Application Study of 300mm Large Size Angle Steel in ±1100kV Ultra-high Voltage Tower Transmission Tower

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Abstract. The limb width and the limb thickness of the large size angle steel are very great, section area is more greater than that of the angle steel in the conventional power transmission tower, which can greatly improve bearing force of the single member. It is considered feasible after analysis that the 300mm single limb large size angle steel is applied to substitute the double combination angle steel; take the JC1 angle tower in ±1100kV Huaidong Transmission ultra-high voltage DC engineering as the analysis object, it optimizes the slope of the tower body and the root open size, economic analysis is carried out when the main member applies the combination angle steel and the large size angle steel respectively. Results show: Weight of the JC1 tower which main member applies the 300mm large size angle steel is 6%~10% lower than that of the combination angle steel tower. Price of every base of the steel tower is 7%~11% lower than that of the combination angle steel tower, which has high economic and social benefit.

Introduction

The limb width of the common angle steel in the domestic power transmission tower is about 200mm and below at present. Following quick development of national economy, the member of the original power transmission tower can't meet with requirements of the ultrahigh voltage power transmission or the same tower multiple circuits power transmission technology, it is essential trend to develop the new member of the power transmission tower. In 2009, State Grid Corporation has started application study works the 220mm and 250mm large size angle steel in the steel tower in the power transmission line, application of the large size angle steel is trial applied about 6000 tons in ±800kV Jinping-Sunan ultra-high voltage DC engineering for first time[1]. Hereafter, the ±800kV Luoxidu – Zhexi, ±800kV Hami – Zhenghou and 1000kV Zhebi- Fuzhou etc ultra-high voltage DC engineering also apply the large size angle steel to substitute the common double splice or the four splice angle steel in the angle steel tower, machining quantity of the steel tower is reduced greatly, safety hidden problem of the steel tower caused by welding quality of the filling boards between the angle steels is reduced; the structure can be optimized, the connection bolt and the filling board can be reduced greatly, construction efficiency of the steel tower is improved; the unreasonable section type can be improved, and steel consumption index of the steel tower is reduced, it can save about 4% tower weight in average, and economic benefit is obvious[2-3].

The ±1100kV Huaidong transmission ultra-high voltage DC engineering will apply the $6 \times 1520mm^2$ or $8 \times 1250mm^2$ conductor, load of the power transmission tower is increased greatly compared to the past ultra-high voltage DC engineering; in additional, the line will pass through the desert, the Gobi and the mountain area etc areas, wind speed is very high（reach 43m/s maximum）, ice thickness at mountain area with high altitude is very great（20mm and above heavy ice area）, these will cause load

of the power transmission tower further increase. Therefore, the main materials of the some power transmission towers in the ±1100kV ultra-high voltage DC line shall apply the double splice or four splice common combination angle steel（even the 220mm and 250 mm large size combination angle steel）, forcing requirements of the structure can be met. This paper selects the JC1 corner tower in the ±1100kV line with high application rate, main materials are designed to apply the 300mm large size angle steel to substitute the double splice or four splice convenient combination angle steel, and investigates its feasibility and carries out economy analysis, which provides reference and basis for application of the 300mm large size angle steel in the main materials of the power transmission tower in the ±1100kV Hudaidong transmission ultra-high DC line.

Feasibility analysis of application of 300mm large size angle steel

At present, the maximum specification of the manufactured and applied angle steel in the domestic power transmission line engineering is L250x35. It is learnt from design specification of the power transmission tower in our country[4], bearing force of the member of the power transmission tower is determined by strength bearing force and stability bearing force two factors, strength bearing force depends on the net area of the member（area of the hole is subtracted from section area）, steel material and section thickness; stability bearing force depends on calculation length, section area of the member, yield strength of the material and rotary radius of the section etc. When material of the angle steel is Q420, refer to Table 1 for maximum bearing force of L250x35 when it is applied in the main material of the tower body.

Table 1 Maximum bearing force of Q420L250x35 angle steel

Specification	Section area (cm^2)	Number of reduced M24 hole	Net area (cm^2)	Stabilization coefficient	Critical slenderness	Critical calculation length (mm)	Bearing force (kN)
L250x35	163.4	2	145.6	0.891	31.4	1526	5240

Seen from the Tab.1, when forcing of the main material exceeds 5240 kN（forcing of the main material of the ultra-high voltage strain tower is commonly greater than this value), if no steel pipe is selected, the combination angle steel type must be applied so as to increase section area and improve bearing capability. The combination angle steel shown in the Fig.1 which is commonly applied by the main material of the tower body is the crossing double splice combination angle steel, its specification parameters are shown as Table 2.
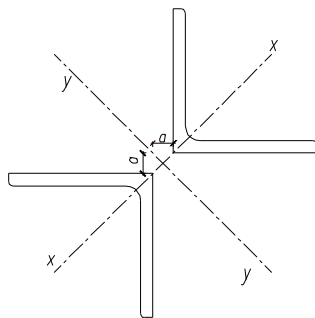

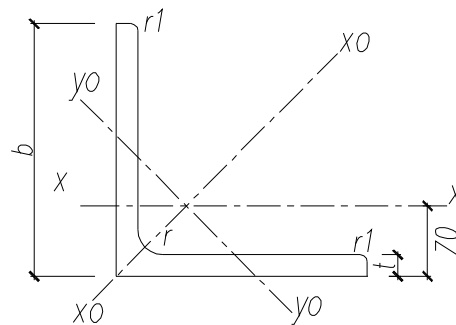Fig.1 Schematic figure of combination angle steel

Fig.2 Schematic figure of 300mm large size angle steel

Table 2 Specification and parameters of crossing double splice combination of convenient large size angle steel

Specification of large size crossing double splice angle steel	Span a (cm)	Area (cm^2)	Rotary radius i_x (cm)	Rotary radius i_y (cm)
2L220x16	1.6	137.153	8.61	10.58
2L220x18	1.8	153.328	8.58	10.81
2L220x20	2.0	169.335	8.55	11.05
2L220x22	2.0	185.175	8.52	11.15
2L220x24	2.4	200.847	8.48	11.51
2L220x26	2.4	216.352	8.45	11.60
2L250x18	1.8	175.288	9.80	12.01
2L250x20	2.0	193.696	9.76	12.24
2L250x22	2.0	211.936	9.73	12.34
2L250x24	2.4	230.008	9.70	12.70
2L250x26	2.4	247.913	9.66	12.80
2L250x28	2.4	265.650	9.63	12.90
2L250x30	3.0	283.219	9.59	13.39
2L250x32	3.0	300.621	9.56	13.49
2L250x35	3.0	326.409	9.51	13.64

Consider to increase section area of the large angle steel member to reach bearing capability of the single member, because the limb width of the 300mm large size angle steel is very great, and section are is more greater than L250x35; when the section area are same, bearing force of the single member is greatly improved because the rotary radius is very great.

It is learnt from investigation the domestic steel works can produce the L300x(20～35) large size angle steel at present, the section area of the angle steel is shown as Fig.2. Table 3 is specification and parameters of 300mm large size angle steel.

Table 3 Specification and parameters of 300mm large size angle steel

Specification of large angle steel	Inner arc r (mm)	Side arc r_i (mm)	Area (cm^2)	Gravity centre Z_0 (cm)	Minimum axle i_{y0} (cm)	Parallel axle i_x (cm)
L300x20	28	6.67	117.492	8.15	5.98	9.32
L300x22	28	7.33	128.612	8.23	5.96	9.29
L300x24	28	8.00	139.648	8.31	5.94	9.26
L300x26	28	8.67	150.600	8.39	5.92	9.24
L300x28	28	9.33	161.469	8.46	5.91	9.21
L300x30	28	10.00	172.253	8.54	5.89	9.18
L300x32	28	10.67	182.954	8.61	5.88	9.15
L300x35	28	11.67	198.848	8.72	5.86	9.11

Bearing force of the main material of the tower body is mainly controlled by the section area of the member. If section areas and slenderness of two members are equivalent, bearing force of these two members shall be equivalent. Section area of the common specification double splice combination angle steel 2L200x24 is 181cm², and minimum rotary radius is 7.8cm[5]; learnt from Tab.2, section area scope of the convenient large size double splice combination angle steel 2L220x16～2L250x35 is

137cm² ～ 326cm², scope of the minimum rotary radius is 8.4cm ～ 9.8cm[6]; scope of the section area of the 300mm large size angle steel is 117cm² ～ 199cm², scope of the minimum rotary radius is 5.8cm ～ 6.0cm. It is learnt the 300mm large size angle steel can completely substitute the common specification double splice combination angle steel（2L200x24 and below）when it is only considered from strength, it can substitute the convenient large size double splice combination angle steel of 2L250x22 and below. When section area is equivalent, rotary radius of the 300mm large size angle steel is 70%~80% rotary radius of the common crossing double splice combination angle steel, 60%~70% rotary radius of the convenient large size double splice combination angle steel, the slenderness ratio of the main material can be reduced suitably to make its stabilization coefficient equivalent.

Structure design of JC1 corner tower

Design conditions and key point

Design conditions of the JC1 corner tower is shown as Table 4. The JC1 tower applies the angle steel structure. The main material at the position below the variable slope of the power transmission tower shall apply the 300mm large size angle steel during design.

Table 4 Design conditions of JC1 corner tower

Grounding conduction wire Model	Model of conductor: 8×JL1/G2A -1250/100
	Model of grounding wire: LBGJ-240-20AC
Main design meteorological condition	Designed wind velocity:30m/s
	Design icing: 15mm for conductor, 20mm for grounding wire
Design span	Horizontal span: 550m
	Representative span:350m/700m
	Vertical span:270m/630m
Altitude height	2,000m
Degree of corner	20°

Optimization of tower body slope and opening width

The slope is determined by the height of the tower body, the width of the opening and the root opening these three independent variables. After type of the tower head and the vertical height are determined, height is a fixed value, slope of the tower body is determined by the width and the root opening (i.e., width of the upper and lower opening). Upper and lower width of the tower body directly affects the whole rigidity and tower weight of the steel tower. Less is opening width, less is rigidity of the tower head, greater are displacement and deformation, and internal force of the main member in head is increased, the tower weight is naturally increased, vice versa, it is reduced; when the opening width is continuously increased, the steel tower is heavier and heavier when the member size is enlarged.

The slope of the tower body at upper section, the top opening and the waist size of the power transmission tower are optimized according to different width and slope, refer to Table 5 for results. After the tope opening and the waist width are determined, carry out optimization design calculation of the root opening of the steel tower, refer to Table 6 and Fig.3 for optimization results.

Table 5 Optimization result of slope and size of tower body at upper section of JC1 tower

Waist size (mm)	Opening at top of tower (mm)	Slope at upper section	Calculation weight (kg)	Foundation action force (kN)	
				Extraction force	Compression force
5700	2800	0.104	106554	3881	-5212
	2900	0.100	106563	3871	-5203
	3000	0.096	106688	3873	-5206
	3100	0.093	106900	3876	-5210
	3200	0.089	107043	3878	-5214
6000	2800	0.114	106712	3889	-5223
	2900	0.111	106774	3892	-5226
	3000	0.107	106762	3890	-5225
	3100	0.104	106854	3895	-5231
	3200	0.100	106967	3899	-5235
6300	2800	0.125	106350	3912	-5244
	2900	0.121	106469	3915	-5248
	3000	0.118	106563	3917	-5251
	3100	0.114	106615	3923	-5257
	3200	0.111	106790	3925	-5261

Note: The slope is double surface slopes.

Table 6 Optimization result of slope and leg root opening of tower body at lower section of JC1 tower

Opening at top of tower (mm)	Waist size (mm)	Centre space (mm)	Slope at lower section	Calculation weight (kg)	Foundation action force (kN)	
					Extraction force	Compression force
2800	6300	19500	0.249	107536	4205	-5543
		20000	0.258	105859	4083	-5412
		20500	0.268	106329	3974	-5306
		21000	0.277	106510	3872	-5205
		21500	0.287	107208	3774	-5112

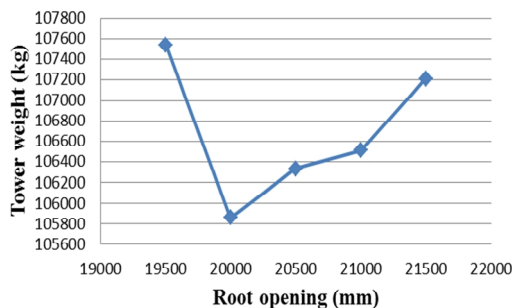Note: The slope is double surface slopes.

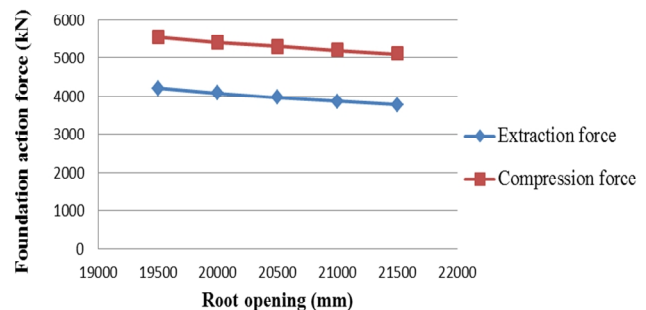Fig.3 Change figure JC1 tower weight following root opening

Fig.4 Change figure of foundation action force of JC1 tower following root opening

Learn from Table 5, slope optimization of the tower body at upper section of the JC1 shall ranged between 0.089～0.125. Weight of the steel tower is lightest at slope of 0.125, it is 106.350t, and corresponding foundation action force is also small. Therefore, slope of the tower body at upper section of the JC1 tower is suggested to apply 0.125, the corresponding opening at top of the tower and the waist size is 2800mm and 6300mm respectively.

Learn from Table 6 and Fig.3, weight of the JC1 tower is lightest when the root opening is 20m, it is 105.859t. Following the root opening is enlarged greatly, the tower weight index rises up. Weight caused by increasing of the length of the slope material exceeds reduction of the tower weight caused by reduction of inner force of the main material when the root opening continues enlarge. In addition. Root opening of the steel tower not only affects the tower weight index but also affects foundation index. Foundation action force can be reduced when the root opening of the steel tower foundation is enlarged, and foundation action force is almost reduced linearly following increasing of the root opening, show as Fig.4. Seen from the figure, its foundation action is also very small when the root opening of the JC1 tower is 20m.

Economic analysis

In order to compare economy of different materials applied in the JC1 tower, two calculation models of the combination angle steel tower and the large size angle steel tower. Structure arrangement way of the combination angle steel tower is same as that of the large size steel angle tower. Refer to Fig.5 for single line figures of the models. Maximum material qualities of the members are classified as Q345, Q420 and Q460 three conditions during structural material selection, refer to Table 7 for concrete analysis results.
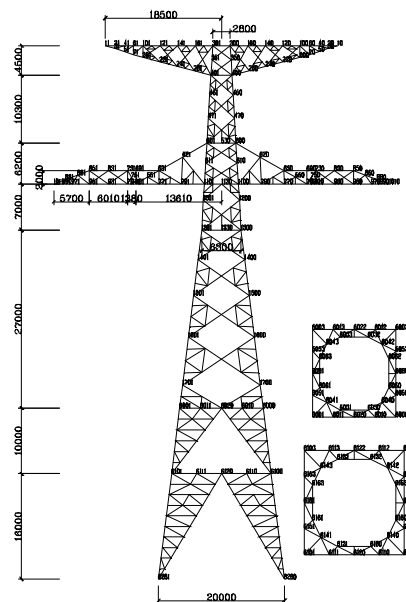

Fig.5 Single line figures of the models of JC1 tower

Table 7 Economy analysis of JC1 corner tower

Item		Combination angle steel tower			Large size angle steel tower		
		Q345	Q420	Q460	Q345	Q420	Q460
Calculation weight(t)		124.2	112.1	108	117.3	107.8	105.2
Total weight of tower material(t)		180.1	162.5	156.6	164.2	150.9	147.3
Total weight comparison of tower material		1.22	1.10	1.06	1.12	1.02	1.00
Economy index of whole tower (ten thousand Yuan)		110.8	102.4	101.8	100.2	94.3	95.0
Economy index comparison		1.17	1.09	1.08	1.06	1.00	1.01
Main member of tower	600- 700	2L200x18H	2L200x14B	2L180x14C	L300x22H	L220x26B	L250x20C
	710-1100	2L200x24H	2L200x18B	2L200x16C	L300x28H	L300x24B	L250x28C
	600-1100	2L180x14H	L200x20B	L200x18C	L220x22H	L200x20B	L200x18C
	1100-1300	2L200x14H	L200x24B	L200x24C	L220x26H	L220x20B	L220x20C
	1300-1500	2L200x24H	2L200x16B	2L200x14C	L300x26H	L250x26B	L250x24C
	1500-1600	2L200x24H	2L200x20B	2L200x16C	L300x30H	L300x26B	L300x24C
	1600-1700	4L180x14H	2L200x24B	2L200x20C	L300x35H	L300x28B	L300x26C
	1700-6100	4L180x14H	2L200x24B	2L200x20C	L300x35H	L300x28B	L300x26C
	6100-6280	4L200x14H	2L200x24B	2L200x24C	2L220x26H	L300x28B	L300x26C

Seen from Table 7: (1) When the JC1 tower applies the large size angle steel tower with the best material quality of Q460, weight of the steel tower is lightest, it is 147.3t; When the steel tower applies the combination angle steel tower with the best material quality of Q345, weight is heaviest; it is 180.1t, which is about 22% heavier than that of the Q460 large size angle steel tower. When the best quality material of the steel tower is same, the large size angle steel tower is lighter, which is 6%~10% lighter than the combination angle steel tower.

(2)When the JC1 tower applies the large size angle steel tower with the best quality material of Q420, total price is lowest, it is 943 thousand Yuan; When the steel tower applies the combination angle steel tower with the best quality material of Q345, total price is highest, it is 1,108 thousand Yuan, it is about 17% higher than that of the former. When the best quality material applied in the steel tower is same, total price of the large size angle steel tower is lowest, it is 7%~11% lower than that of the combination angle steel tower.

(3)When the best quality material is Q420, specification of the maximum main material of the combination angle steel tower is 2L200x24, the large angle steel with single limb of 250mm can't meet with requirements. After the large angle steel with the limb width of 300mm is applied, specification of the maximum main material is L300x28, weight of the tower is reduced about 8%, and price of the whole tower is reduced about 9%. It not only saves the tower material but also saves cost, which has high economical and social benefit.

Summary

(1)The double splice combination angle steel structure is changed to the 300mm single limb large size angle steel, it not only saves 6%~10% tower material but also reduces price of the whole tower 7% ~ 11%.

(2) If the large size angle steel is applied, it can save a large quantity of the filling boards and the bolts, fabrication and installation are more convenient and feasible, and quality is guaranteed.

(3)The combination angle steel members are connected through the filling board, forcing of every member is uneven. Force transmission of the single limb large size angle steel is simple. Section area of

the large size angle steel is lower than that of the combination angle steel under same bearing force requirements, it can save a part of the main material, and it is also safer.

(4)After the main material of the JC1 tower applies the 300mm class Q420 large size angle steel, every base of the steel tower can save about 8% tower material, and price of the whole tower can save about 9%.

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