Tunnel Lining with Corrugated FRP Sheets

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ABSTRACT

This paper represented the numerical analysis of the tunnel lining which was used for maintaining the old tunnel. An old tunnel covered with a concrete is prone to deteriorate due to an aging effect and a water penetration. In the rehabilitation of lining concrete, a steel plate and FRP (Fiber Reinforced Plastics) or carbon sheet have been applied. However, these sheets show small flexural rigidity and do not flow out the penetrating water. In this paper, FRP corrugate sheet was proposed. The tunnel lining was made from FRP corrugate sheet that supported the lining concrete in the tunnel and flowed the water and the moisture swept on the tunnel surface. The FRP corrugate sheet was supported by the anchor bolts. In numerical analyses, the finite element degenerate shell was adopted to represent the FRP sheet behavior. From the numerical analysis, the effectiveness of the FRP corrugate sheet was confirmed.

INTRODUCTION

Tunnels have been used for a road, a railway, a sewage line and industrial usage. In case of the tunnel with large cross section (see Figure 1), the tunnel has been stiffened by a segmental lining or a concrete lining. However, at the crown of the tunnel, a poor concrete has been placed because of the breezing of a concrete. The lining has constructed by pouring the concrete from the top of the cross section. Therefore, the concrete at the arch crown was low strength and was prone to peeling and cracking. Several accidents by a concrete cracks have been reported and a concrete block falling occurred (Asakura 2003). Especially, in the cold region, the water penetrated into the cracks of concrete and cracks opened and closed repeatedly due to the freezing and the melting the water. Therefore, to maintain such a concrete lining, the cover sheet should be placed inside the tunnel. The cover sheet has placed not only to support the falling concrete brocks but also to flow the moisture or the swept water.

This paper represented the numerical analysis of the tunnel lining used for maintaining the old tunnel. The tunnel lining was made from FRP (Fiber Reinforced Plastics) corrugate sheet that supported the lining concrete in the tunnel but also to flow the water or / and the moisture swept on the tunnel surface.

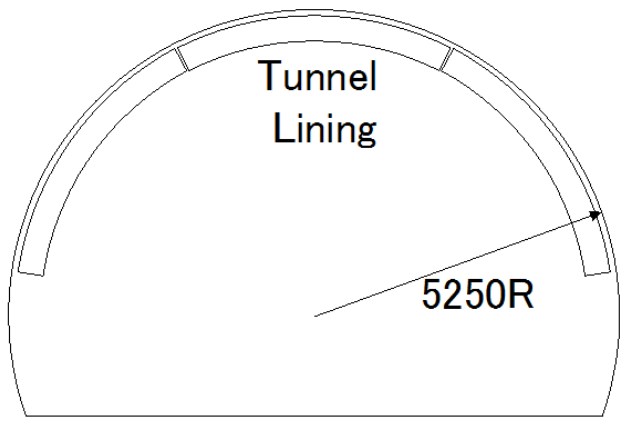


Figure1. Cross section of tunnel

The FRP corrugate sheet was supported by the anchor bolts fixed on the rock. In numerical analyses, the finite element degenerate shell was adopted to represent the FRP behavior. The proposed FRP corrugate sheet was adopted and the distribute load equivalent to the concrete peeled from the tunnel lining was applied and the stresses of the FRP corrugate sheet, the tensile force of bolts and the deflection of FRP corrugate sheet were investigated.

NUMERICAL ANALYSIS

FRP corrugate sheet models and the design load. Figure 1 shows the tunnel cross section. The radius is 5250mm. In this example, three FRP corrugate sheets are placed inside tunnel. Two types of FRP corrugate sheets are proposed.

Table 1. Material properties

Tensile Strength	150MPa
Elastic Mudulus	10.8GPa

One is the FRP corrugate sheet with 4 drains with equal pitch 225mm. This sheet has been used for a tunnel lining to flow out the surface water. The drain shows a half circle of 50mm radius (see Figure 2 (A)). The thickness is 3.3mm. The other is the same FRP corrugate sheet. But the FRP strip plates with 40mm width by 3.3mm thickness are patched on each plateau of FRP corrugate sheet (see Figure 2 (B)) to prevent the punching failure of the FRP corrugate sheet. In-situ hole in anchor bolt is placed on a tunnel lining. The anchor bolts connect between FRP corrugate sheet and the rock behind the concrete liner. Totally 5 bolts are placed in transverse direction.

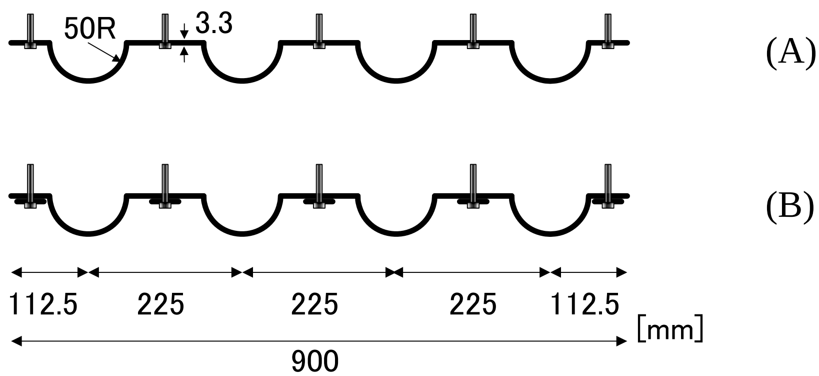


Figure 2. Proposed cross section of FRP corrugate sheet

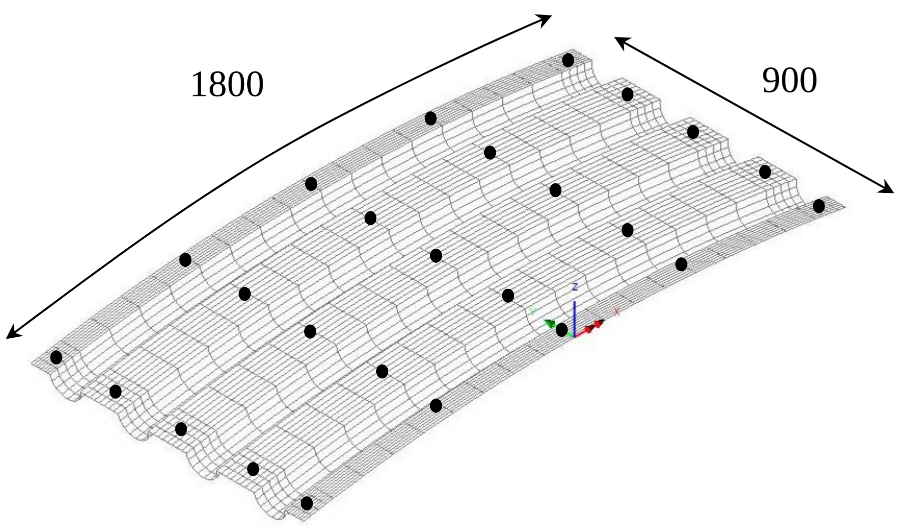


Figure 3. Dimensions of FRP corrugate sheet

In longitudinal direction, these bolts are placed in every 400mm distance from the center to the center. Therefore, totally 25 bolts are used (see Figure 3). The material properties were obtained from the tensile tests of FRP sheet and are shown in Table 1.

The assumed design load is the distribute load equivalent to 300mm concrete cover. Loading is applied only the plateaus of the cross section shown in Figure 2 because the portion of the curved drain is not contact to the lining concrete.

FEM Procedure. In numerical analyses, Finite Element procedure based on the isoparametric degenerate shell representation is adopted (Hara 2009 and Hinton 1984). To simulate the nonlinear behavior, Green-Lagrange strain definition is adopted to represent the geometric nonlinearities and the elastic-plastic stress definitions are adopted considering material nonlinearities. Also, to represent the stress distribution of the shell through the thickness, the layered approach is adopted. The shell is divided into 10 layers. Displacement incremental scheme is adopted in the calculation of nonlinear equation to avoid the numerical instability. In FEM model, the FRP corrugate sheet is divided into 72 and 24 isoparametric 8 node quadratic elements in transverse and longitudinal directions, respectively (see Figure 3).

Numerical results of FRP corrugate sheet under distribute load. To investigate the performance of the FRP corrugate sheet, the corrugate sheet without stiffening strips as shown in Figure 2 (A) is analyzed. The corrugate sheet is supported at 25 points shown in Figure 3. The distributed load is applied gradually until the flexural tensile stress in the FRP corrugate sheet exceeds its tensile strength shown in Table 1. The maximum stress and the deflection under design load are shown in Table 2.

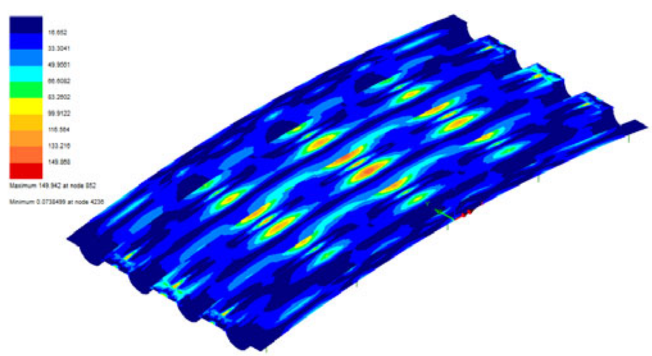


Figure 4. FRP corrugate sheet (A) under distribute loading (stress)

Table 2. Maximum stress and deformation under design load

	FRP(A)	FRP(B)
Max. stress (MPa)	2.80	1.05
Max. displacement (mm)	5.19	3.48

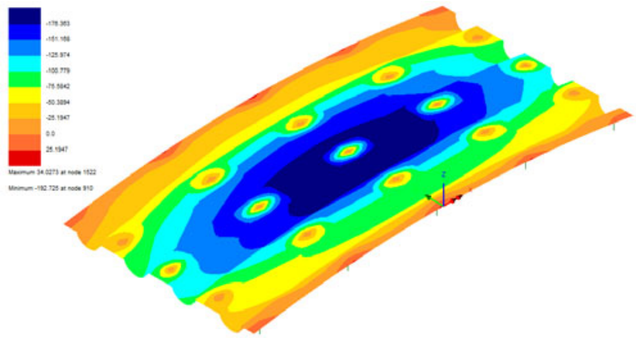


Figure 5. FRP corrugate sheet (A) under distribute loading (deflection)

Figure 4 shows the equivalent stress distribution on the FRP corrugate sheet when the stress in FRP exceeds the tensile strength. The load is 12.4 times of the design load. The stress concentration is arisen around the bolt hole. The maximum axial load applied to the connection volt is 3.644kN. Figure 5 shows the distribution of deflection. The maximum deflection is 192.7mm.

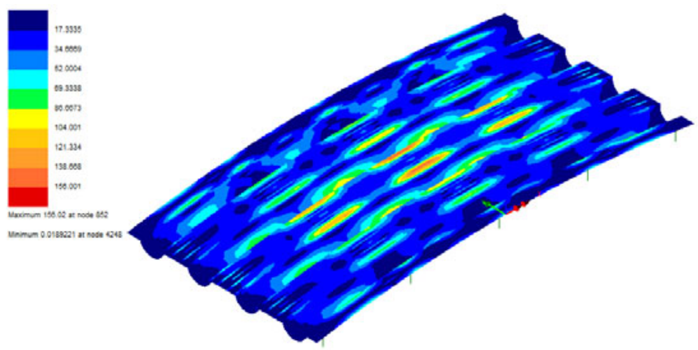


Figure 6. FRP corrugate sheet (B) under distribute loading (stress)

Table 3. Comparison of FRP liners when FRP exceeds tensile strength

Type	$\frac{Max.Load}{DesignLoad}$	Max. Displacement (mm)	Max. Bolt Tension (N)
FRP(A)	12.4	192.7	3644
FRP(B)	16.4	22.2	9569

In FRP corrugate sheet (B), the maximum stress and the displacement under design load are also shown in Table 2. These are smaller than those of FRP sheet (A).

Figure 6 shows the stress distribution of FRP corrugate sheet when the stress exceeds their tensile strength. Comparing with the results of FRP corrugate sheet (A) (see Figure 4), the stresses around the bolt holes are distributed to the elements around it. Therefore, the strips placed at the plateau (see Figure 2) are effective. The maximum load is 16.4 times of the design load. The maximum tensile force in the connection bolt is also 9.569kN. The deformation pattern shows the same distribution as Figure 5. The maximum deformation is 22.2mm. Table 3 shows the comparison of the numerical results of two types of FRP liners. Both liners show the sufficient strength under the assumed design load. However, FRP (B) with stiffening strips represents the better performance concerning the deformation.

Numerical results of FRP corrugate sheet under partially distribute load. Confirming the efficiency of the stiffening strips on the plateau of FRP sheet, FRP corrugate sheet under partially distributed load is investigated. From the report of the accidents of concrete falling in the tunnel, the 30mm-80mm concrete blocks dropped. Therefore, the partially distributed load shown in Figure 7 is applied. In numerical analyses, the effect of arranging of anchor bolts is considered. The drilling work of anchor bolts is laborious and is fairly costly. Three patterns of anchor bolt arrangement are shown in Figure 8. The maximum stress and the displacement under design load are shown in Table 4.

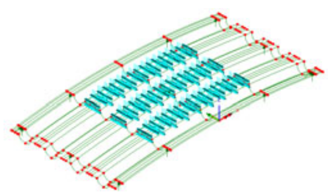
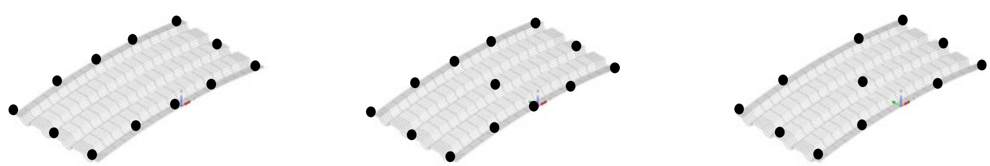


Figure 7 Partially distributed load



(a) **(b)** **(c)**

Figure 8. Arrangement of anchor bolts

Table 4. Maximum stress and deformation under design load

	Anchor (a)	Anchor(b)	Anchor(c)
Max. stress (MPa)	28.64	5.30	9.33
Max. displacement (mm)	28.47	9.46	9.98

Figure 9 shows the equivalent stress distribution on the FRP liner with the anchor pattern (a) when the stress in FRP exceeds the tensile strength. The maximum load is 7.02 times of the design load. The equivalent stress distribution obtained from the anchor pattern (b) is also shown in Figure 10 when the 10.69times of the design load is applied. In case of anchor patterns (c), the stress under the 10.31 times of the design load shows almost the same as Figure 10.

Table 5 shows the numerical results among three types of anchoring pattern. All patterns show the sufficient strength under design load. Comparing with FRP (B) shown in Table 2, the deformations of all patterns show larger than FRP (B). However, the liners show the sufficient strength even small number of anchor bolts. Also, among them FRP (Bc) is suitable

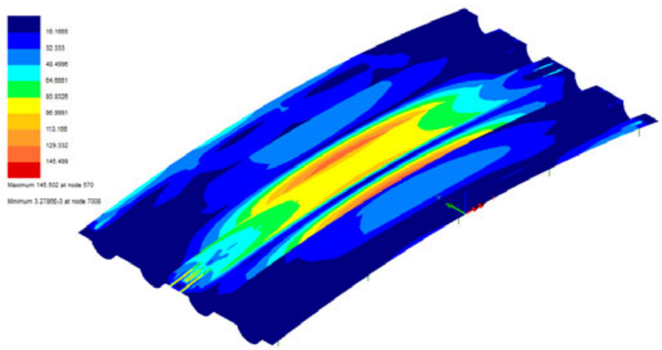


Figure 9. Stress distribution (anchor bolt (a))

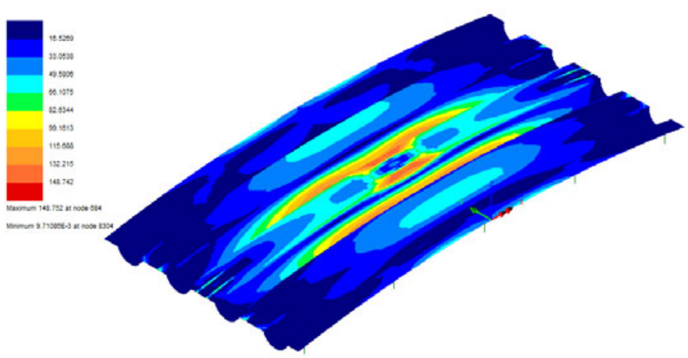


Figure 10. Stress distribution (anchor bolt (b))

Table 5. Comparison of FRP liners when FRP exceeds tensile strength

Anchor Pattern	$\frac{Max.Load}{DesignLoad}$	Max. Displacement (mm)	Max. Bolt Tension (N)
FRP(B-a)	7.02	210.4	8571
FRP(B-b)	10.69	217.8	12131
FRP(B-c)	10.31	205.3	12128

CONCLUSION

From the numerical analysis, following conclusions are obtained.

(1) FRP corrugate sheet shows better performance and the rigidity to repair an old tunnel by using FRP strips and appropriate arrangement of anchor bolts.

(2) To patching the stiffened strip on the cross section prevented the punching by the anchor bolts and showed the better performance for the strength and the rigidity.

(3) To select the appropriate anchoring pattern, FRP corrugate sheet shows the sufficient performance for preventing the concrete fall.

As FRP corrugate sheet has a transparency, it will be possible to find new cracks and the small movement of rocks and concrete. It is easy to monitor and to maintenance the tunnel. Also, the proposed corrugate sheet will flow the water and the moisture penetrating through the concrete. In this analysis, numerical evaluation of FRP liner was presented. The practical application tests are planned both on site and laboratory.

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