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Structural Design of Steel Roof Trusses for the Magnum Opus General Hospital Project, Manado

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ABSTRACT

This article describes the planning of steel roof truss structure in the Magnum Opus Manado General Hospital construction project. This study aims to design a steel roof truss, plan the profile and size of the profile purlins and horses, the diameter of the track, the diameter of the wind ties, plan the connection and gusset plate, also analyze the output/results of structural strength calculations on steel roof trusses. The research method used is to plan and analyze the structure with the help of autocad software to design, loads are calculated manually, and also use SAP 2000 software to analyze the calculation results of the steel roof truss structure. From this study, the calculation results obtained which states that the planning of steel roof truss structure using light Lip channels gording profile measuring 200.75.20.3, 2, trekstang using iron diameter 12 mm, wind ties using iron diameter 19 mm, Double Angle easel profile measuring 2L.90.90.7 (used on rootstock, upright stems, and diagonal stems), 2L.90.90.13 (used on the upper diagonal rods), and the calculation of Bolt connections as many as 3 bolts in each rod, which have been calculated to be strong, safe, and also sturdy in withstanding the loads that work on the roof frame

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INTRODUCTION

In recent years, construction development in Indonesia has continued to grow over time, this is influenced by several factors including stable and strong economic growth, infrastructure investment, construction technology innovation, urbanization, sustainable development, regulations and policies, and earthquake resistance. One of the structural materials that is earthquake resistant is steel, because steel has high tensile strength that can withstand dynamic loads from earthquakes. In addition, the elastic properties of steel can cause steel to experience temporary deformation during an earthquake and then return to its original state which can prevent permanent damage to the structure of a building.

Steel is a type of metal alloy consisting of a mixture of the main elements iron and carbon, and several other elements are added to increase its strength and properties. The steel making process is carried out with guaranteed quality standards, ensuring the availability of various types of steel that are in accordance with the needs and purposes of its use (Putra, FA, & Setiawan, B., 2023). Steel is a material that can be easily shaped according to needs, so it is often the main choice. The quality of steel is guaranteed in the production process, there are various types of steel that are suitable for its needs (Wiseno, E., Irwandi, MA, 2023). The strength of steel material in withstanding loads is greatly influenced by its mechanical characteristics. Mechanical properties include the capacity of the material to withstand pressure from the working loads (Arifi. E., Setyowulan., 2020). One of the advantages of steel as a structural material is its high strength and tensile strength, as well as the ease and practicality of its installation. Apart from its advantages, steel also has disadvantages such as maintenance, high costs, and buckling problems. (Suseno, et al., 2022). The advantages of steel can make it a structural material for use in construction work, one of which is roofing.

The roof is the top part or covering of a building that not only acts as a protector from external weather, but also acts as a component to determine the aesthetics and safety of the building. Visually, the roof is the first part seen by everyone who pays attention to it. (Darmiyanti, L., et al., 2022). The roof continues to experience developments caused by technological advances, sustainability, innovation in construction materials, and changes in architectural design. The development of the roof involves various aspects, including the structure of the roof truss frame and the evolution of roof covering materials. Related to the roof truss frame, the evolution of materials includes the development of structural materials used to make the roof truss frame, which used to use wood as the main material but along with the development of the times and technology and the discovery of other materials, there has been a change in the direction of choosing more innovative and modern materials, namely steel, because currently the use of steel material as a roof frame is increasingly in demand by people.

The roof frame basically consists of a series of rods that form a triangle. Each rod must be designed in such a way that it is sturdy and able to withstand the load without deformation, and the selection of quality materials is very important. (Rahayu, SA, Manalu, DF, 2015). The roof frame is the top part of a building, consisting of a frame structure placed on a plane and connected by joints at the ends, forming a part of the building consisting of triangles. This roof frame has a function, namely to support the load acting on the roof, in addition the roof frame can also be the shape of the roof. The need for roof frame construction depends on various factors such as the span of the building, the type of structural material, the shape and size of the space that needs to be protected, and the covering material used. In its planning, the roof frame has a more primary function, namely to receive loads including dead loads, live loads, rain loads, wind loads, as well as columns, beams and also the lower structure.

LITERATURE REVIEW

The Magnum Opus Manado General Hospital Development Project is located on Jl. Pandu 2, Pandu Village, Bunaken District, Manado City, North Sulawesi, which is a 3-story building with a building area of 4,898.6 m2. This project aims to improve public access to health services without having to travel far, this project has also provided quite complete facilities to handle the health of the surrounding community. In connection with the discussion of the structure above, the roof frame structure on the Magnum Opus Manado General Hospital project does not yet have a plan. Therefore, the author wants to try to plan a roof frame structure using steel on the project to ensure the strength, security, and stability of the building.

The purpose of this study is to design a steel roof frame, plan the profile and size of the purlin and truss profiles, the diameter of the track, the diameter of the wind ties, plan the connections and gusset plates, and also analyze the output /results of structural strength calculations on the steel roof frame.

METHODOLOGY

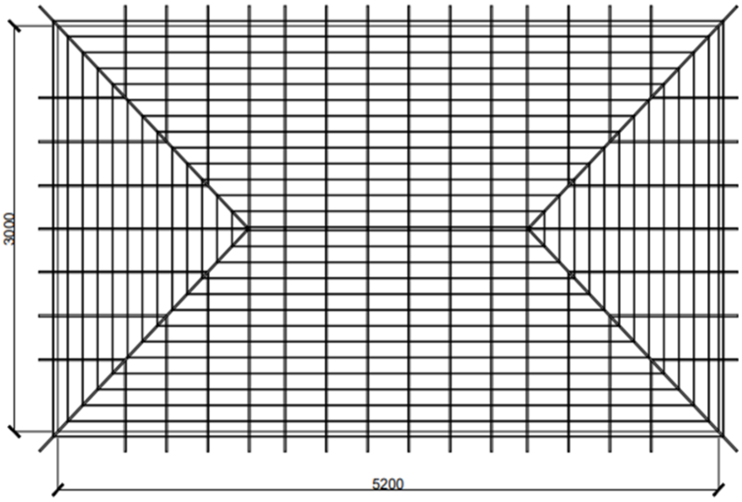
The research method used is to plan and analyze the structure using the help of Autocad software to design, the loads are calculated manually, and also using SAP 2000 software in analyzing the calculation results of the structure to produce strength, safety, and the ability to withstand loads on the steel roof frame structure. This research begins by finding the data needed to make the plan. The data used is in the form of architectural drawings which contain 3D images, plans, details and so on. But because this research is roof planning, the plan used as a reference for its size is the plan on the 3rd floor.

In this study, in planning the steel roof truss structure, the initial step planned is to design the steel roof truss including the roof truss span, the distance between purlins, the distance between trusses, the roof slope angle, the type of profile or the size of the profile to be used, and the type of connection. Then, structural modeling is carried out on SAP 2000 software which will produce output from the bar forces and can be used to control the dimensions of the roof truss profile used. Modeling in this study only uses 2D modeling for the roof truss frame.

RESULTS AND DISCUSSION

In this study, the initial plan made was a roof plan design (Figure 1) in the form of a pyramid with a width of 30 meters and a length of 52 meters, a roof truss frame design (Figure 2) with a span of 30 meters, a distance between purlins of 1.596 meters, a distance between trusses of 3.25 meters, a roof slope angle of 20 □, using a C channel purlin profile/Light Lip Channels with a size of C 200.75.20.3,2 (Figure 3), and a Double Angle truss profile with a size of 2L.90.90.7 and 2L.90.90.13 (Figure 4), and the type of connection using bolted connections.

Figure 1. Floor Plan Plan Roof



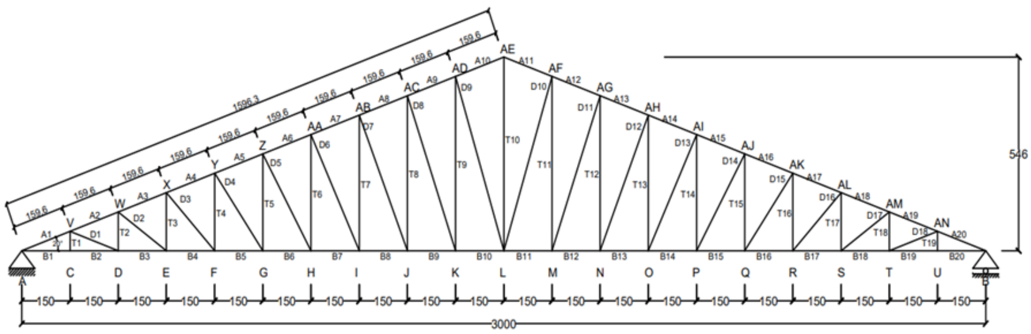


Figure 2. Frame Sawhorse Roof

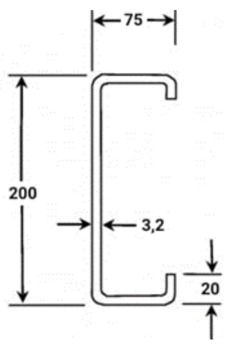


Figure 3. Profile Details Curtain Channel C Size 200.75.20.3,2

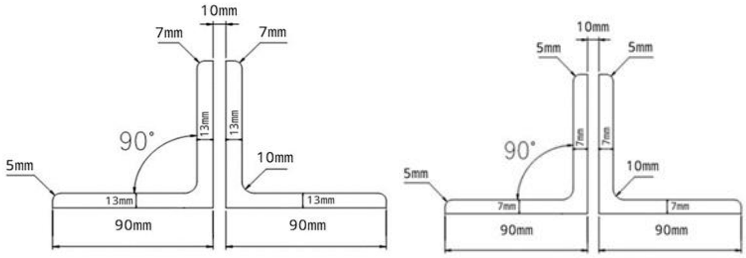


Figure 4. Profile Details Sawhorse *Double Angle* sizes 2L.90.90.7 and 2L.90.90.13

From the calculation planning that has been done both manually and with the help of SAP 2000 software , the results obtained are roof plan design, truss frame plan design, purlin profile, track diameter, wind tie diameter, truss profile, results of calculations of member forces with SAP 2000 software , control of steel roof frame profile, connection calculation, and also gusset plate planning.

In the purlin planning, purlins with a channel profile of C 200.75.20.3.2 were used. In the planning, calculations were made for dead loads, roof live loads, rain loads, and wind loads. The results of the calculation, on the dead load, the total load was obtained = 31.26 kg / m, dead load in the X direction = 10.692 kg / m, dead load in the Y direction = 29.379 kg / m. The moment due to dead load uses 2 tracks, X direction = 14.117 kgm and Y direction = 4.310 kgm. The roof live load used is the concentrated live load according to SNI 1727: 2020 of 1.3 kN = 135.62 kg, roof live load in the X direction = 46.382 kg / m, roof live load in the Y direction = 127.441 kg. The moment due to the live load of the roof uses 2 tracks, X direction = 37.685 kgm and Y direction = 34.515 kgm. The rain load is 103.7 kg, the rain load in the X direction = 35.479 kg, the rain load in the Y direction = 97.483 kg. The moment due to the rain load uses 2 tracks, X direction = 28.827 kgm, and Y direction = 26.402 kgm. The wind load calculated according to SNI 1727:2020 is 687.619 kg. The moment due to the wind load is taken from the combination calculation with the largest value or maximum combination, X direction = 939.226 kgm (taken from combination 4), and Y direction = 47.415 kgm (taken from combination 3). In the bending stress control, the results are 1584.9 kg/ cm2 □1600 kg/cm2 (allowable stress) then meets the requirements. The deflection control of the entire load obtained a result of 0.704 cm □1.3 cm (allowable deflection) then meets the requirements.

In the calculation of the track rod, a track rod with a diameter of 12 mm was obtained. The planning of the wind tie profile diameter obtained a load of 2074.8 kg, with a wind tie length = 16.29 m, a slope of the rod = 78.49 □. The cross-section of the wind tie due to yield stress (f y) = 0.961 cm 2 , due to the breaking limit (f u) = 0.737 cm 2 , then the cross-section needed to be used is the largest value = 0.961 cm 2 . From this calculation, iron with a diameter of 19 mm was used for the wind tie. The profile area control obtained a planned area = 283.529 mm ÷ □99.7 mm (required area) so that it meets the requirements, and the profile length control obtained a planned length = 38 mm ÷ □32.58 mm (required length) so that it meets the requirements.

In the truss design, a truss with a Double Angle profile measuring 2L.90.90.13 was used for the upper bar, and 2L.90.90.7 for the lower bar, diagonal bar, and vertical bar. The truss design was carried out using 2D modeling on SAP 2000 software and the loads that worked were placed on each joint on the truss. In the truss loading, there were additional dead loads, namely purlin loads, roof covering loads, and ceiling loads. Purlin loads were P = 30.128 kg, ½ P = 15.064 kg, roof covering loads were P = 68.47 kg, ½ P = 34.235 kg, ceiling loads were P = 87.75 kg, ½ P = 43.875 kg. The live roof load is taken from SNI 1727:2020 of 135.62 kg, rain load = 103.74 kg, and wind load on the windward side (pressure) and on the windward side (suction) the load is 687.619 kg. Because in SAP 2000 software the load is entered vertically and horizontally, then in the wind load on the windward side (pressure) and the windward side (suction), the horizontal load = 235.180 kg, vertical load = 646.151 kg. When modeling in SAP 2000, a combination of loads according to SNI 1727:2020 is used.

From the results of the calculation of the member forces in the SAP 2000 software , the maximum member forces are taken to control the truss profile as in the following table.

Table 1. Bar Styles Maximum

No. Trunk	**Name of the Stem**	**Bar Force (kg)**		**Length of the stem (m)**
		Stem press (-)	**Rod (+)**	
Stem On	A1	-24060.58	-	1.59 m
Stem Lower	B1	-	27499.09	1.5 m
Diagonal Bar	D9	-6314.39	-	5.66 m
Stem Upright	T10	-	6696.33	5.46 m

After the tensile bar profile control (+) was carried out, the tensile yield results were obtained at the gross cross-section = 52790.4 kg, tensile failure at the net cross-section = 54256.8 kg, but for the tensile strength control, the design used was the smallest value, namely tensile yield at the gross cross-section = 52790.4 kg. In the tensile strength control, the tensile strength must be smaller than the design tensile strength ($\mathbf{P_u \leq \phi_t P_n}$) as in the following table.

Table 2. Control Profile Stem Pull (+)

Rod (+)	**Profile**	**P_u (kg)**	**Notation**	**$\phi_t P_n$ (kg)**	**Caption**
Stem Lower	2L.90.90.7	27499.09	<	52790.4	Fulfil
Stem Upright	2L.90.90.7	6696.33	<	52790.4	Fulfil

After the control of the compression bar profile (-), the results of the critical stress (F_{cr}) of the upper bar = 644.308 kg/cm ^{2}, diagonal bar = 431.782 kg/cm ^{2}, torsional buckling of the upper bar = 27975.85 kg, diagonal bar = 10552.75 kg. In the control of compressive strength, the compressive strength must be smaller than the design compressive strength ($\mathbf{P_u \leq \phi_c P_n}$) such as on table following.

Table 3. Control Profile Stem Press (-)

Stem Press (-)	**Profile**	**P_u (kg)**	**Notation**	**□$_c$P$_n$ (kg)**	**Caption**
Stem On	2L.90.90.13	24060.58	<	25178.27	Fulfil
Diagonal Bar	2L.90.90.7	6314.39	<	9497.48	Fulfil

Then the truss deflection control is carried out, with the allowable deflection = 1/250 ×L = 1/250 ×30 m = 0.12 m. The maximum deflection that occurs at joint 19 is 0.013961 m, which is obtained from the results of SAP 2000 *software* . The maximum deflection is 0.013961 m <0.12 m (allowable deflection), so it meets the requirements.

TABLE: Joint Displacements

Joint	OutputCase	CaseType	U1	U2	U3	R1	R2	R3
Text	Text	Text	m	m	m	Radians	Radians	Radians
18	LIVE	LinStatic	0	0	0	0	0	0
18	Lr	LinStatic	0,001373	0	-0,005248	0	-0,000092	0
18	RAIN	LinStatic	0,001051	0	-0,004014	0	-0,00007	0
18	WIND	LinStatic	0	0	0	0	0	0
18	W1	LinStatic	0,004891	0	-0,012549	0	-0,000535	0
18	W2	LinStatic	-0,00172	0	0,013906	0	-0,000066	0
19	DEAD	LinStatic	0,00223	0	-0,007609	0	-0,00023	0
19	SDL1	LinStatic	0,000328	0	-0,00113	0	-0,000035	0
19	SDL2	LinStatic	0,000745	0	-0,002569	0	-0,00008	0
19	SDL3	LinStatic	0,000955	0	-0,003329	0	-0,000103	0
19	LIVE	LinStatic	0	0	0	0	0	0
19	Lr	LinStatic	0,001475	0	-0,005088	0	-0,000158	0
19	RAIN	LinStatic	0,001129	0	-0,003892	0	-0,000121	0
19	WIND	LinStatic	0	0	0	0	0	0
19	W1	LinStatic	0,005107	0	-0,011684	0	-0,000637	0
19	W2	LinStatic	-0,001992	0	0,013961	0	0,000171	0
20	DEAD	LinStatic	0,002396	0	-0,007176	0	-0,000349	0
20	SDL1	LinStatic	0,000352	0	-0,001071	0	-0,000052	0

Figure 5. Deflection Value Maximum Sawhorse

In the bolt planning calculations, bolts with a diameter of 15.9 mm, a joint plate thickness of 10 mm, and a yield strength steel quality (f_y) were used. = 370 MPa and breaking stress (f_u) = 240 MPa, A325 bolt quality with nominal tensile strength (F_{nt}) = 620 MPa or 90 ksi, nominal shear strength (F_{nv}) = 469 MPa or 68 ksi, and the number of shear planes is 2. The calculation results, the distance between bolts (S_1) and the distance of the bolt to the edge of the connection (S_2) are taken as 50 mm, the shear strength of the bolt (2 shear planes) = 14236.66 kg, the number of bolts needed on each bar is 3 bolts, the bearing strength of the plate between the bolt holes (2 shear planes) = 28795.14 kg, the bearing strength to the edge of the plate = 14397.57 kg, and the total bearing strength = 43192.71 kg. In the bearing strength control (□R n > Pu), the result is □R n = 32394.53 kg □24060.58 kg (nominal strength) so it meets the requirements, and in the bolt shear strength control (□R nv > Pu) , the result is 42709.98 kg □27499.09

(nominal strength) so it meets the requirements. For planning plate knot, namely like on Images following:
following:

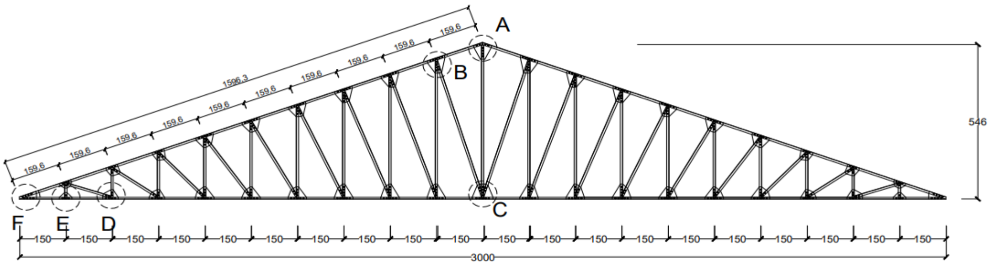


Figure 6. Point modeling plate knot

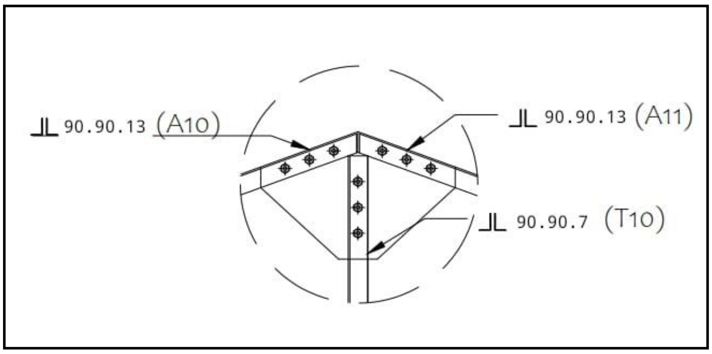


Figure 7. Point modeling plate knot A

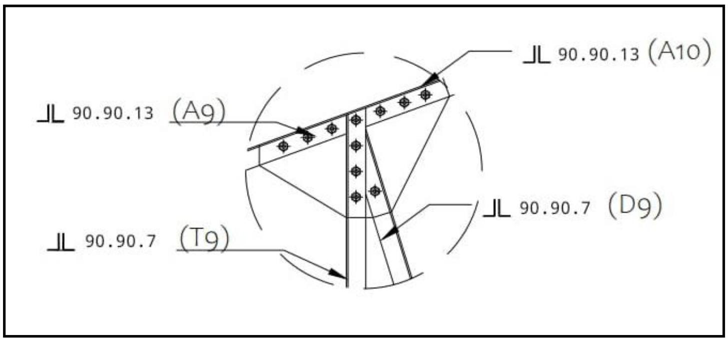


Figure 8. Point modeling plate B knot

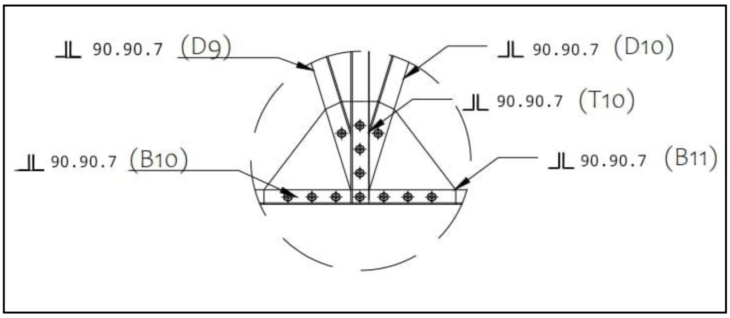


Figure 9. Point modeling plate C knot

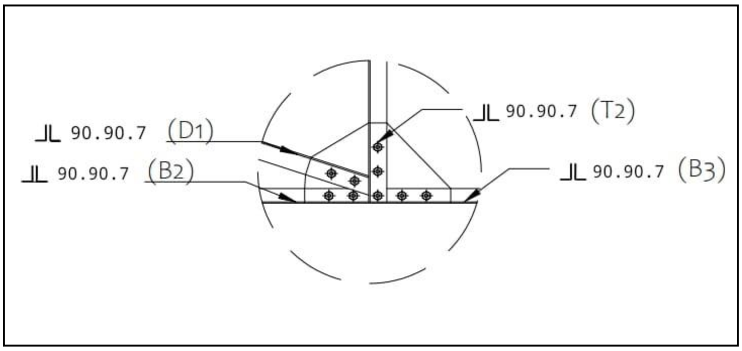


Figure 10. Point modeling plate D knot

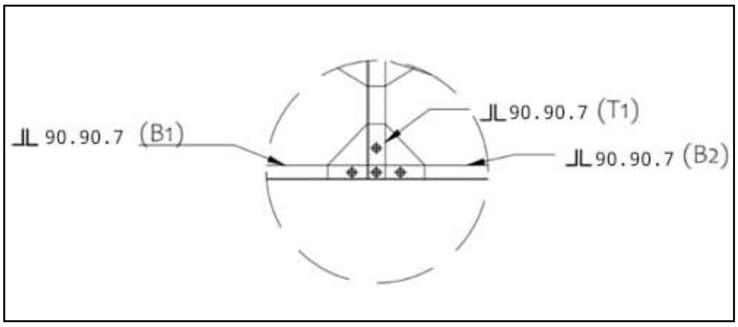


Figure 11. Point modeling plate E knot

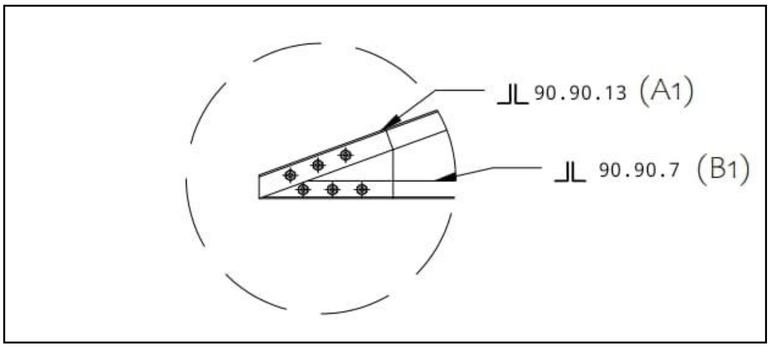


Figure 12. Point modeling plate F knot

CONCLUSION AND RECOMMENDATION

Based on the planning and calculation of the steel roof frame structure for the Magnum Opus Manado General Hospital Development Project, the planning results were obtained, namely, using a Double Angle Profile with sizes 2L.90.90.7 and 2L.90.90.13 for horse stance , Profile Channel C with size C.200.75.20.3,2 for gording , planning track bar used iron with a diameter of 12 mm, and on bond wind use iron with a diameter of 19 mm. Then planning connection use connection bolt measuring 15.9 mm in diameter with amount bolt as many as 3 bolts on each stem, distance between bolt namely 50 mm, and planning plate knot with thick 10 mm plate.

FUTHER STUDY

This research still has delays, so further research is needed on the topic of Structural Design of Steel Roof Trusses for the Magnum Opus General Hospital Project, Manado in order to improve this research and provide insights for the readers.

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