Characteristics of Flexible Pavements: Detailed Study by Using FWD and IIT-PAVE Software

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ABSTRACT: This paper evaluates and compares the deflection of flexible pavement using two methods: The Falling Weight Deflectometer (FWD) test and IIT-Pave software. The data for the project road NH-129 (Numaligarh to Khatkhati) in Assam is utilized for the current investigation. The subgrade modulus and the pavement thickness are obtained from the FWD result and the trial pit data, respectively. These values are then used to calculate the deflection of flexible pavement using IIT-Pave software. Two types of loading are considered for the calculation of deflection values: 20 kN with dual wheel and 40 kN with single wheel. The results of the study reveal that the deflection values calculated from IIT-Pave software are on average 22% and 5% lower than the FWD results for 20 kN dual wheel loading and 40 kN single wheel loading, respectively. During the calculation of deflection values, horizontal tensile strain and vertical compressive strain is also determined for above mentioned two types of loading. The result reveals than the tensile strain values for 40 kN single wheel load are average 8% more than strain values for 20 kN dual wheel load for bituminous layer thickness more than 60mm. And where the bituminous layer is around less than 60mm, strain values for 40 kN single wheel load are average 9% less than strain values for 20 kN dual wheel load. Further for compressive strain, it is average 21% more for 40 kN single wheel than 20 kN dual wheel load. In case of growth of traffic, considering good pavement condition overlay design has been done for first 13 km stretch for different traffic. From the overlay design, it is found that, for increase of each 10 MSA traffic, there is an increase of around 50mm bituminous overlay thickness. These findings provide insight into the reliability and accuracy of IIT-Pave software for assessing the deflection of flexible pavements and emphasize the importance of selecting appropriate loading conditions for obtaining accurate deflection measurements.

**Keywords:** Pavement Evaluation, FWD, Structural Evaluation, Flexible Pavement, IIT-PAVE

1. **Introduction**

Pavement surface deflection measurements are the primary means of evaluating a flexible pavement structure and rigid pavement load transfer. Although other measurements can be made that reflect (to some degree) a pavement’s structural condition. surface deflection is an important pavement evaluation method because the magnitude and shape of pavement deflection is a function of traffic (type and volume), pavement structural section, temperature affecting the pavement structure and moisture affecting the pavement structure. Deflection measurements can be used in back calculation methods to determine pavement structural layer stiffness and the subgrade resilient modulus. Thus, many characteristics of a flexible pavement can be determined by measuring its deflection in response to load. Furthermore, pavement deflection measurements are non-destructive.

Surface deflection is measured as a pavement surface’s vertical deflected distance as a result of an applied (either static or dynamic) load. The more advanced measurement devices record this vertical deflection in multiple locations, which provides a more complete characterization of pavement deflection. The area of pavement deflection under and near the load application is collectively known as the “deflection basin”.

There are three broad categories of nondestructive deflection testing equipment:

• Static deflections

• Steady state deflections

• Impact load deflections (FWD)

Subgrade rutting criteria is used in these guidelines for the design of bituminous pavements. An average rut depth of 20 mm or more, measured along the wheel paths, is considered in these guidelines as critical or failure rutting condition. The equivalent number of standard axle load (80 kN) repetitions that can be served by the pavement, before the critical average rut depth of 20 mm or more occurs. The rutting performance model developed initially based on the MoRTH R-6 Research Scheme performance data was subsequently developed into two separate models for two different reliability levels based on the additional performance data collected for MoRTH R-56 Research Scheme.

IIT-PAVE software is used in these guidelines for the analysis of pavements. For the computation of stresses, strains and deflections in the pavement, thicknesses and elastic properties (elastic modulus and Poisson’s ratio) of different layers are the main inputs. Guidelines for the selection of the elastic modulus and Poisson’s ratio values of different pavement layers are given in different sections of the guidelines. For the calculation of vertical compressive strain on top of the subgrade, horizontal tensile strain at the bottom of the bottom bituminous layer and the horizontal tensile strain at the bottom of base layer, the analysis is done for a standard axle load of 80 kN (single axle with dual wheels). Only one set of dual wheels, each wheel carrying 20 kN load with the centre to centre spacing of 310 mm between the two wheels, applied at the pavement surface shall be considered for the analysis. The shape of the contact area of the tyre is assumed in the analysis to be circular. The uniform vertical contact stress shall be considered as 0.56 MPa. However, when fatigue damage analysis of base is carried out, the contact pressure used for analysis shall be 0.80 MPa. The layer interface condition was assumed to be fully bound. The materials are assumed to be isotropic.

Here FWD is used to validate the deflection result from IIT-PAVE. All impact load devices deliver a transient impulse load to the pavement surface. The subsequent pavement response (deflection basin) is measured by a series of sensors. The most common type of equipment is the falling weight deflectometer (FWD). The FWD can either be mounted in a vehicle or on a trailer and is equipped with a weight and several velocity transducer sensors. To perform a test, the vehicle is stopped and the loading plate (weight) is positioned over the desired location. The sensors are then lowered to the pavement surface and the weight is dropped. Multiple tests can be performed on the same location using different weight drop heights (ASTM, 2000[1]). The advantage of an impact load response measuring device over a steady state deflection measuring device is that it is quicker, the impact load can be easily varied and it more accurately simulates the transient loading of traffic. Results from FWD tests are often communicated using the FWD AREA Parameter.

1. **Objective:**

The objectives of the study are as follows:

a) To compare the deflection obtained from FWD test and that for IIT PAVE analysis for different axle loading.

b) To compare the horizontal and vertical strain for different axle loading.

c) To compare the overlay thickness for a sample stretch for different loading.

1. **Scope of Work:**

To meet the above objectives in the present study, the scope of the work is outlined as follows:

1. Trial pits of were dug at the pavement shoulder interface, extending through the pavement layers down to the subgrade level and the pavement composition (i.e. Bituminous layer, Granular Layer) thickness has been noted down.
2. Nondestructive FWD (Falling Weight Deflectometer) test on existing carriageway at specified intervals as per IRC 115-2014 were conducted and deflection values are measured along with subgrade modulus at all locations are tabulated.
3. Based on the above collected data, deflection value is calculated by IIT-PAVE Software for each location for the following considerations:
4. Single Wheel Load = 20 KN, Dual Wheel
5. Single Wheel Load = 40 KN, Single Wheel

And the following criteria has been kept same for above two considerations:

• Resilient modulus of Bituminous Layer (VG40) = 3000 MPa

• Poissons’s Ratio = 0.35 for all layers

• Tyre Pressure = 0.56 MPa

1. The deflection value obtained from the IIT-PAVE has been compared and validated with the deflection value of FWD test.
2. The horizontal and vertical strains for the two types of loading have also been compared
3. Further, overlay design has been carried out for a selected section with different traffic and compared.
4. **Methodology:**
5. *Collection of Trial Pit data from site:*

The trial pit data for the project road NH-129 (Numaligarh to Khatkhati) in Assam is utilized for the current investigation.

1. *Collection of Falling Weight Deflectometer (FWD) Test Data:*

The FWD test data for the project road NH-129 (Numaligarh to Khatkhati) in Assam is utilized for the current investigation.

1. *Evaluation of Deflection of Pavement Layers with IIT-PAVE:*

Based on the above collected data, deflection value is calculated by IIT-PAVE Software for each location for the following considerations:

* 1. Single Wheel Load = 20 KN, Dual Wheel
	2. Single Wheel Load = 40 KN, Single Wheel

And the following criteria has been kept same for above two considerations:

• Resilient modulus of Bituminous Layer (VG40) = 3000 MPa (As per IRC 37: 2018)

• Poissons’s Ratio = 0.35 for all layers (As per IRC 37: 2018)

• Tyre Pressure = 0.56 MPa (As per IRC 37: 2018)

Resilient modulus of the Granular Layer has been calculated based the below equation (As per IRC 37: 2018):

MRGRAN = 0.2(h)0.45 x MRSUPPORT ………………………………………………………………. (1)

Where, MRGRAN = Resilient modulus of the Granular Layer (MPa)

 MRSUPPORT = Resilient modulus of the Supporting Layer (MPa)

 h = Thickness of Granular Layer (mm)

1. ***Comparison of Deflection, Strain****:*

The deflection values obtained from the IIT-PAVE have been compared and validated with the deflection value of FWD test. As well as, the strain generated for different loading also compared.

1. ***Comparison of Overlay thickness for different traffic:***

As per the site pavement condition, it is found that, for the first 13 kM stretch is road condition, subgrade CBR is good and sufficient embankment height is present for overlay criteria. Hence, this stretch is selected for overlay design for different traffic. To determine the overlay thickness, following steps are followed:

* Resilient Modulus of Subgrade is determined using the following equation no. 4.2 (As per IRC 37: 2018)

MRS = 17.6 x (CBR)0.64 for CBR > 5 % ……….……..……………………………. (2)

Where, MRS = Resilient Modulus of Subgrade

 CBR = California Bearing Ratio of Subgrade

* Resilient modulus of the Granular Layer has been calculated based the below equation no. 4.3.(As per IRC 37: 2018)

MRGRAN = 0.2(h)0.45 x MRSUPPORT ……………………………………………….………. (3)

Where, MRGRAN = Resilient modulus of the Granular Layer (MPa)

 MRSUPPORT = Resilient modulus of the Supporting Layer (MPa)

 h = Thickness of Granular Layer (mm)

* Allowable Horizontal Tensile Strain at Bottom of Bituminous Layer is calculated as per equation no. 4.4. (As per IRC 37: 2018)

Nf = 0.5161 x C x 10-04 [1/εt ]3.89 x [1/MRm ]0.854 (for 90 % reliability) ……...………… (4)

Where, C = 10M, and M= 4.84 x ((Vbe / (Va + Vbe)) – 0.69)

Va = per cent volume of air void in the mix used in the bottom bituminous layer

Vbe = per cent volume of effective bitumen in the mix used in the bottom bituminous layer

Nf = fatigue life of bituminous layer

εt = maximum horizontal tensile strain at the bottom of the bottom bituminous layer

MRm = resilient modulus (MPa) of the bituminous mix

* Allowable Vertical Compressive Strain at Top of Subgrade Layer is calculated as per equation 4.5 (As per IRC 37: 2018).

NR = 1.4100 x 10-08 [1/εv ]4.5337 ………………………………….……………………... (5)

Where, NR = subgrade rutting life

εv = vertical compressive strain at the top of the subgrade

* After computation of allowable strains for different traffic, an overlay thickness is assumed and the overall pavement composition is analyzed in IIT-Pave till the computed strains reaches the allowable limit.

1. **Results:**

The results of the IIT-Pave analysis are presented below Table 1:

**Table 1: Results from IIT-Pave Analysis**

| **Site Data** | **Required Modulus** | **Result with Dual Wheel load 20KN** | **Result with Single Wheel load 40KN** | **Deflection from FWD (mm)** |
| --- | --- | --- | --- | --- |
| **LocationEx. Chainage(KM)** | **Bituminous Layer(mm)** | **Granular Layer(mm)** | **Elastic Modulus of Subgrade Soil from FWD(Mpa)** | **Resilient modulus of the Granular Layer (MPa)** | **Displacement at Subgrade Top (mm)** | **Displacement at Bituminous Bottom (mm)** | **Displacement at Subgrade Top (mm)** | **Displacement at Bituminous Bottom (mm)** |
| 200 | 90 | 330 | 112 | 304.49 | 0.2593 | 0.363 | 0.2721 | 0.4316 | 0.479076 |
| 500 | 91 | 340 | 112 | 308.61 | 0.2534 | 0.3572 | 0.2654 | 0.4241 | 0.4584521 |
| 1000 | 93 | 348 | 112 | 311.86 | 0.2479 | 0.3511 | 0.2592 | 0.4156 | 0.4459388 |
| 1500 | 89 | 352 | 110 | 307.87 | 0.253 | 0.3603 | 0.2646 | 0.4293 | 0.4323051 |
| 2000 | 86 | 356 | 109.9 | 309.16 | 0.2533 | 0.3628 | 0.2653 | 0.4358 | 0.4824306 |
| 2500 | 84 | 368 | 110 | 314.09 | 0.2486 | 0.3607 | 0.2597 | 0.4331 | 0.4361317 |
| 3000 | 87 | 366 | 110 | 313.32 | 0.2475 | 0.3568 | 0.2584 | 0.427 | 0.473116 |
| 3500 | 85 | 368 | 110 | 314.09 | 0.2479 | 0.359 | 0.2565 | 0.4307 | 0.4509429 |
| 4000 | 86 | 372 | 96 | 275.45 | 0.2784 | 0.4025 | 0.2903 | 0.4789 | 0.5334946 |
| 4500 | 85 | 374 | 111 | 319.26 | 0.243 | 0.3538 | 0.2536 | 0.4244 | 0.428644 |
| 5000 | 83 | 378 | 102 | 294.78 | 0.2623 | 0.3829 | 0.2736 | 0.4593 | 0.5084451 |
| 5500 | 82 | 384 | 102 | 296.88 | 0.26 | 0.3821 | 0.271 | 0.4588 | 0.5051388 |
| 6000 | 80 | 380 | 108 | 312.86 | 0.2497 | 0.3685 | 0.2607 | 0.4437 | 0.4712094 |
| 6500 | 92 | 384 | 110 | 320.16 | 0.2359 | 0.3431 | 0.2454 | 0.4073 | 0.4386621 |
| 7000 | 105 | 386 | 110 | 320.91 | 0.2271 | 0.3269 | 0.2355 | 0.3804 | 0.3807804 |
| 7500 | 118 | 396 | 108 | 318.73 | 0.2194 | 0.3138 | 0.2265 | 0.3585 | 0.382878 |
| 8000 | 130 | 399 | 110 | 325.73 | 0.2082 | 0.2952 | 0.2145 | 0.3332 | 0.3338664 |
| 8500 | 145 | 408 | 110 | 329.02 | 0.1978 | 0.278 | 0.2031 | 0.3096 | 0.3445848 |
| 9000 | 160 | 408 | 109.9 | 328.72 | 0.191 | 0.2649 | 0.1957 | 0.2915 | 0.3081155 |
| 9500 | 171 | 410 | 108 | 323.75 | 0.1885 | 0.259 | 0.1929 | 0.2828 | 0.2963744 |
| 10000 | 180 | 410 | 110 | 329.74 | 0.1816 | 0.248 | 0.1857 | 0.2696 | 0.2787664 |
| 10500 | 175 | 406 | 110 | 328.29 | 0.1848 | 0.2528 | 0.1891 | 0.2755 | 0.281561 |
| 11000 | 161 | 396 | 110 | 324.63 | 0.1939 | 0.2668 | 0.1989 | 0.2933 | 0.305032 |
| 11500 | 145 | 374 | 110 | 316.38 | 0.2089 | 0.2875 | 0.2151 | 0.3198 | 0.3335514 |
| 12000 | 125 | 352 | 112 | 313.47 | 0.225 | 0.3108 | 0.2331 | 0.3523 | 0.3818932 |
| 12500 | 110 | 335 | 112 | 306.56 | 0.2422 | 0.3348 | 0.2523 | 0.3861 | 0.4119687 |
| 13000 | 91 | 318 | 109.9 | 293.85 | 0.2696 | 0.3736 | 0.2811 | 0.4354 | 0.4623948 |
| 13500 | 73 | 296 | 110 | 284.78 | 0.2928 | 0.4091 | 0.3179 | 0.5055 | 0.519654 |
| 14000 | 65 | 286 | 109.7 | 279.64 | 0.3145 | 0.4108 | 0.337 | 0.5398 | 0.5916208 |
| 14500 | 58 | 276 | 110 | 275.95 | 0.3288 | 0.4643 | 0.3549 | 0.5713 | 0.6330004 |
| 15000 | 45 | 250 | 107 | 256.74 | 0.3764 | 0.5367 | 0.4145 | 0.664 | 0.732392 |
| 15500 | 48 | 268 | 107 | 264.90 | 0.3559 | 0.5121 | 0.3879 | 0.6322 | 0.6992132 |
| 16000 | 51 | 288 | 112 | 286.40 | 0.3212 | 0.4685 | 0.3471 | 0.5767 | 0.6038049 |
| 16500 | 55 | 299 | 111 | 288.67 | 0.3116 | 0.454 | 0.3346 | 0.5579 | 0.6120163 |
| 17000 | 54 | 332 | 111 | 302.60 | 0.2898 | 0.4371 | 0.3085 | 0.5356 | 0.5345288 |
| 17500 | 52 | 351 | 108 | 301.89 | 0.2868 | 0.4425 | 0.3042 | 0.5471 | 0.558042 |
| 18000 | 58 | 366 | 107 | 304.78 | 0.2754 | 0.4232 | 0.2904 | 0.517 | 0.531476 |
| 18500 | 57 | 375 | 107 | 308.13 | 0.271 | 0.421 | 0.2854 | 0.5143 | 0.5328148 |
| 19000 | 60 | 382 | 107 | 310.70 | 0.2649 | 0.4106 | 0.2782 | 0.501 | 0.530058 |
| 19500 | 63 | 388 | 107 | 312.89 | 0.2596 | 0.4012 | 0.2721 | 0.4887 | 0.530058 |
| 20000 | 62 | 390 | 107 | 313.61 | 0.2592 | 0.4024 | 0.2717 | 0.4904 | 0.530058 |
| 20500 | 61 | 390 | 107 | 313.61 | 0.26 | 0.4046 | 0.2725 | 0.4933 | 0.530058 |
| 21000 | 65 | 390 | 107 | 313.61 | 0.2572 | 0.396 | 0.2693 | 0.4819 | 0.530058 |
| 21500 | 59 | 390 | 107 | 313.61 | 0.2614 | 0.4091 | 0.2742 | 0.4991 | 0.530058 |
| 22000 | 63 | 390 | 107 | 313.61 | 0.2586 | 0.4003 | 0.2709 | 0.4875 | 0.5148 |
| 22500 | 67 | 390 | 103 | 301.89 | 0.2661 | 0.4054 | 0.2765 | 0.4926 | 0.5453082 |
| 23000 | 69 | 390 | 103 | 301.89 | 0.2637 | 0.4012 | 0.2757 | 0.4868 | 0.5432688 |
| 23500 | 71 | 390 | 103 | 301.89 | 0.2623 | 0.3972 | 0.2741 | 0.4812 | 0.5331696 |
| 24000 | 72 | 390 | 103 | 301.89 | 0.2616 | 0.3951 | 0.2733 | 0.4784 | 0.5027984 |
| 24500 | 74 | 390 | 109 | 319.47 | 0.2467 | 0.3721 | 0.2577 | 0.4501 | 0.4487497 |
| 25000 | 75 | 400 | 95 | 281.63 | 0.2745 | 0.4135 | 0.286 | 0.4987 | 0.5515622 |
| 25500 | 71 | 392 | 114 | 334.90 | 0.2375 | 0.3622 | 0.2482 | 0.4392 | 0.463356 |
| 26000 | 69 | 388 | 108 | 315.81 | 0.3523 | 0.3856 | 0.2649 | 0.468 | 0.47736 |
| 26500 | 61 | 372 | 101 | 289.80 | 0.2848 | 0.4351 | 0.2995 | 0.5307 | 0.5349456 |
| 27000 | 67 | 384 | 101 | 293.97 | 0.2733 | 0.4154 | 0.2862 | 0.5047 | 0.5561794 |
| 27500 | 59 | 359 | 101 | 285.20 | 0.2943 | 0.4469 | 0.3106 | 0.546 | 0.566202 |
| 28000 | 52 | 312 | 101 | 267.74 | 0.3336 | 0.4945 | 0.3573 | 0.6074 | 0.6699622 |
| 28500 | 45 | 290 | 117 | 300.12 | 0.3127 | 0.4662 | 0.339 | 0.5727 | 0.5944626 |
| 29000 | 43 | 260 | 117 | 285.73 | 0.3393 | 0.4937 | 0.3728 | 0.6085 | 0.6772605 |
| 29500 | 35 | 245 | 110 | 261.55 | 0.3846 | 0.5646 | 0.4286 | 0.6935 | 0.7191595 |
| 30000 | 30 | 240 | 110 | 259.13 | 0.3966 | 0.5891 | 0.4454 | 0.719 | 0.759983 |
| 30500 | 35 | 257 | 110 | 267.23 | 0.3726 | 0.5539 | 0.4126 | 0.6788 | 0.6916972 |
| 31000 | 41 | 272 | 110 | 274.14 | 0.3513 | 0.5197 | 0.3844 | 0.6392 | 0.7069552 |
| 31500 | 49 | 299 | 110 | 286.07 | 0.3203 | 0.4748 | 0.3451 | 0.5836 | 0.6051932 |
| 32000 | 55 | 331 | 114 | 310.35 | 0.2823 | 0.4248 | 0.3006 | 0.5205 | 0.5522505 |
| 32500 | 67 | 372 | 116.9 | 335.42 | 0.2441 | 0.3698 | 0.2564 | 0.45 | 0.46665 |
| 33000 | 53 | 370 | 117 | 334.89 | 0.2546 | 0.3998 | 0.2688 | 0.4885 | 0.4899655 |
| 33500 | 49 | 396 | 114 | 336.43 | 0.2499 | 0.4063 | 0.2627 | 0.4955 | 0.52523 |
| 34000 | 51 | 419 | 115 | 348.12 | 0.2354 | 0.3881 | 0.2463 | 0.473 | 0.481041 |
| 34500 | 54 | 442 | 117 | 362.79 | 0.2199 | 0.3664 | 0.2291 | 0.4463 | 0.4454074 |
| 35000 | 60 | 460 | 115 | 363.05 | 0.2129 | 0.3535 | 0.2201 | 0.4302 | 0.4697784 |
| 35500 | 61 | 460 | 115 | 363.05 | 0.2124 | 0.3516 | 0.2204 | 0.4278 | 0.4697784 |
| 36000 | 63 | 452 | 115 | 360.20 | 0.2145 | 0.3508 | 0.2227 | 0.4266 | 0.4726728 |
| 36500 | 59 | 434 | 103 | 316.77 | 0.2486 | 0.4031 | 0.2589 | 0.4911 | 0.4999398 |
| 37000 | 63 | 388 | 106 | 309.96 | 0.2619 | 0.4046 | 0.2745 | 0.2928 | 0.317688 |
| 37500 | 64 | 350 | 106 | 295.91 | 0.2825 | 0.4209 | 0.2988 | 0.5133 | 0.317688 |
| 38000 | 65 | 330 | 106 | 288.18 | 0.2941 | 0.4292 | 0.3116 | 0.5236 | 0.317688 |
| 55000 | 55 | 218 | 105 | 236.88 | 0.4019 | 0.5375 | 0.4447 | 0.6677 | 0.7131036 |
| 55500 | 58 | 227 | 105 | 241.23 | 0.3882 | 0.5201 | 0.4265 | 0.6441 | 0.7131036 |
| 56000 | 61 | 250 | 105 | 251.94 | 0.3623 | 0.4935 | 0.3935 | 0.6079 | 0.7131036 |
| 56500 | 60 | 288 | 105 | 268.50 | 0.3316 | 0.4624 | 0.356 | 0.4509 | 0.7131036 |
| 57000 | 57 | 314 | 105 | 279.15 | 0.3152 | 0.4622 | 0.3365 | 0.439 | 0.7131036 |
| 57500 | 59 | 332 | 105 | 286.24 | 0.3008 | 0.4464 | 0.3194 | 0.4251 | 0.7131036 |
| 58000 | 55 | 362 | 105 | 297.60 | 0.2852 | 0.44 | 0.3013 | 0.4139 | 0.7131036 |
| 58500 | 51 | 376 | 105 | 302.73 | 0.28 | 0.4429 | 0.2954 | 0.5414 | 0.7131036 |
| 59000 | 49 | 390 | 105 | 307.75 | 0.2735 | 0.4306 | 0.2878 | 0.5383 | 0.7131036 |
| 59500 | 53 | 405 | 105 | 313.02 | 0.2624 | 0.4232 | 0.2749 | 0.5165 | 0.7131036 |
| 60000 | 50 | 410 | 105 | 314.75 | 0.2619 | 0.4282 | 0.2744 | 0.5225 | 0.5825875 |
| 60500 | 51 | 398 | 105 | 310.58 | 0.2675 | 0.4316 | 0.2809 | 0.5269 | 0.5542988 |
| 61000 | 49 | 374 | 105 | 302.00 | 0.2828 | 0.4493 | 0.2986 | 0.5491 | 0.6122465 |
| 61500 | 48 | 360 | 105 | 296.86 | 0.2922 | 0.4599 | 0.3097 | 0.5624 | 0.6051424 |
| 62000 | 53 | 346 | 112 | 311.05 | 0.2794 | 0.4284 | 0.2965 | 0.5245 | 0.5250245 |
| 62500 | 55 | 334 | 112 | 306.15 | 0.2852 | 0.43 | 0.3033 | 0.5267 | 0.5551418 |
| 63000 | 51 | 305 | 112 | 293.89 | 0.3085 | 0.4576 | 0.3314 | 0.5621 | 0.6008849 |
| 63500 | 49 | 284 | 111.9 | 284.35 | 0.3268 | 0.4774 | 0.354 | 0.5879 | 0.6037733 |
| 64000 | 48 | 295 | 112 | 289.51 | 0.3189 | 0.4726 | 0.3443 | 0.5811 | 0.5805189 |
| 64500 | 52 | 303 | 102 | 266.86 | 0.3375 | 0.4961 | 0.3624 | 0.61 | 0.67344 |
| 65000 | 50 | 304 | 102 | 267.25 | 0.3389 | 0.5017 | 0.3642 | 0.6168 | 0.6408552 |
| 65500 | 52 | 300 | 102 | 265.67 | 0.3399 | 0.4982 | 0.3653 | 0.6126 | 0.6426174 |
| 66000 | 55 | 313 | 102 | 270.79 | 0.3267 | 0.4807 | 0.3492 | 0.59 | 0.61065 |
| 66500 | 51 | 311 | 102 | 270.01 | 0.3323 | 0.4938 | 0.3562 | 0.6067 | 0.6364283 |
| 67000 | 50 | 308 | 102 | 268.83 | 0.3299 | 0.4989 | 0.3604 | 0.6132 | 0.6604164 |
| 67500 | 57 | 302 | 114 | 297.81 | 0.2998 | 0.4363 | 0.3214 | 0.5357 | 0.5646278 |
| 68000 | 59 | 299 | 105 | 273.07 | 0.3242 | 0.4661 | 0.3472 | 0.5719 | 0.6353809 |
| 68500 | 56 | 289 | 105 | 268.92 | 0.3352 | 0.481 | 0.3606 | 0.5915 | 0.604513 |
| 69000 | 59 | 292 | 106 | 272.75 | 0.3266 | 0.4666 | 0.3505 | 0.5729 | 0.6330545 |
| 69500 | 58 | 296 | 106 | 274.42 | 0.3246 | 0.4668 | 0.3482 | 0.5732 | 0.6330545 |
| 70000 | 60 | 300 | 106 | 276.08 | 0.3196 | 0.4589 | 0.3419 | 0.5627 | 0.6330545 |
| 70500 | 62 | 293 | 106 | 273.17 | 0.3227 | 0.458 | 0.3456 | 0.5613 | 0.6330545 |
| 71000 | 67 | 285 | 106 | 269.78 | 0.3234 | 0.4502 | 0.3461 | 0.5502 | 0.6330545 |
| 71500 | 71 | 279 | 106 | 267.21 | 0.3236 | 0.4441 | 0.3461 | 0.5412 | 0.6330545 |
| 72000 | 75 | 272 | 111 | 276.64 | 0.3108 | 0.4214 | 0.3324 | 0.5123 | 0.5107631 |
| 72500 | 77 | 264 | 105 | 258.19 | 0.3311 | 0.4428 | 0.3542 | 0.5368 | 0.5695448 |
| 73000 | 81 | 266 | 111 | 273.87 | 0.3087 | 0.4118 | 0.3296 | 0.4981 | 0.5364537 |
| 73500 | 83 | 267 | 111 | 274.34 | 0.3049 | 0.4092 | 0.3261 | 0.4914 | 0.5364537 |
| 74000 | 80 | 268 | 111 | 274.80 | 0.3084 | 0.4135 | 0.3292 | 0.4997 | 0.5364537 |
| 74500 | 84 | 267 | 111 | 274.34 | 0.3049 | 0.4076 | 0.3248 | 0.4885 | 0.5364537 |
| 75000 | 85 | 268 | 101 | 250.04 | 0.3307 | 0.4415 | 0.3517 | 0.5225 | 0.567435 |
| 75500 | 81 | 276 | 101 | 253.37 | 0.3294 | 0.4438 | 0.3505 | 0.5324 | 0.5760568 |
| 76000 | 79 | 292 | 101 | 259.88 | 0.32 | 0.4375 | 0.3396 | 0.5274 | 0.5760568 |
| 76500 | 72 | 309 | 101 | 266.58 | 0.3154 | 0.4431 | 0.3345 | 0.5381 | 0.5760568 |
| 77000 | 65 | 328 | 101 | 273.84 | 0.3091 | 0.4491 | 0.3276 | 0.5478 | 0.5932674 |
| 77500 | 50 | 329 | 110 | 298.65 | 0.2978 | 0.4531 | 0.3179 | 0.5555 | 0.5993845 |
| 78000 | 48 | 340 | 108 | 297.59 | 0.2974 | 0.4598 | 0.3167 | 0.563 | 0.57989 |
| 78500 | 45 | 354 | 108 | 303.04 | 0.2908 | 0.4601 | 0.3091 | 0.5621 | 0.57989 |
| 79000 | 41 | 358 | 108 | 304.58 | 0.2917 | 0.4694 | 0.3102 | 0.5718 | 0.5838078 |
| 79500 | 35 | 360 | 107.9 | 305.06 | 0.2969 | 0.4902 | 0.3153 | 0.589 | 0.622573 |
| 80000 | 30 | 368 | 108 | 308.38 | 0.2951 | 0.497 | 0.3143 | 0.596 | 0.63474 |
| 80500 | 39 | 370 | 108 | 309.13 | 0.2858 | 0.4683 | 0.3033 | 0.5688 | 0.577332 |
| 81000 | 46 | 371 | 112 | 320.97 | 0.27 | 0.4331 | 0.2857 | 0.5285 | 0.5839925 |
| 81500 | 58 | 372 | 112 | 321.36 | 0.2605 | 0.4033 | 0.2744 | 0.4925 | 0.5383025 |
| 82000 | 66 | 336 | 112 | 306.97 | 0.2749 | 0.4034 | 0.2908 | 0.4919 | 0.511576 |
| 82500 | 78 | 327 | 109.9 | 297.56 | 0.2752 | 0.39 | 0.2902 | 0.4713 | 0.5038197 |
| 83000 | 81 | 329 | 110 | 298.65 | 0.2714 | 0.3831 | 0.2858 | 0.4617 | 0.4732425 |
| 83500 | 82 | 339 | 110 | 302.70 | 0.265 | 0.3767 | 0.2785 | 0.4534 | 0.4570272 |
| 84000 | 85 | 353 | 110 | 308.26 | 0.2554 | 0.3653 | 0.2674 | 0.4383 | 0.4549554 |
| 84500 | 88 | 360 | 112 | 316.65 | 0.2456 | 0.3523 | 0.2566 | 0.4211 | 0.4484715 |
| 85000 | 90 | 370 | 112 | 320.58 | 0.2395 | 0.3456 | 0.2498 | 0.4118 | 0.4398024 |
| 85500 | 81 | 357 | 112 | 315.46 | 0.2519 | 0.3647 | 0.2641 | 0.4393 | 0.4735654 |
| 86000 | 75 | 344 | 112 | 310.24 | 0.2632 | 0.3814 | 0.2771 | 0.4681 | 0.4735654 |
| 86500 | 71 | 342 | 112 | 309.43 | 0.2674 | 0.3901 | 0.282 | 0.4739 | 0.4735654 |
| 87000 | 64 | 330 | 112 | 304.49 | 0.2801 | 0.4109 | 0.297 | 0.5017 | 0.5588938 |
| 87500 | 61 | 316 | 112 | 298.61 | 0.2916 | 0.4253 | 0.3107 | 0.5207 | 0.5644388 |
| 88000 | 59 | 315 | 116 | 308.84 | 0.2845 | 0.4174 | 0.3037 | 0.5119 | 0.5717923 |
| 88500 | 55 | 300 | 116 | 302.13 | 0.2982 | 0.4358 | 0.3202 | 0.5354 | 0.5771612 |
| 89000 | 54 | 288 | 116 | 296.63 | 0.3078 | 0.4457 | 0.3319 | 0.5484 | 0.5632068 |
| 89500 | 52 | 277 | 113 | 283.94 | 0.326 | 0.4692 | 0.3535 | 0.5782 | 0.5886076 |
| 90000 | 50 | 270 | 110 | 273.24 | 0.3426 | 0.4917 | 0.3728 | 0.6067 | 0.6212608 |
| 90500 | 51 | 270 | 110 | 273.24 | 0.3416 | 0.489 | 0.3712 | 0.6029 | 0.6674103 |
| 91000 | 49 | 269 | 110 | 272.78 | 0.3446 | 0.4956 | 0.3754 | 0.6115 | 0.6757075 |
| 91500 | 48 | 274 | 109.9 | 274.80 | 0.3418 | 0.4955 | 0.3718 | 0.611 | 0.627497 |
| 92000 | 53 | 271 | 110 | 273.69 | 0.3384 | 0.4819 | 0.3672 | 0.5943 | 0.6263922 |
| 92500 | 55 | 268 | 107 | 264.90 | 0.3476 | 0.4901 | 0.3769 | 0.6044 | 0.6606092 |
| 93000 | 51 | 301 | 96.9 | 252.76 | 0.3572 | 0.5243 | 0.3838 | 0.6449 | 0.7035859 |
| 93500 | 49 | 296 | 97 | 251.12 | 0.3634 | 0.5341 | 0.3917 | 0.6575 | 0.69432 |
| 94000 | 48 | 315 | 97 | 258.25 | 0.3486 | 0.5237 | 0.3731 | 0.6434 | 0.7000192 |
| 94500 | 52 | 329 | 96.9 | 263.08 | 0.3337 | 0.5019 | 0.3556 | 0.6157 | 0.6304768 |
| 95000 | 50 | 331 | 97 | 264.07 | 0.3339 | 0.5063 | 0.356 | 0.6212 | 0.627412 |
| 95500 | 51 | 330 | 97 | 263.71 | 0.3336 | 0.5039 | 0.3556 | 0.6182 | 0.6726016 |
| 96000 | 49 | 337 | 112 | 307.38 | 0.2884 | 0.4439 | 0.3073 | 0.5436 | 0.5620824 |
| 96500 | 48 | 352 | 112 | 313.47 | 0.2797 | 0.4381 | 0.2971 | 0.5357 | 0.5598065 |
| 97000 | 53 | 369 | 112 | 320.19 | 0.2658 | 0.4164 | 0.2807 | 0.509 | 0.516635 |
| 97500 | 55 | 382 | 112 | 325.22 | 0.2573 | 0.4053 | 0.2708 | 0.495 | 0.497475 |
| 98000 | 51 | 401 | 112 | 332.40 | 0.2502 | 0.4057 | 0.2626 | 0.495 | 0.544995 |
| 98500 | 49 | 410 | 112 | 335.74 | 0.247 | 0.4063 | 0.259 | 0.4953 | 0.4977765 |
| 99000 | 48 | 423 | 112 | 340.49 | 0.2414 | 0.4028 | 0.2526 | 0.4905 | 0.538569 |
| 99500 | 52 | 431 | 112 | 343.37 | 0.2352 | 0.3901 | 0.2445 | 0.4754 | 0.5196122 |
| 100000 | 50 | 440 | 112 | 346.58 | 0.2323 | 0.3908 | 0.2423 | 0.4759 | 0.4906529 |

1. **Discussion:**
2. *Deflection of Flexible Pavements:*

Two types of loading are considered for the calculation of deflection values: 20 kN with dual wheel and 40 kN with single wheel. The results of the study reveal that the deflection values calculated from IIT-Pave software are on average 22% and 5% lower than the FWD results for 20 kN dual wheel loading and 40 kN single wheel loading, respectively. These findings provide insight into the reliability and accuracy of IIT-Pave software for assessing the deflection of flexible pavements and emphasize the importance of selecting appropriate loading conditions for obtaining accurate deflection measurements. A comparison graph is plotted below in Figure 1 to show the deflections for the two cases along with the deflection values of the FWD test.

**Figure 1: Comparison of Deflection**

1. *Horizontal & Vertical Strain:*

Two types of loading are considered for the calculation of strains: 20 kN with dual wheel and 40 kN with single wheel. A comparison graph is plotted below in Figure 2 & 3 to show the strains for the two cases.

**Figure 2: Comparison of Horizontal Tensile Strain**

**Figure 3: Comparison of Vertical Tensile Strain**

1. *Overlay thickness for different MSA:*

As per the site pavement condition, it is found that, for the first 13 kM stretch is road condition, subgrade CBR is good and sufficient embankment height is present for overlay criteria. Hence, this stretch is selected for overlay design for different traffic.

* Average thickness of Existing Bituminous Layer = 87mm
* Average thickness of Existing Granular Layer = 359mm
* Average Elastic Modulus of Subgrade Soil = 109 MPa
* Resilient modulus of the Granular Layer = 307.786 MPa

Based on the above data the overlay thickness for different MSA given in following Table 2.

**Table 2 : Overlay thickness for different MSA**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **MSA** | **Allowable Horizontal Tensile Strain at Bottom of Bituminous Layer** | **Allowable Vertical Compressive Strain at Top of Subgrade Layer** | **Required Overlay Thickness (mm)** | **Horizontal Tensile Strain at Bottom of Bituminous Layer** | **Vertical Compressive Strain at Top of Subgrade Layer** |
| 20 | 0.000225442 | 0.000454945 | 30 | 0.0001881 | 0.0002328 |
| 30 | 0.000203127 | 0.000416024 | 80 | 0.0001948 | 0.0003555 |
| 40 | 0.000188647 | 0.000390446 | 140 | 0.0001820 | 0.0003515 |
| 50 | 0.00017813 | 0.000371694 | 190 | 0.0001738 | 0.0003521 |
| 60 | 0.000169974 | 0.000357043 | 240 | 0.0001643 | 0.0003461 |

A graph is plotted below in Figure 4 to overlay thickness for different msa.

**Figure 4: Overlay thickness for different MSA**

As per Table 1 & Figure 1 following observations can be drawn:

* 1. Deflection values calculated from IIT-Pave software are on average 22% and 5% lower than the FWD results for 20 kN dual wheel loading and 40 kN single wheel loading, respectively.
	2. For first 13km, the deflection values obtained from IIT-Pave for 20 kN dual wheel load is average 10% lower than the deflection values obtained from FWD results.
	3. In figure 1, it can also be observed that from 55000 to 60000, the line for FWD defection is straight as FWD results cannot be done due to poor road condition.
	4. It can also be observed that, the deflection for each loading as well as FWD are decreasing from chainage 6000m till 10000m and again increasing till 13000m. From Table 5.3 it can be observed that the subgrade modulus is increasing from chainage 6000m to till 10000m and again decreasing till 13000m and the existing pavement thickness is also in higher side (more than 500mm) near chainage 10000m.
	5. This same less deflection can be observed near chainage 29000m where modulus of subgrade reaction is 117 MPa and near design chainage 88000m to 89000m where modulus of subgrade reaction is 116 MPa.

As per Table 1, Figure 2 & 3 following observations can be drawn:

1. For the first 13 km, tensile strain values for 40 kN single wheel load are average 8% more than strain values for 20 kN dual wheel load.
2. The tensile strain values for 40 kN single wheel load are average 8% more than strain values for 20 kN dual wheel load for bituminous layer thickness more than 60mm.
3. And where the bituminous layer is around less than 60mm, strain values for 40 kN single wheel load are average 9% less than strain values for 20 kN dual wheel load.
4. Further for compressive strain, it is average 21% more for 40 kN single wheel compared to 20 kN dual wheel load.
5. It can also be observed that, the strains for each loading as well as FWD are decreasing from chainage 6000m till 10000m and again increasing till 13000m. From Table 5.3 it can be observed that the subgrade modulus is increasing from chainage 6000m to till 10000m and again decreasing till 13000m and the existing pavement thickness is also in higher side (more than 500mm) near chainage 10000m.
6. This same less strain can be observed near chainage 29000m where modulus of subgrade reaction is 117 MPa and near design chainage 88000m to 89000m where modulus of subgrade reaction is 116 MPa.
7. Further, in Figure 3, it can be observed that, the compressive strain reaches the peak value near chainage 15000m, 30000m & 55000m. From Table 5.3, it can be observed that the pavement thickness is on lower side (i.e., 295mm, 270mm and 273mm respectively).
8. The strain lines are flat from chainage 16000m to 25000m and from 64000m to 74000m. From Table 1, it can be observed that, the modulus of subgrade reaction and the pavement thickness are not varying too much.

Hence it is very clear that, strength of subgrade modulus is very important factor for determination of deflection of pavement and generated strain (tensile and compressive). Where, subgrade strength is good, deflection and strains are on lower side. And where the subgrade strength is poor, deflection and strains are on higher side.

As per Table 2, Figure 6.4 following observations can be drawn:

1. For increase of each 10 MSA traffic, there is an increase of around 50mm bituminous overlay thickness, which is normal as cumulative wheel load will also increase with increase with traffic.
2. For increase of traffic from 20 MSA to 30 MSA bituminous overlay thickness increases for 167%, from 30 MSA to 40 MSA bituminous overlay thickness increases for 75%, from 40 MSA to 50 MSA bituminous overlay thickness increases for 36%, from 50 MSA to 60 MSA bituminous overlay thickness increases for 26% (Refer. Figure 5), however this percentage increase for overlay thickness is site specific, it may vary in different location.

**Figure 5: Percentage Increase of Bituminous Overlay for Different MSA**

1. **Conclusion:**

The following conclusions may be drawn from the present study:

1. The IIT-Pave analysis result has been successfully validated with the FWD test data reported by M/s. Voyants Solutions Pvt. Ltd. for existing Numaligarh – Khatkhati Road (NH-129) at Assam, India.
2. Two types of loading are considered for the calculation of deflection values: 20 kN with dual wheel and 40 kN with single wheel. The results of the study reveal that the deflection values calculated from IIT-Pave software are on average 22% and 5% lower than the FWD results for 20 kN dual wheel loading and 40 kN single wheel loading, respectively.
3. These findings provide insight into the reliability and accuracy of IIT-Pave software for assessing the deflection of flexible pavements and emphasize the importance of selecting appropriate loading conditions for obtaining accurate deflection measurements.
4. During the calculation of deflection values, horizontal tensile strain and vertical compressive strain is also determined for above mentioned two types of loading. The result reveals than the tensile strain values for 40 kN single wheel load are average 8% more than strain values for 20 kN dual wheel load for bituminous layer thickness more than 60mm. And where the bituminous layer is around less than 60mm, strain values for 40 kN single wheel load are average 9% less than strain values for 20 kN dual wheel load.
5. Further for compressive strain, it is average 21% more for 40 kN single wheel compared to 20 kN dual wheel load.
6. From this study, it is very clear that, strength of subgrade modulus is very important factor for determination of deflection of pavement and generated strain (tensile and compressive). Where, subgrade strength is good, deflection and strains are on lower side. And where the subgrade strength is poor, deflection and strains are on higher side.

From the overlay design, it is found that, for increase of each 10 MSA traffic, there is an increase of around 50mm bituminous overlay thickness.

1. **References:**
	1. Ming Zhang, Nan-nan Li and Min Yang (2022) - “The Multi-Factor Control and Evaluation of Highway Soft Soil Subgrade Stability”
	2. A Zhafirah, A K Somantri, E Walujodjati and S Mulyana (2021) - “Verification of modulus of subgrade reaction experimental based on plate deflection”
	3. Junhui Zhang, Le Ding, Ling Zeng, Qianfeng Gao and Fan Gu (2020) - “Using portable falling weight deflectometer to determine treatment depth of subgrades in highway reconstruction of Southern China”
	4. MANOJ RAMAKANT ANAOKAR (2020) - “Performance Enhancement of Flexible Pavements Founded on Expansive Subgrades”
	5. Binanda Khungur Narzary (2020) - “Estimation of Equivalent Modulus of Fine-Grained Subgrade Soil”
	6. Md Jibon (2019) - “Effect of Subgrade Conditions on Pavement Analysis and Performance Prediction: A Study for Idaho Conditions”
	7. Abhishek Garg, B.L. Swami, Mansha Swami (2019) - “Comparative Study for Strengthening of Existing Flexible Pavement Using Falling Weight Deflectometer and Benkelman Beam Deflection Techniques”
	8. M. Razali, N. A. Che Mahmood, K. A. Hashim, S. Mansor, N. I. Zainuddin (2018) - “The falling weight deflectometer (FWD) for characterization bonding state of subgrade”
	9. Adel Djellalia, Mohamed Salah Laouarb, Behrooz Saghafic, Abdelkader Houamd (2018) - “Deformation Analyses of Pavement Structure Caused by Swell -Shrink of Subgrade Soil”
	10. László Gáspár (2017) - “Predicting subgrade soil strength using FWD and meteorological time series data”
	11. IRC 37: 2018 - Guidelines for The Design of Flexible Pavements (Fourth Revision)
	12. IRC:115-2014 "Guidelines for Structural Evaluation and Strengthening of Flexible Road Pavements Using Falling Weight Deflectometer (FWD) Technique"
	13. Falling Weight Deflectometer Test data and Trial Pit data of Numaligarh – Khatkhati Road (NH-129) by Voyants Solutions Pvt. Ltd.
	14. IRC: SP:84-2019 "Manual of Specifications and Standards for Four Laning of Highways (Second Revision)"
	15. IRC:81-1997 ‘’Guidelines for strengthening of flexible road pavements using Benkleman Beam deflection technique’’
	16. IRC: 73 -2023 “Geometric Design Standards for Non-Urban (Rural) Roads”
	17. IRC: SP:73-2018 "Manual of Specifications and Standards for Two Laning of Highways (Second Revision)"