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Structural Design Model of Aerial Work Truss System for Tunnel Maintenance

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ABSTRACT

This study shows an innovative aerial work truss frame for tunnel maintenance and LCC control to prevent structural disaster such as collapses, which has a significant merit to carries out maintenance construction of tunnels without blocking cars and transportations, and investigate its structural behaviors through analytical method using MIDAS commercial program. According to evaluated appropriate analysis model of space truss frames of numerical examples, it is verified that design parameters are determined to depend on environmental characteristics such as lanes or shape of road tunnels including geometry of the truss frame.

1. INTRODUCTION

For increasing industrial development, infrastructures have to be equipped and reinforced essentially to country. Reducing constructional period and saving cost of them are the primary concern of civil and architectural engineers by which mega structures are both built and repaired or controlled. Limited budget such as resource or money leads to change to the point in which engineers or designers should make an effective use of them instead of buildings them. An increasing significance is now placed on maintenance of infrastructures since their “effective use” is seriously called for.

Road tunnel dealt with in this study is reportedly extended to 2,008 km altogether in republic of Korea under the number of 1,382 (Ministry of land, Transport and Maritime Affairs, 2010) as shown in Fig. 1. As can be seen in Fig. 1, rational and specific ways (Terato et al., 2008; Wang et al. 2007; Lee 1998; Sato et al. 1996) for maintenance of existing tunnels are more urgent than building new tunnels to save constructional costs based on limited budget.

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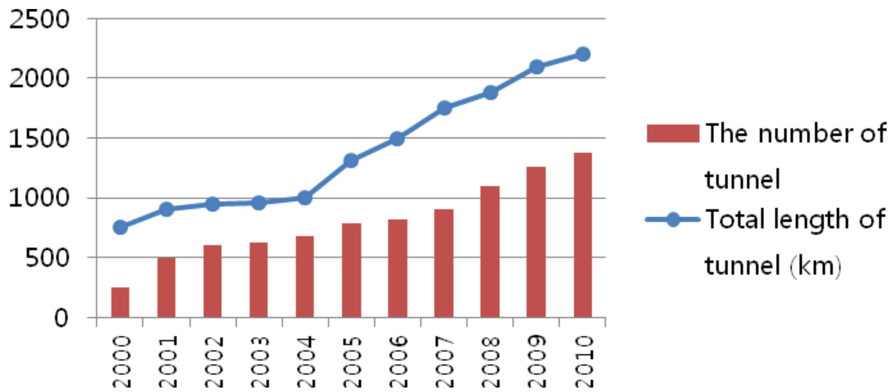


Fig 1. The total length and number of road tunnel in republic of Korea

In order to resolve this problem to maintenance constructions of tunnel, a specific space truss frame apparatus (Lee et al., 2012) only moving inside of a so-called limited building line (Norwegian Public Roads Administration, 2004; World Road Association, 2010) is presented in this study.

This study is divided into 5 sections. Following section 1 to describe scope, objective, and organization in this study, section 2 presents problematic of classical method to carry out tunnel maintenance works. In section 3, an innovative space truss frame apparatus are described as alternative to overcome the problem. Numerical examples to verify structural behaviors of the space truss frame apparatus are studied in section 4, and the conclusions are presented in section 5.

2. PROBLEMATIC of CLASSICAL TUNNEL MAINTENANCE WORKS

It is a dilemma to accomplish both preventing the problematic, i.e., block of moving vehicles, and proceeding favorably typical maintenance construction in tunnels. This situation is a so-called physical contradiction (Cui et al. 2011; William et al. 1969) which has the format given element of the system should have characteristic “A - blocking vehicles in tunnels” in order to realize required function - proceeding maintenance construction - to solve problem and this element should have characteristic “non-A” in order to satisfy existing limitations and requirements.

The existing methodology results in blocking road lanes in tunnel originally to take working areas for maintenance constructions. Therefore it can be found that the problem, i.e., achievement both the construction of maintenance and the movement of vehicles, cannot be solved by using classical equipments and methods.

As shown in Fig. 2, especially, maintenance works of tunnels cannot be carried out in rush hour which traffic jam may often occur. Traffic jam could be getting worse owing to blocking lanes of road tunnels, when maintenance constructions execute in tunnel in rush hour. This means limitation of construction time.

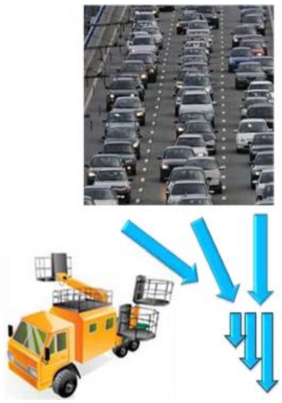
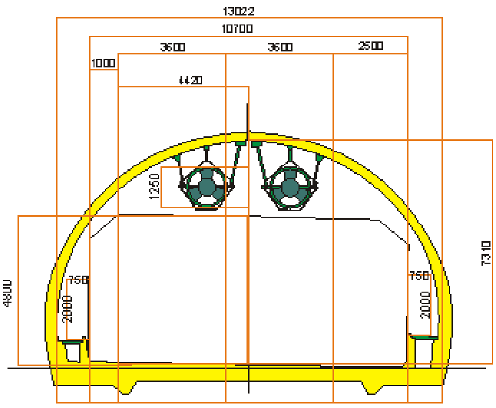


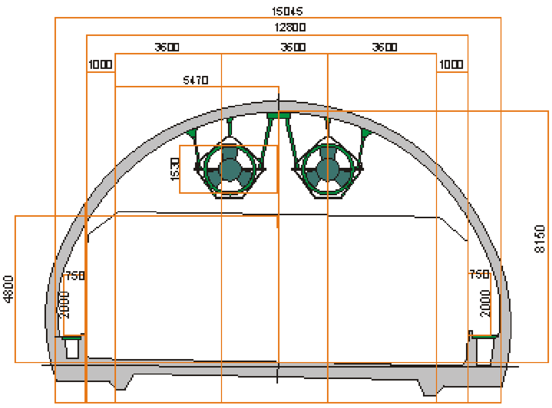
Fig 2. Worse traffic jam problem in city owing to maintenance constructions of tunnels

By utilizing tunnel spaces outside of a so-called limited building line, an innovative space truss frame structure is devised in this study, and it can move or stop through tunnels by using automatic facilities and workmanship inside of standardized limited building lines of tunnel. Most of all, this method overcomes the problematic, which is to block vehicles during construction periods, i.e., typical methods using trucks and scaffolds for tunnel maintenance.

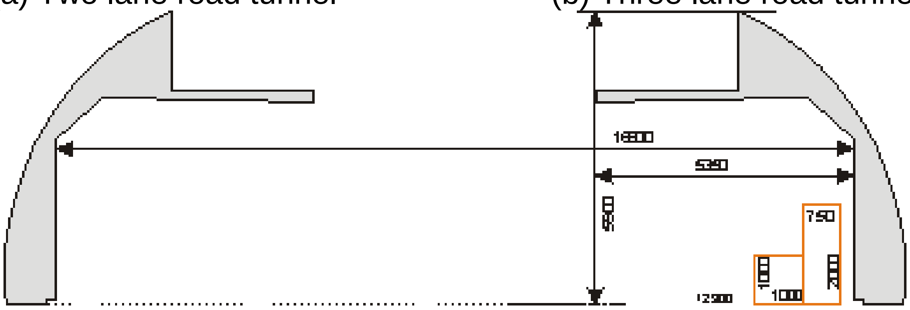
Figure 3 describes useful spaces outside of limited building lines of height and width depending on sizes of road tunnels. Since spaces on the inside of limited building lines are a main passage of vehicles by law, nobody invade the space for maintenance works of tunnels.



(a) Two lane road tunnel



(b) Three lane road tunnel

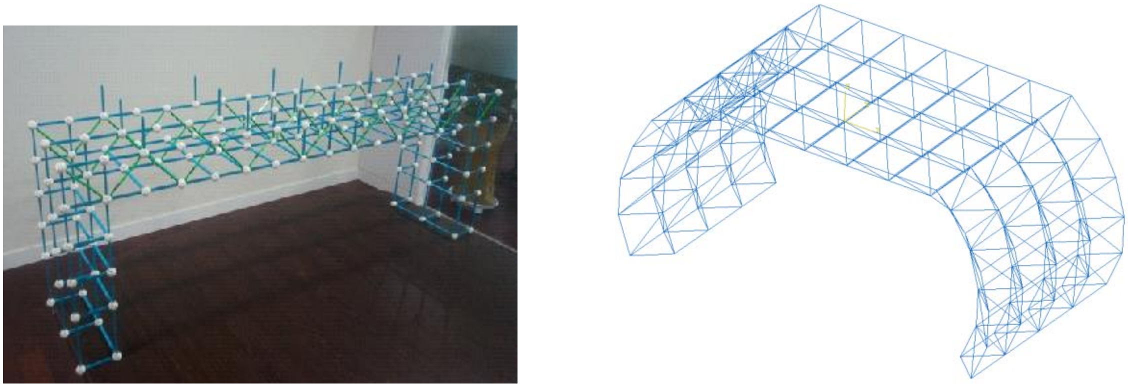


(c) Four lane road tunnel

Fig 3. Useful spaces fixed on the outside of limited building lines of height and width depending on sizes of road tunnels

As can be seen, height of useful spaces is all the same to 2, 3, and 4 lane tunnels. Width of useful spaces of 2, 3, and 4 lane tunnels is, respectively, 10.7m, 12.8m, and 16.8m. The developed useful space can be an appropriate site in which maintenance works of tunnels carry out.

Figure 4 shows the innovative apparatus of space truss frames which can be inserted and then acted in the useful spaces. Owing to curved corner of tunnels, Fig. 4(b) is recommended to move through tunnels. Fig. 4(a) occurs interference owing to sharp corner.



(a) Space truss frame of box shape (b) Space truss frame of curved shape

Fig 4. Space truss frame of box and curved shapes

3. ANALYTICAL TEST OF SPACE TRUSS FRAME APPARATUS

3.1 Setting design conditions

Basic modules of an evaluated temporary space truss system with 4 layers sketched in Fig. 4(b) is described in Table 1 and Table 2, and they depend on the upper span and layers of the temporary system.

Size of temporary space truss systems is shown in Table 3. Here Max. Width and Max. Height are decided by limited building lines. Maximum estimated height of the upper base plate in consideration of the intervention of the tunnel ventilation system is assumed to be Max. 0.6m.

Table 1. Basic modules of temporary space truss systems

Classification	2 Layers	3 Layers	4 Layers
Upper Span of Temporary System (m)	9.76 × 3 (2 Lanes) 12.20 × 3 (3 Lanes) 14.64 × 3 (4 Lanes)	9.76 × 4.5 (2 Lanes) 12.20 × 4.5 (3 Lanes) 14.64 × 4.5 (4 Lanes)	9.76 × 6 (2 Lanes) 12.20 × 6 (3 Lanes) 14.64 × 6 (4 Lanes)

Strength of materials of truss typed temporary structures shown in Table 4 are STK500 and UL700 of steel pipes. Analysis program is MIDAS GEN Ver.7.95 (2012) as shown in Table 5. Applied references are shown in Table 6 to carry out structural analysis.

Table 2. Size of temporary space truss systems

Classification	B		H	
	Total Width	Max. Width	Total Height	Max. Height
2 Lanes	12.3m	10.7m	5.4m	4.8m
3 Lanes	14.4m	12.8m	5.4m	4.8m
4 Lanes	18.2m	16.6m	5.4m	4.8m

Table 3. Strength of materials

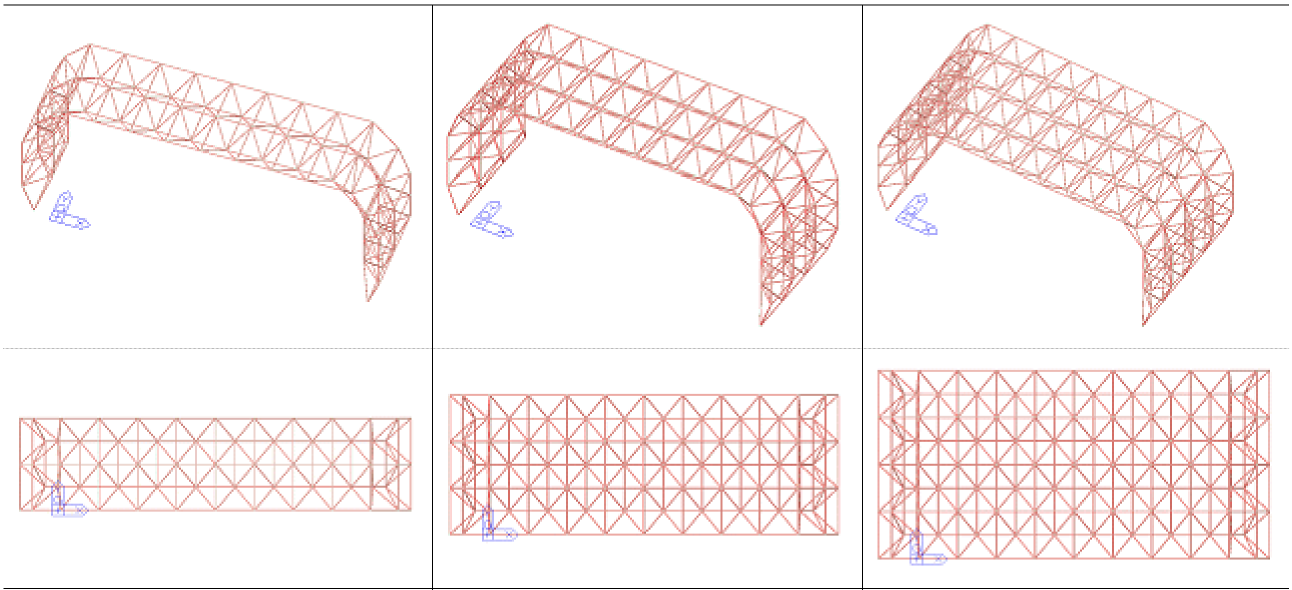
Item		Description
Steel Pipe	STK500	· Fy=325MPa (Whole Member of Framework)
	UL-700	· Fy=590MPa (Whole Member of Framework)

3.2 Analysis method

This temporary system (space frame) aims to design the framework member system based on the elastic analysis. The analysis was conducted through the comparison of a different number of lanes in the temporary system and the comparative review of the external diameters and thicknesses of frames and the different number of layers in the system.

3.2.1 Modeling data

This temporary system is the space frame in a tunnel, modeled in the truss type where a pin moves in an end part. With a width of 10.7m~16.6m (depending on lanes) and a height of 4.8m, the system is designed within the limited building line in consideration of the interference of finishing and equipment. Figure 5 shows the analysis modeling and comparison of a different number of layers.

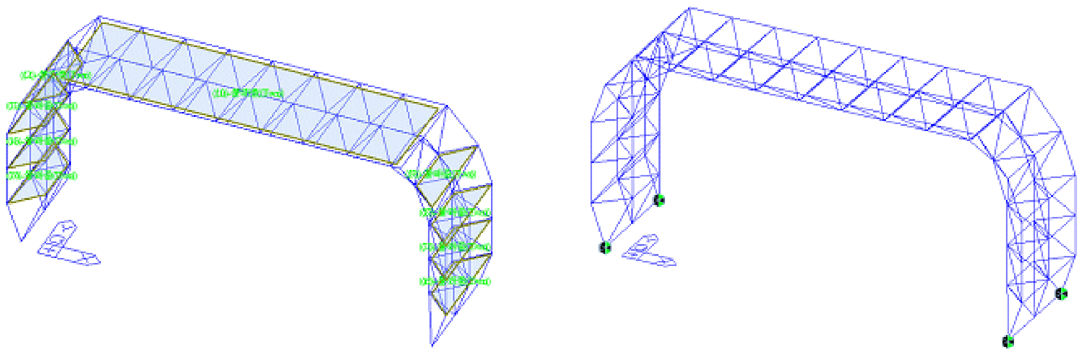


(a) 2 Layers	(b) 3 Layers	(c) 4 Layers

Fig 5. Analysis modeling

3.2.2 Loading range

As shown in Fig. 6(a), the floor load is placed vertically at each member of the framework, reflecting the upwind and downwind conditions on the upper base plate (refer to the load case). Figure 6(b) shows 4 (2×2) reaction points.



(a) Loading points (b) Reaction points

Fig 6. Loading conditions

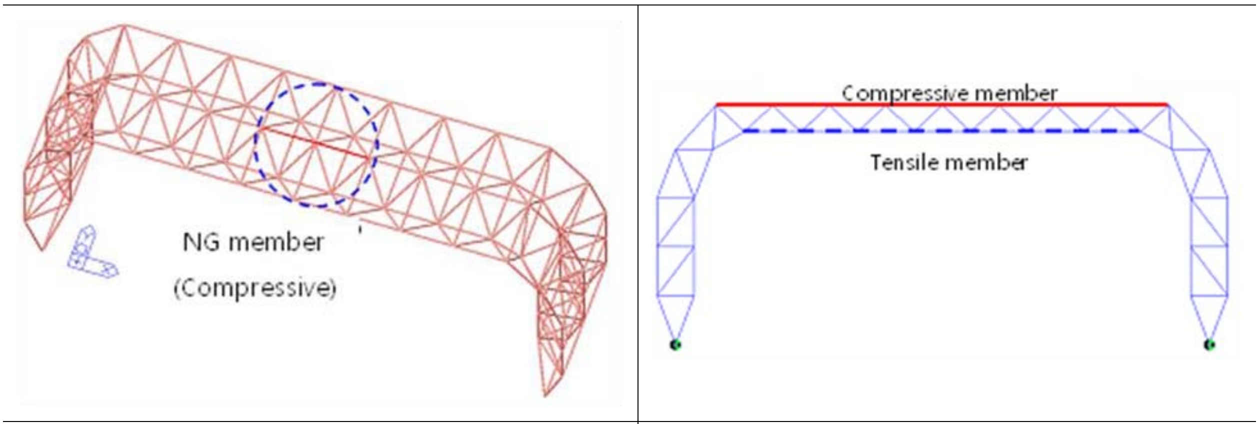
3.3 Analysis results

The following results are from analysis of the framework members. Table 4 compares the two steel grades: UL-700 and STK500, which were compared based on a model with a width of 10.7m and a height of 4.8m.

Table 4. Comparison between STK500 and UL-700

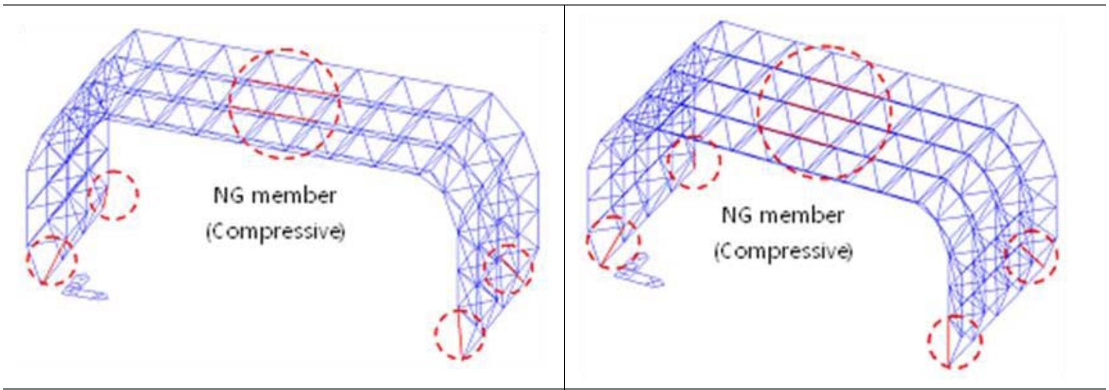
Classification	STK500	UL-700
Size of Member	Φ48.6×2.3	Φ48.6×1.8
Yield Strength (MPa)	325	595
Unit Weight (kg/m)	2.63	2.08
Quantity (kg/Frame)	299	237

Analysis results of truss typed temporary structures with 2~4 lanes and 2~4 layers are shown in Figs.7 and 8. The compressive members in the upper part of the temporary construction materials are judged as NG in -48.6×2.3 (STK500, UL-700), which shows that generally a loading condition with a 1.2D + 1.6L (factored load) (KBC, 2009; IBC, 2009), is the critical load.



(a) STK500 Model NG Member (2 Lanes)	(b) Tensile, Compressive Member (2 Lanes)

Fig 7. NG members (Φ48.6×1.8, STK500)



(a) 3 Layers	(b) 4 Layers

Fig 8. NG members by layers (Φ48.6×1.8, UL-700)

As can be seen, the results of a bearing capacity comparison of a different number of layers indicate the member's yield strength was exceeded in all the critical load cases (1.2D+1.6L) as the number of layers increases. These results show that a compressive fracture happened as the stress was concentrated at a reaction point on the load-supporting members of both sides. In addition, compared with the 3-layer or the 4-layer systems, the 2-layer system is more effective in terms of load de-concentration and the inevitable increase in layers requires the proper selection of steel type and quantity of increase.

Figure 9 shows curves of load and displacement by using STK500 (Φ48.6 x 2.3) and UL-700 (Φ48.6 x 1.8) in case lane 2 and 2 layers. As can be seen, STK500 is 0.5 mm thicker than UL-700 so that it is a bit more suitable than UL-700 in terms of initial strength. But, UL-700 showed three times higher ductility than STK500 and its maximum bearing capacity is also two times higher than that of STK500.

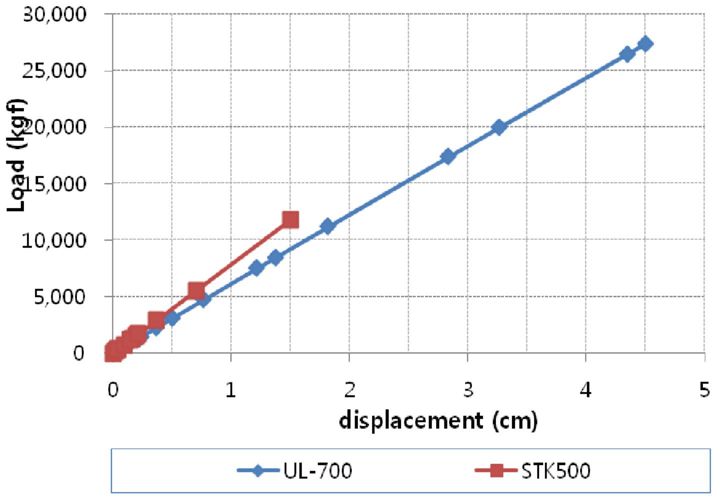


Fig 9. Comparisons between STK500 and UL-700

4. CONCLUSIONS AND REMARKS

This study presents an innovative space truss frame used to maintenance and LCC control constructions of road tunnels, which has a significant merit to carries out maintenance construction of tunnels without blocking cars and transportations, And then its structural behaviors are investigated through analytical method using MIDAS commercial program. Finally appropriate truss typed temporary structures are designed by using structural analysis results.

ACKNOWLEDGMENTS

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