Strengthening of Deteriorated Small-Diameter Sewage Pipes for Increasing their Service-Life and Seismic Resistance

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LISBOA 2012

SUMMARY
In Japan, the extension of sewage pipes has increased to reach actually 420,000 km and the sewage facility stock is increasing more. At the same time, the deterioration of sewage pipes is increasing due to several factors, thus, countermeasures for pipe rehabilitation are urgent. Among the several methods utilized in the rehabilitation of sewage pipes, the self-balance method is frequently utilized because it reduces the bending effect of the pipe to zero. The use of the self-balanced method is improved in this study by placing inside the old concrete pipe a PVC pipe lining wrapped by a coil layer of Glass Fiber Reinforced Plastic, in this form, the resistance of the old concrete pipe is not considered but only the resistance by the PVC pipe wrapped by the GFRP coil layer. Its application is verified herein by performing experiments and analyses.

Keywords: Sewage Pipe Rehabilitation, Static Analysis, Seismic Resistance Countermeasures

1. INTRODUCTION

1.1. Maintenance of sewage system and pipe deterioration in Japan

The development of the sewage system in Japan has progressed rapidly since 1965, and now the sewage treatment penetration rate has reached about 73.7%. As shown in Fig. 1.1, the extension of the sewage pipeline in Japan has increased in the last 30 years by 70,000 km until reach the point to have actually about 420,000 km of pipelines and 2000 sewage facilities. At the same time, the road subsidence that causes penetration of external substances through the ground causing deterioration of sewage pipes such as cracking and corrosion has increased rapidly in the last 10 years as shown in Fig. 1.2. Therefore, it is of great concern the aging of concrete pipes and their service life.

1.2. Earthquake resistant of sewage facilities in Japan

There is a great concern in Japan about the occurrence of a large-scale earthquake that may cause a huge disaster to sewage facilities which may produce an adverse impact on people lives. The actual status of seismic protection upgrading to water treatment plants and sewage main pipelines is shown in Fig.1.3; a 12% corresponds to the earthquake resistant upgrading of water treatment facilities and 14% to the main pipelines. In this situation, it is also necessary to carry out seismic diagnosis of sewage facilities of high-priority in the shortest time to ensure their appropriate seismic performance.

1.3. Sewage pipe rehabilitation methods

There are several methods utilised in recent years to rehabilitate existing deteriorated pipes and to enhance simultaneously their earthquake resistance, Japan Sewage Works Association (2009). Fig.1.4 shows a classification of such sewage pipe rehabilitation methods which are sketched in subsequent figures. On this way, Fig.1.5 shows a sketch of the “inverse method” which consists in introducing a hot PVC pipe in deformed stage with its inner face exposed inside the old concrete pipe, the inner face of the PVC is in inverted position while introducing inside the old concrete pipe, at the same time, the PVC pipe is rolling out inside the old concrete pipe to recover its circular cross-section by applying a cooling process with water. Fig.1.6 shows the "formation method" which consists in introducing a hot PVC pipe in deformed stage with its outer face exposed inside the old concrete pipe, it is done by pulling-out the hot PVC pipe inside the old concrete pipe, thereafter, the PVC pipe recovers its circular cross-section by applying a cooling process with water, and Fig.1.7 shows the spiral liner method which introducing vinyl spiral of proper rigidity inside the old concrete pipe. When taking into account the workability for pipe rehabilitation, the methods for pipe rehabilitation can be classified as follows: a) The "self-balance method" which is frequently utilized because it reduces the bending effect of the pipe to zero, and b) The "Two-layer pipe method" which consists in the placement of a new pipe concentrically to the old concrete pipe, for small pipe diameters such as those less than 800 mm the increase of the thickness of the old pipe causes some difficulties during the rehabilitation work inside the old pipe.

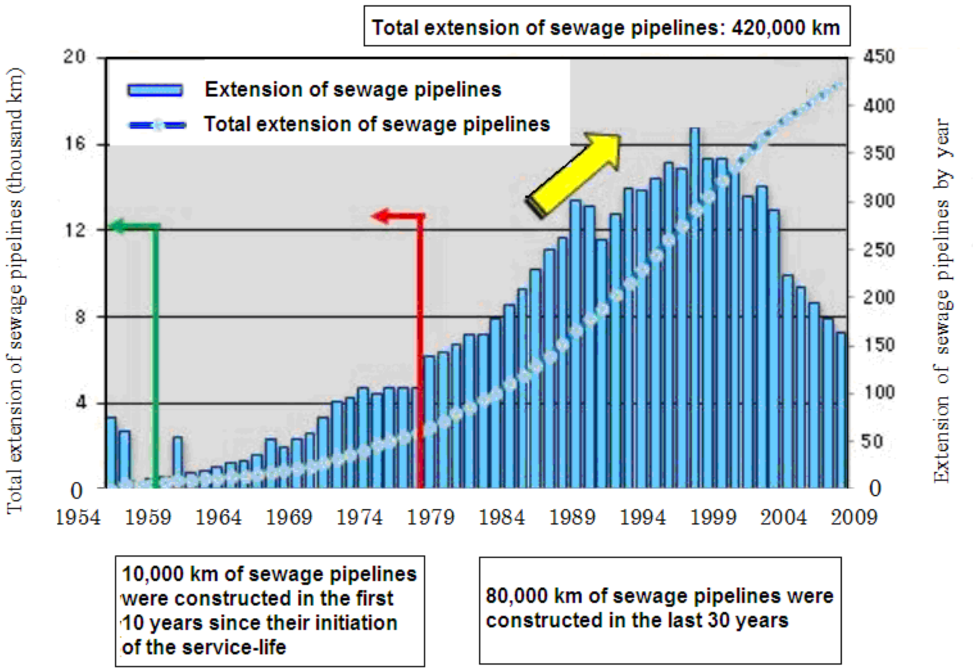


Figure 1.1. Extension of sewage pipe maintenance by year

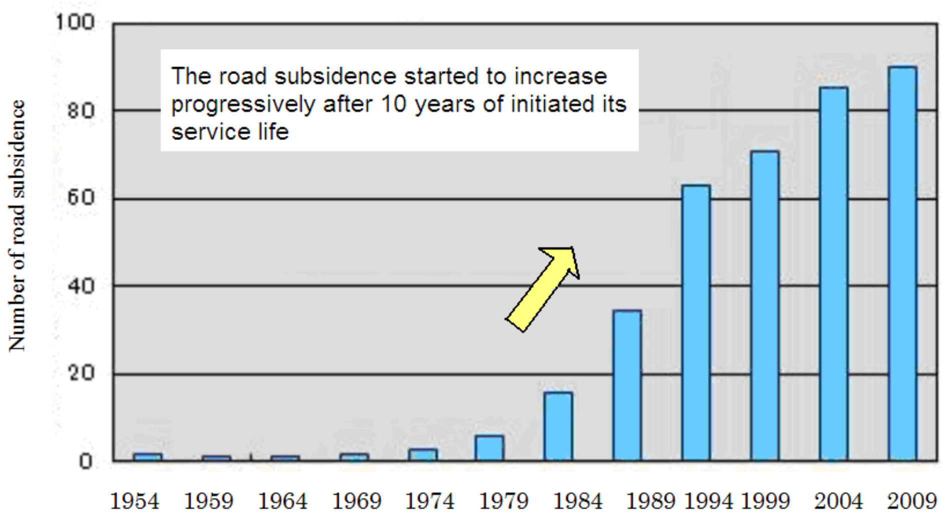


Figure 1.2. Road subsidence in elapsed period of years

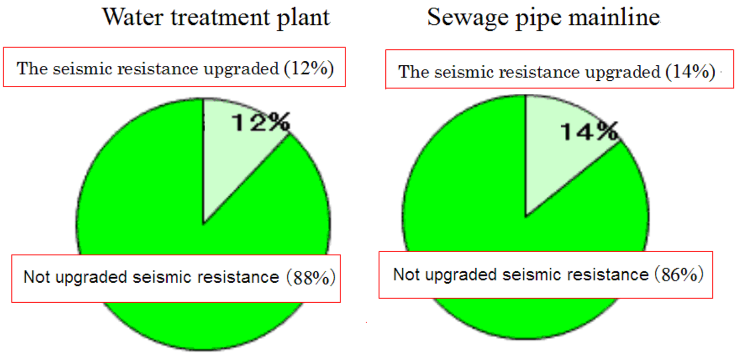


Figure 1.3. Actual status of earthquake-resistance upgrading to water treatment plants and sewage main pipelines in Japan rate of sewage facility

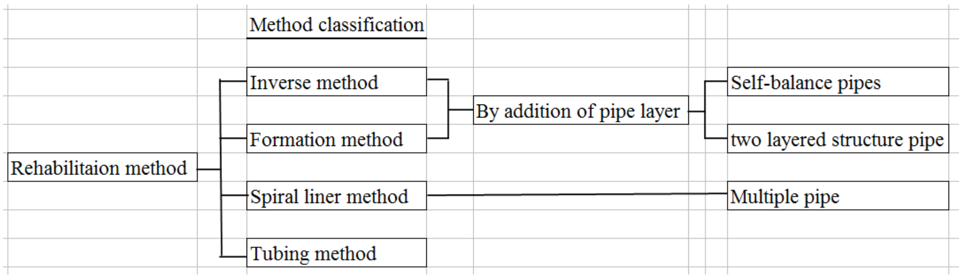


Figure 1.4. Classification of sewage pipe rehabilitation method

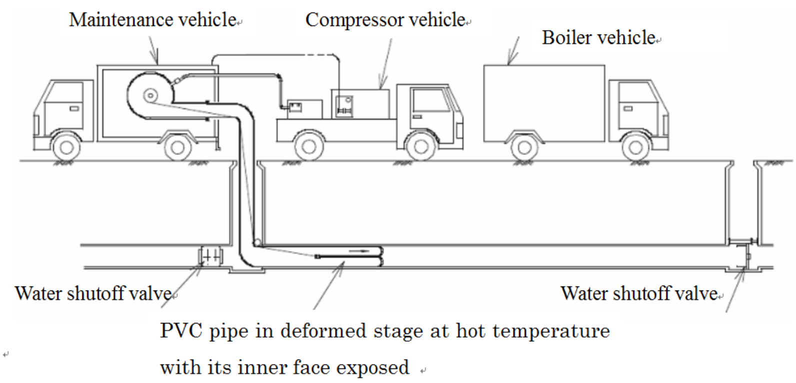


Figure 1.5. Inverse method

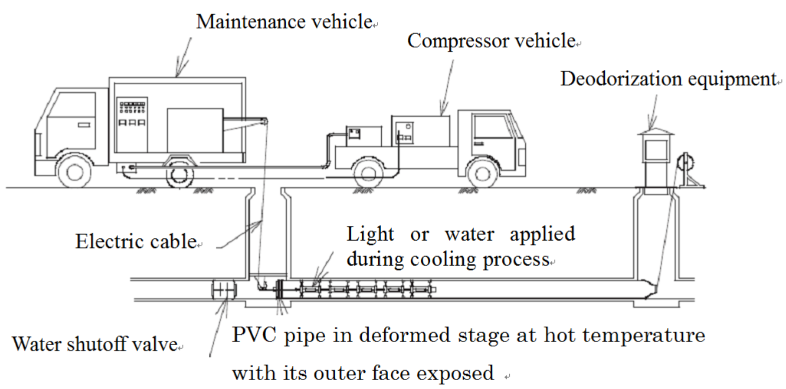


Figure 1.6. Formation method

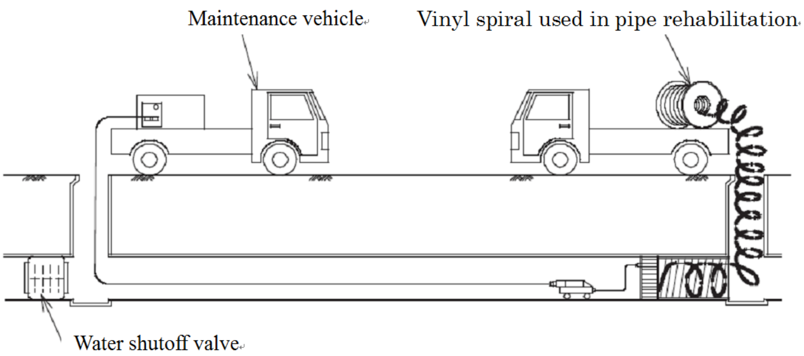


Figure 1.7. Spiral liner method

2. STRUCTURAL DETAILS FOR SEWAGE PIPE REHABILITATION

In practice, ribbed pipes (see Fig.2.2) and corrugate pipes are commonly used for sewage pipe rehabilitation.

Figure 2.1. Ribbed pipe

As mentioned previously herein, the use of the self-balance pipe method is improved in this study by placing inside the deteriorated concrete pipe a PVC lining wrapped by a GFRP coil layer as shown in Fig. 2.2, in this form, the coil layer will increase the strength of the old pipe with a minimum increment of its cross-section, and, at the same time, the PVC lining will protect the inner face of the concrete pipe against penetration of ground water and soil. This composite pipe-coil system is designed herein to resist the ground pressure surrounding the pipe. The double-layered pipe method by using GFRP coil layer treated in this investigation is still not used in large scale in Japan.

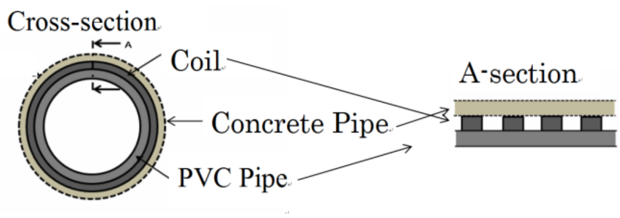


Figure 2.2. Improved Self-balanced method proposed in this investigation

3. EXPERIMENTAL AND ANALYSIS CONSIDERATIONS FOR THE PROPOSED PIPE REHABILITATION MODEL

3.1. Structure of the rehabilitated pipe

As mentioned previously herein, the improved self-balance method proposed in this investigation does not consider the resistance of the old concrete pipe, based on this fact, the only contribution to resistance of the rehabilitated pipe will be given by the PVC pipe lining and by the GFRP coil layer, in this form, the structural analysis of the PVC pipe lining and coil layer can de carry out separately which is advantageous. The models for the experiments and analytical treatment will consider a PVC pipe lining of 450mm outer-diameter and a GFRP coil layer under the following three cases: 1) the PVC pipe lining only as shown in Fig.3.1; 2) A layer of Glass-Fiber Reinforced Plastic coils (GFRP coils) that will be used later to wrap the old pipe (see Fig.3.2); and 3) the PVC pipe–coil system as shown in Fig.3.3.

3.2. Calculation of thickness of the lining material

The thickness of the pipe lining is calculated by using the equation of the ASTM F-1216 which is described in the following:

$$t = \frac{D}{\left(\frac{2C \cdot K \cdot E_L}{P_W \cdot N\left(1-\nu^2\right)}\right)^{\frac{1}{3}} + 1} \tag{3.1}$$

where,

t : Thickness of the pipe lining (mm)
D : Outer diameter of pipe lining (for this study, D = 433.7 mm)
C : Elliptical deformation rate (= 1.0 for new pipes, pipe cross-section is perfectly circular)
$C = \{(1\text{-}q/100)/(1+q/100)^2\}^3$, where, $q = 0$ when old pipe cross section remains circular
K : Buckling progress coefficient which is calculated as:
the buckling force by experiment/ Buckling force by Timoshenko equation,
K=7 is a usual value obtained from the above-mentioned relationship
P_W : Groundwater pressure (Nmm^2)
N : Safety factor, N=2 for PVC pipes
ν : Poisson ratio (0.35)
E_L : Elastic modulus in bending (N/mm^2)

The above equation was obtained when groundwater exists 1.0m below the ground surface and the crown level of the existing pipe is overburden 5.0m, it represents a water level of 4.0m above the crown of the pipe. By using Eq.3.1, the thickness of the pipe lining gives a value of 8.2 mm.

3.3. Design GFRP coil layer

The required thickness of the pipe is selected from the calculation of the vertical deflection at the crown according the following two cases: a) Pipe under live load and vertical ground pressure, and b) bending strength of the pipe according a desired value of vertical deflection at the crown of the pipe. The largest value of coil thickness calculated from the above-mentioned cases is adopted.

The bending stress at the crown and bottom of the pipe is acceptable within the bending strength design value. Also, the design value for the vertical deflection at the crown of the pipe is the 5% of the diameter of the pipe. In this investigation, the ground pressure is supported only by the GFRP coil layer. The thickness of the coil is designed to have a bending stiffness (EI) larger than the PVC pipe, on this basis, the thickness of the coils resulted 8.5 mm. In addition, the field condition is represented by an overburden of 5m and a live load corresponding to a T-25 truck of 25 Ton-f.

3.4. FEM analysis model

When the coil is wrapping the PVC pipe lining the pitch between coils cause the rigidity in the longitudinal direction in the pipe-coil model to be not uniform, it can be seen in Fig. 3.4, in this condition, a two dimensional analysis of the pipe-coil system will give only approximate results because the variation of the rigidity provided by the coil in the longitudinal direction of the pipe is not uniform, by contrary, a three-dimensional finite element analysis will provide accurate results. By taking into account the above-mentioned facts, two-dimensional and three-dimensional finite element analyses for the pipe-only model, coil layer-only model and the pipe-coil model (see Figs. 3.1 to 3.3) were conducted in which calculation was done until reach a maximum displacement at the crown equal to 5% of the diameter of the pipe or coil according the cases evaluated experimentally.

For the analysis, the boundary conditions at the crown and bottom allow only vertical displacement. In the two-dimensional finite element model the pipe and coil are modelled with beam elements as shown in Fig.3.5, while shell elements are used for both pipe lining and coil in the three-dimensional finite element analysis, see Fig. 3.6.

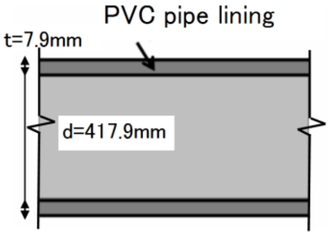


Figure 3.1. PVC Pipe lining

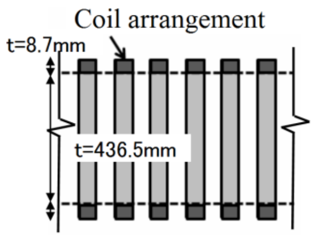


Figure 3.2. Arrangement of coil layer

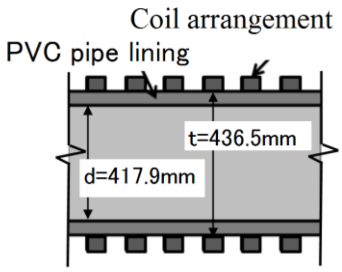


Figure 3.3. Pipe lining+ coil layer

Figure 3.4. Coil layer showing the pitch between coils

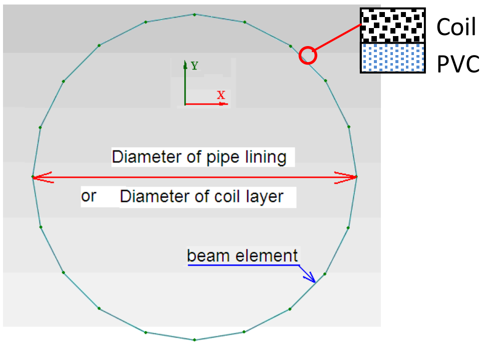


Figure 3.5. Two dimensional FEM model with beam element for pipe lining and/or coil

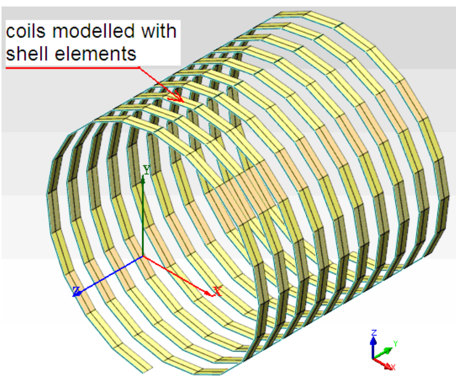


Figure 3.6. Three dimensional FEM model with shell elements (The vertical displacement of the crown was evaluated until reach the 5% of the diameter of the coil

4. EXPERIMENT METHODOLOGY

The experiments to determine the vertical displacement at the crown follows the Japan Sewage Works Association standards JSWAS K-1 as indicated in Fig. 4.1. The experiment is performed for the three analysis cases shown in Section 3 of this paper. Fig. 4.2 shows the PVC pipe lining specimen under vertical load. On the same way, two coil specimens were tested, one coil specimen without pitch as shown in Fig.4.3 and the other considering a pitch of 22.5mm as indicated in Fig.4.4. For the case of the specimen considering the pipe lining wrapped by the coil layer, it was considered only the case of 22.5 mm for the pitch (see Figs.4.5 and 4.6) under the following two loading cases: a) The vertical load “P” acting directly on the coil layer as shown in Fig. 4.5 and, b) the vertical load “P” acting directly on the PVC pipe lining as indicated in Fig. 4.6. The vertical load “P” was applied until reach a maximum displacement at the crown equal to 5% of the diameter of the pipe or coil according the cases evaluated experimentally.

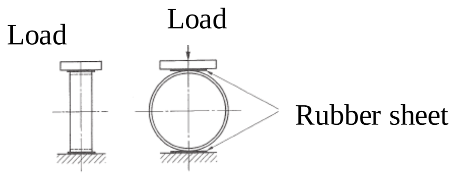


Figure 4.1. Pipe loading tests performed according the Standard of the Japan Sewage Works Association

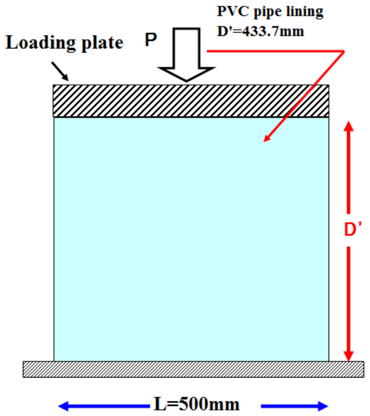


Figure 4.2. Side view of the PVC pipe lining specimen under uniform vertical load along its length (The load P is acting on the surface of pipe lining)

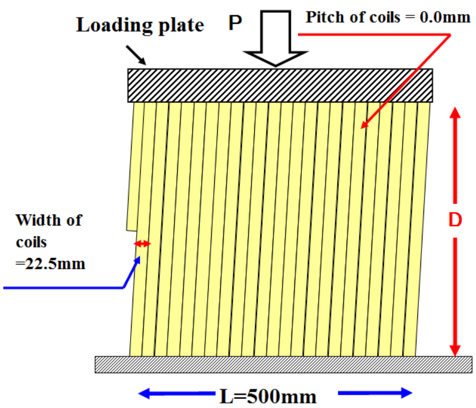


Figure 4.3. Model of coil layer (no pitch is considered) (The load P is acting on the coil layer)

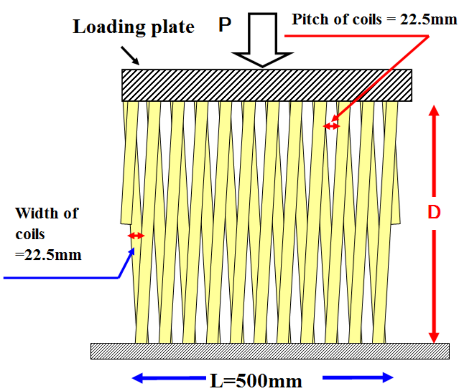


Figure 4.4. Model of coils only (with 22.5mm pitch) (The load P is acting on the coil layer)

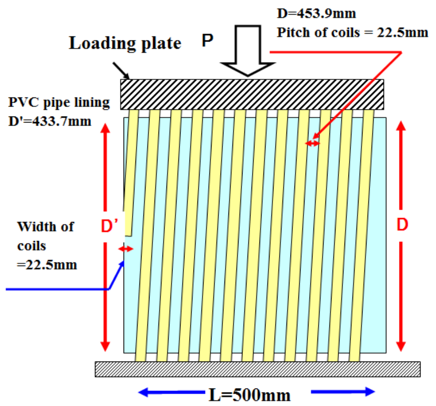


Figure 4.5. Model of PVC pipe lining + coil (The load P is acting on the coil layer)

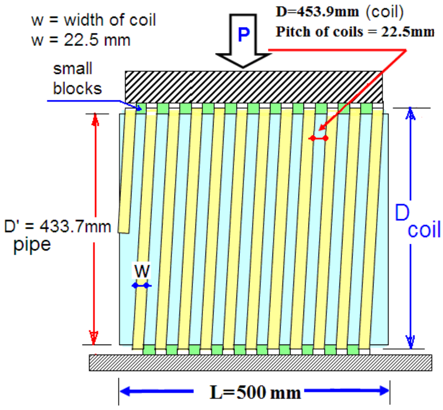


Figure 4.6. Model of PVC pipe lining + coil with 22.5 mm pitch (The load P is acting on the pipe lining)

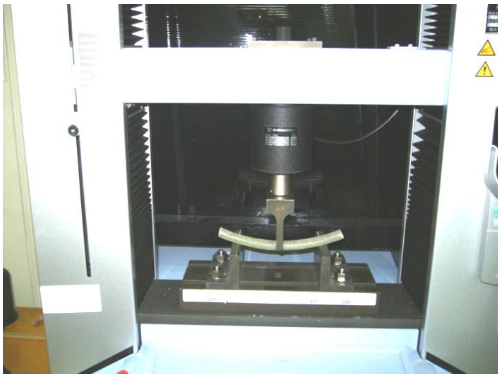
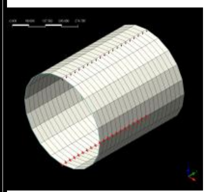
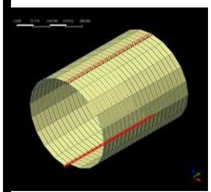
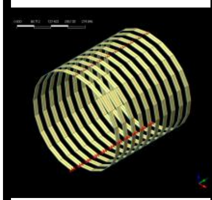
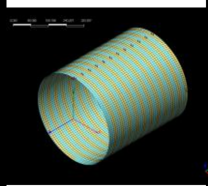
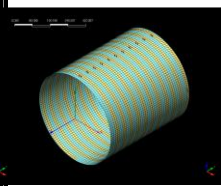


Figure 4.7. Bending test of a piece of coil with vertical load applied in the concave and convex positions

5. EXPERIMENT AND ANALYSIS RESULTS

Table 1 shows the experimental results that correspond to the vertical displacement of 5% of the diameter of the pipe lining for all cases. These experimental results are compared with the analysis results obtained from the two and three dimensional finite element analyses. From Table 1, it can be observed that analysis and experimental match well for the pipe lining specimen.

Table 1. Experiment and Analysis Results

					
Analysis model	Pipe lining	coil（no-pitch）	Coil 22.5mm pitch	PVC pipe Lining + coil 22.5mm pitch (vertical load on coils)	PVC pipe lining+coil 22.5mm pitch (vertical load on PVC pipe lining)
2D-FEM analysis results	0.70 kN	12.77 kN		13.20 kN PVC Pipe lining+ coil	
3D-FEM analysis results	0.62 kN	9.20 kN	4.11 kN	4.95 kN	4.95 kN
Experimental results	0.61 kN	9.63 kN	4.40 kN	5.25 kN	4.68 kN

However, for the coil specimen without pitch, the displacement obtained from the three-dimensional FEM analysis differs only 5% respect to the experimental results, while for the coil specimen with 22.5mm pitch the vertical displacement differs in 7%. For the case of pipe lining wrapped by coil pitched at 22.5mm, the difference between three-dimensional analysis and experimental results is 6%. Thus, it can be said that results of experimental tests and the three dimensional analysis match reasonable. However, when comparing results of the experiments with the ones of the two-dimensional analysis the difference is almost 30% for the case of the vertical displacement at the crown.

6. CONCLUSIONS

An innovative method to rehabilitate old sewage pipes and to upgrade their resistance has been proposed herein. The use of coil layers to wrap the existing pipes is easy to install in-situ and the high-rigidity of the coils fabricated with GFRP ensures an effective control of deflection of old pipes under surfaces that may sustain settlement due to truck loads and the changes of overburden pressure along the life of the sewage pipes. Experimental and analysis results of the pipe lining only model, coil-only model, and pipe lining wrapped by coil models presented herein make clear that the vertical displacement at the crown of all models can be well controlled by using GFRP coils which have high rigidity and strength. This research is being improved by considering the same models described in this paper but under dynamic application of vertical loads and considering the models buried in ground.

ACKNOWLEDGEMENT

The authors appreciate greatly the kind support of Kubota CI Company for the development of this research

REFERENCE

Japan Sewage Works Association. (2009), Japanese Sewage, Japan Sewage Works Association