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Design and Numerical Analysis of a two-passenger Electric Vehicle Chassis

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***Abstract*— This research focuses on the design and numerical analysis of the chassis structure of an electric vehicle with a two-passenger configuration. The chassis type used is a space frame. The aim is to get a strong chassis with resistance to various loads. The test method used is finite element analysis (FEA). Static and dynamic analysis is used to assess the performance of the chassis structure, which is obtained through numerical simulations in ANSYS software. Static analysis is used to obtain maximum von Mises stress, strain, and safety of factor values for the chassis. Dynamic analysis is applied in modal analysis to determine the natural frequency and behaviour of vibration modes. Material variations, namely Al 6061 and AISI 1018, are applied to the chassis structure. The results of the static analysis show that the chassis structure using AISI 1018 material experiences an increase in the safety of factor and maximum von Mises stress values as well as a decrease in the maximum strain value along with an increase in the tensile strength value of the material. The chassis structure using AISI 1018 material shows that the maximum deformation value in each shape mode has decreased. In the future, this chassis can be used experimentally in low-scale production for academic needs.**

***Keywords*—**Chassis, Space Frame, Static Analysis, Modal Analysis

I. INTRODUCTION

The chassis is the main structural frame of the vehicle, on which the vehicle body, engine, suspension system and other components are installed. It provides the foundation for the overall structure of the vehicle and is responsible for supporting the weight of the vehicle, transmitting engine power to the wheels, and absorbing road shocks and vibrations.[1] Strength and rigidity become essential elements in the performance assessment of the vehicle chassis structure. The performance of the vehicle chassis structure is designed to be able to withstand various loads from all vehicle components. The implementation to assess the performance of the chassis structure can use modelling and numerical analysis with finite element methods to calculate the vehicle's capabilities with changes in conditions in the vehicle chassis structure.[2]

Static and dynamic analysis is used to assess the performance of chassis structures, which are obtained through numerical simulations. The chassis structure will support the load of components and passengers, which can be analyzed using static analysis.[3] Dynamic analysis is carried out on the chassis structure of the vehicle. Because the structure of the vehicle chassis is a resonance system with an unlimited number of natural frequencies. Modal analysis can represent behaviour in the resonance region [4], so that the performance of the vehicle chassis structure can be achieved by minimizing unwanted vibrations.[5]

Kengkongan et al. [6] Create an urban vehicle chassis structure by numerical analysis modelling with finite element method. To review the strength of the chassis by performing a static analysis. Alternative urban vehicle chassis designs are modelled and simulated using different materials, different loads, and different thicknesses. With these variations, you can see the strength of the chassis structure under several conditions so that it can be safely used. Majid et al. [7] The chassis model of the vehicle is subjected to static analysis loading. Restrictions on the front axle and rear axle are fixed. Car and passenger loads are applied in vertical force (Y). The results obtained through FEA simulation are stress, deformation, and safety factors that are still in a safe state. Srivastava et al. [8] study aspects of vibration carried out using modal analysis with design changes. The material used by AISI 1018, because it has better weldability and balance between strength and ductility. Marzuki et al. [9] Focuses on the analysis of spatial frame structure design using modal analysis to determine natural shapes, modes, and natural frequency. Knowing the natural frequency and shape characteristics of the mode can be used to ensure that driving comfort avoids resonance. In addition, it can study dynamic behaviour and improve the overall dynamic response of the chassis structure.

This research focuses on designing the chassis structure of electric cars for two passengers that is strong and has resistance to various loads. Electric cars are built using the dimensions of two-passenger vehicles on the market and chassis assembled with a space frame type. The chassis design of the two-passenger electric car is a 3D model CAD

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using Autodesk Fusion 360 software. The test method used to analyze the strength is to use the finite element numerical method using ANSYS software. In the future, this chassis can be used for research materials on low-scale production for academic needs.

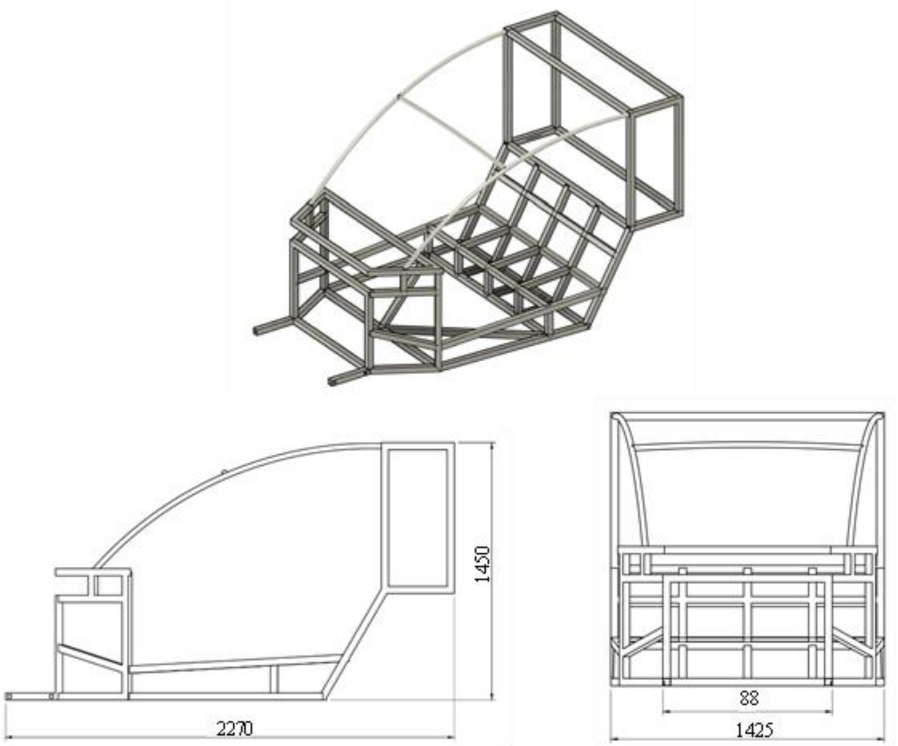

Fig. 1 Two-passenger electric vehicle chassis design

I. DESIGN

The chassis effectively acts as the basic foundation of the vehicle that protects the driver. In general, vehicle chassis is designed with durable, lightweight, and high-performance aspects in mind. Of course, driver safety increases with increasing chassis power. [8] This research aims to find the strongest chassis structure with various material selections.

A.CAD Design of Chassis

The chassis model of a two-passenger electric car is depicted three-dimensionally using Autodesk Fusion 360 software. The chassis type used is a space frame. In general, passenger cars currently use a monocoque-type chassis. Still, space frames are more suitable for use in cars with low volume production, high rigidity, lightweight, and low production investment. So that the space frame chassis type is easy to make and has good structural rigidity.[10] The results of two-dimensional and three-dimensional CAD chassis drawings can be seen in Figure 1. The main chassis is designed using rectangular hollow sections with a profile size of 40x40x2 mm, while the additional top uses pipes with a diameter of 30 mm and a thickness of 2 mm, as can be seen in Figure 3.

B. Material

The choice of material has a significant influence on the strength of the structure, so the basic properties of each material and the limitations must be understood.[10] Material properties are properties of a material that will affect behaviour when applied to loading. So, structures with different properties will have other failure behaviour even with the same loading. AISI 1018 has good yield strength and is easy to find. The Al 6061 has a low density, which is required by electric cars. The material properties used by Al 6061 [11] and AISI 1018[12] can be seen in Table I.

Table I Material properties

Property	Al 6061	AISI 1018
Density (Kg/m^3)	2700	7850
Young Modulus (MPa)	68900	200000
Tensile Strength (MPa)	310	440
Yield Strength (MPa)	275	370
Poisson's Ratio	0.33	0.29

II. METHODOLOGY

In this study, testing was carried out using finite element analysis (FEA) to evaluate the structure that has been given a force on it. ANSYS software is used to assist in simulating chassis strength against structural static analysis and chassis vibration behaviour using modal analysis. After drawing the three-dimensional geometry of the chassis on the Autodesk Fusion 360, the data was imported into ANSYS software. Modelling of element types is converted into shell elements, and mesh convergence is performed to obtain mesh sizes that are independent of von Mises stress. It was accepted that the size of the 9 mm mesh element has converged, which can be used in simulation.

A. Static Analysis

Static analysis is performed by applying static loads applied to the chassis structure. Static analysis uses FEA to investigate the response of a car chassis due to static loads, such as maximum stress, strain, and safety of factor. In static analysis using Al 6061 and AISI 1018 materials to see the

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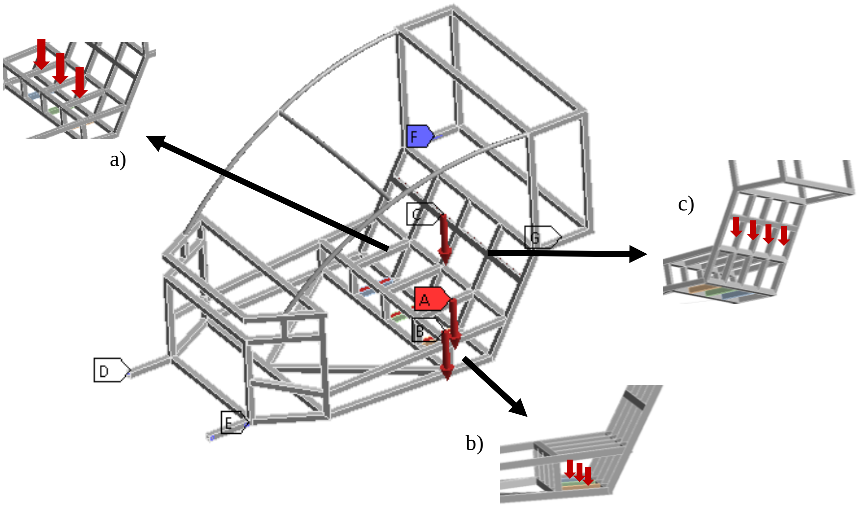

Fig. 3 Chassis structure, where d), e), f), g) is a fixed support; a) the force applied to the y-axis is -1479.2 N; b) the force applied to the y-axis is -1972 N; and c) the force applied to the y-axis of – 512.722 N

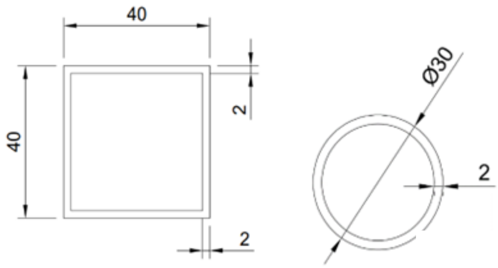

Fig. 2 Dimensions of the rod structure used on the chassis

difference in behaviour in the application of the two materials. The maximum stress displayed is von Mises stress, von Mises stress is not the actual stress but a theoretical value that gives a comparison between three-dimensional normal stress with the uniaxial stress yield limit. Strain is the ratio of deformation to length.[13] Looking at the true stress-strain curve, it shows the allowable elastic strain value in Al 6061 of a maximum of 0.02 mm/mm and AISI 1018 of a maximum of 0.05 mm/mm. Safety of factor is defined as the ratio of the maximum load failing a structural component to the permissible load under operating conditions.[14] The stress should not exceed 67% of the yield strength, so the permissible safety of factor is at least 1.5. Safety of factor is the most important factor in assessing the behaviour of the chassis.[15]

The resulting response from the analysis is maximum von Mises stress, strain and safety of factor will require processing from a set of simultaneous algebraic equations. In static analysis, this equation is an equilibrium equation of the vertices of hundreds or thousands of equations. So, static analysis requires a finite element approach to complete. Equations 1-3 are the basic formulas in static analysis calculations on a designed chassis.

Equation of von Mises stress:

$$\sigma_v = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}} \quad (1)$$

Equation of strain:

$$\varepsilon = \frac{\delta}{L} \quad (2)$$

Equation of Safety Factor:

$$n = \frac{material\ strength}{allowable\ stress} \quad (3)$$

The static load applied comes from a two-passenger load of 150 kg, an engine and transmission of 52 kg, and a battery of 200 kg. Assuming a gravitational acceleration of 9.8 m/s, using F=ma. Produces a force of 1479.2 N applied to the passenger seat, and 1972 N applied under the passenger seat. The force will be applied to the y-axis. In addition, fixed supports are applied to four shafts. There is no influence of gravity or force on the fixed support. Thus, the overall boundary conditions can be seen in Figure 2.

A. Modal Analysis

Modal analysis is used to determine the vibrational characteristics of linear elastic structures. Modal analysis is performed to determine the natural frequency and behaviour of the vibrating mode. The most important reason to know natural frequencies is to avoid resonance at specific frequencies. The deformation behaviour of the structure is observed based on the frequency value. The results of the deformation of the mode shape can be used to evaluate components, as it displays dynamic behaviour in a specific direction.

To solve the dynamic response of a structure, use the equation of motion. For modal analysis, the acceleration, velocity and displacement are unknown. For external loading, it is ignored because the natural frequency and mode shape do not depend on the load. Damping effects are neglected

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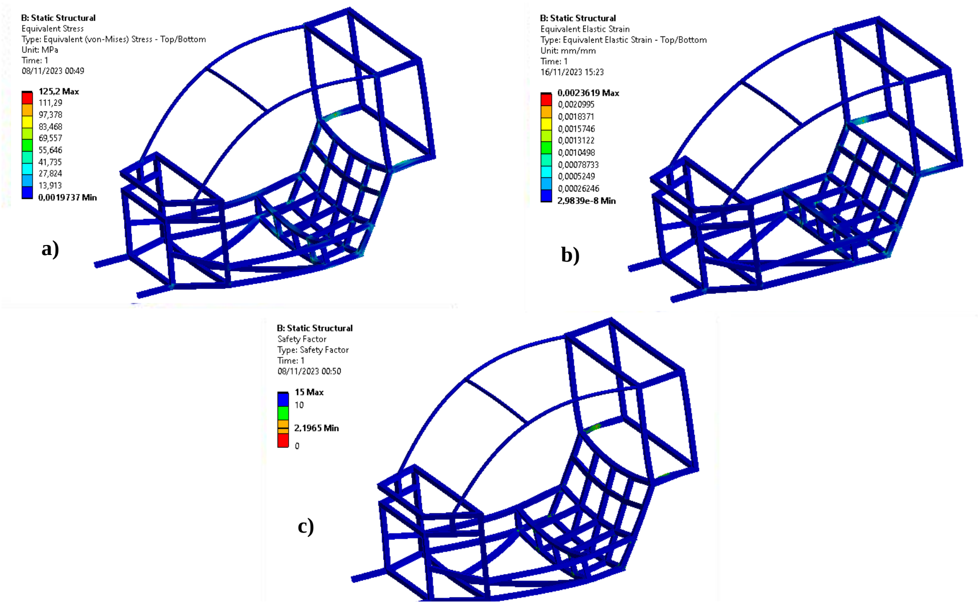

Fig. 4 Static Analysis (Al 6061), where a) von Mises Stress; b) Deformation; c) Safety of Factor

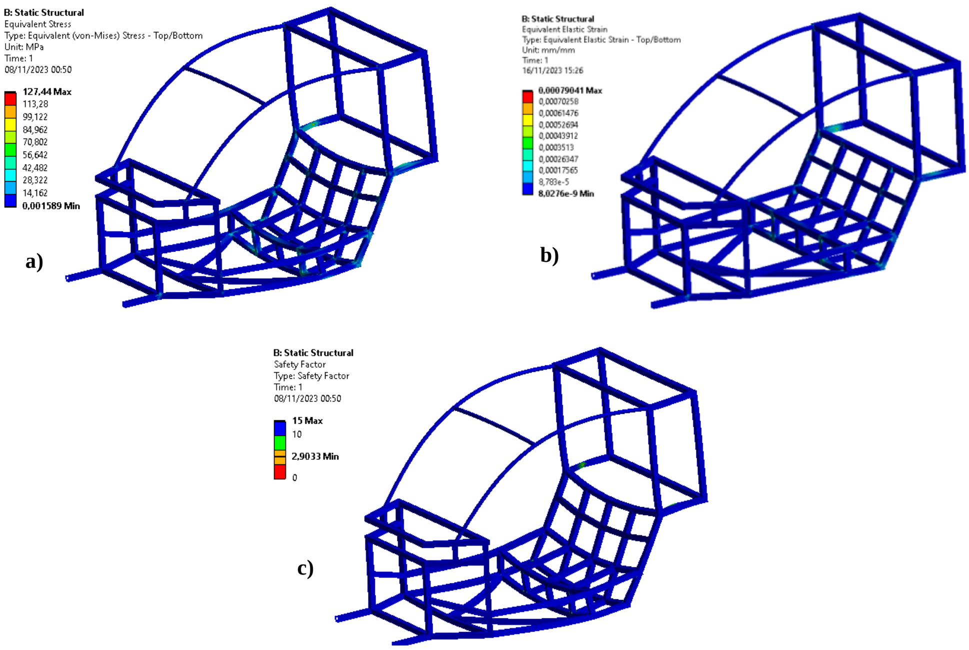

Fig. 5 Static Analysis (AISI 1018), where a) von Mises Stress; b) Deformation; c) Safety of Factor

because damping involves complex numbers to describe the natural frequencies and mode shapes. The equation of motion for the system in modal analysis can be formulated as follows:

$$[M]\{\ddot{u}\} + [K]\{u\} = \{0\} \quad (4)$$

Where M, u, and K are constants that describe the mass, displacement, and stiffness of the system. For a realistic model, K will encounter thousands or millions of DOFs, meaning it will have many natural frequencies. Not every mode participates to the same extent in the deformation of the structure under dynamic loading. The participation factor determines the number of modes and frequencies in the object.

In this study, modal analysis was carried out by extracting the first 15 modes. A review is carried out by looking at the information on the value of the participation factor ratio if there is a value close to 1 in a specific direction. Then, in that mode, there may be a resonance.[16] By applying boundary conditions in the form of fixed support on four shafts. So, there is no influence of gravity or force on modal analysis.

III. RESULT AND DISCUSSION

A. Static Analysis

The chassis of a two-passenger electric car is modelled and simulated using different materials. Based on the results of the overall simulation data on ANSYS from maximum stress, maximum strain, and safety of factor. The effect of the difference in material applied chassis structure. Based on the simulation results, the maximum stress value of 125.2 MPa

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(Al 6061), and 127.44 MPa (AISI 1018) can be seen in Fig. 5-6. The application of these two materials shows a safe limit because it is far from the maximum value based on the yield strength of 275 MPa (Al 6061), and 370 MPa (AISI 1018).

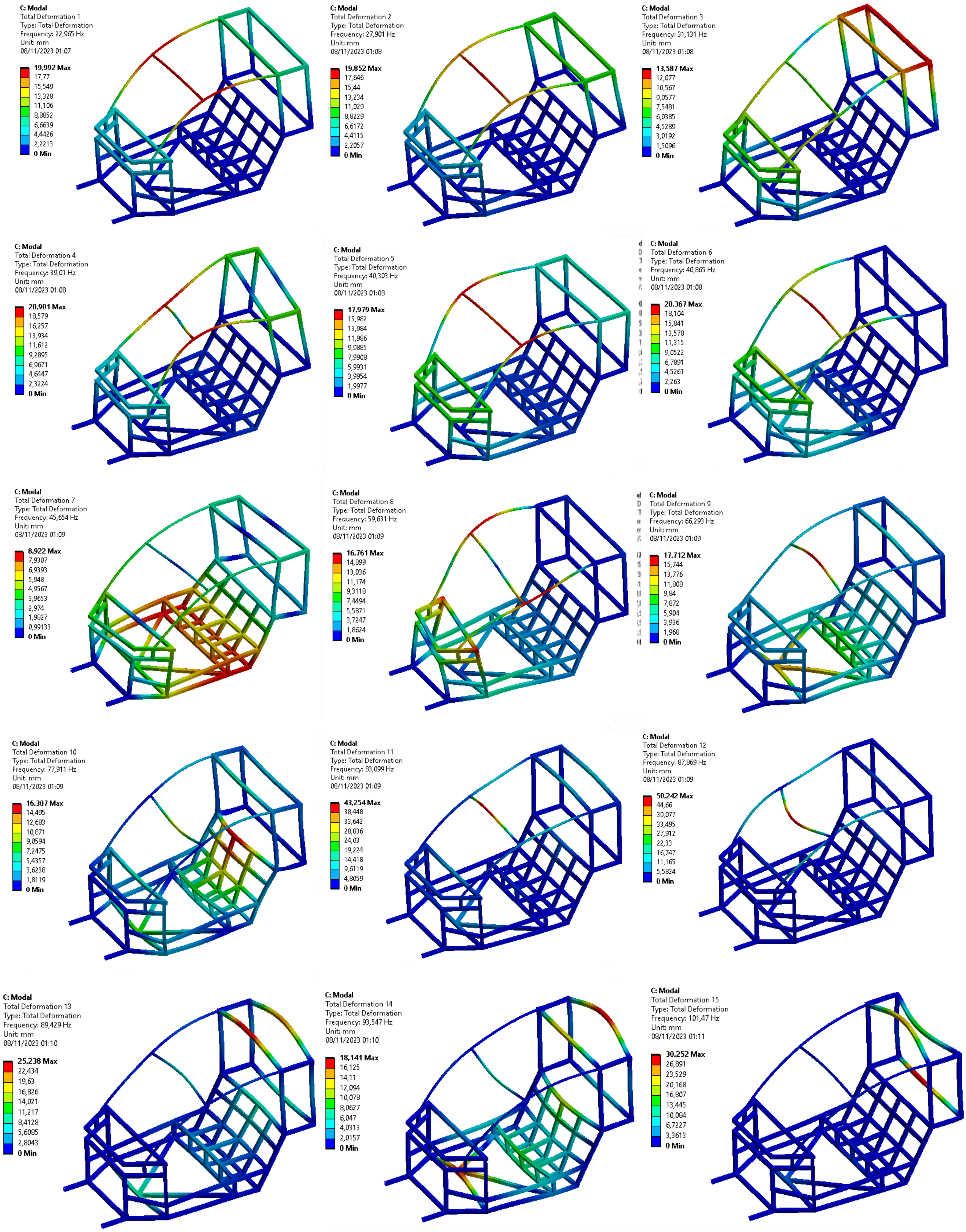

Fig. 6 Vibrational behaviour and deformation of chassis for the first 15 modes (Al 6061)

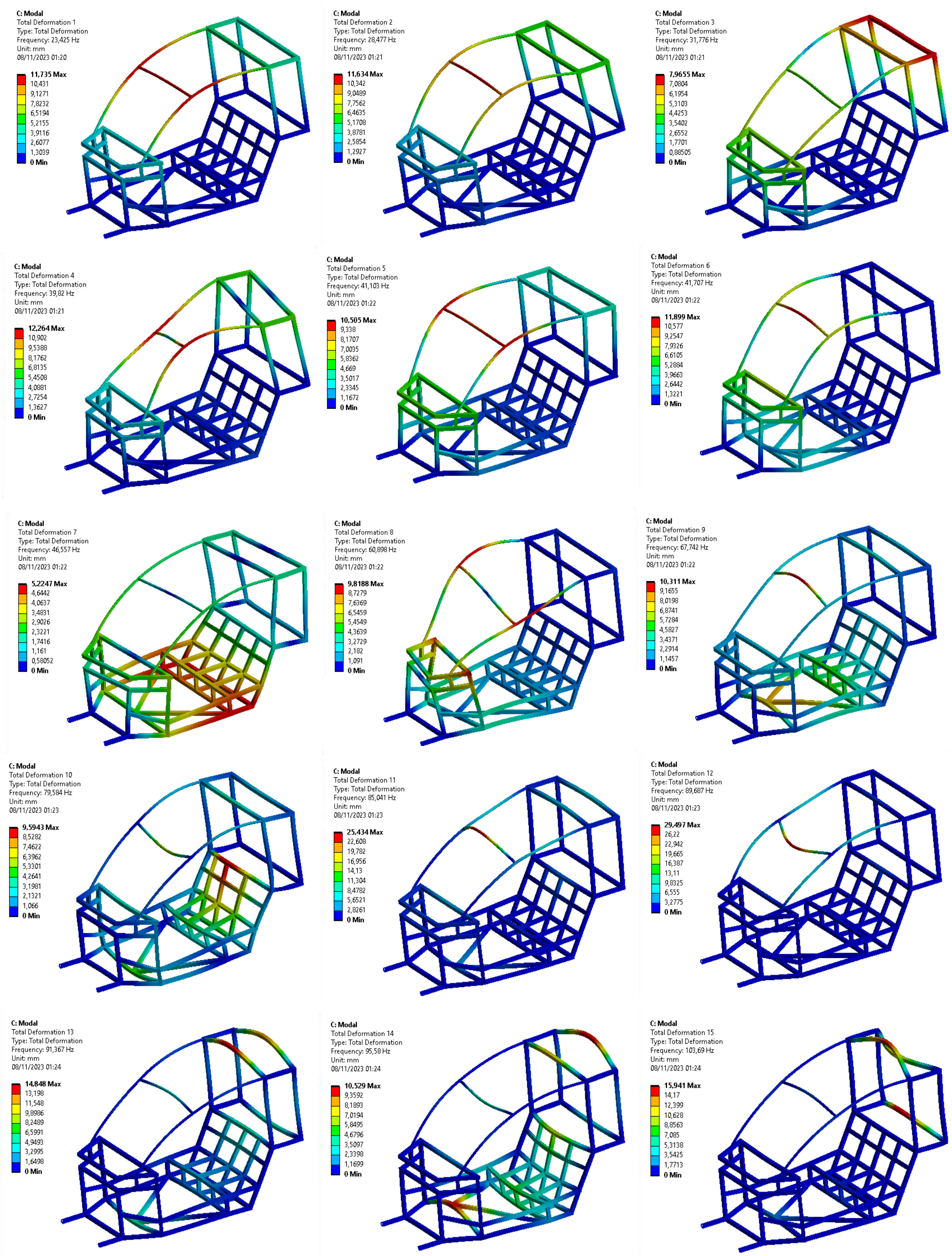

Fig. 7 Vibrational behaviour and deformation of chassis for the first 15 modes (AISI 1018)

Strains of 0.0023619 mm/mm (Al 6061), and 0.00079 mm/mm (AISI 1018) can be be seen in Fig. 5-6. The indicated strains of both materials result in permissible elasticity values of the established limits. This means that the load-affected structure can return to its original shape when the load is released. Safety factors of 2.1965 (Al 6061), and 2.9003 (AISI 1018) can be seen in Fig. 5-6. From these results, the safety of factor produces a value of more than 1.5. So that the safety of factor in both materials is acceptable. Safety of Factor can give an idea of the heaviest load a structure can withstand before failure occurs.

A. Modal Analysis

In the modal analysis, simulations were carried out using Al 6061 and AISI 1018 materials. Predict response under dynamic loading conditions. The shape mode generated from the simulation can provide information about the behaviour of the chassis structure, which will move naturally. The results of extracting the first fifteen modes obtained from simulations on materials Al 6061 and AISI 1018 do not have a factor participation value close to 1, indicating that the chassis structure has no potential for resonance, which can be seen in Table II-III.

The participant factor identifies the amount of mass moving in each direction in the form of a mode. This information is used to eliminate the number of mode forms if there is a potentially resonant structure. In addition, it needs to be traced from the mode shape, and the deformation that occurs can be seen in Fig. 6-7. The highest deformation occurs in the 12th shape of mode shapes with frequencies of 87.869 (Al 6061), and 89.687 (AISI 1018). At this frequency, it causes the highest deformation of 50.242 mm (Al 6061), and 29.497 (AISI 6061).

This phenomenon is likely that the chassis structure will experience excessive deformation and lead to failure when given dynamic loading. When there is excessive deformation due to dynamic loading caused by frequency, repairs can be made by adding a supporting structure or thickness to the structure. However, a review of the participant factor in this study shows that the overall dynamic characteristics are still considered safe for application, so resonance cannot occur. In general, the results of modal analysis are significant to know the dynamic response of the chassis structure. The results were obtained from modal analysis as initial data before being validated using harmonic response analysis and random vibration of road profile characteristics.

Table II Participant Factor (Al 6061)

Al 6061				
Mode Shape	**Frequenzy (Hz)**	**X Direction**	**Y Direction**	**Z Direction**
1	22,965	0,00010	0,00002	0,10349
2	27,901	0,08962	0,03409	-0,00005
3	31,131	-0,00031	-0,00017	-0,00691
4	39,010	-0,00019	-0,00009	-0,00051
5	40,303	-0,00061	-0,00037	-0,07969
6	40,865	-0,06140	-0,03638	0,00132
7	45,654	0,00022	0,00034	0,10312
8	59,631	-0,00010	-0,00006	0,03774
9	66,293	-0,02135	0,12929	-0,00011
10	77,911	0,07495	0,03321	-0,00003
11	83,099	0,02124	0,00242	0,00005
12	87,869	-0,01710	-0,00461	-0,00002
13	89,429	-0,02628	0,03406	-0,00005
14	93,547	0,02582	-0,00979	0,00006
15	101,470	0,00786	0,02163	-0,00002

Table III Participant Factor (AISI 1018)

AISI 1018				
Mode Shape	**Frequenzy (Hz)**	**X Direction**	**Y Direction**	**Z Direction**
1	23,425	0,00018	0,00004	0,17652
2	28,477	0,15274	0,05804	-0,00008
3	31,776	-0,00055	-0,00030	-0,01165
4	39,820	-0,00034	-0,00015	0,00080
5	41,103	-0,00100	-0,00060	-0,13687
6	41,707	-0,10489	-0,06192	0,00225
7	46,557	0,00039	0,00059	0,17525
8	60,898	-0,00017	-0,00013	0,06381
9	67,742	-0,03661	0,22051	-0,00019
10	79,584	0,12831	0,05658	-0,00006
11	85,041	0,03479	0,00465	0,00008
12	89,687	-0,02884	-0,00840	-0,00003
13	91,367	-0,04463	0,05803	-0,00008
14	95,580	0,04406	-0,01711	0,00011
15	103,690	0,01711	0,03216	-0,00007

V. CONCLUSION

In this study, testing was carried out using finite element analysis (FEA) to analyze the strength of the chassis structure of a two-passenger electric car. Static and dynamic analysis is used to assess the performance of chassis structures obtained through numerical simulations. The chassis structure exhibits several different behaviours due to different materials used, albeit with the same loading. The results of static analysis can be observed from the comparison graph shown in Figure 8, showing that the chassis structure using AISI 1018 material has increased safety of factor value and maximum von Mises stress and decreased maximum strain value along with an increase in tensile strength value of the material. The results of modal analysis can be observed in Figure 6-7. The chassis structure using AISI 1018 material shows that the maximum deformation value that occurs in the 12th shape mode decreases and applies to the entire shape mode. The use of different materials can affect the performance of the chassis structure. Thus, AISI 1018 material can be used to produce chassis structures with better chassis strength.

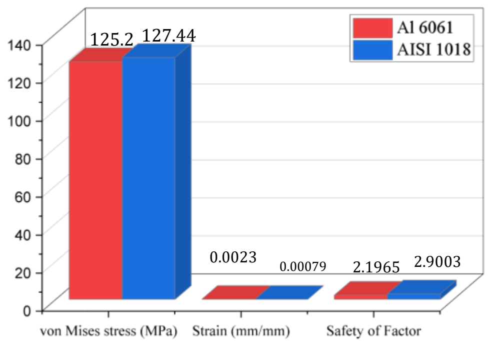

Fig. 8 Comparison of material effects to static analysis

REFERENCES

[1] J. Farabi, "The Design and Analysis of Multiple Monocoque Chassis for Formula Student (FS)racecar," International Journal of Mechatronics and Automotive Research (IJMAR), vol. 3, no. 1, pp. 19–32, 2021, [Online]. Available: https://www.researchgate.net/publication/362943871
[2] S. Stadler, M. Hirz, K. Thum, and P. Rossbacher, "Conceptual full-vehicle development supported by integrated computer-aided design methods," Comput Aided Des Appl, vol. 10, no. 1, pp. 159–172, 2013, doi: 10.3722/cadaps.2013.159-172.
[3] S. Hadi Bayat and M. Zehsaz, "Static and Dynamic Analysis of the Factors Affecting the Fatigue Life of Heavy Truck Chassis Structure," International Journal of Current Engineering and Technology, vol. 7, no. 6, 2015, [Online]. Available: http://inpressco.com/category/ijcet
[4] N. Ahirrao and S. Bhosle, "To Evaluate Chassis Frequency Harmonics of Vehicles by Modal Analysis and Measurement," Lecture Notes in Mechanical Engineering, 2020, [Online]. Available: http://www.springer.com/series/11693
[5] X. Chen and Y. Liu, Finite element modeling and simulation with ANSYS Workbench. CRC Press, 2015.
[6] A. Kengkongan, A. Rio, and F. Imaduddin, "Structural assessment of an energy-efficient urban vehicle chassis using finite element analysis - A case study," in Procedia Structural Integrity, Elsevier B.V., 2020, pp. 69–76. doi: 10.1016/j.prostr.2020.07.010.
[7] I. A. Majid, F. B. Laksono, H. Suryanto, and A. R. Prabowo, "Structural assessment of ladder frame chassis using FE analysis: A designed construction referring to ford AC cobra," in Procedia Structural Integrity, Elsevier B.V., 2021, pp. 35–42. doi: 10.1016/j.prostr.2021.10.006.
[8] J. P. Srivastava, G. G. Reddy, and K. S. Teja, "Numerical investigation on vibration characteristics and structural behaviour of different go-kart chassis configuration," Mater Today Proc, vol. 39, pp. 176–182, 2020, doi: 10.1016/j.matpr.2020.06.488.
[9] M. A. B. Marzuki, M. A. Abu Bakar, and M. F. Mohammed Azmi, "DESIGNING SPACE FRAME RACE CAR CHASSIS STRUCTURE USING NATURAL FREQUENCIES DATA FROM ANSYS MODE SHAPE ANALYSIS," International Journal of Information Systems and Engineering, vol. 3, no. 1, pp. 54–63, Apr. 2015, doi: 10.24924/ijise/2015.11/v3.iss1/54.63.
[10] P. Kasi V Rao, K. Sai Kumar Putsala, M. Muthupandi, and D. Mojeswararao, "Numerical analysis on space frame chassis of a formula student race car," Mater Today Proc, vol. 66, pp. 754–759, Jan. 2022, doi: 10.1016/j.matpr.2022.04.077.
[11] Y. Rui et al., "Biomimetic design of lightweight vehicle structures based on animal bone properties," Adv Mat Res, vol. 633, pp. 3–14, 2013, doi: 10.4028/www.scientific.net/AMR.633.3.
[12] Paul Follansbee, "A Model for Dynamic Strain Aging," in Fundamentals of Strength, 2022, pp. 404–434.
[13] Y. Yang, C. Wu, Z. Liu, J. Li, T. Yang, and X. Jiang, "Characteristics of 3D-printing ultra-high performance fibre-reinforced concrete under impact loading," Int J Impact Eng, vol. 164, no. August 2021, p. 104205, 2022, doi: 10.1016/j.ijimpeng.2022.104205.
[14] Ansel C. Ugural, Stress in Beams, Plates, and Shells, 3rd ed. CRC Press, 2010.
[15] A. Bonsanto Oliveira et al., "Static and Dynamic Analysis of a Chassis of a Prototype Car," SAE International, 2015.
[16] E. Bonisoli, D. Lisitano, L. Dimauro, and L. Peroni, "A Proposal of Dynamic Behaviour Design Based on Mode Shape Tracing: Numerical Application to a Motorbike Frame," in Conference Proceedings of the Society for Experimental Mechanics Series, Springer New York LLC, 2020, pp. 149–158. doi: 10.1007/978-3-030-12184-6_14.