grade CBR % | Traffic CNESA /(msa) | Asphalt Wearing Course (in mm) | Dense Graded Aggregate Base (in mm) |
|--------------------|-------------------|-----------------|----------------------|--------------------------------|-------------------------------------|
| 0+000-21+000 | 1.16 | 5 | 5.13 | 50 | 200 |
| 21+000-45+860 | 0.92 | 8 | 5.13 | 50 | 180 |

Table 05– Design Layer Thicknesses for Widening and Reconstruction Sections.

| Section (Chainage) | Sub grade CBR % | Traffic CNESA /(msa) | Asphalt Wearing Course (in mm) | Dense Graded Aggregate Base (in mm) | Sub Base (in mm) | Capping Layer (in mm) |
|--------------------|-----------------|----------------------|--------------------------------|-------------------------------------|------------------|-----------------------|
| 00+000 - 06+000 | 3 | 5.13 | 50 | 175 | 275 | 200 |
| 06+000 - 14+000 | 5 | 5.13 | 50 | 175 | 325 | - |
| 14+000 - 22+000 | 3 | 5.13 | 50 | 175 | 275 | 200 |
| 22+000 - 34+000 | 5 | 5.13 | 50 | 175 | 325 | - |
| 34+000 - 42+000 | 2 | 5.13 | 50 | 175 | 300 | 300 |
| 42+000 - 45+860 | 5 | 5.13 | 50 | 175 | 325 | - |

*** CBR (4 day soaked) Of DGAB Should be more than 110% and CBR of capping Layer should be more than 15%*

Locations where highly deteriorated or damaged existing pavement, should be reconstruct with layers given for widening by scarify the existing pavement and compacting formed subgrade to achieve 95% MDD at modified Procter compaction

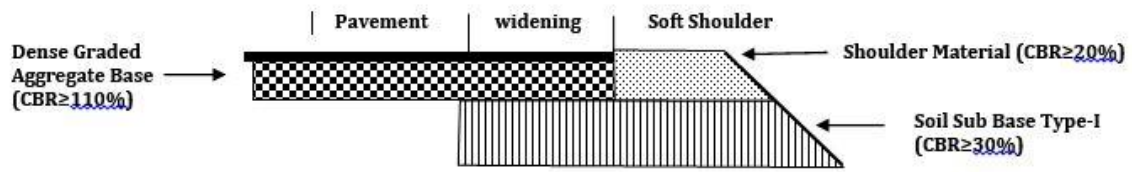


Figure.1 -Typical cross section for Overlay & Widening

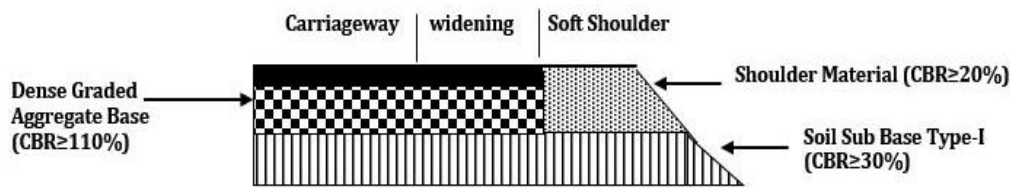


Figure. 2 - Typical cross section for Gravel Sections

6. Summary and Conclusion

Structural capacity of the pavement is poor, and it is not sufficient for cater next 15 year design traffic. Hence road should rehabilitate immediately with layer thicknesses given in Table 04 and Table 05.

Material and method of construction has to be selected according to Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009) and the Employer Requirement.

7. References

- AASHTO Guide for Design of Pavement Structures, 1993
- Transport & Road Research Laboratory, United Kingdom Road Note 18, 1999
- Transport & Road Research Laboratory, United Kingdom Road Note 31, 1977
- “Pavement Analysis and Design”, Yang H. Huang ,2nd Edition
- Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009)
- RDA Pavement Design Guide, 1999
- Guide to Pavement Technology Part 2: Pavement Structural Design, Austroads 2012.

Annex-03-B133 Road

Calculation of Design M_R and SN_{eff} -AASHTO (1993) method

AASHTO (1993) method
Calculation of Design M_R and SN_{eff} -B133 Road

| Chainage | M_R (psi) | Design M_R (psi) | SN_{eff} |
|----------|-------------|--------------------|------------|
| 0 | 22,046 | 7,349 | 1.23 |
| 250 | 34,727 | 11,576 | 1.44 |
| 500 | 20,102 | 6,701 | 1.15 |
| 750 | 52,650 | 17,550 | 1.49 |
| 1000 | 21,607 | 7,202 | 1.40 |
| 1250 | 14,655 | 4,885 | 1.14 |
| 1500 | 27,781 | 9,260 | 1.23 |
| 1750 | 33,917 | 11,306 | 1.23 |
| 2000 | 20,748 | 6,916 | 1.38 |
| 2245 | 48,365 | 16,122 | 1.57 |
| 2500 | 28,662 | 9,554 | 1.45 |
| 2750 | 42,952 | 14,317 | 1.62 |
| 3000 | 44,390 | 14,797 | 1.60 |
| 3248 | 41,147 | 13,716 | 1.47 |
| 3500 | 45,646 | 15,215 | 1.71 |
| 3750 | 33,754 | 11,251 | 1.58 |
| 4000 | 31,274 | 10,425 | 1.61 |
| 4248 | 32,043 | 10,681 | 1.69 |
| 4500 | 17,881 | 5,960 | 1.69 |
| 4750 | 21,050 | 7,017 | 1.51 |
| 5000 | 33,904 | 11,301 | 1.54 |
| 5250 | 30,010 | 10,003 | 1.70 |
| 5500 | 29,795 | 9,932 | 1.62 |
| 5750 | 20,042 | 6,681 | 1.49 |
| 6000 | 32,915 | 10,972 | 1.41 |
| 6250 | 22,093 | 7,364 | 1.45 |
| 6500 | 44,478 | 14,826 | 1.53 |
| 6750 | 24,192 | 8,064 | 1.66 |
| 7000 | 28,462 | 9,487 | 1.70 |
| 7250 | 20,666 | 6,889 | 1.20 |
| 7500 | 25,416 | 8,472 | 1.45 |
| 7750 | 25,826 | 8,609 | 1.24 |
| 8000 | 28,614 | 9,538 | 2.47 |
| 8250 | 21,401 | 7,134 | 1.75 |
| 8500 | 18,300 | 6,100 | 2.11 |
| 8750 | 27,834 | 9,278 | 1.78 |
| 9000 | 21,315 | 7,105 | 1.28 |
| 9250 | 26,107 | 8,702 | 1.70 |
| 9500 | 40,320 | 13,440 | 2.37 |
| 9750 | 45,230 | 15,077 | 1.99 |
| 10000 | 35,926 | 11,975 | 1.17 |
| 10250 | 26,521 | 8,840 | 1.20 |
| 10500 | 25,743 | 8,581 | 2.29 |
| 10750 | 21,556 | 7,185 | 1.56 |

Annex-03-B133 Road

Calculation of Design M_R and SN_{eff} -Simplified method

Calculation of Design M_R -A011-Simplified method

| Chainage (m) | SM calculated at sensor locations | | | | Min SM (psi) | Design M_R (psi) (with correction factor 0.33) |
|-----------------|-----------------------------------|----------|----------|----------|-----------------|--|
| | 300 (mm) | 450 (mm) | 600 (mm) | 900 (mm) | | |
| 0 | 25,720 | 25,488 | 27,204 | 31,436 | 25,488 | 8,496 |
| 250 | 40,515 | 42,315 | 49,246 | 65,662 | 40,515 | 13,505 |
| 500 | 23,453 | 24,832 | 26,631 | 26,756 | 23,453 | 7,818 |
| 750 | 61,425 | 68,007 | 75,165 | 68,007 | 61,425 | 20,475 |
| 1000 | 25,209 | 24,714 | 25,549 | 25,549 | 24,714 | 8,238 |
| 1250 | 17,097 | 19,412 | 24,738 | 38,032 | 17,097 | 5,699 |
| 1500 | 32,411 | 34,375 | 35,898 | 35,012 | 32,411 | 10,804 |
| 1750 | 39,569 | 45,449 | 51,440 | 53,890 | 39,569 | 13,190 |
| 2000 | 24,206 | 24,104 | 28,563 | 28,003 | 24,104 | 8,035 |
| 2245 | 56,426 | 55,873 | 59,365 | 59,365 | 55,873 | 18,624 |
| 2500 | 33,439 | 39,843 | 50,159 | 60,407 | 33,439 | 11,146 |
| 2750 | 50,110 | 48,825 | 50,110 | 50,110 | 48,825 | 16,275 |
| 3000 | 51,788 | 52,267 | 53,254 | 40,905 | 40,905 | 13,635 |
| 3248 | 48,005 | 51,465 | 57,126 | 68,007 | 48,005 | 16,002 |
| 3500 | 53,254 | 52,267 | 53,254 | 48,247 | 48,247 | 16,082 |
| 3750 | 39,380 | 39,518 | 43,318 | 48,131 | 39,380 | 13,127 |
| 4000 | 36,487 | 34,327 | 35,317 | 36,730 | 34,327 | 11,442 |
| 4248 | 37,383 | 33,011 | 31,713 | 30,349 | 30,349 | 10,116 |
| 4500 | 20,861 | 17,748 | 17,045 | 16,065 | 16,065 | 5,355 |
| 4750 | 24,558 | 24,184 | 26,429 | 31,897 | 24,184 | 8,061 |
| 5000 | 39,555 | 41,313 | 45,715 | 47,668 | 39,555 | 13,185 |
| 5250 | 35,012 | 31,511 | 31,165 | 31,511 | 31,165 | 10,388 |
| 5500 | 34,761 | 34,442 | 36,567 | 36,098 | 34,442 | 11,481 |
| 5750 | 23,382 | 22,588 | 24,390 | 28,151 | 22,588 | 7,529 |
| 6000 | 38,401 | 43,256 | 48,663 | 43,759 | 38,401 | 12,800 |
| 6250 | 25,776 | 24,437 | 24,977 | 24,758 | 24,437 | 8,146 |
| 6500 | 51,891 | 57,480 | 68,345 | 88,957 | 51,891 | 17,297 |
| 6750 | 28,224 | 25,088 | 24,331 | 23,230 | 23,230 | 7,743 |
| 7000 | 33,205 | 29,867 | 29,400 | 28,084 | 28,084 | 9,361 |
| 7250 | 24,111 | 26,375 | 31,919 | 39,013 | 24,111 | 8,037 |
| 7500 | 29,652 | 31,135 | 35,027 | 37,362 | 29,652 | 9,884 |
| 7750 | 30,130 | 31,933 | 33,359 | 60,261 | 30,130 | 10,043 |
| 8000 | 44,206 | 33,383 | 29,471 | 26,196 | 26,196 | 8,732 |
| 8250 | 24,968 | 23,855 | 25,305 | 26,751 | 23,855 | 7,952 |
| 8500 | 27,338 | 21,350 | 19,595 | 19,062 | 19,062 | 6,354 |
| 8750 | 32,473 | 28,809 | 30,203 | 34,678 | 28,809 | 9,603 |
| 9000 | 24,867 | 24,596 | 26,627 | 30,349 | 24,596 | 8,199 |
| 9250 | 30,458 | 25,590 | 25,244 | 27,882 | 25,244 | 8,415 |
| 9500 | 47,041 | 37,633 | 35,727 | 38,401 | 35,727 | 11,909 |
| 9750 | 52,769 | 44,698 | 48,297 | 59,365 | 44,698 | 14,899 |
| 10000 | 41,914 | 46,571 | 53,381 | 65,039 | 41,914 | 13,971 |
| 10250 | 30,941 | 34,129 | 36,567 | 37,542 | 30,941 | 10,314 |
| 10500 | 36,098 | 30,034 | 29,639 | 31,285 | 29,639 | 9,880 |
| 10750 | 25,149 | 23,725 | 25,488 | 29,939 | 23,725 | 7,908 |
| 11000 | 24,144 | 22,951 | 24,898 | 29,048 | 22,951 | 7,650 |
| 11250 | 27,874 | 22,190 | 20,957 | 21,193 | 20,957 | 6,986 |

Calculation of SN_{eff}-B133-Simplified method

| Chainage | 0 | 200 | 300 | 450 | 600 | 900 | 1200 |
|----------|-----|-----|-----|-----|-----|-----|------|
| 0 | 493 | 323 | 220 | 148 | 104 | 60 | 35 |
| 250 | 315 | 198 | 141 | 90 | 58 | 29 | 17 |
| 500 | 570 | 374 | 243 | 153 | 107 | 71 | 50 |
| 750 | 223 | 138 | 93 | 56 | 38 | 28 | 21 |
| 1000 | 452 | 312 | 225 | 153 | 111 | 74 | 53 |
| 1250 | 705 | 475 | 327 | 192 | 113 | 49 | 27 |
| 1500 | 417 | 263 | 175 | 110 | 79 | 54 | 39 |
| 1750 | 358 | 219 | 143 | 83 | 55 | 35 | 26 |
| 2000 | 472 | 330 | 236 | 158 | 100 | 68 | 47 |
| 2245 | 220 | 142 | 101 | 68 | 48 | 32 | 23 |
| 2500 | 353 | 249 | 168 | 94 | 56 | 31 | 22 |
| 2750 | 232 | 154 | 114 | 78 | 57 | 38 | 26 |
| 3000 | 226 | 159 | 109 | 72 | 53 | 46 | 41 |
| 3248 | 272 | 177 | 119 | 74 | 50 | 28 | 21 |
| 3500 | 202 | 146 | 106 | 72 | 53 | 39 | 30 |
| 3750 | 283 | 201 | 143 | 95 | 65 | 39 | 28 |
| 4000 | 286 | 209 | 151 | 107 | 78 | 50 | 35 |
| 4248 | 271 | 196 | 151 | 114 | 89 | 62 | 45 |
| 4500 | 411 | 329 | 268 | 210 | 164 | 116 | 87 |
| 4750 | 413 | 300 | 226 | 153 | 105 | 58 | 37 |
| 5000 | 288 | 199 | 141 | 90 | 61 | 39 | 28 |
| 5250 | 283 | 215 | 162 | 120 | 91 | 60 | 41 |
| 5500 | 302 | 224 | 162 | 109 | 77 | 52 | 36 |
| 5750 | 443 | 324 | 242 | 167 | 116 | 67 | 43 |
| 6000 | 330 | 219 | 147 | 87 | 58 | 43 | 34 |
| 6250 | 426 | 301 | 219 | 154 | 113 | 76 | 55 |
| 6500 | 238 | 157 | 108 | 65 | 41 | 21 | 12 |
| 6750 | 341 | 261 | 200 | 150 | 116 | 81 | 60 |
| 7000 | 294 | 224 | 170 | 126 | 96 | 67 | 49 |
| 7250 | 524 | 347 | 233 | 142 | 88 | 48 | 35 |
| 7500 | 382 | 269 | 189 | 120 | 80 | 50 | 36 |
| 7750 | 430 | 280 | 186 | 117 | 84 | 31 | 48 |
| 8000 | 160 | 142 | 128 | 113 | 96 | 72 | 54 |
| 8250 | 348 | 291 | 225 | 157 | 111 | 70 | 50 |
| 8500 | 279 | 237 | 205 | 175 | 143 | 98 | 69 |
| 8750 | 280 | 208 | 173 | 130 | 93 | 54 | 33 |
| 9000 | 479 | 322 | 227 | 153 | 106 | 62 | 41 |
| 9250 | 312 | 227 | 184 | 146 | 111 | 67 | 43 |
| 9500 | 162 | 136 | 120 | 100 | 79 | 49 | 30 |
| 9750 | 188 | 134 | 108 | 85 | 59 | 32 | 18 |
| 10000 | 370 | 211 | 135 | 81 | 53 | 29 | 20 |
| 10250 | 442 | 285 | 182 | 110 | 77 | 50 | 38 |
| 10500 | 207 | 179 | 156 | 125 | 95 | 60 | 41 |
| 10750 | 401 | 286 | 225 | 159 | 111 | 63 | 39 |
| 11000 | 429 | 301 | 231 | 162 | 112 | 64 | 42 |

| Area | A | B | l ₀ (cm) | E _{sg} (Mpa) | SN _{eff} |
|------|-------|--------|---------------------|-----------------------|-------------------|
| 14.6 | 2.371 | 0.1096 | 11.76695 | 175.74 | 1.20 |
| 14.1 | 2.371 | 0.1096 | 11.15988 | 279.34 | 1.40 |
| 14.1 | 2.371 | 0.1096 | 11.13844 | 161.70 | 1.17 |
| 13.8 | 2.371 | 0.1096 | 10.76270 | 423.51 | 1.61 |
| 15.9 | 2.371 | 0.1096 | 13.54805 | 170.40 | 1.19 |
| 13.9 | 2.371 | 0.1096 | 10.88572 | 117.88 | 1.05 |
| 14.1 | 2.371 | 0.1096 | 11.10254 | 223.47 | 1.30 |
| 13.2 | 2.371 | 0.1096 | 10.10069 | 272.82 | 1.39 |
| 15.4 | 2.371 | 0.1096 | 12.83139 | 166.19 | 1.18 |
| 15.0 | 2.371 | 0.1096 | 12.27190 | 385.23 | 1.56 |
| 14.1 | 2.371 | 0.1096 | 11.17005 | 230.56 | 1.31 |
| 15.8 | 2.371 | 0.1096 | 13.43704 | 336.64 | 1.49 |
| 15.8 | 2.371 | 0.1096 | 13.43030 | 282.03 | 1.40 |
| 14.1 | 2.371 | 0.1096 | 11.08697 | 330.98 | 1.48 |
| 16.6 | 2.371 | 0.1096 | 14.63046 | 332.65 | 1.48 |
| 15.6 | 2.371 | 0.1096 | 13.17319 | 271.52 | 1.39 |
| 16.7 | 2.371 | 0.1096 | 14.71631 | 236.68 | 1.32 |
| 18.0 | 2.371 | 0.1096 | 17.04935 | 209.25 | 1.27 |
| 20.3 | 2.800 | 0.1044 | 23.32732 | 110.77 | 1.03 |
| 16.5 | 2.371 | 0.1096 | 14.40151 | 166.74 | 1.18 |
| 15.2 | 2.371 | 0.1096 | 12.58403 | 272.72 | 1.39 |
| 18.0 | 2.371 | 0.1096 | 17.04935 | 214.87 | 1.28 |
| 16.5 | 2.371 | 0.1096 | 14.51203 | 237.47 | 1.33 |
| 16.6 | 2.371 | 0.1096 | 14.63208 | 155.74 | 1.15 |
| 14.2 | 2.371 | 0.1096 | 11.28661 | 264.76 | 1.38 |
| 16.4 | 2.371 | 0.1096 | 14.34242 | 168.48 | 1.18 |
| 14.0 | 2.371 | 0.1096 | 11.04875 | 357.78 | 1.52 |
| 18.5 | 2.371 | 0.1096 | 18.09967 | 160.16 | 1.16 |
| 18.2 | 2.371 | 0.1096 | 17.47403 | 193.63 | 1.24 |
| 13.9 | 2.371 | 0.1096 | 10.87901 | 166.24 | 1.18 |
| 15.2 | 2.371 | 0.1096 | 12.59291 | 204.44 | 1.26 |
| 14.0 | 2.371 | 0.1096 | 10.95881 | 207.74 | 1.27 |
| 25.5 | 3.275 | 0.1039 | 46.32899 | 180.62 | 1.21 |
| 18.8 | 2.371 | 0.1096 | 18.59766 | 164.47 | 1.17 |
| 23.1 | 3.275 | 0.1039 | 36.01150 | 131.43 | 1.09 |
| 18.6 | 2.371 | 0.1096 | 18.12287 | 198.63 | 1.25 |
| 15.1 | 2.371 | 0.1096 | 12.43300 | 169.59 | 1.19 |
| 18.6 | 2.371 | 0.1096 | 18.27741 | 174.05 | 1.20 |
| 22.6 | 3.691 | 0.0948 | 31.31709 | 246.33 | 1.34 |
| 17.7 | 2.371 | 0.1096 | 16.46329 | 308.18 | 1.45 |
| 12.6 | 2.371 | 0.1096 | 9.40007 | 288.99 | 1.42 |
| 13.7 | 2.371 | 0.1096 | 10.65439 | 213.33 | 1.28 |
| 22.3 | 3.691 | 0.0948 | 30.53812 | 204.35 | 1.26 |
| 17.0 | 2.371 | 0.1096 | 15.27532 | 163.58 | 1.17 |
| 16.5 | 2.371 | 0.1096 | 14.44809 | 158.24 | 1.16 |

Annex-03-B133 Road

Overlay Design with AASHTO (1993) method and Simplified method

| Overlay Design-B133 Road-AASHTO (1993) method | | | |
|--|-----------------------------------|------------------|---|
| <u>Calculation of SN_f for B133 road (0 to 21 km)</u> | | | |
| M_R | design subgrade resilient modulus | 9,454 psi | (from calculation) |
| W_{18} | estimated future traffic | 5.13 msa | (from design report) |
| R | reliability | 0.85 | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) |
| S_0 | standard deviation | 0.4 | (cl.4.3 AASHTO (1993)-Part I) |
| ΔPSI | serviceability loss | 1.5 | (cl.2.2.1 AASHTO (1993)-Part II) |
| | SN_f | 3.91 | (cl.3.1.1 AASHTO (1993)-Part II) |

| | | | |
|---|--|---|--|
| <u>Calculation of design overlay thickness for B133 road (0 to 21 km)</u> | | | |
| SN_f | - required structural number to carry future traffic | = | 3.91 |
| SN_{eff} | - effective structural number of the existing pavement | = | 1.54 |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 2.37$ |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 2.37/0.4 = 150.5$ mm |
| T_{pro} | - overlay thickness provided | = | 150 mm |

| | | | |
|--|-----------------------------------|------------------|---|
| <u>Calculation of SN_f for B133 road (21 km to 45.8 km)</u> | | | |
| M_R | design subgrade resilient modulus | 5,430 psi | (from calculation) |
| W_{18} | estimated future traffic | 5.13 msa | (from design report) |
| R | reliability | 0.85 | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) |
| S_0 | standard deviation | 0.4 | (cl.4.3 AASHTO (1993)-Part I) |
| ΔPSI | serviceability loss | 1.5 | (cl.2.2.1 AASHTO (1993)-Part II) |
| | SN_f | 4.75 | (cl.3.1.1 AASHTO (1993)-Part II) |

| | | | |
|---|--|---|--|
| <u>Calculation of design overlay thickness for B133 road (21 km to 45.8 km)</u> | | | |
| SN_f | - required structural number to carry future traffic | = | 4.75 |
| SN_{eff} | - effective structural number of the existing pavement | = | 1.19 |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 3.56$ |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 1.55/0.4 = 226.1$ mm |
| T_{pro} | - overlay thickness provided | = | 230 mm |

Overlay Design-B133 Road-Simplified methodCalculation of SN_f for B133 road (0 to 21 km)

| | | | | | | | | | |
|--------------|-----------------------------------|---------------|-------------|---|--|--|--|--|--|
| M_R | design subgrade resilient modulus | 10,268 | psi | (from calculation) | | | | | |
| W_{18} | estimated future traffic | 5.13 | msa | (from design report) | | | | | |
| R | reliability | 0.85 | | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) | | | | | |
| S_0 | standard deviation | 0.4 | | (cl.4.3 AASHTO (1993)-Part I) | | | | | |
| ΔPSI | serviceability loss | 1.5 | | (cl.2.2.1 AASHTO (1993)-Part II) | | | | | |
| | | SN_f | 3.79 | (cl.3.1.1 AASHTO (1993)-Part II) | | | | | |

Calculation of design overlay thickness for B133 road (0 to 21 km)

| | | | | | | | | |
|------------|--|---|--|----|--|--|--|--|
| SN_f | - required structural number to carry future traffic | = | 3.79 | | | | | |
| SN_{eff} | - effective structural number of the existing pavement | = | 1.55 | | | | | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 2.24$ | | | | | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | | | | | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 2.37/0.4 = 142.2$ | mm | | | | |
| T_{pro} | - overlay thickness provided | = | 145 | mm | | | | |

Calculation of SN_f for B133 road (21 km to 45.8 km)

| | | | | | | | | |
|--------------|-----------------------------------|--------------|-------------|---|--|--|--|--|
| M_R | design subgrade resilient modulus | 6,135 | psi | (from calculation) | | | | |
| W_{18} | estimated future traffic | 5.13 | msa | (from design report) | | | | |
| R | reliability | 0.85 | | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) | | | | |
| S_0 | standard deviation | 0.4 | | (cl.4.3 AASHTO (1993)-Part I) | | | | |
| ΔPSI | serviceability loss | 1.5 | | (cl.2.2.1 AASHTO (1993)-Part II) | | | | |
| | | SN_f | 4.56 | (cl.3.1.1 AASHTO (1993)-Part II) | | | | |

Calculation of design overlay thickness for B133 road (21 km to 45.8 km)

| | | | | | | | | |
|------------|--|---|--|----|--|--|--|--|
| SN_f | - required structural number to carry future traffic | = | 4.56 | | | | | |
| SN_{eff} | - effective structural number of the existing pavement | = | 1.13 | | | | | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 3.43$ | | | | | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | | | | | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 1.55/0.4 = 217.8$ | mm | | | | |
| T_{pro} | - overlay thickness provided | = | 220 | mm | | | | |

Annex-04-B212 Road

Annex-04-B212 Road

FWD Data

IKUAB FWD FILE : B212 Kekirawa Ganewalpola.fwd

HOperator : MRM

HRoad : B212

HWeather : Sunny

IDate Created : 02/11/2017

IVersion : 2.4.75

ILoad Mode : 1 (2 + 2 buffers)

IPlate Radius : 15.0 (cm)

IExtra Field Set : KUAB

IDrop Sequence : 33

INo of drops : 11

IRecord Drop? : NY

IDrop Height : 1 2 3 4

IImpact Load : 15.0 25.0 40.0 50.0 kN

ISensor Number : 0 1 2 3 4 5 6

ISensor Distance : 0.0 20.0 30.0 45.0 60.0 90.0 120.0 (cm)

ISensor Position : CENTER BEHIND BEHIND BEHIND BEHIND BEHIND BEHIND

IReference Offset : 0 m

ITestpoint spacing: 100 m

JDistance Imp Load D0 D1 D2 D3 D4 D5 D6 Air Pave Emod Time

J m Num kN μm μm μm μm μm μm μm $^{\circ}\text{C}$ $^{\circ}\text{C}$ MPa

J-----

D 0 2 41.2 83 68 56 43 33 27 20 24.6 24.5 1848 07:07:24

C Comment at 0 m Time: 07:07:30 :Kekirawa Jnc on A009

D 100 2 40.9 485 325 228 158 108 61 42 24.5 25.5 314 07:08:31

T Mix temperature at 200 m, depth 4 cm :32.0 Time: 07:22:37

C Comment at 176 m Time: 07:22:43 :macadum surface

D 200 2 41.1 456 259 147 73 49 34 26 24.7 25.8 336 07:23:13

D 300 2 40.9 504 320 192 113 77 51 37 25.0 25.0 303 07:24:17

D 402 2 41.4 343 234 137 70 56 46 37 25.0 25.3 448 07:25:13

D 500 2 41.4 600 392 251 154 102 58 38 25.0 25.5 257 07:34:02

D 600 2 41.2 725 465 301 177 113 68 46 25.1 25.1 211 07:34:58

D 700 2 41.0 549 319 203 126 90 63 46 25.2 24.8 279 07:35:52

D 802 2 41.4 344 207 144 108 87 64 47 25.2 25.1 448 07:44:10

D 900 2 40.1 1274 825 538 325 198 92 47 25.0 24.6 117 07:44:53

C Comment at 995 m Time: 07:45:22 :1kmp

D 1000 2 40.7 948 680 474 288 173 92 54 25.1 25.0 160 07:45:51

D 1100 2 40.9 817 551 391 251 172 108 71 25.1 25.4 186 07:49:43

D 1200 2 41.5 325 224 166 122 100 73 51 25.1 24.6 476 07:50:45

D 1300 2 41.6 309 197 113 59 28 25 21 25.1 24.8 500 07:51:39

D 1400 2 41.2 506 325 220 133 84 47 30 25.0 25.3 303 07:52:32

D 1500 2 41.8 258 112 51 35 30 28 23 24.9 25.4 604 07:59:57

D 1600 2 41.9 213 131 96 72 58 42 31 24.9 24.7 733 08:00:50

D 1700 2 41.0 973 632 428 251 157 89 56 25.0 25.7 157 08:01:46

D 1800 2 41.4 324 232 173 120 88 59 42 24.9 25.5 476 08:02:40

C Comment at 1804 m Time: 08:02:46 :ac

C Comment at 1898 m Time: 08:03:05 :ac ends

D 1900 2 41.1 472 313 223 154 111 68 45 24.8 26.3 324 08:03:35

C Comment at 1993 m Time: 08:03:59 :2km

D 2001 2 40.7 513 336 234 156 109 67 46 24.9 26.6 296 08:04:27

D 2100 2 41.4 371 214 151 107 83 59 42 25.0 26.3 416 08:05:21

D 2200 2 41.0 414 281 184 116 78 49 33 25.2 25.3 369 08:06:20

D 2300 2 41.1 341 224 147 97 70 48 35 25.2 25.4 448 08:09:43

D 2400 2 41.1 474 350 253 181 133 85 55 25.1 25.9 323 08:10:35

D 2500 2 41.1 242 154 118 93 74 52 36 25.2 24.6 634 08:11:28

D 2600 2 41.8 459 267 158 76 47 31 23 25.4 24.9 339 08:12:24

T Mix temperature at 2700 m, depth 4 cm :33.0 Time: 08:24:49

D 2700 2 41.1 672 384 223 124 88 56 40 25.2 24.6 228 08:25:18

D 2800 2 41.1 746 489 330 191 114 56 35 25.3 26.3 205 08:26:11

D 2900 2 41.2 602 344 216 134 86 48 32 25.2 26.2 255 08:27:06

C Comment at 2992 m Time: 08:27:34 :3kmp

D 3001 2 41.3 529 309 182 98 66 37 23 25.1 25.8 291 08:28:02

D 3100 2 42.0 179 109 71 48 37 26 20 25.4 25.5 873 08:36:42

D 3200 2 41.8 378 239 161 112 82 52 34 25.3 26.0 412 08:37:33

D 3300 2 40.3 795 541 387 272 194 117 73 25.4 25.4 189 08:38:27

D 3400 2 41.6 563 346 248 186 141 91 61 25.5 25.5 275 08:39:21

D 3500 2 41.3 436 279 176 84 55 34 23 25.5 25.8 353 08:40:15

D 3600 2 40.8 696 505 368 248 179 112 71 25.4 26.4 218 08:49:43

D 3700 2 41.7 611 424 301 211 156 98 64 25.4 27.1 254 08:50:36

D 3800 2 41.3 476 291 198 130 94 58 38 25.4 25.9 323 08:51:36

D 3900 2 41.6 342 224 162 120 94 67 48 25.4 26.1 453 08:52:29

C Comment at 3990 m Time: 08:52:56 :4kmp

D 4000 2 41.0 192 109 64 45 38 29 23 25.4 25.4 794 08:53:25

C Comment at 4005 m Time: 08:53:31 :new macadam surface

D 4100 2 41.4 332 184 109 65 47 33 26 25.3 25.7 465 08:54:15

D 4200 2 40.7 617 427 298 195 133 76 50 25.3 26.3 246 08:55:07

D 4300 2 40.9 499 334 217 129 86 54 38 25.3 26.1 305 08:55:57

D 4400 2 41.3 237 137 83 53 44 36 27 25.3 26.3 648 09:00:23

D 4500 2 41.4 323 190 121 78 61 50 41 25.3 26.8 477 09:09:10

D 4600 2 40.0 1134 826 604 376 223 95 50 25.4 26.4 131 09:10:03

D 4700 2 40.9 383 228 137 76 50 34 25 25.3 26.4 397 09:10:45

D 4800 2 41.0 383 214 113 43 21 13 9 25.5 26.8 399 09:11:29

T Mix temperature at 4900 m, depth 4 cm :34.0 Time: 09:23:28

D 4900 2 41.2 474 336 243 143 77 15 1 25.5 26.6 324 09:24:13

C Comment at 4990 m Time: 09:24:37 :5kmp

D 5000 2 41.2 836 530 335 187 112 54 32 25.5 26.9 184 09:24:55

D 5100 2 41.7 222 147 101 75 52 31 19 25.4 25.3 700 09:33:44

D 5200 2 40.9 999 591 409 272 185 102 56 25.4 27.3 152 09:34:26

D 5300 2 41.7 331 188 117 74 49 32 23 25.4 26.6 470 09:35:23

D 5400 2 41.6 685 421 259 130 77 32 15 25.4 26.7 226 09:36:14

D 5500 2 41.5 515 334 215 135 97 62 42 25.4 27.2 300 09:37:07

D 5600 2 40.9 799 524 368 220 141 74 43 25.5 27.1 191 09:38:03

D 5703 2 41.6 116 75 54 41 34 26 19 25.4 26.7 1337 09:47:26

D 5800 2 41.8 198 68 42 32 26 19 13 25.5 25.9 786 09:50:15

D 5900 2 41.7 250 145 61 43 31 21 13 25.6 26.1 621 09:51:04

C Comment at 5987 m Time: 09:51:34 :6kmp

D 6000 2 41.1 1017 629 397 215 135 72 43 25.5 27.1 151 09:51:52

D 6100 2 41.0 1117 827 603 402 246 90 34 25.4 26.8 137 09:52:38

D 6201 2 41.2 430 202 127 87 63 41 29 25.6 28.0 357 09:53:20

Annex-04-B212 Road

Pavement Design Report

1. Introduction

B212- Kekirawa – Ganewalpola Road is situated at North Central Province in Sri Lanka. Pavement enhancement and widening of B212- Kekirawa – Ganewalpola road from 00+000 km to 06+950 km, proposed to rehabilitate under the ADB Funded Intergraded Road Investment Program (I Road Project). Existing road is Macadam base road and consists of 5.0 m carriageway and soft shoulder of 0.5m. RDA has proposed two lane road with 3.3m carriageway and 1.0 m hard and 1.0 m soft shoulder. In this report asphalt pavement design is presented.

2. Investigation

Non-destructive Testing

Load-Deflection measurement test was carried out by Falling Weight Deflectometer (FWD) in 50 m interval and summary of deflections are given in Annex 3. FWD was conducted by Road Development Authority (RDA).

Since high deflections were observed at Ch.0+900, 3+250 ,5+200, 5+950, 6+000, 6+250 and Ch. 6+600, addition test pits will be carried out in these locations and suitable improvement will be provided where required.

Material Sampling and Testing

Test pit investigations were conducted at 1 km intervals on the existing pavement of the road and widening area. Following tests have been carried out at the test site and the laboratory.

Field tests:

- A log of existing layer profile
- Field Density

Laboratory tests:

- CBR (4 days soaked)
- Modified Proctor Compaction Test
- Atterberg Limits Test

Furthermore, Dynamic Cone Penetrometer (DCP) Test was conducted in test pit locations. (Refer Annex 1).

Summary of test results at existing pavement and widening areas are given under Annex 2. Further hard pavement layer thickness is assumed as 150 mm macadam.

4 day soaked Lab CBR at Field Density under modified conditions of compaction for overlaying section is considered for design calculations. 4 day soaked CBR at 95% of MDD is considered for widening areas.

Lab CBR are used to determine the design Subgrade strength (Design CBR)

Summary of Design CBR values of subgrade are given in Table 01. Refer Annex 2

Table 01: Design CBR Values

| | Chainage | Design CBR/ (%) |
|------------|------------------------|-----------------|
| Overlaying | Ch 00+000 to Ch 06+950 | 15 |
| Widening | Ch 00+000 to Ch 06+950 | 10 |

3. Traffic Forecast

Equivalent Standard Axle (ESA) extract from document which provided for B213 by Planning Division of Road Development Authority and attached under Annex 4A. Annual Daily Traffic (ADT) and growth rate is taken from traffic study report for B212 road. Design traffic can be predicted between 10- 20 years according to “Guide to Structural Design of Road Under Sri Lankan Condition” and 15 years design traffic is predicted. (Annex 4B). The Design Cumulative Number of Standard Axles (CNSA) for 15-year design traffic are summarized in Table 2. Traffic calculation can be extracted from Annex 4C. Since lane width is 3.3 m, Directional factor is considered as 0.60 and Lane Distribution Factor is taken as 1.0.

Table 02: CNSA Value - 15 years

| Road Section | CNSA/msa | Design CNSA/msa |
|----------------------|----------|-----------------|
| Ch 0+000 to Ch 6+950 | 14.85 | 8.95 |

4. Pavement Structural Evaluation

The Falling Weight Deflectometer (FWD) is an excellent device for evaluating the structural capacity of pavements for overlay designs. AASHTO Guide was used to estimate Effective Structural Number of existing top hard layers. FWD data along with the computed Effective Structural Numbers of the existing pavement are presented in Annex 3. Details of the calculations are described below.

- Based on test pit investigation, top hard layer thickness (D) is taken. Top hard layer (D) is assumed as 150 mm macadam.
- Overall Subgrade Resilient Modulus (M_R) below the depth was estimated from Eq.02.

$$M_R = \frac{0.24P}{d_r} \text{-----Eq. 02}$$

where

- M_R = backcalculated subgrade resilient modulus, psi
- P = applied load, pounds
- d_r = deflection at a distance r from the center of the load, inches
- r = distance from center of load, inches

- Minimum distance (r) was determined by following relationship given by Eq03.

$$r \geq 0.7a_e \text{-----Eq. 03}$$

where

$$a_e = \sqrt{\left[a^2 + \left(D \sqrt[3]{\frac{E_p}{M_R}} \right)^2 \right]}$$

- a_e = radius of the stress bulb at the subgrade-pavement interface, inches
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- E_p = effective modulus of all pavement layers above the subgrade, psi (described below)

- Effective modulus (Ep) of all existing pavement layers above the subgrade is calculated from Eq.04.

$$\frac{M_R d_0}{qa} = 1.5 \left\{ \frac{1}{\sqrt{1 + \left[\left(\frac{D}{a} \right)^3 \sqrt{\frac{E_p}{M_R}} \right]^2}} + \frac{1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a} \right)^2}}}{\left(\frac{E_p}{M_R} \right)} \right\} \text{-----Eq. 04}$$

where

- d₀ = deflection measured at the center of the load plate, inches
- p = NDT load plate pressure, psi
- a = NDT load plate radius, inches
- D = total thickness of pavement layers above the subgrade, inches
- M_R = subgrade resilient modulus, psi
- E_p = effective modulus of all pavement layers above the subgrade, psi

- Effective Structural Number of existing pavement layers are computed from Eq.05 and presented under Annex 3.

$$SN_{\text{eff}} = 0.0045 D \sqrt[3]{E_p} \text{-----Eq. 05}$$

- Summary of Effective Structural Number is presented under Table 3 as given below.

Table 03: Summary of Effective Structural Number of the Existing Pavement

| Section | SN _{eff} - Lower 10 percentile value |
|------------------------|---|
| Ch 00+000 to Ch 06+950 | 1.05 |

5. Pavement Thickness Calculation

The design thicknesses of the road overlaying and pavement widening sections for the next 15 years (2020 – 2034) are calculated referring to Road Note 31 and presented in the table 4 and 5 based on the design sub-grade CBR value, Remaining Structure number, condition of existing pavement and the Traffic class. Design calculations are shown in Annex 5.

Table 04– Design Layer Thicknesses for Existing Pavement

| Section (Chainage) | SN _{eff} | Sub grade CBR % | Traffic CNESA /(msa) | Asphalt Wearing Course (in mm) | Dense Graded Aggregate Base (in mm) |
|--------------------|-------------------|-----------------|----------------------|--------------------------------|-------------------------------------|
| 0+000-06+950 | 1.05 | 15 | 8.95 | 50 | 125 |

Table 05– Design Layer Thicknesses for Widening and Reconstruction Sections.

| Section (Chainage) | Sub grade CBR % | Traffic CNESA /(msa) | Asphalt Wearing Course (in mm) | Dense Graded Aggregate Base (in mm) | Sub Base (in mm) |
|--------------------|-----------------|----------------------|--------------------------------|-------------------------------------|------------------|
| 00+000-06+950 | 10 | 8.95 | 50 | 200 | 275 |

*** CBR (4 day soaked) Of DGAB Should be more than 110%*

Locations where highly deteriorated or damaged existing pavement, should be reconstruct with layers given for widening by scarify the existing pavement and compacting formed subgrade to achieve 95% MDD at modified Procter compaction

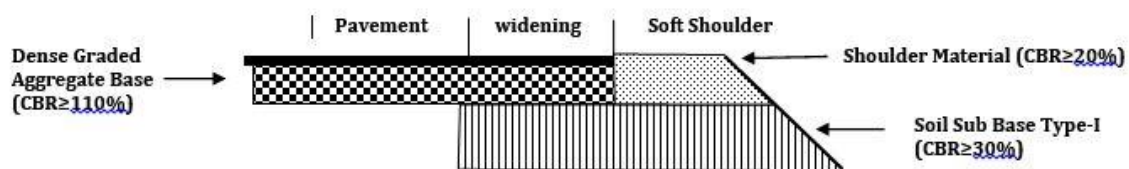


Figure.1 –Typical cross section for Overlay & Widening

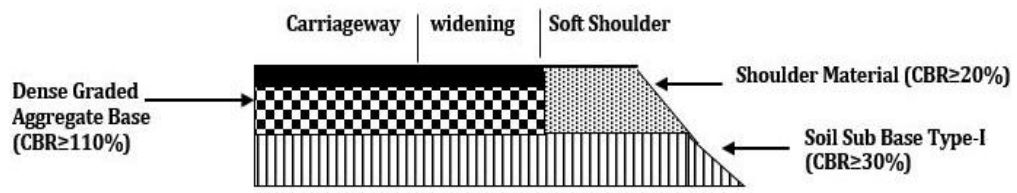


Figure. 2 - Typical cross section for Gravel Sections

6. Summary and Conclusion

Structural capacity of the pavement is fair, but it is not sufficient for cater next 15 year design traffic. Hence road should rehabilitate immediately with layer thicknesses given in Table 04 and Table 05.

Material and method of construction has to be selected according to Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009) and the Employer Requirement.

7. References

- AASHTO Guide for Design of Pavement Structures, 1993
- Transport & Road Research Laboratory, United Kingdom Road Note 18, 1999
- Transport & Road Research Laboratory, United Kingdom Road Note 31, 1977
- “Pavement Analysis and Design”, Yang H. Huang ,2nd Edition
- Standard Specification for Construction and Maintenance of Road and Bridges (SSCM-2009)
- RDA Pavement Design Guide, 1999
- Guide to Pavement Technology Part 2: Pavement Structural Design, Austroads 2012.

Annex-04-B212 Road

Calculation of Design M_R and SN_{eff} -AASHTO (1993) method

AASHTO (1993) method
Calculation of Design M_R and SN_{eff} -B212 Road

| Chainage | M_R (psi) | Design M_R (psi) | SN_{eff} |
|----------|-------------|--------------------|------------|
| 0 | 85,365 | 28,455 | 2.38 |
| 50 | 17,054 | 5,685 | 1.33 |
| 100 | 20,814 | 6,938 | 1.26 |
| 150 | 52,466 | 17,489 | 1.02 |
| 200 | 32,441 | 10,814 | 1.03 |
| 250 | 21,899 | 7,300 | 1.13 |
| 300 | 24,717 | 8,239 | 1.10 |
| 350 | 15,471 | 5,157 | 1.14 |
| 402 | 35,063 | 11,688 | 1.24 |
| 450 | 21,788 | 7,263 | 1.04 |
| 500 | 19,138 | 6,379 | 1.12 |
| 550 | 60,626 | 20,209 | 1.96 |
| 600 | 15,882 | 5,294 | 1.05 |
| 650 | 35,650 | 11,883 | 1.69 |
| 700 | 23,435 | 7,812 | 1.06 |
| 750 | 19,946 | 6,649 | 1.09 |
| 802 | 33,359 | 11,120 | 1.34 |
| 850 | 14,908 | 4,969 | 1.00 |
| 900 | 8,648 | 2,883 | 0.88 |
| 950 | 10,623 | 3,541 | 1.22 |
| 1000 | 9,963 | 3,321 | 1.09 |
| 1050 | 12,638 | 4,213 | 1.09 |
| 1100 | 12,137 | 4,046 | 1.11 |
| 1150 | 14,417 | 4,806 | 1.07 |
| 1200 | 29,008 | 9,669 | 1.54 |
| 1250 | 33,689 | 11,230 | 0.97 |
| 1300 | 42,716 | 14,239 | 1.21 |
| 1350 | 60,279 | 20,093 | 1.52 |
| 1400 | 21,729 | 7,243 | 1.19 |
| 1450 | 22,239 | 7,413 | 1.09 |
| 1500 | 95,099 | 31,700 | 0.98 |
| 1550 | 30,990 | 10,330 | 1.21 |
| 1600 | 50,642 | 16,881 | 1.56 |
| 1650 | 18,441 | 6,147 | 1.03 |
| 1700 | 11,115 | 3,705 | 0.98 |
| 1750 | 13,270 | 4,423 | 1.31 |
| 1800 | 27,767 | 9,256 | 1.58 |
| 1850 | 25,200 | 8,400 | 1.65 |
| 1900 | 21,385 | 7,128 | 1.28 |
| 1950 | 15,805 | 5,268 | 1.24 |
| 2001 | 20,181 | 6,727 | 1.22 |
| 2050 | 24,620 | 8,207 | 1.24 |
| 2100 | 31,812 | 10,604 | 1.23 |
| 2150 | 51,777 | 17,259 | 1.09 |

Annex-04-B212 Road

Calculation of Design M_R and SN_{eff} -Simplified method

Calculation of Design M_R -B212-Simplified method

| Chainage (m) | SM calculated at sensor locations | | | | Min SM (psi) | Design M_R (psi) (with correction factor 0.33) |
|-----------------|-----------------------------------|----------|----------|----------|-----------------|--|
| | 300 (mm) | 450 (mm) | 600 (mm) | 900 (mm) | | |
| 0 | 99,593 | 86,468 | 84,503 | 68,854 | 68,854 | 22,951 |
| 50 | 19,896 | 20,256 | 23,102 | 27,008 | 19,896 | 6,632 |
| 100 | 24,283 | 23,361 | 25,632 | 30,255 | 23,361 | 7,787 |
| 150 | 61,210 | 61,545 | 61,210 | 64,728 | 61,210 | 20,403 |
| 200 | 37,848 | 50,810 | 56,772 | 54,546 | 37,848 | 12,616 |
| 250 | 25,549 | 27,009 | 29,852 | 32,045 | 25,549 | 8,516 |
| 300 | 28,836 | 32,664 | 35,952 | 36,187 | 28,836 | 9,612 |
| 350 | 18,049 | 18,891 | 20,874 | 23,076 | 18,049 | 6,016 |
| 402 | 40,907 | 53,374 | 50,038 | 40,611 | 40,611 | 13,537 |
| 450 | 25,420 | 26,944 | 29,882 | 32,286 | 25,420 | 8,473 |
| 500 | 22,328 | 24,261 | 27,472 | 32,208 | 22,328 | 7,443 |
| 550 | 70,730 | 71,175 | 97,559 | 85,734 | 70,730 | 23,577 |
| 600 | 18,529 | 21,006 | 24,678 | 27,339 | 18,529 | 6,176 |
| 650 | 41,592 | 37,514 | 37,761 | 39,045 | 37,514 | 12,505 |
| 700 | 27,340 | 29,366 | 30,834 | 29,366 | 27,340 | 9,113 |
| 750 | 23,270 | 24,699 | 26,816 | 28,017 | 23,270 | 7,757 |
| 802 | 38,919 | 34,594 | 32,208 | 29,189 | 29,189 | 9,730 |
| 850 | 17,393 | 21,159 | 24,425 | 36,718 | 17,393 | 5,798 |
| 900 | 10,090 | 11,135 | 13,708 | 19,668 | 10,090 | 3,363 |
| 950 | 12,394 | 12,312 | 13,670 | 17,374 | 12,312 | 4,104 |
| 1000 | 11,623 | 12,753 | 15,923 | 19,962 | 11,623 | 3,874 |
| 1050 | 14,745 | 15,670 | 18,122 | 21,524 | 14,745 | 4,915 |
| 1100 | 14,160 | 14,705 | 16,095 | 17,088 | 14,160 | 4,720 |
| 1150 | 16,820 | 17,920 | 19,643 | 20,578 | 16,820 | 5,607 |
| 1200 | 33,842 | 30,698 | 28,089 | 25,652 | 25,652 | 8,551 |
| 1250 | 39,304 | 43,671 | 48,297 | 47,492 | 39,304 | 13,101 |
| 1300 | 49,835 | 63,631 | 100,560 | 75,085 | 49,835 | 16,612 |
| 1350 | 70,326 | 65,161 | 64,075 | 60,070 | 60,070 | 20,023 |
| 1400 | 25,351 | 27,956 | 33,198 | 39,555 | 25,351 | 8,450 |
| 1450 | 25,946 | 28,740 | 31,485 | 31,135 | 25,946 | 8,649 |
| 1500 | 110,949 | 107,779 | 94,307 | 67,362 | 67,362 | 22,454 |
| 1550 | 36,155 | 38,084 | 40,229 | 40,515 | 36,155 | 12,052 |
| 1600 | 59,083 | 52,518 | 48,896 | 45,015 | 45,015 | 15,005 |
| 1650 | 21,515 | 23,725 | 25,720 | 26,945 | 21,515 | 7,172 |
| 1700 | 12,968 | 14,741 | 17,676 | 20,787 | 12,968 | 4,323 |
| 1750 | 15,482 | 15,591 | 17,615 | 20,584 | 15,482 | 5,161 |
| 1800 | 32,395 | 31,135 | 31,842 | 31,663 | 31,135 | 10,378 |
| 1850 | 29,400 | 25,776 | 24,543 | 22,670 | 22,670 | 7,557 |
| 1900 | 24,949 | 24,085 | 25,062 | 27,273 | 24,085 | 8,028 |
| 1950 | 18,439 | 16,973 | 17,789 | 19,073 | 16,973 | 5,658 |
| 2001 | 23,545 | 23,545 | 25,273 | 27,410 | 23,545 | 7,848 |
| 2050 | 28,723 | 27,737 | 28,012 | 26,945 | 26,945 | 8,982 |
| 2100 | 37,114 | 34,918 | 33,761 | 31,663 | 31,663 | 10,554 |
| 2150 | 60,407 | 50,611 | 47,609 | 44,586 | 44,586 | 14,862 |
| 2200 | 30,164 | 31,897 | 35,578 | 37,756 | 30,164 | 10,055 |
| 2250 | 17,351 | 17,378 | 19,733 | 23,647 | 17,351 | 5,784 |

Calculation of SN_{eff}-B212-Simplified method

| Chainage | 0 | 200 | 300 | 450 | 600 | 900 | 1200 |
|----------|------|-----|-----|-----|-----|-----|------|
| 0 | 83 | 68 | 56 | 43 | 33 | 27 | 20 |
| 50 | 530 | 379 | 281 | 184 | 121 | 69 | 45 |
| 100 | 485 | 325 | 228 | 158 | 108 | 61 | 42 |
| 150 | 346 | 150 | 92 | 61 | 46 | 29 | 23 |
| 200 | 456 | 259 | 147 | 73 | 49 | 34 | 26 |
| 250 | 548 | 330 | 222 | 140 | 95 | 59 | 43 |
| 300 | 504 | 320 | 192 | 113 | 77 | 51 | 37 |
| 350 | 664 | 430 | 303 | 193 | 131 | 79 | 53 |
| 402 | 343 | 234 | 137 | 70 | 56 | 46 | 37 |
| 450 | 595 | 349 | 221 | 139 | 94 | 58 | 39 |
| 500 | 600 | 392 | 251 | 154 | 102 | 58 | 38 |
| 550 | 152 | 100 | 80 | 53 | 29 | 22 | 15 |
| 600 | 725 | 465 | 301 | 177 | 113 | 68 | 46 |
| 650 | 253 | 185 | 138 | 102 | 76 | 49 | 35 |
| 700 | 549 | 319 | 203 | 126 | 90 | 63 | 46 |
| 750 | 604 | 380 | 242 | 152 | 105 | 67 | 46 |
| 802 | 344 | 207 | 144 | 108 | 87 | 64 | 47 |
| 850 | 803 | 491 | 323 | 177 | 115 | 51 | 23 |
| 900 | 1274 | 825 | 538 | 325 | 198 | 92 | 47 |
| 950 | 818 | 600 | 450 | 302 | 204 | 107 | 63 |
| 1000 | 948 | 680 | 474 | 288 | 173 | 92 | 54 |
| 1050 | 821 | 546 | 381 | 239 | 155 | 87 | 51 |
| 1100 | 817 | 551 | 391 | 251 | 172 | 108 | 71 |
| 1150 | 767 | 493 | 334 | 209 | 143 | 91 | 63 |
| 1200 | 325 | 224 | 166 | 122 | 100 | 73 | 51 |
| 1250 | 490 | 224 | 145 | 87 | 59 | 40 | 30 |
| 1300 | 309 | 197 | 113 | 59 | 28 | 25 | 21 |
| 1350 | 197 | 116 | 82 | 59 | 45 | 32 | 23 |
| 1400 | 506 | 325 | 220 | 133 | 84 | 47 | 30 |
| 1450 | 557 | 346 | 216 | 130 | 89 | 60 | 40 |
| 1500 | 258 | 112 | 51 | 35 | 30 | 28 | 23 |
| 1550 | 394 | 239 | 158 | 100 | 71 | 47 | 32 |
| 1600 | 213 | 131 | 96 | 72 | 58 | 42 | 31 |
| 1650 | 677 | 412 | 263 | 159 | 110 | 70 | 49 |
| 1700 | 973 | 632 | 428 | 251 | 157 | 89 | 56 |
| 1750 | 634 | 472 | 355 | 235 | 156 | 89 | 56 |
| 1800 | 324 | 232 | 173 | 120 | 88 | 59 | 42 |
| 1850 | 334 | 253 | 192 | 146 | 115 | 83 | 61 |
| 1900 | 472 | 313 | 223 | 154 | 111 | 68 | 45 |
| 1950 | 604 | 410 | 301 | 218 | 156 | 97 | 64 |
| 2001 | 513 | 336 | 234 | 156 | 109 | 67 | 46 |
| 2050 | 450 | 286 | 197 | 136 | 101 | 70 | 50 |
| 2100 | 371 | 214 | 151 | 107 | 83 | 59 | 42 |
| 2150 | 312 | 161 | 93 | 74 | 59 | 42 | 30 |
| 2200 | 414 | 281 | 184 | 116 | 78 | 49 | 33 |

| Area | A | B | l ₀ (cm) |
|------|-------|--------|---------------------|
| 20.8 | 2.800 | 0.1044 | 24.60998 |
| 15.3 | 2.371 | 0.1096 | 12.62904 |
| 14.5 | 2.371 | 0.1096 | 11.58772 |
| 10.9 | 2.371 | 0.1096 | 7.85384 |
| 11.3 | 2.371 | 0.1096 | 8.15802 |
| 13.1 | 2.371 | 0.1096 | 9.96814 |
| 12.6 | 2.371 | 0.1096 | 9.40206 |
| 14.0 | 2.371 | 0.1096 | 11.01231 |
| 13.1 | 2.371 | 0.1096 | 9.91065 |
| 12.5 | 2.371 | 0.1096 | 9.32705 |
| 13.2 | 2.371 | 0.1096 | 10.04314 |
| 14.9 | 2.371 | 0.1096 | 12.11411 |
| 13.0 | 2.371 | 0.1096 | 9.82361 |
| 16.5 | 2.371 | 0.1096 | 14.47315 |
| 12.6 | 2.371 | 0.1096 | 9.45454 |
| 13.1 | 2.371 | 0.1096 | 9.93332 |
| 14.5 | 2.371 | 0.1096 | 11.58479 |
| 12.5 | 2.371 | 0.1096 | 9.37474 |
| 12.9 | 2.371 | 0.1096 | 9.80120 |
| 15.7 | 2.371 | 0.1096 | 13.28544 |
| 14.3 | 2.371 | 0.1096 | 11.32142 |
| 14.0 | 2.371 | 0.1096 | 10.93996 |
| 14.5 | 2.371 | 0.1096 | 11.58635 |
| 13.6 | 2.371 | 0.1096 | 10.58360 |
| 16.3 | 2.371 | 0.1096 | 14.18125 |
| 11.1 | 2.371 | 0.1096 | 8.03475 |
| 11.6 | 2.371 | 0.1096 | 8.48364 |
| 14.1 | 2.371 | 0.1096 | 11.08953 |
| 13.3 | 2.371 | 0.1096 | 10.19030 |
| 12.8 | 2.371 | 0.1096 | 9.59499 |
| 10.1 | 2.371 | 0.1096 | 7.14392 |
| 13.2 | 2.371 | 0.1096 | 10.05470 |
| 15.1 | 2.371 | 0.1096 | 12.42029 |
| 12.8 | 2.371 | 0.1096 | 9.61286 |
| 13.3 | 2.371 | 0.1096 | 10.19412 |
| 15.8 | 2.371 | 0.1096 | 13.46662 |
| 16.0 | 2.371 | 0.1096 | 13.70666 |
| 17.6 | 2.371 | 0.1096 | 16.26993 |
| 14.7 | 2.371 | 0.1096 | 11.90399 |
| 15.3 | 2.371 | 0.1096 | 12.75102 |
| 14.2 | 2.371 | 0.1096 | 11.27368 |
| 14.3 | 2.371 | 0.1096 | 11.30820 |
| 13.9 | 2.371 | 0.1096 | 10.87957 |
| 12.1 | 2.371 | 0.1096 | 8.97037 |
| 13.8 | 2.371 | 0.1096 | 10.72964 |

| E _{sg} (Mpa) | SN _{eff} |
|-----------------------|-------------------|
| 474.73 | 3.49 |
| 137.18 | 1.19 |
| 161.07 | 1.15 |
| 422.03 | 1.07 |
| 260.95 | 0.95 |
| 176.16 | 1.02 |
| 198.82 | 1.00 |
| 124.44 | 1.00 |
| 280.00 | 1.18 |
| 175.26 | 0.95 |
| 153.94 | 0.98 |
| 487.67 | 1.74 |
| 127.75 | 0.90 |
| 258.65 | 1.68 |
| 188.51 | 0.99 |
| 160.44 | 0.98 |
| 201.25 | 1.24 |
| 119.92 | 0.84 |
| 69.57 | 0.73 |
| 84.89 | 1.06 |
| 80.14 | 0.89 |
| 101.66 | 0.93 |
| 97.63 | 0.97 |
| 115.97 | 0.94 |
| 176.86 | 1.45 |
| 270.99 | 0.95 |
| 343.60 | 1.08 |
| 414.17 | 1.50 |
| 174.79 | 1.04 |
| 178.89 | 0.98 |
| 464.44 | 1.01 |
| 249.28 | 1.15 |
| 310.37 | 1.53 |
| 148.34 | 0.93 |
| 89.41 | 0.83 |
| 106.74 | 1.16 |
| 214.67 | 1.49 |
| 156.31 | 1.60 |
| 166.06 | 1.19 |
| 117.02 | 1.14 |
| 162.34 | 1.12 |
| 185.78 | 1.17 |
| 218.31 | 1.19 |
| 307.41 | 1.10 |
| 207.97 | 1.16 |

Annex-04-B212 Road

Overlay Design with AASHTO (1993) method and Simplified method

| Overlay Design-B212 Road-AASHTO (1993) method | | | | |
|--|-----------------------------------|--------------|-------------|---|
| <u>Calculation of SN_f for B212 road (0 to 6.95 km)</u> | | | | |
| M_R | design subgrade resilient modulus | 8,548 | psi | (from calculation) |
| W_{18} | estimated future traffic | 8.95 | msa | (from design report) |
| R | reliability | 0.85 | | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) |
| S_0 | standard deviation | 0.4 | | (cl.4.3 AASHTO (1993)-Part I) |
| ΔPSI | serviceability loss | 1.5 | | (cl.2.2.1 AASHTO (1993)-Part II) |
| | | SN_f | 4.42 | (cl.3.1.1 AASHTO (1993)-Part II) |

| | | | | |
|---|--|---|--|----|
| <u>Calculation of design overlay thickness for B212 road (0 to 6.95 km)</u> | | | | |
| SN_f | - required structural number to carry future traffic | = | 4.42 | |
| SN_{eff} | - effective structural number of the existing pavement | = | 1.03 | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 3.39$ | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 2.37/0.4 = 215.3$ | mm |
| T_{pro} | - overlay thickness provided | = | 215 | mm |

| Overlay Design-B212 Road-Simplified method | | | | |
|--|-----------------------------------|--------------|-------------|---|
| <u>Calculation of SN_f for B212 road (0 to 6.95 km)</u> | | | | |
| M_R | design subgrade resilient modulus | 9,171 | psi | (from calculation) |
| W_{18} | estimated future traffic | 8.95 | msa | (from design report) |
| R | reliability | 0.85 | | (Table 2.2 AASHTO (1993)-Part II, Table 4.1 AASHTO (1993)-Part-I) |
| S_0 | standard deviation | 0.4 | | (cl.4.3 AASHTO (1993)-Part I) |
| ΔPSI | serviceability loss | 1.5 | | (cl.2.2.1 AASHTO (1993)-Part II) |
| | | SN_f | 4.31 | (cl.3.1.1 AASHTO (1993)-Part II) |

| | | | | |
|---|--|---|--|----|
| <u>Calculation of design overlay thickness for B212 road (0 to 6.95 km)</u> | | | | |
| SN_f | - required structural number to carry future traffic | = | 4.31 | |
| SN_{eff} | - effective structural number of the existing pavement | = | 0.80 | |
| SN_{OL} | - required structural number of asphalt overlay | = | $SN_f - SN_{eff} = 5.34 - 4.00 = 3.51$ | |
| a_{OL} | - structural layer coefficient of asphalt overlay | = | 0.4 | |
| T_{OL} | - required overlay thickness | = | $SN_{OL}/a_{OL} = 2.37/0.4 = 222.9$ | mm |
| T_{pro} | - overlay thickness provided | = | 225 | mm |