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Stiffness Improvement of Corrugated Metal Roofs through Cross-Sectional Geometry Modification

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Abstract
Nowadays, many Indonesians commonly use metal trapezoidal corrugated roofs for their residential needs. Nevertheless, the roofs often deformed or failed due to heavy rains or storms, especially in tropical regions like Indonesia. Therefore, a new model was investigated and proposed in this research to enhance the stiffness-to-weight ratio of the roofs. Computational simulation was conducted to compare the existing and the proposed model of the roofs. The addition of some small folds in certain positions successfully increases the stiffness-to-weight ratio of the roof by 11.58% compared to the existing model.

1 Introduction

Metal trapezoidal corrugated roofs is one of the most popular types of roofing in Indonesia for various applications in residential areas, including canopies, garages, and the main roof of a house [1]. The popularity of the roof is because it is easier to install, lighter, and cheaper compared to tile and slate roofs. Moreover, metal corrugated roofs are known to be more durable than polycarbonate, zinc, or UPVC roofs [2]. Not only that, but the production process of the roof is also relatively simple and easy to scale up the production capacity [3].

Although it is popular, metal corrugated roofs have a main weakness in their inability to withstand loads of heavy rain and storms in tropical regions like Indonesia, which is causing some deformation or failure in the roof [4]. The failure commonly occurred in the roof, which is applied for low slope roofs, like canopies. In practice, the construction workers reduce the span between roof supports to avoid this failure. But this approach increases the material usage to accommodate the additional structure and make the metal corrugated roof less economical.

One of the solutions to increase the roof stiffness without significant addition of material usage is by modifying the cross-sectional geometry [5]. This method aims to eliminate the need for additional structure so the roofing system would still be economical. The main challenge, besides maintaining adequate draining performance, is to ensure that the stiffness-to-weight ratio of the modified roof cross-sectional design is better than the existing design.

The common method used by roofing industries to enhance roof stiffness is by adding localized folds at specific locations. However, the corrugated roof designs from different manufacturers are typically not interchangeable. Therefore, this research aims to investigate and propose a new cross-sectional geometry model of the metal corrugated roof which improves the stiffness-to-weight ratio, enabling the new roof model to withstand more load while maintaining material usage and compatibility with existing roof design.

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2 Research Methods

2.1 Product Design Specification

The design process commenced with the definition of user specifications for the metal trapezoidal corrugated roof. The new model of metal trapezoidal corrugated roof must meet the following requirements:

1. The thickness of the roof sheet shall be 0.42 mm.
2. The effective width of the roof shall be 760 mm.
3. The overall height and width of the roof's hill and valley shall be the same as the existing roof design.
4. The roofing material shall utilize a G550-grade metal base, in accordance with applicable standards.
5. It must possess sufficient strength and stiffness to function as a roof structure with internal purlin spacing of up to 1.2 meters.
6. It must exhibit an increase in stiffness of at least 10% compared to the existing model.

2.2 Simulation Environment

Subsequently, a simulation environment was developed using Free-CAD, incorporating loading parameters, boundary conditions, and support types [6]. Figure 1 illustrates the free-body diagram used in the computational analysis. The roof model is supported at both ends using simple pinned supports. The load is modeled as a uniformly distributed load representing the effect of rainfall. The magnitude of the applied load on the roof is 25 kg/m^2 [7], or 245.25 N/m^2.

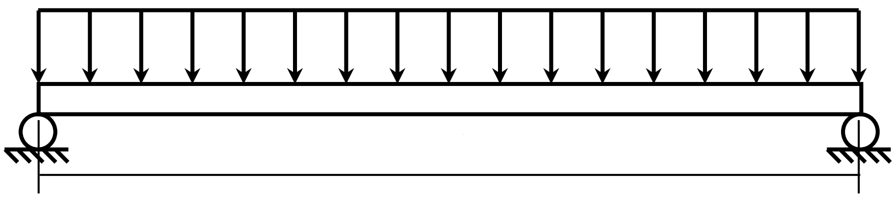


Figure 1. Free body diagram of the computational analysis model

2.3 Validation

The validation of this research was conducted using a simplified geometry, and the results were verified through analytical calculations to ensure the accuracy of the numerical model. An analytical calculation was performed based on the free-body diagram illustrated in Figure 1, assuming a simply supported beam with a rectangular cross-section measuring 760 mm in width and 5 mm in thickness. The mechanical properties of the material are listed in Table 1. The beam was subjected to a uniformly distributed load, and the maximum deflection was calculated using classical beam theory, as expressed in Equation (1) [8]. This calculation resulted in a maximum deflection of 3.19 mm.

$$\delta_{max} = \frac{5wL^4}{384\,EI} \quad (1)$$

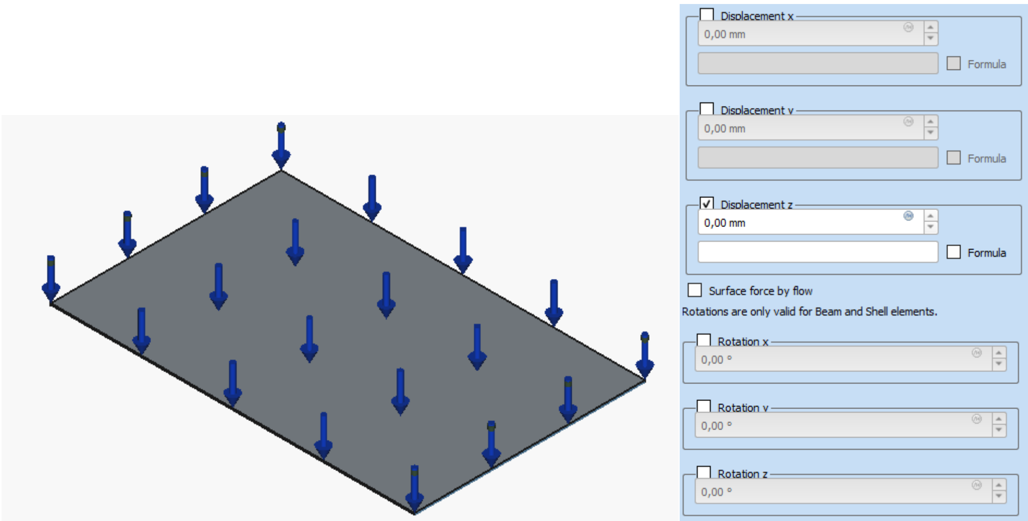
where,

δ_{max} : maximum deflection (m)
w : distributed load (N/m)
L : span length (m)
E : elastic modulus (Pa)
I : moment of inertia (m^4)

On the other hand, a computational simulation was conducted by applying a uniform pressure load of 245.25 N/m² on the top surface of the beam. To replicate the simply supported condition, boundary constraints were applied at both ends of the beam by restricting translation in the z-direction only, as shown in Figure 2, while allowing free movement in other translational and rotational directions. Under this simulation setup, the resulting maximum deflection along the z-direction was found to be 3.28 mm, which closely matches the analytical result with a deviation of only 2.98%. Therefore, the simulation is valid [9].

Table 1. Mechanical Properties of the material [7]

Propertes	Value
Steel Grade	G550
Yield Strength (MPa)	550
Ultimate Tensile Strength (MPa)	550
Density (kg/m^3)	7400
Elastic Modulus (GPa)	200
Shear Modulus (GPa)	80
Poisson Ratio	0,3



(a) (b)

Figure 2. (a) Load and (b) boundary constraints of the computational simulation

2.4 Design and Evaluation

A commercially available trapezoidal metal corrugated roof profile, as illustrated in Figure 3, was then subjected to reverse engineering and evaluated under certain load conditions via computational analysis. Based on the analysis, a new model of cross-sectional geometry was developed iteratively, as shown in Figure 4, by adding small folds in regions exhibiting high deflection in the previous simulation, while maintaining product specification. The fold was added at the region with high deflection based on the simulation of existing design. This design was selected because the addition of local folds in high-deflection areas could increase the local moment of inertia thereby enhancing stiffness without significantly increasing the material usage [10]. The revised model was then evaluated under the same computational conditions, and its performance was compared with the existing model to assess improvements in stiffness-to-weight ratio.

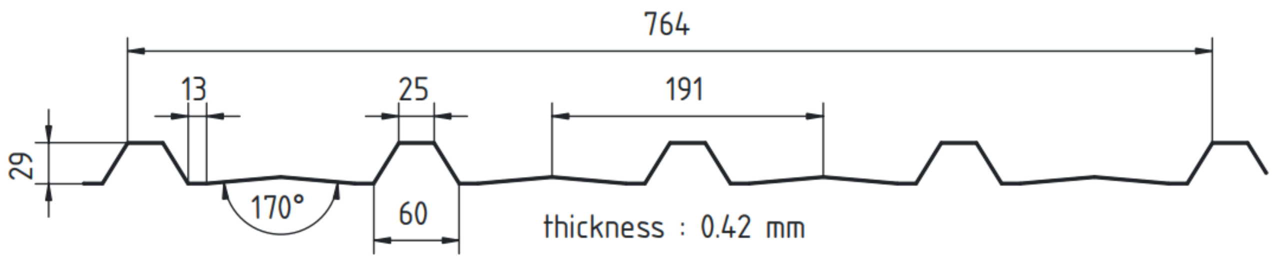


Figure 3. Existing cross-sectional geometry of trapezoidal corrugated roof

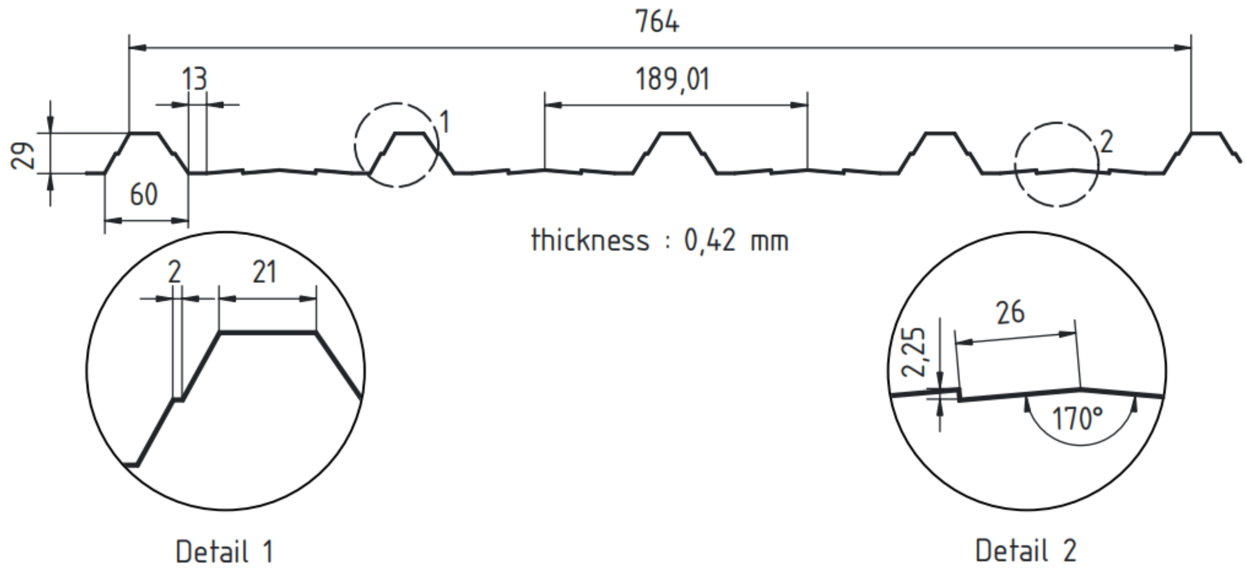


Figure 4. Proposed cross sectional geometry of trapezoidal corrugated roof

3 Result and Discussion

The existing cross-sectional geometry of the trapezoidal corrugated roof with a thickness of 0.42 mm is illustrated in Figure 3. The geometry was modelled using Free-CAD software by sketching the cross section and applying an extrusion operation to generate the full roof sheet model. Subsequently, the loading conditions and boundary constraints were applied in accordance with the free body diagram presented in Figure 1, following the same simulation setup as described in the validation section. Upon completing the computational simulation, the resulting maximum deflection along the z-direction was found to be 0.95 mm, as shown in Figure 5.

Based on the results obtained above, a modified cross-sectional geometry of the trapezoidal corrugated roof was proposed. The primary strategy to reduce maximum deflection is to increase the structural stiffness, which can be achieved by enhancing the moment of inertia of the cross-sectional area. While increasing the material thickness or the hat height of the profile can improve stiffness [11], such approaches tend to raise material usage inefficiently. Therefore, introducing localized folds at specific positions—illustrated in Figure 4—serves as an effective method to increase the moment of inertia without significantly increasing the material consumption [10].

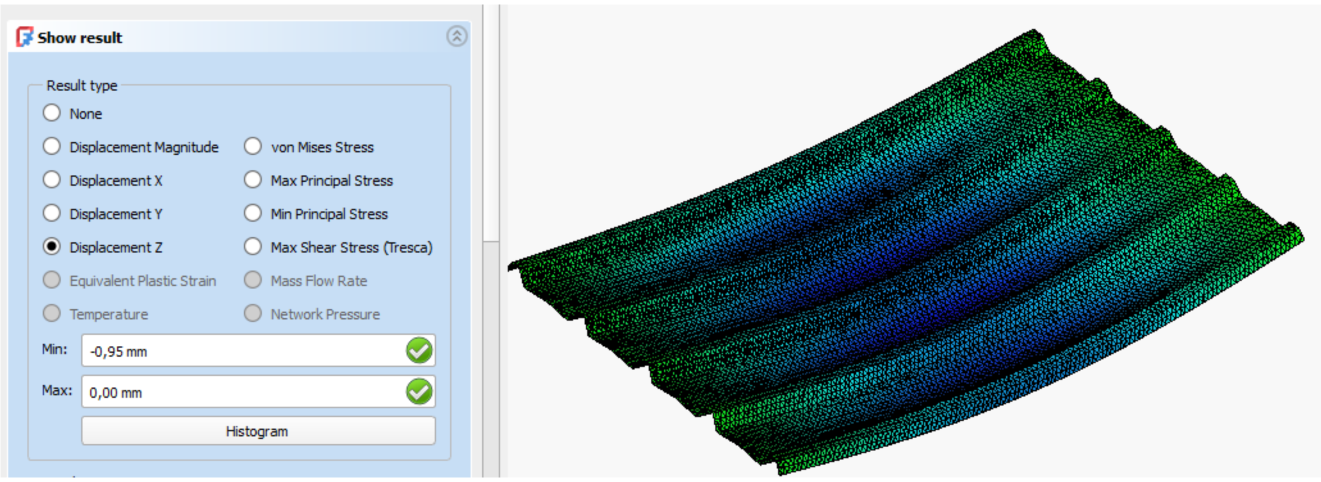


Figure 5. Simulation results of existing trapezoidal corrugated roof

The proposed geometry was subsequently modelled and simulated using Free-CAD software, following the same simulation procedure as described previously. The results show a significant reduction in maximum deflection along the z-direction, decreasing by 11.58% to 0.84 mm, as shown in Figure 6. This improvement was achieved with only a 1.36% increase in material usage. Furthermore, the structural performance was increased by 13.10% improvement in the stiffness. A detailed comparison between the existing and proposed models is presented in Table 2.

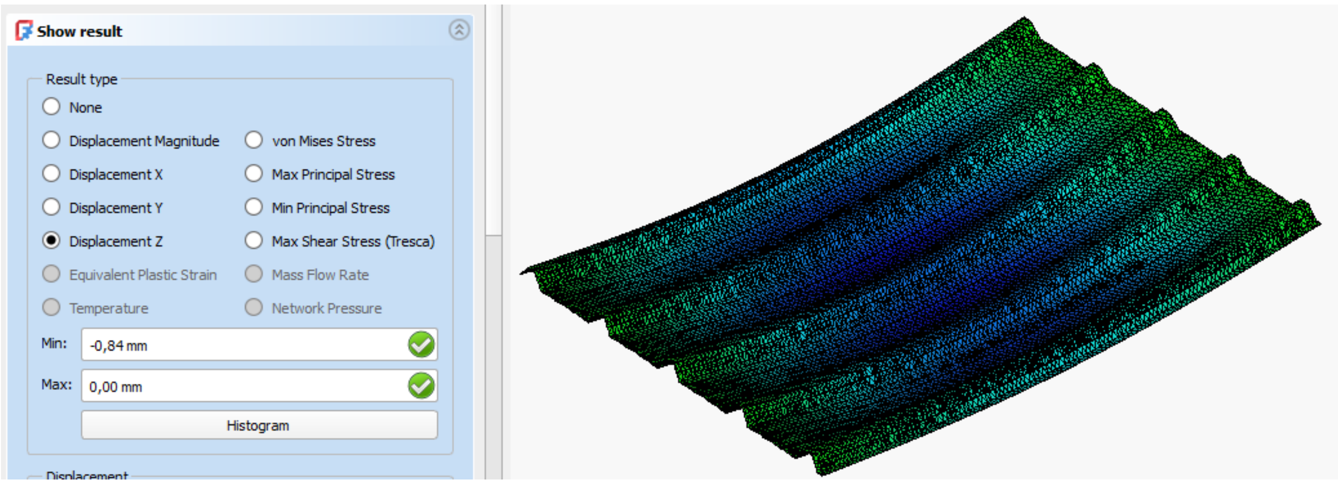


Figure 6. Simulation results of proposed trapezoidal corrugated roof

Table 2. Detailed comparison of existing and proposed model

Properties	Existing	Proposed	Improvement
Maximum deflection (mm)	0.95	0.84	11.58%
Stiffness (Nm^2)	6970.26	7883.04	13.10%
Weight (kg)	3.69	3.74	-1.36%
Stiffness-to-weight ratio (Nm^2/kg)	1888.96	2107.76	11.58%

These improvements are due to the increase in the load-carrying capacity and transverse shearing rigidity on the proposed model [11]. Both properties significantly affect the stiffness of a structure subjected to bending moment load. The folds at the appropriate location could act as a stiffening ribs and limit both lateral and vertical deformation. This modification could enhance the stiffness-to-weight ratio of the structure.

4 Conclusion

This research successfully proposes a new cross-sectional geometry for a trapezoidal corrugated metal roof with an 11.58% improvement in stiffness-to-weight ratio. The results confirm that modifying cross-sectional geometry by adding small folds at specific locations can significantly improve the stiffness without substantially increasing material usage. It is hoped that these findings will contribute to the further improvement of design practices in related industries.

Furthermore, this study demonstrates the potential benefits of using computational simulations to modify and evaluate the roof geometry prior to fabrication. The iterative approach of developing the new geometry model of the roof could help identify an optimum model that achieved the expected stiffness-to-weight ratio. Future research may focus on evaluating the proposed model under real loading conditions and considering manufacturing constraints to ensure the proposed model is feasible for large industrial scale.

References

1. S. Tiwari, K. Roy, Z. Fang, and J. B. P. Lim, “Metal roof cladding system under wind loading: State-of-the-art,” *J. Wind Eng. Ind. Aerodyn.*, vol. 257, p. 105939, 2025, doi: 10.1016/j.jweia.2024.105939.
2. I. Qiram and G. Rubiono, “Pengaruh sudut kemiringan atap seng dan plastik gelombang terhadap tingkat kebisingan akibat air hujan,” *Dinamika Teknik Mesin*, vol. 6, no. 2, 2016, doi: 10.29303/d.v6i2.12.
3. M. Alfiqzani, L. Lamatinulu, and Y. Herdianzah, “Perencanaan kapasitas produksi spandek dengan menggunakan metode rough cut capacity planning (RCCP) di PT. Sermani Steel Makassar,” *Scientica: Jurnal Ilmiah Sains dan Teknologi*, vol. 3, no. 1, pp. 1–9, 2024. [Online]. Available: https://jurnal.kolibi.org/index.php/scientica/article/view/3503
4. L. A. Welan, P. G. Tamelan, and J. J. Messakh, “Desain struktur atap rumah tinggal untuk meminimalisir kerusakan setara badai siklon tropis Seroja di Kota Kupang: Residential roof structural design to minimize damage equivalent to tropical cyclone Seroja in Kupang City,” *Batakarang*, vol. 4, no. 2, pp. 16–22, 2023.
5. D. Setyanto, “Design and FE modeling of uPVC corrugated hollow roofing sheet,” in *MATEC Web Conf.*, vol. 258, p. 01017, EDP Sciences, 2019.doi:10.1051/matecconf/201925801017
6. N. F. S. Pratama and D. D. Saputro, “Design and Validation of Horizontal Steam Retort with Capacity of 100 kg Presto milkfish Using Finite Element Method (FEM),” *Jurnal Inovasi Mesin*, vol. 6, no. 2, pp. 18–24, Oct. 2024, doi: 10.15294/jim.v6i2.12160.
7. N. V. Diredja, B. Nuranita, E. Desimaliana, and A. C. Pertiwi, “Kajian analisis perbandingan rangka atap kuda-kuda menggunakan kayu LVL dan baja ringan,” *RekaRacana: Jurnal Teknik Sipil*, vol. 7, no. 3, pp. 148–156, 2021, doi:10.26760/REKARACANA.V7I3.148
8. F. Beer, E. Johnston, J. DeWolf, and D. Mazurek, *Mechanics of materials, 8th SI Edition*.2020.
9. H. M. Silva and J. Wojewoda, “An Analytical Model for the Prediction of the Stiffness Behavior of Thin-Walled Beams,” *Engineering Proceedings*, vol. 87, no. 1, 2025, doi: 10.3390/engproc2025087015.
10. H. A. Abedzade Atar, M. Zarrebini, H. Hasani, and J. Rezaeepazhand, “The effect of core geometry on flexural stiffness and transverse shear rigidity of weight-wise identical corrugated core sandwich panels reinforced with 3D flat spacer knitted fabric,” *Polymer Composites*, vol. 41, pp. 3638–3648, 2020. doi: 10.1002/pc.25662
11. J. Papangelis, C. Li, L. Yi, and F. Yue, “Torsional restraint of roof sheeting on cold-formed steel hat sections,” *Thin-Walled Structures*, vol. 209, Apr. 2025, doi: 10.1016/j.tws.2024.112882.