Skid Resistance of Manhole Covers: Current Situation in Taiwan

Chia-pei CHOU  
Professor  
Department of Civil Engineering  
National Taiwan University  
No.1, Sec.4, Roosevelt Rd., Taipei, 10617 Taiwan  
Fax: +886-2-23639990  
E-mail: cpchou@ntu.edu.tw

Ning LEE  
Ph.D. Candidate  
Department of Civil Engineering  
National Taiwan University  
No.1, Sec.4, Roosevelt Rd., Taipei, 10617 Taiwan  
Fax: +886-2-23639990  
E-mail: f95521512@ntu.edu.tw

Abstract: Although there are so many manhole covers, which cause skid risk to two-wheel vehicles under wet weather condition, installed on the road, so far there is no related specification in Taiwan. The Ministry of Transportation and Communication (MOTC) created a research project in cooperate with National Taiwan University, to provide necessary information before setting a skid resistance requirement for iron-casted manhole covers. This paper introduces the survey and analysis done in the project, and the result shows that most of covers in use do not have good enough skid resistance. This could be attributable to that most of covers have been installed too long, so their texture is too wearing to maintain its function. Nevertheless, since the new-casted covers all performed good skid resistance in the survey, the current situation can be rectified by replacing used covers with new ones.

Key Words: Iron-casted Manhole covers, Friction, Skid Resistance, Texture

1. INTRODUCTION

The progresses of Asian cities and Western cities are very different. Asian cities, especially some Southeast Asian cities, often have much more manhole covers set on roads and also more two-wheel vehicle usage. In the capital city of Taiwan, Taipei, approximate 100 thousands of iron-casted covers are densely installed per km square. If the iron castings do not provide good enough skid resistance, such large number of covers will potentially cause danger under wet weather conditions. Although iron-casted covers have only slight effect to four-wheel vehicles, it increases the risk of skid of two-wheel vehicles because the contact area between tires of two-wheel vehicles and the road surface is smaller than the one of four-wheel vehicles. Passing a manhole cover can be even more dangerous to a two-wheel vehicle when it is making turns, because during the process of changing directions, it is harder to keep balance than when moving straightly forward. According to statistic, there are 14 million scooters and motorcycles in Taiwan at the end of 2010, taking 2/3 part of all motorized vehicles. Also, many skid related accidents and incidents occur under wet weathers frequently. To secure two-wheel vehicles a safe driving environment, it is necessary 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 spite of the importance of the skid resistance issue, including Taiwan, 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. To help the safety of two-wheel vehicles, the road authority of Taiwan, Ministry of Transportation and Communication (MOTC), planning to set a reasonable and practicable skid resistance regulation. Cooperating with National Taiwan University, a research project,
which related to the skid resistance of manhole covers, was done. The primal aim of this project is to provide necessary information for the future enforcement of friction regulation. Skid resistance data of several types of iron-casted covers was surveyed, and some specifications of other countries and references related to manhole covers, road skid resistance, and friction testing were studied. This paper introduces the survey and analysis done in the project, including the data collected by four different types of testing, discussions about the effect to the road caused by manhole covers, and the right approaches to make the road safer for two-wheel vehicles.

2. SURVEY EQUIPMENTS AND METHODS

The objective of the survey is to find out which tester is better for expressing the skid resistance of manhole covers and if the currently in-used manhole covers can satisfy the requirement once a specific standard of skid resistance value has been set. This chapter introduces the essence of skid resistance and the survey equipments used in the project.

2.1 Skid Resistance

Skid resistance, the ability to prevent vehicles from hydroplaning, comes from a complex mechanism among the road surface, the tires, and the environment. It is closely related but not completely equal to the friction coefficient between the tire rubber and the pavement, because the skid resistance of a surface is a synthesis of the friction coefficient and all the other exterior factors, such as the texture of pavement, the characteristics of tires, and the thickness of water film on the road. Generally, a rough road surface often provides higher friction and better skid resistance to the vehicles running on it. Therefore, some methods that define skid resistance of the test surface by measuring its mean texture depth have been developed.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Wavelength</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-texture</td>
<td>&lt; 0.5 mm</td>
<td>1 μm - 500 μm</td>
</tr>
<tr>
<td>Micro-texture</td>
<td>0.5 mm ~ 50 mm</td>
<td>0.1 mm - 20 mm</td>
</tr>
<tr>
<td>Mega-texture</td>
<td>50 mm ~ 500 mm</td>
<td>0.1 mm - 50 mm</td>
</tr>
<tr>
<td>Unevenness</td>
<td>&gt; 500 mm</td>
<td>no specific range</td>
</tr>
</tbody>
</table>

International Standardization Organization (ISO) classifies texture as four classifications, micro-texture, macro-texture, mega-texture, and unevenness, according to its wavelength and amplitude, as listed in Table 1 (ISO, 2004). Two out of the four types of texture affect the skid resistance. The micro-texture controls the friction between the tires and the road surface when the running speed is low; on the other hand, the macro-texture, mainly provide skid resistances by distort the tire rubber and drain out the water film during wet weathers (Stroup-Gardiner et al., 2001). Varied skid resistance testers measure the skid resistance value in different ways, and during the measurement, the degrees that each tester reflects the effects of micro-texture and macro-texture are also varied. Each skid resistance tester obtains friction values in completely different systems, and so far there are no reliable correlation equations to transform one system to another. Accordingly, if a skid resistance value has set as the minimum requirement of manhole covers, it is also needed to define which equipment should be used. In the project, three different skid resistance testers were used to measure the skid resistance values of manhole covers, pavements and road markings, and the sand patch method is also used to evaluate the mean texture depth of the covers.
2.2 GripTester

The first equipment is a continuous skid resistance tester, GripTester (Figure 1). Being towed behind a van, the GripTester can be used for long-distance survey in normal driving speed, usually 50 km/hr on roads and 65 km/hr on airport runways. The measuring tire of GripTester is a smooth tire. When the survey is carried out, the slip ratio 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), and 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 (P&E Consultant Pte. Ltd., 1997). Because of its features mentioned above, GripTester is a good skid resistance tester which can simulate the friction that a vehicle experience when driving on the test section. Additionally, because of the smooth tire used and the water film provided during the survey, more conservative values can be obtained. 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. 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. The project 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. The survey result will be discussed in Chapter 3.

![Figure 1 GripTester](image)

2.3 British Pendulum Tester and Dynamic Friction Tester

The next tester is the British Pendulum Tester (BPT). This pendulum-type skid resistance tester was 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. As shown in Figure 2, there is a rubber slider installed in the end of the pendulum. After properly adjustment, the rubber slider contacts the surface when the pendulum swinging freely. A drag pointer, which is pushed by the pendulum, indicates the British Pendulum Number (BPN) after the swing. 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 (2008), 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.

Figure 2 British Pendulum Tester (BPT)

The Dynamic Friction Tester (DFT) is another type of portable skid resistance tester. It 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. As shown in Figure 3, there are three small rubber sliders attached on the disk in the bottom of the main body. It spins the disk parallel to the test surface to measure the skid resistance. While doing the measurement, the disk first is lifted up and also accelerated to specific tangential velocity, and then put down to contact the test surface. A water film about 1 mm thick is maintained during the measurement. Because of the friction between the rubber sliders and the test surface, the rotation speed decreases gradually until stop. The torque signal is monitored during the spin and transformed to friction coefficients along the change of tangential velocity, and then a curve of friction-speed relationship can be plotted. The skid resistance value under specific slip speed, \( DFT_V \) (\( V \) is the slip speed, km/hr), can be read from the curve. 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. Since the tangential speed of the rubber sliders is often high, macro-texture plays an important role to the \( DFT_V \) because the macro-texture drains and avoids water accumulation on the test surface. When the slip speed is high, the ability of drainage affects the skid resistance the most. ASTM also has standard operation method of the DFT published. According to ASTM E1911 (2002), the friction value obtained by DFT is not directly correlated with the skid resistance value obtained by other equipments.

Figure 3 Dynamic Friction Tester (DFT)

BPT and DFT are both fix-pointed skid resistance testers and often used to test the skid resistance of road markings and manhole covers, where do not have large enough area for other skid resistance testers. However, as mentioned above, the mechanisms of them are
totally different. Therefore, values obtained by the two testers cannot be transformed from one to another because of their variances on size of the rubber sliders and slip speeds (Gendy and Shalaby, 2007). The survey and analysis on manhole covers using BPT and DFT will be discussed in Chapter 4.

2.4 NTU Improved Sand Patch Method

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 (Fwa et al., 2003; Marubayashi et al., 2008; Huang, 2010). In other words, 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. 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.

ASTM E 965 and some other specifications (ASTM, 1996; New Zealand Transportation Agency, 1981) 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 conventional method in ASTM E 965 is designed for pavements rather than manhole covers. Because 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. To solve this problem, the conventional sand patch method has been slightly changed in this project as the “NTU improved sand patch method.” In Figure 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. Calculate the amount of sand that used to fill the gaps up and the sum of area of all gaps, then the mean depth of the texture within the 10cm* 20 cm area can be estimated.

![Figure 4 Appling NTU improved sand patch method on a iron-casted cover](image)

3. 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. From Section 1 to Section 8 are urban streets, and from Section 9 to Section 20 are rural highways. As mentioned before, one GN data can be obtained in a 10-meter-long subsection. 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 2 is the GN values
obtained from the twenty sections of roads. According to the UKPMS user manual (UKPMS, 2005), 0.53 GN was selected as the reference to decide whether the GN in a subsection is high enough or not. In Table 2, the GN of urban streets are about 0.60~0.72, and the ones of rural highways are about 0.55~0.78. There is no significant difference between the two types of roads.

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. For example, Figure 5 shows the GN along Section 7. Within a 400-meter-long interval, the GripTester passed 8 manhole covers. It can be seen that the GN shook in the interval, but it never dropped to values that lower than 0.60. The other half of Section 7 does not have any manhole covers installed on the test trail of the GripTester. In this part of curve, the subsection with road markings can be easily recognized, and all GN values of those subsections dropped below 0.60.

To further clarify the effects on skid resistance caused by manhole covers and 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. Table 3 listed the comparison. 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. In other words, the manhole covers do not reduce the GN of the subsections as much as the road markings.

### Table 2 GripTester survey results of the twenty test sections

<table>
<thead>
<tr>
<th>No.</th>
<th>Urban Street</th>
<th>Rural Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GN</td>
<td>% of GN lower than 0.53</td>
</tr>
<tr>
<td>1</td>
<td>0.6266</td>
<td>640</td>
</tr>
<tr>
<td>2</td>
<td>0.6807</td>
<td>640</td>
</tr>
<tr>
<td>3</td>
<td>0.7203</td>
<td>570</td>
</tr>
<tr>
<td>4</td>
<td>0.7074</td>
<td>720</td>
</tr>
<tr>
<td>5</td>
<td>0.5957</td>
<td>460</td>
</tr>
<tr>
<td>6</td>
<td>0.6087</td>
<td>160</td>
</tr>
<tr>
<td>7</td>
<td>0.6703</td>
<td>900</td>
</tr>
<tr>
<td>8</td>
<td>0.6468</td>
<td>280</td>
</tr>
<tr>
<td>9</td>
<td>0.624</td>
<td>670</td>
</tr>
<tr>
<td>10</td>
<td>0.6657</td>
<td>610</td>
</tr>
<tr>
<td>11</td>
<td>0.6936</td>
<td>710</td>
</tr>
<tr>
<td>12</td>
<td>0.7886</td>
<td>500</td>
</tr>
<tr>
<td>13</td>
<td>0.761</td>
<td>420</td>
</tr>
<tr>
<td>14</td>
<td>0.7813</td>
<td>420</td>
</tr>
<tr>
<td>15</td>
<td>0.7552</td>
<td>480</td>
</tr>
<tr>
<td>16</td>
<td>0.4949</td>
<td>660</td>
</tr>
<tr>
<td>17</td>
<td>0.5501</td>
<td>930</td>
</tr>
<tr>
<td>18</td>
<td>0.6675</td>
<td>710</td>
</tr>
<tr>
<td>19</td>
<td>0.6737</td>
<td>840</td>
</tr>
<tr>
<td>20</td>
<td>0.6505</td>
<td>800</td>
</tr>
</tbody>
</table>

Note: Section 7, Section 13, and Section 14 have more manhole covers installed.
Figure 5 GN along Section 7 (subsection length: 10 meter)

But does this also mean that manhole covers do not cause negative impact as much as road markings? Figure 6 shows the relationship between the GN values of subsections with manhole covers or road markings and the subsections closest to them. From the regression result, it can be seen that the GN of subsections with manhole covers have a higher correlation with the pavement close to them, but for those subsections with road markings, it seems their GN value do not related to the nearby pavements. This is because the length of manhole covers is much shorter than the length of subsections, and the GN of a subsection in fact an average value of 10-meter-long interval, the real low GN of the manhole cover would be omitted. On the other hand, the road markings are relatively longer than the manhole covers and take larger parts in the subsection, so it controls the GN of the subsection rather than the original pavement. This is why the $R^2$ of the regression between the subsections with covers and the pavement (0.7658) is higher than the $R^2$ between the subsections with road markings and the pavement (0.3865).

Table 3 Effects caused by manhole covers and road markings

<table>
<thead>
<tr>
<th></th>
<th>GN values of subsections with manhole covers or road markings</th>
<th>GN Reduction due to manhole covers or road markings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Std.</td>
</tr>
<tr>
<td>Road Markings</td>
<td>0.4962</td>
<td>0.0951</td>
</tr>
<tr>
<td>Manhole covers</td>
<td>0.6469</td>
<td>0.0599</td>
</tr>
</tbody>
</table>

Figure 6 GN values with and without manhole covers or 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 changes the skid resistance in 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.

4. SKID RESISTANCE ANALYSIS OF MANHOLE COVERS

4.1 Test positions and Indices

To figure out the skid resistance of single covers under different conditions, the project randomly selected in-used manhole covers with varied texture design on urban streets and also some new covers from manufacture factories. All the manhole 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 curve. Because the dangerous toward two-wheel vehicles is likely caused by the changes of skid resistance between different surfaces, the pavement, road markings, and manhole covers should have close skid resistance. Therefore, the project also tested some samples of pavements and road markings, and then compared them with the data of manhole covers.

Before doing the analysis, the tested position on a manhole cover and the indices used to analysis should be decided first. 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. The rotated paths of the rubber sliders are shown in Figure 7. As for the BPT test, because the contact area of rubber slider and the test surface is small, and the direction of swing may also affects the BPN obtained, it is necessary to select contact positions properly. When surveying on pavements or road markings, the direction of swing can be simply parallel with the traffic. However, before a manhole cover being installed on the road, it is impossible to know which direction on it will be parallel with the traffic. Even for those already installed on the road, the two-wheel vehicles would not always pass it from the same direction.

To solve the problem, the swing directions are first defined according to the direction of word marking on the covers. Almost all covers have a logo on it to mark its function. Therefore, the definition of the swing directions can be set as shown in Figure 8. The survey obtained the BPN from both transverse (T) and longitudinal (L) directions, and then the two BPN values were compared in pair to check if there are any relationships between them.

According to the regression result, the BPN values of the two directions are highly correlated ($R^2 > 0.9$) with each other. Also, not always the values of one direction are greater than the ones of another direction. Because no matter which direction is surveyed, the covers with greater overall skid resistance are likely to have larger BPN obtained, this project tested the BPN values from both directions, and then average the BPN values from each position as the mean BPN of the cover. Ninety-nine manhole covers were surveyed in this project by both BPT and DFT. Fifty-one of the ninety-nine covers surveyed were in used, and the other forty-eight covers were new casted.
Many countries do not state a minimum skid resistance value for pavement due to the possible dispute after traffic accidents; nevertheless, road markings have more clearly prescribed skid resistance requirements. The MOTC, Taiwan, requires all the road markings have more than 45 BPN under wet condition (MOTC, 2009). Besides Taiwan, many countries have similar specifications for road markings (UKDOT, 2007; New Zealand Transportation Agency, 2009; Oklahoma DOT, 2009; Alabama DOT, 2009; Harlow, 2005). As to manhole covers, Japan has the most completed specifications, in which skid resistance requirements and test methods are stated by several city governments (Hitoyoshi City, 2007; Izumi City, 2008; Kawachinagano City, 2009; Yamanashi Prefecture, 2009). Most of them set the minimum skid resistance of manhole covers at $DFT_{60}$ equal to 0.45. The analysis of skid resistance in this project use wet BPN equal to 45 and $DFT_{60}$ equal to 0.45 as the referenced thresholds of skid resistance values.

### 4.2 Skid Resistance of Manhole Covers in Taiwan

Figure 9 shows the survey result of the manhole covers, pavements and road markings. The figure is divided into four phases by $DFT_{60}$ equal to 0.45 and wet BPN equal to 45. The samples locate in Phase I satisfy the requirement on both indices, the ones locate in Phase II and Phase IV satisfy only one of the two indices, and the ones locate in Phase III are failed to satisfy both of the standards of $DFT_{60}$ and wet BPN. Unfortunately, according to the data shown in Figure 9, most of in used manhole covers surveyed in this project are located at Phase 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 Phase II and Phase IV.

The accumulation curves of all manhole covers’ $DFT_{60}$ and BPN are shown in Figure 10 and Figure 11. In both of the figures, the curves of the new castings and the in-used covers are generally parallel, which means the distribution of the skid resistance of new castings and in-used covers are similar. However, the former ones have much greater skid resistance than the later ones. About 90% of in-used covers do not meet the standard of wet BPN equal to 45, and
also only 25% of them have DFT$_{60}$ over 0.45. It is clear that most of in-used covers may need to be improved. 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. To find out the reason why the in-used covers performed such low skid resistance, some agencies of manhole covers were interviewed. All of them claimed that they do not change the old covers by new ones unless the old covers are distorted or broken. Many covers have been installed on the road for more than 15 years, even more than 20 or 30 years. Thus, such low skid resistance of in-used covers might because of their overly worn textures.

![Skid Resists of Manhole Covers, Pavements and Road Markings](image)

**Figure 9** Skid Resistances of Manhole Covers, Pavements and Road Markings

![Accumulation curves of wet BPN and DFT$_{60}$](image)

**Figure 10** Accumulation curves of wet BPN

**Figure 11** Accumulation curves of DFT$_{60}$

### 4.3 Effects on Skid Resistance Caused by Textures

Generally, the thicker water film on the test surface, the lower skid resistance will be observed. Therefore, 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. Figure 12 are the pictures of the fives textures, and Figure 13 are the skid resistance values of them, from which the difference of the textures can be easily observed. All the tested samples in Figure 13 are new castings.
In Figure 13, the wet BPN and DFT\textsubscript{60} of the covers correlated to each other roughly, and the \( R^2 \) values of their regressions are from 0.10 to 0.95. The \( R^2 \) values for Texture A to Texture E in sequence are 0.32, 0.10, 0.49, 0.92, and 0.95. Some of them are high, which means there are closer relationships between the two kinds of skid resistance indices, but some of them are low, which means its wet BPN and DFT\textsubscript{60} do not correlate with each other that much. Since the five curves in Figure 13 all have different slopes and \( R^2 \) values, it is hard to build an equation to transform one of the two skid resistance values to another. Standards of skid resistance should be stated independently for each kind of skid resistance tester used.

Also, the result shown in Figure 10 indicates that 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 (Marubayashi, 2008; Huang, 2010) and Japanese specifications (Izumi City, 2008) all suggests that the textures should have open gaps from any directions. Both of Marubayashi (2008) and Huang (2010) 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.

Another 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. To confirm the statement, this project measured the mean texture depth of seven Texture B covers, which is one of the most widely used textures in Taiwan, and tried to find out the relationship between the mean texture depth and skid resistance. 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. In Figure 14, 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. As mentioned in Chapter 2, BPT mainly reflects the micro-texture condition of test surfaces, but the function of drainage is provided by the macro-texture of the surface. For a specific type of manhole cover, all samples may have similar microtextures, but different macro-textures due to the degree of worn, so the fact that only DFT$_{60}$ correlates with the mean texture depth can be explained. It also explains why there is higher percentage of in-used covers meet the threshold of DFT$_{60}$ than the one of wet BPT. The reason is that the approach that used to design the texture of manhole cover is primarily focus on the need of high-speed vehicles rather than relatively low-speed pedestrians.

![Figure 14 Skid resistance and mean texture depth of Texture B](image)

During the survey, many manhole covers on the road were found that their textures were polluted by road marking paint or asphalt concrete (Figure 15). 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.

![Figure 15 Manhole covers which are polluted by asphalt concrete or road marking paint](image)
5. SUMMARY AND CONCLUSIONS

In this project of manhole covers, several types of skid resistance testers, including GripTester, BPT and DFT were used to figure out the friction characteristic of manhole covers in Taiwan. 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.

According to the result of GripTester survey, manhole covers do not have significant negative effects to the road. This is because the GN obtained in each subsection is an average of the entire 10-meter-long interval. However, the skid resistance of manhole covers still needs to be monitored since it is necessary to keep it consisting with pavements and road markings. 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, and choose the proper tester for different locations. For example, BPT is better for measurements on slow-speed areas like sidewalks, and DFT is better for lanes on where two-wheel vehicles run.

“DFT_{60} equal to 0.45” and “wet BPN equal to 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. Comparing the five types of texture of covers, the ones with open gaps apparently has better skid resistance than the one with closed-from texture, and the larger mean texture depth also leads to better skid resistance. Therefore, 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

Caltrans Division of Maintenance (2007) MTAG Volume II - Rigid Pavement


