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The Effect of Slope Geometry and Shoulder on Rutting Depth of Flexible Pavement

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Abstract: The slope and width of the road shoulder are important parameters in geometry of the road pavement. Therefore, it is important to comply with the requirements relating to the slope and width of the shoulders. So that by using the minimum width and slope of the shoulders according to regulations not only stresses and strains transferred to the lower layers will decrease, but also reduces damages in asphalt layers, base, and sub-base. Therefore, it is vital to conduct analyses which can bring good amount of accuracy in assessment of the stress and settlement due to shoulder width and slope. The aim of this study is to investigate the effect of geometry of the shoulder on the performance and behavior of weak or strong pavement. For this purpose, numerical two-dimensional modeling of the road pavement (asphalt base sub-base) on which the axel load is placed was done using finite element method, ABAQUS, and the effect of the shoulder width and slope on the stresses and settlements caused by the strong and weak pavement have been studied. Also for verification of the software, several obtained field values are compared to each other. The results indicate that the increase in the width of the shoulders and the decrease in the slope will cause in decrease of the stress and settlements in different layers of the roadways. Thus, creating less steeper shoulder and wider pavement can reduce damages and will contribute to the increased safety and sustained life of the pavement.

Keywords: rutting depth, flexible pavement, shoulders width, Side slope, finite element method.

1. Introduction

Main thickness, width and slope of road shoulder are different in design in the regulations of various countries, and often shoulders are not built in some countries. The width of shoulder refers to the distance between sidewalk and roadway which is used for sidewalks, bicycle routes, and for emergency stops of cars in case of necessity [1]. Since making of rural and urban roads is one of ways for developing transportation, it is significant to pay attention to effective operation and useful life of roads. The important parameters in increasing the efficiency of roads are road width, shoulder width, shoulder type, the radius of horizontal curve, curves radius, length of curve, and etc [1].

Some road failures elements include transverse and longitudinal cracks, rutting and runoffs due to lack of suitable drain systems that incorrect implementation of layers and line geometry are main reasons in creation of these failures [2], [3]. The non-normative and inappropriate performance of shoulder and its slope are some of the existing errors in geometry that results to road failures [2]. The results indicate that increase in the shoulder width and decrease in its slope is effective in decreasing accidents along the road line. Wide shoulders are effective in decrease of accidents in highways because they allow the drivers to regain the control of their vehicles during the accident [4], [5].

As mentioned before, decrease of slope of the roads has effects on decrease of stresses and settlements and in increase of safety factors of roads, but this slope should be performed in roads longitudinally because of the exit of runoff and it's drainage operation [6], [7]. Shoulder width and shoulder slope should have appropriate amount, high strength and stability and also they should be smooth. Their features are effective in decrease of creation of cracks and rutting due to the load of wheels. [6] Shoulders can be made from different materials such as bitumen, concrete, aggregate, asphalt or composite. In the present study, it is considered as an asphalt layer.

Structural resistance of the road depends on factors such as number of layers, the kinds of materials used, use of sound materials, thickness of layers, and implementation of shoulder. These factors are operated in order to decrease the transferred stresses to the roads and underlying layers [5].

According to AASHTO manual, the width of shoulder should be 3 meters in roads with high traffic, although it is impossible to implement this shoulder in mountain roads with low traffic. Nevertheless, the minimum of shoulder width must be 0.6m, and the width between 1.8m to 2.4m is efficient [8]. The minimum width of shoulder can be one of these numbers, 0.6m, 1.5m, 1.8m and 2.4m; based on the design volume, design speed and the width of roads [5], [8]. Manufacturing of shoulder has effects not only on reducing exerted vertical

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stresses, but also it increases the lateral resistance of lane which is effective in decrease of settlements [9], [10]. Lack of shoulder gradually leads to creation of cracks along the edges of the roads that is a kind of longitudinal cracks and it occurs out of the wheel path in 0.6m of lateral edge of surface layer. This kind of crack is called alligator crack that initiates from the lateral edge and develops to the middle of the road [2], [3], [11]. Consequently, it must be considered a safe slope for shoulders according to FHWA manual. Experiences have indicated that drivers left the roads, for different reasons and if the shoulder is vertically, this diversion from the route could result in losing the control of vehicle by drivers. Moreover, the safe slope is useful in stability of line and in increase of lateral resistance. In the regulations mentioned above, the slope of 30 degrees is a favorable slope and its maximum amount is 40 degrees [12], [13].

2. Devastations in Shoulder

2.1 Shoulder dropping

Dropping refers to the level differences between the wheel path and surface layer with shoulder. Dropping occurs where the surface materials are different from shoulder materials, also low width of the shoulder and the use of inappropriate materials result in dropping. Fig. 1 shows that the dropping is oblique or vertical [3].

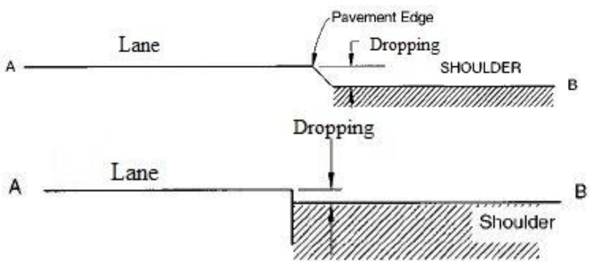

Fig. 1 Oblique dropping (top) and vertical dropping (down) [3].

2.2 Shoulder separation

The widening of the distance between surface layer and shoulder is called separation which same as dropping depends on some factors such as the difference between surface and shoulder materials, low width of shoulder, and the use of inappropriate materials (Fig. 2) [3].

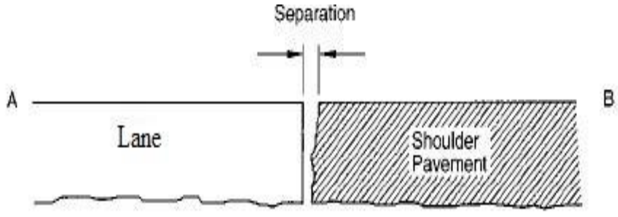

Fig. 2 Shoulder separation [3].

2.3 Alligator Crack

As mentioned above, this kind of crack occurs in 0.6m of lateral edge of the road when the shoulder is not implemented or it is made of inappropriate materials and materials with high moisture or even underground water causes in decrease of line resistance [11]. The alligator crack causes the thinning of surface layer and lack of suitable drainage which decreases resistance. Furthermore, the passing of wheels near the shoulder leads to more settlement of line [2].

3. Numerical Modeling

Examining the behavior of pavements is difficult because of their heterogeneous, nonlinear and non-isotropic behaviors. Thus, to conduct such a complicated examination, it is vital to use a numerical analysis program with high features. In this study, we used a finite element program. In this numerical model, some hypotheses have been considered such as:

- Since created stresses and strains are being considered for prediction of the pavement failure, considering behavior of layers based on plastic behavior is essential. Therefore, behavior of all layers was considered Mohr Coulomb plasticity.
- Loading, boundary conditions, and the location of wheel load are similar to the real ones.
- In order to reduce the time of software calculation, half of the model was considered symmetrically.
- For modeling, it was used from shell elements which were two-dimensional elements (symmetric four node quadratic element with plane strain (CPE4R).

3.1 Model dimensions

The effect of wheel load has been light in more than 2 meters of around and under the asphalt layer. To reduce the analysis time of software, it can be considered as the model dimensions so that the load has effect on that area.

3.2 Shoulder geometry

The shoulder slope has been modeled with angle changes in 5 forms of angles 32.5, 35, 37.5, 40 and 42.5 degree and shoulder width has been modeled in 6 forms in width 30, 60, 90, 120, 150 and 180cm.

3.3 Mechanical properties of layers

Table 1 shows layers properties such as elastic and plastic properties. As mentioned before, the modal from the viewpoint of mechanical properties is divided into weak and strong pavements that the differences of these two pavements are expressed via changes in modulus of elasticity of sub-base layer. Structural number of strong pavement is Greater than 4 (SN>4) and weak pavement vice versa (SN<4). It is worth mentioning that properties of all layers were considered base on [14].

3.4 Loading and meshing

Loading is done in two steps. The first step is the gravity load which imposed in all layers. The second one is the load of a single wheel with amount of 4000 kg based on previous researches and suggestions of regulations. This load can be considered in two forms: a circle with a diameter of 15cm or rectangle with the length of 18.8cm, the width of 9.4cm and the amount of 5.6 kg/cm^2 [15]. In this study, the load of wheel is compressively exerting with amount of 5.6 kg/cm^2 in length of 9.4 cm from the 0.5 m of inside edge of the shoulder on the surface layer (refer Fig. 3). Furthermore, Fig. 4 indicates a view of mesh in this study.

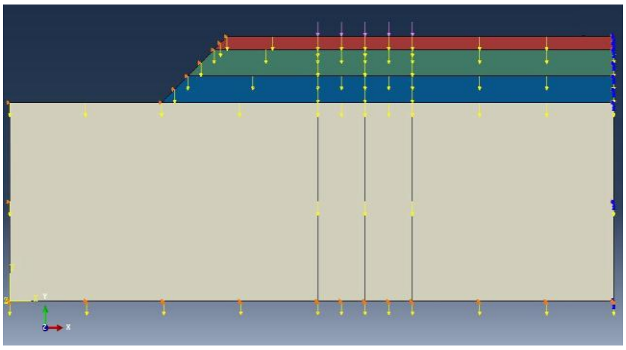

Fig. 3 Loading condition.

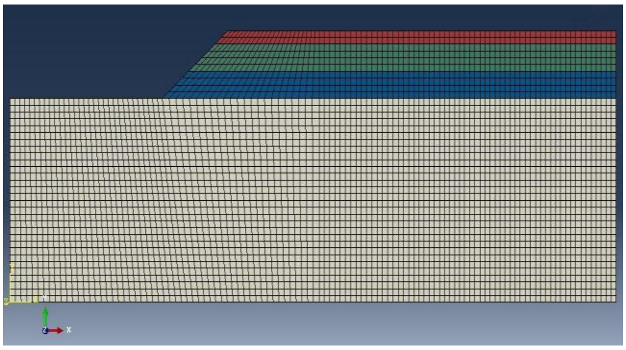

Fig. 4 Model meshing.

Suppose that we have selected 5 forms of shoulder slope, 6 forms of shoulder width and 2 kind of pavement (weak and strong) so the modeling was done 60 times and the results were calculated based on stresses and settlements on the asphalt at the middle of the wheel load and on the sub-grade. The obtained results are illustrated according to the slope angle, shoulder width and the kind of pavement in following diagrams. Remember, the settlement unit is cm and the stress unit is kPa. Fig. 5 and 6 present one sample of strain and stresses transferred into layers.

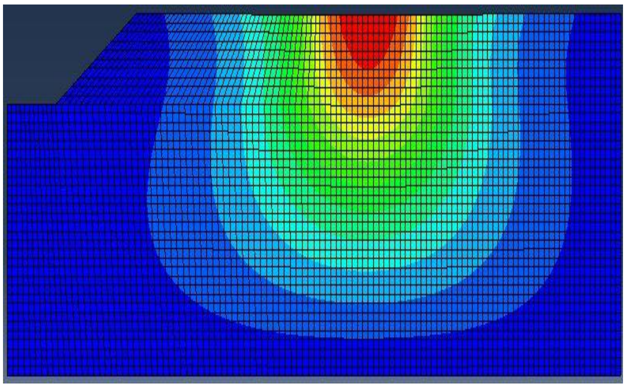

Fig. 5 The strain transferred to layers.

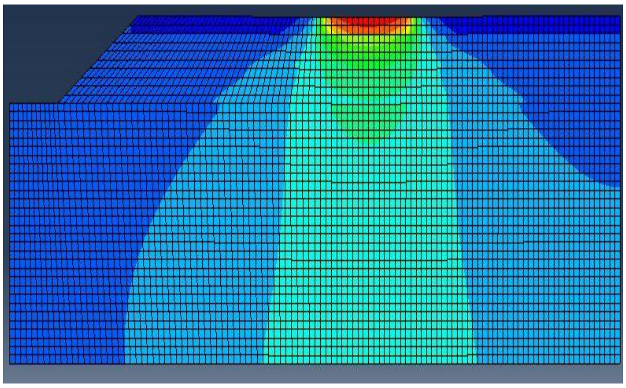

Fig. 6 The stress transferred to layers.

Fig. 7 to Fig. 11 indicate the settlement changes in week pavement for different forms of shoulder widths and shoulder slopes.

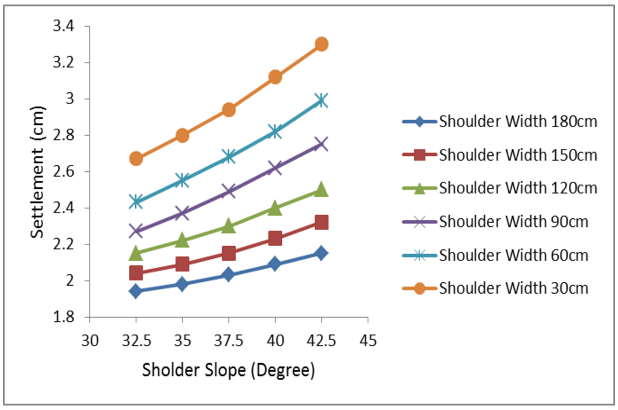

Fig. 7 The settlement based on different shoulder widths and shoulder slopes on the asphalt layer at the middle of the wheel load for the strong pavement.

Table 1 Layer geometry and mechanical property.

elastic				*Plastic*			*layer*
Specific weight γ (kg/m^3)	*Poisson's ratio (v)*	*Modulus of elasticity (MPa)*	*Thickness (cm)*	*Cohesion (kPa)*	*Dilation angle (degree)*	*Angle of internal friction (degree)*	
2200	0.35	4000	10	250	12	42	Surface
2000	0.30	240	20	0	11	41	Base layer
1800	0.30	140	20	0	16	46	Sub-base
1800	0.30	100	20	0	8	38	layer
1800	0.35	900	150	0	6	36	Sub-grade

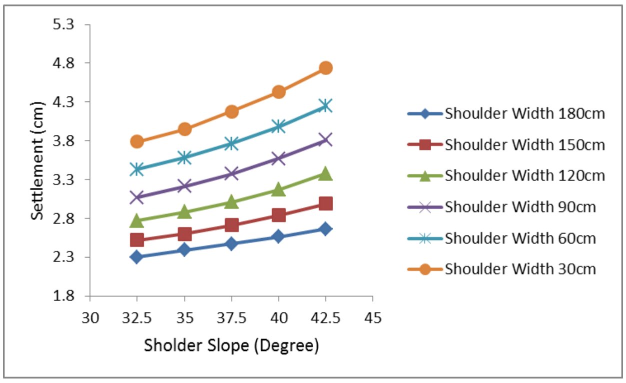

Fig. 8 The settlement based on different shoulder widths and shoulder slopes on the asphalt layer at the middle of the wheel load for the weak pavement.

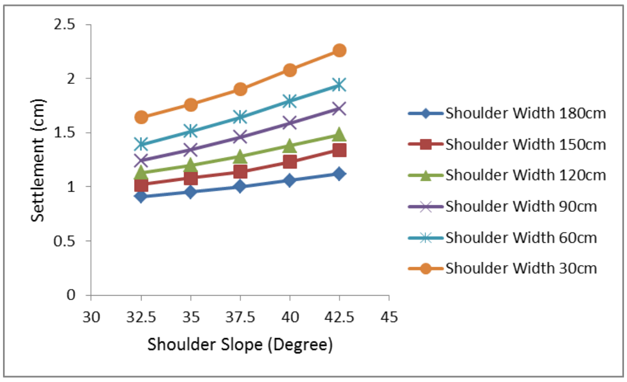

Fig. 9 The settlement based on different shoulder widths and shoulder slopes on the sub-grade for the strong pavement.

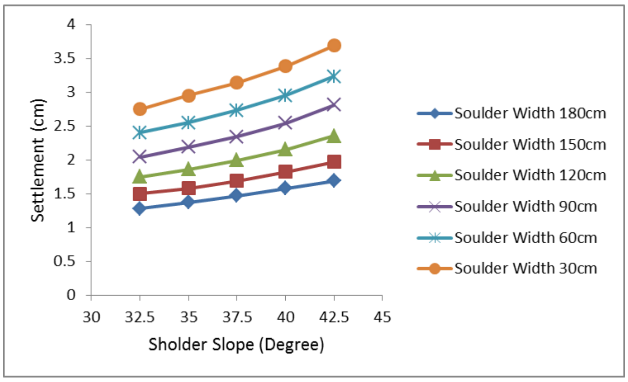

Fig. 10 The settlement based on different shoulder widths and shoulder slopes on the sub-grade for the weak pavement.

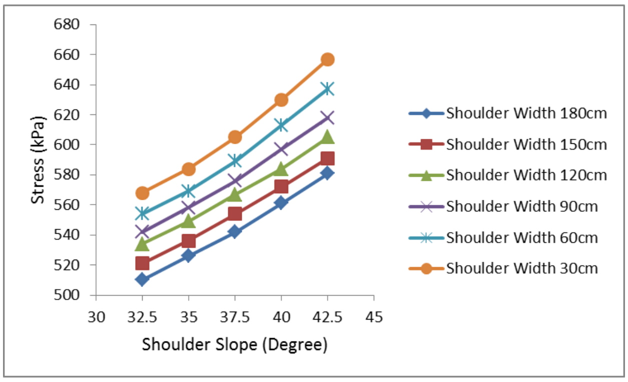

Fig. 11 The stress based on different shoulder widths and shoulder slopes on the asphalt layer at the middle of the wheel load for the weak pavement.

As the above diagrams show increasing the shoulder width and reducing the shoulder slope will result in decrease of the stress and settlement transferred to the structure. In addition, implementing a stronger pavement and using more appropriate materials will reduce the settlements and stresses.

4. The Comparison of Field Survey and Numerical Modeling

After performing the numerical modeling, we should be assured of the accuracy of the obtained results from of this software. For this purpose, some surveys were done about the settlements in place of wheel load in Esfahan - Tehran road, 20 KM road near Shahin-Shahr, on dates 17/3/2013 at 4:55 PM.

According to 20 field surveys done on shoulders with different widths and slopes and with averaging the samples, the amount of obtained deformation was about between 1.5 cm to 6 cm (Fig. 12 and Table 2). As can be seen, the changes of strain have coordination with the amount of strains obtained from the software analysis. Thus, the field results show that the analysis and numerical modeling are reliable.

Fig. 12 A view of field surveys.

Table 2 Filed survey (at 50 cm from shoulder edge).

Asphalt layer thickness (cm)	*Rutting depth (cm)*	*shoulder slope degree*	*shoulder width (cm)*
10	4.8	30	30
10	5	30	30
10	5.5	30	30
15	5.8	30	30
15	6	32	30
15	4.5	30	45
10	5	32	45
10	3.5	30	60
10	3.7	35	60
10	4	38	60
15	4.5	40	90
15	2	30	90
10	2.5	35	90
15	3	40	60
15	1.5	30	120

5. Results and Discussion

In the present study, the changes of the stress and settlement on the pavement layers were examined by changing the ranges of width in 6 forms in width of 30, 60, 90, 120, 150 and 180cm and slope of shoulder in 5 forms of angles 32.5, 35, 37.5, 40 and 42.5 degree for both strong and weak pavements. Therefore, the following results were obtained:

- Creation of shoulder with appropriate width has the greatest role in reducing the pavement failure and increasing the pavement resistance.
- The created deformations are common in unstable shoulders and their repairing is expensive
- Increasing the shoulder width and decreasing its slope is effective in stress distribution in lower layers and in decreasing of settlements. As a result, they will increase the longevity and operation of line.
- Comparison of created deformation from numerical modals and field surveys shows that results have a good coordination with each other; so that, the maximum of obtained settlement in numerical modal was around 5 cm, but the observed strain in field survey was approximately between 1.5 cm to 6 cm; because the field surveys were measured by ruler and eyes.
- To complete this article, another similar study can be conducted about the effect of changing the distance of wheel load to the shoulder and changes in the sort of shoulder materials with different properties. The materials can be composite, concrete or aggregate.

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