Field Investigation of Flexible Pavement Rutting Damage Using the Transverse Surface Profile

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Abstract: The pavement deterioration over time is demonstrating in several distresses types; however, flexible pavement rutting represent major failure mode. Recently, surface distress survey has conducted in the Egyptian road network showed that pavement rutting represent one of the main pavement distresses. This paper presents a case study of one road within the Egyptian road network that showed sign of major premature rutting. Identifying the pavement layer that cause the majority of rutting is important to properly prescribe the right treatment. Field investigation of the transverse surface profile as nondestructive simple method was carried out to locate the origin of the rutting within the pavement layers. The transverse surface profile at 10 sections was analyzed for Belbis - Zagazig road. The analysis of the transverse surface profile has proven a good diagnostic tool to determine where the majority of the rutting failure resulting from. The transverse surface profiles analysis of the road segment showed that 60% of tested sections has showed rutting failure in the hot mix asphalt, 30% in the base layer, whereas 10% in the subgrade layer. The analysis indicated that the pavement is under designed and the construction records showed defects in quality of the hot asphalt mixture used in construction of the road.

[Mahmoud El-Saied Solyman and Hassan Salama. **Field Investigation of Flexible Pavement Rutting Damage Using the Transverse Surface Profile.** *J Am Sci* 2012;8(8):44-50]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 7

Keywords: Pavement rutting, transverse surface profile, Layer rutting, field investigation, truck traffic.

Introduction

Among several distress types causing pavement deterioration, the flexible pavement rutting represents major failure mode. It has been assumed in the literature that the major rutting contribution is mainly produced from the subgrade layer and both Asphalt Institute and Shell rutting models were accounting only for the subgrade rutting [1,2] respectively. Investigating these assumptions indicated that all pavement layers have shares in the total surface rutting. This share can be varies from section to another depending on several factors such as material characteristics, pavement layers thicknesses, traffic volumes and loads, and environmental conditions. A study was done on AASHO road test to determine the percent contribution of each pavement layer on the total surface rutting showed that the subgrade of AASHO road test had only 9% rutting only as presented in Ullidtz's literature review [3], see Table 1.

Gillespie and Karamihas [4], and **Southgate** [5], stated that the primary source of rutting is the harmful effects of heavy axle loads. They concluded that the effect of static loads create more pavement strains than those created by dynamic loads. **Phang** [6] confirmed this conclusion and revealed that plastic deformations increase as the time which loads are applied (duration) increases. Analysis of traffic factors of those researchers showed that exceeding the maximum permissible load causes significant increase in rutting.

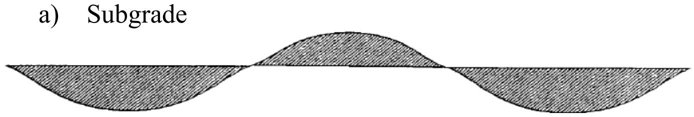
Table 1. Percent layer distribution of rutting [3]

Pavement layer	Percent observed rutting
Asphalt concrete	32
Base	14
Subbase	45
Subgrade	9

The pavement surface distress survey for Egyptian road network which have been conducted by General Authority for Roads, Bridges & Land Transport (GARBLT) at early 90's have showed that pavement rutting is representing one of the main pavement distresses. This distress survey showed that Belbis – Zagazig road had average rut depth of 13.2 mm and extended along 46% of the road length. Based on this survey, **Ahmed** [7], conducted a comprehensive study on rutting for Egyptian Road network. The study was concluded that hot mix asphalt, base, and subgrade layers had a contribution of 79%, 17% and 4% of the total surface rutting, respectively. Core tests for Belbis – Zagazig road indicated that the road has a major rutting problem resulting from the pavement layers especially the hot mix asphalt layer. The two selected sections showed total surface rutting ranged from 20 to 25 mm resulting from top pavement layers.

One of the main tasks on the Pavement Management System (PMS) is to diagnose what is the cause of the pavement distresses to properly prescribe the right treatment. Executing this task for pavement rutting distress requires locating the origin of the rutting within the pavement layers. The common practice which has been in use was distractive testing such as, cutting trenches or taking cores. Recently, researchers have been recognized that the transverse surface profile has information which can be used to locate the origin of the rutting within the pavement layers. **White *et al.***[8],**Simpson *et al.*** [9] have conducted studies which analyze the pavement transverse profile to determine the pavement layer that have the major share on the total surface rutting. Figure 1 shows the original and the final pavement surface for various rut mechanisms.


a) Subgrade


b) Base

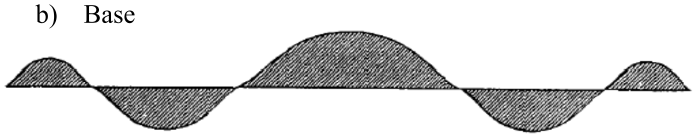

c) Hot mix asphalt

Figure 1. Transverse surface profile for various rut mechanisms[8,9]

Description ofBelbis–Zagazig Road

This study was conducted on one of the main road on the Egyptian road network which is Belbis – Zagazig Road. The road considers one of the main feeders of the construction materials (natural and crushed aggregate, sand, cement) for many governorates in the delta area such as Sharkia, Dakhliya, and Domiat. The road length is about 20 km in an agricultural area. The cross section of the road is two lanes in each direction with central New Jersey / narrow median. Accordingly trucks loaded with aggregate and sand use the subject link from Belbis to Zagazig and unloaded trucks use the other direction from Zagazig to Belbis. Table 2 shows AADT at year 2009 on the Belbis – Zagazig direction where the trucks are fully loaded.

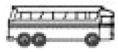
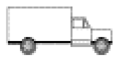
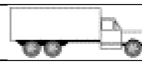
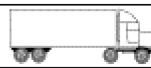
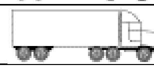
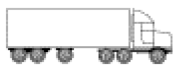
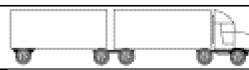
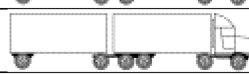
Pavement Analysis of Belbis – Zagazig Road

The Equivalent Single Axle Load (ESAL) was calculated using the collected traffic which is 20,986 at year 2009. The road has a major rehabilitation on year 1999 and on year 2009 which indicates that the life span of the pavement was 10 years. The total ESAL during the 10 years of the pavement design life is calculated as 24.3 Millions with a growth rate 3%, see Table 2. This traffic load requires 5.5 Structure Number (SN), whereas calculating the SN of the existing pavement cross section gives 4.5. This indicates that the structural capacity of the existing pavement is insufficient. Back calculation of the ESAL showed that the existing pavement cross section can carry up to be 5.1 Millions ESAL. This indicates that the road carried19.2 million ESAL after failure. In addition, Egyptian trucks have 49% exceed the maximum permissible axle load at permanent weight control stations in compare to 79% at portable stations. Theses analysis clarifies the premature rutting that appears in the road at early stage. Due to the fact that the relationship between the ESAL and SN is not linear, if the cross section of the road could have increased by 5 inches base and 1 inch HMA, the pavement cross section would be sufficient.

Field Data

The transverse surface profile at 10 sections on Belbis – Zagazig Road was measured. 9 sections were taken in the North bound (toward Zagazig) where majority of the trucks are fully loaded with construction materials whereas only one section was taken in the south bound. The road levels in the transverse cross sections at each intersection were measured using the rod and level each 20 cm for the entire direction. These levels were used to form the transverse surface profile of the road. Also, the maximum rut depth in each section was measured. Figure 2 shows the process of measuring the transverse surface profile and the maximum rut depth. Since the truck drivers do not always stick to the right lane of the road, the traffic lane that shows higher rutting distresses was considered in the analysis. Figure 3 a and b shows the survey of the transverse profile and the measurement of the maximum rut depth.

Table 2. Annual average daily truck traffic and ESAL calculations

Vehicle Class	Description	Schema	AADT	Truck Factor	ESAL
2	*Passenger Cars*		20794	0.010	208
3	*Two-Axle, Four-Tire Single Unit Vehicles*		3053	0.057	174
4	*Buses*		392	0.104	41
5	*Two-Axle, Six-Tire, Single-Unit Trucks*		514	6.426	3,303
6	*Three-Axle Single-Unit Trucks*		81	6.590	534
7	*Four or More Axle Single-Unit Trucks*		92	9.450	869
8	*Four or Fewer Axle Single-Trailer Trucks*		186	9.450	1,758
9	*Five-Axle Single-Trailer Trucks*		100	6.590	659
10	*Six or More Axle Single-Trailer Trucks*		42	7.214	303
11	*Five or fewer Axle Multi-Trailer Trucks*		608	16.766	10,193
12	*Six-Axle Multi-Trailer Trucks*		236	12.475	2,944
Total ESAL					**20,986**

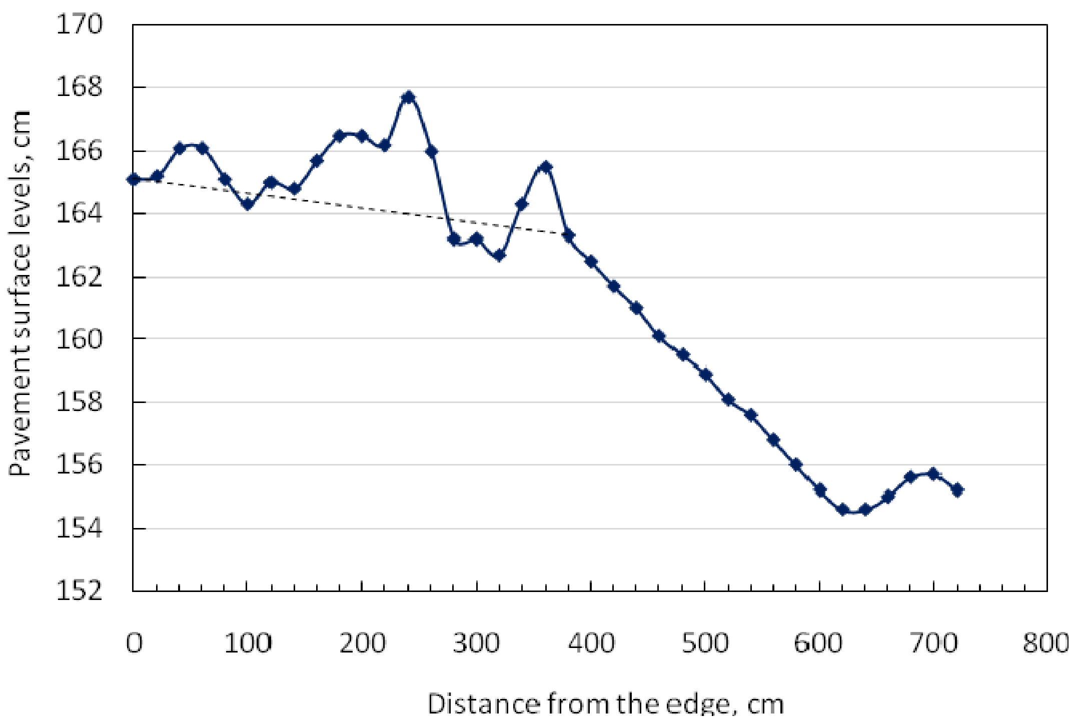


Figure 2. Actual transverse surface profile measurements at section 6

(a) Survey the transverse surface profile (b) Measuring the maximum rutting

Figure 3. Transverse surface profile measurements

Analysis

The following equations represent the criteria developed by **White *et al.***[8], to determine the failed layer identity using transverse surface profile data:

$$A = A_p + A_n \quad (1)$$

$$R = \left| \frac{A_p}{A_n} \right| \quad (2)$$

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

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

$$C_3 = (-2{,}120.1)D - 407.95 \quad (5)$$

where:

A = total area, mm^2

A_p = positive area mm^2 (see Figure 4)

A_n = negative area mm^2 (see Figure 4)

R = area ratio

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 (see Figure 4)

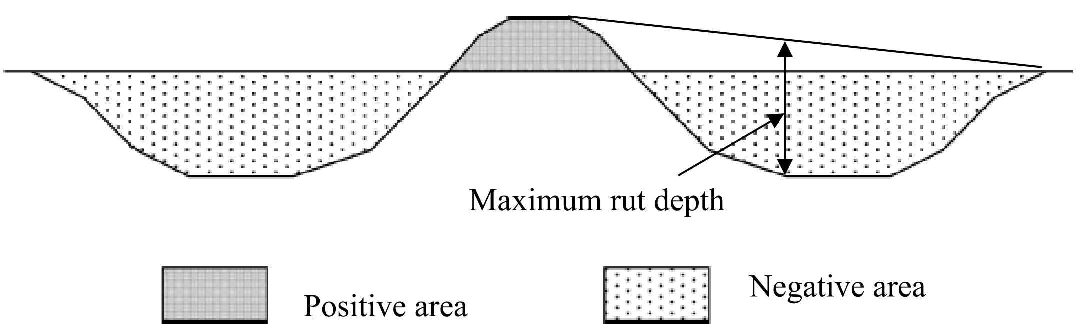


Figure 4. Definition of positive and negative area as well as maximum rut depth the in transverse surface profile[8]

Based on the characteristics of a given surface profile and the criteria described above, the following outcomes can be predicted:

(a) Failure will occur in the HMA layer if:

$R > 0.05$ and $A > (C_1+C_2)/2$

(b) Failure will occur in the base/subbase layer if:

$R < 0.05$ and $A > (C_2+C_3)/2$

(c) If none of the above criteria are satisfied, that suggests subgrade layer failure.

Analysis of transverse surface profile data

Applying the above criteria on the collected data of the transverse profile identified the failed pavement layer at each intersection. Table 3 shows the transverse surface profile parameters calculations for the ten sections. Figure 5 shows examples of each failure mechanism for different pavement layers along with photos for these sections. The transverse surface profiles analysis of the road segment showed that 60% of the failure occurred in the hot mix asphalt, 30% of the failure on the base layer, whereas 10% on the subgrade layer. This indicates that rutting resulting from the pavement layers represent 90% along the road segment. In addition the only section that shows failure in the subgrade layer was on the border between the base and subgrade failure. These results show that the main rutting problem in this road mainly related to pavement layers.

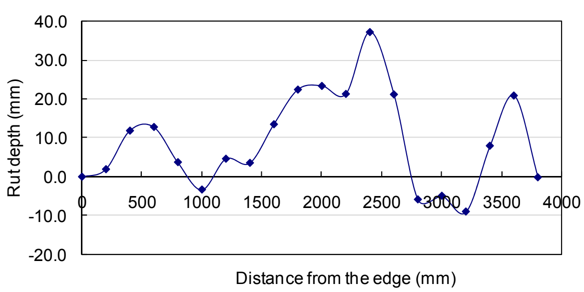
Since majority of the trucks drive in the left lane, the analysis indicated that 8 sections out of 10 had rutting failure in the inner lane which consider as the truck lane. All 9 sections in the north bound (toward Zagazig) are showed maximum rut depth more than 22 mm which is higher than the failure threshold. This indicates that the heavy truck traffic load is one of the major factors that cause the north bound to have major rutting problem. Section number 10 located in the South bound (toward Belbis) where most of the truck traffic are empty showed maximum rut depth 7 mm which is less than the rutting failure threshold. Figure 6 shows the maximum rut depth for the ten pavement sections.

Table 3. Analysis of the transverse surface profiles

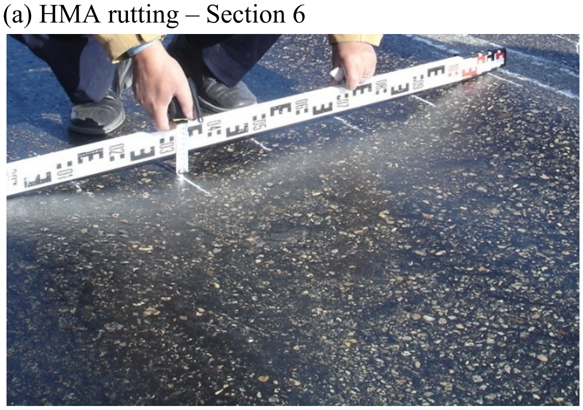
Sec. No.	A	A_p	A_n	R	C_1	C_2	C_3	D	Rut Location*	Traffic Lane
1	930	1843	-914	2.02	-5886.0	-11811.1	-16597.8	28.00	HMA	Outer
2	-42900	4600	-47500	0.10	-5027.8	-10302.1	-14477.7	40.00	HMA	Outer
3	10000	18100	-8100	2.23	-14936.2	-27724.1	-38955.2	24.00	HMA	Inner
4	-65200	336	-65536	0.01	-6744.2	-13320.1	-18717.9	45.00	Base	Inner
5	-63200	528	-63728	0.01	-6510.2	-12908.5	-18139.7	35.00	Base	Inner
6	37000	39558	-2558	15.46	-7758.5	-15103.4	-21223.5	38.00	HMA	Inner
7	16200	36954	-20754	1.78	-7134.3	-14006.0	-19681.6	65.00	HMA	Inner
8	-41000	184	-41184	0.00	-7368.4	-14417.5	-20259.8	22.00	SG	Inner
9	-57100	818	-57918	0.01	-5808.0	-11673.9	-16405.1	45.00	Base	Inner
10**	17700	19833	-2133	9.30	-5573.9	-11262.3	-15826.9	7.00	HMA	Inner

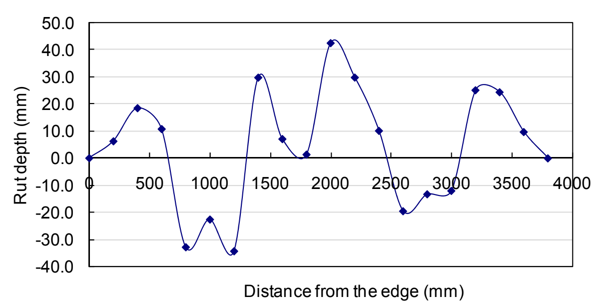
* HMA = Hot Mix Asphalt layer, SG = Subgrade layer

** Section 10 is the only one tested on the opposite direction (Zagazig – Belbis)



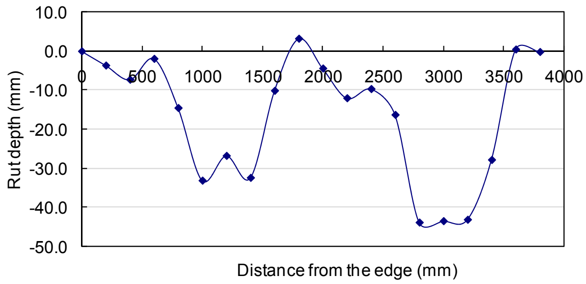
(a) HMA rutting – Section 6



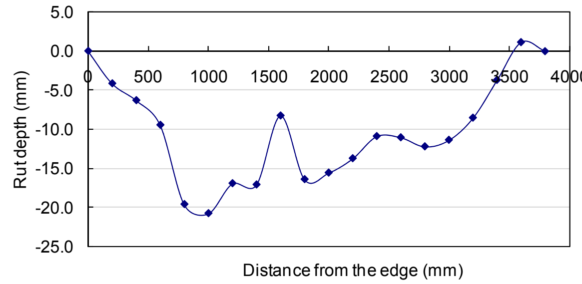


(b) HMA Rutting –Section 7

(c) Photo at section 6



(d) Photo at section 7



(e) base rutting – Section 5

(f) SG rutting – Section 8

(g) Photo at section 5

(h) Photo at section 8

Figure 5. Various rut mechanism at different locations along the road

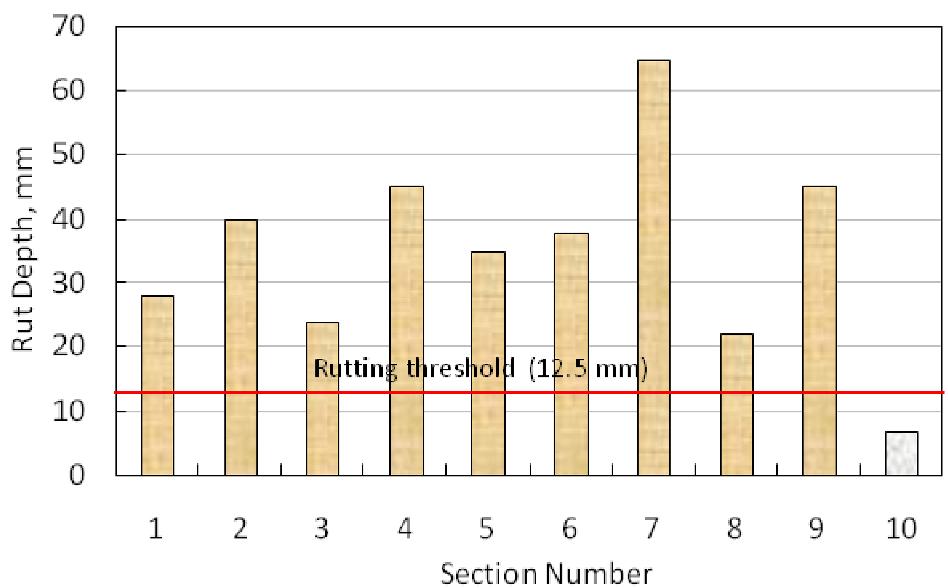


Figure 6. Maximum rut depth on the transverse surface profiles

Analysis of the transverse surface profile indicates that there are construction-related rutting and structure rutting. All sections that have rutting failure in hot mix asphalt layer are due to construction-related problem. This is due to the premature rutting problem that has been appeared at the early stage of the pavement life. Moreover, investigation of the construction files of the road indicated that there were problems in the asphalt plant where the asphalt feeder was not accurately calibrated to supply the optimum asphalt content. On the other hand, sections that have failed in base and subgrade are due to the fact that the structure capacity of the pavement under-designed to carry the traffic load and about 35.42 millions ESALs are more that what the cross section can carry. Also, comparing the rutting damage in both directions of the road support this conclusion where the maximum rutting the unloaded direction still did not exceed the threshold of the rutting failure criteria (section 10 – see Figure 6).

Although the several maintenance implementations the field investigation of the subject paper shows that Zagazig- Belbis road is still suffering and in more intensity from rutting. In the last 2 years, GARBLET was studying to bid maintenance of this road in different way based on that the contractor will be responsible to keep the road conditions as rut depth and IRI value at certain level however the maintenance implementations. At the end and after this study, GRABLET replaced the flexible pavement with rigid pavement at the low speed segments of the road in Subject.

Conclusions

Based on the analyses of transverse surface profile data from in-service pavements for 10 sections on one of the Egyptian Road network, the field investigation of flexible pavement rutting damage can be summarized as follows:

1. The transverse surface profiles analysis of the road segment showed that 60% of the failure occurred in the hot mix asphalt, 30% of the failure on the base layer, whereas 10% on the subgrade layer.
2. All sections that have rutting failure are due to insufficient pavement cross sections and construction-related problem especially in HMA. The premature rutting damage that has been appeared at the early stage of the pavement life assures this conclusion.
3. The resulting rut damage is due to heavy truck axle loads where this road carried significant excess heavy trucks in addition 49 % of these trucks are violating the legal axle load.
4. Since the GARBLT is changing the pavement type to rigid pavement for some of the sections, as long as the pavement cross section is underdesigned as the case for flexible pavement, there will be sever pavement distresses unless proper design has been guaranteed.
5. The analysis of the transverse surface profile has proven a good diagnostic tool to determine layer rutting contribution from each pavement layer and choose the proper maintenance strategy to mitigate the rutting distresses.

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6/15/2012