American Journal of Civil Engineering and Architecture, 2013, Vol. 1, No. 6, 174-180
Available online at http://pubs.sciepub.com/ajcea/1/6/7

DOI:10.12691/ajcea-1-6-7

Determining the Contribution of Different Structural Layers of Asphalt Pavement System to Rutting Using Transverse Profile Analysis

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Received August 06, 2013; Revised November 20, 2013; Accepted November 21, 2013

Abstract Rutting is one of the major distresses which cause hydroplaning and structural failures in a flexible pavement. The extent of damage depends upon the load induced and the strength of each pavement layer. Rutting can occur due to the failure of the subgrade, the base or at the wearing surface/ hot mixasphalt (HMA) layer(s).In order to take remedial measures, it is imperative to be cognizant of the contribution of each layer to ascertain the cause of underlying phenomena of rutting. This research study demonstrates the analysis of the pavement transverse surface profile that could be used to identify the layer responsible for the permanent deformation. Transverse surface profiling techniqueis easier, non-destructive, and economicalas compared to traditional methods of coring and trenching to examine underlying layers. A 300 meter section on National Highway (N-5) was selected exhibiting severe rutting to perform transverse profile analysis. Results of this study suggest that rutting at the selected site is mainly due to the shear failure of HMA layer. These results were also validated by field trenching on the test section. The study concluded that HMA layer should be removed and replaced with appropriately designed high performance mix specifications.

Keywords: *rutting, hot mix asphalt, rut depth, transverse profile*

Cite This Article: Hussan S., Kamal M. A., Khan M. B., Irfan M., and Hafeez I., "Determining the Contribution of Different Structural Layers of Asphalt Pavement System to Rutting Using Transverse Profile Analysis." *American Journal of Civil Engineering and Architecture* 1, no. 6 (2013): 174-180. doi: 10.12691/ajcea-1-6-7.

1. Introduction

An organized and well maintained system of roads is the most significant contributing factor in the rapid and cost-effective growth of a country. In recent years, Pakistan has started to focus on this aspect. Due to increasing temperature and unregulated heavy truck traffic in the country, the pavements are under very high stresses and strains. As the result of these high stresses, pavements are subjected to different distresses. Rutting is one of the major distresses which are associated with flexible pavements. Rutting in flexible asphalt pavements is generally dependent on various factors such as asphalt mix properties which further include aggregate gradation, types of aggregates, binder type and properties, extent of applied compaction effort. Factors related to loading pattern includes types of vehicles, type of the tire and tire pressure, speed of vehicles, axle load. Similarly environmental factors such as climatic conditions of the area and pavement temperature also affect the typeand extent of rutting. Likewise layer thicknesses, material properties of base and subbase layers and bearing capacity of subgrade also play a vital role.

Asphalt pavement rutting is a problem not only in recent era; it affects the design criteria and methodology since innovation of flexible pavements. It is important to note that material quality of surface, base, subbase and subgrade layers should be well designed because if the material properties are not properly designed, it is impossible to reduce rutting susceptibility no matter how much layer thickness is provided or how much construction quality control is to be taken care of [1]. In Pakistan rutting of flexible pavements is commonly observed in extremely left lanes i.e., lanes reserved for heavy traffic. It is common observation that volume of heavy vehicles, loading magnitude and tire pressure is expected to increase day by day. The only solution to avoid or contain rutting within permissible limits, is to improve the properties of materials of different layers specifically the hot mix asphalt (HMA) layer. This solution appears to be a very simple one but it should be kept in mind that an improvement in one property may lead to detrimental effect on the other one. For instance, reduction in asphalt content may decrease rutting susceptibility but on the other hand it may decrease fatigue resistance. Similarly, increasing viscosity of asphalt cement may decrease liability to rutting but it makes mix more likely to be cracked in the presence of environmental effects. Therefore, corrective action will be applied keeping in view all the pros and cons.

In view of above discussion, it is necessary to predict the possible cause of rutting in an economical and timely manner, so that appropriate corrective actions may be taken. Transverse profile measurement proves to be a very effective non-destructive method to measure the rut depth.The collection of transverse profile has become very simple due to the availability of different electronic profilers. International Cybernetics Corporation (ICC) SurPRO 2000 Multipurpose Profiler which is used in this research is one of them. This research paper reviews important features of the criteria which utilize transverse profile parameters to predict failed layer. It further explains complete application procedure by considering one of the collected transverse profiles. After using complete transverse profile results, failed layer (i.e., layer contributing to rutting)is predicted at the test site and required maintenance or rehabilitation measures are recommended. At the end this non-destructive procedure is validated by comparing its results with those obtained by field trenching.

2. Literature Review

A rich body of knowledge is available which links the rut depth and prediction of layer contributions to transverse pavement profiles. A study to determine causes of permanent deformation in Alberta, Canada divided rutting in three basic types based on their rut phenomenon. These three types were structural rutting, instability rutting and wear rutting. This study explained results of 11 trenches excavated and concluded that HMA failure was the main reason behind observed premature rutting [2]. A research analyzing transverse and longitudinal profiles to predict whether statistical parameters from transverse profile analysis indicate cause of rutting or not revealed that results of transverse profile analysis can be used to predict rehabilitation or maintenance activities, even in the absence of structural or traffic loading data [3]. The author measured effect of heavy commercial vehicles on the development of rutting by graphically developing a practical relationship between distance of tires and distance among ruts [3]. It is inferred by studying different static and dynamic methods of rut depth measurement, that transverse profile has several advantages as compared to traditional rut depth measurement [4]. Variation analyses between the rut depth results obtained by all these methods indicate that variation is maximum between rut bar and straightedge and minimum between rod and level and dipstick profiler [5]. It was concluded that shape, position and depth of pavement rutting can be better analyzed by using transverse profile [4]. It was concluded in a research that transverse profile contains enough important information about the rut contribution of different flexible pavement structural layers [6]. Evaluation study of Transverse Profilograph and Road Surface Profiler for rut depth determination also concluded that transverse profile measurement was most accurate method [7]. A study carried out to interpret transverse profile data to predict the source of rutting, revealed that collection of transverse profile is one of most accurate and precise methods of rut depth determination [8]. The approach developed by the research team used elimination technique by first considering surface layer compaction, then base/subbase layer compaction, subgrade compaction and at the end surface layer instability. Results of trenching, coring and Falling Weight Deflectometer (FWD) Test data obtained from twelve effected sections were used to validate the technique developed [8]. Recently with the advancements of technology, accuracy of transverse profiles obtained by laser technology has increased a lot [9]. Measurement procedure of laser technology for rut depth determination, along with other modern techniques was explained by Wang [10]. Simpson et al. concluded as a result of hypothesis that area under transverse surface profile could be used to predict and find layer contributing to rutting in a flexible pavement system [11]. In order to refine the rutting prediction models, the authors tried to divide a large set of data in small subsets based on rut failure mode. These small subsets were categorized as subgrade rutting, surface course rutting, base rutting and rutting due to subgrade heave [11]. A study on characterization of transverse profile revealed six indices of significant importance which includes rut depth, rut width and transverse profile area [12].

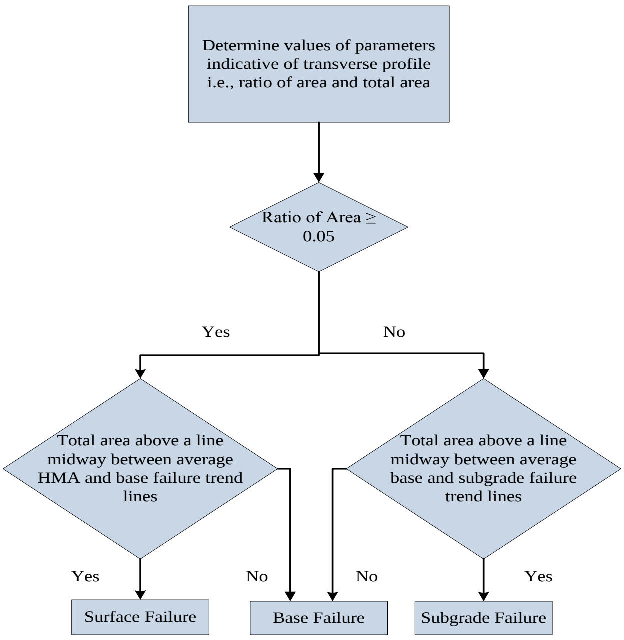


Figure 1. Illustration of procedure for failed layer prediction [13,14]

A study conducted to develop general criteria for interpretation of transverse profile to find the cause of rutting, initially included detailed finite element analyses of sixteen different typical representative sections to simulate rutting failure modes. Three different failure modes consisted of surface mixture, base courses and subgrades [13,14]. Distortion parameters i.e., positive areas (profile areas above original surface), negative areas (profile areas below original surface) and maximum rut depths were computed to represent transverse profile [12,14]. Failure chart with total area (in square millimeters) on ordinate and rut depth (in millimeters) on abscissa was developed by finite element analyses of all typical sections, and trend lines were drawn for each failure mode [13,14]. Analysis of wide range of typical asphalt pavement sections indicated that HMA failure is not observed if ratio of positive of negative areas less than 0.05 [13,14]. Based on results of all these analyses flowchart showing the procedure of computation of failed layer is shown in Figure 1.

This research utilizes the above failure criteria to predict failed layer at one of effected section. The results were then validated by comparing them with results of destructive pavement trenching.

3. Study Methodology

3.1. Site Testing and Layout Plan

The section under consideration starts 500 meter away from Haro Toll plaza at National Highway (N-5). The North Bound of N-5 has been selected for detailed analysis. It has been observed that rutting distress occurs in only the extreme left lane or truck lane so only that particular lane is studied in detail. The present form of pavement is constructed as a result of complete rehabilitation carried out in 1997-1998. The layer thicknesses used initially consist of 290 millimeters of asphaltic concrete layer and 300 millimeters of granular subbase layer. Figure 2 below describes whole layout in an effective way. It shows different features present at the effected site along with dimensions of effected portions.

In Figure 2, purple shaded and hatched blocks in the truck lane shows severely rutted portions out of whole section of 1183 meters in length. The hatchedblocksshow the tested portion while purple-shaded blocksindicate the portion for which testing could not be carried out due to site constraints such as safety concerns. Twenty transverse profile measurements were taken at a longitudinal spacing of 15 meters.

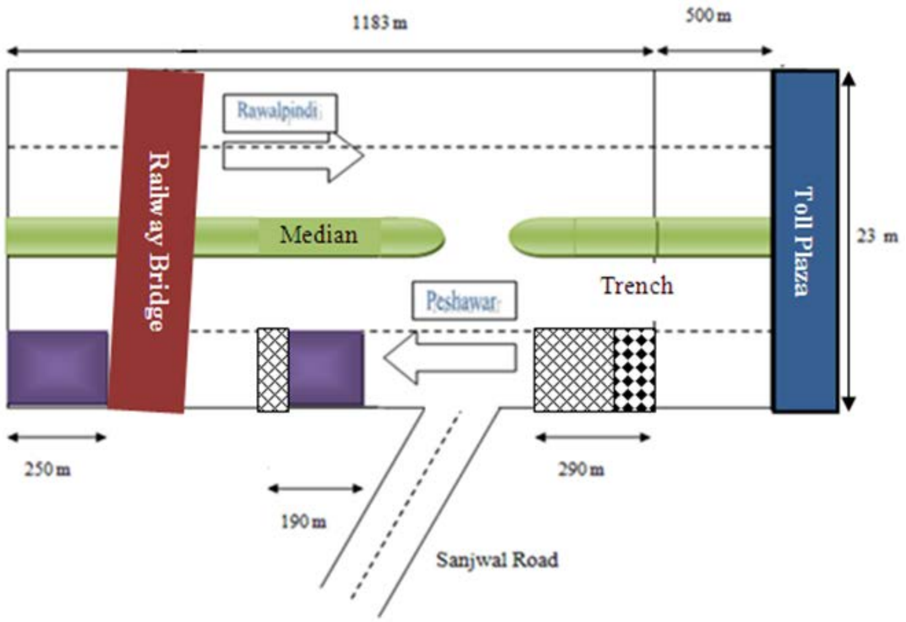


Figure 2. Site layout and testing plan of selected National Highway (N-5) portion

3.2. Transverse Profiling

The International Cybernetics Corporation (ICC) SurPRO multipurpose surface profiler was used for transverse profiling which is relatively lightweight, compact, dependable, quick in on-site preparation and easy to operate. The test surface was cleaned prior to start of data collection so that it would be free from debris. Proper marking of profile line was done by using white paint. Data was collected and transferred to the computer, then detailed analysis of transverse profiles was done by using criteria developed by Haddock et al. (2005) as shown in Figure 1.

3.3. Calculation of Distortion Parameters

Once the transverse profile is plotted, first and last points of the profile line are joined to establish a reference line. The portion of area above that reference line is considered as positive area and the portion below that line was considered as negative area. The maximum rut depth is computed by firstly drawing a line joining high points of the profile known as wire line; maximum rut depth is then equal to line of maximum length drawn between profile line and wire line in a direction perpendicular to the wire line. The distortion parameters i.e., ratio of area and total area are computed by following equations.

$$A = A_p + A_n \tag{1}$$

$$R = A_p / A_n \tag{2}$$

Where,

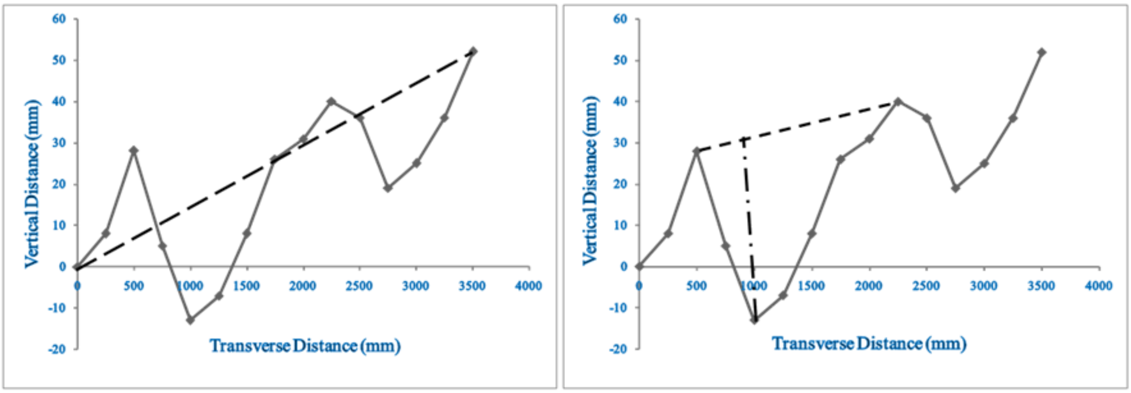
$A = Total\ Area\ \ (mm^2)$

$R = Ratio\ of\ \ area$

$A_p = Positive\ Area\ \ (mm^2)$

$A_n = Negative\ Area\ \ (mm^2)$

The maximum rut depths, positive and negative areas are computed graphically by plotting on-scale profile in AutoCAD Software. The transverse profile adjacent to first point which is designated as Profile # 01 is explained in detailas a sample. Figure 3 below shows these distortion parameters for this specific profile in detail. Figure 3(a) indicates positive and negative areas with reference to straight line joining end points of transverse profile while Figure 3(b) specifies maximum rut depth with reference to the wire line formed by joining high points of the profile. The distance should be perpendicular to the wire line.



(a) Profile indicating positive and negative areas

(b) Profile indicating maximum rut depth

Figure 3. Profiles showing distortion parameters of profile # 01

The results of all other twenty profiles are inferred by similar process. Now for Profile # 01

$$A_p = 7994.937 (mm^2)$$

$$A_n = 29321.17 (mm^2)$$

$$A = 7994.937 - 29321.17 = -21326.233 (mm^2)$$

$$R = 7994.937/29321.17 = 0.273$$

3.4. Prediction of Failed Layer

In the procedure of prediction of layer in which rutting distress occurs, first step is to calculate critical coefficients by following equations. These are equations of trend lines for HMA, base and subgrade failure mode in failure criteria [13].

$$C_1 = (-858.21) D + 667.58 \quad (3)$$

$$C_2 = (-1509) D - 287.78 \quad (4)$$

$$C_3 = (-2120.1) D - 407.95 \quad (5)$$

Where,

C_1 = Theoretical average total area for HMA Failure(mm^2)

C_2 = Theoretical average total area for base/subbase Failure(mm^2)

C_3 = Theoretical average total area for subgrade Failure(mm^2)

D = Maximum Rut Depth(mm)

Next step is to apply different checks to infer mode of failure.

Failure has occurred in the HMA layer if both the following conditions are satisfied:

$$R > 0.05 \quad (6)$$

$$A > (C_1 + C_2)/2 \quad (7)$$

If above conditions does not satisfy then we make another comparison i.e.,

$$A > (C_2 + C_3)/2 \quad (8)$$

Now we predict failed layer in transverse profile designated as Profile # 01. First calculate critical coefficients by Equations (3) - (5)

$$C_1 = (-858.21) * 43 + 667.58 = -36226.42 (mm^2)$$

$$C_2 = (-1509.0) * 43 - 287.78 = -65174.78 (mm^2)$$

$$C_3 = (-2120.1) * 43 - 407.95 = -91572.25 (mm^2)$$

First Check is applied by using Equation (6). For Profile # 01 value of R = 0.273 it means this condition is satisfied.

Second Check is applied by using Equation (7). For Profile # 01

$(C_1 + C_2)/2 = (-36226.42 - 65174.78)/2 = -50700.6 (mm^2)$ Similarly value of total area previously calculated is $A = -21326.233\ (mm^2)$

These values indicate that second check is also satisfied, so the failure occurred in Hot Mixed Asphalt/Surface layer

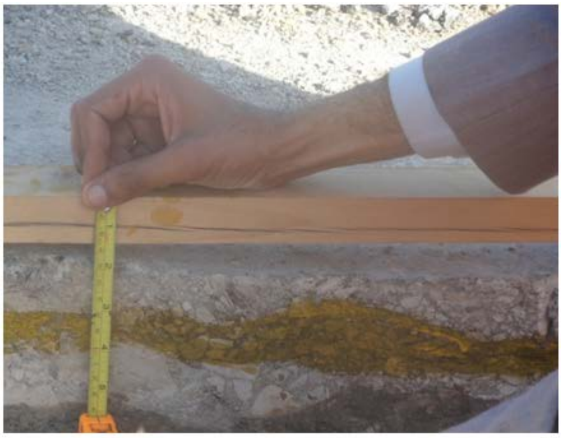
3.5. Validation of Predicted Failed Layer by Field Trenching

It is beneficial to validate above approach by comparing results with a destructive technique which is accepted worldwide. As methodology used in this research is a non-destructive technique i.e., use of transverse profiles, it seems more suitable to compare it with a destructive technique rather than another non-destructive method. So trenching technique is used to validate above calculated results. Location of field trench is shown in Figure (2) above by dotted hatched portion. Trench dimensions are 12' by 4' and its depth is upto subgrade.

The detailed steps for field trenching of particular pit or trench, adjacent to transverse profile designated as Profile # 01 are explained in detail. First step is to get permission from the concerned authorities i.e., Highway Police and

National Highway Authority. As the site selected for trenching is located on National Highway (N-5), proper approval is required as whole traffic lane is to be blocked for at least 24 hours. Second step is to mark exact location of the trench, keeping in view the aim of study along with safety concerns. Third step is to cut the surface layer by using road cutter. The road cutter is used instead of manual digging so that minimum time is consumed and smooth edge surface can be achieved. Fourth one is to remove the material of surface and underlying layers mechanically. Fifth step is to clean edge adjacent to profile # 01 so that layer can be identified clearly. Next step is to separate boundaries of different layers with the help of yellow paint in order to identify layer variation, Figure 4(a) elaborates it. In the last step wooden straightedge is used as a reference, and layer thickness variations are measured relative to that straightedge. The reading is taken at a transverse spacing of 0.25 m (10 in.). Figure 4(b) elaborates it. The results are then used to draw trench profile which is then compared with results from transverse profile failure analysis.

(a) Marking layer boundaries



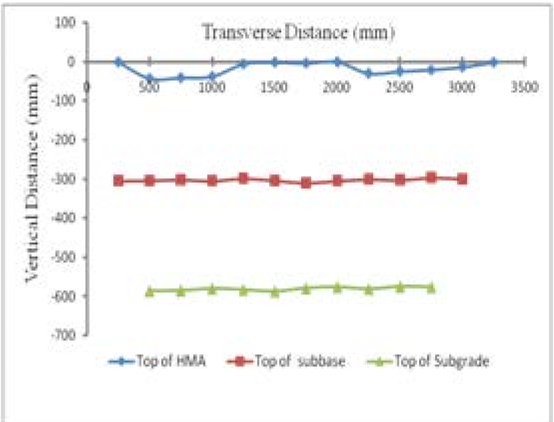
(b) Variation in layer thickness

Figure 4. Measurement of rut depth in each layer byfield trenching

(a) HMA Failure in Left Wheel Path

(b) HMA Failure in Right Wheel Path

(c) Stable Underlying Layers



(d) Trench profile analysis

Figure 5. Rut depth measurements using straight edge by visual inspection

4. Results and Discussions

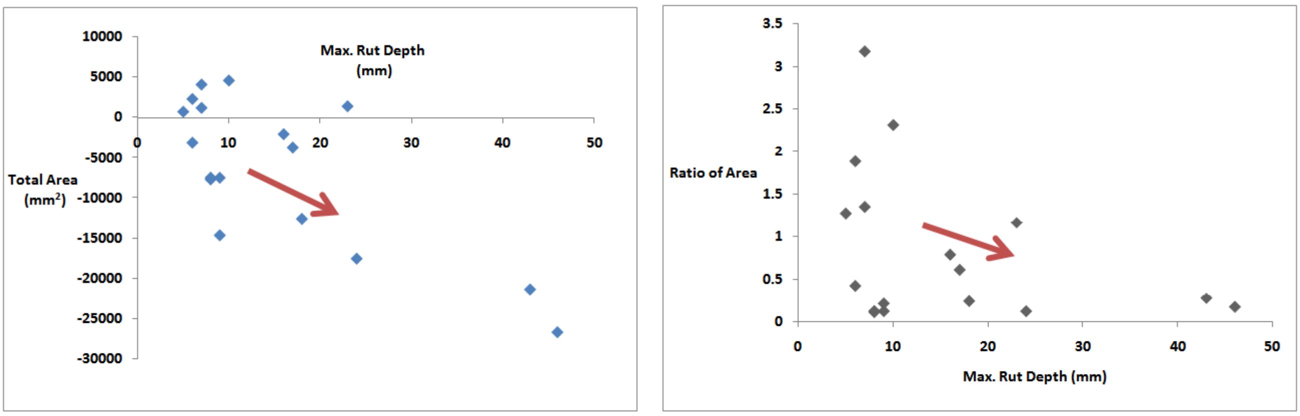
This section first explains results of destructive pavement test, and then transverse profile results are elaborated for the whole section. At the end comparison between both results are made to verify effectiveness of transverse profile analysis approach.

Our purpose to excavate a trench is to determine layer thickness variation with reference to the straightedge throughout the lane width, layer thicknesses are measured at a spacing of 0.25 m. Figure 5(a) shows the left wheel path in which maximum rut depth is measured. It is clearly visible from the figure that thickness of HMA is less at the wheel path and increases as we move towards the center. Similarly Figure 5(b) shows the right wheel path. It also indicates the problem in HMA layer but the rut depth is less as compared to that in left wheel path. Figure 5(c) shows the deformation of the underlying layers. It is obvious that subbase and subgrade layers are not deformed to a considerable extent. This shows that these layers are intact. So it becomes certain that Hot Mix Asphalt (HMA) Layer has been failed. This is reconfirmed by drawing a trench profile from layer thickness variations measured at a transverse spacing of 0.25 m, as shown in Figure 5(d).

Table 1. Failed Layer Predictions from Transverse Profile Analysis

Sr #	A (mm^2)	A_p (mm^2)	A_n (mm^2)	R	C_1 (mm^2)	C_2 (mm^2)	C_3 (mm^2)	D (mm)	Failed Layer
1	-21326.2	7994.936	29321.18	0.272668	-36235.5	-65174.8	-91572.3	43	HMA
2	1427.10	10189.55	8762.425	1.162868	-19071.3	-34994.8	- 49170.3	23	HMA
3	-2037.30	7493.739	9531.034	0.786246	-13063.8	-24431.8	-34329.6	16	HMA
4	-3703.80	5773.858	9477.678	0.609206	-13922.0	-25940.8	-36449.7	17	HMA
5	11550.4	24037.08	12486.69	1.925017	-33660.8	-60647.8	-85212.0	40	HMA
6	-7450.60	1958.256	9408.814	0.208130	-7056.31	-13868.8	-19488.9	09	HMA
7	-14597.0	1958.256	16555.18	0.118287	-7056.31	-13868.8	-19488.9	09	HMA
8	1227.90	4715.054	3487.114	1.352137	667.58	-287.780	-407.950	07	HMA
9	-3095.10	2265.288	5360.374	0.422599	-4481.68	-9341.78	-13128.6	06	HMA
10	2334.90	4974.354	2639.439	1.884626	-4481.68	-9341.78	-13128.6	06	HMA
11	750.000	3477.525	2727.525	1.274975	-3623.47	-7832.78	-11008.5	05	HMA
12	4625.00	8139.579	3514.579	2.315947	-7914.52	-15377.8	-21609.0	10	HMA
13	-7660.09	1034.359	8694.444	0.118968	-6198.10	-12359.8	-17368.8	08	HMA
14	-7437.59	885.9497	8323.535	0.106439	-6198.10	-12359.8	-17368.8	08	HMA
15	4125.00	6014.583	1889.583	3.183021	-5339.89	-10850.8	-15248.7	07	HMA
16	-12565.1	3886.657	16451.74	0.236246	-14780.2	-27449.8	-38569.8	18	HMA
17	-17500.0	2317.269	19817.27	0.116932	-19929.5	-36503.8	-51290.4	24	HMA
18	-68818.0	628.7425	69446.79	0.009054	-30228.0	-54611.8	-76731.6	36	SG
19	-26627.2	5385.757	32012.96	0.168237	-38810.1	-69701.8	-97932.6	46	HMA
20	-19054.7	168.1922	19222.85	0.008750	-7056.31	-13868.8	-19488.9	09	SG

A is total area, A_p and A_n are positive and negative areas, R is ratio of area, D is max. rut depth and C_1, C_2, C_3 are theoretical average total areas for surface, base and subgrade failure respectively. HMA is hot mixed asphalt layer and SG is subgrade layer



(a) Relationship between maximum rut depth and total area

(b) Relationship between maximum rut depth and ratio of area

Figure 6. Relationships between distortion parameters

Now results of analysis of transverse profiles are tabulated for all the captured profiles as shown in Table 1. The methodology followed is same as explained in previous section of this research paper.

Above results indicate that majority of profile sections showed HMA failure apart from two exceptions which indicated subgrade layer failure. The trench excavated gives similar results of HMA failure, so by comparing output results of both destructive and non-destructive methodologies it is inferred that this procedure of transverse profile analysis is a valuable tool to predict failed layer. Inter-relationship was found between different transverse profile distortion parameters (i.e., total area, ratio of area and maximum rut depth) as shown by Figure 6. Figure 6(a) indicates the relationship between maximum rut depths obtained by wire line method and total areas obtained by summation of positive and negative areas. This relationship shows that as rut depth increases negative area goes on increasing. Figure 6(b) indicates relationship between maximum rut depth and ratio of area. It illustrates that increase in rut depth decreases ratio of area. As ratio of area is ratio of positive to negative areas so decrease in area ratio means increase in negative area.

5. Conclusions and Recommendations

This study aimed to investigate, (i) whether the transverse surface profile analysis could be effectively used to determine the contributions of different structural layers of asphalt pavements to rutting, and (ii) demonstratea systematic approach for measuring each layer contributions to total rutting. It was concluded that by considering data from literature review, transverse profile analysis, and field trenching, objectives or goals of research defined initially were successfully achieved. The distortion parameters failure criteria proved to be a valuable tool to determine layer contributions to permanent deformation in the particular environmental conditions of Pakistan. This research highlighted the use of "ICC SurPRO 2000 Profiler" as a practical tool for transverse profile data collection. It was observed through analysis that majority of the pavement transverse profiles indicated HMA layer failure for the selected portion on National Highway (N-5).It was also observed that two test section profiles indicated failure of underlying layer (i.e., subgrade layer).

By the use of collected data, the trends were found between transverse profile distortion parameters (i.e. total area, ratio of area and maximum rut depth). It was concluded that as the rut depth increases negative area also goes on increasing and positive area reduces. The results from this study couldbe applied to pavement on system wide basis to evaluate the properties of materials, test specifications, pavement thickness design.

It has been observed that the results from transverse profile failure criteria agree well with the results of excavated trench section. But in order to generalize this approach, layer thickness variation data should be collected by non-destructive methods at different affected sites, so that results of transverse profile failure criteria can be validated in more precise manner. It is also suggested that a user friendly software should be developed for the transverse profile failure criteria in order to increase its adaptability by different transportation departments.

Acknowledgement

The authors would like to acknowledge Dr. Shafiq Ahmed fromNational Highway Authority (NHA) Pakistan for assistance in field trenching.And thesupport from National University of Sciences & Technology (NUST) is also appreciated for funding this research project.

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