THE STUDY ON THE RELASIONDHIP OF LOW SEVERITY PAVEMENT RUTTING AND ACCIDENT RATE

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Abstract*-The influence factors between rutting depth and traffic safety is educed through the analysis of the mechanism that how rutting affects traffic safety. The investigation is presented in Feng-Yong Expressway, concerning rut depth, traffic accidents, weather and road alignment data. The wet-weather accident rate(WAR), wet-weather accident rate in curve(WARC) and so on, as main indictors, are used in analysis and evaluation. The relationship between rutting depth and traffic safety, associated with the weather and road alignment, is obtained. And based on the data analysis, the criterion of the rutting depth for maintenance in this region is proposed

***Keywords*-rutting depth;hydroplaning;accident rate; relationship; weather;road alignment**

I. INTRODUCTION

According to past literature, the main concern with rutting is related to driving safety, although there is no clear and definite relationship between rut depth and traffic accidents (Start et al. 1998, Christensen and Ragnoy 2006)[[1,2]]. Since the early 1970s, pavement engineering researchers have produced experimental evidence that ponding of pavement ruts could lead to hydroplaning and loss of skid resistance. Barksdale [3](1972) concluded from his study that in pavements with rut depths of about 0.5 in. (12.7 mm), ponding is sufficient to cause automobiles travelling at speeds of 50 mph (80.5 km/h) or more to hydroplane. Lister and Addis[4] (1977) also found from their experience in the United Kingdom that pavements with ruts deeper than approximately 0.5 in. (12.7 mm) could result in ponding of water and cause hydroplaning or loss of skid resistance.

The Wisconsin Department of Transportation(WisDOT) (1998) analyzed the relationship between the rutting depth, traffic volume and traffic accidents, and the result indicated that the accident rates related to rutting was significantly increased when the rutting depth reached up to 7.6mm, resulting hydroplaning[5]. In a study on preventive maintenance treatments for flexible pavement, Hicks et al.[6] (2000) adopted the following three severity levels for ruts based on the potential for hydroplaning and wet weather accidents:

a. Low severity - Rut depth is less than 6 mm. Problems with hydroplaning and wet weather accidents are unlikely.

b. Moderate severity - Rut depth is in the range of 7 to 12 mm. Inadequate cross slope can lead to hydroplaning and wet weather accident.

c. High severity - Rut depth is greater than 13 mm. The potential for hydroplaning and wet weather accidents is significantly increased.

Horne's studies [7] showed that the calculation method of the minimum speed occurring hydroplaning, and that the minimum speed is not only related to the tire pressure, but also the length and width of the tire contacted with the ground. Ivey et al. [7] acquired the calculation of the minimum speed when the truck tire came about completely hydroplaning through test, and the minimum speed is proportional to the tire pressure P0.21.

In the provision of Highway asphalt pavement maintenance and technical standard[8], which is combined the foreign standards with China's actual situation, the deformation which is considered as rutting was greater than 15mm for expressway and first class highway, and the rutting is considered as low severity rutting when the depth is less than 25mm, and the other is high severity. Japan Hanshin Expressway Public Corporation divides rutting into four grades: grade A, rut depth greater than 20 mm; Class B, 10 to 20 mm; grade C, 3 ~ 10 mm. The grade A is the worst and the rutting depth less than 3mm is OK. FHWA, U.S. Federal Highway Administration also divides rutting into four grades: slight hydroplaning, 5to 6 mm; 6 ~ 13 mm: 13 to 25 mm; 25 mm or more. According to their specific circumstances, many countries proposed their allowable rut depth as their maintenance standards. Some national standards are as follows: United Kingdom, 20 mm; American Society of asphalt, 13 mm; Belgium, 12 mm (arterial highway)[9].

The researchers study the relationship between rutting depth and security primarily based on the hydroplaning, considering water depth, tire pressure and speed, but lacking road alignment and other factors. In addition, although the rutting depth has been divided into many grades based on safety at home and aboard, but the indexes

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are not uniform. So it is necessary to study the characteristics of the relationship between rutting depth and traffic safety with the real data in various regions, combining with the weather and road alignment. In this way, the turning point in the rutting depth-accident rate curve can be founded, providing guidance and advice fort for road maintenance in this region.

II. THE INFLUENCE MECHANISM OF THE RUTTING ON TRAFFIC SAFETY

A. Braking performance

The ability of vehicles to stop within a short distance and to maintain the driving directional stability, as well as the ability to maintain a certain speed when going downhill are called braking performance, which has a direct impact on traffic safety. Research shows that serious accidents are often associated with the long braking distance and vehicle skidding occurred in emergency brake. Therefore, excellent braking performance is an important guarantee for vehicle safety. "Trench effect" caused by pavement rutting directly affect the interaction between the vehicle and the road, that is, affect the vehicle's braking performance and the directional stability, and the former is particularly significant[10].

B. Handling stability

According to the route and traffic conditions, vehicles have change among the straight-driving, curve-driving and overtaking conditions. In unforeseen circumstances, the drivers need to make emergency steering operation to avoid the accident. This requires that the vehicle must have good handling stability, that is, the vehicle can follow the drivers’ operation through the steering system and steering wheel in a given direction, and the driving car is able to maintain the stability in dangerous. Therefore, the handling stability is the lifeblood of high-speed driving. The ability of handling stability depends on the traits of the vehicle itself and the condition of the road. "Trench effect" caused by pavement rutting as well as stagnant water in rutting will result in vehicle steering out of control, and even hydroplaning phenomenon, which have a serious impact on vehicle handling stability[10]. In addition, the different depth of the right and left rutting contributes to partial load and roll, which is extremely detrimental to traffic safety. We can conclude that the rutting not only affects the vehicle's braking performance but also the handling stability. However, the relationship between them needs further discussion. Studying the allowable rutting depth research from a security perspective has practical significance..

C. Hydroplaning

When the vehicle is traveling on the water surface with a certain speed, the water between the tire and road surface can discharge from the rear through the tire ground pressure and tread pattern. When the volume of stagnant water exceeds the drainage capacity, the water film will be gradually immersed in the tire and road surface, forming hydroplaning phenomenon. Fig.1[11]shows the partial hydroplaning phenomenon. At this point, there are three characteristic regions exist in the tire contact length. That is, completely hydroplaning District, partial hydroplaning areaⅡ, full contact zone Ⅲ. Of course, with the speed changing, the mutual relations of the above three regions will change too. For example, with the speed increasing, region Ⅰ and Ⅱ are expanded and region Ⅲ is gradually reduced, until the tire separate from the road completely, then the tire will happen complete hydroplaning. Under the condition of region Ⅰ and Ⅱ, the hydrodynamic pressure generated by squeezing water film due to tire makes the tire floating, and the adhesion coefficient between the tire and road is reduced. In this condition, the vehicle is easy to slip. Cars even move forward in the case of front wheel does not rotating, so the car's handling stability decreased seriously, which affect traffic safety significantly.

In summary, in addition to rutting depth, the difference of the rutting depth and other factors of rutting itself have impact on traffic safety, speed, the degree of wet of surface, road alignment and other factors also exacerbated the impact. This paper conducts the study on the relationship of rutting depth and accident rate combining with the weather and road alignment.

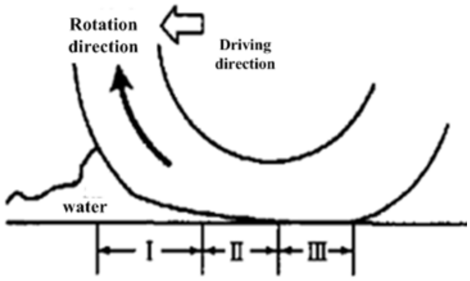

Figure 1. [11] Part Hydroplaning State

III. ANALYSIS OF THE RELATIONSHIP BETWEEN ACCIDENT RATE AND TRAFFIC SAFETY

A. Data Survey

The first is the accident data survey. The traffic administrative department provided the detailed information of every accident occurred in Feng-Yong Expressway, BinXian to ChangWu segment, from January 2010 to November 2010, including the specific accident time, place (Roadway Stake), as well as weather conditions.

Then is the rutting survey. The information provided by Highway Maintenance Department includes the place of rutting (Stake) and rut depth. In order to statistics, the rutting depth is divided into four intervals and corresponding to each interval is a level, as shown in Table 1.

Table1. Rutting Level

Rutting Level	Ⅰ	Ⅱ	Ⅲ	Ⅳ
Corresponding Region	＜ 2.5mm	2.5-5mm	5-7.5mm	7.5-10mm

Finally, the road geometry survey. Determine the location of the accident is at curve or straight line, comparing with the accident site and road alignment.

Match each traffic accident site with the corresponding rut depth, and then calculate the number of the accidents in each rutting level according to Table 1. Finally calculate the total accident rate (TAR) of this rutting level, according to Equation 1(the equations of the accident rate in curve (ARC) and the accident rate in straight line (ARS) are similar with TRA).

$$TAR = \frac{\text{the number of accident with given rutting level} \times 10^8}{\text{the corresponding road length} \times AADT \times \text{suvery days}}$$
(1)

In general, the time of rainfall is much less than the non-rainfall time within one year, to differentiate the rainy time from sunny time on calculation and analysis of results, an indicator ,Wet-weather accident rate (WAR) , is defined, and the method of calculation is shown as equation 2 (Dry-weather accident rate(DAR) is similar with WAR). The statistical number of rainy days can be obtained according to the meteorological data.

$$WAR = \frac{\text{the number of accident with given rutting level}(wet-weather) \times 10^8}{\text{the corresponding road length} \times AADT \times \text{rainy days}}$$
(2)

In order to take the road alignment and weather factors together into consideration, the number of accidents happened in curve and straight sections on rainy days and sunny days should be investigated respectively, and then calculate the Wet-weather accident rate in curve (WARC) according to equation 3(wet-weather accident rate in straight line (WARS), dry-weather accident rate in curve (DARC) and Dry-weather accident rate in straight line (DARS) are similar with WARC).

$$WARC = \frac{\text{the number of accident with given rutting level}(wet, curve) \times 10^8}{\text{the corresponding curve length} \times AADT \times \text{rainy days}}$$
(3)

Due to lacking of annual average daily traffic volume data (AADT), this study adopts the value of 30,000 as the representation of AADT, which is the average value for general expressway. As the paper mainly conducts comparative study, so AADT has no effect on the results of the analysis.

B. Data Statistics

Attached table 2 shows the statistical results of traffic accidents and rutting investigation on a section (from BinXian to ChangWu) of Fong-Yong Expressway from January 2010 to November 2010. The days of investigation are 304, including rainy days (93) and sunny days (211).

Fig.2, Fig.3 and Fig.4 represent the relationship between rut depth and accident rate under different factors respectively, and the source of the data are from attached table 2.

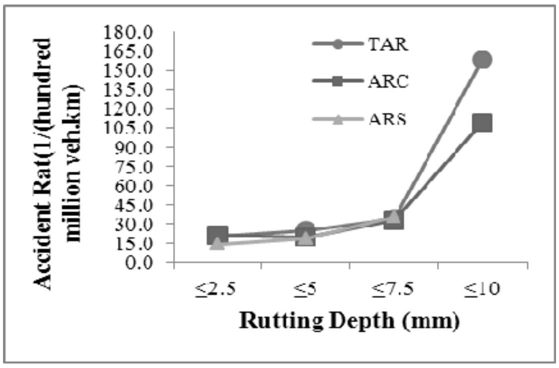

Figure2. the Relationship of Accident Rate, Rutting Depth and Road Alignment

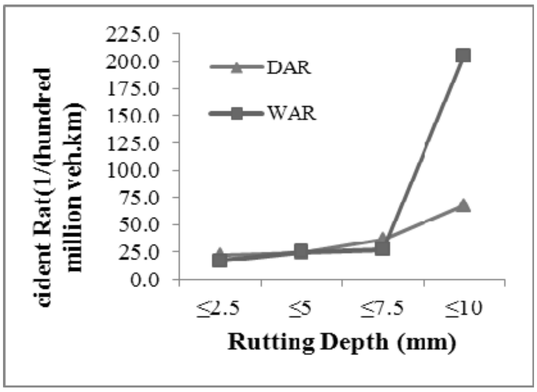

Figure3. the Relationship of Accident Rate, Rutting Depth and Weather

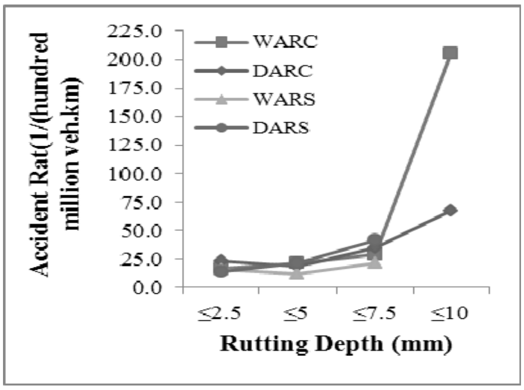

Figure3. the Relationship of Accident Rate, Rutting Depth ,Road Alignment and Weather

C. Data Analysis

We can see from the above statistical table, there is no straight line segments in rutting level Ⅳ , so the corresponding mileage and the number of accidents are 0. But there are actual values in the other rutting levels.

We can see from Fig.2 clearly that the accident rates rise with the increase of the rut depth under the same traffic volume. What's more, the accident rates represent a slow growth when rut depth is less than 7.5mm, while the accident rates rise sharply when the rut depth is greater than 7.5mm. The result is consistent with the conclusion that MARC R. START et al. got from the study about the relationship between the rutting depth, traffic volume and traffic accidents with the data provided by Wisconsin, that is, the accident rates related to rutting was significantly increased when the rutting depth reached up to 7.6mm. In addition, comparing RAC with RAS, we can find that the potential of traffic accident in curve is slightly higher than that in straight line, which accords with the fact that the sight horizon is poor and the vehicle is difficult to control when steering in the curve segment.

From Fig.3, it is not difficult to find that the growth rate of the WAR and DAR accord with the above conclusion, that is, the accident rates represent a slow growth when rutting depth is less than 7.5mm, while the accident rates rise sharply when the rutting depth is greater than 7.5mm. In addition, the growth rate of WAR is much larger than that of DAR when the rutting depth is greater than 7.5mm, while the growth rate of them is similar when rutting depth is less than7.5mm. This is because that the potential for poor skid resistance of pavement and hydroplaning increases, when the vehicle run in the rainy days. And Hicks et al. (2000) pointed that only when the rutting depth is greater than 7mm can the rutting contribute to hydroplaning and wet weather accidents.

Fig.4 shows the relationship between rut depth and accident rate under different weather and road alignment conditions. We can conclude that the variation of WARC and WARS is consistent with that of WAR. In addition, we can see the value of WARC is slightly higher than WARS when the rutting depth is less than 7.5mm, which is similar with the result obtained from Fig.2. But the conclusion can't be used in sunny days. The value of DARC is greater than that of DARS in rutting level Ⅰ and Ⅱ,but the trend goes into reverse in rutting level Ⅲ.The reason is probably that the driver is difficult to find the rut whose depth is less than 5mm, and the rutting with 5-7.5mm depth can be found easily. Moreover the driver's psychological quality and attention are also related to the poor regularity of statistical results.

IV. CONCLUSION

1. Rutting mainly affects the braking performance and handling stability of the vehicle. The weather, differences of the right and left rutting depth and road alignment closely relate to the traffic safety, besides rutting depth.

2. The accident rates rise with the increase of rutting depth; and the growth is relatively flat when the rutting depth is less than 7.5mm, but the accident rate has a rapid growth when the rutting depth is greater than7.5mm. The conclusion is consistent with that of MARC R. START's. Therefore the local maintenance personnel should take action to timely maintenance when the rut depth reaches 7.5mm.

3. Comparing the curve of WAR with DAR, when rutting depth is less than 7.5mm, wet-weather has little effect on the accident rates, when the rut depth is greater than 7.5mm, the wet-weather plays an important role in accident.

4. When the rutting depth is less than 7.5mm, the relationship between rut depth and accident rate is not uniform between straight line segments and curve segments. When the rutting depth is greater than 7.5mm, the trend of the accident rate in straight line sections is unknown, due to lacking data, so further research is needed。

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Attached table2. Traffic Accidents and Rutting Investigation on a Section of Fong-Yong Expressway

Rutting Level	Ⅰ	Ⅱ	Ⅲ	Ⅳ
Corresponding Mileage(km)	17.0	45.2	17	0.7
The number of Accident	32	102	52	7
TAR[(1 · (hundred million veh.km)-1)]	20.6	24.7	33.5	158.0
WAR[(1 · (hundred million veh.km)-1)]	16.9	25.4	27.4	204.8
DAR[(1 · (hundred million veh.km)-1)]	22.3	24.5	36.2	67.7
Curve Mileage(km)	14.7	48.9	13.6	0.7
Straight line Mileage(km)	2.3	9.4	3.4	0
The number of accident(curve)	29	86	41	7
The number of accident(straight line)	3	16	11	0
ARC[(1 · (hundred million veh.km)-1)]	21.6	19.3	33.1	109.6
ARS[(1 · (hundred million veh.km)-1)]	14.3	18.7	35.5	0
The number of accident(wet-weather, curve)	7	29	11	4
The number of accident(wet-weather, straight line)	1	3	2	0
The number of accident(dry-weather, curve)	22	57	30	3
The number of accident(dry-weather, straight line)	2	13	9	0
WARC[(1 · (hundred million veh.km)-1)]	17.1	21.3	29.0	204.8
WARS[(1 · (hundred million veh.km)-1)]	15.6	11.4	21.1	0.0
DARC[(1 · (hundred million veh.km)-1)]	23.6	18.4	34.8	67.7
DARS[(1 · (hundred million veh.km)-1)]	13.7	21.8	41.8	0.0