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DESIGN OF DSCT WIND TURBINE TOWER CONSIDERING LARGE DISPLACEMENT EFFECT

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A double-skinned composite tubular (DSCT) offshore wind power tower was designed. Because a heavy wind power turbine is supported by a slender tower, the actual resisting moment capacity of the tower against wind load becomes less than its original moment capacity as its lateral displacement increases. Therefore, its actual moment capacity should be found for safe design by considering large displacement effect. In this study, 40 sections of DSCT wind power towers were designed for a 5.0MW turbine and the performances of the designed 40 sections were analyzed with and without considerations of large displacement effect. In designing and analyzing them, the material nonlinearity and the confining effect of concrete considered. The comparison of the analysis results showed the moment capacity loss of the wind power tower by the mass of the turbine is significant and the large displacement effect should be considered for the safe design of the wind power tower.

Keywords: Nonlinear, Column, Composite, Concrete, Wind power.

1 INTRODUCTION

Because of the high quality wind, offshore wind farm increases. Its generating turbines, blades, and towers are getting bigger and taller. However, as the tower becomes taller, its slenderness ratio increases. This large slenderness ratio makes a tower easy to be buckled or to fail as shown in Figure 1. Therefore, to reduce the failure possibility of a tall tower, a new-type tower structure, which has high strength, is required. In this study, a double-skinned concrete filled tube (DSCT) was adopted as the wind power tower to enhance the load resisting capacity of a wind tower. Han *et al.* (2014) developed an automatic section design software of a DSCT wind power tower based on the nonlinear material model (Han *et al.* 2010) and the nonlinear column model (Han *et al.* 2013) considering the confining effect of concrete.

By using the developed design software, forty DSCT wind power tower sections were designed for 5MW turbines in this study. The performance analyses were performed for the designed DSCT wind towers with and without the consideration of large displacement effect by the mass of a wind turbine.

2 ANALYSIS MODEL

2.1 Column Model

The strain compatibility of DSCT tower is derived from the section and the relation of curvature and lateral displacement is defined. In the nonlinear material model proposed by Han *et al.* (2013), the confining stress is derived from the free body diagram as shown in Fig. 1. The failure of the inner tube depends on its buckling strength, yielding strength, and the confining stress.

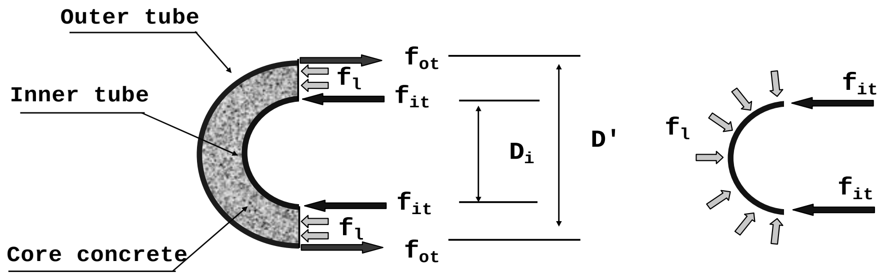


Figure 1. Confining stress on concrete in a DSCT column (Han *et al.*, 2010).

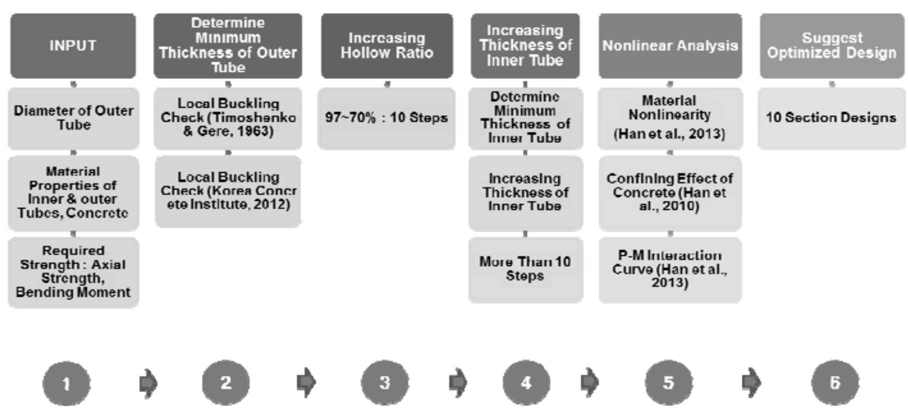


Figure 2. Design process.

2.2 Automatic Design Program

The automatic design program (Auto DSCT) performs the section design of a DSCT tower in the procedure as shown in Figure 2. The program performs the analyses of P-M interaction and P-Δ relation when it is given the input data which are the outer diameter, the material properties, the required bending moment and axial strength of the tower. As the results, the program shows the optimum then design cases which satisfy the required capacities.

2.3 Large Displacement Effect

The mass of wind turbine which is located on the top of a slender wind tower makes additional moment by gravity as the wind tower is bent by the lateral force such wind load. In this case, the lateral displacement is the moment arm of the vertical force by the turbine mass and gravity as shown in Figure 3. This additional moment makes the tower which cannot exert its original moment resisting capacity against the lateral force.

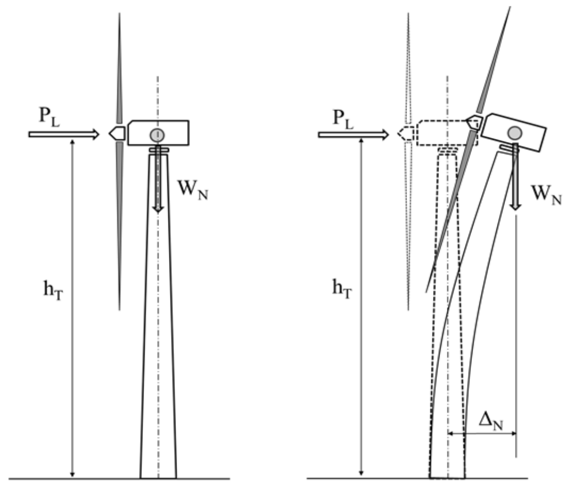


Figure 3. Large Displacement Effect by Turbine.

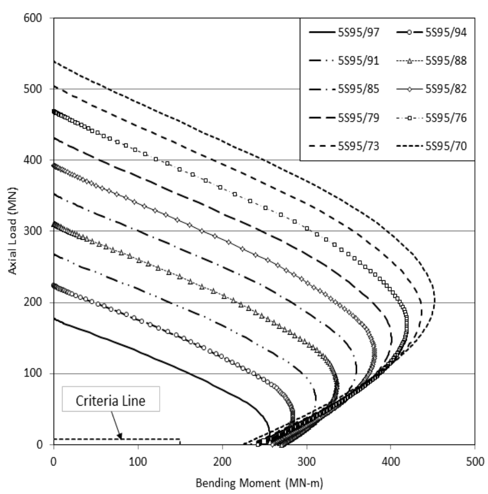


Figure 4. P-M Interaction Curve of 5S95.

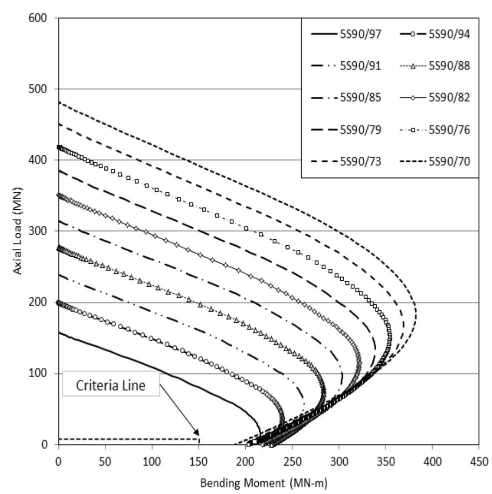


Figure 5. P-M Interaction Curve of 5S90.

3 ANALYSIS

3.1 Section Design

DSCT wind tower sections were designed for 5MW turbines. The required capacities were 7.10MN as vertical load and 150MN-m as extreme bending moment. The height of the tower was 6,000mm (Ljjj & Gravesen 2008). The diameters of the DSCT towers were 5,700mm, 5,400mm, 5,100mm, and 4,800mm as shown Table 1. Based on these 4 outer diameters, 40 sections were designed. For each outer diameter, the tower has ten different hollow ratios from 0.7 to 0.97 with the step of 0.03. The inner and outer tubes have 313.60MPa of yield strength and 490.50MPa of ultimate strength. The compressive strength of unconfined concrete was 29.43MPa. Table 2 shows the dimension of designed sections and Figure 4 and Figure 5 show the P-M interaction curves of the designed sections.

Table 1. Section Design Case of DSCT Wind Power Tower.

Diameter Ratio	**Diameter**	**Design Case**
0.95	5,700mm	5S95
0.90	5,400mm	5S90
0.85	5,100mm	5S85
0.80	4,800mm	5S80

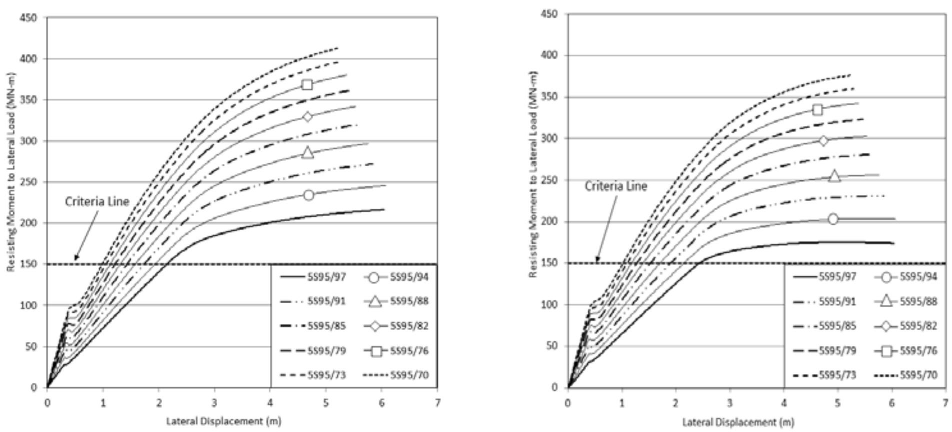
Table 2. Designed Section of DSCT Wind Power Tower.

Design Case for 5S95	5S95/97	5S95/94	5S95/91	5S95/88	5S95/85	5S95/82	5S95/79	5S95/76	5S95/73	5S95/70
L (mm)	5,700	5,700	5,700	5,700	5,700	5,700	5,700	5,700	5,700	5,700
D_i (mm)	5,529	5,358	5,187	5,016	4,845	4,674	4,503	4,332	4,161	3,990
D_i/L	0.97	0.94	0.91	0.88	0.85	0.82	0.79	0.76	0.73	0.7
t (mm)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
t_i (mm)	13.99	13.56	13.13	12.7	12.26	11.83	11.4	10.96	10.53	10.1
Design Case for 5S90	5S90/97	5S90/94	5S90/91	5S90/88	5S90/85	5S90/82	5S90/79	5S90/76	5S90/73	5S90/70
L (mm)	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400
D_i (mm)	5,238	5,076	4,914	4,752	4,590	4,428	4,266	4,104	3,942	3,780
D_i/L	0.97	0.94	0.91	0.88	0.85	0.82	0.79	0.76	0.73	0.7
t (mm)	7	7	7	7	7	7	7	7	7	7
t_i (mm)	13.16	12.75	12.35	11.94	11.53	11.12	10.72	10.31	9.9	9.5
Design Case for 5S85	5S85/97	5S85/94	5S85/91	5S85/88	5S85/85	5S85/82	5S85/79	5S85/76	5S85/73	5S85/70
L (mm)	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100	5,100
D_i (mm)	4,947	4,794	4,641	4,488	4,335	4,182	4,029	3,876	3,723	3,570
D_i/L	0.97	0.94	0.91	0.88	0.85	0.82	0.79	0.76	0.73	0.7
t (mm)	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
t_i (mm)	12.32	11.94	11.56	11.18	10.8	10.42	10.04	9.66	9.27	8.89
Design Case for 5S80	5S80/97	5S80/94	5S80/91	5S80/88	5S80/85	5S80/82	5S80/79	5S80/76	5S80/73	5S80/70
L (mm)	4,800	4,800	4,800	4,800	4,800	4,800	4,800	4,800	4,800	4,800
D_i (mm)	4,656	4,512	4,368	4,224	4,080	3,936	3,792	3,648	3,504	3,360
D_i/L	0.97	0.94	0.91	0.88	0.85	0.82	0.79	0.76	0.73	0.7

t (mm)	6.5	6.5	6.5	6.5	6.5	6.5	7	7	7.5	8
t_i (mm)	11.96	11.59	11.22	10.85	10.48	10.11	10.1	9.72	9.66	9.57

3.2 Lateral Behavior and Performance

The moment-displacement relation analyses were performed for the designed 40 DSCT wind towers by CoWiTA (ver. 2.1, KIOST, 2015). In the analyses, material nonlinearity and confining effect of concrete were considered. Following figures show the analysis results and comparison when large displacement effect was considered and not considered. As shown in Figure 6(a) and Figure 7(a), all designed sections satisfy the required capacity when the large displacement effect was not considered. However, as shown in Figure 7(b), some designed sections may not satisfy the required capacity when the large displacement effect was considered. Therefore, the large displacement effect should be considered for when a slender column such as a wind tower.

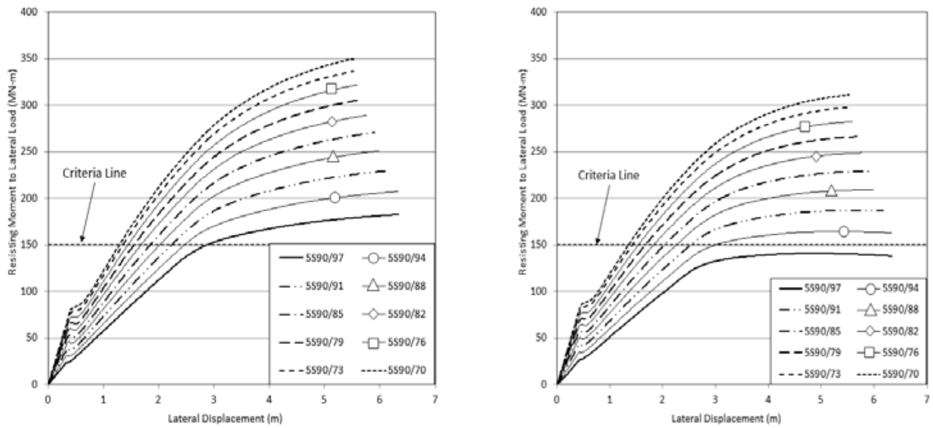


(a) No Consideration of L.D.E. (b) Consideration of L.D.E.

Figure 6. Moment-Displacement Relation of DSCT Wind Power Tower (5S95).

4 CONCLUSION

In this study, DSCT wind towers were designed for 5MW turbines and performance analyses were carried out with consideration of large displacement effect. Analysis results showed the designed sections were reasonable but large displacement effect makes the slender tower to lose much of its moment resisting capacity. Therefore, for the safety, large displacement effect should be considered in designing wind power towers.



(a) No Consideration of L.D.E. (b) Consideration of L.D.E.

Figure 7. Moment-Displacement Relation of DSCT Wind Power Tower (5S90).

Aacknowledgments

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