The Stability of Banjar Traditional House "*Bubungan Tinggi*" Roof Truss Structure

Miftahul Iman[1*], Muhammad Yusuf Amir[2], Aminullah[3], Fitriansyah[4], Dewi Sulistyorini[5]

[1]Civil Engineering Departement, Universitas Borneo Tarakan, Indonesia
[2]Civil Engineering Departement, Universitas Muhammadiyah Palu, Indonesia
[3]Civil Engineering Departement, Universitas Nahdlatul Ulama Banjarmasin, Indonesia
[4]Civil Engineering Departement, Universitas Achmad Yani Banjarmasin, Indonesia
[5]Civil Engineering Departement, Universitas Sarjanawiyata Tamansiswa, Indonesia
**Corresponding author: Email: miftah@borneo.ac.id*

ABSTRACT
Banjar traditional house architectural had been identified by symbolization that was emphasized on roof truss structure, ornamental style, decorative and symmetrical. Since 1871-1935 Banjar traditional house had been populer in Borneo people environmental. *Bubungan Tinggi* was one of the famous Banjar traditional house. Considering the geometric and the durability of the material the roof truss structure of *Bubungan Tinggi* should be evaluated in strength design and buckling capacity. This research investigated the strength and stability of the Bubungan Tinggi roof truss structure by performing the numerical analysis that were based on finite element method. Several idealization had been developed in this research such in 2D truss and 3D solid element by conducting some numerical software analysis then to be compared. The direct symmetrical property had been involved by introducing the material nonlinearity. Furthermore in buckling analysis, the 3D solid had been run in eigen value analysis. The results showed that the Bubungan Tinggi roof truss structure strong enough for supporting the loads. The result also showed the chord of the roof truss structure had high vulnerability in buckling failure. More stiffener member had been recommended to avoid the buckling failure occurred immediately.

Keywords: *Banjar, House, Seismic, Traditional, Truss*

1. INTRODUCTION

The Banjar traditional house as an heritage building architectural of Banjar ethnics. They had been identified by symbolization that was emphasized on roof truss structure, ornamental style, decorative and symmetrical. Since 1871-1935 Banjar traditional house had been populer in Borneo people environmental. *Bubungan Tinggi* was one of the famous Banjar traditional house (Figure 1). Considering the geometric and the durability of the material the roof truss structure of *Bubungan Tinggi* should be evaluated in strength design and buckling capacity. This research investigated the strength and stability of the *Bubungan Tinggi* roof truss structure by performing the numerical analysis that were based on finite element method.

Figure 1. *Bubungan Tinggi Banjar* traditional house

Manthani & Fauzan [1]had been modeling the traditional house “Rumah Gadang” using SAP2000 v14. The results showed that buckling does not occur when the ultimate compressive force carried on. The maximum deflection occured on the member of roof 1.08 cm because the cross-sectional height of the roof is smaller than the cross-sectional width.

Suwantara and Suryantini [2] had performed numerical modeling of the structure of Ammu Hawu, a traditional house with Lontar (Borassus flabelifer) wood structure. The results of the analysis showed that the deformation that occured exceeds the performance of the service limit, but had not exceeded the performance of the ultimate limit required by the Indonesian earthquake regulations, the structural performance had been considered in good because the internal forces that was occured in the structural elements are smaller than the compressive strength of Lontar wood. (failure) after performing numerical analysis with time history earthquakes.

Yosafat & Palapessy [3] had been conducted the experimental test for Bending strength and modulus of elasticity laboratory for Ulin (Eusideroxylon Zwageri) timber based on ASTM D143. The results showed that Fb 52,45 MPa (standard deviation 226.34 MPa and coefficient of variation 25,40%), MoE 5573,79 MPa, and MoR 85,92 MPa (standard deviation 112.55 MPa and coefficient of variation 7.71%).

Miftahul et.al [4] had performed numerical modeling of pitting corrosion effect on the tubular compression member platform structures when a protective coating is damaged. The results showed that: (a) the presence of cutout reduced the buckling load significantly, (b) the reduction ranging from 3% to 10% depending on the hole positions, (c) the maximum reduction occurs when the hole position was in the middle of the member length, (d) compared to experimental results, the critical buckling load obtained from buckling analysis deviated 1~4% while those of nonlinear analysis deviated 1~5%, (e) the buckling mode corresponded with member bent away to opposite side of the cutout position.

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \quad (1)$$

The elastic buckling theory formula had been introduced by Leonhard Euler (1718-1781) as shown as in Equation 1. The critical load (P_{cr}) was indicated buckling load. The bending stiffeness (*EI*)and effective length (*KL*) had been considered in this formula, where *K* had been defined as boundary coefficient (K = 1 for simply supported)

1. METHODS

Several idealization had been developed in this research such in 2D truss and 3D solid element by conducting some numerical software analysis then to be compared. The direct symmetrical property had been involved by introducing the material nonlinearity. Furthermore in buckling analysis, the 3D solid had been run in eigen value analysis.

The Banjar traditional house roof truss structure *Bubungan Tinggi* had been considered in this research. (Figure 2). The geometric properties of the member had been determined (Table 1). *Ulin* timber had been selected as truss structure material. The ulin material properties can be shown in Table 2.

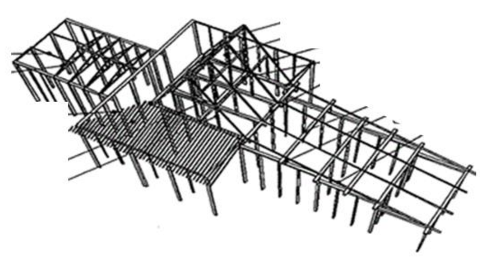

Figure 2. *Bubungan Tinggi* truss prototype

Figure 2 showed *Bubungan Tinggi* truss structure prototype that was modelled in 2D and 3D truss idealization (Figure 3). Truss modelling utilized SAP2000 version 11.00 in static load analysis case. The load combination had been determined 1,2*D* + 1,6*L* where *D* and *L* had been defined in dead and live load.

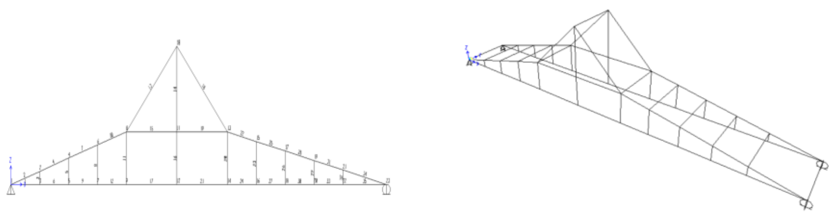

Figure 3. ***Bubungan Tinggi*** **truss model**

The truss idealization had been conducted to find out the largest axial compression load. Based on gravity load the compression member of truss structure can be identified. The purlin member had been idealized in 3D frame element (3D truss model). The single compression member also had been modelled in this research for linear buckling analysis (Figure 4).

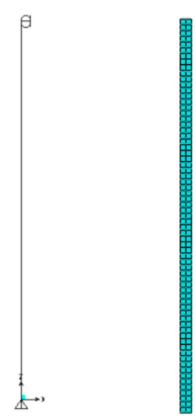

Figure 4. ***Single compression member model***

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Figure 4 showed 3D frame and 3D solid idealization of single compression member. 3D solid idealization utilized Abaqus for performing linear buckling analysis. The slenderness ratio of the member had been determined spesifically.

Table 1. Geometric properties data

Member	Dimension (cm)	Max. length (m)
Top chord	6/12	3,06 (C)
Bottom chord	6/12	3,50 (T)
Vertical chord	5/10	3,50 (C)

Table 1 showed that the major chord member of Bubungan Tinggi truss structure consisted 3 chords type: top chord, bottom chord, and vertical chord. Table 1 also showed the maximum member length was 3,50 m and it had been identified as compression member. It was meant the chord member used a whole *ulin* member without any connection spot (L = 4,00 m).

Table 2. Material properties data (*Ulin* timber)

Mechanical properties	value
Modulus of elasticity, E (MPa)	10560
Poisson's ratio, v	0,24
Bulk modulus (MPa)	6769,2
Shear modulus (MPa)	4258,1
Compressive ultimate strength (MPa)	22,56
Compressive yield strength (MPa)	17,45
Tensile ultimate strength (MPa)	25,38

Table 2 showed the mechanical properties of *Ulin* (*Eusideroxylon Zwageri*) timber. The mechanical properties had been input for material type for 2D or 3D truss modelling even 3D solid idealization modelling. Table 2 also showed the compressive and tensile ultimate strength of *Ulin* timber. Furthermore, this number had been used for compressive and tensile member design.
Finally, the results had been compared by buckling theorithical theory Euler's formula (Equation 1). The critical load (P_{cr}) also verified by numerical finite element analysis (3D frame and 3D solid idealization). Potential buckling failure had been evaluated by comparing the normal compressive load and the critical load number that was achieved. All step procedure haan been described in research flow chart (Figure 5).

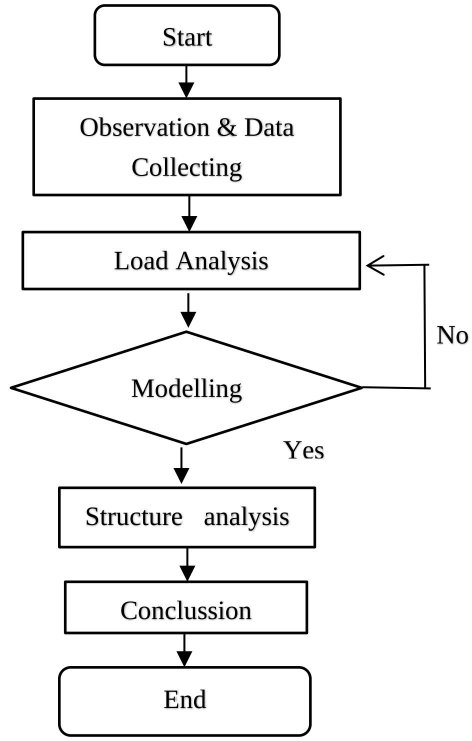


Figure 5. Flow chart

2. RESULTS AND DISCUSSION

2D and 3D Truss Model

Based on the static load analysis case results the member type could be identified based on Normal Force Diagram (Figure 6). Top chord member had been identified as compression member. Conversely, the bottom chord had been identified as tension member. The normal load that was occurred in truss structure system had been caused by gravity load combination (1,2*D* +1,6*L*).

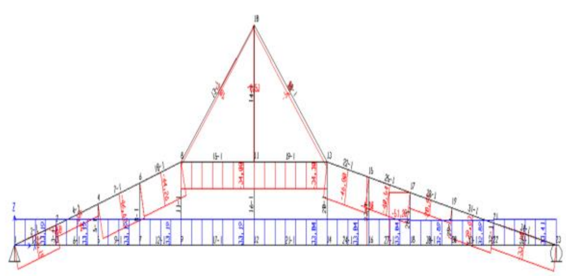
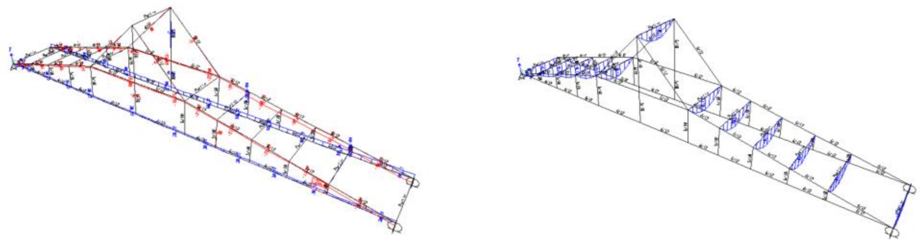


Figure 6. Normal force diagram

Figure 6 also showed that vertical and diagonal chord member had been identified as compression member. Some vertical chord member had not any normal load was carried on. It was meant some vertical chord member had been used as stiffener of the truss structure system.



(a) (b)

Figure 7. Normal force diagram (3D case)

Similarly 2D truss model, the 3D truss model also showed normal force diagram (Figure 7a). The normal load had been caused by gravity load that was carried on every node of the truss structure. The bending moment diagram could be shown only on the purlin member. There was not any bending action occurred on the chord member because the truss structure system only accommodate the normal (axial) load such in: compression and tension load. This research emphasized on compression member that was potentially had buckling failure.

Table 3. Maximum compression load

Chord	Compression load (kN)	Length (m)
Top01 (34)	74,36	3,06
Bottom (15-19)	35,12	3,50
Vertical (32)	204,80	0,59
Top02 (13-18)	7,10	4,95

Table 3 showed the number of maximum member compression load. The largest compression load was occurred on vertical chord member (204,80 kN) with 0,59 m for its length. The lowest compression load was occurred on top chord member 02 (7,10 kN) with 4,95 m for its length. This top chord was characteristhic of Banjar traditional house *Bubungan Tinggi*. The angle of this chord had been determined 45^0 was more sharper than the first top chord (Top01) with 15^0 for the angle.

Table 4. Euler buckling load

Chord	P_{cr} (kN)	KL/r
Top01 (34)	96,17	88,34
Bottom (15&19)	73,51	101,04
Vertical (32)	1247,52	20,44
Top02 (13&18)	36,75	142,89

Table 4 showed the number of critical load (P_{cr}) that was achieved by the member based on Euler linear buckling theory (Equation 1). The lowest critical load had been achieved by top chord (Top02; 36,75 kN). Hence the top chord (Top02) was most potentially had buckle failure early than another chord member. Table 4 also showed the slenderness ratio (KL/r) of the member chord. The highest KL/r number was denoted on Top02(13-18; 142,18). Based on this number the Top02 (13&18) had been classified as slender member. The slenderness ratio had significant effect on buckling failure.

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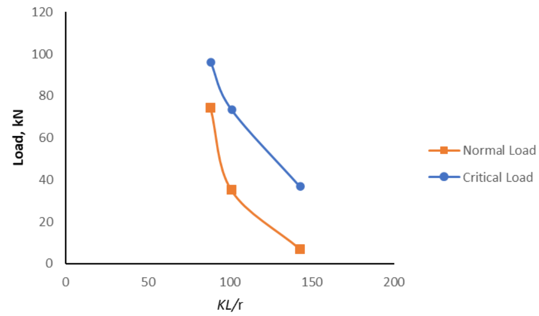


Figure 8. Critical load vs normal load

Figure 8 showed the comparison between critical load and normal load curve due to the slenderness ratio (*KL*/*r*). Both of them showed that the load decreased due to the slenderness ratio increased. The chord member that were compared had similar area (6/12) but had different length. Figure 8 also showed that critical load number larger than the normal load of the chord member. The bucling failure had not occurred on the chord member because the maximum normal load had carried on the chord member early (material failure) theorithically.

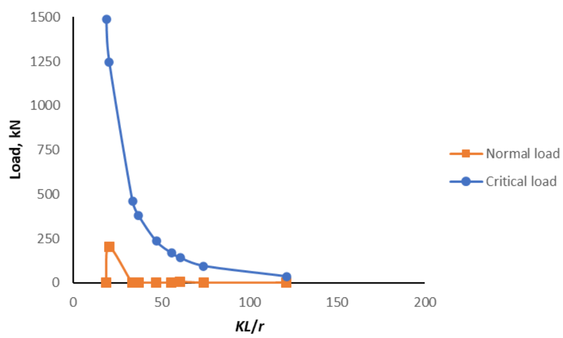


Figure 9. Critical load vs normal load (vertical chord member)

In another hand, vertical chord had various slenderness ratio. The lowest critical load had been achieved by V14 (35,45 kN). This member had highest slenderness ratio (121,24) that was caused the member potentially had buckle early. However, based on static load analysis case results the maximum normal compressive load was occurred on the member lower (0,35 kN) than buckling load (35,45 kN). It was indicated there was no buckling failure was occurred on the vertical member (Figure 9).

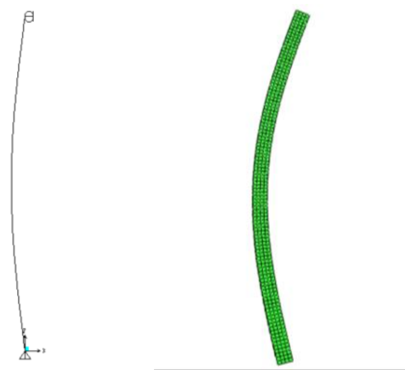
Numerical Verification

The numerical verification had been conducted in this research by performing linear (eigen value) and nonlinear buckling analysis for some single compressive member (top and vertical chord member). The numerical model had been performed in 2 model idealization: 2D truss and 3D solid. The member model that was choosen had highest slenderness ratio.

Table 5. Eigen value buckling analysis

Member	Eulr	FEA (eigen value)	
		2D truss	3D solid
A34	96,17	95,81	90,05
A15&19	73,51	73,30	68,87
A13&18	36,75	36,70	34,46

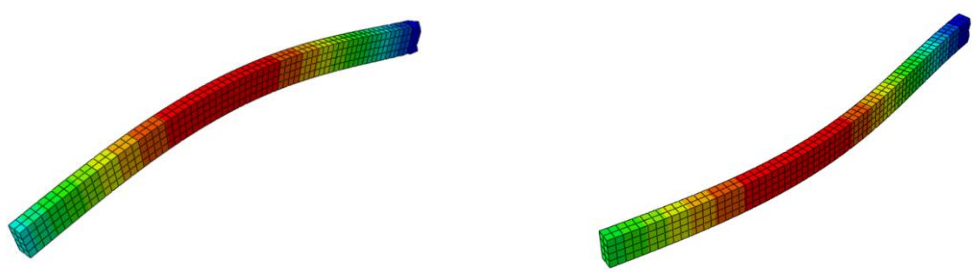
Table 5 showed the numerical verification by eigen value buckling analysis. The lowest critical load (P_{cr}) had been selected in this research. Table 5 also showed that numerical results (2D truss and 3D solid) had comfirmed the theorithical linear buckling analysis (Equation 1).



2D truss 3D solid

Figure 10. Buckling pattern at first mode

Figure 10 showed the buckling pattern of 3D single compression member of *Bubungan Tinggi* truss structure. The buckling pattern had been recognized in first mode. This buckling pattern was similar with the theorithical buckling pattern (single curvature). Figure 10 also showed buckling pattern of 2D truss single compression member idealization. Similarly 3D solid idealization the buckling pattern of 2D truss also satisfied the buckling pattern theorithic (single curvature).



out of plane in-plane

Figure 11. 3D solid buckling pattern orientation

Figure 11 showed the 3D solid idealization buckling pattern respectively: out of plane buckling and in-plane buckling. The buckling pattern orientation had been caused by the presence of strong or weak axis. It was indicated by radius of gyration (r). The lower number of r caused the member buckle in this direction (axis). The radius of gyration itself was a function of moment of inertia (I) and cross section area of the member (A). conversely in 2D problem the out of plane buckling had not occurred because the degree of freedom in this axis was inactive.

Table . 6 Critical stress Mpa

Member	Yield stress	FEA (nonlinear)	
		2D truss	3D solid
A34	17,45	13,31	12,51
A15&19	17,45	10,18	9,57
A13&18	17,45	5,10	4,79

Table 6 showed the numerical numerical critical stress by eigen value buckling analysis. The lowest critical stress (F_{cr}) had been selected in this research (A13&A18; 4,79 MPa). Table 6 also showed that critical stress was lower than yielding stress of *Ulin* timber. That was meant the buckling failure was occurred before the material had its yielding stress.

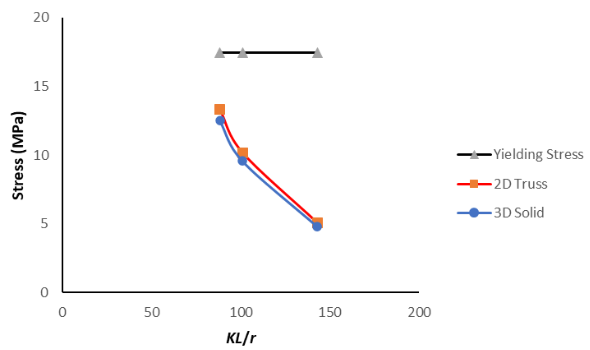


Figure 12. Stress versus slenderness ratio

Figure 12 showed the comparation of stress versus slenderness ratio (*KL*/*r*) curve. Based on the curve the numerical critical stress curve decreased due to the *KL*/*r* increased. The buckling failure potentially was occurred at the lowest critical stress (4,79 MPa). Figure 12 alo showed that the critical stress was lower than the yielding stress. It showed that the buckling failure was occurred in elastic linear curve of Ulin timber material properties. The percentage critical stress on the yielding stress correspondently: 70,79% (2D truss) and 72,57% (3D solid) for the lowest critical stress.

3. CONCLUSION

The results showed that the Bubungan Tinggi roof truss structure strong enough for supporting the loads. The result also showed the chord of the roof truss structure had high vulnerability in buckling failure. More stiffener member had been recommended to avoid the buckling failure occurred immediately.

1. Generally the roof truss structure of Banjar traditional house Bubungan Tinggi strong enough for supporting the limit load was carried on (ulin)
2. Some compression load member potentially had buckling failure (geometrical failure) especially in case of truss top chord.
3. The numerical buckling analysis model used different element (2D truss, 3D truss, and 3D solid) satisfied the Euler buckling theoretic formula.
4. The percentage critical stress on the yielding stress correspondently: 70,79% (2D truss) and 72,57% (3D solid) for the lowest critical stress.
5. The top chord member potentially get buckle failure early do to the wood strength class decreased

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