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# DEVELOPMENT OF BRACKET FOR CROSS ARM STRUCTURE IN TRANSMISSION TOWER: EXPERIMENTAL AND NUMERICAL ANALYSIS

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**Abstract.** In this study, an experimental and numerical examination was conducted on the fabrication of bracket structures for application in the 13L 123 KV cross-arm. Brackets structure has been developed with the aid of conceptual design techniques. Conceptualization processes of the bracket structure for application in the cross-arm have been described accordingly. The bracket structure design is two symmetric U shapes installed on both sides of the tie member of the cross-arm structure. SkyCiv Structural 3D V4.0.0 software was employed to analyze the entire body of the cross-arm to determine the internal force and its direction in each member connected to the bracket structure. An axial stress distribution (Von Mises stresses) was used to determine the appropriate thickness for the bracket's new structure. Bracket structures are distorted if they are less than 5 mm thick, according to FEM studies. 0.00364 MPa was found to be the maximum stress in the entire body, with stress levels as low as 0.00364 MPa in the same body with the same boundary configurations.

***Keywords:*** *Optimization, bracing member, FEM, cross-arm, brackets design, conceptual design.*

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## 1. Introduction

Bracket structure is an important part of the cross-arm structure for the reason the of connection between the main body and the supported members (Jia *et al.*, 2019; Pidaparti & Kalaga, 2017). Several experiments showed that the bracket mechanical behavior is described by numerical simulations using extensive finite-element (FE) models and experimental testing in the Constructing and Materials Mechanical Laboratis is recorded and discussed (D'Arenzo *et al.*, 2018; 2019). It is assured a very quick

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deployment, as only four calibrated bolts are required to connect an X bracket to the CLT or the foundation (Marchi *et al.*, 2017). Bolts were to be inserted in panel holes to protect the braces. Type 1 bracket must be used on both sides of the panel in a set. A base curb or lower rail is always necessary. Alternative approaches are possible to prevent the embedding of wood both for visible and secret uses (Shinde & Ghugal, 2017). Other studies have shown that the four different patterns of bracing are K bracing, XBX bracing, X-X bracing and W bracing in the tower frame. The bracing members increase rigidity and decrease the slender tower ratio. The study covered the pattern of bracing and its effect on the axial forces and, deflections under the same load pattern (as per IS 802 (1995)). Wind analysis is carried with IS 802 (1995) (Pathrikar & Kalurkar, 2017). For the numerical observations, TSLSP commercial finite-element software ANSYS was developed to model the residual stress field characteristics in the TSLSP-affected metal plate which were validated as an effective method to assess residual stress caused by LSP (Sakhvadze *et al.*, 2016; Guo *et al*., 2017; Sapuan, 2005).

There were two successive stages in the simulation process, namely a dynamic analysis stage and a static analysis stage (Guo *et al*., 2017). The dynamic analytics process was performed using the ANSYS / Explicit Code to investigate the dynamic response of laser-impacted materials and then with the Ansys / Standard Code to release the residual stress field with the status of the stored elastic strain energy in the material created by the high-speed dynamic deformation process (Sapuan, 2005; Hambali *et al.*, 2009). Nowadays, conceptual design has become the first step of any design in different aspects of engineering (Davoodi *et al*., 2008; Sapuan *et al*., 2005). Conceptual designs are among the most important early-stage product development in which possible solutions are developed to accomplish the appropriate product design goals (Amaral *et al*., 2018). Project, project idea, or conceptualization is usually the start of the design process after the identification of need (Meng *et al*., 2019). Creativity is tied to conceptualization since conceptualization is a way of identifying viable solutions by alternatives and creativity is a way of generating alternatives (Mansor *et al*., 2014; Davoodi *et al.*, 2011).

For the purpose of establishing a connection between the primary body and the components that it supports, the bracket structure is an essential component of the cross-arm structure (Davoodi *et al.*, 2008; 2011; Sharaf *et al*., 2020). The mechanical behavior of the bracket was shown to be represented by numerical simulations employing sophisticated finite-element (FE) models, and actual testing was conducted in the Constructing and Materials Mechanical Laboratories, where the results were recorded and discussed (He *et al.*, 2020; Tianying *et al*., 2021; Cui *et al.*, 2021). Because there is only a need for four calibrated bolts to attach an bracket or the foundation (Ravichandran *et al*., 2021; Topac *et al.*, 2020), the deployment time is guaranteed to be extremely short. To ensure the braces' safety, bolts were supposed to be installed in the panel holes (He *et al.*, 2018). A bracket of type 1 must be used on both sides of the panel in order for the set to be considered complete (Zaitsev *et al*., 2018; Liao & Liao, 2020; Vlădulescu & Constantinescu, 2020). There is always a requirement for a foundation curb or lower rail (Tran & Jeong, 2021). There are other methods that can be used to prevent the embedding of wood, which can be used for either obvious or covert purposes (Marchi *et al.*, 2020; Hashemi & Quenneville, 2020). The bracing components make the structure more rigid and reduce the slender tower ratio at the same time (Durgesh *et al*., 2018; Klippstein *et al*., 2018; Miyamoto *et al*., 2020). The pattern of bracing and its influence on the axial fand for forces and deflections under the same load pattern were both analyzed (Wang *et al.*, 2018; Lukacs *et al.*, 2019). Numerical observations were utilized to develop the model (Ahmed *et al*., 2019; Dai *et al*., 2022). The simulation procedure was broken down into two distinct steps that occurred one after the other: the dynamic analysis stage and the static analysis stage (Wang *et al*., 2020; Bishay-Girges, 2020). During the dynamic analytics process, the ANSYS was used to investigate the dynamic response of laser-impacted materials (Ito *et al.*, 2020). After that, the Ansys was used to release the residual stress field with the status of the stored elastic strain energy in the material, which was produced by the high-speed dynamic deformation process (Talay *et al.*, 2021). Both of these codes were used in order to investigate the dynamic response of laser-impacted materials (Tchemodanova *et al.*, 2019). These days, conceptual design is the first phase in any design process, and it may be found in a variety of technical specializations (Ambroziak *et al.*, 2018; Zhang *et al*., 2018). The development of feasible solutions to achieve the required product design goals is one of the most significant and time-consuming aspects in the early stages of product development, which is when conceptual designs are created (Hussein, 2022; Trutalli *et al*., 2019). After determining the requirements, the first step in the design process is typically the formulation of a concept, idea, project, or another similar endeavor (Asyraf *et al*., 2022). Because conceptualization is a method of determining viable solutions via alternatives, and creativity is a method of generating alternatives, creativity and conceptualization are closely related to one another (Syamsir *et al.*, 2022).

There are many different advantages to utilizing a device that is supported by a pole. However, a system that is going to be effective needs to be designed in such a way that it may be restarted whenever it is necessary (Wang *et al*., 2022). Entomic, sensitive, versatile, capable of going on the outside, and sturdy enough for a variety of applications, such as being used outside (Ezami *et al*., 2023).

This type of application can make use of light poles that are rather lengthy (varying from 35 to 100 feet in length) in order to offer intense illumination to wide-spreading applications such as fields (Singh & Gautam, 2022; Gao *et al.*, 2022). In the majority of outdoor applications, the poles are made smaller to use the least amount of materials possible and to lower the amount of resistance they have to wind (Zhao *et al*., 2022; Zhang *et al*., 2022a). Because of this, the surface of the pole cannot serve as a space where new identifiers or structures can be put, nor as a method of transferring them to distance, and neither do these structures (for example, sometimes hundreds of feet away) (Guan *et al*., 2022).

In addition, it would be counterproductive to install more hardware on the poles in order to ignite the lights as it is already sufficient to do so. There is no way that one could ever fortify the pole in such a way that it would compromise the pole's structural soundness. Inappropriate behavior would be creating an imbalance in the power of the poled branch (Zhong *et al*., 2022). Strong craftsmanship must be compensated in order to avoid the accumulation of unwanted wind loads. These concerns can be serious if they occur in any of these scenarios, especially outside when there is a strong wind load present (Chen *et al*., 2022; Fang *et al*., 2022).

This (is a particular object of this shelf invention to offer simple wallboard that may be mounted to the vertical studs or fastened to the shelf on vertical brackets) is the surfacing wallboard or horizontal board which may be moved up and down, making it possible to accommodate a variety of shelves or both while still being intact (Song *et al.*, 2022). This (is a particular object of this shelf invention to offer simple wallboard that may be mounted to the vertical studs or fastened to the shelf on vertical brackets) (Shen *et al.*, 2022). The purpose of the current innovation is to come up with a way to create a vertical or upright metal structure that is simple to construct and that can be used in storage facilities and other similar establishments (Fu *et al*., 2022). Moreover, depending on the arrangement, the shelf can be effortlessly extended to a stage that is either higher or lower than it was initially. A further objective of the invention is to provide a stud assembly with brackets, which are utilized for the shelf, and which is linked with or received into their respective studs in order to make it possible for the shelf to be leveled (Lin *et al*., 2022; Shehata & Damatty, 2022).

To my best knowledge, not so many bracket designs are seen in the previous studies focusing on the idea of developing carbon steel for the bracket structure that Iused in the rma-wood cross arm structure.

The most significant thing that this study has contributed is a specification for a new design of the conceptual design that can be made and used in wooden transmission towers. This is the most essential thing that this study has contributed. This is the most important thing that can be taken away from the findings of this study. This very point, right here, is the part of the study that has made the most substantial contribution. The most significant limitation of this study is the fact that very few previous studies explain the method of constructing the bracket structure that will be installed in the wooden cross-arm structure. This is the constraint that has the most impact on the findings of this study. This is the most serious flaw in the inquiry that has been found. This is by far the most major gap in the previous study that has been carried out, and it has to be addressed.

Thus, the purpose of this study is to present a new conceptual design of bracket structure, which can be used to connect the bracing members to the main body of the wooden cross arm. The optimization to develop a new design of the bracket structure is uctedcond by employing systematic exploitation of proven ideas method.

## 2. Methods and materials

### *2.1. Research flowchart*

The configuration of the bracket construction that has been utilized in transmission towers over the years. The conceptual design phase has always been regarded as the first and most important stage of the main design. The boundary conditions have been taken into consideration using the data that TNB has provided.

The conceptual design of the bracket structure has been numerically optimized as part of the third step in the process. The final design of the bracket structure will be carried out by these instructions.

### *2.1. Idea generation techniques*

The conceptual design focuses primarily on creating ideas to satisfy the need. Several methods are available for the creation of hypotheses or ideas (Zhang *et al*., 2022c), such as the use systematic exploitation of proven id or extending the search space, morphological chart, gallery method and voice of customers (Gayathri *et al.,* 2022). These methods are well developed, with relevant books being consulted by interested readers.

#### *2.1.1. Systematic exploitation of proven ideas*

In this study, the method called systematic exploitation of proven ideas or experience formalized by Zhang et al. (2022b) was employed. The analysis of existing systems is one way of initiating new or improved solutions. This analysis involves the mental or physical analysis of finished products.

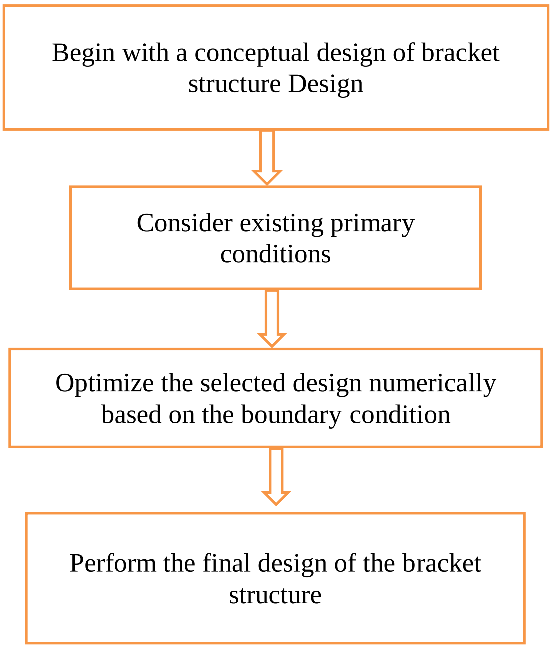



**Figure 1.** The whole process of the conceptual design of the bracket structure

### *2.2. Primary conditions*

Based on the analysis that has been done by SKYCIV STRUCTURAL 3D V4.0.0 software bracket structure is connected to the following members (D'Arenzo *et al*., 2018; Marchi *et al*., 2017; Shinde & Ghugal, 2017; Pathrikar & Kalurkar, 2017). Table 1 showed the components of the forces in each member Stainless steel has been used for fabrication the bracket structure. Table 2 showed the mechanical properties of the stainless steel.

**Table 1.** Internal force details of the bracing and tie member of the cross-arm

| Member | Force components (X,Y,Z) | Cross-section details (mm) |
|---|---|---|
| Member 3 (main) | 3500,0,0 | 102 X 102 |
| Member 4 (bracing) | 0, -14.5, -25.115 | 50 X 50 |
| Member 5 (bracing) | 0, 14.5, -25.115 | 50 X 50 |
| Member 6 (bracing) | 0, -40.4, -32.7 | 50 X 50 |
| Member 7 (bracing) | 0, -40.4, -32.7 | 50 X 50 |

**Table 2.** Mechanical properties of the brackets

| Martial | Density kg/m3 | Passion's ratio | Modulus of Elasticity MPa |
|---|---|---|---|
| Carbon steel | 7850 | 0.28 | 200 |

### *2.3. Meshing and geometry*

In this project bracket system has been developed. Three bracket structures are used to connect the bracing members to the main body of the cross-arm. Two similar bracket structure are installed at the main members of the cross-arm and the other on is installed on the tie member. They are meshed analyzed by employing ANSYS software.

*2.3.1. Bracket on the main members*

AUTOCAD software was used to produce the geometry for of the bracket. Two similar bracket structures are installed on the right and left main members of the crossarm structure. It consists of the two similar sides with a tee fixed as shown in figure 2. Four bolts M10 are used to fix the bracket's sides each together by grabbing the main members (right or left). Based on the conceptualization processes, the thickness of the plate that used to fabricate this bracket is 5 mm.

In this project, ANSYS has been used to construct the mesh for the geometric representation of the problem. Due to the symmetry and by applying appropriate boundary condition constraint on symmetry, only one-two of the plate (side) was modeled and analyzed. The model has been meshed by two different approaches. One of these methods uses the mapped mesh and the other uses finer mesh near to the discontinuity. Tri-type paves meshed elements model was use for the complicated areas such as corners and bolts.

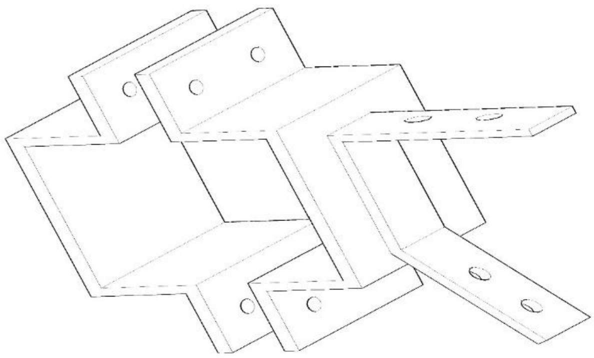


**Figure 1.** Geometry of the bracket structure (On the main members)

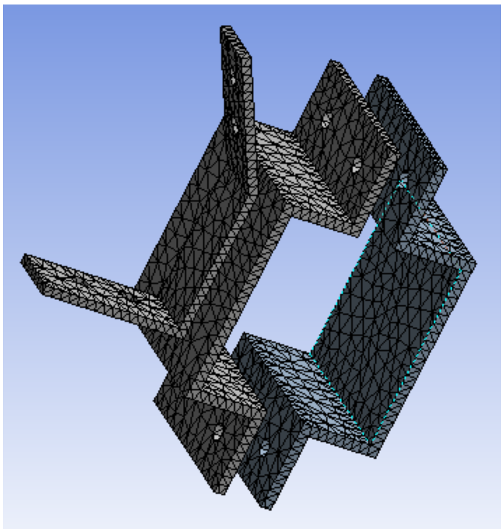


**Figure 2.** The meshed model of the bracket structure on the main members

While, quad type paves were conducted for the rest of the bracket body as shown in Figure 3. ANSYS provides a complete mesh flexibility with amorphous meshes the solution and it may be polished or roughened the grid depending on the solution. The second approach uses the finer mesh near the hole and coarse mesh otherwise. The interface of dissimilar meshes are linked together by developing degree of freedom (DOF) equations that connect the nodes of one mesh to the elements of the other. This model has been examined using ANSYS software. ANSYS is a well-known software for the simulation of static structure for equations solving and solutions produced.

*2.3.2. Bracket on the tie members*

Similar to the bracket structure of the main members AUTOCAD software also conducted to produce the geometry for of the bracket. Two similar bracket structures are installed on tie member of the crossarm structure. This structure constructs of the two similar sides with 4 tees fixed at on the of these sides of the bracket. Four bolt M10 are used to fix these brackets on the member. Brackets with its tees are constructed with thickness 5 mm as shown in Figure 3.

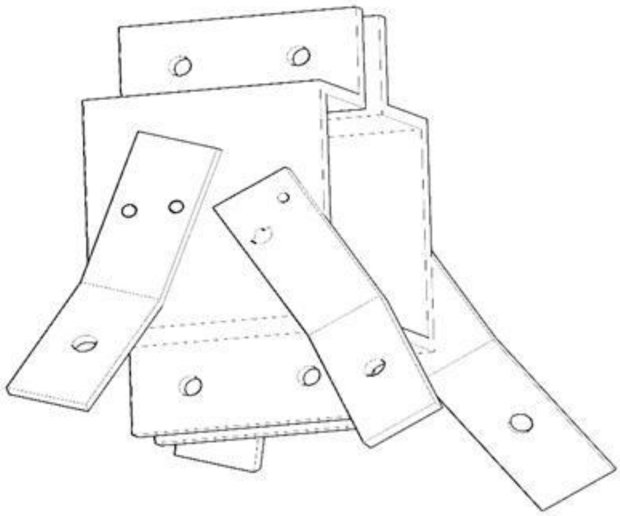


**Figure 3.** Geometry of the bracket structure (On the tie members)

Also ANSYS software has been conducted to construct the mesh for the geometric representation of the problem. Also ,Due to the symmetry and by applying appropriate boundary condition constraint at the of symmetry, only one-two of the plate (side) was modeled and analyzed.. The model has been meshed by two different approaches, one of this method is by using a mapped mesh and the other approach is by using finer mesh near to the discontinuity and applying constraint equations between the different meshes. Also Tri type pave meshed elements model was use for the complicated areas such corners and bolts. While, quad type paves were conducted for the rest of the bracket body as shown in Figure 4. ANSYS provides a complete mesh flexibility with amorphous meshes the solution and it may be polished or roughened the grid depending on the solution.

Another approach is by using a finer mesh near the hole and coarse mesh otherwise. The interface of dissimilar meshes are linked together by developing degree of freedom (DOF) equations that connect the nodes of one mesh to the elements of the other. This geometry has been analyzed conducting ANSYS software. ANSYS is a well-known software for the simulation of static structure for equations solving and solutions produced.

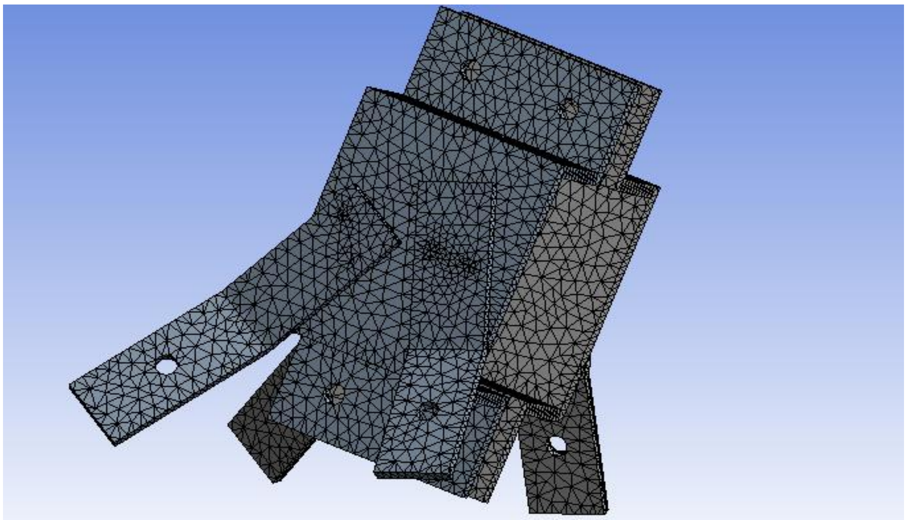


**Figure 4.** The meshed model of the bracket structure on the tie members

## 3. Experiments

In developing the conceptual design of the brackets structure, systematic exploitation of proven ideas or of experience (Davoodi *et al*., 2011) was employed. Bracket structure P1048 by UNISTRUT® as shown in figure 5 has been followed as a guide to be modified by conducting some modifications.

### *3.1. Structural development*

In developing the conceptual design of the brackets of cross arm that used in transmission towers, systematic exploitation of proven ideas or of experience was used. Bracket structure P1048 by UNISTRUT® as shown in Figure 5 has been followed as a guide to be modified by conducting some modifications by employing systematic exploitation of proven ideas or of experience. Bracket structure P1048 is fabricated of carbon steel that meets the physical requirements of ASTM A1011 SS Grade 33.

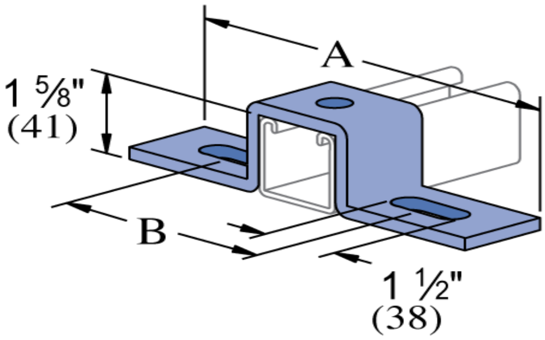
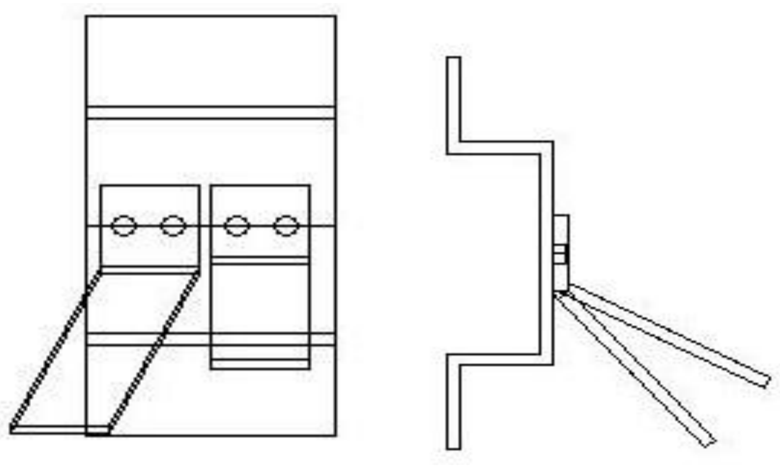



**Figure 5.** Bracket structure P1048 by UNISTRUT®



(a) (b)

**Figure 6.** The modified design of the bracket structure

In this study two symmetric parts of brackets structure will be suggested to be installed on the tie member. These parts will grab the tie member and they will be fixed by using four bolts. The modification will be limited to weld to tees on each part of bracket as shown figures 6(a ,b). These tees are connected to the bracing members.

***3.2. Experimental work***

A modified 13L 123 KV Cross-arm structure has been analyzed by using structural analysis software SKYCIV STRUCTURAL 3D V4.0.0. A standard load 1.5 KN by considering safety factor was applied in case of the normal condition. In this study a Standard load calculations by Tenaga Sdn Bhd (TNB) of 123 KV 13L Cross-arm were considered as shown in figure 7. The resultant force is Fr = 7.98 KN with angle Θ = 54.2º at YZ plan from Y axis were applied on 8 standard steps.

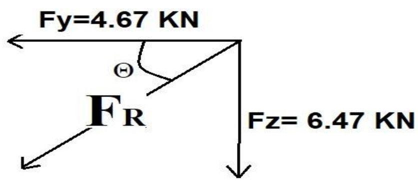



**Figure 7.** Analyzing of the resultant force of the applied load of the normal condition

Calculations of Tenega Sdn Bhd:

$F_{Z}$= 4.67 KN

$F_{Y}$= 6.47KN

$F_r = \sqrt{Fy^2 + Fz^2}$

$F_r = \sqrt{4.67^2 + 6.47^2}$

Fr = 7.98 KN

$\Theta = tan^{-1} \frac{6.47}{4.67}$

Θ = 54.2º

Based on the Standard Calculation safety factor 1.25 thus, load 1.5 KN was employed for the current study. The results of the analyzed cross-arm structure are listed in Table 3 that shows the internal force each of the members and location of each maximum force in each member as well. Figure 8 shows node 5 represents the location of the brackets structure on the tie member of the cross-arm.

**Table 3.** Internal forces of the cross-arm members

| Member | Station Location (M) | Internal Force (KN) |
|---|---|---|
| 1 | 1.413 | 2.092 |
| 2 | 1.413 | 2.092 |
| 3 | 1.872 | -3.546 |
| 4 | 1.290 | 0.052 |
| 5 | 1.032 | 0.052 |
| 6 | 0.356 | -0.029 |
| 7 | 0.356 | -0.029 |
| 8 | 0.310 | 0.016 |

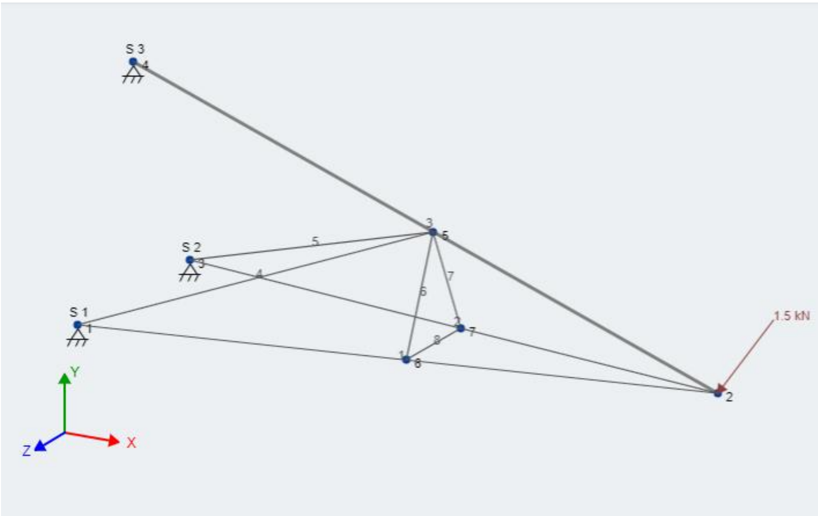



**Figure 8.** The analyzed structure of cross-arm by SkyCiv Structural 3D V4.0.0 software

## 4. Results and discussion

### *4.1. Grid independent study*

In order to proceed in numerical analysis of the bracket structure, a grid independent test will be conducted with specific boundary conditions of the Bracket on the main members and Bracket on the tie member.

#### *4.1.1 Bracket on the main members*

Predicted results are reported for fully developed of the bracket structure that fixed on the main members. Based-on structural analyses that have been obtained by employing SKYCIV STRUCTURAL 3D V4.0.0 software , the internal load at the main member is 2.092 KN and the internal load in the bracing members (member No. 7 is -0.029 KN and member No. 8 is 0.016 KN) as shown Table 3. The total deformation of the main body has considered as index of choosing the optimum mesh to be used for the further analysis. Thus, total Deflection has been calculated for four different grid densities of 40,960 elements, 45,950 elements, 51,140 elements, 55,069 elements, and 60,992 elements and a near wall elements spacing are presented in figure 9.

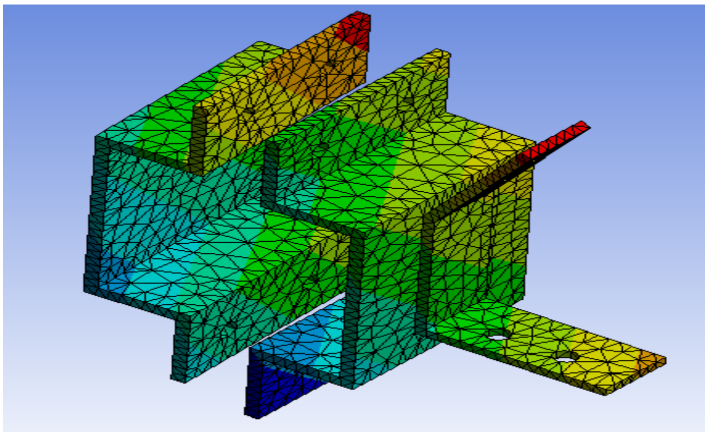


**Figure 9.** Simulation of the total deflection behavior with chosen No. of element 55,069

For grid independence test, the number of elements is varied from 40,960 to 60,992 in various steps. Numerical results have revealed that no change in the total deflection with grids having 55,069 to 60,992 elements at the same applied loads as shown in figure 10. It is found that after 55,069 elements, no further variation in the deflection values thus, it is taken as criterion for grid independence.

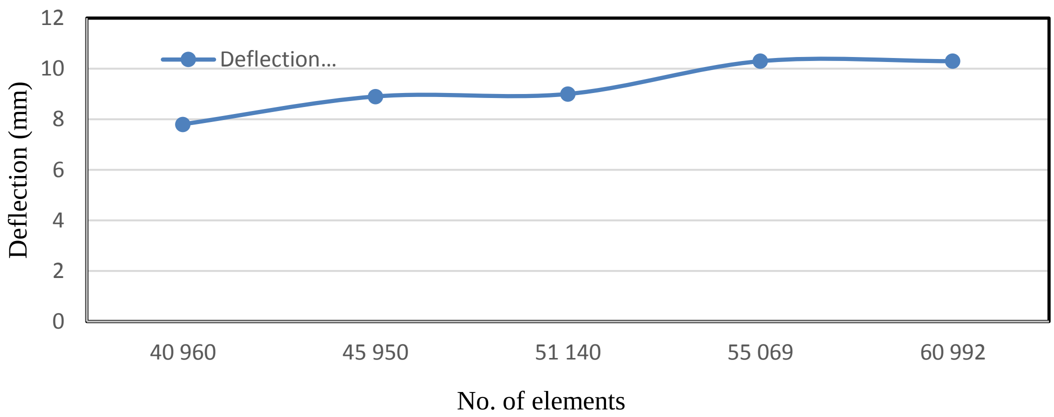



**Figure 10.** Grid independent results of the bracket structure on the main member at 0.7 KN

*4.1.2. Bracket on the tie members*

Similar to the previous procedure of the bracket on the tie members , also the Predicted results are reported for fully developed of the bracket structure that fixed on the tie member. Based-on the structural analyses, that have been obtained by conducting SKYCIV STRUCTURAL 3D V4.0.0 software, the internal load at the tie member is -3.546 KN and the internal load in the bracing members (member No. 4 is 0.052 KN, member No. 5 is 0.052 KN , member No. 6 is -0.029 KN and member No. 7 is -0.029 KN) are shown Table 3. The total deformation of the main body has considered as index of choosing the optimum mesh to be used for the further analysis. Thus, total Deflection has been calculated for four different grid densities of 45,960 elements, 49,950 elements, 58,140 elements, 66,069 elements, and 70,992 elements and a near wall elements spacing are presented in figure 11.

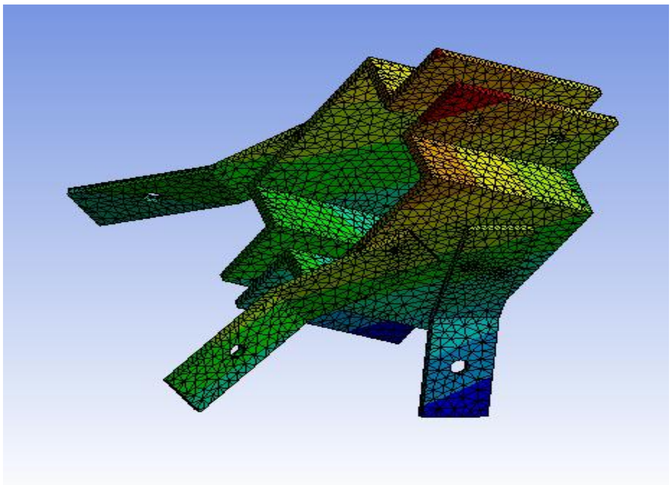


**Figure 11**. Simulation of the total deflection behavior with chosen No. of element 66,069

For grid independence test, the number of elements is varied from 45,960 to 70,992 in various steps. Numerical results have revealed that no change in the total deflection values with grids having 66,069 to 70,992 elements at the same applied loads as shown in figure 12. It is found that after 66,069 elements, no further variation in the deflection values thus, it is taken as criterion for grid independence

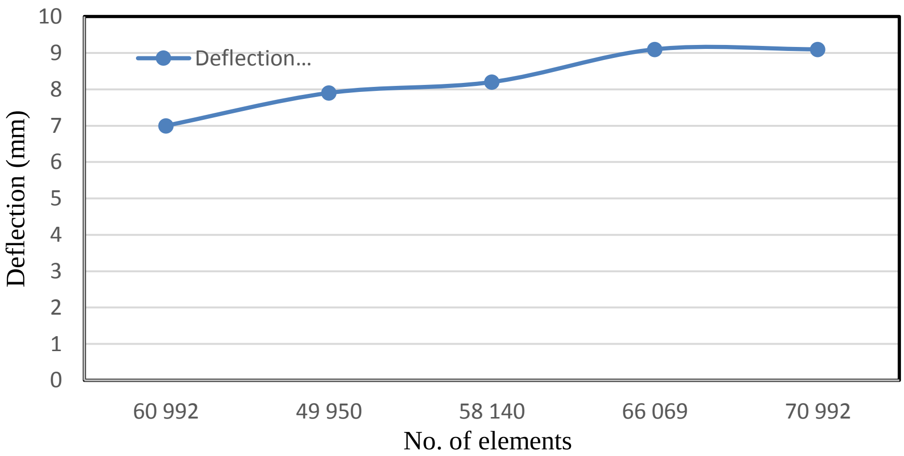



**Figure 12.** Grid independent results of the bracket structure on the tie member at 0.7 KN

### *4.2. Calculation of the optimum design of the brackets*

Modified design that gotten based on the Systematic exploitation of proven ideas has conducted to be analyzed by using FEM in order to set up the geometry in term of thickness.

#### *4.2.1. Calculation of plate thickness of the brackets*

A stress distribution in axial direction were investigated to find out the best thickness of the modified design of the structure of the bracket. FEM results have proven that the brackets structure is deformed in case of less 5 mm thickness due to applied load as shown in figure 13. Where the results showed that max stress in the whole body is equal to 0.00364 MPa and the minimum stress in the same body with same boundary conations.

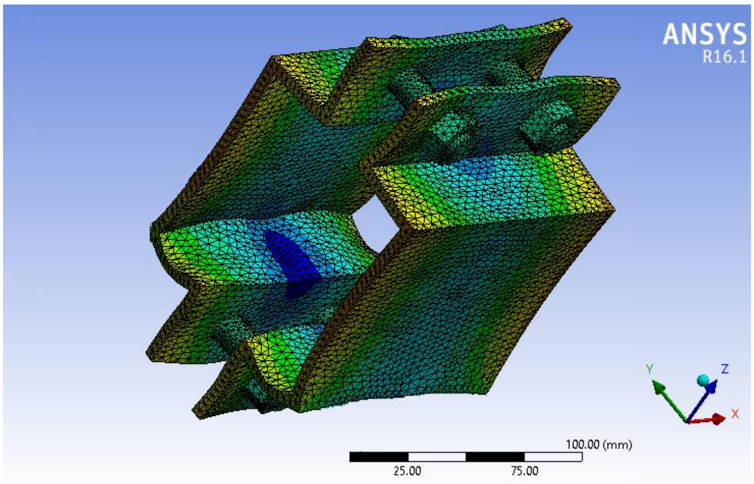



**Figure 13**. Bracket structure under working loads with thickness less than 5 mm

On the other hand simulation results have shown that the bracket structure is not deformed when the equal to 5mm thickness as shown in figure 14, the simulation results has shown that the maximum value of stress is 1.96 MPa and the minimum results is -2.56 MPa. The concentration of stress occurs at the top of the bracket structure in the bolted zone. The reason of high stress at the top of structure is such that the internal load in the bracing members at -z direction thus the top zone exposed to the maximum tension stress.

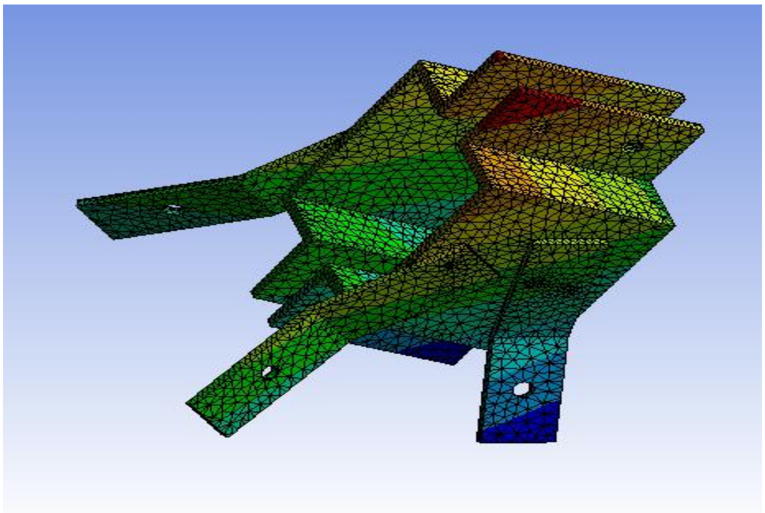


**Figure 14.** Bracket structure under working load with thickness equal to 5 mm

### *4.3. Final design*

Figure 15 shows the current design based on the modification from Figure 2. Based on the previous analysis, it is evident that stainless bracket structure can be a good substitute to be connecter between tie and bracing members in the cross-arm structure. Also, Figure 16 shows the schematic drawing of the current design. In this figure it can be seen that a fabricated bracket structure with 5 mm is installed on the tie member of the cross-arm.

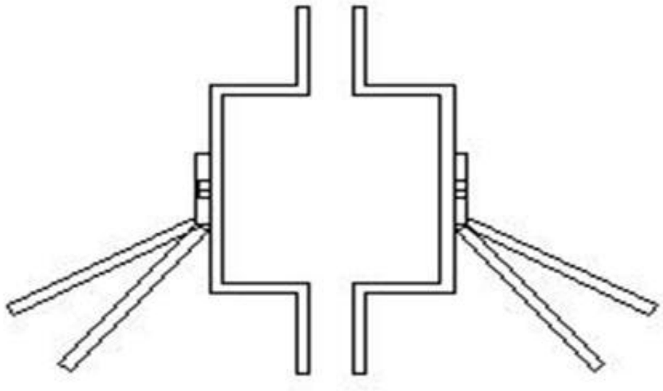


**Figure 15.** A schematic drawing of the current design of the brackets

For mounting the bracket structure, it consists of the two symmetrical parts of steel plates that will be placed in the left and right sides of the tie member of cross. The detail close up view of the fixing method of bracket structure to the left plate and right side of the tie member in figure 10.

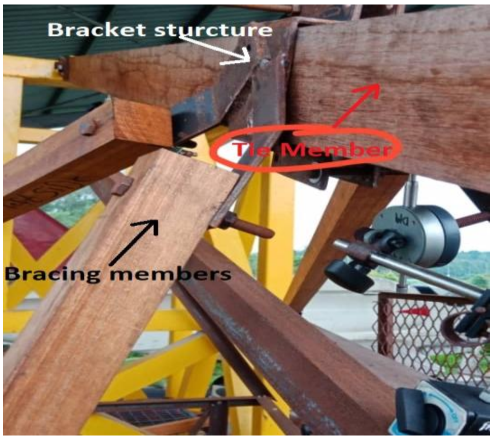



**Figure 16.** Close up view of the fabricated bracket structure

## 5. **Conclusions**

In conclusion, based on the information provided, it was suggested that the conceptual design of the structure of the bracket that was used in the cross-arm be utilized. The present study provides a description of the application of brackets as a structural component in cross-arm in transmission towers. The bracket structure P1048 by UNISTRUT® was used as a reference, and then certain adjustments were made by applying systematic exploitation of proven principles or experience. This was done so that the structure could be updated. The physical requirements of the ASTM A1011 SS Grade 33 have been satisfied by the construction of the bracket structure P1048, which is made of carbon steel. The change that will be made to the design before it is produced will be restricted to welding two tees onto each section of the bracket. These tees are fastened to the bracing components that are a part of the framework for the cross-arms. A specification for a new design of the conceptual design that can be constructed and utilized in wooden transmission towers is the most significant item that has been generated as a result of this study. This is the most significant contribution that can be made as a result of this study. The conclusions of this study have shown that this is the single most important item that can be taken away from them. This very point, right here, is the component of the investigation that has made the most significant contribution to the field as a whole. The fact that very few previous studies explain the method of manufacturing the bracket structure that will be installed in the wooden cross-arm structure is the most significant limitation of this study. This is also the most significant limitation of this study. In order to determine the internal fore and its direction in each member attached to the bracket structure, the SkyCiv Structural 3D V4.0.0 program was used to conduct an analysis of the overall structure of the cross-arm. The new and enhanced brackets structure was put through its paces by the finite element method (FEM) with the help of the static structural tool. The numerical analysis, which was conducted on the basis of the stress distribution technique, determined that the thickness of the plate that was employed in the redesigned design of the bracket structure should not be less than 5 millimeters. This was determined to be the case.

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