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Development of a height-adjustable manhole

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Materials

ABSTRACT

Purpose: It is found that to determine optimal dimension of gear-shaped parts through bending stress formulas and Taguchi orthogonal array table.
Design/methodology/approach: Whole parts of real manhole were manufactured experimentally by casting nodular graphite cast iron according to the Korean Standard. It can be used as water supply and drainage, sewage, telecommunication cable, traffic sign, electricity supply, etc. with better performance.
Findings: This manhole consists of cover, outer cylinder and inner cylinder. The gear-shaped stairs are extruded on the outer wall of inner cylinder, and on the inner wall of outer cylinder. The outer cylinder has three columns of 4~5 receptacles, and the inner cylinder has three columns of 6~7 protrusions. The inner cylinder shall be slided into the outer cylinder and then be rotated within the outer cylinder in order to lock the protrusions into the receptacles. The stairs on outer cylinder and inner cylinder allow workers to control the height of manhole because the height is controlled by adequate locking them on sidewall in installation or rehabilitation of manholes. It is designed for the perfect lock.
Practical implications: Use of this manhole must be drastically economical because it requires only 1-2 workers and simple adjustment of the height comparing with that the existing manholes is required 4-5 workers and reconstruction because conventional should be entirely excavated to reinstall or repair. This entire excavation of a manhole causes too much time-consuming work, waste of resources, and obstruction of traffic.
Originality/value: This paper describes an optimal design of manhole, which deals with design elements of manhole which has gear-shaped stairs on the road to adjust its height.
Keywords: Metallic alloys; Nodular graphite cast iron; Casting; Taguchi method; Optimal design

1. Introduction

1.1. Background

There are many kinds of manholes on residential streets such as for water supply and drainage, sewage, telecommunication cable, traffic sign, electricity supply, etc. According to their applications, cast iron, polyethylene, or concrete is used as the material. Traditionally manhole is repaired by excavation, manhole replacement, backfilling and then restoration of the site to its original condition.

The existing manholes are not constructed to adjust their height, therefore they should be entirely excavated to reinstall. This entire excavation of a manhole is not cost-effective. The manholes are sunk due to the road repair, which becomes the safety issue for pedestrians and drivers on uneven roads especially at night.

1.2. Purpose

The purpose of this paper is to introduce new-developed manhole and to determine optimal design by Taguchi orthogonal array table. This manhole is consists of cover, outer cylinder and inner cylinder which has gear-shaped stairs to adjust their heights. With the development of this height-adjustable manhole, the remediation and rehabilitation of underground manhole can be drastically improved.

The replacement of new-developed manhole must be economical because it requires only 1-2 workers and simple adjustment of the height comparing with that the existing manholes is required 4-5 workers and reconstruction. The maintenance of this height-adjustable manhole only requires periodic check-ups. Inconvenience of reconstruction is totally eliminated. Use of this manhole must be drastically economical to install and rehabilitate manhole

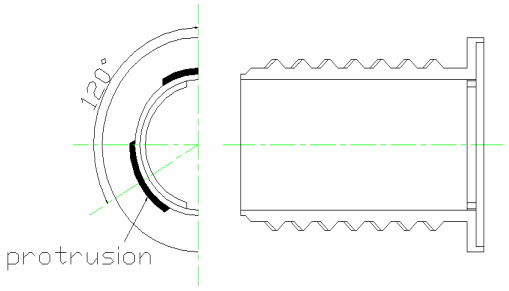
Optimal design is performed to determine optimal dimension of gear-shaped parts through Taguchi orthogonal array table and bending stress formulas. And the real parts of manhole are also manufactured by nodular graphite cast iron.

2. Design of a new-developed manhole

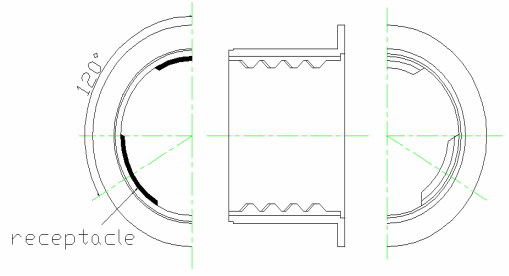
2.1. Structure of a new manhole

This height-adjustable manhole is consisted with the cover, inner cylinder, and outer cylinder. The outer cylinder has three columns of 4~5 receptacles, and the inner cylinder has three columns of 6~7 protrusions as shown in figure 1.

Each column is parted by 120 degrees. The gear-shape stairs are extruded on the outer wall of inner cylinder, and on the inner wall of outer cylinder.



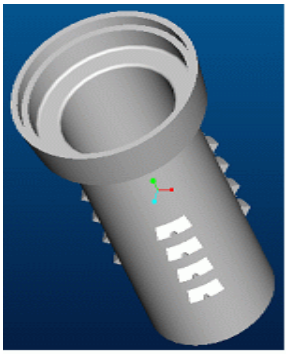
(a) Inner cylinder



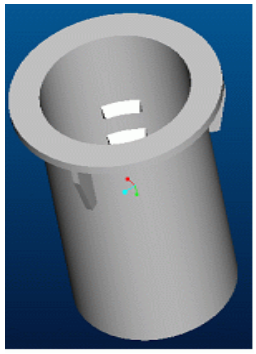
(b) Outer cylinder

Fig. 1. Schematic drawing of a manhole

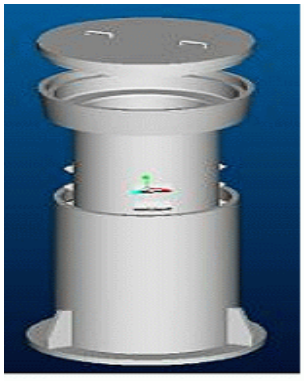
The inner cylinder shall be slided into the outer cylinder and then be rotated within the outer cylinder in order to lock the protrusions into the receptacles. The stairs on outer cylinder and inner cylinder allow workers to control the height of manhole because the height is controlled by adequate locking them on sidewall in installation or rehabilitation of manholes. It is designed for the perfect lock.



(a) Inner cylinder



(b) Outer cylinder



(c) Assembly

Fig. 2. Each part and assembly of a manhole

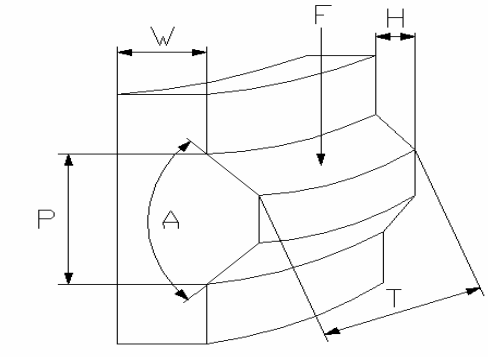


Fig. 3. Schematic drawing of a stair

The outer cylinder shall be installed permanently into the ground, however the inner cylinder is adjustable or replaceable.

By rotating the inner cylinder and moving the protrusions to the higher level, the height of the height-adjustable manhole will be adjustable to the ground level as shown in figure 2, the 3-D diagram for the design and assembly.

2.2. Mechanical design

To bear the load on the total work area of gear-type stairs (receptacles and the protrusions of cylinders), the optimal dimensions(H×P×W) of this one stair on tapered height-adjustable manhole should be determined as shown in figure 3.

The stair is assumed to have the shearing and fatigue force on one extruded stair.

The bending at fracture in bending is known as the modulus of rupture, or rupture strength, and is obtained the formula

$$\sigma = \frac{M}{Z} \tag{1}$$

where M is known as the bending moment, and Z is the section modulus.

The bending moment M is obtained from the formula

$$M = F(W + H) \tag{2}$$

where F is the load, W, the thickness of material, and H is the height of extrusion as shown in figure 3 respectively. The section modulus Z of equation (1) is obtained from the following equation

$$Z = \frac{TP^2}{6} \tag{3}$$

where **T** is the width of extrusion and **P** is the lateral height of extrusion.

Therefore equation (1) can be rewritten from equation (2) and (3) as follows.

$$\sigma = \frac{6F(W + H)}{TP^2} \tag{4}$$

The stress equation (4) shows the maximum stress in straight beam, however the stress in tapered beam should be calculated considering the coefficient of taper angle as follows

$$\sigma_1 = \eta \cdot \frac{6F(W + H)}{TP^2} \tag{5}$$

where η is the coefficient of taper angle in extrusion.

If the taper angle in tapered beam is small for example, five or less degrees, equation (4) can be applied because there is no difference between the tapered and straight beam. However the taper angle is over five degrees, the different stress value must be applied according to the taper angles. For example, it is 10, 15, 30, 45 degrees, the stress value may be calculated approximately 0.97, 0.95, 0.9, 0.85 times of the stress in straight beam respectively.

The cyclic load of vehicles is applied to manholes. The fatigue load for N cycles is expressed as follows.

$$\sigma_2 = \sigma_1 - \left(\frac{\sigma_1 - \sigma_w}{6}\right) \log_{10} N \tag{6}$$

where σ_w is the fatigue limit, which is 0.3 for the manhole. N is the number of the cycles, 10^6.

Therefore, the final stress equation considering the shearing and fatigue force on one stair is determined as follows.

$$\sigma_2 = 0.3 \cdot \eta \cdot \frac{6F(W + H)}{TP^2} \tag{7}$$

In case of one stair, the actual area supporting the load is obtained as

$$A = 3 \times T \times P \tag{8}$$

Therefore the load equation is expressed as follows.

$$F' = \sigma_2 \times A = 0.3 \cdot \eta \cdot \frac{6F(W + H)}{TP^2} \cdot A \tag{9}$$

If the number of stairs is n, the total load is as follows.

$$F' = n \cdot A \cdot 0.3 \cdot \eta \cdot \frac{6F(W + H)}{TP^2} \tag{10}$$

The total load equation (10) and Taguchi method were used to get the optimal dimensions(H×P×W) of this extrusion on tapered height-adjustable manhole as shown in figure 3.

Table 1
Input values of Taguchi orthogonal array table

No.	H[mm]	n	P[mm]	W[mm]	F[kgf]
0	14	0.95	35	15.5	10000
1	15	0.90	40	16.5	10000
2	16	0.85	45	17.5	10000

2.3. Optimal design by Taguchi method

Using Taguchi orthogonal array table, the different values of one stair are input as shown in Table 1. For the varieties of experimental restrictions of real manholes to height H of stairs and material thickness W, three cases are shown in this Table.

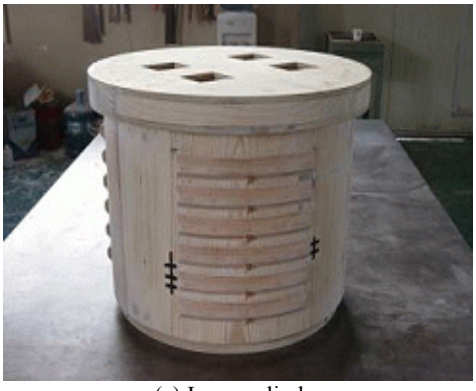
Table 2 shows that optimal dimension of a gear-shaped stair was determined by the result of Taguchi method as shown in Table 1. When W is 14 mm, it is thought to be the most stable.

3. Manufacturing of a real manhole

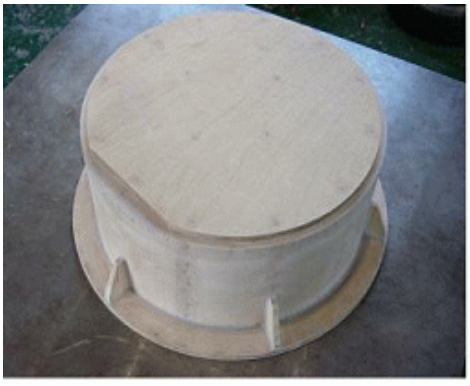
3.1. Wooden flasks for casting

Whole parts of a real manhole were manufactured experimentally by choosing proper material according to the Korean Standard KSD 4302. Adopting the inner diameter 698 mm of a real manhloe

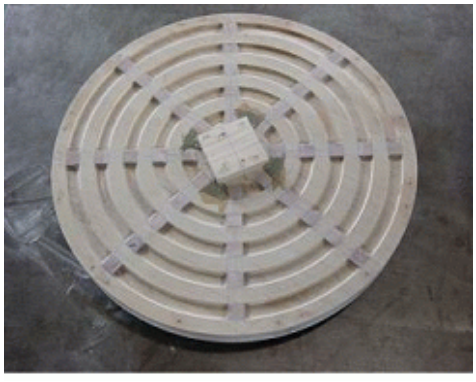
cover according to the Korean Standard KSD 6127, the dimensions of the two cylinders were calculated based on it.



(a) Inner cylinder



(b) Outer cylinder



(c) Cover

Fig. 4. Wooden flask for casting

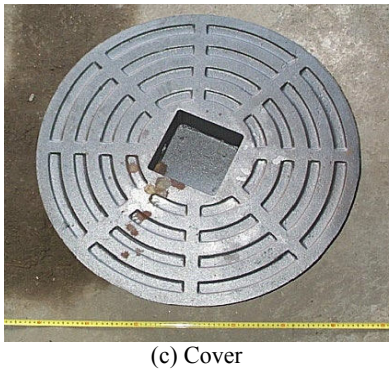
Table 2
Optimal values by Taguchi orthogonal array table

H[mm]	n	P[mm]	W[mm]	T[mm]
14	0.85	45	15.5	157.55

Figure 4 shows the wooden flasks for metal-castings inner cylinder, outer cylinder, and cover respectively. Each flask has sprue, core, mold cavity, and gate-runners etc. in it. The molten metal is poured through a pouring basin and then flows through the sprue and runners into the mold cavity.

(a) Inner cylinder

(b) Outer cylinder



(c) Cover

Fig. 5. Real cast parts of a manhole

3.2. Practical implication

The real parts of a manhole using the wooden flask are shown in figure 5. They were made of casting nodular graphite cast iron.

The use of the new-developed manhole results in improved efficiency, time saving of replacement, and elimination of the need for complicated process of install.

It can be used as water supply and drainage, sewage, telecommunication cable, traffic sign, electricity supply, etc. with better performance.

3.3. Originality value

This paper describes a new manhole design that is very practical and yet not come out in the world. International patents are pending for this system in some countries.

3.4. Research limitation

Additional research is currently being conducted into ways of doing supplementary experiments and for conveying CAE analysis for optimal casting process to check whether new manhole system is optimal to bear the vertical load on it.

4. Conclusions

The new-developed manhole has gear-shaped stairs to adjust their heights. This manhole is consists of cover, outer cylinder and inner cylinder. With the development of this height-adjustable manhole, the remediation and rehabilitation of underground manhole can be drastically improved.

This manhole requires only 1-2 workers and simple adjustment of the height, however the replacement of the existing manholes is required 4-5 workers and reconstruction. The maintenance of this manhole only requires periodic check-ups. Inconvenience of reconstruction is totally eliminated.

From the stress formula considering the shearing and fatigue force on one stair, the optimal dimensions of gear-shaped stairs could be determined.

Mechanical design is performed to determine optimal dimension of gear-shaped parts from the stress formula considering the shearing and fatigue force on one stair and Taguchi orthogonal array table. The real parts of manhole are also manufactured by casting nodular graphite cast iron according to the Korean Standard. Adopting the inner diameter 698 mm of real manhloe cover according to the Korean Standard KSD, the dimensions of the other parts were calculated based on it. The city government authority is considering whether to apply new manhole system.

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