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STUDY OF RESISTANT EARTH QUAKE BUILDING OF TIMBER ROOFS STRUCTURE AND ITS RETROFIT AND REDESIGN AFTER THE SEPTEMBER 28 2018 EARTHQUAKE

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Abstract
Palu's Earthquake on 28 September 2018 had caused structural failure including buildings with wooden structures which were knew as an earthquake-resistant structures. This study will discuss existing building timber roofs structure were damaged after the earthquake, various and caused of the damaged. Existing and retrofitted timber rooss and alternatives design of the roofs structures will be compared. Retroffited timber roof, truss roof with 70x70x6 double angle and gable frame roof structure with WF 250x125 will be design with 15 m length span and 45° slope. Based on these data collected from initial assessment of that buildings, analysis was conducted. Detailed assessments were carried out, when analysis of the truss, frame and joint of roofs structures were needed. Results of the initial assessment of wooden structure, showed that damages occurred at the many joints of member joints and joint-connection between wall and truss as the poor connection system. Redesign showed were structural behavior of retrofitted timber roof, double angle truss roof and gable frame roof structure showed better strength, stiffness and ratio of member force to self-weight.

Keywords: Assessment, Damages, Timber Roof Structures, Retrofit, Alternatives Design

Abstrak
Gempa Palu pada tanggal 28 September 2018 telah menyebabkan kegagalan structural bangunan termasuk bangunan dengan bahan kayu, yang mana selama ini bangunan dari bahan kayu dikenal sebagai bangunan tahan gempa. Dalam studi ini akan membahas bangunan eksisting dengan rangka atap kayu yang juga mengalami kerusakan akibat gempa, variasi kerusakan serta penyebabnya. Rangka atap kayu eksisting akan dibandingkan rangka kayu yang diperkuat serta alternatif desain lainnya. Rangka kayu yang diperkuat, desain dengan baja siku 2x70x70x6, dan struktur atap dengan gable frame WF 250x125 akan didesain dengan bentang yang sama 15 m dan kemiringan atap 45°. Data-data desain tersebut didasarkan pada asesmen awal pada bangunan eksisting yang menjadi dasar analisis nantinya. Asesmen detail akan dilakukan pada saat analisis dari rangka kayu dan sambungannya dari system rangka atap tersebut pada saat dibutuhkan. Hasil asesmen awal menunjukkan pada struktur atap kayu pasca gempa terjadi kerusakan pada beberapa titik sambungan, kelemahan pada sambungan dan alat sambungnya serta pada titik tumpuan antara rangka atap dengan dinding penopangnya. Hasil redesain dari struktur rangka atap ini menunjukkan perilaku structural dari perkuatan rangka atap kayu, rangka kap dengan baja siku ganda dan atap gable frame lebih baik dibandingkan dengan rangka atap eksisting dari segi kekuatan, kekakuan dan rasio gaya dalam terhadap berat sendiri strukturnya.

Kata kunci: Penilaian, Kerusakan, Struktur Atap Kayu, Perkuatan, Desain Alternatif

1. Introduction

Used of wood as a structural material, especially buildings and bridges has been used for a long time. Wood for building materials was used before concrete and steel. In North America, wood as the main material for housing and commercial buildings has been used since the early 20th century (Larsen, 2016) After the earthquake, many reinforced concrete and wooden structures were damaged. The major damage occurs due to several vulnerabilities such as the design that has not complied with the technical aspects, including the connection system between the structural elements that is not yet

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good. Previous research related to this research include: Performance of wooden structures after the earthquake, lack of cross-bearing in the stilts after the Sabah Earthquake, Malaysia (Alih & Vafaei, 2019). Damage to typical Aceh wooden houses (Rumoh Aceh), damage due to earthquake on the Aceh wooden house (Idris et al., 2019). Lessons from Damaged Historic Buildings in the Sichuan Earthquake A Case Study in Zhaohua Sichuan Province (Liu, 2018). As well as the implementation of reconstruction with high vulnerability after the Java earthquake (Cholis Idham & Mohd, 2018). Similarly, after the Palu earthquake on September 28 2018, also caused damage to building structures made of concrete, steel and wood. In the wooden structure, the dominant damage occurred at the bottom base of the column due to poor anchorage, the column structure without lateral stiffeners and the detachment of several connections to the wooden roof truss and wall mount with truss frame structures. This is due to the insufficient number of connecting tools, both pegs, nails and bolts. On a wall mount with an easel frame caused by poor anchorage. Earlier studies among others: An interactive rectification procedure analysis for historical timber frame, application to a cultural heritage Chinese Pavilion (Li et al., 2021). The wooden roof structure of Zulawi Region arcaded house of type III-research, current state and analysis (Zybała, 2019). Researched design of rural building based on the theory of anti-seismic design (Wu et al., 2020). Studied seismic performance evaluatiom for a traditional Chinese Timber-Frame Structure (Wu et al., 2020). Fragility assessment of roof-to-wall connection failures for wood-frame house in high wind (Gavanski & Kopp, 2017). Evolution of predicted seismic performance for wood-frame building (Sutley & van de Lindt, 2016), A practical modelling to asses the performance of wood frame roofs under extreme wind loads (Stevenson et al., 2019).

2. Data, Materials and Methods

2.1. Data

The data used in this study are the results of assessments on building structures with wooden roof trusss in the city of Palu, Sigi and Donggala districts. The data taken in the form of the type and level of damage to the building structure. The age of the building, the type of material and the size of the roof truss material are also measured. The data obtained are as follows:

Table 1. Result of Building Assessment with Wooden Roof Truss

City or Regency	*Building age (Year)*	*Number of building*	*Type of damages*	*Category of damages*	*Timber Dimention (mm)*	*Span of truss (m)*
Palu	32	10	Join	Moderate	60x120	12
Sigi	25	10	Join & RWCs	Moderate	80x160	15
Donggala	43	10	Join	Moderate	60x120	10

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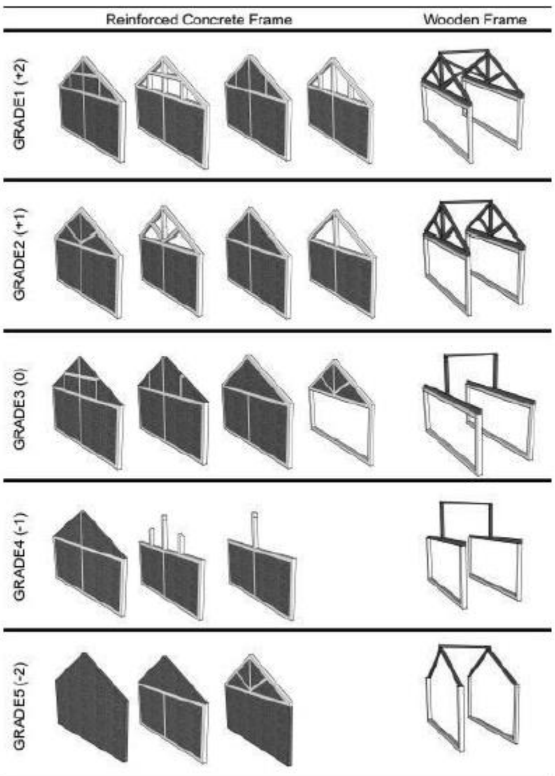
Fig. 1. Damages of Timber Joints of Timber Truss of Sigi Regency

Fig. 2. Damages of Timber Joints of Timber Truss of Sigi Regency



Structural Definition	
GRADE 1 (+2)	**Strong Connection** Completed roof frame with more than three connection to the main frame either with or without walled brick in between. While for wood has 3 D connection to other frame. When earthquake strike it will stand completely
GRADE 2 (+1)	**Less Strong Connection** Completed roof frame with less connection to the main frame. For concrete categorized as upper group as long as has rigid connection (3D connection) to other frame, for wood less connect. When earthquake strike it will little affected and still stand completely
GRADE 3 (0)	**Sufficient Connection** Uncompleted roof frame structure or completed one but less sufficient support bellow. For wood has no diagonal element for both sides. When earthquake strike it will severe affected but still stang completely.
GRADE 4 (-1)	**Weak Connection** Uncompleted roof frame structure but still has sufficient connection with the main frame bellow. For wood has no diagonal element for both sides with small horizontal under. When earthquake strike it will affected easily and some part will easily collapsed.
GRADE 5 (-2)	**Very Weak Connection** Incompleted roof frame structure with improper structural system without any connection between roof and main structural system. For wood without horizontal bracing member. When earthquake strike it will affected easily and the whole roof structure will easily collapsed.

Fig 3. Grading Systems Criteria for Timber Gable Roof Structure (Cholis Idham & Mohd, 2018)

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If based on the research of Idham, et al, the criteria for damage to wooden roof structures affected by the earthquake in the city of Palu, Sigi and Donggala districts are in the grade 3 (0) category, namely the incompleteness of the roof truss structural elements and the lack of connecting tools.

2.2. Materials

The materials used in this study are wood and steel ionic WF profiles and double angles which will be used in alternative designs for typical roof truss structures. The material data for the results of testing in the laboratory are as follows:

1. Solid wood 80x160 and 60x120 strength class I, with E_w = 12.250 MPa, fill weight = 830 kg/m^3

a. Timber tensile test b. Timber compression test

Fig. 3 Setting Up of Tensile and Compression Timber Test

Table 2. Tensile Test Results Parallel to Wood Grains

No.	Codes	$f_{t\ max}$ (MPa^2)	σ_{max}	Trend Curves
1.	TR1	7,03	8,72	Linier
2.	TR2	6,66	9,28	Linier
3.	TR3	6,80	9,68	Linier
	Average	6,83	9,23	-

2. profile steel of WF 250x125 and 70x70x6 elbow steel with fy = 250 MPa and fu = 378 MPa

Fig. 4 Materials, Setting-Up Test and Tensile Curve of Steel

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2.3. Methods

This experimental research was carried out follows: to get an overview of the level and causes of damage to the wooden frame structure, an assessment was carried out in the earthquake affected area. After obtaining the assessment results in the form of damage points and types, structural modeling is carried out using material data from existing buildings. Calculation and modeling of roof truss structure using SAP2000 software. In the design alternative, the existing roof truss structure model is 15 m span and the roof slope is 45°. Furthermore, the existing wooden roof truss structure is reinforced at the joints with the addition of incomplete vertical bars. On the other hand, the alternative design is done by replacing the 80x160 solid wood roof truss with 70x70x6 double angle steel and the gable frame with 250x125 profile steel. Furthermore, the 4 (four) models of the roof truss structure were analyzed and compared the properties of the material and the results of the analysis were: self-weight, internal forces and support reactions, deformation and the ratio of force to weight of each of the roof truss structures.

3. Results and Discussion

3.1. Field Assessment

Field surveys showed that buildings with wooden roof trusss in all study areas (Palu, Sigi and Donggala) suffered typical damage as follows:

1. Damage to the lower end of the column due to poor anchorage
2. Excessive lateral deflection due to the absence of lateral stiffeners in the wooden column
3. The detachment of several wooden elements from the joint due to insufficient connection tools, either wooden pegs, nails or bolts.
4. Insufficient anchorage at the junction of the wall and roof truss.
5. Insufficient number of elements in a joint, for example vertical bars as clamps are not present in some joints.

Fig. 5. Insufficient Armature In Mounts, Joining Elements and Connector.

Based on Figure 5 above, it can be shown that at the wall connection with the roof truss (Roof to Wall Connections = RWCs) there is no armature to hold the roof truss in the event of horizontal and

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vertical earthquake forces. In the middle and right images it is shown that there is no vertical clamp on each vertical rod module. The right picture shows only 1 (one) connection tool for each joint which should have at least 2 (two) bolts. Figure 2 above also shows the inadequacy of the dowels and bolts, so that in the tension element, failure occurs in the form of a broken dowels and the bolts attachment is pulled out of the joint. Several survey results in the city of Palu showed that there was a lateral shift in the entire roof truss with a distance of about 20 cm. This occurs due to the absence of anchorage from the walls and columns on the roof truss mount, given the acceleration of the ground surface and the large horizontal and vertical deflections when the earthquake occurred. In this case, anchorage is required at the top end of each column or a wooden beam is installed along the top of the wall. Anchoring can be done by mining(double and triple grip steel plates).

3.2. Properties of Material for Altenative Design

Test results of wood and steel materials to be used as materials in alternative designs:

Table 3. Wood Material Test Results

No.	Codes	f_t(MPa)	f_c (MPa)	τ (MPa)
1.	S1	7,03	11,25	1,29
2.	S2	6,66	10,58	1,45
3.	S3	6,80	12,17	1,19
	Average	6,83	11,33	1,31

Based on testing of the wood material on the existing roof truss, the results as shown in table 3 concluded that the characteristics of the wood belong to the C30-C35 strength class.

Table 4. Characteristics of Various Wood Strength Classes (Kermani, 1999)

Strength class[a]	Building // to grain, $\sigma_{m,g,//}$ (N/mm²)	Tension // to grain, $\sigma_{t,g,//}$ (N/mm²)	Compression // to grain, $\sigma_{c,g,//}$ (N/mm²)	Compression ⊥ to grain,[b] $\sigma_{c,g,\perp}$ (N/mm²)		Shear // to grain, $\tau_{g,//}$ (N/mm²)	Modulus of elasticity E_{mean} (N/mm²)	Modulus of elasticity E_{min}	Density[c] ρ_k (kg/m³)	Density[c] ρ_{mean}
C14	4.1	2.5	5.2	2.1	1.6	0.60	6800	4600	290	350
C16	5.3	3.2	6.8	2.2	1.7	0.67	8800	5800	310	370
C18	5.8	3.5	7.1	2.2	1.7	0.67	9100	6000	320	380
C22	6.8	4.1	7.5	2.3	1.7	0.71	9700	6500	340	410
C24	7.5	4.5	7.9	2.4	1.9	0.71	10800	7200	350	420
TR26[d]	10.0	6.0	8.2	2.5	2.0	1.10	11000	7400	370	450
C27	10.0	6.0	8.2	2.5	2.0	1.10	12300	8200	370	450
C30	11.0	6.6	8.6	2.7	2.2	1.20	12300	8200	380	460
C35	12.0	7.2	8.7	2.9	2.4	1.30	13400	9000	400	480
C40	13.0	7.8	8.7	3.0	2.6	1.40	14500	10000	420	500
D30	9.0	5.4	8.1	2.8	2.2	1.40	9500	6000	530	640
D35	11.0	6.6	8.6	3.4	2.6	1.70	10000	6500	560	670
D40	12.5	7.5	12.6	3.9	3.0	2.00	10800	7500	590	700
D50	16.0	9.6	15.2	4.5	3.5	2.20	15000	12600	650	780
D60	18.0	10.8	18.0	5.2	4.0	2.40	18500	15600	700	840
D70	23.0	13.8	23.0	6.0	4.6	2.60	21000	18000	900	1080

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While the test results on the tensile strength of angled steel and profile steel obtained a yield stress of 250 MPa and a maximum stress of 375 MPa, this is in accordance with the low quality of steel for structural steel.

3.3. Alternatives Review Design of Roofs Structure

The configuration of the existing roof truss is as shown in the following picture

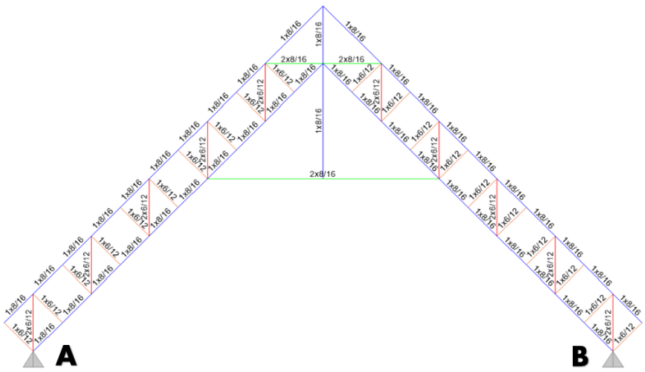

Fig. 6. Configuration of The Existing Wooden Roof Truss With Solid Wood Of 80x160 & 60x120

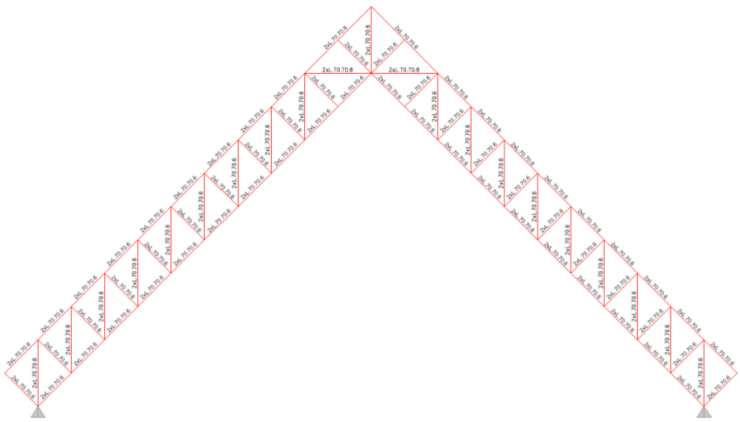

Fig. 7. Alternative Redesign with Double Angle 70x70x6

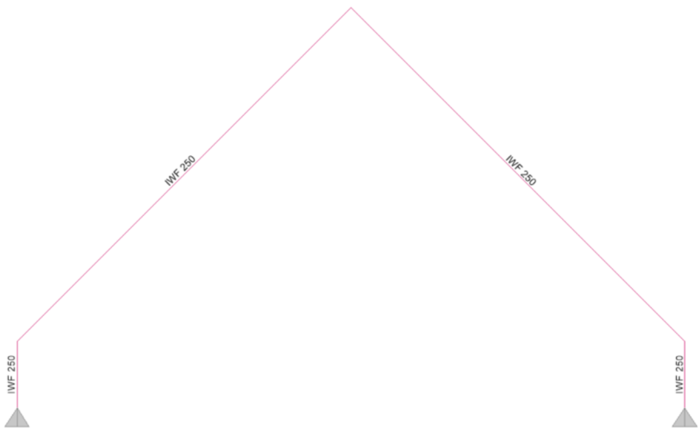

Fig. 8. Alternative Redesign with WF 250x125

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Based on the structural data from laboratory tests and the configuration of the structure in Fig. 6,7 and 8 carried out structural analysis using SAP2000 software after which a comparison of the behavior of the structure and internal and supporting forces was carried out. After that, the ratio of the maximum force on each roof truss structure to its own weight is also calculated.

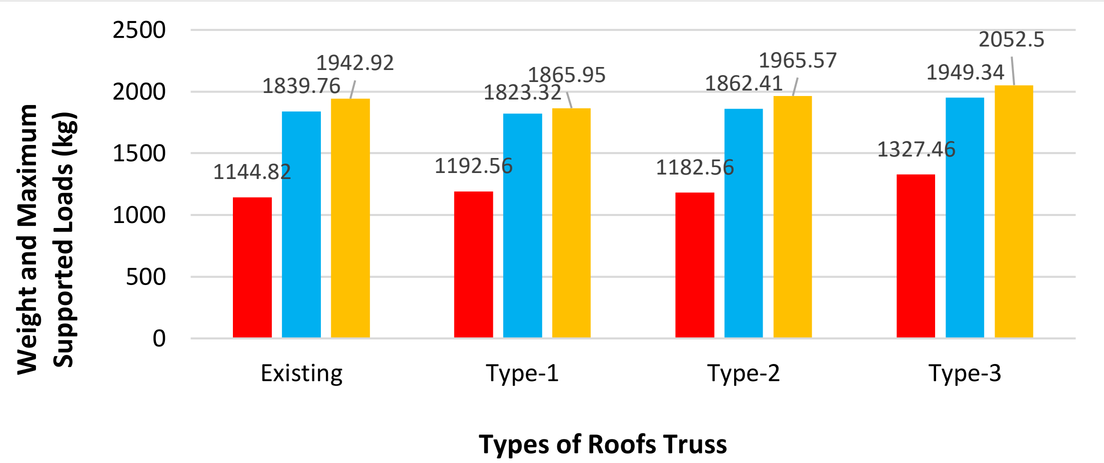

Fig. 9. Comparison of Support and Self-Weight Reactions of Each Roof Truss Structure

Table 5. Comparison of Structural Behavior of Various Roof Truss Structures

Codes	*Horizontal Deflection (mm)*	*Vertical Deflection (mm)*	*Maximum Member Force (kg)*	*Selfweight of Roof (kg)*	*Force To Weight Ratio*	*Roofs Structure Criteria*
Existing	0.404	0.732	1,424.85	1,191,42	1.196	Existing timber
Type 1	17.541	1.576	2,298.2	1,192.56	1.927	Double angle
Type 2	0.227	0.234	1,475.85	1,182.56	1.248	WF 250x125
Type 3	0.359	0.494	1,445.09	1,327.46	1.089	Retrofit timber

4. Conclusions

Field assessment showed the failures of timber roof trusses at the joints. Insufficiency connector at the joints caused shear failure on members within tension load. The member within lateral load caused lateral deflection at the joint. At the region Roof to Wall Connections (RWCs) the horizontal deflection happens. Retrofitted these timber roof trusses due to added connectors at the joints, and many connectors will be recommended for these timber roof trusses likely double and triple steel grip connectors.

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Alternative redesign for the roof structure to develop a resistant earthquake building in the future. A Gable frame with WF 250x125 and double angle 70x70x6 has been analyzed for the alternative redesign**.** The ratio of maximum member force to selfweight showed 1.196; 1.927; 1.248 and 1.089 for the existing timber roof truss, double angle roof truss, gable frame roof structure and retrofitted timber roof trusses respectively.

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