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STANDARD SECTION DESIGN OF ICH RC TOWER SUPPORTING 5.0MW WIND TURBINE

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A new-type wind power tower, internally confined hollow reinforced concrete (ICH RC) tower was developed and its standard sections were designed. Its targeting turbine capacity was 5.0 MW and the large displacement effect by turbine weight was considered. CoWiTA which is a non-linear analysis program was used for analyzing each section. Initial bottom diameter of the tower was 5.5 m with hollow ratios; 0.9, 0.85, 0.80, and 0.75 and 10% smaller diameter case was also considered with the same hollow ratios. In addition, the ICH RC tower could be separated into some modules for convenience of construction and installation. Each cross section at top and bottom of modules was designed and analysis of the sections was performed as well. As a result, all design cases except one case showed enough performance to support a 5.0 MW turbine. Also, it was confirmed that the modularized ICH RC wind tower satisfied with required load condition at each height by analyzing modules.

Keywords: Wind power, Confined, Composite, Concrete.

1 INTRODUCTION

Among the renewable energies, the wind energy has been growing fast over the world during the last decades (Watts *et al*. 2016). World wind energy association announced that 63 GW was added within the year 2015 and the total wind capacity of the world has reached 432.9 GW, representing cumulative market growth of more than 17% (GWEC 2016). 186 governments have agreed with the Paris agreement in late 2015 and it makes the wind energy market to grow continuously.

According to Klaassen *et al*., the capacity of wind turbine is growing not only to increase energy efficiency but also to reduce the unit cost of construction by public research and development (Klaassen *et al*. 2005). By this trend, longer blades and bigger towers have been required to operate wind turbine system. This trend makes tall steel tower which has high slenderness ratio could not be safe enough from risk of buckling failure. About the buckling failure of the wind towers were conducted by Kimopoulos and Gantes (2012). For the concrete structures, they have different stress-strain relation between confined concrete and unconfined concrete structure. Popovics conducted study about experimental justification about confined concrete (Popovics 1973). Based on the confining effect of the concrete, Han *et al.* found that the inner tube and transverse reinforcements make the concrete in a tower to be triaxially confined state so that the strength of the tower could be enhanced (Han *et al.* 2010). In this study, the ICH RC wind tower which is composed of inner tube, reinforcements, and concrete is suggested, sectionally designed and analyzed. Figure 1 shows composition of ICH RC wind tower and it was applied confining effect by the components.

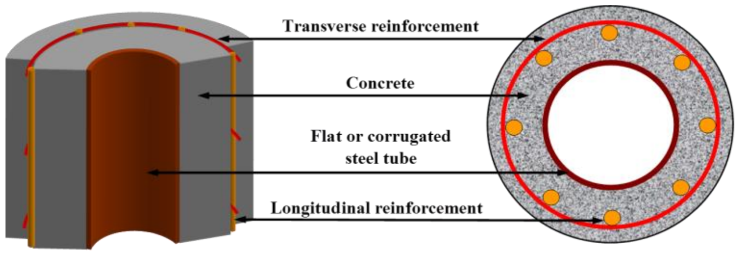

Figure 1. Composition of ICH RC tower.

2 SECTION DESIGN

Cross section of the ICH RC tower for supporting 5.0 MW wind turbine was designed. Load condition was based on literature review of existing steel tower which supports a 5.0 MW turbine. It indicates that the moment at the tower bottom, the moment at the tower top, and the axial force by turbine weight are 159,000 kN-m, 31,800 kN-m, and 4,185 kN respectively (Kim *et al.* 2016). The diameters at the tower bottom and at the tower top were selected as 5.5 m and 3.9 m, respectively. The diameter at the tower top was considered connecting area where the bottom of a nacelle assembly placed. The tower height was set as 95 m during section design of the ICH RC wind tower. Based on the case 01: 5.5 m (DB_0) bottom diameter, the case02: 90 percent of the DB_0 (5.5 x 0.9 = 4.95 m) was considered. In addition, various hollow ratios; 90, 85, 80, and 75 were applied to each case, and specific cases were represented as CaseAA_BB. AA should be 01 or 02, and they mean 5.5 m of the tower bottom diameter case and 4.95 m of the bottom diameter case, and BB indicates hollow ratio. For example, Case01_75 means the case of the tower has 5.5 m of bottom diameter with 75% of hollow ratio. Finally, total eight cases of tower section design were designed and analyzed to find optimum section design. The calculation process for tower section design is shown at figure 2. All required equations, design condition, and design factors of the ICH RC wind tower followed Korean concrete structure design standard (Korea Concrete Institute, 2012).

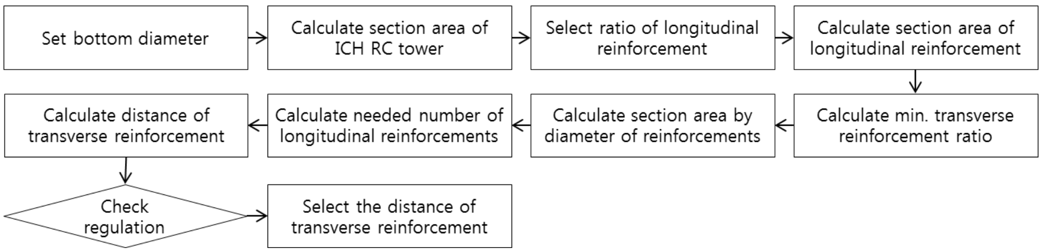

Figure 2. Design process of ICH RC tower.

The section design results of the ICH RC wind tower is shown at table 1. Safety factor 1.2 was applied and 60 mm of concrete cover was selected. The ICH RC wind tower was assumed operating in land and the 60 mm of concrete cover thickness is regulated in the Korean concrete structure design standard. It provides the thickness of concrete cover depending on environmental conditions and construction situations.

Table 1. Section design of the ICH RC wind tower.

	D'(mm)	H/R	D_i(mm)	A_g(mm^2)	A_s(mm^2)	A_c(mm^2)	$\rho_{s,min}$	R_t/No.
Case01 (1.0x DB_0)	5500	0.90	4,950.0	5,562,111	66,745	5,495,365	0.000524	D41/52
		0.85	4,675.0	7,640,962	91,691	7,549,270	0.000524	D41/68
		0.80	4,400.0	9,601,021	115,212	9,485,809	0.000524	D51/60
		0.75	4,125.0	11,442,289	137,307	11,304,981	0.000524	D51/68
Case02 (0.9x DB_0)	4950	0.90	4,455.0	4,600,764	55,209	4,545,555	0.000524	D41/44
		0.85	4,207.5	6,284,633	75,415	6,209,217	0.000524	D51/40
		0.80	3,960.0	7,872,281	94,467	7,777,814	0.000524	D51/48
		0.75	3,712.5	9,363,708	112,364	9,251,343	0.000524	D51/56

where, D': tower diameter without concrete cover, D_i: tower inner diameter without inner tube, A_g: area of ICH RC tower, A_s: area of longitudinal reinforcement, A_c: area of concrete, $\rho_{s,min}$: distance ratio of transverse reinforcement, R_t: diameter of longitudinal reinforcement, No.: number of longitudinal reinforcement

The longitudinal reinforcement ratio was applied as 0.012 that is a regulated minimum value 0.01 with safety factor 1.2. By choosing the minimum value of the ratio, the lowest construction cost was expected. The ICH RC wind tower could be divided into some modules for the convenience of construction and transportation. The number of longitudinal reinforcements was calculated by following process in figure 3, but it was selected multiples of four in range between 30 and 70. The number of longitudinal reinforcement can be reduced from lower module to upper module for cost efficiency and for keeping the ratio of longitudinal reinforcement. About the reducing longitudinal reinforcements is mentioned at module analysis part below. For the transverse reinforcements, 16 mm-diameter rebar was selected. The distance between transverse reinforcements was decided as 660.8 mm. For the convenience of construction and for enhancing safety of the tower, it was set as 600 mm. Thickness of inner tube can be obtained from CoWiTA program (Han 2015). It was 4 mm, but 5 mm of inner tube was selected to use factory-made products and to reduce manufacturing cost.

3 ANALYSIS

With the section design results, the ICH RC wind tower was analyzed by non-linear program CoWiTA. The needed input data of material properties were yield stress, ultimate stress, and elastic modulus of the reinforcements and the inner tube, and they were 313 MPa, 490 MPa, and 206,101 MPa respectively. 30 MPa of compressive strength was used as the concrete input data.

An additional moment by large displacement effect (LDE) was considered when the ICH RC tower was analyzed with CoWiTA. As figure 3 represents, tower top moves from the left to the right by wind thrust. This displacement and the weight of nacelle parts including turbine and blades generate additional moment.

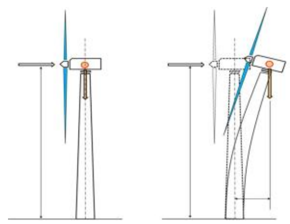

Figure 3. Large displacement effect.

4 RESULTS

4.1 Single Body Type of ICH RC Tower

Figure 4 and figure 5 represent the P-M interaction curves and the moment-curvature curves of the designed ICH RC towers, respectively. In case01, with any of hollow rations the ICH RC wind tower were satisfied with required moment load. When it comes to the case02, the tower has 4.95 m of bottom diameter also could be resisted safe to its demand load except the case of 90% hollow ratio. By comparing figure 4 and figure 5, the lines were located slightly above the required load line in figure 5 than in figure 4. The large displacement effect mentioned above could be a reason of it. The P-M interaction curves indicate its own property of the ICH RC wind tower so that they do not include the large displacement effect. The moment-curvature curves in figure 5, however, applied the large displacement effect so that the analysis results lines were located more close with the required moment load line.

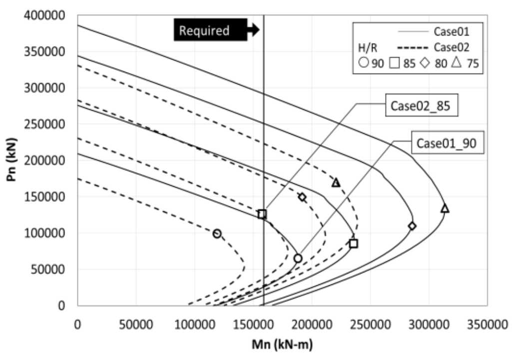

Figure 4. P-M interaction curve.

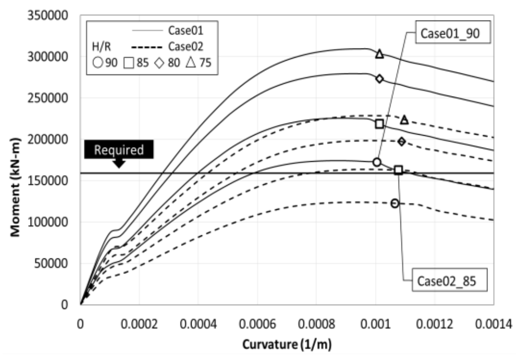

Figure 5. Moment-curvature curve.

4.2 Modular ICH RC Tower

The tall towers such as offshore wind tower could have difficulties of construction, installation, and transportation. The modularized ICH RC wind tower can be an answer of them. In this study, two cases were chosen; case01_90 and case02_85 to design modularized ICH RC wind tower. They not only satisfied with required moment but have the greatest hollow ratio among having different tower diameter cases. The height of each module was determined based on the road traffic law in Korea (Korean National Police Agency, 2016) which presents maximum length of the transporting structure. Each module height was set about 15 m but the height of the lowest module was selected different value as 5 m as shown in figure 6. The module 1 located at the lowest part of the ICH RC wind tower has plastic hinge area so that it was designed to have larger diameter and more transverse reinforcements than any other modules.

The cross-sectional area of the modularized ICH RC wind tower decreases from bottom to top. By reducing the amount of longitudinal reinforcements, the modular ICH RC wind tower can have uniform ratio of them and it increases economic feasibility. As module height goes up, four longitudinal reinforcements were eliminated double-symmetrically for convenience of construction and the balance of bending stiffness. However, if the ratio of longitudinal reinforcement was dropped under 0.012 chosen before, numbers of the transverse reinforcement was maintained.

Table 2. Section design of the modular ICH RC wind tower.

Case01_90		**D' (mm)**	**D_i (mm)**	**No.**	**Dist. (mm)**	**Case02_85**		**D' (mm)**	**D_i (mm)**	**No.**	**Dist. (mm)**
Module1	Bottom	5,500	4,950	52	300	Module1	Bottom	4,950	4,208	40	300
	Top	5,416	4,874				Top	4,895	4,161		
Module 2	Bottom	5,416	4,874	52	600	Module 2	Bottom	4,895	4,161	40	600
	Top	5,247	4,723				Top	4,784	4,067		
Module 3	Bottom	5,247	4,723	48	600	Module 3	Bottom	4,784	4,067	36	600
	Top	4,995	4,495				Top	4,618	3,926		
Module 4	Bottom	4,995	4,495	44	600	Module 4	Bottom	4,618	3,926	32	600
	Top	4,742	4,268				Top	4,453	3,785		
Module 5	Bottom	4,742	4,268	40	600	Module 5	Bottom	4,453	3,785	28	600
	Top	4,473	4,025				Top	4,276	3,634		
Module 6	Bottom	4,473	4,025	36	600	Module 6	Bottom	4,276	3,634	24	600
	Top	4,203	3,783				Top	4,099	3,484		
Module 7	Bottom	4,203	3,783	32	600	Module 7	Bottom	4,099	3,484	24	600
	Top	3,900	3,510				Top	3,900	3,315		

where, Dist.: distance between transvers reinforcements

Table 2 shows the result of section design of each module. CoWiTA was used for analysis of each section at its height and figure 7 shows the results.

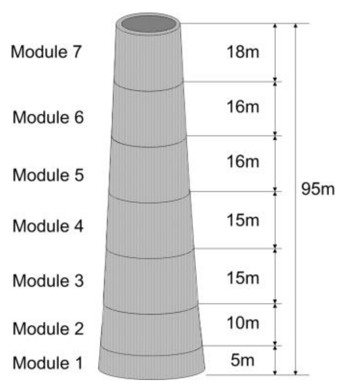

Figure 6. Section height.

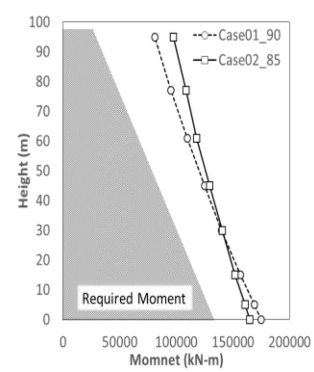

Figure 7. Results of modular ICH RC tower.

The maximum moment of the modular ICH RC tower at the tower bottom were 174,974 kN-m on case01_90 and 164,976 kN-m on case02_85. They were 110% and 104% of the required moment load respectively. The results of modular ICH RC wind tower indicated that moments at tower top could be safe until 255% and 307% of required moment on case01_90 and case02_85. Finally, all modularized tower sections were confirmed to satisfy with the required moment at each height.

5 CONCLUSION

An ICH RC tower was suggested for supporting 5.0 MW wind turbine. The different sections which have two different tower diameters with various hollow ratios were designed and analyzed by CoWiTA. The large displacement effect was applied in analysis and all design cases except case02_90 showed enough performance to support a 5.0 MW turbine. Two cases among the 8 cases of section design were chosen to modularize. They satisfied with required moment and they have the greatest hollow ratio among having different tower diameter cases. The modularized ICH RC wind tower which has advantages of construction and transportation were sectionally designed and analyzed. By analyzing each module, it was confirmed that the modularized ICH RC wind tower satisfied with required load condition at each height. As a result, the ICH RC tower could support 5.0 MW wind turbine and could be modularized. Finally, the modularized ICH RC wind tower could be an alternative wind power tower instead of the steel towers having risk of buckling failure, and could be applied as offshore wind tower which requires large capacity and tall height.

Acknowledgments

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