THE EFFECTS OF THE ANGLE OF CARBON FIBER FOR THE STRENGTHENING OF STEEL STORAGE TANKS UNDER BENDING SHEAR LOAD

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1. INTRODUCTION

Large thin-walled cylindrical steel storage tanks (CSSTs) have been widely used in many fields as fluid tanks, chemical, electric power, food engineering, etc. They play important roles in the development of economy and infrastructures. However, a large number of CSSTs have appeared increasing signs of deterioration and reducing load-carrying capacity because of corrosion or ageing degradations. In order to achieve the sustainable development of the economy and infrastructures, these existing tanks need to be strengthened. The conventional method often involves adding of heavy and bulky plates that are difficult for fixing and can interrupt the production. In recent years, the use of carbon fiber reinforced polymers (CFRPs) with many outstanding characteristics such as lightweight, high strength, and high corrosion resistance to increase the load capacity and ductility of steel structures proved to be an economical and reliable strengthening solution. In this paper, the strengthening effects of the angle of carbon fiber on the increase of the load-carrying capacity of CSSTs will be investigated under bending shear loads.

2. MATERIAL PROPERTIES OF CFRP AND STEEL STORAGE TANKS

In this paper, two types of CFRP layers were used to strengthen CSSTs. Type-A has total circumferential CFRP layers. Type-B has ±45 degree directional CFRP layers. Table 1 shows the evaluated properties of CFRP layers. In the table, E_x and E_y are the longitudinal and transverse elastic modulus of CFRP layers, G_{xy} is the shear modulus of CFRP layers. E_x and E_y are also elastic modulus of CFRP layers in the circumferential (x) and vertical (z) direction in FEA. Steel storage tanks use SS400 steel with the material properties shown in Fig. 3.

Table 1 The properties of CFRP layers

	E_x (MPa)	E_y (MPa)	G_{xy} (MPa)	Poisson ratio
Type-A	124550	8065	2946	0.3
Type-B	37742	37742	32198	0.844

Table 2 The models in FEA

Model	Strengthening type
A1, B1	Without strengthening
A2, B2	$0_{12;0\text{-}100}$
A3, B3	$0_{18;0\text{-}100}$
A4, B4	$(\pm 45)_{12;0\text{-}100}$
A5, B5	$(\pm 45)_{18;0\text{-}100}$

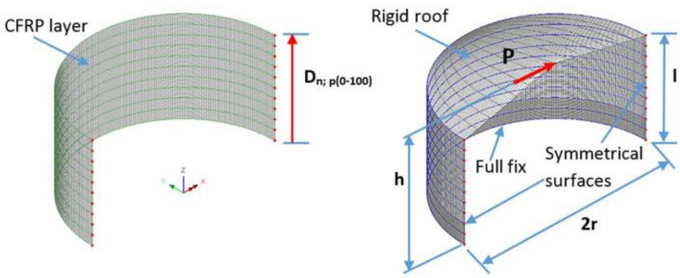

Fig.1 Half models in finite element analysis

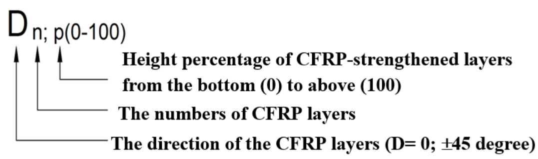

Fig. 2 Explanation about the types of CFRP-strengthened layers

3. FINITE ELEMENT ANALYSIS

3D nonlinear analysis (LUSAS package) was used to analyze the failure buckling modes and the ultimate strength of CFRP-strengthened CSSTs subjected to internal pressure under bending shear load. The internal pressure with the ratios between tensile hoop stress to yield stress of tank's material σ_h/σ_y = 0.5 and 0.7 was analyzed. In total, there were 10 models in finite element analysis as shown in Table 2. Half models were used because of symmetrical conditions. CFRP layers are modelled as surface elements at the outside of the tank's walls as shown in Fig. 1.

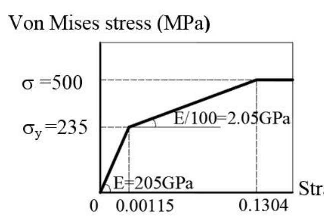

Fig. 3 The material property of SS400

In this paper, the analysis tank has the parameters $h/l/r/t$ (mm) = 6200/5000/7490/10. In these parameters, h is the distance between the lower edge of the tank to point where horizontal loading is applied, r is the inside radius of the tank, l is the height of the tank, and t is the thickness of the tank. 8 models with different types of CFRP-strengthened layers

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were divided following the notation $\boldsymbol{D_{n;\,p(0\text{-}100)}}$. Fig. 2 describes the parameters of this notation. Models from (A1) to (A5) were subjected to the internal pressure with σ_h/σ_y =0.5, while models from (B1) to (B5) were subjected to the internal pressure with σ_h/σ_y =0.7.

4. RESULTS AND DISCUSSIONS

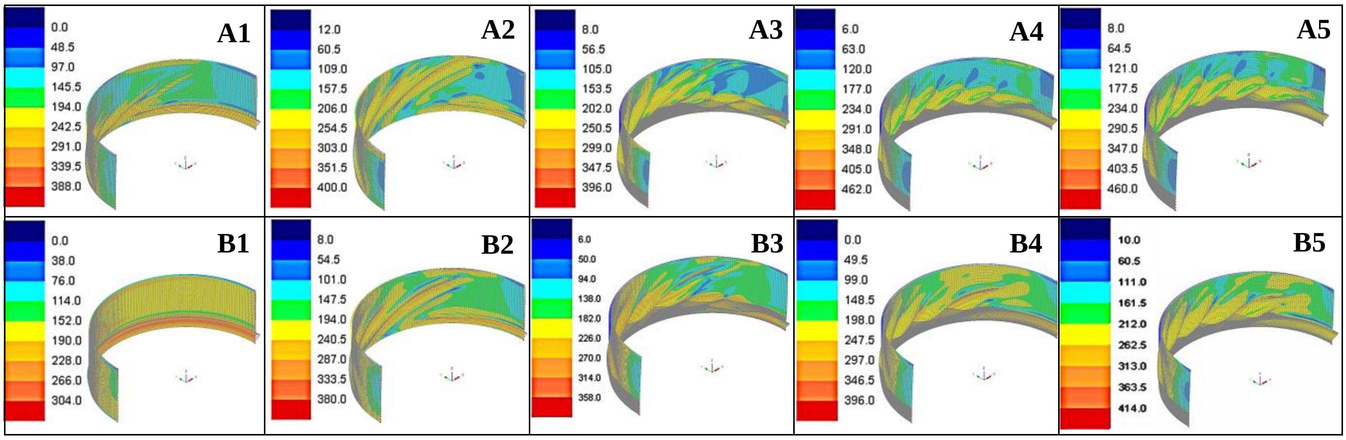

Fig. 4 Von Mises stress of the tanks. Unit: MPa

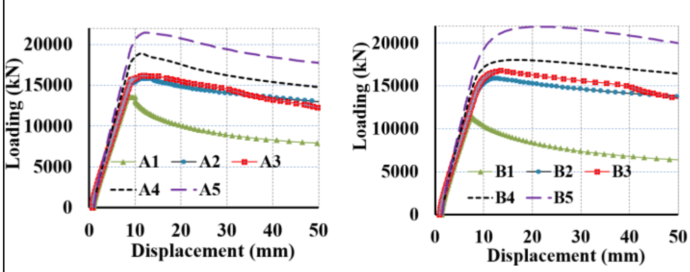

Fig. 5 The loading-displacement relationships

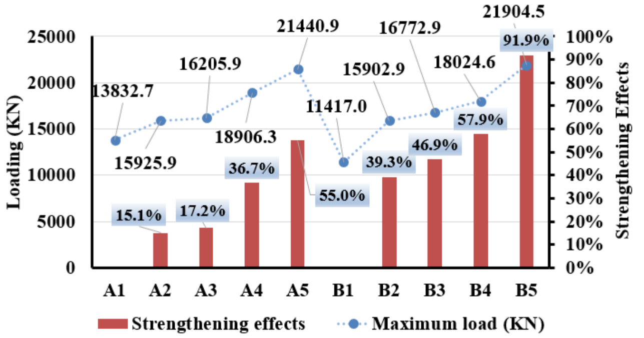

Fig. 6 The maximum loading and strengthening effects of CFRP layers

Fig. 4 shows the Von Mises stress and deformation of the tanks obtained from FEA. The main failure mode of tanks without strengthening was elephant foot bugle, while shear bucking was main failure mode of tanks with CFRP strengthening. The unidirectional CFRP-strengthened layers (type-A) had a significant effect on the increase of the load-carrying capacity of tanks when the tanks had the small ratio of *r/t*. However, the strengthening effects of the unidirectional CFRP-strengthened layers is lower for the tanks had larger ratios of *r/t* (Nhut et al. (2018)). In this paper, the angled-CFRP layers (type-B) were used for strengthening and they proved remarkable effects for the increase of ultimate strengthening of the tanks. Fig. 6 shows the maximum loads and strengthening effects of CFRP-layers on tanks comparing with tanks without strengthening. It is clear that comparing with the unidirectional CFRP layers having the same thickness, the angled-CFRP layers bring significantly higher effects if the tanks having the high ratios of *r/t*, especially for the tanks subjected to high ratios of σ_h/σ_y. Fig. 5 shows the relationships between loading and displacement of the top point of the tanks. When using the angled-CFRP layers, the loading decrease slowly and more stable than unidirectional CFRP layers.

5. CONCLUSION

In this paper, the strengthening effects of angled-CFRP layers were investigated. The results show that for the tanks having high ratios of *r/t*, the angled-CFRP layers bring remarkable effects comparing with unidirectional CFRP-layers on the increase of the ultimate strength of the tanks and decrease of the impact of shear buckling.

REFERENCES

Nhut, PV. and Matsumoto, Y.: The Effects of Carbon Fiber Reinforced Polymer Strengthening on Cylindrical Steel Storage Tanks under Bending Shear Load, 2018 3rd International Conference on Building Materials and Construction (ICBMC 2018), 2018.