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Pattern Design of Manhole Cover and Its Influence on Skid Resistance

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Abstract: The number of manholes appeared on urban streets has increased significantly in the last decade in Taiwan. Due to the material characteristic, manhole surface is rather slippery in the raining days if no good skid resistance design is provided. Based on the findings of the literature review, sample collection of the Taiwan existing manhole pattern, and skid tests on all collected manhole surfaces, this study created a series of experimental design of patterns and conducted the British Pendulum Tester and Dynamic Friction Tester tests on the specimens. The design factors of the pattern include bump spacing, bump area, bump shape, bump height, and the bump alignment. Dozens of specimens were designed, cast, and tested; and it was found that the manhole surface pattern with the following characteristics gives the best performance: spacing between bumps- 15 mm; shape and area of each bump- 15 mm x 15 mm square; minimum height of bump: 3mm; alignment of the bumps: chessboard. Full scale manhole covers were cast and tested. Manhole cover design with chessboard pattern indeed can provide a significant improvement in skid resistance, increases of 11.8% of BPT_{wet} value and 47% of DFT_{60} value, compared with the ones available in the market. Micro-texture and macro-texture are two major factors that affect skid resistance of a surface. On a road surface, micro-texture is a function of time (wearing). Testing only new manhole cover may not represent the long term effect of the new design.

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***Key words**: British pendulum tester; Dynamic friction tester; Nodular graphite cast-iron manhole cover; Skid resistance.*

Introduction

In the past decades, Taiwan government has completed 80% of the work to bury civil supply lines, including electric power, telecommunication, gas, and water, underground in the urban area. By doing so, not only the civil supplies can have longer service life but also the street scenery is improved. However, the number of manholes installed on the pavement surface has increased significantly. The major function of manholes is to provide access to the maintenance personnel for inspection or maintenance.

Due to the material characteristics, manhole cover surface is relatively slippery compared to pavement surface if no skid resistance design is provided. From traffic safety point of view, having a high skid resistance manhole cover is essential. This study mainly focused on the evaluation of skid resistance of the existing manhole cover pattern, and searched for an optimum pattern that offers the highest skid resistance. The major tasks include but not limited to the following four items.

(a) Review the related literatures of the manhole pattern design and evaluate the various design theories and its skid resistance. Most of the previous studies were done in British, Korea, Singapore, Japan, and Australia, and there is almost none of that can be found in Taiwan [1- 7].

(b) In this study, various patterns of manhole cover were designed and test specimens were cast in plaster in the laboratory. All designs were tested by British Pendulum Tester (BPT), and some of them were also tested by Dynamic Friction Tester (DFT). Analysis and comparison of the skid resistance results were conducted for the designed patterns.

(c) Select the most promising pattern(s) and cast the samples with various depths. The BPT was used to test the skid resistance of these samples to decide the required minimum depth of surface texture for maintaining the skid resistant function.

(d) Cast the final select pattern(s) with nodular graphite cast-iron materials and test the skid resistance by BPT and DFT. Compare the testing results of newly designed pattern(s) to that of the existed manhole covers, and present the findings.

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Literature Reviews

Previous studies regarding the manhole surface design were reviewed. Published papers addressed some research works done in British, Korea, Singapore, Japan, and Australia. However, only literatures published in Japan contain the materials of specification of manhole characteristics. Through the literature review, it is found that British Pendulum Tester (BPT) was the main instrument used to test the skid resistance of manhole surface, and British Pendulum Number (BPN) 45 was designated as the minimum threshold under the wet surface condition.

It was found that the Japanese manhole cover casting company provides a very special skid resistance design [5]. In this design, all the individual bumps are separated so the water can flow among them. In addition, the shapes of bump surfaces are designed with mix of triangle and square to provide the best skid resistance (Fig. 1). Furthermore, the edge of the cover has special outlets for water flowing away from the cover surface (Fig. 2). The company owns the patent.

Fwa et al. [6] evaluated the effectiveness of aggregate spacing on skid resistance of asphalt pavement. Although the analyzed target was asphalt pavement surface rather than manhole cover, the experimental design and analysis methodology provided valuable

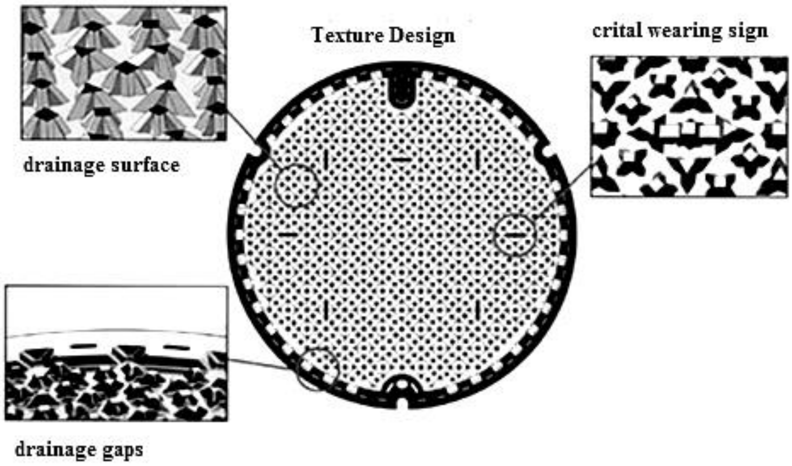


Fig. 1. The Design Concept of a Japanese Manhole Cover [5].

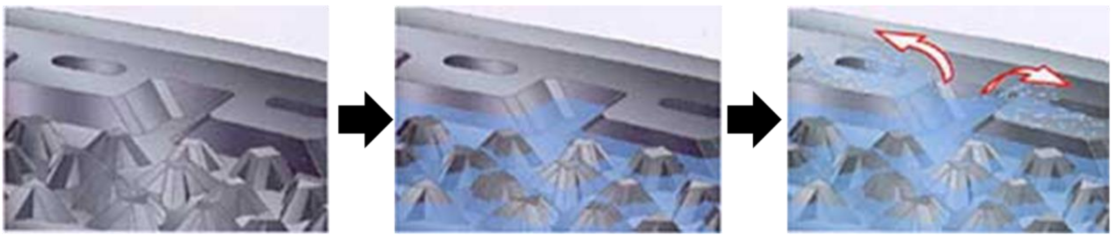


Fig. 2. The Water Flow Outlet of ASPS Design Manhole Cover [5].

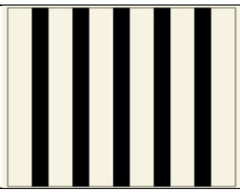
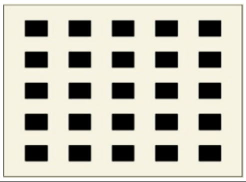
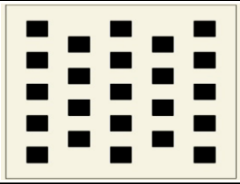
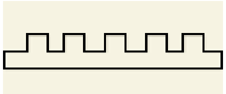
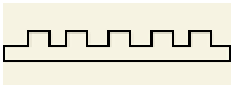
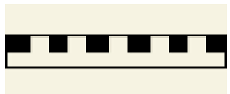
Pattern	A	B	C
Top View			
Cross view			
Description	• Strip width 15 mm • Spacing width varies from 3 mm to 15 mm	• Tsting contacted area fixed at 48.3cm^2 • Bump surface size from 5×5 mm2 to 25×25 mm^2	• Contacted area fixed at 15 cm^2 • Spacing width varies from 5mm to 25mm

Fig. 3. Samples Casted by Cement Mortar for Skid Resistance Testing. [6]

information for this study. Portland cement mortar was used to cast testing samples with various texture pattern, sizes, spacing, and layout as shown in Fig. 3. British Pendulum Tester was adopted in the research work for testing the BPN. It is found that contacted area, number of contacted surfaces, and spacing between contacted surfaces are main factors that affect the BPN. Data analysis reveals that the contacted area has a significant effect on the skid resistance value. Furthermore, if the contacted area is kept constant, the more gaps (spacing) within that area are, the higher the BPN value is.

Marubayashi et al. [7] had conducted a series of experiments to test the manhole cover skid resistance and safety. Testing samples were cast with resin materials of different bump sizes, spacing, and depth. In their study, most bump surfaces are square while a small portion are rectangular as shown in Fig. 4. Furthermore, some samples contained bumps in different depth, 2 mm and 3 mm, while most of others had uniform depth. The testing equipment used in this research work was also BPT. The major findings included the followings.

(a) The bump spacing has a very high influence on the measured BPN. A smaller spacing related to a higher BPN reading. When the spacing is 20 mm, it has the highest BPN value.
(b) The effect of total contacted area between sample and BPT is not significant on the BPN values.
(c) The height variation between the adjacent bumps gives better skid resistance.
(d) For sample with rectangular stripe surface, the BPT rubber slider sliding on the surface in perpendicular direction to the long edge of stripe has higher BPN value than that of the short edge.

Experimental Design, Skid Resistance Tests, and Results

Experimental design was conducted in this study to create the optimum pattern of manhole cover in terms of skid resistance. The factors of the experimental design include (1) the spacing of the stripes, (2) the top area of a bump, (3) the shape of bumps, (4) the height of bump, and (5) the alignment of bump. The British Pendulum Tester was used to test the skid resistance of specimens. The device's operational instruction was followed to perform the testing and each specimen was tested three times under the same condition. The average BPN was then calculated and presented hereinafter. All the BPN values shown in this paper are the average of the three duplications. It should be mentioned that the experiments were conducted step by step with the factors mentioned above. That is the specimens designed for any factor were cast and tested based upon the tested results of the specimens designed for the previous factor. The sequence of the design factors is listed from (1) to (5) shown above. Plaster was selected in this study as casting material due to its availability, efficiency, and economy. The various levels of each design factor are presented as following.

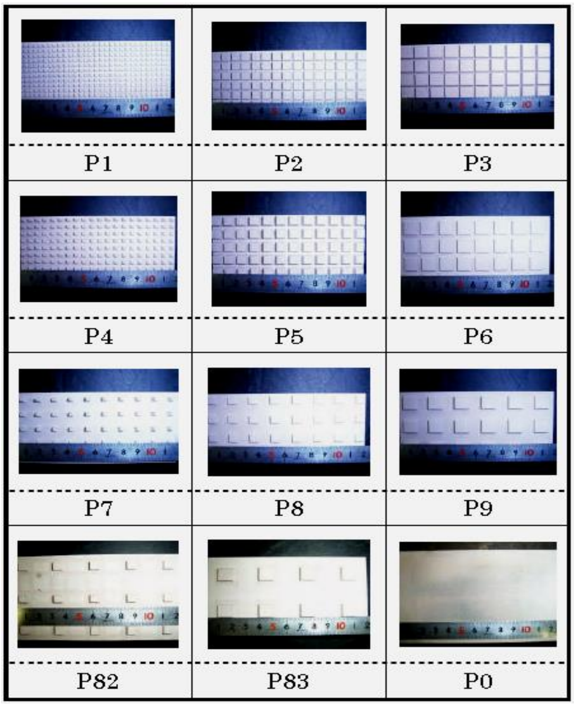


Fig. 4. Samples of Manhole Cover with Various Bump Sizes, Spacing, and Depth [7].

Spacing of the Stripes.

Design and Cast

The first step of experiment is to study the effect of stripe width and spacing. Two sets of six specimens with various spacing width were cast (Fig. 5). By using the stripe, the spacing factor can be controlled as a one dimensional variable. Six specimens with various stripe spacing, 3 mm, 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm, were cast for testing the influence of spacing on BPN. The width of stripes of the first set of 6 specimens is fixed at 25 mm, and a second set of six specimens were cast with stripe width of 15 mm. The reason of casting two sets of specimens with different stripe width is to evaluate (1) how the stripe width affects the BPN value and (2) if the two sets of specimens have similar tendency of BPN values along the variation of stripe spacing.

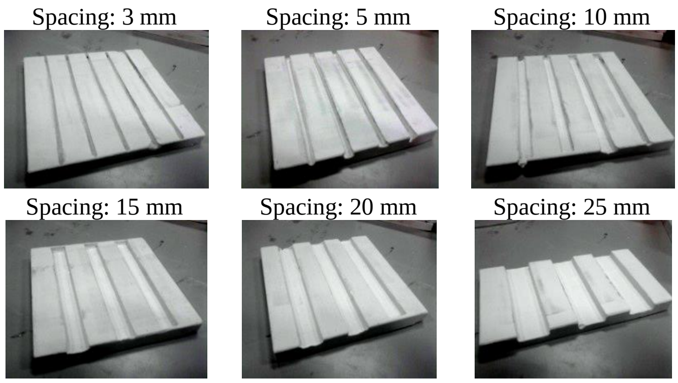


Fig. 5. Specimens with Various Levels of Stripe Spacing.

Test and Results

In this set of experiment, the BPT's rubber slider slid on the surface perpendicular to the stripe in order to evaluate how the stripe spacing affects the testing results. Although it is well understood that the wet skid is more important than dry skid, the majority tests conducted in the study were done under the dry condition. This is mainly because the plaster will absorb moisture when it is wetted, and consequently softens the specimens and the testing procedure may damage the bump. However, researchers indeed tested the first set of specimens in both wet and dry conditions to investigate the effect of these conditions It should be emphasized that the researchers are interested in the relative comparison rather than the absolute comparison of these tests. The comparison of BPN results of wet and dry test conditions of the first set of six specimens are presented in Fig. 6.

From Fig. 6, it is found that the BPN values increase as the size of stripe spacing increases from 3 mm to 15 mm. It reaches a peak when spacing is 15mm, and then drops quickly when the spacing increases from 15 mm to 25 mm. When the rubber slider slides on the specimen's surface, the contact action causes rubber to deform and compress. However, when it slides over the space between two stripes, the stress is released and transformed into energy and partial of that is thermal energy which will form the hysteresis. Therefore, the size of spacing will affect the amount of released energy which will consequently influence the skid resistance.

The second set of 6 specimens with stripe width of 15 mm was tested, and the results showed exactly the same tendency as Fig 6. It is concluded that stripe spacing of 15 mm can provide the maximum skid resistance under the testing condition.

The Top Area of Bump

Design and Cast

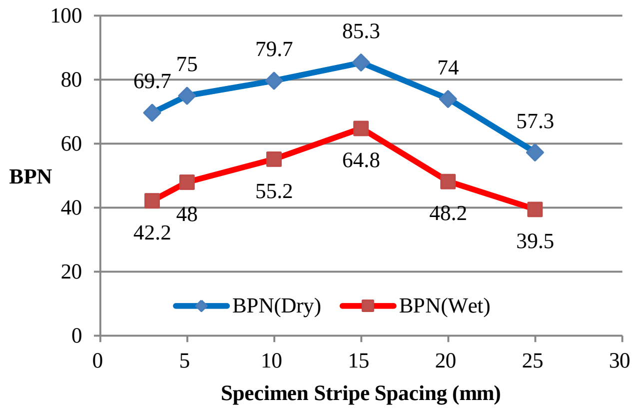


Fig. 6. The Effects of Specimens Stripe Spacing on BPN at Both Dry and Wet Conditions (Stripe Width: 25mm).

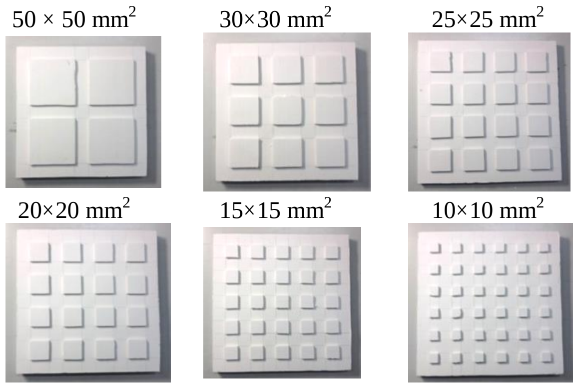


Fig. 7. The Specimens with Various Square Bump Sizes and Fixed Spacing of 15 mm.

The second step is to test specimens of different bump size. A set of six specimens were cast with different sizes of square bumps, namely, 10 mm, 15 mm, 20 mm, 25 mm, 30 mm, and 50 mm in width. From the previous step, it is known that the optimal spacing between stripes is 15 mm. Therefore, all the six specimens spacing is 15 mm. Fig. 7 illustrates the set of specimens.

Test and Results

In this test set, the total number of bump gaps (spaces) that each time the BPT rubber slider slides over the specimen surface has a significant effect on the BPN value. In general, the more the bump gaps that the slider contacts, the higher the BPN value is. This is due to the formation of hysteresis from the thermal energy release. From Fig. 8, it is clear to observe that the BPN values significantly increase when the square bump sizes decrease. The trends of both data sets of dry and wet conditions are very similar. Therefore, data obtained from dry testing condition shall be able to predict that of the wet testing condition. The average dry BPN value of specimen 50 mm x 50 mm square bump is 69.5 (35 in wet) and it reaches the highest value of BPN 90.5 (70 in wet) of specimen 15 mm x 15 mm square bump. The increase is almost 30 %. However, the BPN value drops dramatically to 75.5 (57.5 in wet) when the square bump size decreases to 10 mm x 10 mm. Test results indicated that BPN reached a peak when the square bump is 15 mm by 15 mm.

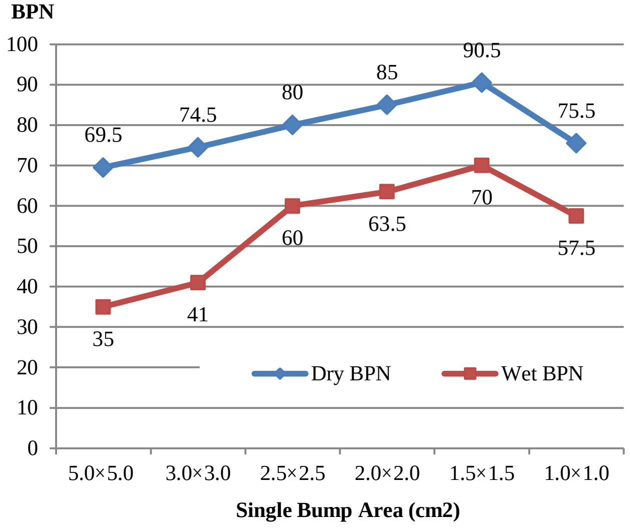


Fig. 8. The Effect of Square Bump Sizes on BPN at the Dry and Wet Conditions.

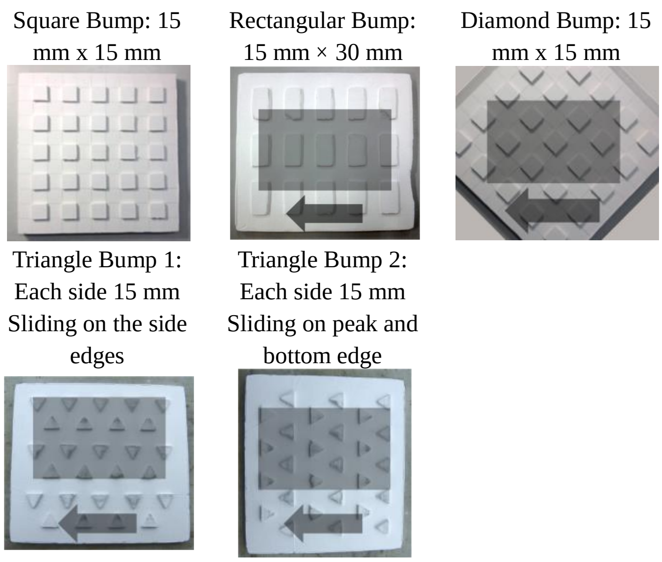


Fig. 9. Display of Specimens with Different Bump Shapes and Rubber Sliding Direction.

Shapes of the Raised Bumps

Design and Cast

The third factor that was adopted in the experimental design is the shapes of the raised bumps. Through the field survey, it was found that the existing manhole covers have several different bump shapes. It is indeed a very important factor that shall be taken into account for the optimal pattern design. Therefore, specimens with four types of bump shapes, namely square, rectangular, diamond, and triangle, were designed and cast in order to evaluated which shape may give the best skid resistance. Based upon the previous findings, the bump spacing was fixed at 15 mm for all the designs. Fig. 9 displays the four types of bump shapes, in which the triangle bumps specimen was tested twice with different sliding directions.

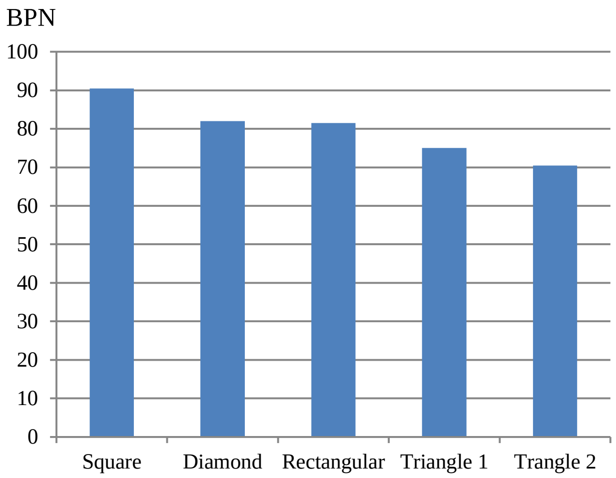


Fig. 10. The Comparison of BPN Values with Various Shapes of Bump.

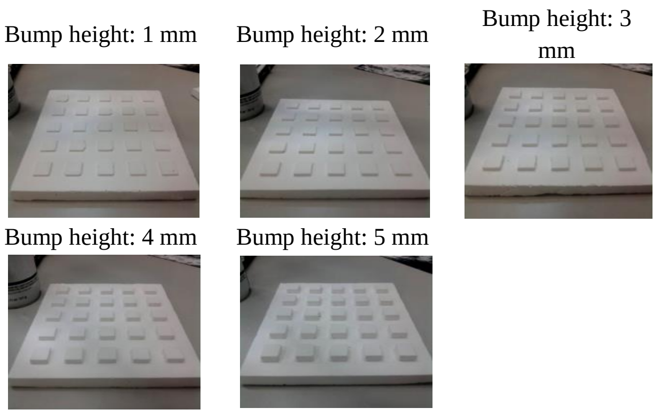


Fig. 11. Specimens with Various Heights of 15 mm x 15 mm Square Bumps.

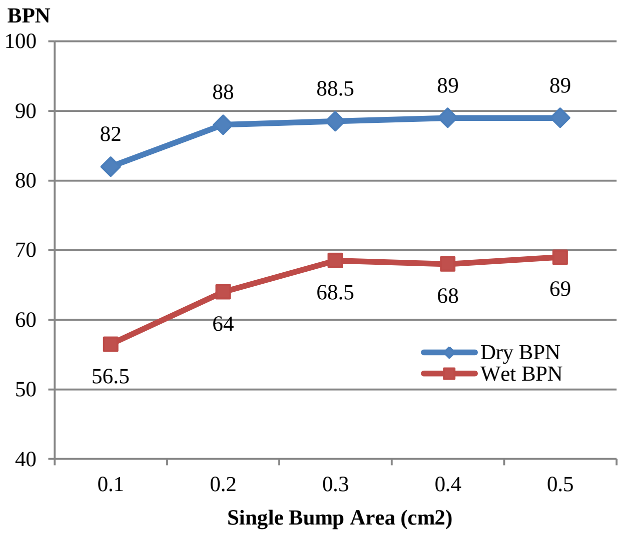


Fig. 12. The Relationship between BPN Values and the Bump Depth.

Test and Results

From Fig. 10, it is obvious that the square bump has the highest BPN value, although the diamond shape and rectangular shape are closely follow. No matter which the testing direction is, the BPN values of triangle bump are lower than 80. It is concluded that square bump is the optimal shape while compared to the other three shapes used in this study.

The Height of the Raised Bumps

Design and Cast

Specimens with 15 mm x 15 mm square bumps were designed and cast at five different heights. Fig. 11 displays the five specimens that have bump height from 1 mm to 5 mm. From the past studies, it has been noted that gaps between raised bump provide the ability of releasing compressive stress of rubber slider as well as a channel for water flow away from surface. In general, the deeper the gap is, the easier the water flows away; therefore, the BPN values are increased with the bump height.

Test and Results

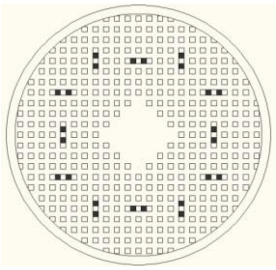
In order to understand how the height of bumps affects the specimens' skid resistance especially when the surface has running water, the BPT tests were conducted in dry as well as wet conditions. Fig. 12 shows the tested results. First of all, the tendencies of BPN values of both dry and wet conditions are the same. The specimen with bump depth of 1 mm has the lowest BPN values, 82 (dry) and 56.5 (wet). The BPN values increase with the bump depth. However, the increasing diminishes when the bump height is over 3 mm. The results show that the minimum bump height shall be at least 3 mm in order to obtain a good skid resistance capability. In addition, it is recommended that the newly cast manhole cover must have bump height of 5 mm for wearing. Further studies regarding the wearing resistance to traffic are very important and highly recommended.

New Designed Pattern for Manhole Cover and Test Results

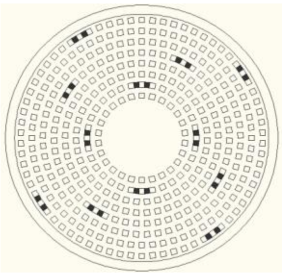
Test results from this study showed that stripe spacing, bump size, bump shape and height are important factors to BPN. After completing the above series of design, casting, and testing, the final step is to use the integrated findings for the full scale manhole cover design. It is found the optimal design parameters include the following:

(1) Bump shape: square
(2) Bump size: 15 mm x 15 mm
(3) Bump gaps: 15 mm in two directions
(4) Bump height: 5 mm

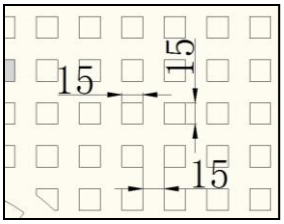
Because the manhole cover is commonly round shape, two types of bump alignments were chosen in the final stage design, namely chessboard design and radial design, as shown in Fig. 13. The center of the manhole cover usually is left blank for adding the logo of the manhole company. For each alignment design, there are 12 sets of black dots that are uniformly distributed on the surface. The black dots are special bumps that designed with 3 mm depth and arranged



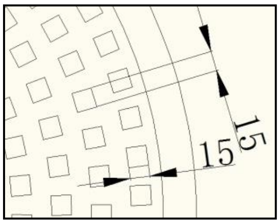
(a)Square bumps in chessboard layout



(b) Square bumps in radial layout



(c) Size of bumps and gaps in (a) design (mm)

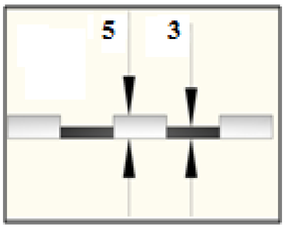


(d) Size of bumps and gaps in (b) design (mm)

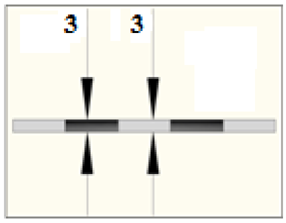
Fig. 13. Layouts of Two Final Manhole Cover Designs.

adjacent to the regular 5 mm bumps. The purpose of this special design is for visual inspection of manhole cover wearing condition. Fig. 14 illustrates the cross section of this special design in detail. A newly cast manhole cover has a normal cross section shown as Fig. 14(a). Once the bumps are worn down to 3 mm as Fig. 14(b), they can be easily identified through visual inspection. Actions such as maintenance or replacement of manhole cover can be scheduled thereafter.

The two new patterns manhole covers (Fig. 13) were cast in full scale with the commonly used materials, nodular graphite cast-iron. Two samples were made for each design plus new manhole covers obtained from the market make up the six specimens. They were tested by BPT as well as the DFT. Fig. 15 shows the three types of design for the BPT and DFT tests.



(a) When cover is new.



(b) When cover is worn down

Fig. 14. The Special Design for Visual Inspection of Bump Wearing Condition

BPT tests, in dry and wet conditions, were firstly conducted on the six manhole cover samples followed by the DFT tests. BPT was placed on each sample surface with two directions that are perpendicular to each other. The mean BPN value was calculated by averaging the readings obtained from both directions. Although the DFT is always tested under wet condition, the tests were conducted a couple of hours after BPT tests in order to allow the cover surface to dry out. Due to the dynamic characteristics of DFT tests, readings of dynamic friction can be obtained from speed range of relatively low speed (10 km/ hr) up to 80 km/ hr. In this study, dynamic friction of 60 km/ hr, DFT_{60}, was chosen as the comparison reference. The major reason of choosing 60 km/hr is because the city street speed limit is 50 km/ hr, and an additional 10 km/ hr was given for conservative safety purpose. Table 1 provides the data obtained from the tests of BPT under dry and wet conditions as well as the DFT_{60}.

From Table 1, it is obvious that the improvement of skid resistance, in terms of the BPN and DFT_{60} values, of both new design patterns is significant while compared to that of the market design. The chessboard pattern has an average DFT_{60} of 0.935 that is 47% better than that of the existing pattern. And the radial pattern has an average of BPN_{wet} 90.0 that is 11.8% better than that of the existing pattern. The results are very positive and it indicates that the two new patterns are very promising for providing better skid resistance than that of the existing design.

New Pattern: Chessboard

New Pattern: Radial

Market Existing Pattern

Fig. 15. Manhole Covers of the Two New Design Patterns and the Market Existing Pattern.

Table 1. Data Collected from BPT and DFT Tests on New and Existing Cover Patterns.

Patterns	Dry BPN	Avg. Dry BPN	Wet BPN	Avg. Wet BPN	DFT_{60}	Avg. DFT_{60}
Chessboard (Two Samples)	95 92	93.5	85 88	86.5	0.93 0.94	0.935
Radial (Two Samples)	100 100	100.0	90 90	90.0	0.80 0.80	0.80
Existing(Two Samples)	90 85	87.5	81 80	80.5	0.63 0.64	0.635

Conclusions

In this study, a comprehensive experiment design of manhole cover pattern was studied for finding the optimal design in terms of skid resistance. Design factors include raised bump gaps, bump size, bump shape, bump height, and bump alignment. The series of experiments were conducted factor by factor in order to find the optimal conditions. Dozens of specimens were cast and tested by BPT and DFT, and it was found that sample with square bumps of 15 mm x 15 mm, bump gap 15 mm, and bump height 5 mm can provide the best skid resistance. Finally, full scale manhole cover samples with two new design patterns, chessboard and radial bump alignment, were cast by nodular graphite cast-iron. A special design to aid visual inspection of bump height wearing was also incorporated in the full scale samples. By conducting BPT and DFT tests on the two newly design patterns and the market existing pattern, it was concluded that the manhole cover design with chessboard pattern indeed can provide a significant improvement in skid resistance, increases 47% of DFT_{60} value, compared with the existing one.

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