**Technical Paper**

ISSN 1996-6814 Int. J. Pavement Res. Technol. 6(4):344-350


# Investigations of Skid Resistance of Manhole Covers in Taiwan

Chia-Pei Chou[1] and Ning Lee[1+]

**Abstract:** In Taiwan, many manhole covers, which cause skid risk to two-wheel vehicles under wet weather condition, are installed on the road. To reveal how the manhole covers affect the road safety, this study carried out a survey that investigated the skid resistance of 99 manhole covers with 3 different instruments, the GripTester, the British Pendulum Tester, and the Dynamic Friction Tester. The result shows that most of the covers currently on the road do not have good enough skid resistance, while the new-casting covers all performed good skid resistance in the survey. Accordingly, the skid resistance of roads should be rectified by replacing overly old covers with new ones.

**DOI**:10.6135/ijprt.org.tw/2013.6(4).344

***Key words**: Friction; Iron-casted Manhole covers; Skid Resistance; Texture.*

## Introduction

Passing a manhole cover can be more dangerous to two-wheel vehicles comparing with that to four-wheel vehicles. Therefore, it is important for the road authorities to regulate the skid resistance of iron-casted covers, especially in those countries with numerous manhole covers, high two-wheel vehicle usage, and wet climate. In Taiwan, there are more than 15 million scooters and motorcycles at the end of 2011, taking 2/3 part of all motorized vehicles, and approximate one thousand iron-casted manhole covers per km square are densely installed on the road. Skid related accidents and incidents of two-wheel vehicles related to manhole covers under wet weathers conditions occur frequently. Therefore, it is important to make sure all those covers have enough skid resistance to prevent skid accident of road users.

To secure two-wheel vehicles a safe driving environment, the Ministry of Transportation and Communication (MOTC) is preparing to set a regulation on the skid resistance of manhole covers. Since most of countries only prescribe the material, dimensions, loading test methods and marking in their specifications of manhole covers, but seldom mention skid resistance or friction requirements, this study investigated the skid resistance of iron-casted manhole covers with three different methods, to provide useful information for the future enforcement of friction regulation. In the paper, the results of skid resistance survey by each instrument are presented, and suggestions to improve the current situation are also brought out.

## Equipments and Methods

There are many types of skid resistance tester. Each of them obtains friction values in completely different systems, and so far there are no reliable correlation equations to transform one system to another [1]. Accordingly, a proper tester should be selected carefully to set related regulations. Three different skid resistance testers were used in this study. In addition to confirm if the currently in-used manhole covers can satisfy the requirement once a specific standard of skid resistance value has been set, the testers are also evaluated to find out which of them express the skid resistance of manhole covers better.

Skid resistance comes from a complex mechanism among the road surface, the tires, and the environment. Out of all the factors that affect the skid resistance of a surface, the texture is the only thing that can be controlled through engineering ways. Many studies which focused on the relationship between texture design and skid resistance showed that when the texture on the test surface is arranged orderly, its skid resistance will be affected by the shape, size, and depth of the texture [2- 4]. To confirm the relationship does exist between the texture depth and the skid resistance, this project obtained a set of mean texture depth data for one of the commonly used texture designs by sand patch method.

### GripTester

The GripTester (Fig. 1) is a continuous skid resistance tester that can be used for long-distance survey in normal driving speed, usually 50 km/hr on roads and 65 km/hr on airport runways. It is a good skid resistance tester which can simulate the friction that a vehicle experience when driving on the test section. The Griptester measures with a smooth test tire. When the survey is carried out, the GripTester is towed behind a vehicle, and the slip ratio of its test tire is fixed to 14.5% (if the slip ratio is 100%, it means the tire is fully locked and the slip ratio is 0%, it means the tire is free rolling). The vertical force and the towing force applied on the measuring tire are monitored during the survey, and then used to calculate a ratio, Grip Number (GN), as the skid resistance value. One GN value can be obtained per 10 meter along the test section. A water film with specific thickness is also applied to the measured surface by a water spray in front of measuring tire. The thickness of the water film is usually 0.25 mm on roads and 1.00 mm on airport runways [5]. Mostly, the value of GN is between 0 and 1, but in some special cases, the GN may exceed 1, which implies that the surface is extremely rough.

[1] Department of Civil Engineering, National Taiwan University, Taipei, Taiwan 10617.

[+] Corresponding Author: E-mail f95521512@ntu.edu.tw
Note: Submitted January 15, 2013; Revised May 22, 2013; Accepted May 23, 2013.

**Fig. 1.** GripTester.

This study used the GripTester to survey the synthetic skid resistance of several road sections, including rural highways and urban streets. Some of the road sections have manhole covers installed on the surface, so the synthetic skid resistance of the road sections with and without manhole covers can be compared.

### British Pendulum Tester (BPT)

The British Pendulum Tester (Fig. 2) is a pendulum-type skid resistance tester developed by British Road Research Laboratory, and has become one of the most widely used portable skid resistance testers. It is also the standard test equipment for road markings in Taiwan. It measures the skid resistance of a surface by quantifying the energy loss during the swing process. There is a rubber slider installed in the end of the pendulum. When the pendulum swinging freely, the rubber slider contacts the surface, and then a drag pointer pushed by the pendulum indicates the British Pendulum Number (BPN) after the swing according to the energy loss during the contact. Zero (0) BPN means the pendulum swings completely free (no friction), and a larger BPN will be read if the friction between the rubber slider and the test surface is greater, because more energy loss during the contact.

A specification stated by American Society for Testing Material, ASTM E303 [6], has listed all details of the mechanism, operations, and calibration of BPT. According to ASTM E303, the BPN neither numerically equals to other similar pendulum-type testers nor correlates with other skid resistance testers. Since BPN represents the degree of energy loss, it does not have any meanings of the friction coefficient. Nevertheless, BPT is a good equipment to measure the quality of micro-texture of the surface because of its low slip speed, which is only about 10 km/hr.

### Dynamic Friction Tester (DFT)

The Dynamic Friction Tester is also a portable skid resistance tester. Its system is combined by three parts, a main body, an X-Y recorder or a portable computer as the control unit and data collector, and a water supply system (Fig. 3). There is a disk with three small rubber sliders in the bottom of the main body. While doing the measurement, the disk first is lifted up, spun parallel to the test surface, and accelerated to specific tangential velocity. After that,


**Fig. 2.** British Pendulum Tester.

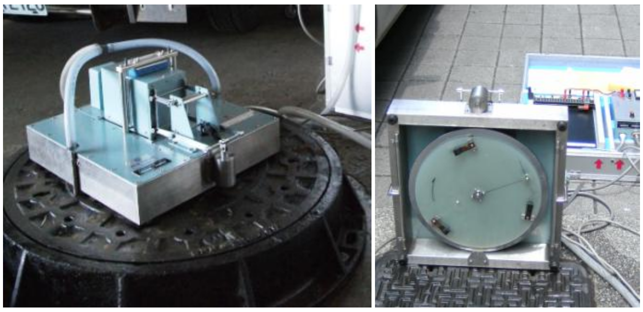


**Fig. 3.** Dynamic Friction Tester

the disk is put down to contact the test surface, and then the rotation speed decreases because of the contact. During the deceleration process, the torque that the rubber sliders bear are monitored and transformed to friction coefficients along the change of tangential velocity, to obtain the skid resistance value under specific slip speed, $DFT_V$ (V is the slip speed, km/hr). A water film about 1 mm thick is maintained during the measurement.

The maximum tangential speed of DFT is 90 km/hr, and usually the friction value at 20, 40, 60, and 80 km/hr will be recorded to analysis. According to ASTM E1911 [7], the friction value obtained by DFT is not directly correlated with the skid resistance value obtained by other equipment.

### NTU Improved Sand Patch Method

The design and the wearing on texture may affect the skid resistance of manhole covers. For one texture design, it is likely that deeper texture brings greater skid resistance, and the agencies may decide if an old manhole cover is too wearing and should be replaced. Many specifications [8, 9] have state the standard operations of using sand patch method. The conventional sand patch method measures the mean texture depth by laying a fixed ration of standard sand on the test surface, calculate the area which are covered by the sand, and then estimate the mean texture depth of the test surface. However, the depth and width of the texture on manhole covers are obviously much larger than the ones of pavements, it is difficult to control the shape covered by standard sand when applying the sand patch method on manhole covers. To solve this problem, the "NTU improved sand patch method" was used instead of the conventional method in the study.

As shown in Fig. 4, a 10cm*20cm frame is first put on the manhole cover, and then the space under it is filled with clay. This is to prevent the sand from leaking out. After that, standard sand is gently laid in the frame, until all the gaps among the textures are filled. The mean texture depth within the 10cm* 20 cm area can be estimated by the amount of sand that used to fill the gaps up.

## Synthetic Effects to Road Surface Caused by Manhole Covers

Twenty test sections, about 12 km long in total, are surveyed by GripTester in this research project. Those test sections were selected averagely from three different regions in Taiwan, including urban streets and rural highways. During the operations, a camera was used to record the test trail of the GripTester, in order to find out the reasons why lower GN occurs in some subsections. Table 1 is the GN values obtained from the twenty sections of roads. There is no significant difference between the two types of roads. The GN of urban streets are about 0.60~0.72, and the ones of rural highways are about 0.55~0.78.

Three out of the twenty test sections, Section 7, Section 13 and Section 14, have more manhole covers located on the test trails of the GripTester. However, the GN values of the three sections do not lower than what obtained on other sections. The reasons of the low GN values were found by rechecking the films of the survey. Apparently, passing road markings may make the GN of a subsection low, in addition to passing the manhole covers.

Fig. 5 shows the GN along Section 7 as an example. At the test section, there are 8 manhole covers installed on the test path in the first half of the test section, while the other half of Section 7 does not have any manhole covers installed. The GN shook when the tester pass through the area with manhole cover installed, but it never dropped to values that lower than 0.60. On the other hand, the subsection with road markings can be easily recognized, because all GN values of those subsections dropped below 0.60.

Table 2 listed the comparison of the GN values of plain pavement and those of pavement with manhole covers or road markings. Assuming the skid resistance of a road section is homogeneous before the manhole covers and the road markings are set, the GN values of subsections with road markings and manhole covers are picked out and compared with the closest subsections without manhole covers and road markings. It is obvious that the GN reduction due to road markings is larger than the one caused by manhole covers. Also, the subsections with manhole covers have higher GN than the ones with road markings. Although GN values in subsections with manhole covers are not low, it does not mean that manhole covers do not have negative effects to road safety at all. Since the manhole covers still affects the safety at specific locations, and the sudden change causes skid risk to two-wheel vehicles (Anderson *et al.*, 1982), it is necessary to use other type of skid resistance testers to make sure the skid resistance of manhole covers consist to the other components of the road.

**Fig. 4.** Appling NTU Improved Sand Patch Method on a Iron-casted Cover.

## Skid Resistance Survey by DFT and BPT

To figure out the skid resistance of single covers under different conditions, 99 manhole covers with several common texture designs were surveyed in the study, 48 of them are in-used manhole

**Table 1**. GripTester Survey Results of the Twenty Test Sections.

| Urban Street | | | | Rural Highway | | | |
|---|---|---|---|---|---|---|---|
| No. | Average GN | Section Length (m) | % of GN Lower than 0.53 | No. | Average GN | Section Length (m) | % of GN Lower than 0.53 |
| 1 | 0.6266 | 640 | 3.13% | 9 | 0.624 | 670 | 23.88% |
| 2 | 0.6807 | 640 | 4.69% | 10 | 0.6657 | 610 | 0.00% |
| 3 | 0.7203 | 570 | 1.75% | 11 | 0.6936 | 710 | 0.00% |
| 4 | 0.7074 | 720 | 5.56% | 12 | 0.7886 | 500 | 2.00% |
| 5 | 0.5957 | 460 | 17.39% | 13 | 0.761 | 420 | 0.00% |
| 6 | 0.6087 | 160 | 6.25% | 14 | 0.7813 | 420 | 0.00% |
| 7 | 0.6703 | 900 | 3.33% | 15 | 0.7552 | 480 | 0.00% |
| 8 | 0.6468 | 280 | 7.14% | 16 | 0.4949 | 660 | 65.15% |
| | | | | 17 | 0.5501 | 930 | 38.71% |
| | | | | 18 | 0.6675 | 710 | 19.72% |
| | | | | 19 | 0.6737 | 840 | 3.57% |
| | | | | 20 | 0.6505 | 800 | 2.50% |

Note:
[1]Section 7, Section 13, and Section 14 have More Manhole Covers Installed.
[2]The Value 0.53 GN was Selected as theReference to Decide Whether the GN in a Subsection is High Enough or not According to a UK Report [10].

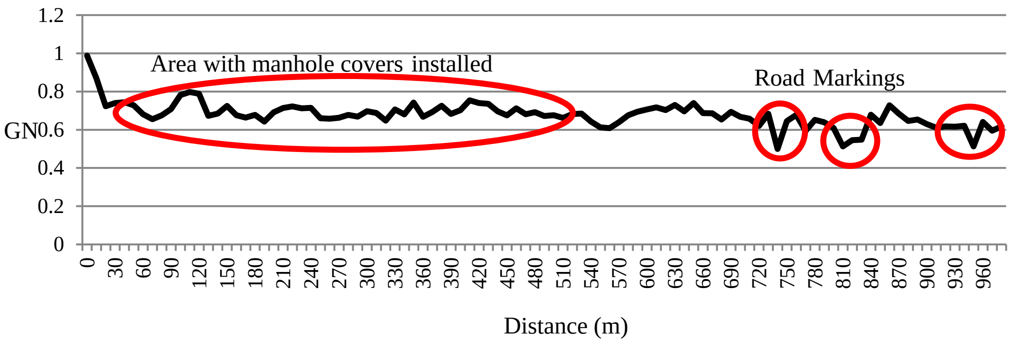



**Fig. 5.** GN Along Section 7 (Subsection Length: 10 Meter).

**Table 2.** Effects Caused by Manhole Covers and Road Markings.

| | GN Values of Subsections with Manhole Covers or Road Markings | | | GN Reduction Due to Manhole Covers or Road Markings | | |
|---|---|---|---|---|---|---|
| | Average | Std. | CV | Average | Std. | CV |
| Road Markings | 0.4962 | 0.0951 | 0.1917 | 0.1916 | 0.0803 | 0.4190 |
| Manhole Covers | 0.6469 | 0.0599 | 0.0925 | 0.0877 | 0.0300 | 0.3418 |

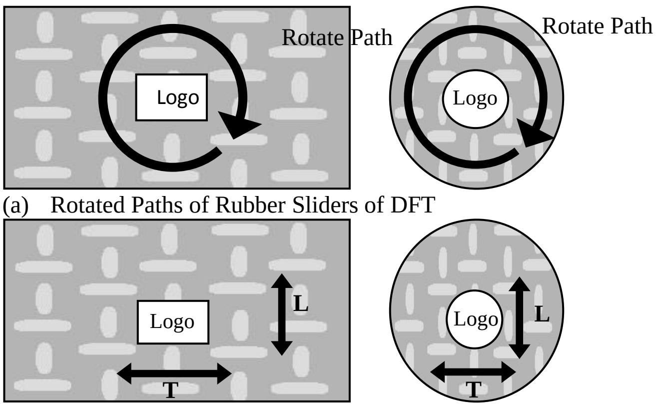
covers that are installed on roads and the 51 others are new covers stored in the manufacture factories. All sampled covers, no matter it is installed on the road already or not, are tested to get its own skid resistance values, including BPN under dry condition, BPN under wet condition, and $DFT_V$ curve. The skid resistance of samples of pavements and road markings are also surveyed and compared with those of the sampled manhole covers.

### Test Positions on Manhole Covers

The tested position of the DFT and BPT on a manhole cover are shown in Fig. 6. The rotate path of rubber sliders of DFT is circular with a diameter about 30 cm. It is large enough to cover most part of the textured area on the cover, so the DFT was put in the middle of the covers to survey. As to the BPT test, the survey obtained the BPN from both transverse (T) and longitudinal (L) directions, and then average the BPN values from each position as the mean BPN of the cover.

### Referenced Thresholds

Many countries have state a minimum skid resistance value for road markings In Taiwan, the road markings must have more than 45 BPN under wet condition [11], and many countries have similar specifications for road markings [12-17]. As to manhole covers, Japan has the most completed specifications, in which skid resistance requirements and test methods are stated by several city governments [18-21]. Most of them set the minimum skid resistance of manhole covers at $DFT_{60}$ equal to 0.45. The value of skid resistance thresholds would become more convictive if it can be related to accident rates, but currently there is no enough related information available in Taiwan. Therefore, following the specifications of other countries, this study uses wet BPN equal to 45 and $DFT_{60}$ equal to 0.45 as the referenced thresholds of skid resistance values. Related issues that how skid resistance effects traffic accident occurrence is a potential topic in the future.




(b) Swing Directions and Positions of BPT on Manhole Covers
**Fig. 6.** Test Positions on Manhole Covers.

## Survey Results

### Skid Resistance of In-Used and New Casting Covers

Fig. 7 shows the survey result of the manhole covers, pavements and road markings. The figure is divided into four quadrant by $DFT_{60}$ = 0.45 and wet BPN = 45. The samples locate in quadrant I satisfy the requirement on both indices, the ones locate in quadrant II and quadrant IV satisfy only one of the two indices, and the ones locate in quadrant III are failed to satisfy both indices. According to Fig. 7, most of in used manhole covers surveyed in this project are located at quadrant III, namely most of in used manhole covers do not have good enough skid resistance. On the other hand, most of the new castings satisfy the two indices, having skid resistance values higher than the ones of pavements, only few of new castings locate in quadrant II and quadrant IV.

The accumulation curves of all manhole covers' $DFT_{60}$ and BPN are shown in Fig. 8. The distributions of the skid resistance of the in-used covers and that of the new casting covers are similar; however, the new casting ones have much greater skid resistance than those in-used ones. Only about 10% of in-used covers meet the

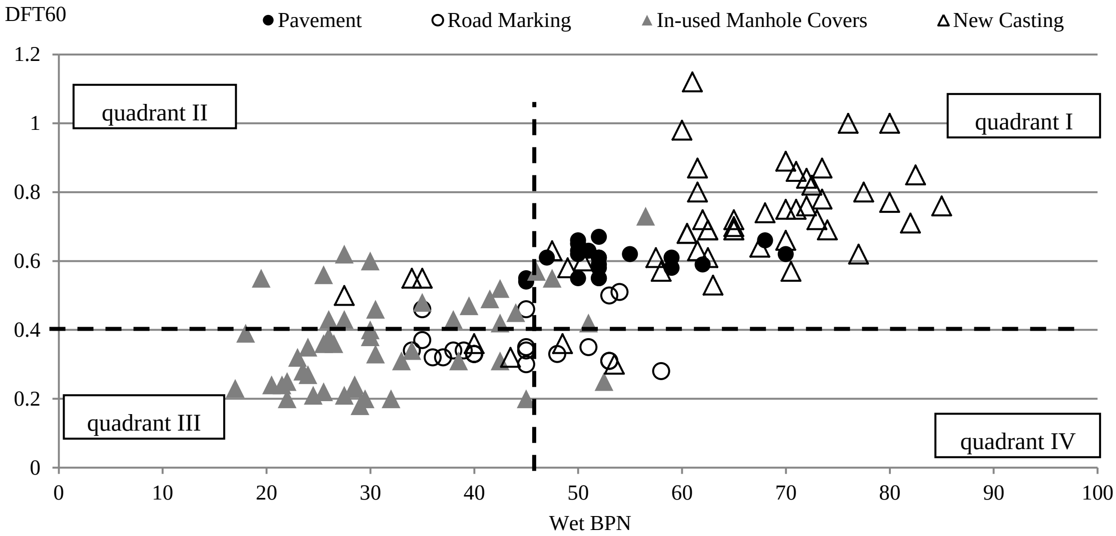



**Fig. 7.** Skid Resistances of Manhole Covers, Pavements and Road Markings.

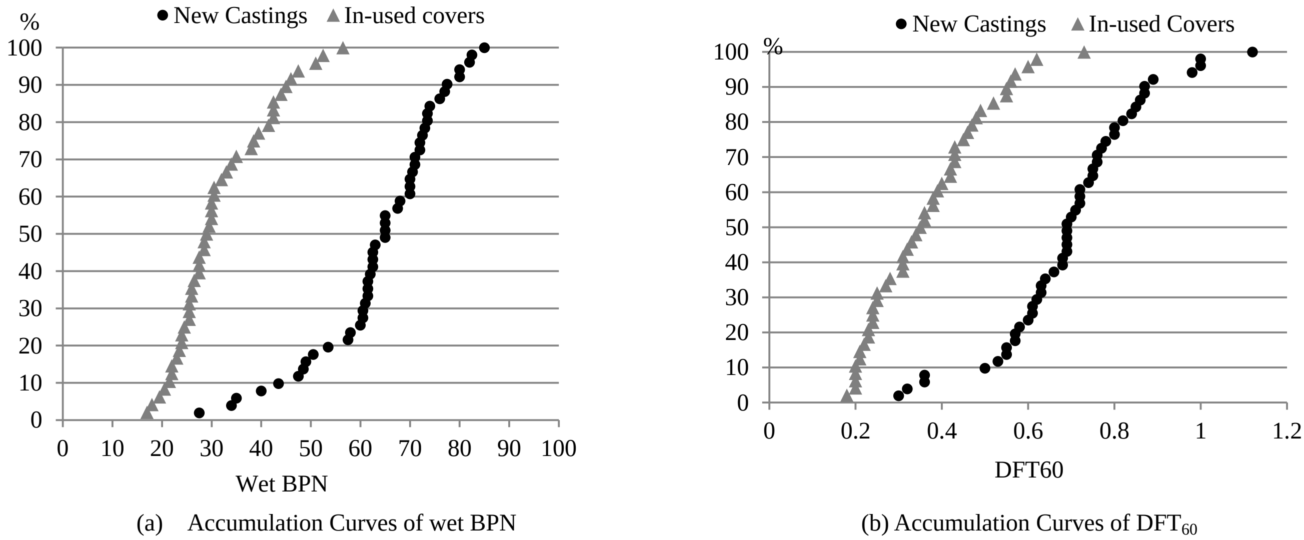



**Fig. 8.** Accumulation Curves of the Skid Resistance of Manhole Covers.

standard of wet BPN equal to 45, and 25% of them have $DFT_{60}$ over 0.45. It is clear that most of in-used covers may need to be improved.

Such low skid resistance of in-used covers might because of their overly worn textures. Some agencies of manhole covers claimed that they do not changes the old covers by new ones unless the old covers are distorted or broken. Therefore, many covers have been installed on the road for more than 15 years, even more than 20 or 30 years. Since most of the new castings can easily meet the standards of both indices, replacing the old covers with new castings seems the simplest way to rectify this situation.

## Effects on Texture Designs

The texture, which functions as drainage, is the most important characteristic for manhole covers. To further understand the effects caused by the textures and find out ways to improve the covers' performance, skid resistance values of five types of texture commonly used in Taiwan were surveyed. Fig. 9 shows the pictures of the fives textures and the skid resistance values of them. All the tested samples here are new casting. The texture design indeed affects the skid resistance. Out of the five texture designs, Texture B seems to have the best performance, and then are Texture C, Texture A, Texture E, and the last one is Texture D. Although the sample size of each type of textures is small, it still can be told that a texture design with open gaps, namely good potential on drainage, may perform better on skid resistance. On the other hand, the closed-form texture, for example, Texture D, is not that good comparing with the other textures. This is because the open-form texture design avoids water or mud accumulation on the surface of covers. Some studies that tried to find out texture design with high skid resistance [3, 4] and Japanese specifications [19] all suggests that the textures should have open gaps from any directions. Also, previous researchers [3, 4] designed new high-skid-resistant covers and those newly designed covers with open gaps from all directions indeed got better performance than other texture designs.

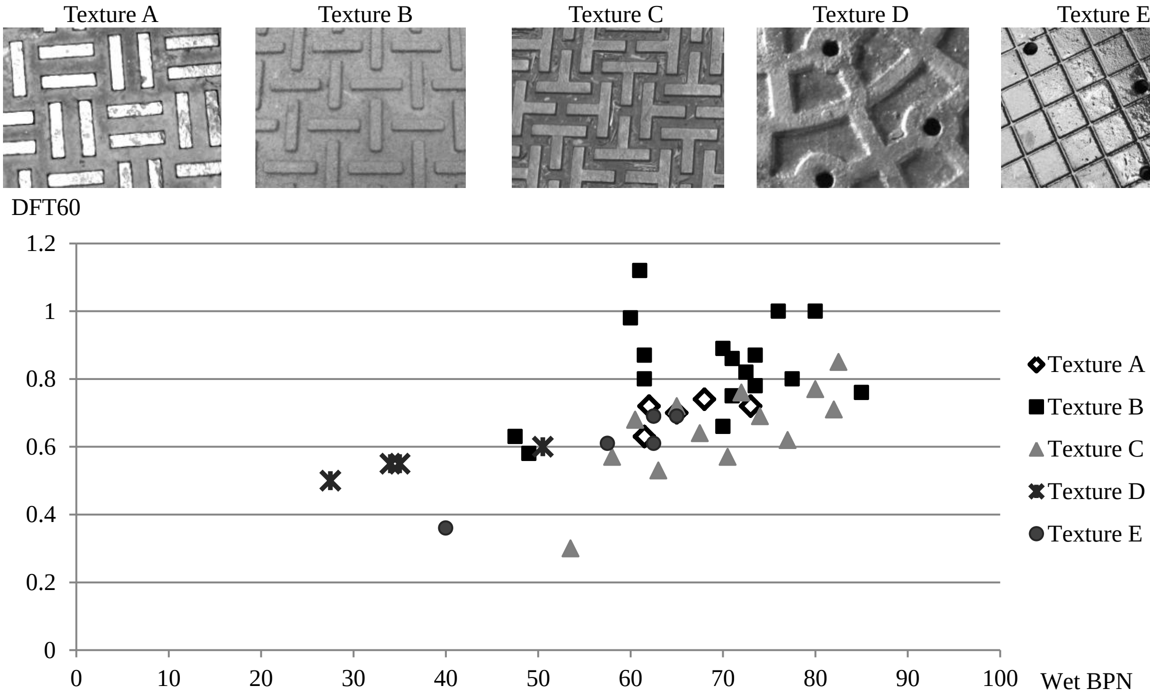



**Fig. 9.** Skid Resistance of Manhole Covers with Five Common Textures of Manhole Covers in Taiwan.

## Effects on Texture Depths

The key point to secure good skid resistance of manhole covers is to keep its function of drainage. It is important to make sure that the textures on the covers not being too wearing after installed on the road for over long periods. Basically, for a single type of texture design, it is likely that the deeper texture, the better drainage, and then the skid resistance values can be obtained. This study measured the mean texture depth of seven covers with Texture B, which is one of the most widely used textures in Taiwan, and found out the relationship between the mean texture depth and skid resistance by regression. The seven samples were randomly selected on the road, and the range of their mean texture depth is from 0.5 mm to 3.1 mm. Fig. 10 shows the result. Although there is no significant correlation between the wet BPN and the mean texture depth, it is obviously that the larger mean texture depth, the greater $DFT_{60}$ it is. This is because BPT mainly reflects the micro-texture condition of test surfaces, but the function of drainage is provided by the macro-texture of the surface, so the $DFT_{60}$ correlates with the mean texture depth better.

Macro-texture plays an important role to the $DFT_V$ because the macro-texture drains and avoids water accumulation on the test surface. During the survey, many manhole covers on the road were found that their textures were polluted by road marking paint or asphalt concrete. These in-used covers all performed poor skid resistance in both wet BPN and $DFT_{60}$ because their textures have lost the ability of drainage. This kind of situation should be avoided for locations where high skid resistance is needed.

## Conclusions

The aim of the survey is to understand the generally situation of skid resistance of manhole covers, and also prepared the necessary information for the further statement of skid resistance regulation. Several types of skid resistance testers were used to figure out the friction characteristic of manhole covers. The findings are listed below:

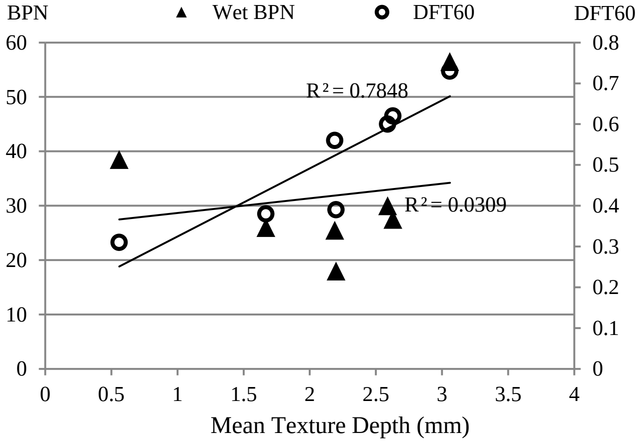



**Fig. 10.** Skid Resistance and Mean Texture Depth of Texture B.

1. From an overall approach, manhole covers do not have significant negative effects to the road comparing with road marking. This is because the size of manhole covers is relatively small comparing with the road markings. However, the skid resistance of manhole covers still needs to be monitored for wet weather safety.
2. Portable skid resistance testers, like BPT and DFT, are more suitable for surveying the manhole covers. Since the values obtained by the two testers cannot be transformed directly to each other, it is important to set two separate standards for each tester.

3. "$DFT_{60}$ = 0.45" and "wet BPN = 45" were selected as the referenced thresholds in this study. Most of in-used manhole covers do not have high enough skid resistance and need to be improved, because most of them have been used for overly long period and already too worn. On the other hand, most of new castings satisfy both of the thresholds. The manhole covers without high enough skid resistance should be replaced by new castings to secure a safer driving environment.
4. As to the effects on textures, the covers with open-gap textures apparently has better skid resistance than the one with closed-from texture; and the larger mean texture depth also leads to better skid resistance. It is important to maintain the function of drainage of the texture on manhole covers.

## Acknowledgements

This paper is based on the findings of a research project supported by the Materials Testing Laboratory, Directorate General of Highways, MOTC (project number: 99-01). Authors would like to give their appreciation to who contribute their knowledge and support this project.

## References

1. Gendy, A.E. and Shalaby, E. (2007). Mean Profile Depth of Pavement Surface Macrotexture Using Photometric Stereo Techniques, *Journal of Transportation Engineering*, 133(7), pp. 433-440.
2. Fwa, T.F., Choo, Y.S., and Liu, Y. (2003). Effective of aggregate spacing on skid resistance of asphalt pavement, *Journal of Transportation Engineering*, 129(4), pp. 420-426.
3. Marubayashi, R., Shibata, S., and Fujikawa, T. (2008). The Surface Shape which Affects the Slip Resistance of the Manhole Cover for the Walkway, Report No. 32, Mie Prefecture Industrial Research Institute.
4. Huang, C.-K. (2010). Evaluation of Skid Resistance of Pattern Design for Manhole Cover, Master Thesis, National Taiwan University, Taipei, Taiwan (in Chinese).
5. P&E Consultant Pte. Ltd. (1997). GripTester Operation & Survey Processing Manual.
6. ASTM E303 (2008). Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester.
7. ASTM E1911 (2002). Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester.
8. ASTM E965 (1996). Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique.
9. New Zealand Transportation Agency, TNZ T3 (1981). Standard Test Procedure for Measurement of Texture by the Sand Circle Method.
10. UKPMS (2005). Manual 03 11, the UKPMS User Manual, Volume 3: Machine Data Collection for UKPMS, Chapter 11: GripTester.
11. MOTC (2009). Traffic Engineering Manual, Ministry of Transportation and Communications, Taipei, Taiwan.
12. UKDOT (2007). TD 26-07: Inspection and Maintenance of Road Markings and Road Studs on Motorways and All-Purpose Trunk Roads, Design Manual for Road and Bridges. Vol. 8, Sec. 2, Chapter 2: Road Markings. Department for Transportation, UK.
13. New Zealand Transportation Agency (2009). TNZA M 07: Specification for Roadmarking Paints.
14. Oklahoma Department of Transportation (2009). Specification book, Oklahoma City, OK, USA.
15. Georgia Department of Transportation (2010). Supplemental Specification Section 657: Preformed Plastic Pavement Markings, Atlanta, GA, USA.
16. Alabama Department of Transportation (2009). Acceptance Program for Traffic Marking Materials, ALDOT-420-05, Birmingham, AB, USA.
17. Harlow, A. (2005). Skid Resistance and Pavement Marking Materials, Surface Friction International Conference. Christchurch, New Zealand.
18. Hitoyoshi City (2007). Specifications for manhole covers. Kumamoto, Japan.
19. Izumi City (2008). Specifications for manhole covers. Kagoshima Prefectural, Japan.
20. Kawachinagano City (2009). Specifications for manhole covers. Osaka, Japan.
21. Yamanashi Prefectural Planning Department (2009). Specifications for manhole covers, Yamanashi Prefecture, Japan.