EVALUATING THE INFLUENCE OF REGIONAL FACTORS ON THE DESIGN QUALITY OF TRUSSED STEEL TOWERS

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Abstract

This paper researches on typical design problem of steel tower truss structure. Assess the advantages and disadvantages of the typical steel tower truss design, which has been widely used in Vietnam. Use specialized software to calculate and evaluate the safety and usability of a typical design. From there, proceed to adjust the design parameters in the direction of saving materials, easy processing and erection. Thereby, evaluate the effectiveness of the typical design adjustment plan. Give comment and recommendations for similar structures.

Keywords: *Steel tower truss; regional factors; typical design; specialized software.*

1. Structure of steel tower truss

1.1. Steel tower truss and typical design

Self-standing steel tower truss is a popular structural form, increasingly popular and used in Vietnam. Currently, most of the vertical pyramids (electric poles, antenna tower, microwave tower...) choose to design in the form of staging. Depending on the height and bearing load, the number of element can reach hundreds or even thousands [7].

Me Tri television tower

In order to facilitate the design, fabrication and erection processes in different localities, typical designs are often used. Typical design can be understood as design pattern, design with the most adverse load and impact conditions, suitable for climatic and stormy conditions of one or several typical regions with the factor of safety. certain. Therefore, the sample design can be machined and erection for Tower in many different regions, without having to adjust the

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structure. Typical design can be deployed quickly, responding well to the bearing capacity, but it causes waste of materials, increasing construction costs [3].

1.2. Typical design adjustments according to the criteria of material weight reduction

For steel tower truss, the wind load is usually the load that has the greatest impact on the safety of the structure. Therefore, when using a typical design tower with wind zone IIB to arrange the tower in the lower wind areas (regions IA, IB, IIA) [6, 7], the wind load will be significantly smaller, internal force and stress, because it is also much smaller, leading to material waste. From there, it shows that the adjustment of the typical design, taking into account the wind load factor by region, is a necessary job.

The purpose of this paper is to study and evaluate the effectiveness of the steel tower truss design plan when regional factors are taken into account. These studies are used as the basis to build the problem of determining the reasonable parameters of the steel tower structure.

2. Reasonable design problem for steel tower truss

2.1. Reasonable design problem

Reasonable design, not optimal design problem. The criterion of rational design is to calculate and adjust the steel tower truss design parameters so that it can save materials reasonably, while ensuring the durability and stability of the structure [5, 7]. The logical design sequence is as follows:

- Calculate the values of the types of loads. In particular, the wind load according to the location of the tower's construction;
- Analyse internal force, stress and displacement of steel tower truss;
- Statistics results are calculated according to the group of indexes of the cross-section;
- Evaluate the factor of safety for each group of statistical cross-sections. Proposing to change the size or thickness of the section to reduce the weight of tower;
- Redefine load components and load combinations;
- Analyse internal force, stress and displacement of the tower;
- Check for durability, stability for tower structure. If any element fails, increase the area of the section, and solve again;
- Compare the steel mass of the existing tower, with the tower mass from typical design;
- Evaluate the advantages and disadvantages of the design options.

2.2. Specialized software TowerVN

TowerVN software is specialized software used for designing and calculating steel tower truss structures according to TCVN [1, 2, 8, 9]. This software is designed and programmed by the authors: Tran Nhat Dung [MTA] - Lo Ba Tho [EVN].

TowerVN is finite element method (FEM) software, specialized for calculating steel tower structure according to 3 dimension problem. TowerVN has a Vietnamese interface with a handy Menu and Toolbar system, capable of generating data quickly, strongly, accurately, with rich and vivid graphics. All figures and results from the TowerVN can be displayed in graphic format, easily recorded or printed. TowerVN is used to examine the numerical test problem in item 3 below.

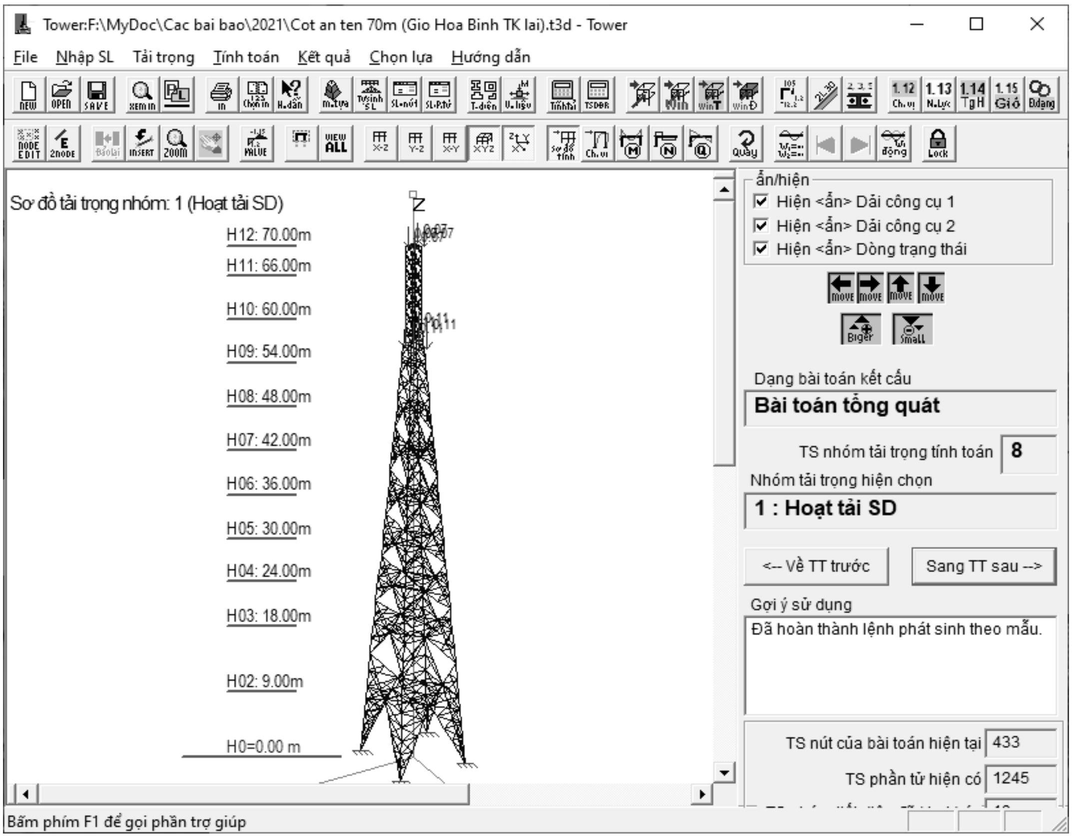


Figure 1. Main interface screen of TowerVN.

3. Testing problem of steel tower truss design

3.1. Describe the test project, the steel tower truss problem according to a typical design

3.1.1. Description of the test project

The test tower is the radio and television broadcasting tower of Hoa Binh Provincial Radio and Television Station. The tower is built according to a typical design that can be installed in representative wind areas: IA, IIA, IB, IIB. The project was started construction from October 2010 to February 10, 2015, it was officially put into use [5].

SEGMEN	SEGMEN 1	SEGMEN 2	SEGMEN 3	SEGMEN 4	SEGMEN 5	SEGMEN 6	SEGMEN 7	SEGMEN 8	SEGMEN 9	SEGMEN 10	SEGMEN 11
White	White	Red	White	Red	White	Red	White	Red	White	Red	White
Height	9000	9000	6000	6000	6000	6000	6000	6000	6000	6000	4000
Wing element	L200x15	L200x15	L175x15	L175x15	L150x15	L150x15	L130x15	L130x12	L130x12	L100x12	L100x12
Cross bar	L80x6	L75x5	L63x5	L63x5	L50x5	L50x5	L50x5	L50x5	L50x5	L50x5	L50x5
Oblique bar	L100x12	L100x7	L80x6	L80x6	L75x5	L75x5	L75x5	L63x5	L63x5	L63x5	L63x5
Side bar	L100x7	L100x7	L100x7	L80x6	L75x5	L75x5	L75x5	L75x5	L75x5	L75x5	L75x5
Connection bar	L80x6	L80x6	L100x7	L80x6	L75x5	L75x5	L63x5	L63x5	L63x5	L63x5	L63x5

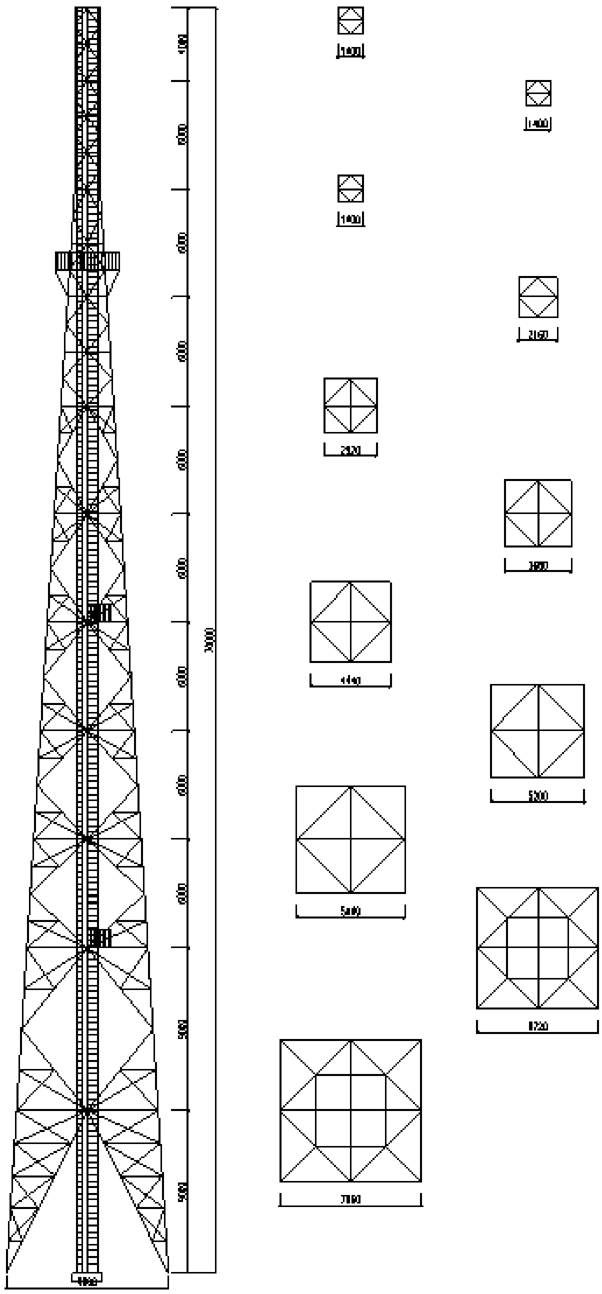


Figure 2. Technical design of the tower.

The tower has a total height of 70m, the tower body is made of angled steel, linked together by high-strength bolts, the main bar system, the slant bar and the belly bar are all made from angle steel with different sizes, depending on the bar's position and role.

Tower structure is made from construction steel, with elastic modulus

E = 21000000 T/m^2; standard compressive tensile strength: 2100 daN/cm^2; natural weight ρ = 7.85 T/m^3.

The tower is designed with 11 segments, with 02 segments 9m high; 08 segments 6m high and 01 burn 4m high.

3.1.2. Loads and combinations

Basic load groups (05 groups) [3, 6, 7]:

- Dead load (group 0): weight of tower itself (calculated by the software);
- Live load (group 1): usage load, repair load, suspended load. Live load value and location are the same for all three options;
- Wind X (group 2): includes static and dynamic components of wind;
- Wind Y (group 3): includes static and dynamic components of wind;
- Wind cross 45° (group 4): includes the static and dynamic components of the wind.

Wind load groups (Wind X, Wind Y, Diagonal wind 45°): automatically calculated by TowerVN software based on parameter selection (Figure 3), based on the shape and size of the bar section. After calculating the wind load parameters, it is automatically converted to the node load.

Combined load groups (03 groups):

- The first load combination (TH1): (group 0) + (group 1) + (group 2)
- The second load combination (TH2): (group 0) + (group 1) + (group 3)
- The third load combination (TH3): (group 0) + (group 1) + (group 4)

3.1.3. Design options for numerical trials

Numerical test will perform 3 options, namely:

Option 1: Solve the typical design problem, with the representative wind load being region IIB (standard wind load: 95 daN/m^2). The design calculation results, used to assess the safety level of typical design.

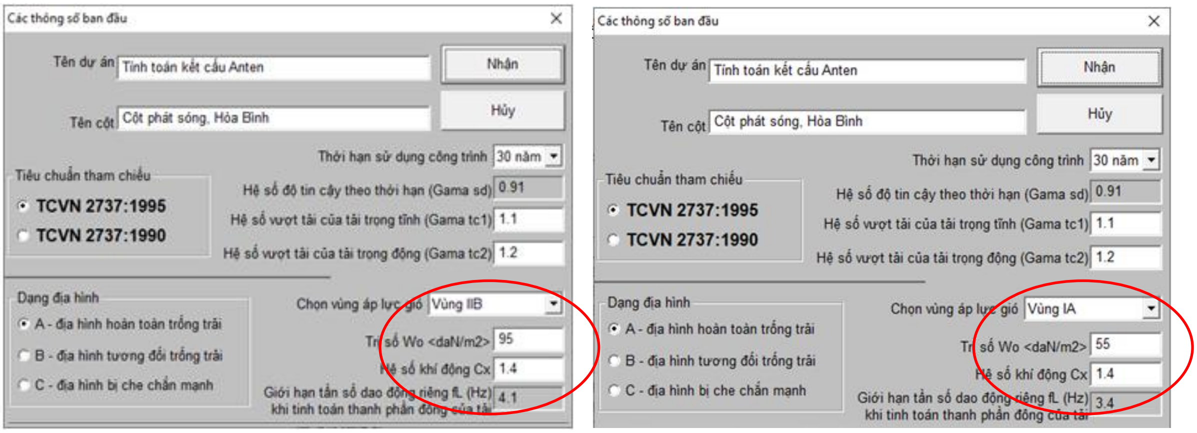
Option 2: Solve typical design problem, with actual wind area, Hoa Binh, (wind in IA region, standard wind load: 55 daN/m^2). Using calculation results, to consider and select sections that can be adjusted to reduce weight for the structure.

Option 3: Based on the results of the calculation of option 2, reduce the cross-section of the bars, in order to reduce the structural weight for each group of bars and for the whole tower, while ensuring the durability and stability of the tower structure.

From the results of the three plans above, compare and evaluate the safety level; The level of savings of the design problem is reasonable compared to typical design plans.

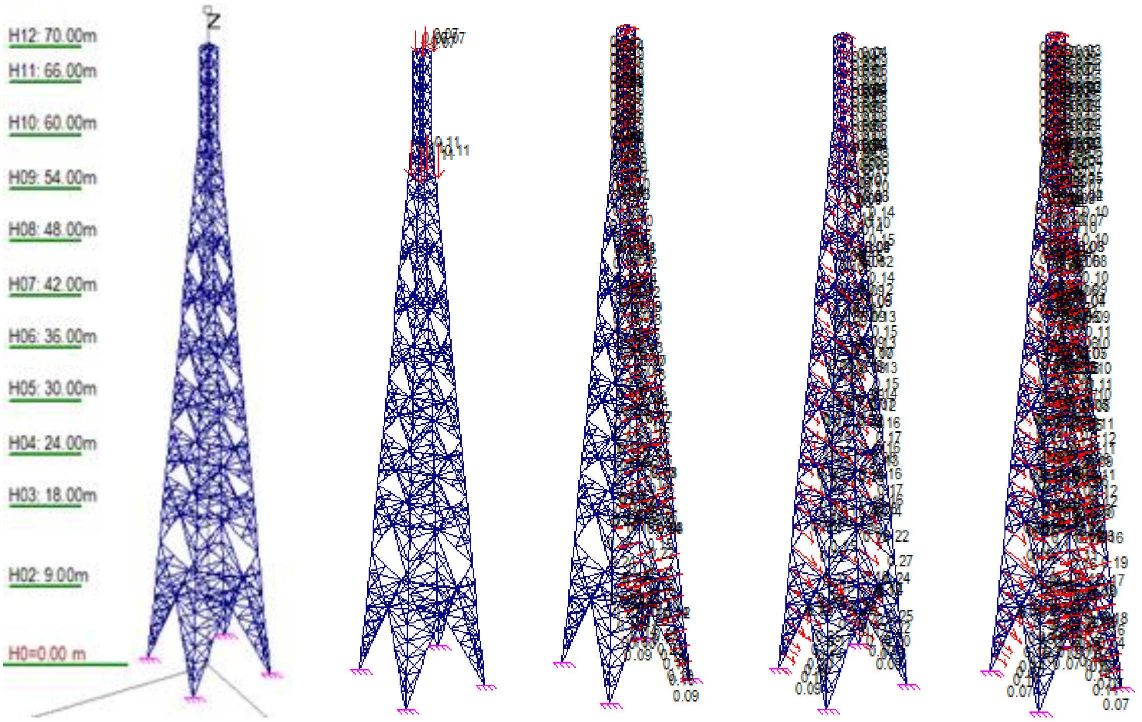
3.1.4. General figures of the tower design problem

Most of the arrays of input data can be used for all 3 options. That is the data of nodes, elements, materials... With 03 design options, it is just the difference in the parameters of wind load (load of groups 2, 3, 4); and the adjusted geometrical cross-section adjustment difference of option 3 problem compared with option 1 and option 2.



a) Declare wind load Option 1. *b) Declare wind load Option 2, 3.*

Figure 3. Declare the wind load input parameters by regional factor.



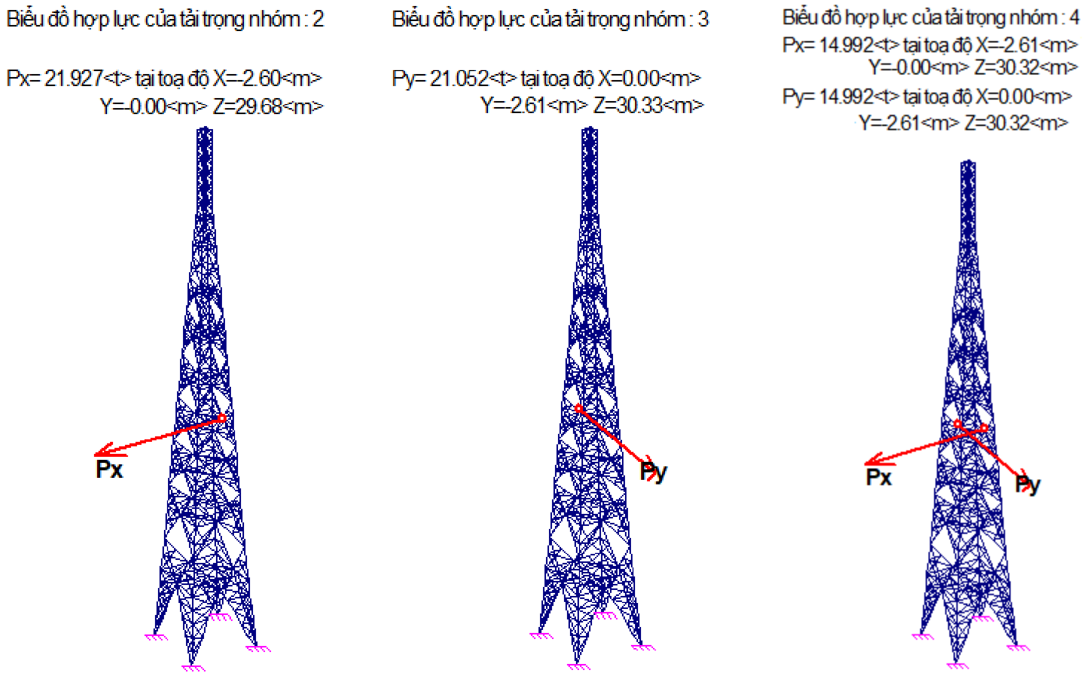
Dead load (0) Live load (1) Wind X (2) Wind Y (3) Cross wind 45° (4)

Figure 4. Geometry diagram and 05 load groups of the problem.

3.2. Steel tower truss structural calculation numerical test

3.2.1. Option 1

Structure calculation according to typical design and wind load in region IIB. The parameters for calculating wind load are shown in Figure 3a.



Wind X (2) Wind Y (3) Cross wind 45° (4)

Figure 5. Combination of wind loads (region IIB) calculated by option 1.

Table 1. Statistics of results of calculating Option 1 (wind region IIB) typical design problem

No	Size & shape (mm)	elements assigned	Mass (ton)	Tensile stress max (kG/cm²)	At ele...	Load group	Compre... stress max (kG/cm²)	At ele...	Load group	Section description
1	L:200x15	36	3.6050	**1616.99**	52	4	1370.77	52	4	Main column Đ1,Đ2
2	L:175x15	32	2.0910	1283.55	242	4	1283.78	308	4	Main column Đ3, Đ4
3	L:150x15	32	1.7790	1029.17	191	4	1116.13	175	4	Main column Đ5, Đ6
4	L:130x15	16	0.7650	876.00	207	4	895.49	207	4	Main column Đ7
5	L:130x12	32	1.0320	659.79	605	TH3	664.15	296	4	Main column Đ8, Đ9
6	L:100x12	48	0.9360	567.42	250	4	516.62	250	4	Main column Đ10, Đ11
7	L:80x6	31	0.8540	621.04	860	3	772.17	46	2	Cross element at Đ1
8	L:75x5	8	0.1570	335.41	33	4	346.94	33	4	Horizontal element Đ1
9	L:63x5	29	0.4150	900.37	663	TH1	901.42	663	TH1	Side bar at Đ1, Đ2
10	L:50x5	261	1.6450	981.55	330	TH3	989.86	330	TH3	Side bar at Đ1, Đ11
11	L:100x12	41	1.6190	730.46	4	2	998.69	838	TH2	Cross bar Đ1
12	L:80x6	64	1.0810	665.31	287	4	688.64	883	4	Cross bar Đ3, Đ4

No	Size & shape (mm)	elements assigned	Mass (ton)	Tensile stress max (kG/cm²)	At ele…	Load group	Compre… stress max (kG/cm²)	At ele…	Load group	Section description
13	L:75x5	112	1.4680	608.89	279	4	625.41	891	4	Cross bar Đ5,Đ6,Đ7
14	L:63x5	224	2.0890	493.46	462	TH2	495.72	462	TH3	Cross bar, sub-bar
15	L:100x7	136	3.7080	968.08	1038	3	968.95	868	3	Horizontal ele.. Đ2,Đ3
16	L:80x6	16	0.3660	162.31	1150	TH1	162.31	1151	TH1	Horizontal ele…30m
17	L:75x5	95	0.8900	143.33	1155	4	143.33	1154	4	Crossbar 6-11
18	L:80x6	32	0.6800	682.63	23	2	817.74	28	2	Side bar at Đ1

The total volume of tower according to Option 1 (18 sections) is: 25.179 <T>

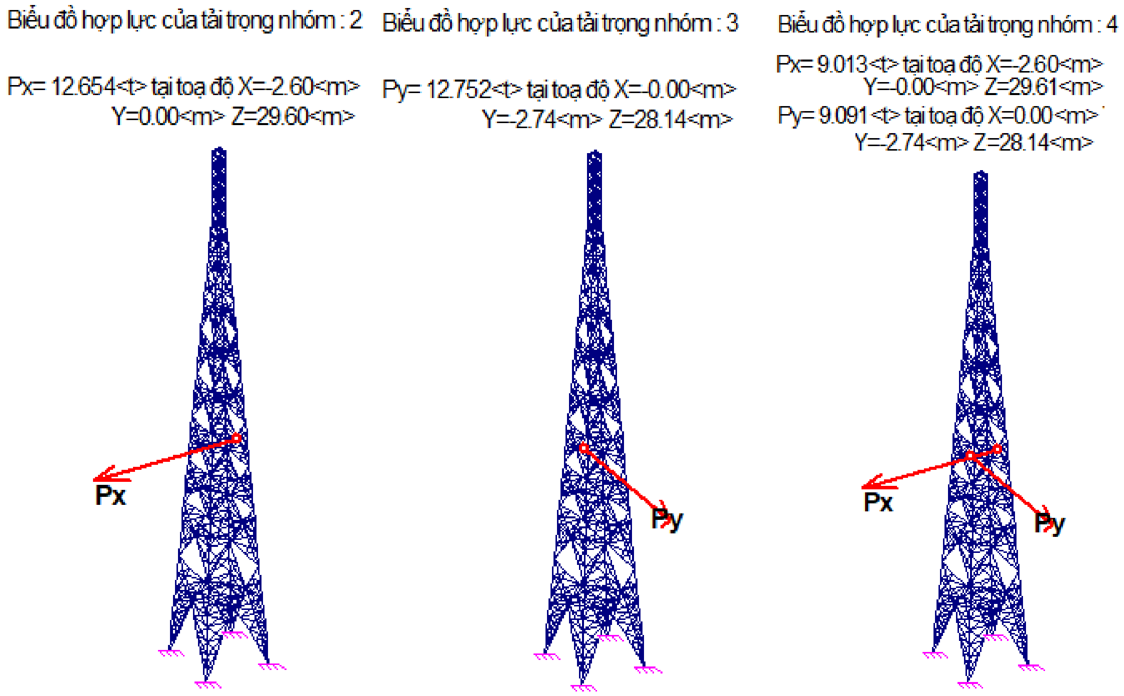
• *Comment:*

Typical design is one with high safety. The maximum stress in the structure is 1616.99 kG/cm², which is only about 77% of the permissible stress limit ([σ] = 2100 kG/cm²).

Calculating structure, typical design with representative wind load (zone IIB), result shows all structural elements are safe. That means when using this design for other representative areas (IA, IIA, IB), the structure is safe.

3.2.2. Option 2

Calculation the structure with typical design and wind load in the IA region



Wind X (2) Wind Y (3) Cross wind 45° (4)

Figure 6. Synergies of wind loads (region IA) option 2 typical design problems.

Table 2. Statistics of results of calculating Option 2 (wind region IA) typical design problem

No	Size & shape (mm)	elem assign	Mass (ton)	Tensile stress max (kG/cm²)	At ele...	Load group	Compr... stress max (kG/cm²)	At ele...	Load group	Section description
1	L:200x15	36	3.6050	**911.56**	52	4	782.50	364	TH3	Main column Đ1,Đ2
2	L:175x15	32	2.0910	714.77	242	4	715.04	308	4	Main column Đ3, Đ4
3	L:150x15	32	1.7790	559.20	191	4	611.30	176	4	Main column Đ5, Đ6
4	L:130x15	16	0.7650	464.78	207	4	480.05	207	4	Main column Đ7
5	L:130x12	32	1.0320	374.52	605	TH3	358.42	605	TH3	Main column Đ8, Đ9
6	L:100x12	48	0.9360	293.27	250	4	267.41	250	4	Main column Đ10, Đ11
7	L:80x6	31	0.8540	418.04	860	3	500.14	861	3	Cross element at Đ1
8	L:75x5	8	0.1570	197.90	33	4	207.02	33	4	Horizontal element Đ1
9	L:63x5	29	0.4150	536.23	663	TH1	539.79	663	TH1	Side bar at Đ1, Đ2
10	L:50x5	261	1.6450	600.90	840	TH3	604.37	330	TH3	Side bar at Đ1, Đ11
11	L:100x12	41	1.6190	459.91	830	3	690.72	838	TH2	Cross bar Đ1
12	L:80x6	64	1.0810	388.61	1034	4	394.19	883	4	Cross bar Đ3, Đ4
13	L:75x5	112	1.4680	349.90	279	4	353.43	891	4	Cross bar Đ5,Đ6,Đ7
14	L:63x5	224	2.0890	303.37	960	TH1	304.50	462	TH3	Cross bar, sub-bar
15	L:100x7	136	3.7080	652.58	1038	3	653.11	868	3	Horizontal ele.. Đ2,Đ3
16	L:80x6	16	0.3660	151.61	1150	TH1	151.61	1151	TH1	Horizontal ele...30m
17	L:75x5	95	0.8900	123.38	1165	TH2	123.34	1167	TH2	Crossbar 6-11
18	L:80x6	32	0.6800	420.67	842	3	535.69	846	3	Side bar at Đ1

The total volume of tower according to Option 2 (18 sections) is: 25.179 <T>

• *Comment:*

The calculation results of Option 2 show that the maximum stress in the structure is only 911.56 kG/cm^2 belonging to the main Tower Đ1, Đ2. The other elements are only about 700 kG/cm^2 or less. It shows that it is possible to reduce the adjustments for most of the declared sections of the typical design.

The results of Option 2 also show that it is possible to adjust downward for all 18 types of cross-sections, but normally, people only choose to adjust the sections used on many bars, those with a total structural mass are large enough. Then the new adjustment has high efficiency.

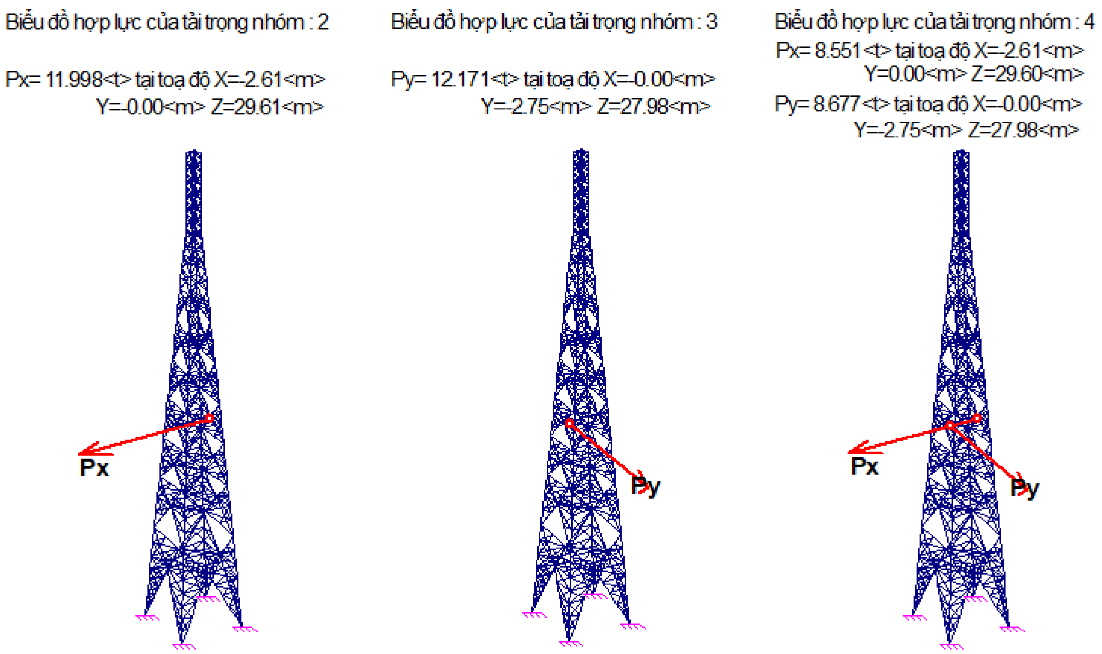
Table 3. List of section with reduced size for problem of option 3

No	Section description	Option 1			Option 2			Option 3
		Size & shape (mm)	Mass (ton)	Tensile stress max (kG/cm²)	Size & shape (mm)	Mass (ton)	Compr... stress max (kG/cm²)	Size & shape (mm)
1	Main column Đ1,Đ2	L:200x15	3.6050	**1616.99**	**L:200x15**	3.6050	**911.56**	**L:200x10**
2	Main column Đ3, Đ4	L:175x15	2.0910	1283.55	**L:175x15**	2.0910	714.77	**L:175x10**
3	Main column Đ5, Đ6	L:150x15	1.7790	1029.17	**L:150x15**	1.7790	559.20	**L:150x10**
4	Main column Đ7	L:130x15	0.7650	876.00	**L:130x15**	0.7650	464.78	**L:130x10**
5	Main column Đ8, Đ9	L:130x12	1.0320	659.79	**L:130x12**	1.0320	374.52	**L:130x10**

No	Section description	Option 1			Option 2			Option 3
		Size & shape (mm)	Mass (ton)	Tensile stress max (kG/cm²)	Size & shape (mm)	Mass (ton)	Compr... stress max (kG/cm²)	Size & shape (mm)
6	Main column Đ10,Đ11	L:100x12	0.9360	567.42	**L:100x12**	0.9360	293.27	**L:100x10**
7	Cross element at Đ1	L:80x6	0.8540	621.04	L:80x6	0.8540	418.04	L:80x6
8	Horizontal element Đ1	L:75x5	0.1570	335.41	L:75x5	0.1570	197.90	L:75x5
9	Side bar at Đ1, Đ2	L:63x5	0.4150	900.37	L:63x5	0.4150	536.23	L:63x5
10	Side bar at Đ1, Đ11	L:50x5	1.6450	981.55	L:50x5	1.6450	600.90	L:50x5
11	Cross bar Đ1	L:100x12	1.6190	730.46	**L:100x12**	1.6190	459.91	**L:100x10**
12	Cross bar Đ3, Đ4	L:80x6	1.0810	665.31	**L:80x6**	1.0810	388.61	**L:80x5**
13	Cross bar Đ5,Đ6,Đ7	L:75x5	1.4680	608.89	**L:75x5**	1.4680	349.90	**L:63x5**
14	Cross bar, sub-bar	L:63x5	2.0890	493.46	**L:63x5**	2.0890	303.37	**L:50x5**
15	Horizontal ele.. 2,Đ3	L:100x7	3.7080	968.08	**L:100x7**	3.7080	652.58	**L:80x6**
16	Horizontal ele…30m	L:80x6	0.3660	162.31	L:80x6	0.3660	151.61	L:80x6
17	Crossbar 6-11	L:75x5	0.8900	143.33	L:75x5	0.8900	123.38	L:75x5
18	Side bar at Đ1	L:80x6	0.6800	682.63	L:80x6	0.6800	420.67	L:80x6

3.2.3. Option 3

Typical design adjustment with regional wind load IA. Reducing the size of the section according to Table 3 (11/18 sections).



Wind X (2) Wind Y (3) Cross wind 45° (4)

Figure 7. Synergies of wind loads (region IA) Option 3 reasonable design problems.

Table 4. Statistics of calculation results Option 3 (wind region IA) reasonable design problem

No	Size & shape (mm)	elem assign	Mass (ton)	Tensile stress max (kG/cm²)	At ele…	Load group	Compr… stress max (kG/cm²)	At ele…	Load group	Section description
1	**L:200x10**	36	2.434	**1297.10**	52	4	1105.59	52	4	Main column Đ1,Đ2
2	**L:175x10**	32	1.415	1019.33	159	4	1004.39	308	4	Main column Đ3, Đ4
3	**L:150x10**	32	1.207	802.88	191	4	854.44	175	4	Main column Đ5, Đ6
4	**L:130x10**	16	0.520	652.22	207	4	666.47	207	4	Main column Đ7
5	**L:130x10**	32	0.867	418.44	605	TH3	406.50	296	4	Main column Đ8, Đ9
6	**L:100x10**	48	0.788	328.84	250	4	301.16	250	4	Main column Đ10, Đ11
7	L:80x6	31	0.854	487.26	860	3	577.70	864	3	Cross element at Đ1
8	L:75x5	8	0.157	243.96	33	4	250.97	33	4	Horizontal element Đ1
9	L:63x5	29	0.415	713.41	663	TH1	714.80	663	TH1	Side bar at Đ1, Đ2
10	L:50x5	261	1.645	776.76	330	TH3	779.37	330	TH3	Side bar at Đ1, Đ11
11	**L:100x10**	41	1.363	555.69	830	3	702.05	838	TH2	Cross bar Đ1
12	**L:80x5**	64	0.907	464.30	1034	4	457.52	883	4	Cross bar Đ3, Đ4
13	**L:63x5**	112	1.225	451.68	1027	TH1	453.26	359	TH3	Cross bar Đ5,Đ6,Đ7
14	**L:50x5**	224	1.640	598.35	462	TH3	601.19	462	TH3	Cross bar, sub-bar
15	**L:80x6**	136	2.536	926.01	1038	3	926.56	868	3	Horizontal ele.. Đ2,Đ3
16	L:80x6	16	0.366	152.13	1150	TH1	152.13	1151	TH1	Horizontal ele…30m
17	L:75x5	95	0.890	126.20	1165	TH2	126.16	1167	TH2	Crossbar 6-11
18	L:80x6	32	0.680	476.15	841	4	570.82	846	3	Side bar at Đ1

The total volume of tower according to Option 3 (18 sections) is: 19.910 <T>

• *Comment:*

All the elements in the tower designed according to option 3 have significantly less stresses than allowable stresses. Element with maximum stress is only 1297.10 kG/cm^2. All elements of the tower design according to option 3, have stresses significantly less than allowable stresses [7].

Adjustings the cross-section of option 3, the effect is that the total volume of the tower has decreased from 25.179 T (option 1) to 19.910 T (down 5.269 tons, about 21%). This is a remarkable reduction, bringing about economic and technical efficiency.

4. Conclusion

Although typical designs are still widely used in Vietnam at present, the redesign the steel towers is feasible and economically and technically efficient. If the work is only 01 single tower, the effectiveness of the redesign calculation is low efficiency, but if the number of towers is large enough (such as the transmission poles system) [3], the redesign will bring obvious results and the amount of steel saved is good result.

This article also shows that the study of rational design calculation for steel tower structure is a scientific and practical work.

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ĐÁNH GIÁ ẢNH HƯỞNG CỦA YẾU TỐ VÙNG MIỀN ĐẾN CHẤT LƯỢNG THIẾT KẾ CỘT THÉP DẠNG THANH GIÀN

***Tóm tắt:** Bài báo nghiên cứu bài toán thiết kế điển hình kết cấu cột thép tự đứng; đánh giá ưu nhược điểm của thiết kế cột thép điển hình, hiện đã và đang được sử dụng rộng rãi ở Việt Nam. Sử dụng phần mềm chuyên dụng để tính toán, đánh giá mức độ an toàn và tiện dụng của thiết kế điển hình. Từ đó tiến hành điều chỉnh các thông số thiết kế theo hướng tiết kiệm vật liệu, dễ gia công, lắp dựng. Qua đó, đánh giá hiệu quả của phương án điều chỉnh thiết kế điển hình. Nhận xét, đánh giá và kiến nghị cho các kết cấu tương tự.*

Từ khóa: Cột giàn thép; yếu tố vùng miền; thiết kế điển hình; phần mềm chuyên dụng.

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