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# Precast Reinforced Concrete Pipe Lined with Polymer Mortar

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Synopsis: Reinforced concrete pipe used as sewer pipe is required to have excellent durability, especially chemical resistance, in addition to high strength and good economy. A precast composite pipe, in which a reinforced concrete pipe is lined with polymer mortar as soon as centrifugal compaction and drainage has been completed, was developed and investigated.

Chemical resistance of the polymer mortar used to acidic water and alkaline water was first studied by the immersion tests and manufacturing process of the composite pipe was introduced secondly. Subsequently, the load tests were carried out and elastic behavior, cracking and breaking strength of the pipes were investigated. Furthermore, a reasonable design method for the composite pipe is discussed and proposed.

Keywords: Chemical attack; compaction; cracking (fracturing); expansive cement concretes; mortars (materials); pipe (tubes); polymer concrete; precast concrete pipe; sewer pipes; strength

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## INTRODUCTION

The main function of sewer pipe is to smoothly transport sewage and rainfall from one place to another. Sewer pipes are normally buried in the earth,and so require high strength and durability along with chemical,corrosion and abrasion resistance. Earthenware pipe, polyvinyl choride(PVC) pipe and reinforced concrete pipe including jacking pipe satisfy these requirements. Figure 1 shows the fiscal 1988's actual records of sewer pipes in Japan corresponding to the diameters of pipes.

Earthenware pipe and PVC pipe have excellent chemical resistance, but because of their lower strength, particularly their low impact resistance, they are used primarily for diameters less than 300 mm and almost never for sizes greater than 500 mm.

Reinforced concrete pipe, on the other hand, has excellent strength and is ideal for transporting water, but it has some shortcomings when used for sewer pipe. Both concrete and steel are susceptible to chemical attack, especially from acids. The interior surface of sewer pipes is in direct contact with waste water, and concrete pipe will corrode if exposed to an environment (1) that is more acidic than pH 4. The various thechnologies available for lining the interior surface of reinforced concrete pipe with anti-corrosive materials such as polymer paste, polymer mortar, and polymer-impregnated concrete have been introduced and developed(2).

In this study, a precast composite pipe lined with polymer mortar was tested as follows:

First, chemical resistance of the polymer mortar used to the solutions of hydrochloric acid, sulphuric acid, sodium hydroxide and sodium chloride was clarified by the immersion tests.

Second, centrifugal lining method of polymer mortar was developed and introduced as soon as centrifugal compaction and drainage of base core reinforced concrete pipe had been completed. Expansive concrete was used for base reinforced concrete pipe in order to obtain high cracking strength.

Third, cracking and breaking loads were measured by loading tests and those results are discussed and compared with the analysed data.

Finally the optimum design method for the composite pipe considering lining depth of polymer mortar and thickness of concrete composing the base concrete pipe was investigated.

## MATERIALS USED FOR REINFORCED CONCRETE PIPE

Plain concrete and expansive concrete were used to make the base reinforced concrete pipe and their mix proportions and physical properties are shown in Table 1 and 2. The expansive additive used was a lime system and the relationship between expansive strain and reinforcing steel ratio are shown in Fig. 2, according to Japanese Industrial Standards(JIS) A 6202.

## PROPERTIES OF POLYMER MORTAR AS THE LINING MATERIAL

The hydrophilic polymer used is composed of epoxy polymer as the principal ingredient and modified polyamine as the hardener. A properly graded chamotte, that is ceramics powder of the maximum size 1.5 mm as fine aggregate was used. Weight ratios of polymer paste and chamotte to polymer mortar were 0.5 and 0.5. The physical properties of polymer mortar are summarized in Table 3.

Chemical resistance of polymer paste and mortar to acidic and alkaline water are shown in Fig. 3 to 6. The weight change of polymer paste was not significantly observed and the absolute values of the weight change were less than 1 %. These pastes were especially stable for alkali.

On the other hand, weight changes of polymer mortars immersed in the solutions of sulphuric acid and hydrochloric acid of 10 % concentration were larger than those in city water of pH 6.6. As polymer mortar was composed of polymer paste and fine aggregate as anti-corrosive materials, it seemed weight changes were caused by swelling and corrosion of polymer mortar. The increases of weight changes of polymer mortars immersed in alkaline water were stopped at six months, however those immersed in acidic water were approximately proportional to the immersion period and they did not stop at two years.

Roughness of the interior surface of this composite pipe was measured by surface trace with needle. Figure 7 shows the surface roughness of the proposed composite pipe, centrifugally compacted concrete pipe using ordinary concrete on site.

According to JIS K 7204, abrasion resistance of polymer mortars and concrete by abrasion wheels were tested. Abrasion loss in weight at 1000 revolutions for polymer mortar and ordinary cement concrete are shown in Fig. 8. From this result, weight loss of this polymer lining pipe is about one-third smaller than that of concrete pipe and abrasion level of this pipe is adequate to be used for sewer pipe.

## MANUFACTURING PROCESS

Flow chart for manufacturing the proposed polymer lined pipe is shown in Fig. 9. Ordinary reinforced concrete pipe using expansive concrete as structural member is first made by centrifugal compaction. As soon as compaction and drainage have been completed, the polymer mortar lining is performed by use of machine or by hand as shown in Fig. 10. Polymer mortar must be hydrophilic with low shrinkage. Therefore special epoxy polymer as the binder and a properly graded chamotte as fine aggregate were used.

When the designed lining depth was attained, the interior surface was finished as shown in Fig. 11, and this lined pipe was cured by far infrared rays and steam.

Composite centrifugal reinforced concrete pipes of length 1200 mm, internal diameter 1000 mm and total thickness 82 mm as shown in Fig. 12 were made and tested. The lined depth of polymer mortar for all pipes was 5 mm. Three kinds of base concrete pipes in order to investigate the effects of expansive concrete were chosen as follows:

Pipe[1]: Reinforced concrete pipe using expansive concrete only,
Pipe[2]: Reinforced concrete pipe using ordinary concrete cast in outer half layer and expansive concrete cast in the inner half layer,
Pipe[3]: Reinforced concrete pipe using ordinary concrete cast in outer three quarter layer and expansive concrete cast in a quarter layer.

## STRENGTHS OF COMPOSITE PIPE

### Cracking Strength

Cracking load Pcr of the composite pipe (6) may be calculated by the following equation,

$$P_{cr} = \frac{\sigma_{bt} + \sigma_{cp} + \sigma_d}{\sigma_{qr}} \quad \text{------------------} \quad 1)$$

where

$\sigma_{bt}$ is flexural tensile strength of concrete,
$\sigma_{cp}$ is chemical prestress induced by use of expansive concrete,
$\sigma_d$ is flexural stress due to self weight of the pipe,
$\sigma_{qr}$ is flexural stress due to the unit applied load in the loading test.

Distribution of chemical prestress estimated by theory of elasticity (3,4) and the results are shown in Fig. 13. Compressive stresses were observed in the layer of expansive concrete and tensile stress was generated in the layer of polymer mortar, the exterior layer of ordinary concrete and the reinforcing steel as the result of restraining the strain of expansive concrete. Table 4 shows the chemical prestress, the stress (5) due to self weight of pipe and the stress (6) generated by the unit load (9.8kN/m).

## Breaking Strength

The breaking load Pu (6) based on limit analysis for reinforced concrete pipe can be given by the following equation,

$$Pu=2(MuA + MuB)/r - 0.66W \qquad \text{----------------- 2)}$$

where MuA is ultimate strength of the cross section at the top and bottom position of the pipe,
MuB is the ultimate strength of the cross section at the lateral diameter of the pipe,
r is the radius of the pipe,
W is the weight of the pipe per unit length.

## Cracking Load and Breaking Load

A load test was carried out according to JIS A 5303. Figure 14 and 15 show the relationships between load and strain, and load and deflection of pipe[1]. From these figures, strain and deflection linearly increased with load before cracking and strains observed at cracks were about 250 to $300 \times 10^{-6}$.

## Bond strength

Onto the interior surface of the pipe, a square steel plate was affixed with epoxy polymer. Along the edge of the plate a split was cut to the base concrete. The specimen was tested by using a portable uni-axial tension testing machine equipped with a center hole jack. The whole broken surface was in the base concrete and the bond strength was 2.4 and 2.2 MPa at the age of 14 days and 18 months, respectively.

Cracking loads and breaking loads tested were obtained as shown in Table 5. Experimental cracking loads were about 20 % higher than analytical ones. As the lining polymer mortar has very high extensibility, cracks were normally observed at the base concrete as shown in Fig. 16.

On the other hand, breaking strengths calculated by Eq. 2) agreed relatively well with experimental measurements. As the reinforcing steel ratio of the composite pipe is designed to be much smaller than the balanced steel ratio at the ultimate strength of the cross section at the bottom and at the lateral diameter of composite pipe, the ultimate strength depends strongly on yielding strength of the tensile reinforcing steel. And so, theoretical breaking strengths of composite pipes agreed well with experimental ones.

## DESIGN OF COMPOSITE PIPE

Characteristics of composite pipe has been investigated from the view point of manufacturing, durability and strengths. With regards to design of composite pipe, lining depth of polymer mortar, depth of expansive concrete and reinforcement should be properly determined by considering total cost of pipe. Lining depth depends on workability, centrifugal compaction, chemical resistance, hydraulic properties, bond strength and extensibility of polymer mortar. Several kinds of polymer mortar were tested in the same conditions and it seemed the polymer mortar described above were the best one. It is recommended that the lining depth of polymer mortar corresponding to the diameters of pipes 400mm to 800mm, 900mm to 1350mm, and 1500mm to 3000mm are 4mm, 5mm and 6mm, respectively, because of workability and the maximum size of the fine aggregate used.

On the other hand, the depth of expansive concrete is determined by the cracking strength related to chemical prestress. Figure 17 shows the relationship between cracking strength and depth of expansive concrete. Judging from this result, the depth of expansive concrete is desirable to be about 0.27 of total thickness of pipe. This depth is corresponding with the critical values of both crack modes at boundary of plain concrete and expansive concrete, and at outer surface of lateral diameter. Ultimate strength is mainly a function of reinforcing steel, especially yielding and arrangement of reinforcing steel. These factors are relatively easy to control, and therefore breaking strength of composite pipe can be precisely designed.

Furthermore, in order to perform the quality control of this proposed composite pipe, loading tests depending on the diameters of the pipes to be the same as for ordinary reinforced concrete pipe are carried out as follows:

There will be one of every 200 pieces for 400 to 900 mm, every 150 pieces for 1000 to 1800 mm, every 130 pieces for 2000 to 2400 mm and every 100 pieces for 2600 to 3000 mm, respectively.

The manufacturing process introduced in this paper is applicable for the sandwiched pipe, in which both exterior and interior surfaces of reinforced concrete pipe are lined with polymer mortar required in the environment of strong chemical attack condition such a hot spring zone. The practical composite pipe was used for the sewer pipe in the acidic hot spring zone as shown in Fig. 18.

## CONCLUSIONS

A reinforced concrete pipe lined with polymer mortar applied for sewer pipe was tested. This proposed pipe has a number of advantages compared to the conventional concrete pipe. The results obtained by this study are summarized as follows:

1. Excellent chemical resistance to acidic and alkaline water can be expected.

2. High cracking strength due to chemical prestress by use of expansive concrete is obtained.

3. The interior part would be protected by the lined polymer mortar because of high extensibility of polymer mortar if the deformation of the pipe is large and the concrete part is cracked.

4. As the polymer mortar is lined as soon as centrifugal compaction and drainage of base concrete pipe is completed, manufacturing process flows continuously and this system will be adopted to wide range of diameter from 400 to 3000 mm.

5. The excellent abrasion and flatness of the lined polymer is advantageous from the viewpoint of hydraulic engineering.

## ACKNOWLEDGMENT

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TABLE 1 — MIX PROPORTION OF THE USED CONCRETE

| Concrete | Gmax (mm) | Slump (cm) | W/(C+E) (%) | s/a (%) | Unit weight ($kg/m^3$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | W | C | S | G | Ex | Admixture |
| Plain | 20 | 3±2 | 35 | 37 | 158 | 450 | 679 | 1164 | -- | 3.2 |
| Expansive | 20 | 3±2 | 31 | 40 | 149 | 430 | 733 | 1108 | 50 | 3.4 |

TABLE 2 — PHYSICAL PROPERTIES OF THE PLAIN AND EXPANSIVE CONCRETE

| Concrete | Compressive strength (MPa) | Flexural strength (MPa) | Modulus of elasticity (GPa) | Poisson's ratio |
|---|---|---|---|---|
| Plain | 59.1 | 5.4 | 34 | 0.2 |
| Expansive | 63.2 | 7.9 | 34 | 0.2 |

TABLE 3 — PHYSICAL PROPERTIES OF POLYMER MORTAR

| Property | results (unit) | Remarks |
|---|---|---|
| Compressive strength | 36.6 ( Mpa ) | JIS K 7208 |
| Tensile strength | 13.6 ( MPa ) | JIS K 7113 |
| Flexural strength | 20.6 ( MPa ) | JIS K 7203 |
| Modulus of elasticity | 2.74 ( GPa ) | JIS K 7203 |
| Poisson's ratio | 0.31 | |
| Coefficient of thermal expansion | 53 $\times 10^{-6}$ ( /℃ ) | JIS K 7113 |
| Extensibility | 3.42 ( % ) | JIS K 7113 |
| Setting shrinkage | 8.8 $\times 10^{-4}$ | |

TABLE 4 — STRESS DISTRIBUTION OF COMPOSITE PIPE

| kind of pipe | Chemical prestress (MPa) | | | Stress due to self weight (MPa) | | | Stress due to unit external load (MPa) | | |
|---|---|---|---|---|---|---|---|---|---|
| | (S1) | (S2) | (S3) | (S1) | (S2) | (S3) | (S1) | (S2) | (S3) |
| Pipe(1) | −2.08 | −1.78 | — | 0.28 | 0.72 | — | 1.62 | 0.73 | — |
| Pipe(2) | −2.69 | 1.73 | −2.50<br>1.85 | 0.28 | 0.72 | 0.03 | 1.62 | 0.73 | 0.006 |
| Pipe(3) | −3.01 | 0.58 | −2.90<br>0.64 | 0.28 | 0.72 | 0.31 | 1.62 | 0.73 | 0.75 |

(S1): inner surface at bottom

(S2): outer surface at lateral diameter

(S3): boundary of plain concrete and expansive concrete

(-): compressive stress

(+): tensile stress

TABLE 5 — CRACKING LOAD AND BREAKING LOAD OF COMPOSITE PIPE

| kind of pipe | Cracking load (kN/m) | | Breaking load (kN/m) | |
|---|---|---|---|---|
| | Experimental | Theoretical | Experimental | Theoretical |
| Pipe(1) | 63.7 | 55.8 | 87.4 | 91.3 |
| Pipe(2) | 58.8 | 45.5 | 91.1 | 91.3 |
| Pipe(3) | 60.4 | 58.0 | 87.8 | 91.3 |

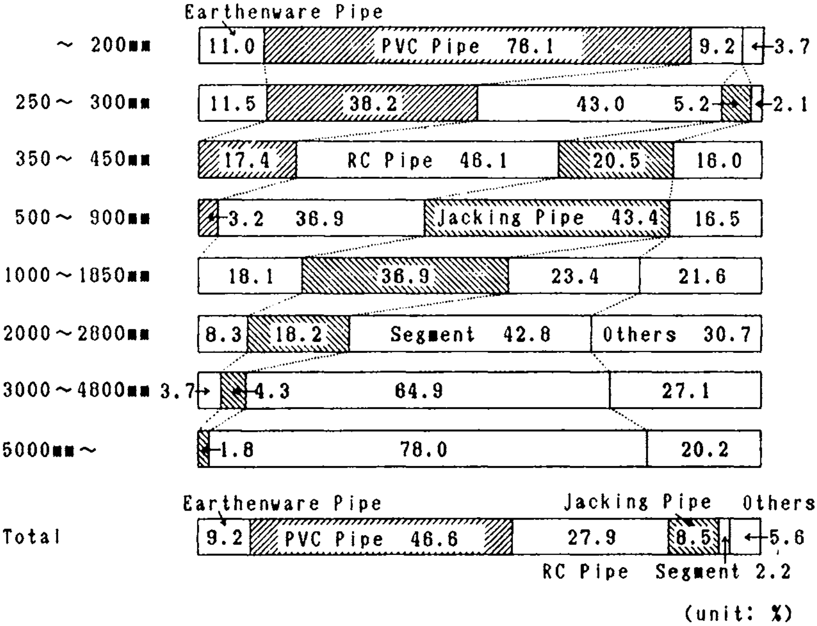


Fig. 1—Share of sewer pipe in Japan