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# REHABILITATION METHOD FOR INCREASING FLOW VELOCITY AND REDUCING SEDIMENTATION

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**ABSTRACT**: This paper presents the development of non-circular modified CIPP to reduce sedimentation and increase the flow velocity in the existing combined sewer system.

The sedimentation in the bottom of the combined sewer causes serious problems such as reducing flow capacity and hygienic hazards. The magnitude of flow velocity is one of the major factors governing the rate of sedimentation. Therefore, increasing flow velocity in the combined sewer can significantly reduce the rate of sedimentation. Since most combined sewer systems use gravitational potential as their driving force, it is almost impossible to increase the flow velocity without the re-installation of the sewer.

KICT (Korea Institute of Construction Technology) has developed a new combined sewer rehabilitation method using a non-circular modified CIPP. This method has been initiated to reduce the rate of sedimentation in the existing combined sewer without sacrificing either the control of storm flooding or sewage transportation.

This new method enables us to increase the flow velocity by modifying the pipe section shape during CIPP installation process for the combined sewer rehabilitation project. This method is most suitable where the sewer system has somewhat excessive designed capacity due to very uneven precipitation patterns during a year, and where the degree of in-line slope is not steep enough to maintain the flow velocity.

This paper will describe the effect of increasing the flow velocity in various sizes of modified section and the installation process of the non-circular modified CIPP rehabilitation method.

## 1. INTRODUCTION

There are three types of sewer systems: 1) A sanitary sewer carries domestic and industrial sewage to a wastewater treatment plant; 2) A storm sewer carries rainfall runoff to streams or other surface water bodies; and 3) A combined sewer carries both sewage and runoff through a single pipe. The installation of separated sanitary sewer systems and storm sewer systems is beneficial for various reasons. The biggest benefit of a combined sewer system is cost effectiveness. It is much cheaper than constructing two separate systems. Availability of the public land could be a reason for constructing the combined sewer system. For example, most old cities in South Korea do not provide enough land to install two separate sewer systems in many times. South Korea has constructed a combined sewer system for more than half of the nation's sewer systems because it was cheaper and a faster solution during the rapid economical development period in the 1970s and the 1980s. One of the disadvantages of a combined sewer system is the difficulty of controlling wastewater during heavy rainfall. Major disadvantages of a combined sewer systems are as follows: 1) A combined sewer system requires higher capacity at the wastewater treatment plant. 2) A combined sewer system tends to have significant sediment deposits in the sewer system due to its inability to maintain minimum velocity during the dry seasons. 3) Combined Sewer Overflow (CSO) causes environmental contamination and posses a hazard to public health.

As public authorities increase environmental awareness, the combined sewer system requires improvement. Additionally, many old sewer systems show severe problems due to deterioration. Korea Institute of Technology has been involved in solving the problems from excessive sedimentation and deterioration for the existing combined sewer system. Consequently, the Modified Sectional Cured in Place Pipe (MSCIPP) has been developed.

This paper presents research about increasing flow velocity by modifying the section of the combined sewer when implementing ordinary Cured-In-Place-Pipe (CIPP) rehabilitation methods in the existing system. Pilot testing procedures are also demonstrated in the paper.

## 2. BACKGROUND OF MSCIPP DEVELOPMENT

Annual precipitation in South Korea is 1,283mm. More than 70% of total precipitation is concentrated in the rainy season, which is from June to September. The storm water during the rainy season is highly intense with relatively short precipitation duration. Topographic and ground surface condition usually results in a high runoff coefficient. Therefore, a combined sewer system tends to be designed for multiple times of normal capacity to handle maximum flow in the rainy season. Most combined sewer systems use circular reinforced concrete pipe. Circular concrete pipes are easy to handle and manufacture, but the circular shape has one major drawback. Flow velocity slows when flow quantity is very limited in the dry season. This is the reason for utilizing egg shapes or non-circular sewer systems. Slow flow velocity accelerates sedimentation on the bottom of the combined sewer. More deposit reduces the flow velocity.

The generic term sewer sediment is used to describe any type of settleable particle material that is found in storm water or wastewater and is able to form bed deposits in sewers and associated hydraulic structures (Fan et al, 2001). Sedimentation causes severe problems including reduction in flow capacity and velocity. Reduction in flow capacity may cause combined sewer overflow (CSO) when the rainy season starts. The sedimentation and slow velocity provide an excellent environment for Thiobacillus bacteria that oxidize sulfide to sulfuric acid causing concrete sewer corrosion (Islander et al, 1991). The concrete corrosion rate by corrosive bacteria can be more than 5mm per year (Mori et al, 1992). Sedimentation and low velocity provide good environmental conditions for hazardous bacterial growth in a combined sewer system. This causes serious potential risks for the public.

A conventional method to increase flow velocity in a circular shape combined sewer is either entirely new construction of a separate sewer system or re-installation of the combined sewer system. A separate sewer system, which carries only sewage and industrial wastewater, has less deposit materials. Most sedimentation components in a combined sewer are derbies carried by storm runoff. Adequate flow velocity is the key to reduce sedimentation in the combined sewer system. When gravity is the only driving force for the circular shape combined sewer system and flow quantity stays constant, only increasing the slope of the sewer can increase flow velocity. A new combined sewer system installation just for increasing sewer slope is an expensive way to reduce sedimentation. Therefore, KICT launched a research program to find an effective method. The research program reduced sedimentation and rehabilitated of the old sewer system.

## 2. RANGE OF APPLICATION

Korean Institute of Construction Technology (KICT) has developed modified Sectional Cured in Place Pipe (MSCIPP) in 2004. MSCIPP is only applicable where the maximum flow quantity is less than the combined sewer system capacity. In other words, additional design capacity in the current combined sewer system is necessary to apply the modified section of the CIPP on the bottom side of the combined sewer system because the modified section of pipe reduces the existing sewer's flow capacity.

MSCIPP is a modification of the CIPP rehabilitation method. It can be applied where CIPP can be installed. Some additional processes are required to install the modified section in the existing pipe.

## 3. INTRODUCTION OF CONCEPT AND HYDRAULIC MODELING

Without re-installation of a combined sewer system, the only possible idea was changing the sectional shape of the pipe in order to increase flow velocity.  This concept is based on Manning's hydraulic equation. To create the bulge shape in the existing combined sewer, CIPP must be installed above the inflating tube. The inflating tube is later filled by cement mortar and keeps the modified shape permanently. A hydraulic model is developed to find out the most hydraulically efficient shape. Figure 1 shows the concept of MSCIPP.

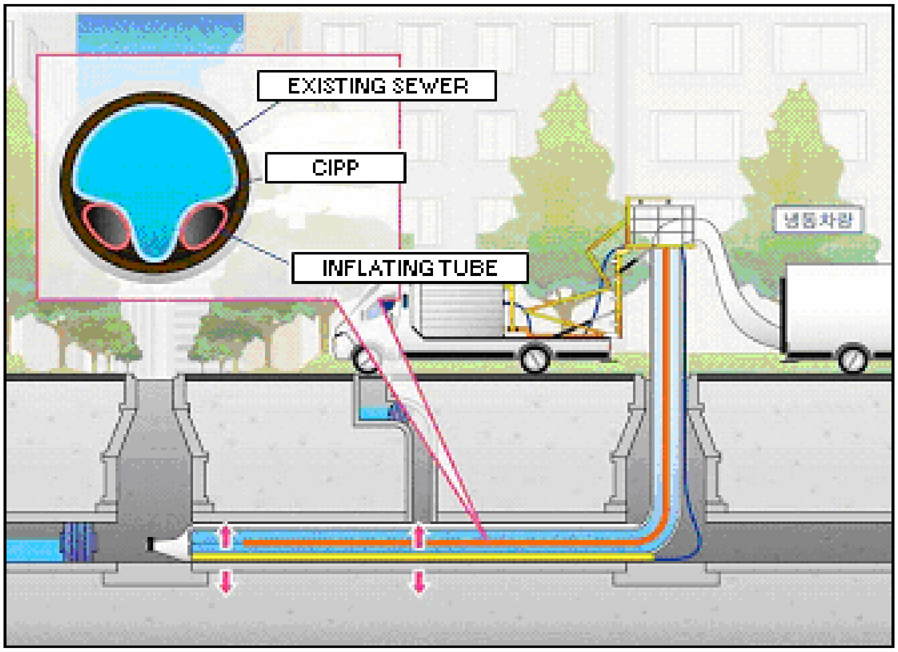


Figure.1 Concept of MSCIPP

Several different shapes were tested in the testing bed (Figure 2.). The hydraulic test was conducted by measuring the velocity and flow depth for each different test shape. Sewage and runoff flows in a combined sewer are considered as open channel flow. Open channel flow is sewage and runoff flowing with a free surface exposed to the atmosphere.  Flow characteristics are controlled by fluid momentum and gravity.  The Bernoulli's (Energy) Equation is used to determine the flow and depth relationship.

When Energy Grade Line (EGL), Hydraulic Grade Line (HGL), and channel slope are parallel, uniform flow occurs. There are many empirical equations that can be used to determine the normal depth ($y_n$) to flow rate relationship for uniform flow conditions.

The general form of the flow velocity equation is expressed as below:

$V = K\ C\ R^x\ S^y$ (Equation 1)

where, v = Fluid Velocity, K = Unit Conversions, C = Roughness Coefficient, R = Hydraulic Radius, S = Channel Slope, and x, y = Fitting Parameters

$Q = V\ A$ (Equation 2)

Where, Q = Fluid Volumetric Flow Rate, and A = Fluid Cross-Sectional Area of Flow

Manning's equation is one of most widely known empirical equation. The test employed Manning's equation for the hydraulic modeling and testing.

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \quad \text{(Equation 3)}$$

$$V = \frac{1}{n} R^{2/3} S^{1/2} \quad \text{(Equation 4)}$$

Where, Q = Flow, ($m^3/s$), V = Velocity, (m/s), A = Area of flow, ($m^2$), R = Hydraulic radius (A/P), (m) n = Roughness Factor, and S = Slope

Figure 2. Hydraulic Model Testing Bed

A minimum velocity requirement for combined sewer systems in South Korea is generally higher than 0.6 m/s. Figure 3 (see next page) shows testing results comparing flow velocity of a circular shape to a modified shape. Testing bed was built for circular concrete pipe with 400 mm in diameter and 0.1% of slope. The flow velocity was measured then, 45mm inflated rate was applied for modification of pipe sectional shape. Flow velocity increased significantly in most of the flow quantities as much as 30%. Tests were done by applying various dimensions of the pipe, modification, and slope changes. These test results are used as a baseline for building a hydraulic model based on the magnitude of the inflating tube and changes of flow velocity. The hydraulic modeling revealed that a much lower flow quantity was required to achieve the minimum velocity (0.6m/s) in the modified sections. Manning's equation was used in the model. The hydraulic modeling parameters including slope, hydraulic radius, and sectional area were prepared for reinforced concrete pipe and MSCIPP. A roughness factor 0.013 for concrete was used. Since surface roughness of CIPP is much lower than reinforced concrete pipe surface, the roughness factor should be different. CIPP was assumed as 0.010.

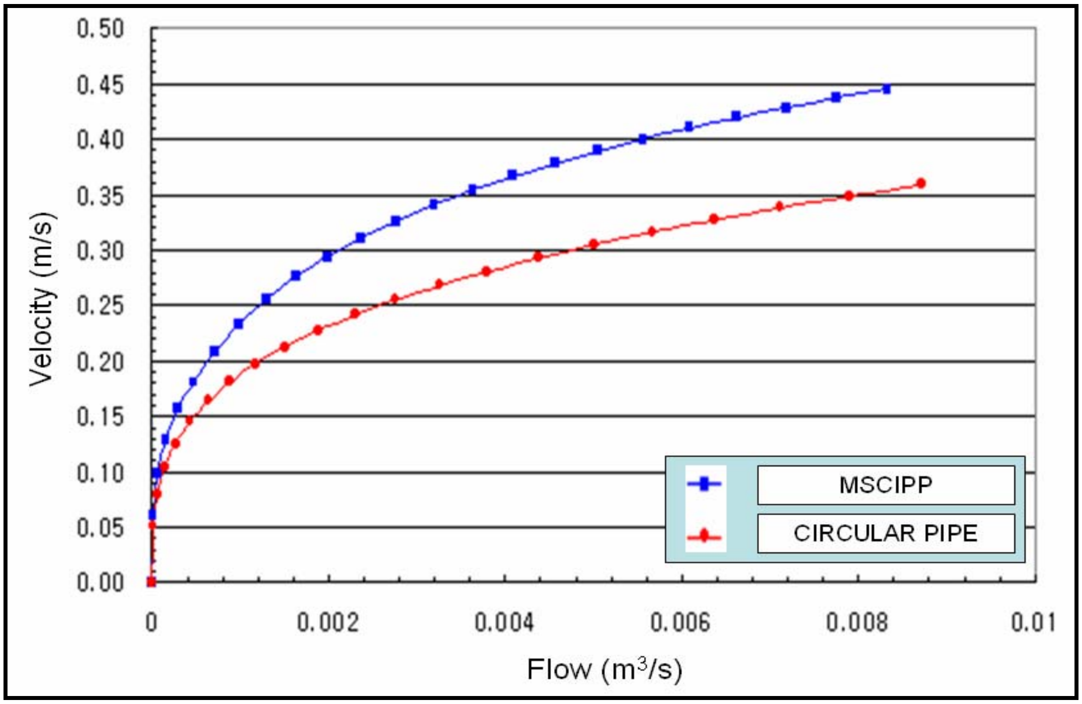


Figure 3. Velocity of MSCIPP Compared to Circular Pipe

## 4. PILOT TESTING PROJECT AND APPLICATIONS

Ordinary CIPP materials were used for this pilot testing project. After testing various tube materials, high-pressure flexible water tube was selected for the inflating tube. The testing results showed that the high-pressure flexible water tube was the most appropriate material. The high-pressure water tube is cost effective, waterproof, flexible and durable. Cement grouting mortar was chosen as the filling material after inflating the tube. Ordinary cement grouting mortar is cost effective, and easy to work and pump.

New methods were developed to make the modified section for MSCIPP. The first method is for medium to small diameter pipe. Two inflating tubes were attached on the outside of the resin-filled felt. Resin-filled felt and attached inflating tubes were inverted simultaneously into the existing pipe. The second method is for larger diameter sewers. Two flexible tubes would be installed on the sewer (mostly at the 4 and 6 o'clock position) before inversion process. After the inversion process, air inflates the inflating tube. This inflated space will be filled with cement mortar. Air pressures ranging from 0.5 kg/cm$^2$ - 2.5 kg/cm$^2$ were tested. The higher pressure creates the larger inflated space behind of the CIPP. Twenty-four different modified sectional shapes were created and tested in the testing bed. The identification number designates modified section information. For example, sectional identification number 30654555 consists of 300mm in diameter size of existing pipe, 65 mm for the installed flexible pipes, 45º degrees to the center point, and inflation rate 55 mm. Figure 4 shows the dimensions of sectional identification number 3065455. Figure 5 demonstrates various cross sectional shapes modified by different angles and air pressures.

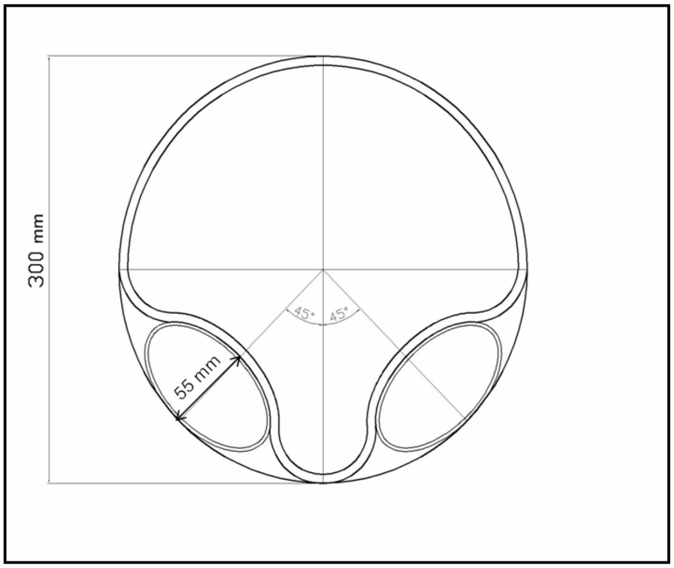


Figure 4. Dimensions of Sectional Identification No. 3065455

| Angle | Pressure | Cross Sectional View | |
|---|---|---|---|
| 30° | 0.5kg/㎠ |  |  |
| 50° | 1.0kg/㎠ |  |  |
| 50° | 1.5kg/㎠ |  |  |

Figure 5. Cross Sectional Views of MSCIPP

## 4.1 MSCIPP Installation Process

As stated in the previous section, the MSCIPP installation process is basically adding extra steps to the ordinary CIPP installation process to create a modified CIPP. Five major steps in MSCIPP are demonstrated as follows:

Step 1) Preparation Materials and Equipment

Ordinary CIPP felt and resin can be used for MSCIPP installation. High-pressure flexible water tube is prepared for the modifying section. The existing combined sewer should be cleaned before installation. Bypassing may be required for not disturbing sewer service. Figure 5 shows the prepared felt and inflating tube before installation.

Step 2) Inversion

MSCIPP is placed in the inversion tube and inverted through the existing combined sewer. Hydrostatic pressure is normally used to drive inversion process.

Step 3) Inflating Tube using Pressurized Air

After completing inversion process, air pressure inflates the high-pressure flexible water tube, which is now located between the CIPP and the existing pipe interior wall. This process is important because air pressure inflates and keeps the modified shape during resin curing. The inflation rate should be inspected to check the shape of the modified section before curing. Figure 6 shows connecting an air pump to the high-pressure flexible water tube.

Step 4) Resin Curing Process

Most CIPP methods use hot water for resin curing. The curing process chosen depends on properties of resin. MSCIPP uses hot water to harden the CIPP.

Step 5) Cooling and Mortar Injection

After curing, cold water circulates in the MSCIPP to cool down the CIPP. Air pressure in the inflating tube is released, and then cement mortar is pumped into the high-pressure flexible water tube. Figure 7 shows mortar injection and shape of MSCIPP.

Step 6) Lateral Connection Finishing Process

The finishing process includes cutting and cleaning, inspection, and lateral connection. Lateral connection may require a special robotic cutting machine because ordinary robotic machines may have difficulties maneuvering in the modified section.

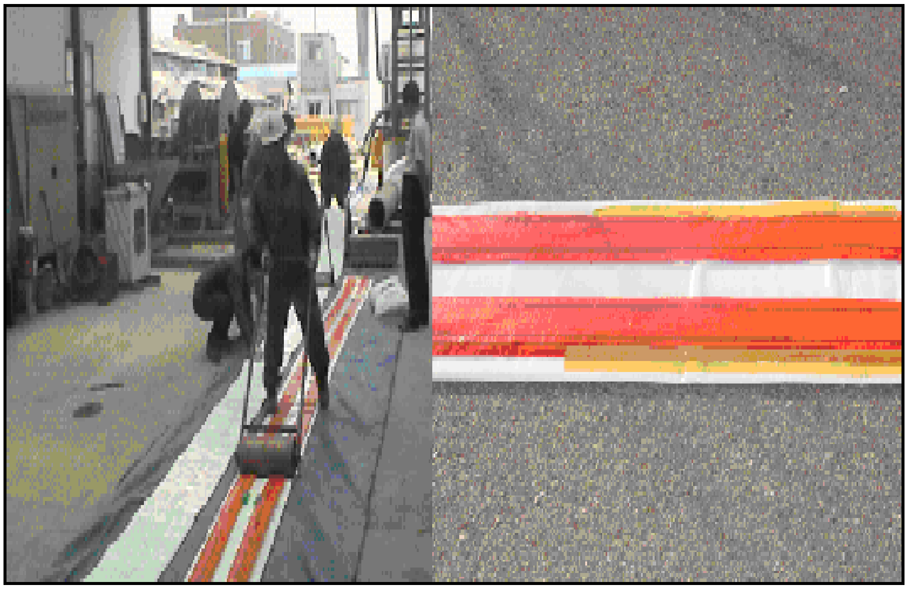

Figure 5. Inflating Tube Preparation

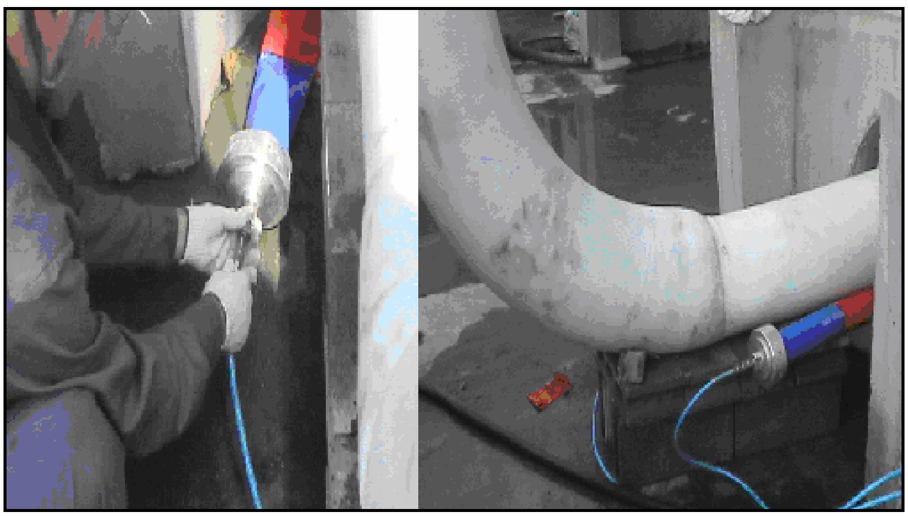

Figure 6. Air Pressure Inflating Tube after Inversion Process

Figure 7. Mortar Injection and Completed shape of MSCIPP

## 5. CONCLUSION

Pilot testing evaluation concluded that MSCIPP was a successful program and would be worth testing in a real rehabilitation project. Flow velocity was increased higher than 20% by modifying the section of a combined sewer. MSCIPP can reduce the rate of sedimentation effectively in a combined sewer without reinstallation of the sewer system. MSCIPP can be a good solution for a combined sewer system rehabilitation project if the existing sewer system has a low flow velocity problem.

A few things should be improved for increasing the productivity of field installation. Special equipment including a specialized lateral connection robot are currently developing. There are some ideas for utilizing inflated space instead of filling the cement mortar. Inserting a small diameter pipe in the modified section for communication lines including high-speed Internet and fiber optic line will be a good way to maximize the efficiency of underground infrastructure. More research efforts are required to improve current sewer system rehabilitation applications.

## 6. REFERENCES


Fan, C., Rield, R., Pisano, C. W., Barsanti, J., and Joyce, J. J. (2001). Sewer and Tank Flushing for Sediment, Corrosion, and Pollution Control, *Journal of Water Resources Planning and Management*, Volume 127, No. 3, pp. 194-201.

Islander, L. R., Devinny, S. J., Postyn, A., and Shih, H. (1990). Microbial Ecology of Crown Corrosion, *Journal of Environmental Engineering*, Volume 117, No. 6, pp. 751-769.

Mori, T., Nokaka, T., Koga, M., Hikosaka, Y., and Noda, S. (1992). Interactions of Nutrients, Moisture and pH on Microbial Corrosion of Concrete Sewer Pipes, *Water Resource*, Volume 26, No. 1, pp. 29-37.