# Stress Analysis and Determination of Effective k-value for Rigid Pavement

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**ABSTRACT**

EverFE is a user-friendly 3D finite-element analysis tool for simulating the response of jointed plain concrete pavement (JPCP) systems to axle loads and environmental effects. EverFE is useful for both concrete pavement researchers and designers who must perform either complex nonlinear or simple linear stress analyses of JPCP. With help of this develop any type of model of rigid pavement considering practical condition thus getting more accurate and advance analysis for rigid pavement. It can also determine effective k-values for different combination of granular sub-base and dry lean concrete. A comparative study is done for two types of loading i.e. single and tandem axle. Edge and Corner stresses are also calculated for Class-AA of loading. Also calculate moment and shear force transfer by dowel bar by EverFE.

**Keywords:** Edge stress, Corner stress, modulus of subgrade (k)

## 1. INTRODUCTION

Roads of life line of any country and design of safe and economic roads is very important for development of a country. Roads are one of the important modes of transport and thus play important role in economy of country. In India two types of road are constructed i.e. rigid pavement and flexible pavement. From last few years more emphasis is given to rigid pavement due to its various advantages over flexible pavement. But rigid pavement is new to study and lots of studies are still to be done for its safe design considering practical condition.

Several factors are responsible for design of rigid pavement and modulus of subgrade (k-value) is one of key factor for its safe design. But rigid pavement can't be laid directly on soil due to various properties of soil which affect main slab. In order to overcome problems due to soil certain layers are provided between soil and slab so that load can be easily transferred on slab to soil.

After providing layers above soil it is necessary to estimate effective k-value because layers provided above soil increased its sugrade reaction. This improvement is due to compaction provided by layers. But in the field need effective k-value for combination, estimation of which is difficult task. After design of rigid pavement its maintenance is very important. Though rigid pavement needs less maintenance then flexible pavement but must know stresses for different loads applied to the pavement so that it may not damaged by over stress. Distribution of load and load value are two factors consider for load stress analysis. Different type of load application cause different stresses but to calculate stress for all combination of load is not possible with present methods adopted. The equation provided by westergaurd which is used for design of rigid pavement does not consider many condition of rigid pavement. Modification of westergaurd equation and equation provided by Picket and Ray consider many problems but still there is lots of confusion in design of rigid pavement.

## 2. OBJECTIVES OF THE STUDY

This study has been done for following objectives:

1**.** To check the feasibility of tool used for the purpose. For this to compare result of EVERFE with knows values from Westergaurd and picket and ray solution.

2. To calculate reduced stresses with different thickness of granular sub layer and dry lean concrete below pavement slab.

3. To calculate effective value of modulus of sub-grade reaction (k-value) with different thickness of granular layer and dry lean concrete below pavement slab.

4. To determine load stresses for Class-AA loading of vehicle.

5. To compare performance of rigid pavement for single axle loading and tandem axle loading through deflection.

## 3. METHODOLOGY

### *I. Tool used for Analysis*

In present work EverFE is used for the analysis of rigid pavement. In all EverFE models, the slab, base and sub-base layers are treated as 3D linearly elastic, isotopic continue. Each layer is decentralized with standard 20-noded ‘serendipity’ brick element. The finite element meshes are rectilinear and same numbers of element divisions are used of each slab and base/sub-base layers interface.

### *II. Modelling*

The rigid pavement slab is modelled considering that it rest on granular sub base and dry lean concrete layer. Unbounded condition assumed between the layers. The input data are modulus of subgrade reaction of soil, properties of concrete, dimensions of slab, temperature differential. To apply various classes of load all standard load condition and there distributions are used. In case of single and tandem axle load, the load values are calculated as per recommendation old code (IRC: 58:2012) and then load is assumed to be distributed in rectangular shape. Each tyre considers separately and load is applied directly to slab. Below the slab different thickness of granular sub-base and dry lean concrete is provided. For temperature differential the values given in code (IRC: 58:2012) for various temperature zones are adopted.

### *III. Meshing*

Meshing is done to check the accuracy of results. When the grid is made with number of division for slab and sub-base layer, the number of which model is divided effect the results. Thus refinement analysis is done to know in how much part the model is divided to get most accurate results. For refinement analysis the model is divided in different number of parts and deflection is determined. The most accurate meshing is that in which results varies least. In present after refinement analysis the optimum size of mesh adopted is 16x16x2.

### *IV. Determination of Effective k-value*

Following steps are adopted for determination of Effective k-value:

1. Stress value determined for a load case on pavement slab.

2. Layers of granular material and layer of dry lean concrete provided below concrete slab.

3. The reduced stress determined for combined effect.

4. Layers provided below pavement slab removed.

5. The k-value increased up to that level at which original slab without layers give same stress value as determined after providing layers.

6. The determined k-value consider as effective k-value for the combined effect of all the three layers including soil.

## 4. RESULTS and ANALYSIS

Edge stress and Corner stress, from EverFE with Westergaurd's solution for constant thickness of 30 cm with respect to different k-value, are shown in Table 1.

Table1. Comparison of Edge stress and Corner stress from EverFE with Westergaurd's solution for constant thickness of 30 cm

| S.N. | k-value ($kg/cm^2/cm$) | Edge stress ($kg/cm^2$) | | Corner stress ($kg/cm^2$) | |
|---|---|---|---|---|---|
| | | EverFE | WASTERGAURD | EverFE | WASTERGAURD |
| 1 | 6 | 14.63 | 12.14 | 13.06 | 13.86 |
| 2 | 6.5 | 14.5 | 10.02 | 13.01 | 13.6 |
| 3 | 7 | 14.83 | 11.92 | 12.97 | 13.56 |
| 4 | 7.5 | 14.27 | 11.82 | 12.91 | 13.49 |
| 5 | 8 | 14.15 | 11.73 | 12.87 | 13.44 |
| 6 | 8.5 | 14.05 | 11.64 | 12.83 | 13.38 |
| 7 | 9 | 13.95 | 11.56 | 12.79 | 13.3 |
| 8 | 9.5 | 13.86 | 11.49 | 12.75 | 13.28 |
| 9 | 10 | 13.77 | 11.41 | 12.71 | 13.23 |

Edge stress and Corner stress from EverFE with Westergaurd's solution for constant k-value (k=10) with respect to varying Pavement Thickness are given in Table 2.

Table2. Comparison of Edge stress and Corner stress from EverFE with Westergaurd's solution for k-value (k=10 $kg/cm^2/cm$)

| S.N. | Thickness in mm | Edge stress ($kg/cm^2$) | | Corner stress ($kg/cm^2$) | |
|---|---|---|---|---|---|
| | | EverFE | WASTERGAURD | EverFE | WASTERGAURD |
| 1 | 22 | 24.1 | 19.65 | 21.04 | 22.97 |
| 2 | 24 | 20.7 | 16.94 | 18.92 | 19.62 |
| 3 | 26 | 17.94 | 14.74 | 16.07 | 17.08 |
| 4 | 28 | 15.67 | 12.94 | 14.24 | 14.96 |
| 5 | 30 | 13.77 | 11.42 | 12.71 | 13.24 |
| 6 | 32 | 12.18 | 10.14 | 11.44 | 11.79 |
| 7 | 34 | 10.82 | 9.07 | 10.35 | 10.77 |
| 8 | 36 | 9.65 | 8.15 | 9.4 | 9.53 |

Edge stress from EverFE with Picket and Ray solution for constant k-value (k=6 kg/cm$^2$/cm) for Single & Tandem axle load of 20 tonnes, with respect to varying Pavement Thickness, are given in Table 3.

Table3. Comparison of Edge stress from EverFE with Picket and Ray solution for constant k-value (k=6 kg/cm$^2$/cm) for different axle load

| S.N. | Thickness in mm | Edge stress (kg/cm$^2$) for Single axle load of 20 tonnes | | Edge stress (kg/cm$^2$) for Tandem axle load of 20 tonnes | |
|---|---|---|---|---|---|
| | | EverFE | PICKET and RAY | EverFE | PICKET and RAY |
| 1 | 14 | 75.63 | 69 | 29.45 | 30 |
| 2 | 16 | 62.69 | 62 | 24.57 | 27 |
| 3 | 18 | 52.19 | 51.5 | 20.89 | 23.5 |
| 4 | 20 | 45.76 | 45 | 18.34 | 20 |
| 5 | 22 | 39.95 | 39 | 16.41 | 17.5 |
| 6 | 24 | 35.15 | 35 | 14.78 | 16 |
| 7 | 26 | 31.29 | 30.5 | 13.35 | 14.5 |
| 8 | 28 | 27.93 | 27.5 | 12.13 | 13 |
| 9 | 30 | 24.97 | 25 | 11 | 12.5 |
| 10 | 32 | 22.52 | 23 | 9.98 | 11 |
| 11 | 34 | 20.38 | 20.5 | 9.07 | 10 |
| 12 | 36 | 18.45 | 19.5 | 8.35 | 9.5 |
| 13 | 38 | 16.71 | 17.5 | 7.65 | 8 |

Edge Stress for Class-AA Wheel Loading, with respect to varying Pavement Thickness, is shown in Table 4.

Table4. Edge Stresses for Class-AA Wheel Loading

| S.N. | Thickness in mm | k-value (kg/cm$^2$) | | | | |
|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 15 | 30 |
| 1 | 14 | 34.15 | 30.17 | 27.42 | 23.54 | 18.75 |
| 2 | 16 | 31.95 | 27.52 | 24.87 | 20.8 | 16.2 |
| 3 | 18 | 29.26 | 25.59 | 23.03 | 19.16 | 14.48 |
| 4 | 20 | 27.23 | 23.95 | 21.61 | 17.84 | 13.25 |
| 5 | 22 | 25.59 | 25.52 | 20.29 | 16.82 | 12.23 |
| 6 | 24 | 23.85 | 21.2 | 19.27 | 15.9 | 11.52 |
| 7 | 26 | 22.22 | 19.88 | 18.14 | 15.19 | 10.9 |
| 8 | 28 | 20.69 | 18.65 | 17.12 | 14.37 | 10.39 |
| 9 | 30 | 19.16 | 17.43 | 16.1 | 13.65 | 9.99 |
| 10 | 32 | 17.73 | 16.31 | 15.19 | 13.04 | 9.48 |
| 11 | 34 | 16.41 | 15.29 | 14.27 | 12.33 | 9.17 |
| 12 | 36 | 15.29 | 14.17 | 13.35 | 11.72 | 8.77 |

Corner Stress for Class-AA Wheel Loading, with respect to varying Pavement Thickness, is given below in Table 5.

Table 5. Corner Stresses for Class-AA Wheel Loading

| S.N. | Thickness in mm | k-value ($kg/cm^2$) | | | | |
|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 15 | 30 |
| 1 | 14 | 48.01 | 46.38 | 45.67 | 44.03 | 40.25 |
| 2 | 16 | 38.94 | 37.1 | 35.88 | 34.86 | 32.42 |
| 3 | 18 | 32.21 | 30.68 | 29.45 | 28.34 | 26.6 |
| 4 | 20 | 27.11 | 25.9 | 24.87 | 23.55 | 22.32 |
| 5 | 22 | 23.04 | 22.01 | 21.2 | 19.88 | 18.96 |
| 6 | 24 | 19.78 | 18.96 | 18.25 | 17.12 | 16.31 |
| 7 | 26 | 17.13 | 16.41 | 15.8 | 14.88 | 14.27 |
| 8 | 28 | 15.09 | 14.27 | 13.86 | 13.05 | 11.54 |
| 9 | 30 | 14.37 | 12.74 | 12.13 | 11.52 | 11.11 |
| 10 | 32 | 13.56 | 12.13 | 11.01 | 10.4 | 9.95 |
| 11 | 34 | 12.74 | 11.52 | 10.6 | 9.38 | 8.97 |
| 12 | 36 | 12.03 | 11 | 10.09 | 8.56 | 9.7 |

Reduction in Stress and Effective k-value, with different combination of DLC & GSB, for constant Pavement Thickness of 30 cm are given in Table 6.

Table 6. Reduced Stresses and Effective k-value for PAVEMENT THICKNESS of 30 cm

| S.N. | DLC in mm | GSB in mm | PAVEMENT THICKNESS of 30 cm | | | |
|---|---|---|---|---|---|---|
| | | | Original stress | Reduced stress | Original k-value | Effective k-value |
| 1 | 100 | 100 | 1.59 | 1.486 | 2.1 | 5.1 |
| 2 | 100 | 150 | 1.59 | 1.462 | 2.1 | 6 |
| 3 | 100 | 200 | 1.59 | 1.431 | 2.1 | 7.3 |
| 4 | 100 | 250 | 1.59 | 1.396 | 2.1 | 9 |
| 5 | 100 | 300 | 1.59 | 1.357 | 2.1 | 11.2 |
| 6 | 125 | 100 | 1.59 | 1.447 | 2.1 | 6.6 |
| 7 | 125 | 150 | 1.59 | 1.422 | 2.1 | 7.7 |
| 8 | 125 | 200 | 1.59 | 1.39 | 2.1 | 9.3 |
| 9 | 125 | 250 | 1.59 | 1.345 | 2.1 | 11.3 |
| 10 | 125 | 300 | 1.59 | 1.316 | 2.1 | 14.3 |
| 11 | 150 | 100 | 1.59 | 1.399 | 2.1 | 8.8 |
| 12 | 150 | 150 | 1.59 | 1.373 | 2.1 | 10.2 |
| 13 | 150 | 200 | 1.59 | 1.341 | 2.1 | 12.3 |
| 14 | 150 | 250 | 1.59 | 1.306 | 2.1 | 14.9 |
| 15 | 150 | 300 | 1.59 | 1.268 | 2.1 | 18.5 |

Comparison of maximum Deflection for Single and Tandem Axle load is shown in Table 7.

Table 7. Deflection for different Axle load

| S.N. | Load in ton | Deflection for Single Axle in cm | Deflection for Tandem Axle in cm |
|---|---|---|---|
| 1 | 10 | 0.016 | 0.007 |
| 2 | 15 | 0.02 | 0.01 |
| 3 | 20 | 0.027 | 0.012 |
| 4 | 25 | 0.033 | 0.015 |
| 5 | 30 | 0.038 | 0.017 |
| 6 | 35 | 0.042 | 0.02 |
| 7 | 40 | 0.046 | 0.022 |

Comparison of Moment and Shear Transfer by Dowel Bar for Edge Loading are given in Table 8.

Table 8. Comparison of Moment and Shear Transfer by Dowel Bar for Edge Loading

| S.N. | Moments(N-mm) | | Shear (N) | |
|---|---|---|---|---|
| | Single Axle | Tandem Axle | Single Axle | Tandem Axle |
| 1 | 32141.51 | 23929.99 | 881.61 | 748.65 |
| 2 | 21687.76 | 14216.83 | 488.02 | 395.89 |
| 3 | 13024.58 | 7909.99 | 172.02 | 179.18 |
| 4 | 10350.85 | 5644.6 | 83.13 | 133.79 |
| 5 | 9925.96 | 5551.05 | 83.26 | 135.1 |
| 6 | 10859.18 | 6574.86 | 113.8 | 147.99 |
| 7 | 11727.84 | 7018.97 | 149.33 | 152.04 |
| 8 | 10609.84 | 5852.93 | 123.55 | 131.83 |
| 9 | 8314.25 | 4694.19 | 77.24 | 124.84 |
| 10 | 7053.96 | 4161.59 | 69.84 | 123.55 |
| 11 | 6313.86 | 3820.74 | 68.98 | 122.05 |

Based on the above Tables following points have been derived for the work:

1. The variation between the result of EverFE and Wastergaurd equation is negligible and does not exceed 14%.
2. The result of EverFE is almost the same as determined from Picket and Ray solution.
3. The load stresses are not very high and for edge loading maximum stress is 34.15 kg/cm$^2$ for Class-AA wheel loading.
4. The load stress for corner loading maximum stresses is 48.05 kg/cm2 for Class-AA wheel loading.
5. There is more than 50% variation in deflection for single and tandem axle loading.
6. Percentage reduction in stress for 10 cm GSB and 15 mm DLC is 33.36% for single axle load and 43.90% for tandem axle load.

## 4. CONCLUSIONS

Based on present study following conclusions has been drawn:

1. The effective k-value given in code for different thickness of layers is on higher side and thus increased temperature stresses.
2. For the design of rigid pavement effective k-value is needed for combination of layers and not separately. So value must be known for combination of different layers,
3. The performance of rigid pavement is affected by load applied on it. Thus highest load must be carried on tandem axle and not on single axle.
4. Proper distribution of load is important in pavement. Due to proper distribution even the high load of Class-AA causes less stresses.

5. In India most of vehicle are heavily loaded and thus cross the legal limit of load for single axle load. Thus restriction must be imposed on extra weight and all higher loads must be carried on tandem or tridem axle load.

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