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STANDARD SECTION DESIGN OF FRP DSCT TOWER SUPPORTING 3MW WIND TURBINE

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A modular FRP DSCT (Fiber Reinforced Polymer Double-Skinned Composite Tubular) wind power tower was suggested and its standard section supporting 3MW wind turbine was designed. An FRP DSCT tower is composed of two concentric FRP tubes and concrete filled between the inner and outer tubes. A DSCT structure has hollowed section which reduces its self-weight. Due to inner and outer tubes, concrete is confined to increase strength and ductility. The performance of the new-type wind power tower was assessed via structural analysis. Design and analysis were carried with AutoDSCT and CoWiTA programs with consideration of confining effect of concrete and large displacement by wind turbine weight itself. The bottom diameter of the tower was set as 4.5 m as a standard. The towers which have 100%, 95%, 90% and 85% of bottom diameter were considered for design. Top diameter of the tower was set as 3.6m. For the consideration of constructing and installing the tower, each tower was divided into modules. The module sections were designed on the basis of the idea that module sections should satisfy the required bending moment and axial load. As a result, bottom diameter of 4.5m with hollow ratios below 0.85 satisfied the required load capacity and the bottom diameter of 95%, 90% and 85% with the hollow ratios below 0.82, 0.76 and 0.7 satisfied the required capacity.

Keywords: Wind power tower, Concrete, Column, CoWiTA, AutoDS.

1 INTRODUCTION

Wind power energy is one of the most efficient renewable energies and is economically feasible. Nowadays, the wind turbine tower needs to be high enough to support the turbine size of which is directly proportional to the energy generated. As a result, the slenderness of ratio increases and it is the main cause of buckling in the event of heavy weather that can eventually make the tower collapse and the residents live in fear (Han 2015). Thus, the wind turbine tower must be strong enough to withstand the buckling phenomena. Another problem is the corrosion caused by saltwater reacting with steel made offshore wind turbine tower.

In this research, an FRP DSCT structure is applied to wind power tower to suggest a new type of tower section design supporting 3MW wind turbine. FRP as a material is known to have small weight-strength ratio and corrosion resistance. It is also durable and long-lasting. A DSCT column which was researched by Shakir-Khalil and Illouli in 1987 is composed of two concentric tubes and concrete (Shakir-Khalil and Illouli 1987). Such composition is actively being studied in order to maximize the function of the hollowed section to decrease the weight of the tower. Recently, Han *et al.* (2013) suggested the nonlinear material column model of DSCT structure (Han *et al.* 2013).

2 SECTION DESIGN

2.1 Automatic Design Program, AutoDSCT

AutoDSCT (Han 2014) is a program based on the strain compatibility of a DSCT tower developed from the section analysis and the interactions between axial load and bending moment considering material nonlinearity and confining effect of concrete (Han *et al*. 2013). In this research, AutoDSCT was used for generating bottom design sections of DSCT tower. The design process of AutoDSCT is shown in Figure 1. It automatically creates bottom sections of the tower with variety of hollow ratios, inner and outer tube thicknesses by processing input including outer diameter, the mechanical properties of materials, required bending moment and axial force. AutoDSCT not only creates most economical design sections, but also provides axial load-bending moment (P-M) interaction curves and lateral force-lateral displacement (P-Δ) curves which can help understanding in terms of strength of the tower. At every run, ten cases of the sections are produced with hollow ratios varying from 97% to 70% by decreasing steps of 3% (Han *et al.* 2010). Decision of outer diameter of inner tube depends on hollow ratio.

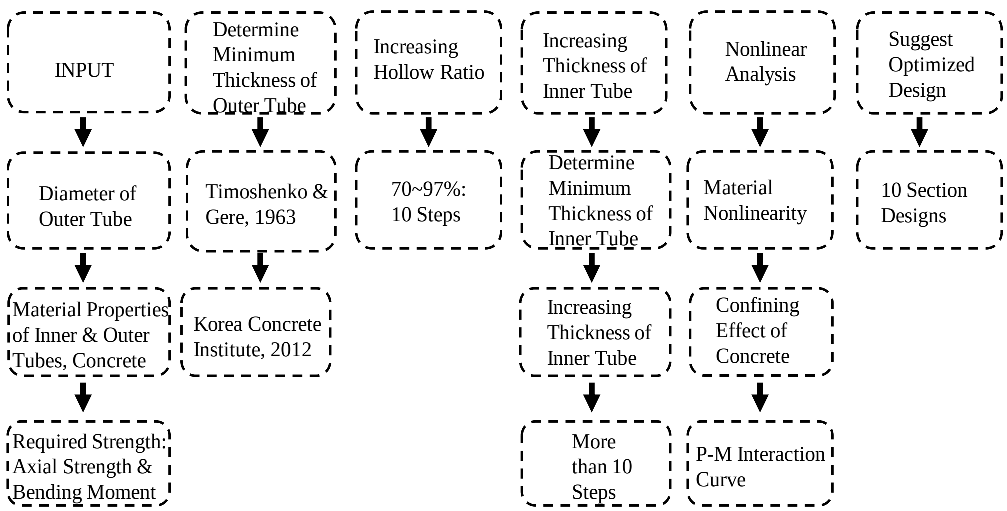


Figure 1. Design process in AutoDSCT program.

2.1.1 *Design sections generated by AutoDSCT*

In this research, basis of the steel tower suggested by Ljjj and Gravesen in 2008 was considered and its bottom diameter was used (Ljjj and Gravesen 2008). The bottom and top diameters of the tower were set as 4.5 m and 3.6 m respectively. The height of the tower was set as 90 m. For the thickness of the FRP outer and inner tubes, 35mm was used as a random value. The axial force of 2,835kN and bending moment of 88,000kN-m were calculated by considering 3 MW wind turbine applied on the top of the tower. The FRP mechanical property calculated based on FRP tension test is shown in Table 1 and the forty cases of bottom sections generated from AutoDSCT are shown in Table 2.

Table 1. Material mechanical properties.

Material Property Information	
Nominal Compressive Strength of Unconfined Concrete	30 MPa
Density of Concrete	2,300 kg/m^3
Ultimate Strain of Concrete	0.003
Yield Strength of Outer/Inner Tube	48.685 MPa
Ultimate Strength of Outer/Inner Tube	230.25 MPa
Modulus of Elasticity of Outer/Inner Tube	1,5436.7 MPa
Ultimate Strain of Outer/Inner Tube	0.0244 MPa
Density of FRP	1,500 kg/m^3

Table 2. Design sections generated by AutoDSCT.

Design Case (4.5m)	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
	3F100/97	3F100/94	3F100/91	3F100/88	3F100/85	3F100/82	3F100/79	3F100/76	3F100/73	3F100/70
D	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
D_i	4365	4230	4095	3960	3825	3690	3555	3420	3285	3150
t	31	19.5	13	12	12	12	12	12	12	12
t_i	36.386	27.966	22.105	20.538	19.838	19.138	18.437	17.737	17.037	16.337
Design Case (4.275m)	3F95/97	3F95/94	3F95/91	3F95/88	3F95/85	3F95/82	3F95/79	3F95/76	3F95/73	3F95/70
D	4275	4275	4275	4275	4275	4275	4275	4275	4275	4275
Di	4146.75	4018.5	3890.25	3762	3633.75	3505.5	3377.25	3249	3120.75	2992.5
t	36	24	17	13	11.5	11.5	11.5	11.5	11.5	12
t_i	38.412	30.24	24.638	20.835	18.928	18.26	17.592	16.924	16.256	15.923
Design Case (4.05m)	3F90/97	3F90/94	3F90/91	3F90/88	3F90/85	3F90/82	3F90/79	3F90/76	3F90/73	3F90/70
D	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050
Di	3928.5	3807	3685.5	3564	3442.5	3321	3199.5	3078	2956.5	2835
t	40	30	22	17.5	15	13.5	13	13	13.5	14
t_i	42.68	32.907	27.281	23.529	21.041	19.257	18.205	17.514	17.143	16.74
Design Case (3.825m)	3F85/97	3F85/94	3F85/91	3F85/88	3F85/85	3F85/82	3F85/79	3F85/76	3F85/73	3F85/70
D	3825	3825	3825	3825	3825	3825	3825	3825	3825	3825
Di	3710.3	3595.5	3480.8	3366	3251.3	3136.5	3021.3	2907	2792.3	2677.5
t	44.5	35.5	28.5	23	19.5	17.5	17	16.5	16.5	17.5
ti	47.482	36.707	30.176	26.214	23.315	21.307	20.232	19.176	18.419	18.189

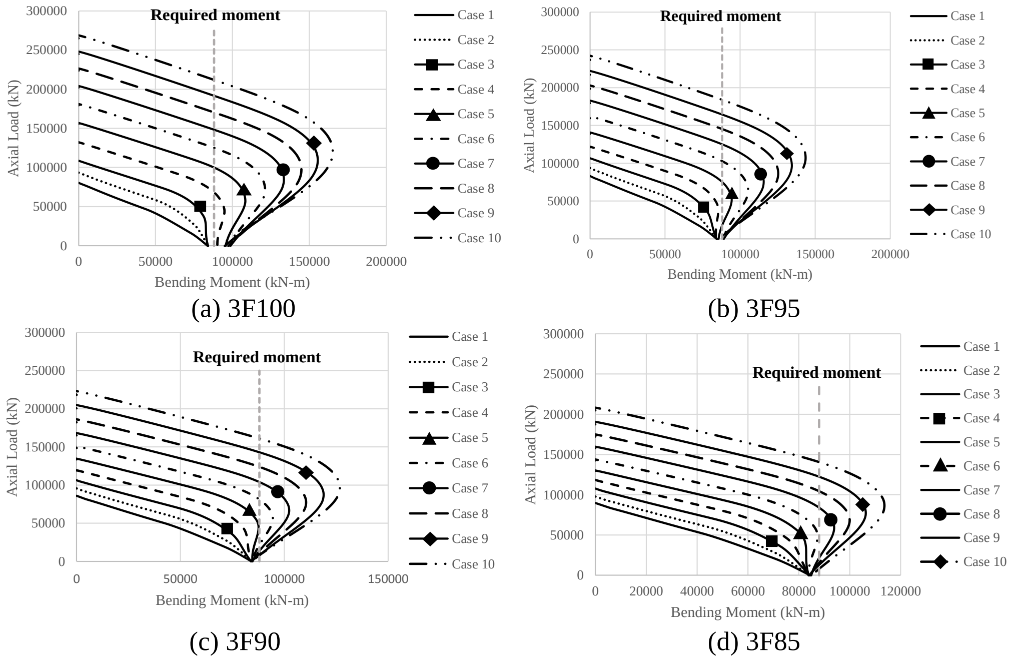


Figure 2. Axial load-bending moment curves (P-M interaction curves) for DSCT tower supporting 3MW wind turbine.

2.2 Nonlinear Analysis by CoWiTA

To prevent buckling failure, each bottom section designed from AutoDSCT was performed for nonlinear analysis. The performances of the designed sections were conducted via CoWiTA (Han 2015) which evaluates bending performance of a column considering material nonlinearity, confining effect of concrete, and large displacement effect. Cases with satisfying the required moment strength from P-M interaction curves shown in Figure 2 were selected for nonlinear analysis through CoWiTA. Figure 3 presents the lateral load-lateral displacement relation curves of the DSCT tower. As the lateral load becomes larger, the lateral displacement increases. In the case of the tower with bottom diameter, 4.5m, design sections with hollow ratios from 85% to 70% have higher moment strength than the required strength. This means that the tower with designed sections of those hollow ratios can support the 3MW wind turbine without in the event of buckling. For the cases of 3F95, 3F90 and 3F85, the hollow ratios of 82% to 70%, 79% to 70% and 76% to 70% exceeded the required bending moment.

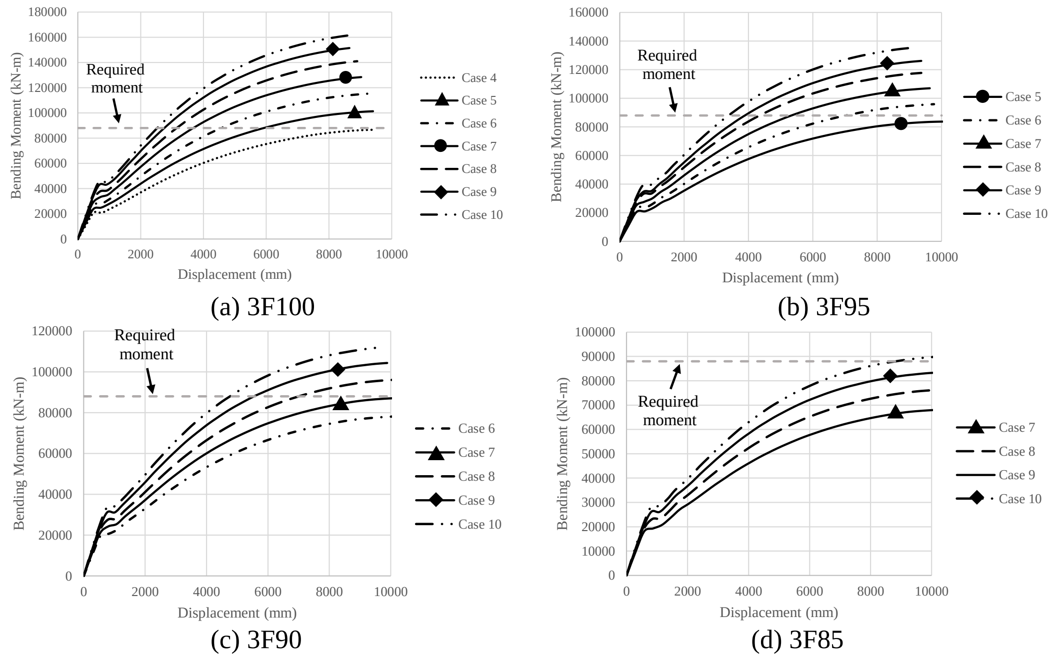


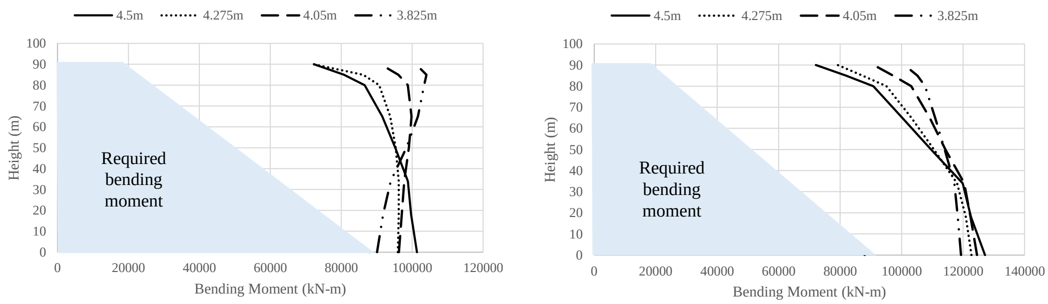
Figure 3. Lateral load-lateral displacement curves for DSCT tower supporting 3MW wind turbine.

2.2.1 *Modular FRP DSCT tower*

For the consideration of installing and transporting the tower, each tower was split into seven modules and Table 3 shows dimensions of each module for four towers. Figure 4 appears that the bending moment of the tower modularized according to module height from the bottom to the top of the whole tower by considering large displacement effect and without large displacement effect.

Table 3. Section design of modular FRP DSCT.

		Module height (m)	4.5m		4.275m		4.05m		3.825m	
	Hollow ratio		1	0.85	1	0.82	1	0.76	0.7	
Module 1	Bottom	5	4500	3825	4275	3505.5	4050	3078	3825	2677.5
	Top		4450	3782.5	4237.5	3474.75	4025	3059	3812.5	2668.75
Module 2	Bottom	5	4450	3782.5	4237.5	3474.75	4025	3059	3812.5	2668.75
	Top		4400	3740	4200	3444	4000	3040	3800	2660
Module 3	Bottom	15	4400	3740	4200	3444	4000	3040	3800	2660
	Top		4250	3612.5	4087.5	3351.75	3925	2983	3762.5	2633.75
Module 4	Bottom	15	4250	3612.5	4087.5	3351.75	3925	2983	3762.5	2633.75
	Top		4100	3485	3975	3259.5	3850	2926	3725	2607.5
Module 5	Bottom	16	4100	3485	3975	3259.5	3850	2926	3725	2607.5
	Top		3940	3349	3855	3161.1	3770	2865.2	3685	2579.5
Module 6	Bottom	16	3940	3349	3855	3161.1	3770	2865.2	3685	2579.5
	Top		3780	3213	3735	3062.7	3690	2804.4	3645	2551.5
Module 7	Bottom	18	3780	3213	3735	3062.7	3690	2804.4	3645	2551.5
	Top		3600	3060	3600	2952	3600	2736	3600	2520



(a) Large displacement effect (b) No large displacement effect

Figure 4. Tower height-bending moment curves.

3 CONCLUSION

Design sections of modular FRP DSCT tower were suggested. The tower of the bottom diameter of 4.5m with hollow ratios below 0.85 satisfied the required load capacity. For the towers of the bottom diameter of 95%, 90% and 85%, the hollow ratios below 0.82, 0.76 and 0.7 satisfied the required capacity to support 3MW wind turbine. The suggested design sections of modular FRP DSCT tower can withstand the required moment strength which means it is proven to be safe in the event of buckling.

Acknowledgments

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