Journal of Al-Azhar University Engineering Sector

Vol. 18, No. 67, April 2023, 360-370

OPTIMUM SPACING AND MEMBER GROUPS RECOMMENDATIONS FOR A TRANSMISSION LINE SYSTEM

Mohamed H. Awadeen*, Ahmed A. Ghaleb, Mohammed N. Abou El-Saad

Structural Engineering Dept., Faculty of Engineering, Mansoura University, Mansoura, Egypt.

*Correspondence: Engi_m.h_neer@yahoo.com

Citation:

M. H. Awadeen, A.A. Ghaleb, and M. .N. Abou El-saad " Optimum Spacing and Member Groups Recommendations for a Transmission Line System", Journal of Al-Azhar University Engineering Sector, vol. 18, pp. 361-371, 2023.

Received: 27 September 2022

Accepted: 23 December 2022

ABSTRACT

Transmission towers play an important role in the recent community and the development of various areas of huge infrastructures. Developing countries give a high priority to power development programs. Full-scale tests were usually managed to investigate the load-bearing capacity and failure mechanism of power transmission towers subjected to various loading patterns (broken lines, wind, and ice). The present work shows the efforts concerning an optimization procedure for the overall weights depending on unusual grouping systems in addition to the most convenient spacing that could be executed within the whole transmission line to serve the process. Therefore, the analysis and design processes of a self-supporting 400 KV steel power transmission tower considering different parameters is performed. The studied towers are categorized as suspension type and are designed for constant height, common clearances, common span, common conductor, and ground wire specifications. These would be performed in a sequence of implemented procedures relying on conventional design of transmission towers versus the developed investigations progressively.

KEYWORDS: Transmission tower, Optimum spacing, Optimum grouping, FORTRAN program.

التباعد الأمثل وتوصيات تقسيم العناصر لنظام أبراج الضغط العالى

محمد هانئ عوضين*، أحمد أمين غالب، محمد نجيب أبوالسعد

قسم الهندسة الأنشائية، كلية الهندسة، جامعة المنصورة، المنصورة، مصر

*البريد الاليكتروني للباحث الرئيسى: Engi_m.h_neer@yahoo.com

الملخص

تلعب أبراج الضغط العالي دورًا مهمًا في المجتمع الحديث وتطوير المناطق المختلفة من حيث البنية التحتية الضخمة. حيث تعطي البلدان النامية أولوية عالية لبرامج تطوير الطاقة. كانت الاستنتاجات السابقة تدار عادةً للتحقق من قدرة الأبراج على التحمل وآلية الأعطال لأبراج نقل الطاقة المعرضة لأنماط تحميل مختلفة (خطوط مكسورة، ورياح، وجليد). لذلك يُظهر البحث الحالي الجهود المتعلقة بإجراء تحسين للأوزان الإجمالية اعتمادًا على أنظمة التجميع غير العادية بالإضافة إلى التباعد الأكثر ملاءمة الذي يمكن تنفيذه داخل خط فعلى طوله 173250 متر. لذلك، يتم إجراء تحليل وتصميم برج نقل فولاذي ذاتي الدعم 400 كيلو فولت مع الأخذ في الاعتبار المؤثرات المختلفة. حيث ان الأبراج المدروسة هي من النوع المعلق وهي تتميز بثبات الارتفاع، والخلوص المشترك، والمدى المشترك، والموصل المشترك ، ومواصفات الأسلاك الأرضية. سيتم تنفيذ ذلك في سلسلة من الإجراءات المنفذة بالاعتماد على التصميم التقليدي لابراج الضغط العالى مقابل الاستنتاجات المقدمه تدريجياً.

الكلمات المفتاحية: أبراج الضغط العالى، التباعد الامثل، التقسيم الامثل، برنامج FORTRAN

1. INTRODUCTION

Transmission towers are protracted structures having a height that is much more than their lateral dimension. They are an integrated system made up of steel sections and include a conductor as well as a ground wire subsystem and one subsystem for each class of the support structure. They are tailored to support an overhead power line. So, they are crucial for supplying electricity to different regions of the nation. These lines have to be stabled and carefully designed to avoid failure during a natural disaster. The user and structural designer are responsible for settling the height of the tower and designing the general configuration, members, and joints details. The tower acts like a single cantilever, freely self-supporting structure that is fixed at its base; while the guyed mast is a pin shape linked to its foundation and braced with guys or other elements [1]. Transmission towers are used in both high alternating current (AC) and direct current (DC) voltage and are derived in different sizes and shapes. In the past, structure optimization -regarding shape and weight- through mathematical programming methods caught attention. For weight optimization, member sectional areas are taken into consideration as design variables. By combining the obstacles of shape and weight optimization, the weight of the structure is a vastly nonlinear function of the design variables. Thus, these are the nodal coordinates. Hence, the member lengths (on which the member sectional areas are based) differ at each stage of repetition. Consequently, the complexity of that optimization approach lies on the growing number of design variables [2, 3].

Many researchers have paid efforts towards design and analysis of transmission line towers using various configurations and softwares. Gust factor method is used to make a comparative analysis of various heights of towers by different bracing systems for various earthquake forces and wind zones [4]. This was carried out to analyze wind loads, model analysis, and response spectrum analysis, used for earthquake loads. Design and analysis are performed for multi circuit dead end angle transmission tower [5]. The tower was divided into panels comprising A and X pattern bracings and leg members. Single angle sections for belt members were used to reduce the weight. ANSYS is used to study the static reaction and corresponding strain results of transmission tower structure due to wind load at one static immediate time on vertical and transverse positions [6]. Also, loose vibrational analysis characteristics of the transmission tower were studied. Finally, brief dynamic analysis of transmission tower was performed to highlight the evaluation of dynamic response of transmission tower due to different time wind load with different wind speeds such as displacement and axial force. Static analysis is performed using STAAD Pro to propose the joint with the most stress [7]. Subsequently, the analysis of this joint was performed in ANSYS via the Finite Element Method. The results demonstrated that strain values increased with joint details consideration. This shows that joints and connections play a vital role in stress distribution inside the transmission tower and can significantly increase the strain produced on the members. Static and dynamic assessment of transmission tower (X form of the bracing machine) are carried out using ANSYS software program [8]. The masses applied on the tower were useless load, live load, and dynamic hundreds (Seismic and wind). Static, modal, reaction spectrum, and wind analysis were accomplished. Consequently, the maximum deformation, combined stresses, and direct strain were attained and plotted graphically. ANSYS software is used to examine the static and dynamic analysis of transmission tower under seismic loads considering a square tower as an example [9]. Various types of bracing systems were compared considering different seismic zones. The study was performed for different load cases. Finally, K type bracing system demonstrated lower deflection compared to X type. Besides, K type bracing system demonstrated the least weight compared to X type. Dynamic analysis of transmission tower is studied for various sectional properties with fluid viscous dampers taking into account earthquake loads [10]. They noted that dampers decreased the accumulation of the strain energy particularly near the resonance condition. Also, the angle section was found to be better than box section after providing the dampers. Dynamic response is studied for self-supported power transmission towers exposed to wind action [11]. Different factors like height above the ground, diverse values of wind speed, and various wind angle of attack were included to perceive their effect on the dynamic response of the structure. The effect of the wind on the displacement of the structure was pinpointed by comparing the results gained in a linear static analysis which considered the load combination with and without the presence of wind action. It was revealed from this study that displacement via dynamic analysis is superior to a static linear one. Moreover, the studied factors gave a remarkable effect on the dynamic response of the structure and the outcomes revealed that dynamic analysis is pivotal in structural design. STAAD.ProV8i is used to develop 400 KV dual circuit tower of angle and tubular sections for wind load; through linear static and P-delta analysis [12]. The results revealed a saving of steel weight up to 20.9% when tubular section was compared to angular section.

This work aims to investigate and optimize the design of transmission towers and achieve their minimum weight. All the used computer programs in FORTRAN and their verifications that are written by [13] have high reliability when compared to other programs in this field.

2. TRANSMISSION TOWER

A transmission tower which is also named a power transmission tower or electricity pylon is a tall steel structure supporting an overhead power line. In electrical grids, transmission towers are used to carry high voltage transmission lines that are responsible for transporting bulk electric power from generating stations to electrical substations. Transmission towers must carry the heavy conductors at an adequate safe height from the ground. Moreover, all towers have to withstand all types of natural disasters. So, the design of transmission tower is a prime engineering job where civil, mechanical, and electrical engineering concepts are equally applicable.

2.1. Transmission Tower Parts

The transmission tower is a main part of a power transmission system. It consists of the following parts as shown in (Fig. 1):

2.1.1. The cross arm of the transmission tower

Cross arms carry the transmission conductor (Fig 1-a). Their dimension depends on the level of transmission voltage, configuration, and the minimum forming angle for stress distribution

2.1.2. Transmission Tower Body

It is the portion from the lower cross arms up to the ground level (Fig. 1-b). This portion plays an important role in keeping the required ground clearance of the lower conductor of the transmission line.

2.1.3. Cage of transmission tower

It is the portion between the tower body and the peak (Fig. 1-c). This portion of the tower holds the cross arms.

2.1.4. The peak of the transmission tower

It is the portion above the upper cross arm (Fig. 1-d). Generally, earth shield wire connects to the tip of this peak by an earth arm.

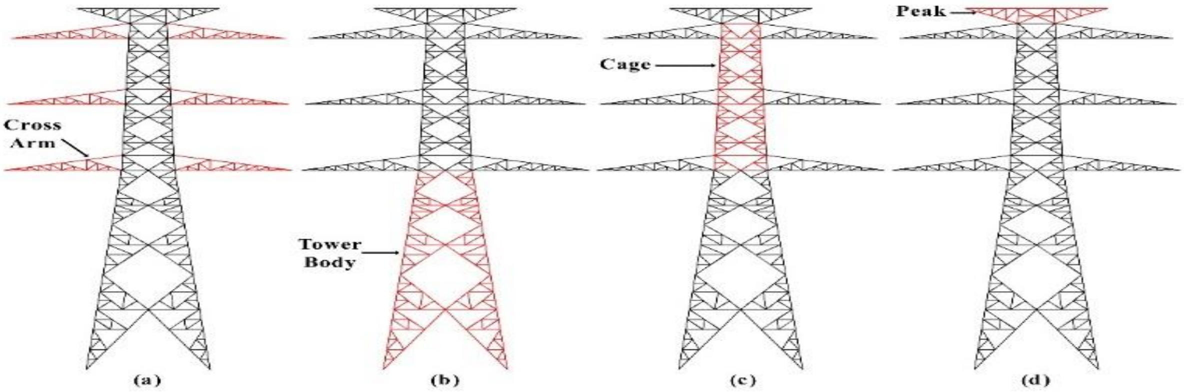


Fig. 1: Transmission tower parts a- Cross arm b - tower body c- cage d-peak

2.2. Transmission Tower Model Dimensions

For the aim of the study, the data for 400 KV transmission line tower is adopted. The body of a typical single tower exposed to the vertical load is considered for the parametric study of the effect of the element's cross sections on the tower weight. Different grouping of elements in which each group have a number of members having the same area and the same other properties are chosen and the weight of the structure under the same vertical load is found. The height of the tower is kept constant and variation in the member's cross-section is considered.

2.3. Tower's Geometric Configurations

As shown in (Fig. 2) the tower body is 33.25m in height. (Fig. 3-a) shows the cross-section plane of the tower with a square shape in plane 14*14m at the base level (ground level) and 6*6 m at the top level of the tower body under the lowest cross arm (Fig. 3-b). Followed by cage part with a height of 24.50m (Fig. 2), with a square shape in plan 6*6 (Fig. 3-b) at the start and 4.2*4.2 at the top (Fig. 3-c). Cross arms are 13.25 m cantilever on each side (Fig. 3-b), with a height of 2.5 m at the connection point to the tower. These cross arms were connected at levels of 33.25 ,44.25, and 55.25. At the top, there is a separate arm for the earth wire cable (Fig. 2).

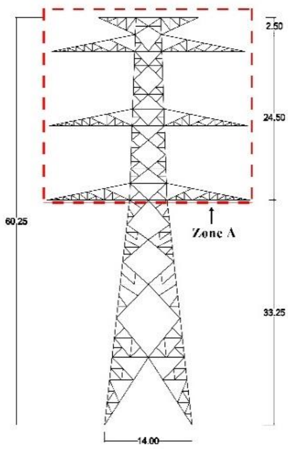
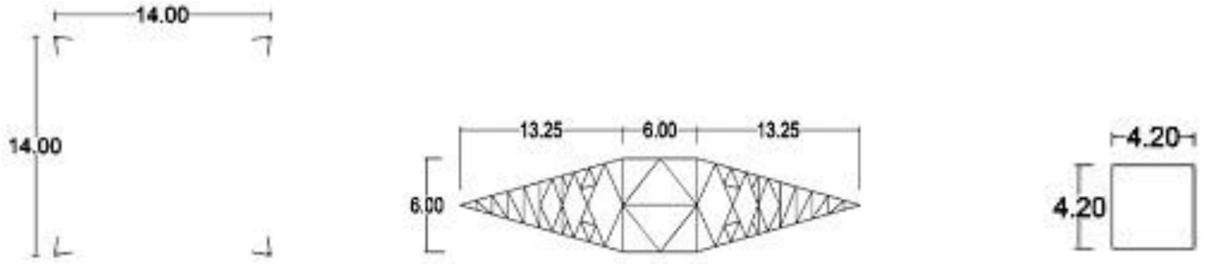


Fig. 2: Tower geometry



a- Cross section at base level

b- Cross section at lower cross arm

c- Cross section at top of the cage

Fig. 3: Tower Cross Sections

In this study, total potential energy (TPE) method was used to determine the structure equilibrium as a repetitive process of minimizing TPE. The equilibrium occurred when the TPE is minimum. The analysis in this work is carried out using a computer program in FORTRAN [13] based upon TPE using the conjugate gradient (CG) method. The analysis results from the FORTRAN program were verified using a commercial Finite Element program (SAP2000), then different spans between the towers were studied to obtain the optimum span for the transmission line. After that, the optimum span was tested with different member cross-section grouping to determine the optimum tower cross-section grouping.

3. LOADS ON TRANSMISSION STRUCTURES

Prevailing practice and most stated laws require the design of transmission lines to be minimum to satisfy the demands of the current edition of the National Electrical Safety Code (NESC). NESC's rules for selecting the capacity factors of loads and overload are stated to establish a minimum acceptable level of safety.

Vertical Loads

The vertical load on supporting structures consists of the weight of the structure plus the superimposed weight (including all wires).

Vertical Wire Load On Structure= V_m*Vertical Design Span*Load Factor………………….. (1)

Where:

- V_m : Vertical load of wire in. (t/m)
- Vertical design span (V): is the distance between low points of adjacent spans and is indicated in (Fig. 4).

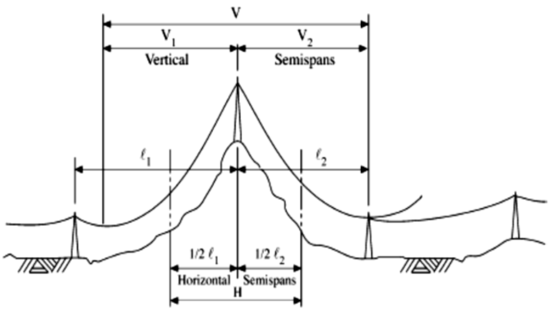


Fig. 4: Indication of vertical design span.

For the case study, the loads were carried out by the previous formula and the calculated loads on the tower for 550 m spacing transmission line are shown in (Fig. 5).

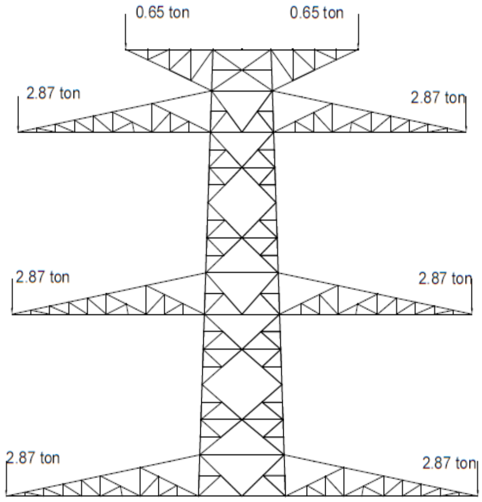


Fig. 5: Example of determination of vertical design load for the tower under consideration (Zone A).

4. FORTRAN PROGRAM VERIFICATION

For verification of the FORTRAN program, the model was created with the same geometry and loading case on both the FORTRAN program and SAP2000. The deflection of the cross arm that is shown in (Fig. 5) revealed a high agreement between the FORTRAN and SAP2000 (Fig. 6).

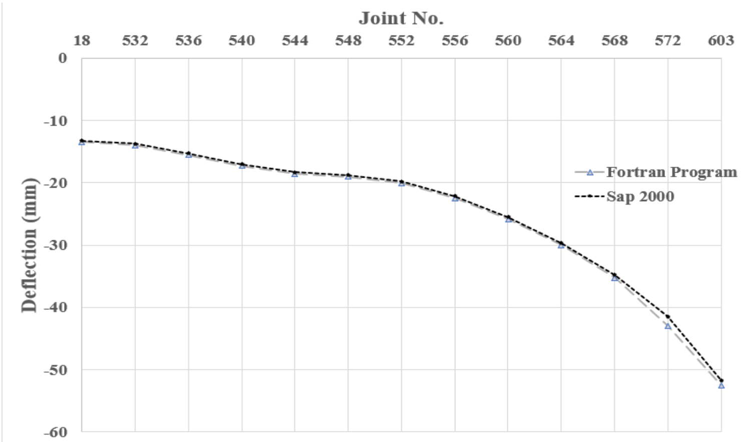


Fig. 6: Cross arm deflection verification between SAP 2000 and FORTRAN program.

The two models of the FORTRAN program and SAP2000 member's cross sections were divided into three groups as illustrated in (Fig. 11), and the internal force was examined in a sample of each group. The results are presented in (Figs. 7, 8, and 9) respectively, and showed a very good agreement between the SAP2000 and FORTRAN program as follows:

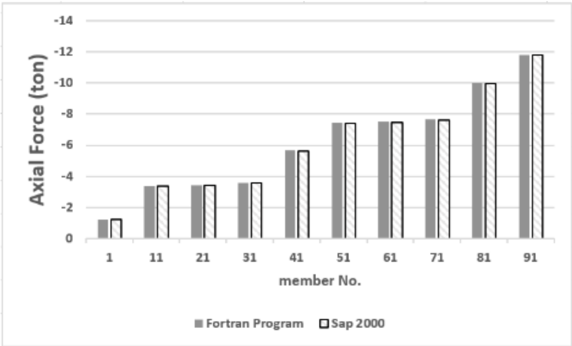


Fig. 7: Axial force for member group 1.

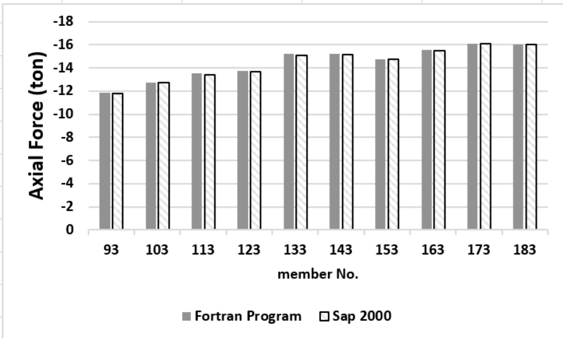


Fig. 8: Axial force for member group 2.

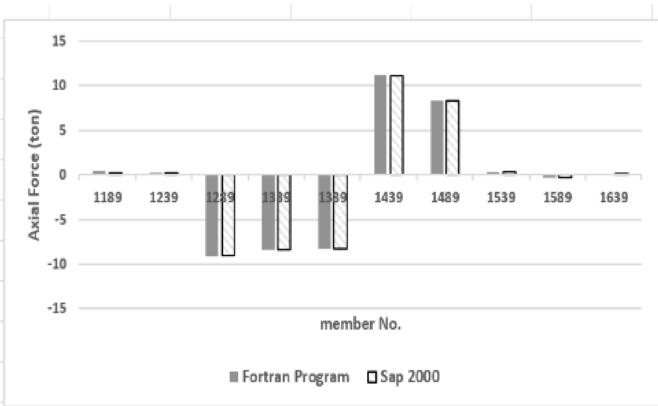


Fig. 9: Axial force for member group 3

From (Figs. 7, 8, and 9), it could be noted that the FORTRAN program gives very accurate results compared to the SAP2000 model.

5. OPTIMIZATION ACCORDING TO SPACING IN TRANSMISSION LINE

Four models were carried out using FORTRAN program. The models have the same loads, shape, and dimension but with different spacing between the tower which affect the load acting on the tower. Each tower has three groups, and each group assumes its cross section initially. After that, each group is designed according to the resulting internal force and the designed cross-section is redefined to obtain the real deflection and internal force for each model

Figure (10) shows the deflection of the cross arm for different spacing of the tower. It is noticed from using the traditional way of grouping (three groups) that, the larger span presented more deflection for each cross arm, in general. For the vital point at the end of the cross arm, it is recorded that a growth in deflection for span 250 m, almost about (17.3%, 38.7%, and 41.3%) for spans 350, 450, and 550, respectively.

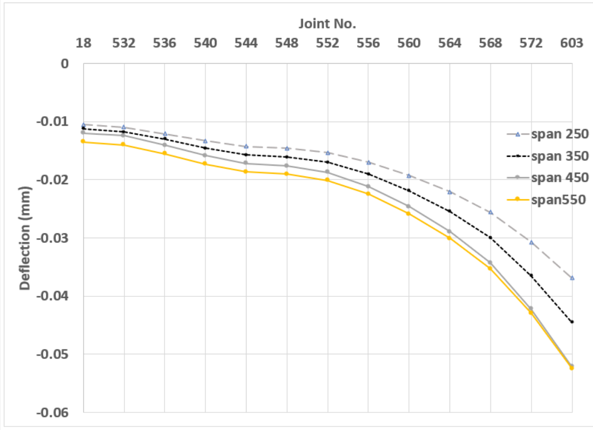


Fig. 10: Cross arm deflection for different tower spanning.

Regarding total line weight -T.L.W. as indicated in Table 1, it was noticed from using the traditional way of grouping (three groups) that, the larger span showed less weight up to 350 m. Whereas, both spans of 450 m and 550 m donated slight difference. Concerning the overall deflection, Span 450 m was chosen as the optimized one because it showed lower deflection than span 550 m (Fig. 10).

Table 1: Single tower weights and total line weights for different spans for 173250 m transmission line

Span (m)	Single tower weight (ton)	No. of towers	Total line weight (ton)
550	53.183	315	16752.65
450	43.534	385	16760.59
350	43.534	495	21549.33
250	43.534	693	30169.06

For more optimization, the tower member cross-section is divided into more groups. Firstly, a 450 m span tower is divided -as the traditional way- into three groups. The main legs were divided into two groups and all other members as one group (Fig. 11).

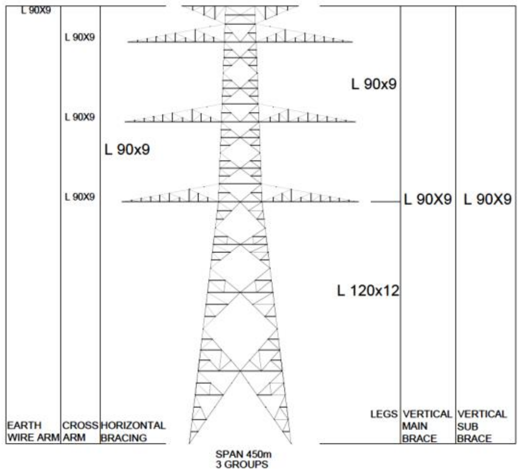


Fig. 11: 450 m span tower divided into 3 groups.

For more optimization, the optimum tower was divided into more groups as shown in (Fig. 12, six groups) and (Fig. 13, eleven groups).

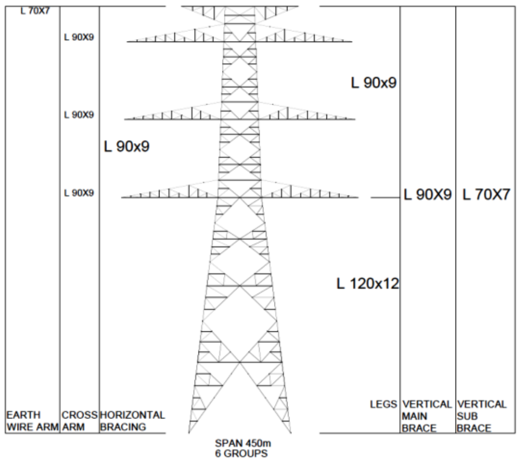


Fig. 12: 450 m span tower divided into 6 groups.

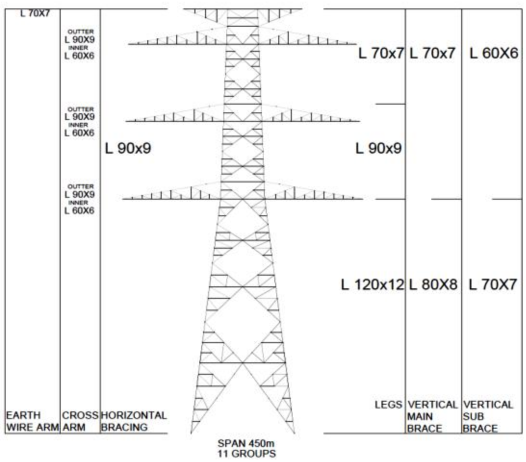


Fig. 13: 450 m span tower divided into 11 groups.

For the most optimized span (450 m), dividing a single tower weight -S.T.W- into 11 groups lead to more decrease in deflection by about 6 % and 2% when compared to the 3 and 6 groups, respectively (Fig. 14). Thus, detecting the vital position of the cross arm. This means that increasing the number of groups may result in a stiffer composition.

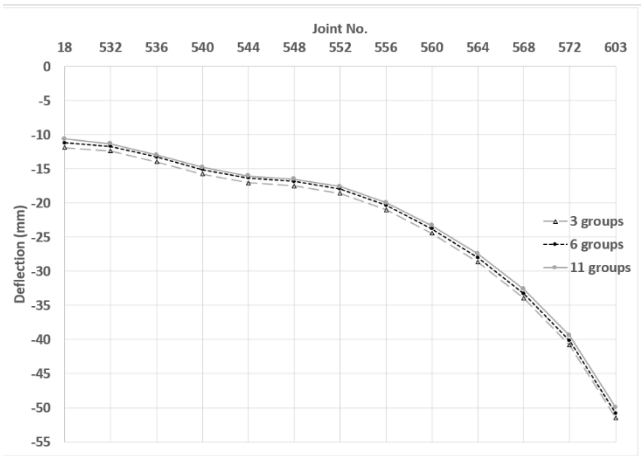


Fig. 14: Cross arm deflection for different groping groups.

For the most optimized span (450 m), dividing the weight into 11 groups lead to more decrease in S.T.W. by about 24% and 12% when compared to the 3 and 6 groups, respectively. This means that increasing the number of groups may result in less weight (Fig. 15).

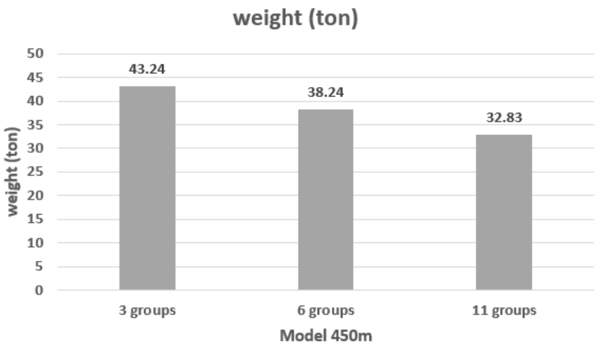


Fig. 15: Weights of tower for different grouping systems.

CONCLUSIONS

The importance of this manuscript can be texted below:

1) The ultimate load-bearing capacity and failure mode of the tower, which is obtained from numerical simulation by SAP2000, are very similar to those of the same run by the FORTRAN program.
2) Increasing the number of groups may lead to more economic cross-sectional design by more than 24% reduction of the overall consumed cost for the most optimized selected spacing (450 m).
3) Considering both serviceability and economic conditions (deflection and overall line weight), a span of 450 m would be recommended as the most optimized spacing for a transmission line system.

CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

[1] B. Jyothi, S. Mahesh, "Design Transmission Tower and Its Foundation, ". IJSETR, vol. 6, issue 6, pp. 1008 – 1014, 2017.

[2] T. Reddy, K. Murali, D. Chekravarty, P. Sagar, "Analysis and economical design of transmission line towers of different configurations subjected to wind load, " IJCIET, vol. 9, issue 1, pp. 388 – 397, 2018.

[3] P. Gujjewar, S. Rathore, A. Baig, "Static and dynamic analysis of transmission tower to wind and seismic loads, " IRJMETS, vol. 4, issue 6, pp. 3925 – 3933, 2022.

[4] S. Panwar, Y. Kaushik, A. Singh, N. Sharma, "Structural Analysis and Design of Steel Transmission Tower in Wind Zones II and IV-A Comparative Study," Int. j. eng. technol. manag. appl. Sci, vol. 4, pp. 168 – 177, 2016.

[5] T. Sakthivel, R. Sanjeevi, "Analysis and Design of multi circuit transmission line tower, " IJETCSE, vol. 13, issue 1, pp. 56 – 61, 2015.

[6] P. Murahari Krishna, G.N. Ganesh, "Dynamic analysis of electrical transmission tower using finite element technique, " Int. J. Eng. Res, vol. 4, issue 5, pp. 47 – 56, 2016.

[7] Z. Itam, S. Beddu, N.L.M. Kamal, K.H. Bamashmos, "Finite element analysis of the maximum stress at the joints of the transmission tower, " in IOP Conf. Series: Earth and Environmental Science, 2016.

[8] H. Parashuram, K. Sachin, "Static and dynamic analysis of transmission line tower, " IJERMT, vol. 6, issue 2, pp. 147 – 154, 2017.

[9] S. Karthik, G.V. Sowjanya, "Static and dynamic analysis of transmission line tower under seismic loads, " IJERT, vol. 4, issue 8, pp. 29 – 33, 2015.

[10] Mujamil., G.N. Banulatha, G. Narayan, S.J. Rajeeva, "Dynamic analysis of transmission line tower for different sectional properties with fluid viscous dampers, " IJARET, vol. 2, issue, 2, pp. 134 – 137, 2015.

[11] N.M. Hamzah, F. Usman, M.Y.M. Yatim, "Dynamic response of self-supported power transmission tower subjected to wind action, " Int. J. Eng. Vol. 7, issue 4, pp. 476 – 481, 2018.

[12] R . Vinay, A. Ranjith, A. Bharath, "Optimization of transmission line towers: P-delta analysis, " IJIRSET, vol. 3, issue 4, pp. 14563 – 14569, 2014.

[13] M. Naguib, "Effect of Initial Sag and Initial Tension in Cables on outcome response in Cable Structure, " MEJ, vol. 30, issue 4, pp. C.37 – C.56, 2005.