IOP Conf. Series: Materials Science and Engineering **392** (2018) 022007 doi:10.1088/1757-899X/392/2/022007

Research on the Application of High Strength Steel for 750kV Combined Framework

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Abstract: With the high strength steel being used widely in engineering, it's certainly meaningful to research the application of high strength steel to substation frameworks.Using high strength steel of different grades including Q420, Q460, Q550 and Q690 for a 750kV combined framework instead of common steel, researchers have run its finite element analysis with different steel materials by SAP2000 and preliminarily designed its section, as well as valued its cost. The result demonstrates that the application of high strength steel in substation frameworks has certain economic and social benefits.

1. Introduction

The 750kV substation is a special ultra large substation in the nation's power grid, a very important role in the main UHV grid.As the main structure of the substation, the frame occupies a large area and costs amount of labor force, which consequently have a great influence on the layout and cost of the whole substation.For a long time, the steel's grades used for transmission and transformation stations in our country are limited to Q235 and Q345,and the scarce types and the low strength of steel have led to a larger cross-section of frame,as well as increased the workload on installation,the investment and the waste of resources.High strength steel has the advantages of high strength and good bearing capacity, which can effectively smooth these above contradictions[1-2].

With a substation project in Xinjiang as the object, the SAP2000 as a calculation and analysis software,respectively adopting common steel and high strength steel such as Q420、Q460、Q550、Q690 steel , and carrying out finite element modeling and analysis with reference to the actual traverse load, local wind pressure and earthquake influnence,as well as under the condition that the bearing capacity and displacement can meet the requirement of specifications, this paper analyzes the benefits of the employment of high strength steel for the substation frame and provides a theoretical basis for relevant researches.

2. Introduction to the calculation model

The overall schematic diagram of this 750kV substation frame is shown as Figure 1. Take the typical parts to study on and the related dimensions are shown in Table 1.The structure's form is a lattice construction.The open root modeled and analysed is a square of 9.0m long and 4.0m wide. And high strength steel of four grades---Q420,Q460, Q550 and Q690 are used.

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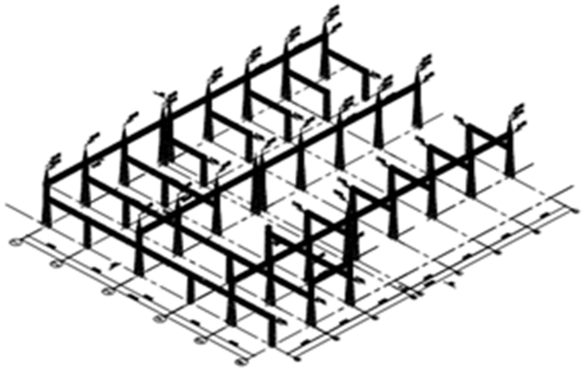


Figure 1. The whole diagram of the substation frame.

Table 1. Dimension Information of a Substation Project in Xinjiang

project	Dimension information
Lower chord elevation of the busbar beam	27.000m
Lower chord elevation of the beam containing inlet and outlet lines	40.000m
Top chord elevatioof the column containing land-lines	58.000m
Span of the beam containing inlet and outlet lines	42.0m
Span of the busbar beam	41.0m

Considering the small sizes of the frame beam members and their small internal force mainly controlled by deflection rather than strength , the use of high strength steel is restricteded by the aspect ratio and size specification, so the frame beam continues to use common steel. While the materials ued for lightning rod,as well as frame columns containing inlet and outlet lines and generatrix that bear larger load all are high strength steel.

Generally,there are two ways to integrally model a combined frame:practical modeling method and simplified modeling method.The former is to establish models of frame beams and columns and land-line columns according to the real situation, while the latter is to simplify a beam to a single member under the principle of equal rigidity and weight, and then model and calculate the beam separately.In order to make the calculation model more paralleled to the pratice,actual modeling method is used in this paper by the SAP2000 [3].All members are set as beam elements, and the connections between beams and columns are hinged.

3. Select the cross section

The cross section of each model member with steel and high strength steel are respectively compared as shown in Table 2. All sizes and materials used can meet the relevant provisions to stee-l structure.

Table 2. Comparison of the cross section of each model with steel and high strength steel

Component.			Common iron	Q420	Q460	Q550	Q690
Gear of the inlet and outlet line	Frame column	Main material	Φ325×10	Φ325×8	Φ299×8	Φ273×7	Φ230×6
		Cross bar	Φ89×5	Φ89×5	Φ89×5	Φ89×5	Φ89×5
		Diagonal bar	Φ121×5 Φ180×5	Φ121×5 Φ180×5	Φ121×5 Φ180×5	Φ133×5 Φ180×5	Φ152×5 Φ180×5
	Frame beam	Chord member	Φ114×5	Φ114×5	Φ114×5	Φ114×5	Φ114×5
		Web member	Φ114×5	Φ114×5	Φ114×5	Φ114×5	Φ114×5
		Diagonal bar	Φ95×5	Φ95×5	Φ95×5	Φ95×5	Φ95×5
Gear of the busbar	Frame column	Main material	Φ245×7	Φ230×6	Φ219×6	Φ194×5	Φ180×5
		Cross bar	Φ76×5	Φ76×5	Φ76×5	Φ76×5	Φ76×5
		Diagonal bar	Φ89×5 Φ140×5	Φ89×5 Φ140×5	Φ89×5 Φ140×5	Φ89×5 Φ140×5	Φ89×5 Φ140×5
	Frame	Chord member	Φ76×5	Φ76×5	Φ76×5	Φ76×5	Φ76×5

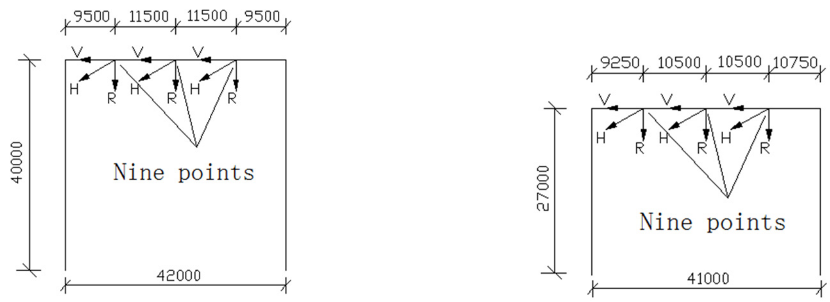
	beam	Web member	Φ76×5	Φ76×5	Φ76×5	Φ76×5	Φ76×5
		Diagonal bar	Φ70×5	Φ70×5	Φ70×5	Φ70×5	Φ70×5
Land-line column	Main material		Φ95×5	Φ95×5	Φ95×5	Φ95×5	Φ95×5
	Cross bar		Φ83×5 Φ140×6	Φ83×5 Φ140×6	Φ83×5 Φ140×6	Φ83×5 Φ140×6	Φ83×5 Φ140×6
	Diagonal bar		Φ83×5	Φ83×5	Φ83×5	Φ83×5	Φ83×5
Lightning rod			Φ273×7	Φ230×6	Φ219×6	Φ219×6	Φ245×7

Note: the cross sections are all circular steel pipe and the unit is mm.

4. Load calculation of the frame

4.1. Conductor load

The conductor load is concentrated at three fixed points of the beams containing inlet and outlet lines and the busbar beams, among which the busbar beams on both sides settle wires in their side faces. （the load perpendicular to the frame beams) is the larger one between R_A and R_B. The schematic diagram of conductor load is shown as figure 2, obtained from electrical engineering and the traverse load is shown in Table 3 and 4.



(a)Gears of the inlet and outlet lines in beams (b)Gears of the busbar beams

Figure 2. Conductor load schematic diagram

Table 3. The calculation results of the load on inlet and outlet lines (750 sideways)

Status	Horizontal tension(H)	Unit	Perpendicular(RA)	Load (RB)	Unit
Max load	96008.562	N	3639.616	3210.904	kgf
Max wind velocity	77735.717	N	3034.084	2711.896	kgf
Min temperature	59054.274	N	2496.056	2245.484	kgf
Construction installation	5877.931	N			kgf
Three-phase weight of workers	61131.675	N	2548.292	2403.480	kgf
One-phase weight of workers	74527.804	N	2688.716	2863.052	kgf
Lateral wind pressure	1161.418				kgf

Table 4. The calculation results of the load on gears of busbar(750 lengthways)

Max load	47662.97	N	1884.76	1884.76	kgf
Max wind velocity	39541.59	N	1611.496	1611.496	kgf
Min temperature	32670.38	N	1401.248	1401.248	kgf
Construction installation	32427.50	N			kgf
Three-phase weight of workers	35727.51	N	1457.860	1548.768	kgf

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One-phase weight of workers	46734.22	N	1621.374	1985.132	kgf
Lateral wind pressure	589.483				kgf

4.2. Wind load

According to Code for load on Building structures(GB50009-2012) [4],the standard value of wind load is calculated by formula 1：

$$\omega_K=\beta_Z\mu_Z\mu_S\omega_0 \qquad (1)$$

ω_K（kN/m^2） is the standard value of wind load； β_Z is a vibration factor； μ_Z is a variable coefficient of wind pressure height； μ_S is the structural shape factor of wind load ； ω_0 （kN/m^2）is the fundamental wind pressure。

Considering different kinds of wind speed , the basic wind pressure can be approximately calculated by formula 2.

$$\omega_0=\upsilon^2/1600 \qquad (2)$$

υ (m/s) is the wind speed.

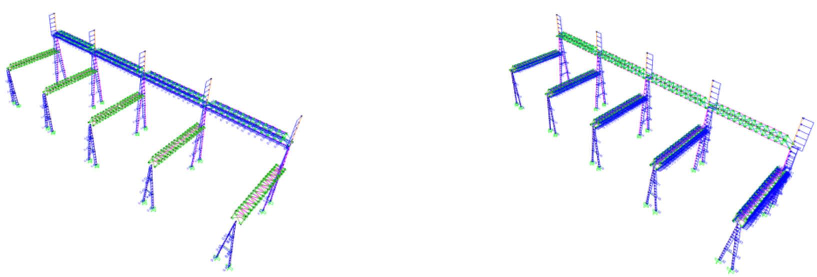
Referring to the Design Manual for Substation frame[5],the basic wind pressure corresponding to the wind speed of 10m/s is taken under the small wind conditions(0.063kN/m^2) and the wind pressure of the region once in 50 years under gale conditions, but not less than 0.3kN/m^2. According to Code for load on Building structures ,the basic wind pressure in this area is 0.85kN/m^2 once in 50 years.

For the herringbone columns,the latticed columns and the frame columns, the windshield coefficient can be calculated according to the net and contour area of bars and nodes.Then search for the wind load body size coefficients through the Table 3-3 and 3-4 in the Manual for the Design of Substation frame.The shape coefficients of the wind load on the of herringbone column structures are listed in Table 3-2.

The value of the wind-induced vibration factor is determined by referring to the Article 5 of Code for the Design of Building structures (4.4.2):the wind vibration coefficient of the herringbone columns is 1.2, the lattice type tower structures 1.5, the single Steel pipe columns (h>8m) 2, and the steel pipe concrete columns 1.7.

As for the variable coefficient of wind pressure height, considering the geographical environment of substation, it can be adopted according to the type-A ground (desert) and by the Table 3-5 in the Design Manual for substation frame in detail .

Value of the wind load acting on the frame columns equals to the standard one on each column section multiplied by its member diameter.Then convert it into the line load on each column segment, which is applied in the form of uniform line load in SAP2000 .And value of the wind load acting on the busbar beams equals to the windshield area multiplied by the standard value. After discounted by the windshield coefficient , the wind load is symmetrically distributed to the upper and lower chords of the truss beams, and finally applied in the form of uniform line load. The effects are shown in Figure 3.



(a) X direction (b) Y direction

Figure 3. Wind load effect diagram

4.3 Earthquake action

According to Code for Seismic Design of buildings[6]（GB50011-2010,Partial revision）,the seismic fortification intensity of the site is 8 degrees, and the basic design seismic gravity acceleration is 0.2 g(the second group).

5. Bearing capacity and displacement analysis

5.1 Bearing capacity analysis

Fig. 4 is a cloud diagram of stress ratio between common steel and high strength steel generated by the SAP2000. It can be seen that the maximum stress ratio appears in the position where the land-line columns are connected with the lightning rod, and the stress ratio at the bottom of frame columns is also large, while the stress ratio of frame beams are relatively small.The maximum stress ratio and the control conditions with the common steel and the high strength steel are shown in Table 5, which show that all the schemes are competent in bearing capacity

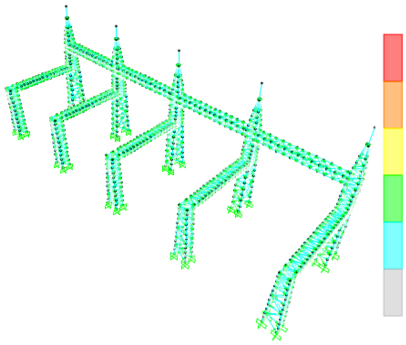


Figure 4.The stress ratio cloud diagram

Table 5.Maximum stress ratio and Control conditions

Steel type	Max stress ratio	Control condition
Common	0.739	great wind, unfavorable-X
Q420	0.746	great wind ,unfavorable-Y
Q460	0.783	great wind ,unfavorable-Y
Q550	0.805	great wind ,unfavorable-Y
Q690	0.771	great wind ,unfavorable-Y

5.2 Displacement analysis

According to the Technical Specification for structural Design of Substation buildings[7](DL/T 5457-2012), the displacement of a substation frame should be calculated under the load of serciceablity limit states. For latticed tower structure(750kV), it is mainly controlled by the following two aspects:

（1） The allowable deflection in the middle of frame beams is H/400.For busbar beams, it’s 102.5mm(41000/400), while for beams containning inlet and outlet lines,it is105mm (42000/400)。

（2）The allowable deflection of independent lightning rods is H/70 (Steel Tube) .For framework lightning rods,it’s 614mm (43000/70).

The calculated displacement of lightning rods and the maximum displacement in the middle of beams are shown in Table 6 to 8 and both can meet the requirements of code.

Table 6. The displacement of lightning rods

Steel type	Direction x		Direction y	
	Max displacement	Control condition	Max displacement	Control condition
Common	40.4	Gale condition	15.2	Gale condition
Q420	29.2	Gale condition	28.6	Gale condition
Q460	25.3	Gale condition	33.6	Gale condition

Q550	17.3	Gale condition	43.5	Gale condition
Q690	13.8	Gale condition	56.3	Gale condition

Note: units in the table are all mm.

Table 7. The displacement in the middle of the beams containning input and outlet lines

Steel type	Direction x		Direction z	
	Max displacement	Control condition	Max displacement	Control condition
Common	25.5	Gale condition	27.7	Gale condition
Q420	28.9	Gale condition	28.6	Gale condition
Q460	30.2	Gale condition	29	Gale condition
Q550	35.1	Gale condition	30	Gale condition
Q690	42.7	Gale condition	32.1	Gale condition

Table 8. The displacement in the middle of the beams of the busbar beams

Steel type	Direction-y		Direction-z	
	Max displacement	Control condition	Max displacement	Control condition
Common	71.3	Gale condition	49.1	Gale condition
Q420	75.2	Gale condition	50.4	Gale condition
Q460	76.7	Gale condition	50.9	Gale condition
Q550	82.4	Gale condition	52.7	Gale condition
Q690	87.1	Gale condition	53.9	Gale condition

6. Economic analysis

Referring to relevant databases[8], the unit prices when using common steel and various high strength steel are shown in Table 9.With this model, the consumption and the cost of different steel are shown in Table 10.

Table 9. The unit prices when using different steel

Steel type	Detailed	Unit price
Common	Q235	4050
	Q345	4470
High strength	Q420	4640
	Q460	5060
	Q550	5410
	Q690	6560

Note: the price unit is yuan / ton

Table 10. The quantity and cost of steel

Steel type	Steel quantity			Steel cost	Percentage decreaseds of cost
	Common steel		High-strength steel		
	Q235	Q345			
Common	107.65	117.35	0.00	96.05	0
Q420	106.02	24.69	75.82	89.16	7.2%
Q460	106.02	24.69	70.10	89.45	6.9%
Q550	108.47	24.69	55.31	84.99	11.5%
Q690	112.45	24.69	53.57	91.72	4.5%

Note: quantity unit is t, cost unit is ten thousand yuan. The percentage reduction in cost is based on the amount of common steel used .

According to the table, using high strength steel can obviously reduce the amount of steel used and reduce the total cost.Among them, the cost of Q550 steel is the lowest, which is lower than that of the common steel by 11.5%.It is economically more competent.From the economy, because the high strength steel has the characteristics of high strength and outstanding bearing capacity which can meet the engineering requirements well, the corresponding reduction of steel will not only save the cost, but also significantly reduce the cost of transportation and installation. From the social benefits, the use of high-strength steel conforms to the national reforms to save energy and reduce emission.In the long run, the use of high-strength steel will generate obvious economic and social benefits.

References

[1] Ricai Guo,Changhua He, Xilai Li. The application of high strength steel to transmission tower[J]. Power system Technology, 2006, 30(23): 22-25.
[2] Zan Gao.Study on the structural optimization of 750kV substation frames [D]. Lanzhou: Lanzhou University, 2012.
[3] Yuandong Yao .Optimization design and application of the concrete-filled steel tubes to 750kV transformer frames [D]. Xi'an: Xi'an University of Architectural and Technology,2016.
[4] (GB50009—2012) Load Code for the Design of building structures[S]. Beijing: China Construction Industry Press,2012.
[5] Central South Power Design and Research Institute. Manual for the Design of Substation frames[M]. Wuhan: Hubei Science Press,2006.
[6] (GB50011—2010) Code for seismic design of buildings[S]. Beijing: China Construction Industry Press, 2010.
[7] (DL/T 5457—2012)Code for structural design of substation buildings[S].Beijing: China Planning Press,2012.
[8] China steel price net [CP]. http://tg.zh818.com/, 2018-04-04.