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Numerical Analysis of the Behavior of Pressurized Underground Pipelines Rehabilitated by Cure-In-Place-Pipe Method

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Contents

1. Introduction

- Numerical simulation software ABAQUS was used to simulate different geometries of underground pipelines, i.e. straight line and curved pipeline, damaged by corrosion and the performance of the Cured-In-Place-Pipe (CIPP).
- The results suggest that it can reinforce the damaged pipe by reducing the stress concentration and reducing the differential displacement.
- The design of the CIPP liner could be further optimized in terms of its design.

Corroded pipelines

Corroded void

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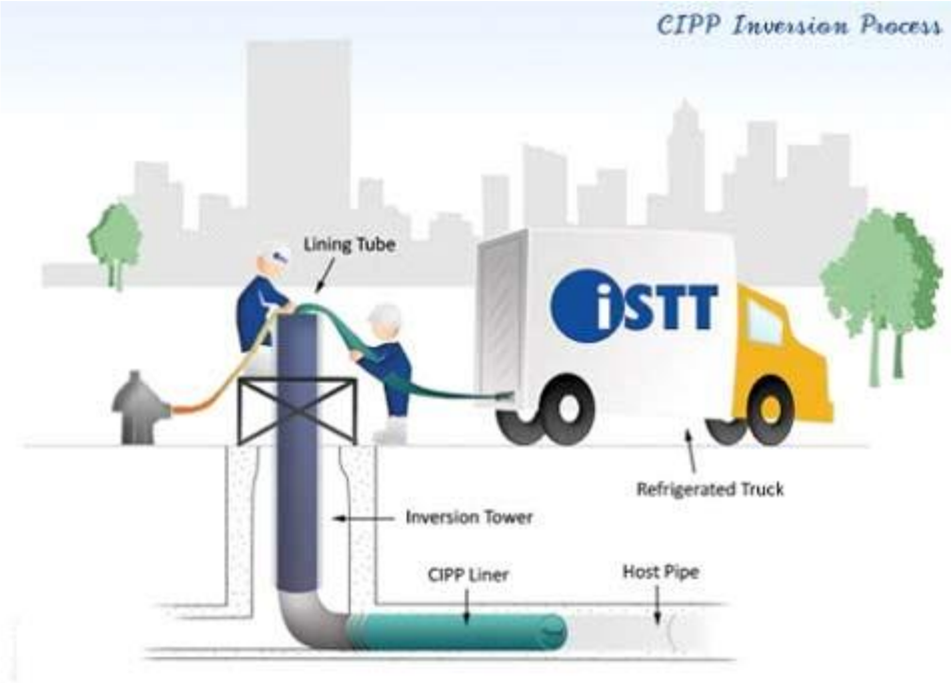

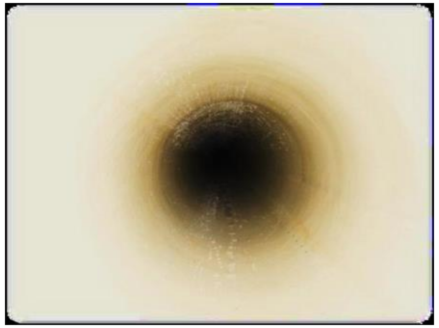

2. Methodology

2.1 Meshes and Boundary Conditions

- The three-dimensional functions of the finite element software ABAQUS (Abaqus, Inc.,2005) were applied in this study.
- three-dimensional solid elements (C3D8R) are used to simulate the soil, the pipe, and the liner
- interface elements are applied to simulate the soil-pipe frictional behavior and the pipe-liner bounding behavior .
- the bottom face is confined by hinges and the surrounding vertical faces are framed by rollers

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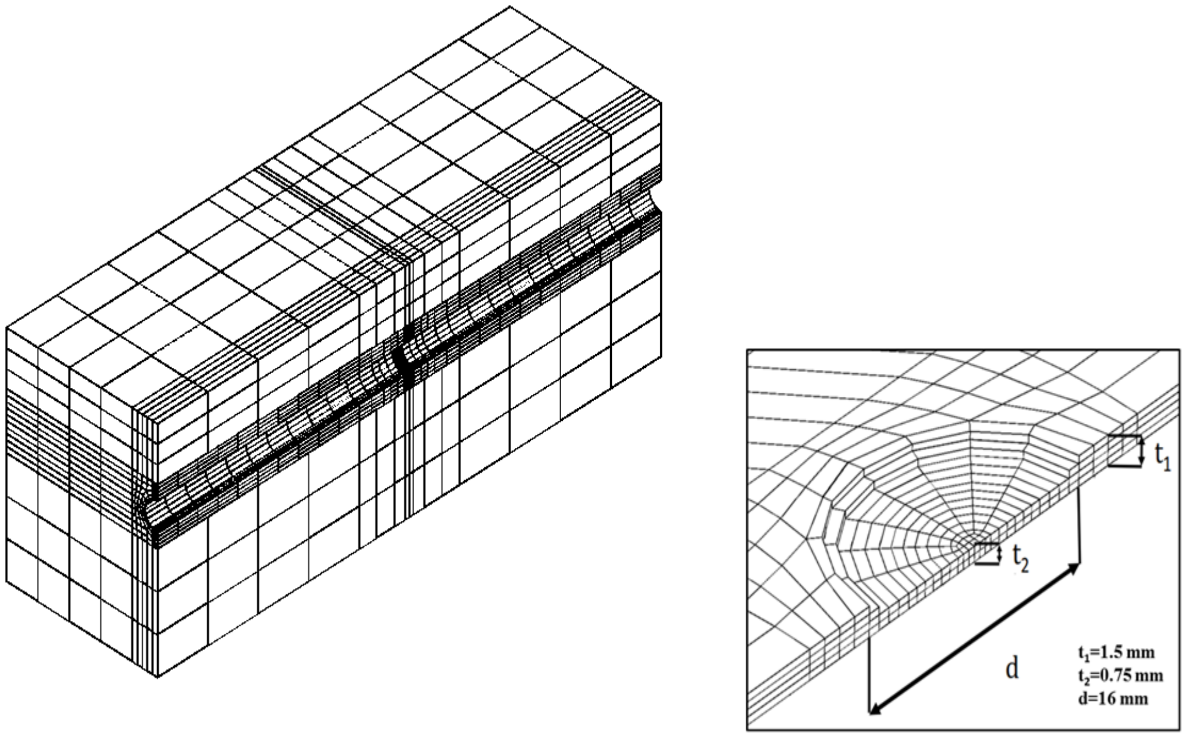
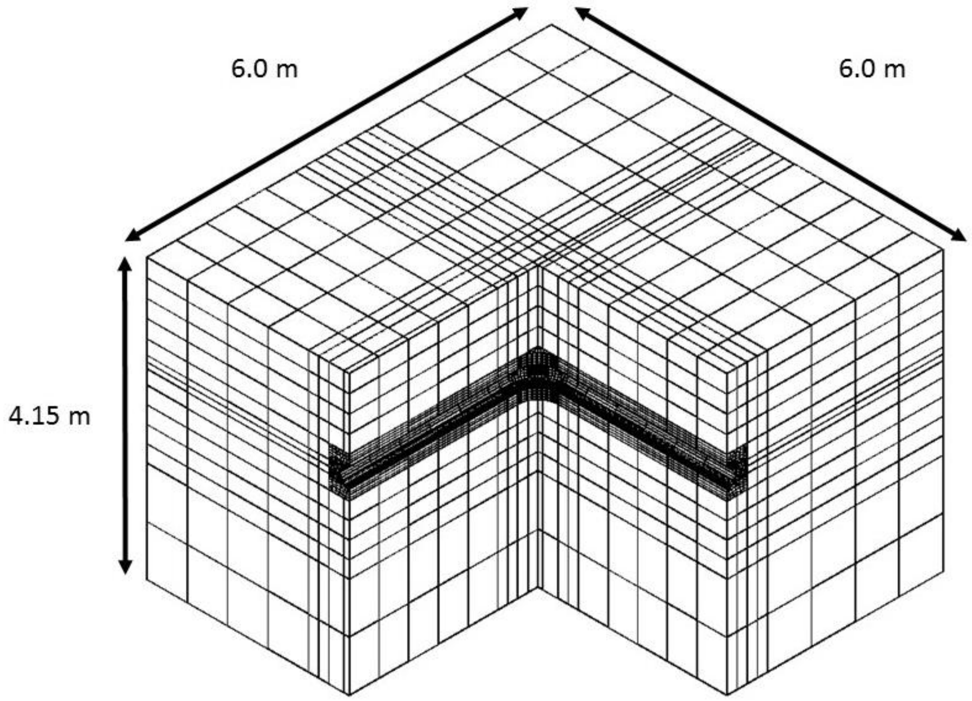


Straight-line case



Curved case

- Interface elements were applied to simulate the interfaces between the soil and pipe, and the interface between the pipe and liner.
- For the interface elements, hard contact was considered as the normal behavior, and the penalty function was considered as the tangential behavior.
- The properties of contact were obtained by lab. tests. frictional coefficient in the tangent direction was set to 0.46 based on the study by Yen and Shou (2015)
- The behavior in the normal direction, it was set to be hard contact in which the contact pressure=0 for the tolerance of contact pair > 0; the contact pressure≥0 for the tolerance of contact pair≤0. Contact pressure on the pipe would be created from the weight of the soil.

3. Numerical Modeling

Parameter	Sandy soil	Gravelly soil	Aluminum Pipe	Carbon Steel Pipe	Rehab. Liner
γ_t (kN/m^3)	16.7	21.6	26.9	77.0	18.5
ϕ (˚)	38.3	40	---	---	---
Ψ (˚)	8.3	10	---	---	---
c (MPa)	0.0137	0.015	---	---	---
K_o	1	0.398	---	---	---
ν	0.3	0.3	0.330	0.286	0.385
E (MPa)	1.90	300	68000	205700	13000

The soil parameters were based on rational assumptions from the aforementioned studies.
The properties of the rehabilitation liner were from Ashimori Industry Co (2016).

- Typical pipe diameters were chosen based on Chinese National Standard (CNS) 4626 G3111 of Taiwan (2012), that defines the specifications of carbon steel pipes for operation under pressure.
- The size of the modeled soil mass differed according to the size of the pipes. The distances from the left and right boundaries of the soil mass to the center of the pipe were about six times the diameter of the pipe. The distances from the bottom boundary of the soil mass to the center of the pipe were about five times the diameter of the pipe. Both the soil and the pipe were 10m in length.
- Detailed dimensions of the models are listed in Table 2.

Case	Shape of pipe	Area of Damage (mm^2)	Location of Damage
1	Straight-line	2826	Top
	Curved	15133	Inner and outer side
2	Straight-line	7850	Top
	Curved	55296	Inner and outer side
	Curved-small	18432	Inner side

4. Results and Discussion

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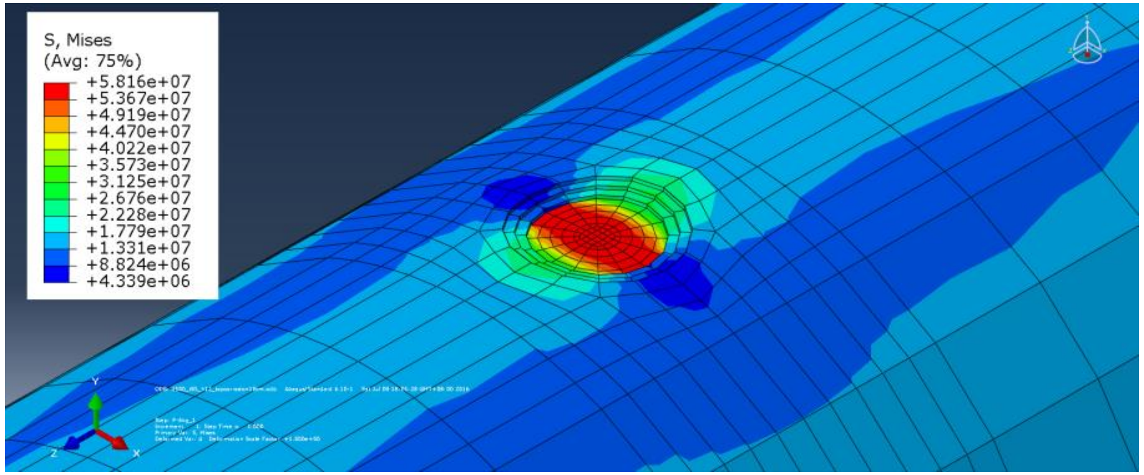
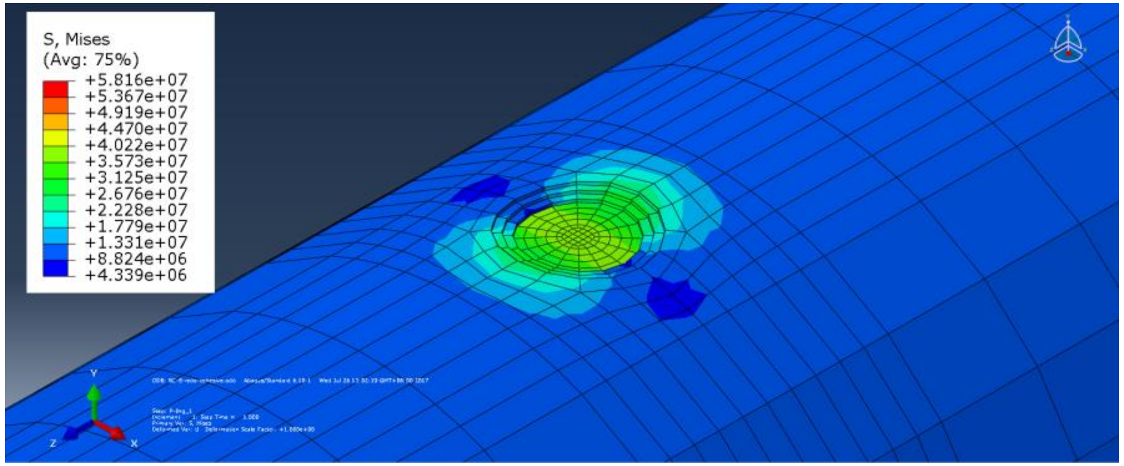


Before liner installation



After liner installation

The stress fields before and after the installation of liner for the straight-line case with internal pressure 588.4 kPa.

The results reveal the effect of internal air pressure, i.e., the stress increases about 1.8 times more comparing Case 2 with Case 1 as pressure increases up to 588 kPa.

The impact of internal air pressure on the displacement is even more significant, increasing about 2.5 times more comparing Case 2 with Case 1 as pressure up to 588 kPa.

The comparison shows that the stress concentration and displacement due to the damage are more serious for the case with larger diameter and smaller pipe wall thickness. Nevertheless, the installation of CIPP liner can significantly reduce the stress concentration and displacement, especially for the case with higher internal air pressure.

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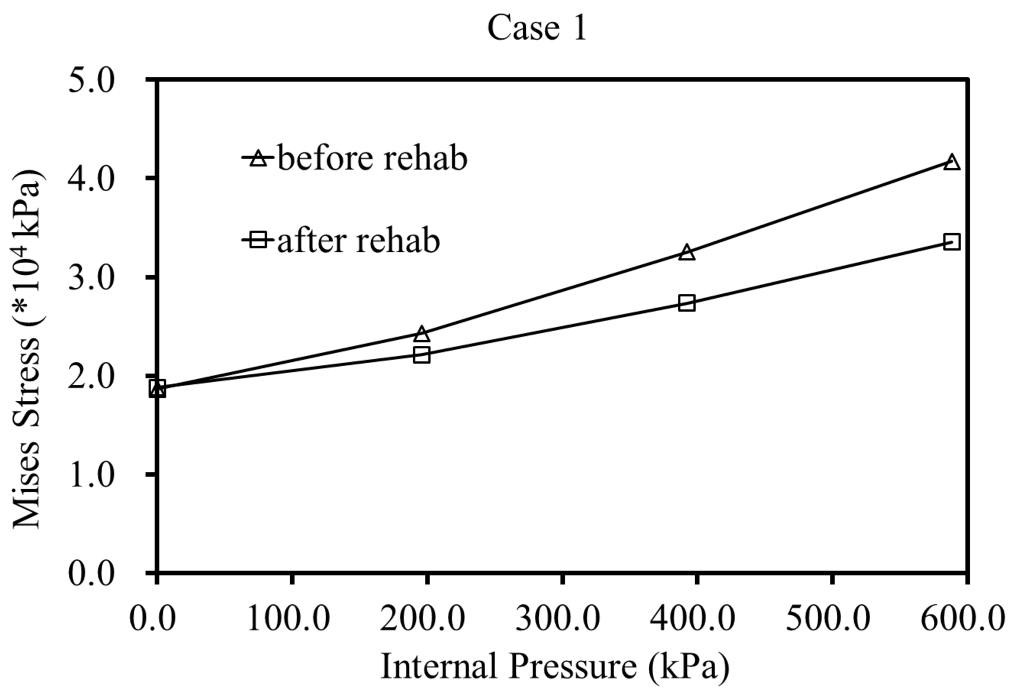

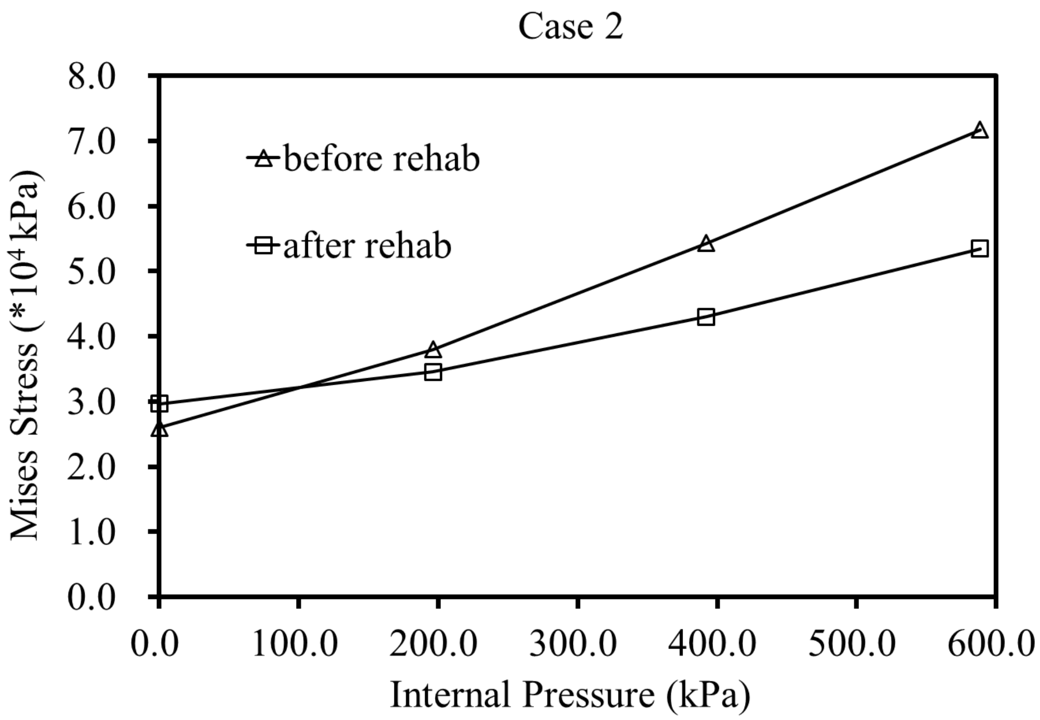

The stress and displacement at the void center before and after the installation of liner for the straight-line case with surface loading

- The results suggest that there is stress concentration in the damage area for both Case 1 and Case 2; however, it is more significant for Case 2. The vertical displacement is strongly influenced by the surface loading; the displacement increases to 0.71 mm and 0.99 mm for Case 1 and Case 2 without internal air pressures. However, the displacement can be reduced slightly when the internal air pressure increases. Similarly, the installation of CIPP liner can significantly reduce the stress concentration and displacement.

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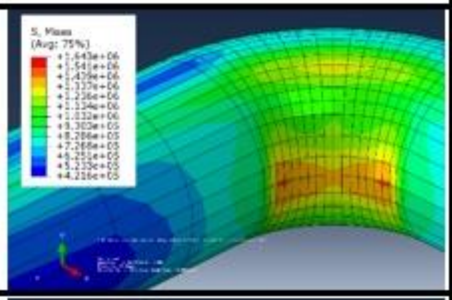
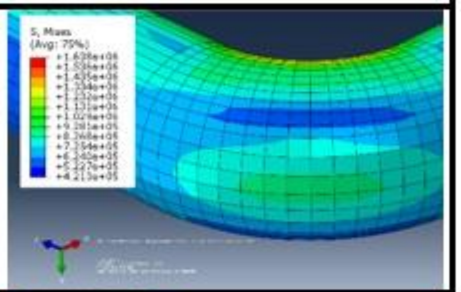
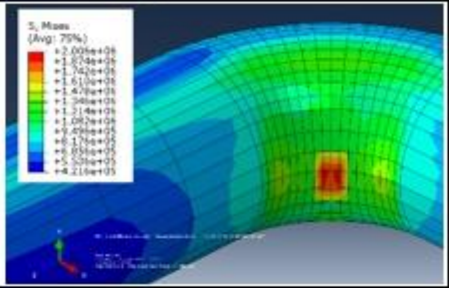
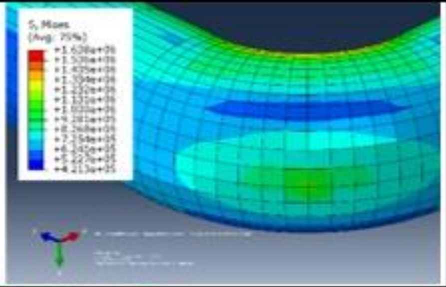
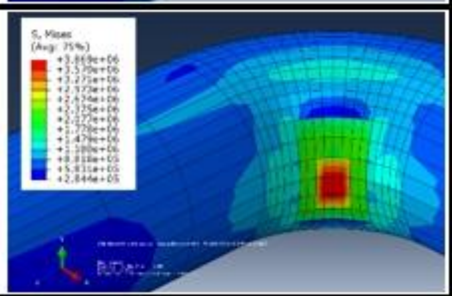
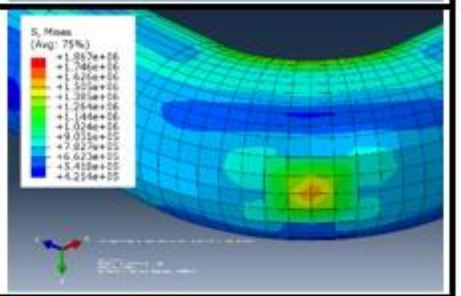
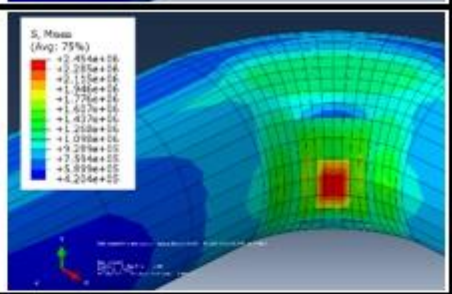
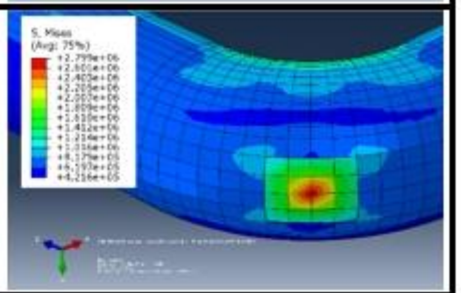
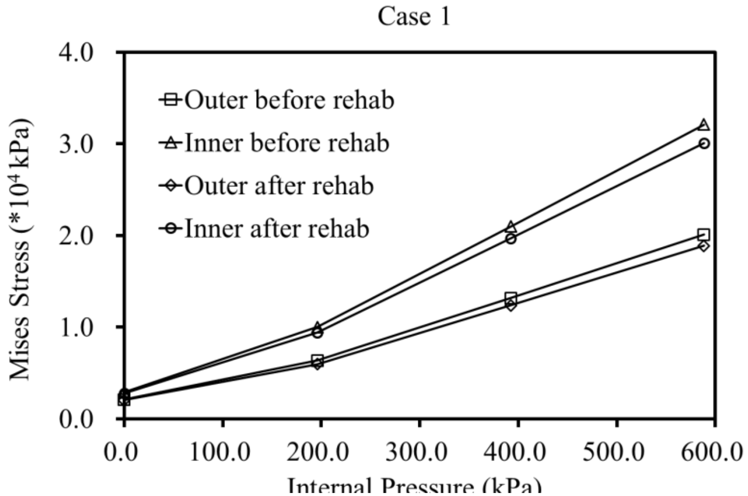
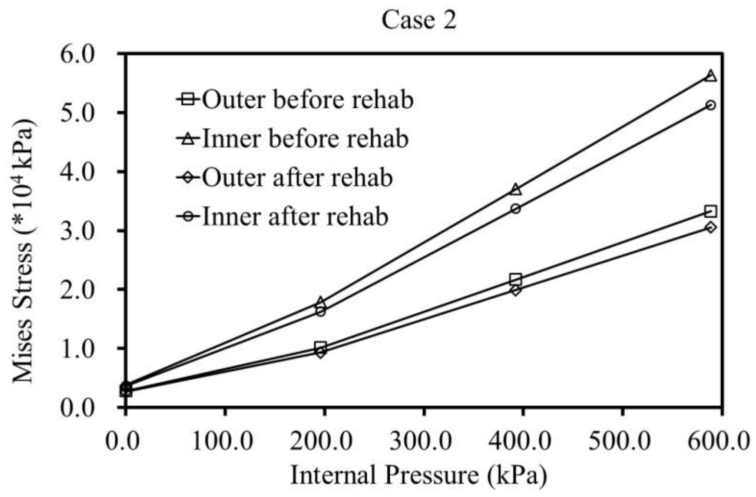
step	Inner side	Outer side
No corrosion		
Step 1 corrosion		
Step 2 corrosion		
Final step corrosion		





The stress fields and the stress at the void center before and after the installation of liner for the curved case without internal pressure

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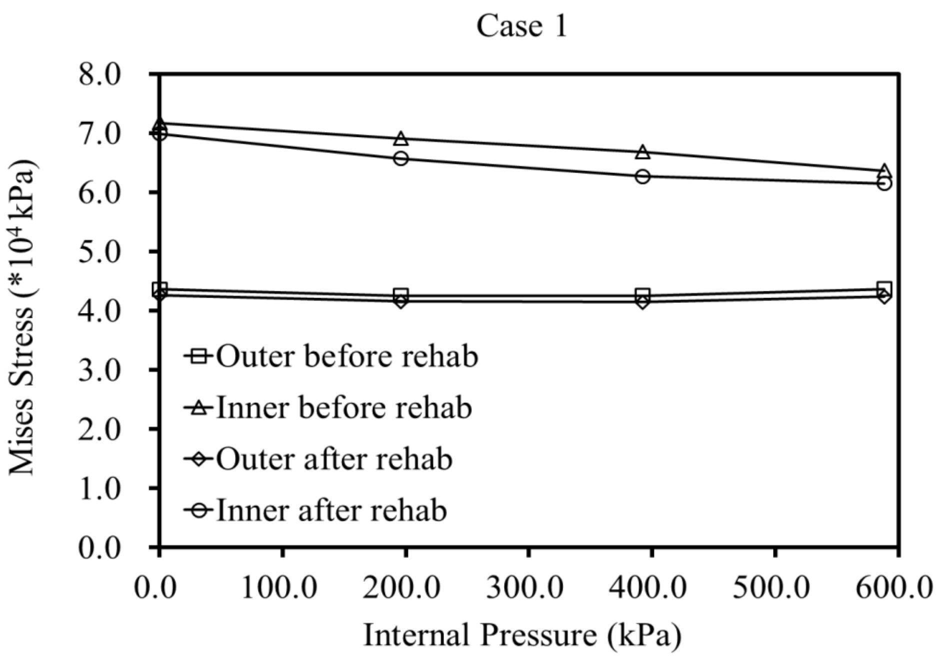

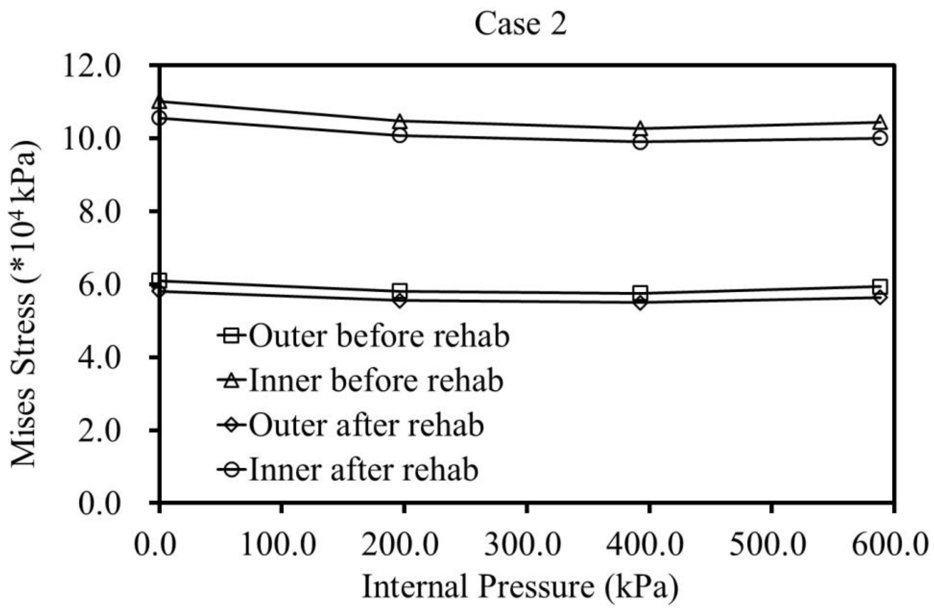

The stress at the void center before and after the installation of liner for the curved case with surface loading.

For the curved cases, the results show that the stress concentrations are influenced by the internal air pressure, the location and size of the damage. The stress increases as the internal air pressure increases. Case 2 is more critical than Case 1. And the impact is more significant for the case with damage at the inner side of the curved pipe. The results in Fig. 6 suggest that the above influences are more significant for the cases with surface loading. After the installation of CIPP liner, the stress reduces, though it is comparatively less significant comparing with the straight-line cases.

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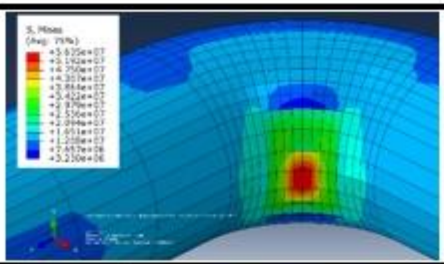
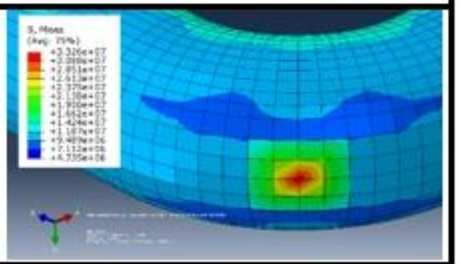
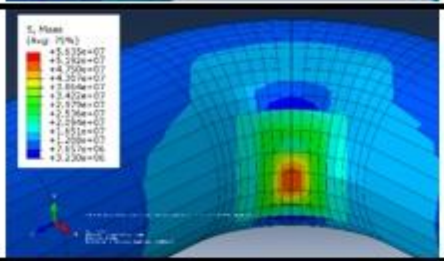
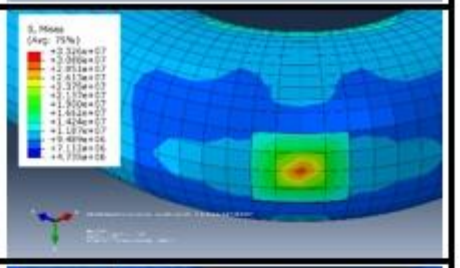
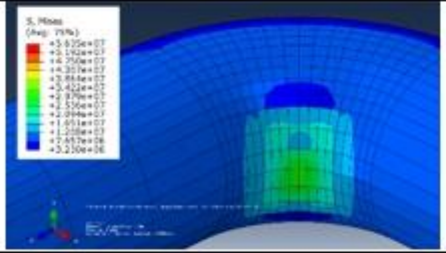
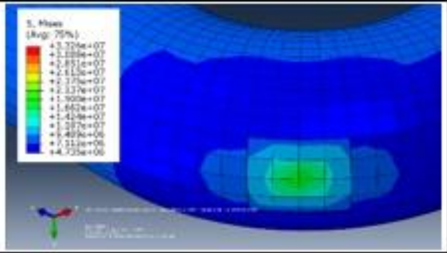
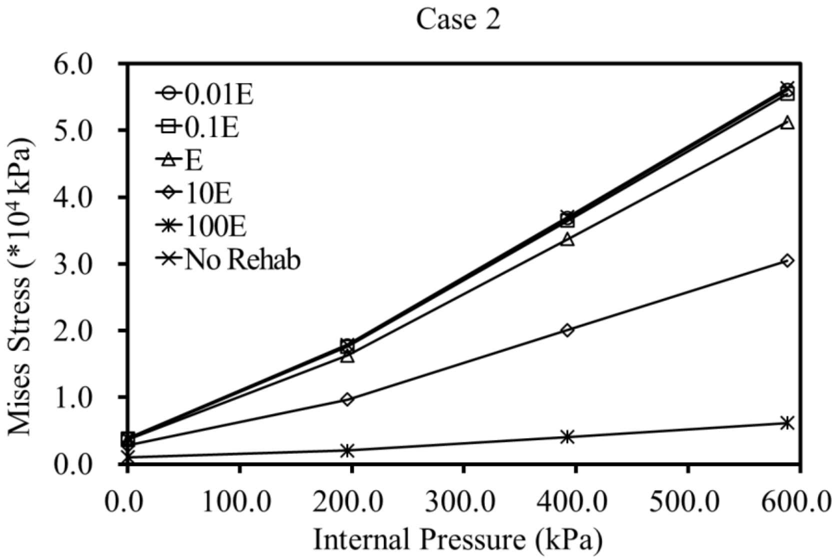
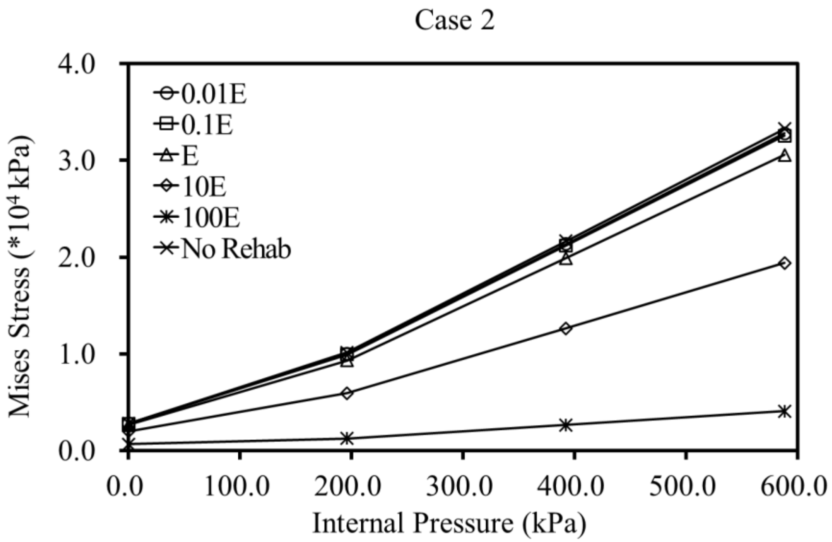
type	Inner side	Outer side
No liner		
Regular liner with E		
Stronger Liner with 10E		





The stress fields and the stress at the void center before and after the installation of liner for the curved case with different liner deformation property

In order to further investigate the performance of the CIPP liner, this study changes its Young's modulus and the strength of pipe-liner interface. The various parameters include two interface strength, i.e., regular and high strength, and five different Young's moduli, i.e., 0.13, 1.3, 13, 130, and 1300 GPa. The results in Figs. 7-8 reveals that the change of stress is insignificant for the cases of smaller Young's modulus, however, the stress can be reduced significantly for the cases of larger Young's modulus.

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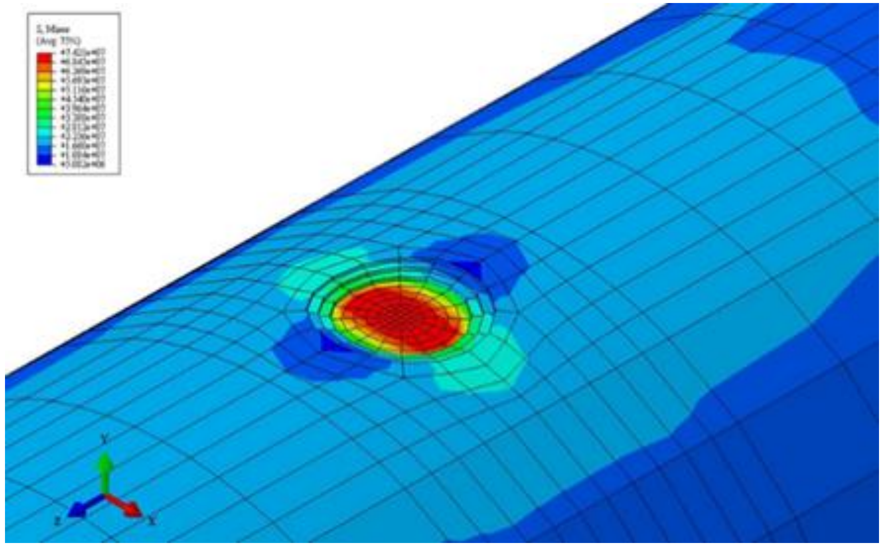

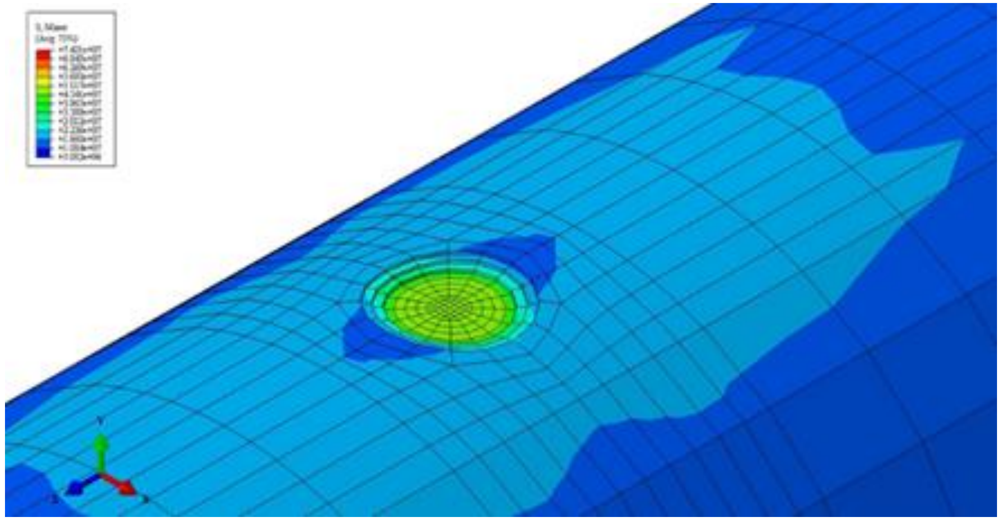

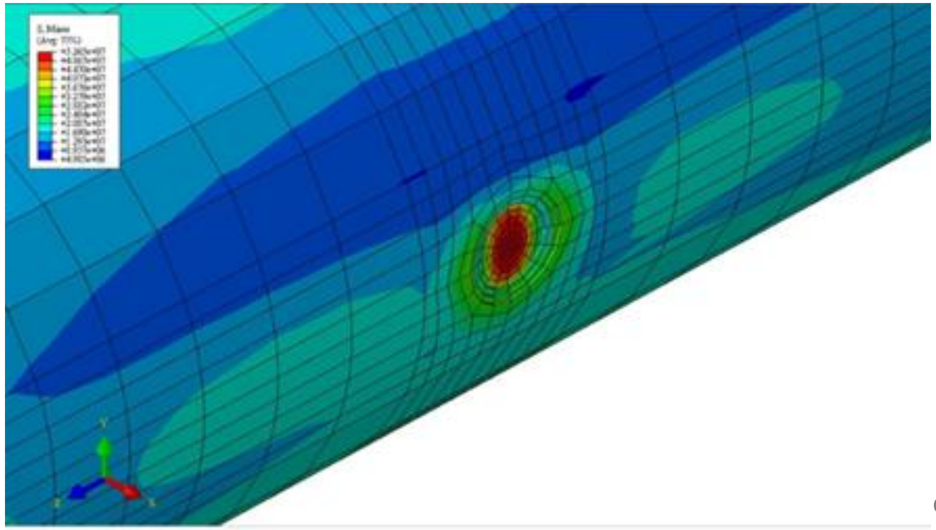

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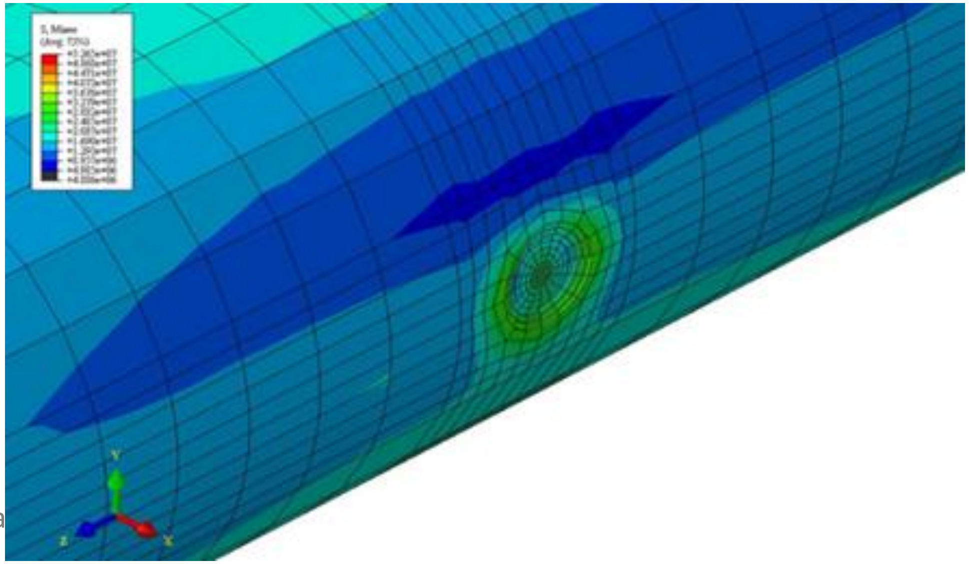

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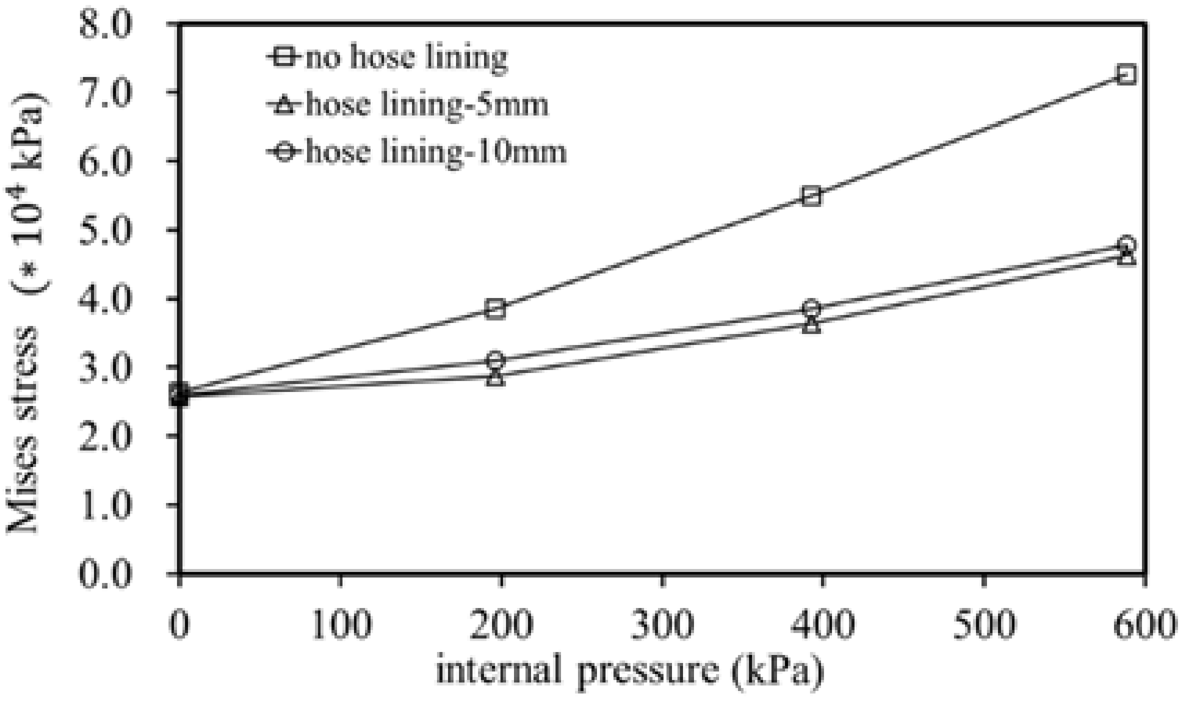

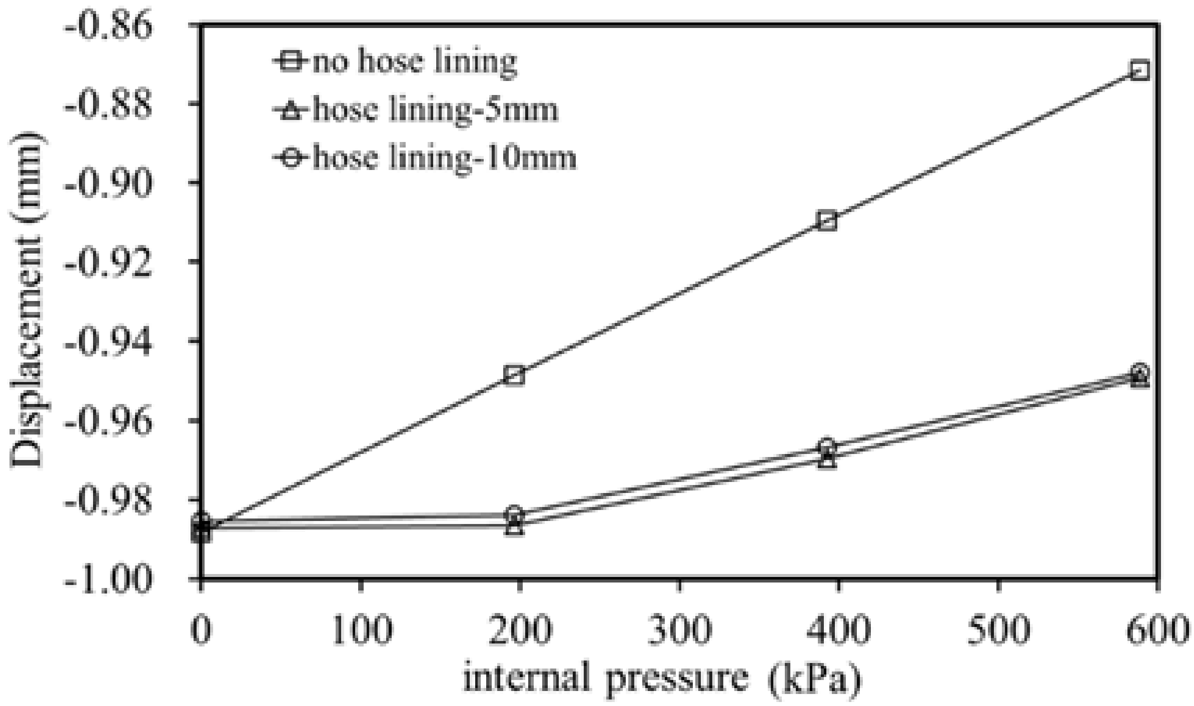

5.Conclusion and Suggestions

- From the parametric study for the corrosion damaged buried pipe, it shows that the thickness of the pipe wall in the most critical factor.
- A larger diameter to thickness ratio (D/t), i.e., a small pipe wall thickness, resulted in a greater increase of stress and displacement at the corrosion void. And the increase in stress and displacement was positively correlated to the size of the void.
- The results also suggest that the liner could be designed to economically optimize its thickness. In addition, more comprehensive analysis are necessary for the typical problems about the CIPP construction quality, such as the imperfect adhesion of the liner to the old pipe, etc.

- The influence of pipe wall thickness on the stress concentration at the void is similar for the straight-line case and the curved case. For the curved pipe, the stress at the center of the void increases as the internal air pressure increases, for both the case with a void at the inner side and the case with a void at the outer side. However, the case with a void at the inner side in more critical than the other case.
- The performance of the rehabilitation is strongly affected by the deformability of the liner. The higher the Young's modulus of liner is, the lower stress concentration at the center of the void will be. In addition, for the case of curved pipe, a relatively higher liner Young's modulus will be necessary to assure the rehabilitation performance.
- Properly Installation of the CIPP liner in the corroded pipe can significantly reduce the stress concentration near the void area, which can reduce the risk of pipe bursting and extend the service life of the pipe.

Thanks you for your Attention

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