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# Topography Optimization of Cabin Floor of Commercial Vehicle

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**Abstract:** The cabin floor of a vehicle plays a critical role in structural integrity, NVH (Noise, Vibration, Harshness) performance, and crashworthiness. Optimization of the cabin floor can significantly improve stiffness, modal frequencies, and durability without substantially increasing mass. Topography optimization is a subset of structural optimization techniques where design features such as ribs, beads, and surface reinforcements are intelligently placed on a base surface to improve stiffness, reduce stress concentrations, and control deformation modes under given loading conditions. Unlike topology or shape optimization, which can drastically alter geometry, topography optimization maintains the overall shape but refines the surface features, making it especially useful for components like floor panels in automotive or aerospace applications.

The floor panel under study is subjected to real-world loading scenarios such as distributed loads, point loads, and boundary conditions and support regions. The primary objectives are to maximize stiffness (minimize compliance), reduce mass, and maintain acceptable vibration and NVH (Noise, Vibration, Harshness) performance. Commercial CAE tools such as Altair Optistruct are used to carry out the finite element analysis and optimization process.

A baseline design is first analyzed to understand its deformation and stress distribution. Then, topography optimization is performed to introduce bead patterns that improve stiffness with minimal material addition. Design constraints include manufacturing feasibility, such as draw directions for stamping and limits on bead height and spacing. The optimized design is then evaluated against the baseline in terms of weight, stiffness, natural frequency, and stress distribution.

## 1. Introduction

The continuous evolution of the automotive industry has driven engineers toward designing lighter, stiffer, and more cost-efficient vehicle structures without compromising on safety and comfort. Vehicle performance is no longer judged only by acceleration and fuel efficiency but also by passenger comfort, acoustic quality, and durability. Among the various subsystems in a vehicle's body-in-white (BIW), the cabin floor plays a crucial role in structural rigidity, vibration isolation, and overall NVH (Noise, Vibration, and Harshness) performance. A poorly designed floor can lead to structural resonance, reduced stiffness, and increased noise transmission, directly affecting passenger comfort. Hence, achieving the optimum balance between stiffness and weight is an essential design target. With the development of modern CAE (Computer-Aided Engineering) tools, optimization-driven design has become a practical and efficient approach to achieve this balance.

The cabin floor structure directly influences the dynamic and acoustic behavior of the vehicle. It contributes significantly to the global bending and torsional stiffness of the body-in-white, which affects both ride comfort and noise isolation. When subjected to road excitations, powertrain vibrations, or acoustic loading, the floor acts as a transmission path for vibration and noise into the passenger compartment. Therefore, optimizing the cabin floor is essential for achieving superior NVH performance. Structural engineers face challenges in managing trade-offs between stiffness, weight, and manufacturability. Conventional reinforcement techniques, such as adding thicker sheets or extra cross members, increase the overall mass and cost. To overcome this, the implementation of topography optimization provides a systematic method to enhance structural performance through intelligent feature design rather than material addition.

Topography optimization is a structural optimization technique specifically developed for thin sheet metal components. Topography optimization differs fundamentally from topology and shape optimization. While topology optimization determines the best material layout within a design space and shape optimization refines contour boundaries, topography optimization modifies the surface geometry by creating local features such as beads, ribs, or embossments. These surface modifications help in locally increasing stiffness without a significant rise in mass. The algorithm defines bead directions, spacing, and depth parameters to achieve the best possible stiffness-to-weight ratio. This technique is particularly suited for thin sheet metal components, such as automotive floor panels, roofs, and door inners. The implementation of topography optimization within CAE tools such as Altair OptiStruct enables engineers to integrate optimization-driven design directly into the vehicle development cycle.

One of the strongest advantages of topography optimization is its ability to incorporate manufacturing constraints directly during optimization. Parameters such as minimum bead width, maximum bead width, draw height, draw angle, and bead direction can be specified to ensure that the generated bead patterns are compatible with sheet metal forming processes such as stamping. This ensures that the optimized design is not only structurally efficient but also practically manufacturable.

The scope of this research is to apply topography optimization to a typical vehicle cabin floor and to demonstrate its effect on the stiffness, modal characteristics, and NVH behavior. Using Altair HyperMesh for pre-processing, OptiStruct for optimization and analysis, and HyperView for post-processing and mode shape evaluation, the complete workflow will be demonstrated. The goal is to achieve a significant frequency improvement raising the baseline first bending frequency from while maintaining a neutral or minimal increase in mass. Design constraints will include bead height, spacing, and direction, ensuring that the optimized geometry remains feasible for manufacturing and compliant with stamping limits.

**1.1 Objective**

1. To develop the 3D CAD model of a vehicle cabin floor.
2. To perform modal analysis of the baseline cabin floor model.
3. To apply topography optimization on the cabin floor panel.
4. To validate the vehicle cabin floor model.

## 2. LITERATURE REVIEW

| Sr. No. | Author | Year | Method | Application | Findings |
|---|---|---|---|---|---|
| 1 | Bendsoe & Kikuchi | 1988 | Homogenization-based topology optimization | Structural design optimization | Introduced topology optimization concept for optimal material distribution and structu |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | ral sti ff ne ss im pr ov e m en t. |
| 2 | Suzuki & Kikuchi | 1 9 9 1 | Shape and topology optimization | S tr u c t u r a l o p ti m i z a ti o n | E xt en de d ho m og en iz ati on m et ho d fo r co m bi ne d sh ap e an d to po lo gy op ti mi za tio |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | n applications. |
| 3 | Wang et al. | 2020 | Literature review | Vehicle road noise | Reviewed structure-borne road noise mechanisms and highlighted importance of panel sti |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | ffness in NVH control. |
| 4 | Sharma & Kumar | 2019 | Experimental NVH analysis | Passenger vehicle booming noise | Identified low-frequency body resonance as a major source of interior booming noise. |

| | | | | | |
|---|---|---|---|---|---|
| 5 | Lee et al. | 2021 | Experimental vibration analysis | Road-induced vibration | Investigated effect of road inputs on vehicle vibration and structural dynamic response. |
| 6 | SAE International | 2011 | CAE-based bead optimization | Vehicle floo | Demonstrated that fl |

| | | | | | |
|---|---|---|---|---|---|
| | | | | r panel | oor bead optimization significantly improves low-frequency NVH performance. |
| 7 | Kumar & Patel | 2018 | Contribution analysis | Vehicle interi | Showed that floor panels |

| | | | | | |
|---|---|---|---|---|---|
| | | | | or noise | significantly contribute to cabin noise and must be shifted away from excitation frequencies. |
| 8 | SAE International | 2003 | Road load development | Road no | Developed re |

| | | | | | |
|---|---|---|---|---|---|
| | | | | ise analysis | presentative road input loads for accurate vehicle NVH analysis. |
| 9 | Gibson & Stölken | 2003 | Gibson & Stölken | Beaded sheet structur | Confirmed that bead features improve lo |

| | | | | | |
|---|---|---|---|---|---|
| | | | | es | cal bending stiffness of thin sheet structures. |
| 10 | Zhao et al. | 2015 | Topography optimization | Automotive floor panel | Improved floor panel stiffness and natural frequencies thro |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | ugh optimized bead generation. |
| 11 | Singh & Kumar | 2018 | Modal-based topography optimization | Automotive floor structure | Demonstrated significant modal frequency improvement using topography |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | optimization. |
| 12 | Yang et al. | 2019 | Manufacturing-constrained optimization | Automotive sheet metal | Showed importance of manufacturability constraints like bead width and draw angle in optimiza |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | tion. |
| 13 | Choi & Lee | 2020 | Multi-objective optimization | Automotive floor | Combined thickness and topography optimization for stiffness and weight reduction. |
| 14 | Schramm & Zhou | 2006 | Commercial implementation review | Structur | Reviewed indu |

| | | | | | |
|---|---|---|---|---|---|
| | | | | aloptimizationsoftware | strial adoption of topology/topography optimization in commercial CAE platforms. |

## 2.1 Research Gap

Although topography optimization has been extensively studied for various automotive sheet metal components, limited research has been specifically focused on the cabin floor structure of commercial vehicles, which is a critical load-carrying and vibration-sensitive component of the vehicle body. Commercial vehicle cabin floors differ significantly from passenger vehicle floor structures due to their larger dimensions, different loading environments, and higher exposure to road-induced dynamic excitation, making dedicated investigation essential. Most existing studies primarily emphasize general structural stiffness improvement or weight reduction; however, comparatively less attention has been given to modal-frequency-based stiffness enhancement, particularly for improving the lower-order natural frequencies that directly influence cabin floor vibration behaviour and NVH performance.

Another major limitation in available literature is the use of simplified or idealized boundary conditions, which may not accurately represent actual vehicle assembly conditions. In real applications, the cabin floor is connected to adjacent BIW components through multiple spot weld joints and structural interfaces, and these connections significantly influence the dynamic response of the structure. Limited studies have incorporated such realistic connection modelling into topography optimization.

Furthermore, although several optimization studies report numerical improvements, manufacturing feasibility constraints such as bead width, draw angle, draw height, and forming limitations are often insufficiently addressed. This creates a gap between theoretical optimization results and practical industrial implementation.

Therefore, the present research aims to address these gaps by developing and implementing a practical CAE-based topography optimization methodology for a commercial vehicle cabin floor, considering realistic boundary conditions, manufacturing constraints, and modal-performance-based stiffness improvement to achieve enhanced NVH performance with minimum mass increase.

## 3. Methodology

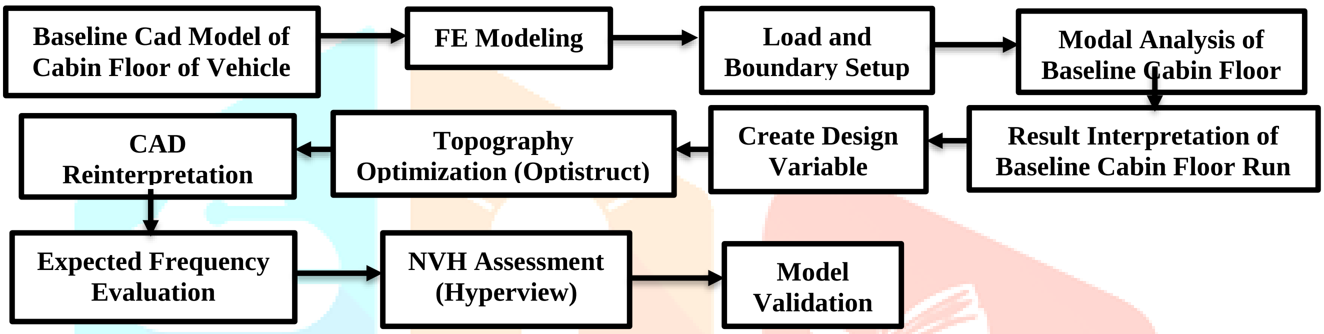



**Fig 1 Block Diagram of Workflow**

### 3.1 Baseline CAD Model of Cabin Floor of Vehicle

The study begins with the preparation of the baseline CAD model of the commercial vehicle cabin floor. The model represents the original floor geometry without any stiffness enhancement features such as beads. Proper geometric continuity and structural completeness were ensured so that the model could accurately represent the real cabin floor behaviour during analysis.

### 3.2 FE Modeling of Cabin Floor of Vehicle

The CAD geometry was converted into a finite element model using shell elements suitable for thin sheet metal structures. Material properties and thickness were assigned to represent the physical floor accurately. Mesh quality was maintained within acceptable limits to ensure reliable numerical results.

### 3.3 Load and Boundary Setup

To simulate actual vehicle mounting conditions, boundary constraints were applied at spot weld locations. These joints were represented using hexa and RBE3 elements to achieve realistic load transfer without introducing artificial stiffness into the model.

### 3.4 Modal Analysis of Baseline Cabin Floor

Baseline modal analysis was carried out using OptiStruct to extract the natural frequencies and corresponding mode shapes of the cabin floor. The EIGRL method was used for eigenvalue extraction to identify the critical vibration modes of the structure.

### 3.5 Result Interpretation of Baseline Cabin Floor Run

The baseline modal results were analysed to identify regions showing maximum deformation in lower-order modes. These high-deformation areas indicated low stiffness zones and were selected as the primary regions for further optimization.

### 3.6 Create Design Variable

Based on the baseline mode shapes, the design region was defined over the critical deformation areas. Topography design variables were assigned to allow controlled bead formation only in selected regions while keeping mounting and non-design areas unchanged.

### 3.7 Topography Optimization (OptiStruct)

Topography optimization was performed in OptiStruct with the objective of maximizing the first four natural frequencies. Manufacturing constraints such as bead width, draw height, and draw angle were included to ensure that the optimized design remained practically manufacturable.

### 3.8 CAD Reinterpretation

The optimized bead patterns generated by the solver were interpreted and converted into practical geometric features. This step ensured that the optimized design could be implemented in an actual CAD model for production use.

### 3.9 Expected Frequency Evaluation

The optimized cabin floor model was re-analysed using the same modal setup as the baseline model. The updated natural frequencies and mode shapes were compared to evaluate the stiffness improvement achieved through optimization.

### 3.10 NVH Assessment (HyperView)

Post-processing was carried out in HyperView to compare deformation behaviour and mode shape patterns between baseline and optimized models. The frequency shift and reduced deformation confirmed improved NVH performance.

### 3.11 Model Validation

The final optimized model was validated by maintaining identical analysis conditions between baseline and optimized cases. Frequency trends, mode shape behaviour, and manufacturability of bead patterns were reviewed to confirm the reliability and practical applicability of the optimization results.

## 4. Tools

### 4.1 CATIA V5 – CAD Modeling Tool

CATIA V5 (Computer Aided Three-Dimensional Interactive Application) is a widely used CAD software in the automotive industry for creating accurate 3D models and assemblies. In this study, CATIA V5 was used to develop the baseline cabin floor geometry of the commercial vehicle. The model included major structural regions such as flat surfaces, curved sections, and mounting areas representing the actual sheet metal floor structure. Parametric modelling and geometric constraints were used to maintain dimensional accuracy and design flexibility. Geometry verification was also performed to remove issues such as surface gaps, intersections, and discontinuities, ensuring a clean CAD model suitable for CAE analysis.

### 4.2 HyperMesh – Finite Element Preprocessing

HyperMesh was used for converting the CAD model into an analysis-ready finite element model. The imported geometry was first cleaned to remove topological errors such as free edges and duplicate surfaces. Since the cabin floor is a thin sheet metal component, shell elements were used for meshing, while spot weld regions were represented using solid elements and RBE3 connections. Appropriate mesh quality criteria were maintained to ensure numerical accuracy and solver convergence. Material properties and shell thickness were assigned using solver-compatible cards, and the final FE model was exported in OptiStruct format for analysis and optimization.

### 4.3 Optistruct – Modal Analysis and Topography Optimization

OptiStruct was used as the primary solver for modal analysis and topography optimization. Initially, modal analysis was performed to extract the natural frequencies and mode shapes of the baseline cabin floor using the EIGRL method. The lower-order modes were analysed to identify weak structural regions. Based on these results, topography optimization was carried out by defining design variables over selected regions using the DTPL card. The objective was set to maximize the first four natural frequencies while maintaining manufacturing feasibility through bead-related constraints. OptiStruct iteratively generated optimized bead patterns to improve structural stiffness and dynamic performance.

### 4.4 HyperView – Result Visualization and Validation

HyperView was used for post-processing and interpretation of simulation results. It enabled visualization of mode shapes, deformation patterns, and displacement contours for both baseline and optimized models. Mode shape animations helped identify deformation-prone regions and validate stiffness improvements after optimization. HyperView's comparison capability was also used to evaluate baseline and optimized models side-by-side, confirming frequency improvement and reduced deformation. This tool played an important role in validating the effectiveness of the topography optimization process.

## 5. Design/Modeling

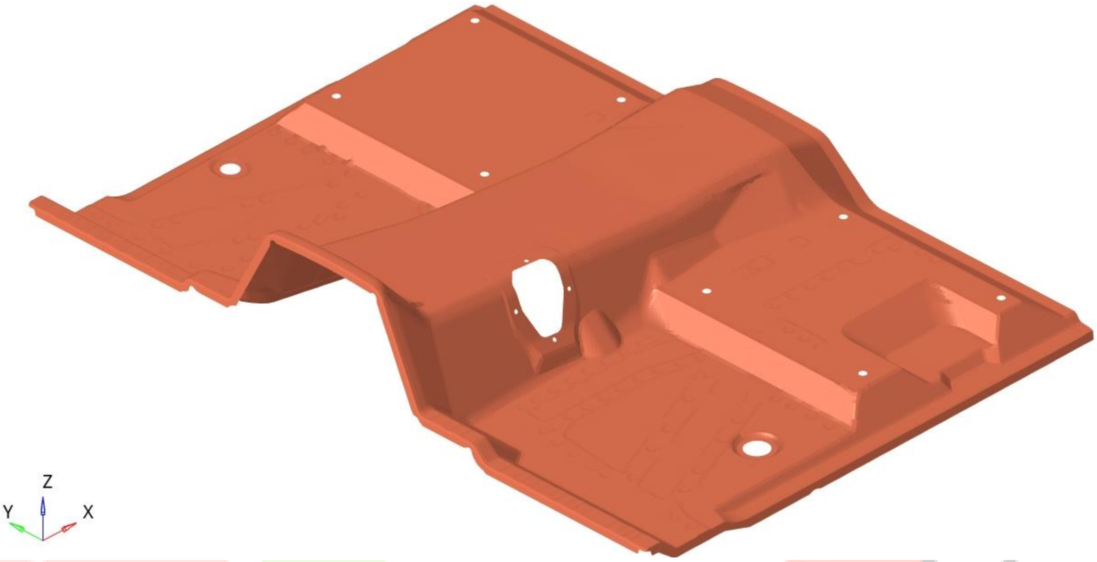



**Fig 5.1– Cad model**

**Table No. 5.1 Specifications of Cabin Floor**

| | |
|---|---|
| Thickness | 0.8 mm |
| Material | Steel |

**Table No. 5.2 Material Properties of Steel**

| Sr No. | Material Properties | Values |
|---|---|---|
| 1 | Young's Modulus | 2.1 E5 N/mm2 |
| 2 | Density | 7.85 E-9 Tonne/mm3 |
| 3 | Poison's Ratio | 0.3 |

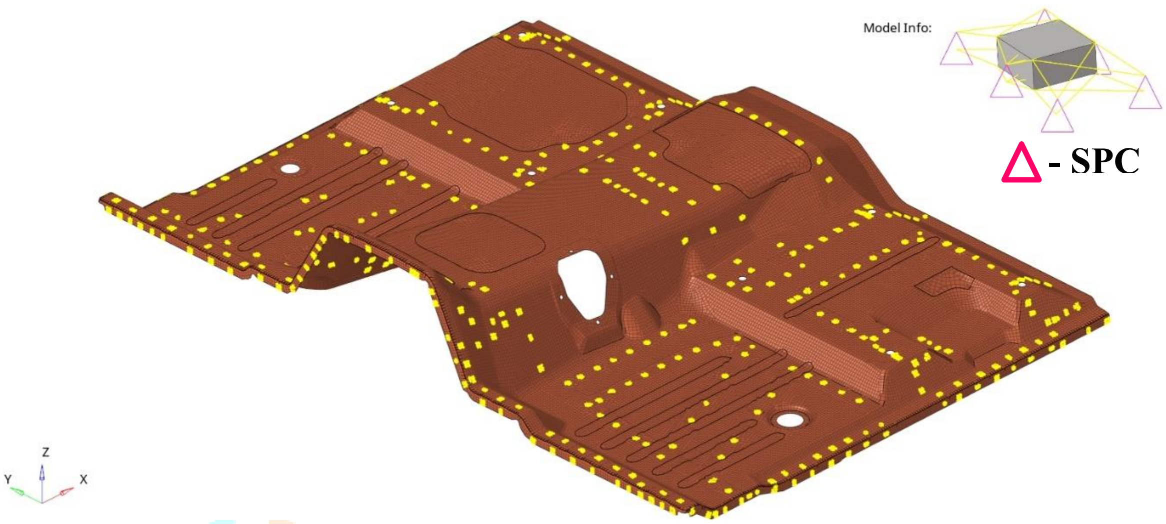



**Fig 5.2- Mesh Model and Boundary Conditions**

Appropriate boundary conditions were applied to simulate realistic mounting conditions of the cabin floor within the vehicle structure. The accuracy of modal analysis largely depends on proper representation of support conditions, as the applied constraints directly influence the stiffness distribution, natural frequencies, and mode shapes of the structure. Therefore, special attention was given to defining boundary conditions that closely replicate the actual assembly conditions of the cabin floor within the vehicle Body-in-White (BIW). In the present study, the spot weld locations were modelled using a combination of solid (hexa) elements and RBE3 elements. The hexa elements were used to represent the local physical stiffness of the weld region, while the RBE3 elements were employed to distribute loads and constraints from surrounding shell nodes to a central reference node. This approach helps simulate realistic structural connectivity between the floor panel and adjacent components.

### 5.1 Solver and Analysis Type

The structural analysis and optimization in the present study were performed using the OptiStruct solver, developed by Altair. OptiStruct is a widely used finite element solver in the automotive and aerospace industries due to its advanced capabilities in structural analysis and optimization. It supports multiple types of analyses such as static, dynamic, fatigue, durability, and optimization studies, making it highly suitable for CAE-driven product development.

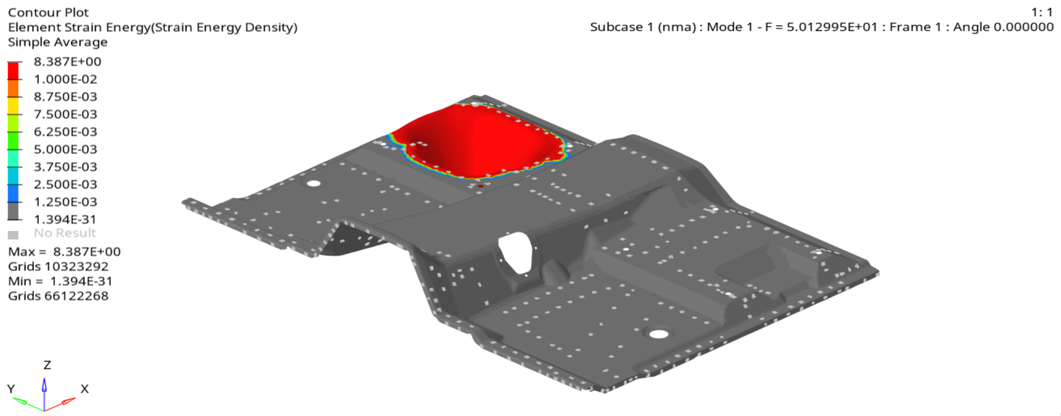
In this work, the selected analysis type was modal analysis, as the primary objective was to evaluate and improve the dynamic performance of the vehicle cabin floor. Modal analysis is a fundamental dynamic analysis technique used to determine the natural frequencies and corresponding mode shapes of a structure under free vibration conditions. These parameters represent the inherent vibration characteristics of the structure and depend mainly on the stiffness and mass distribution of the system.

The purpose of performing modal analysis is to identify the fundamental vibration characteristics of the cabin floor and understand how the structure behaves under free vibration conditions. Every physical structure possesses natural frequencies at which it tends to vibrate when excited. If these frequencies coincide with external excitation sources such as engine vibrations, road irregularities, or drivetrain inputs, resonance may occur, resulting in excessive vibration, increased noise levels, and reduced passenger comfort. Hence, identifying and improving these frequencies is essential for achieving better NVH (Noise, Vibration, and Harshness) performance. In this study, eigenvalue extraction was carried out using the EIGRL (Eigenvalue Real Lanczos) card available in OptiStruct. The EIGRL method is widely used for modal analysis because it efficiently extracts the required number of natural frequencies and corresponding mode shapes within a specified frequency range. This method is particularly suitable for large automotive finite element models due to its computational efficiency and numerical stability.

## 6. Result and Analysis

### 6.1 Baseline Cabin Floor Model Modal Analysis

Initially, a baseline model of the cabin floor was analysed to establish a reference condition for the subsequent optimization process. The baseline model represents the original cabin floor design without any additional stiffness enhancement features such as bead patterns or embossments. This initial analysis is an important step because it provides a clear understanding of the inherent structural and dynamic characteristics of the existing design and serves as the benchmark for evaluating the effectiveness of topography optimization. The modal analysis was performed using the same boundary conditions and material properties defined during the finite element model setup to ensure consistency and accuracy in the simulation process. Special focus was given to the first few modes, as these lower-order modes are generally associated with global bending and torsional behaviour of the cabin floor and are most




sensitive to structural stiffness variations.

**Fig 6.1 Mode 1- 50 Hz**

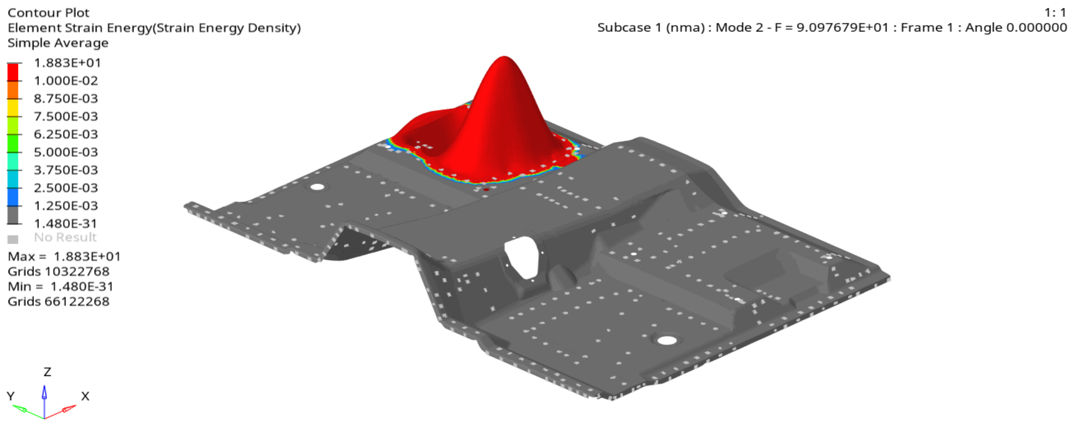



**Fig 6.2 Mode 2- 90.97 Hz**

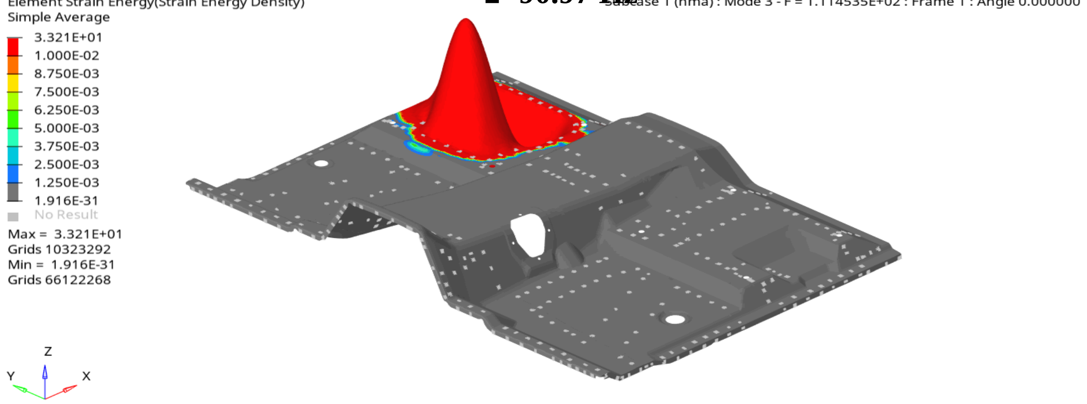


**Fig 6.3 Mode 3- 114.53 Hz**

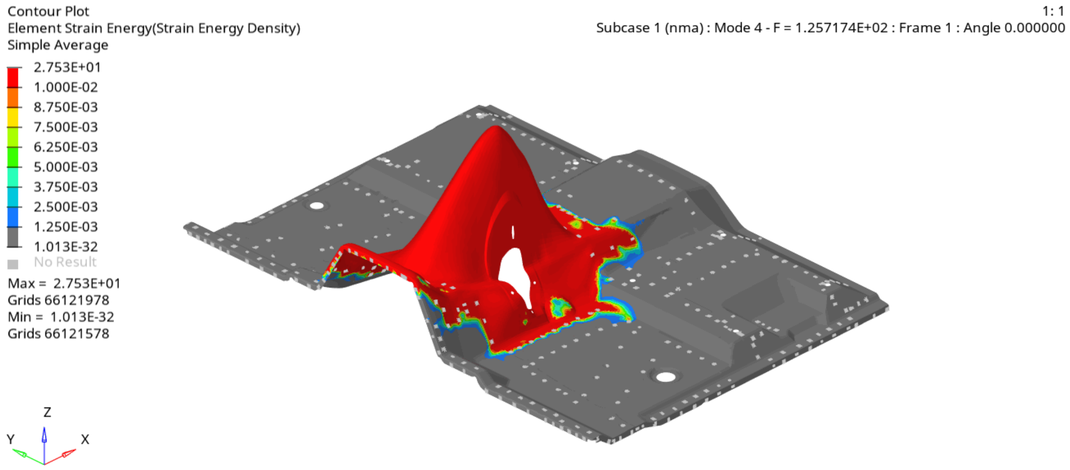



**Fig 6.4 Mode 4- 125.71 Hz**

From the obtained results, it was observed that all four natural frequencies were below 130 Hz. According to vehicle NVH design criteria, the frequency range below approximately 130 Hz is considered critical because this range is highly susceptible to road excitation inputs. Road-induced vibrations generated due to tire-road interaction can excite structural components within this frequency range, potentially causing resonance and resulting in increased cabin vibration, noise transmission, and reduced passenger comfort. The corresponding mode shape animations were carefully examined to identify the deformation behaviour of the cabin floor at each natural frequency. It was observed that certain regions of the floor panel exhibited higher deformation amplitudes, indicating local structural weakness and insufficient stiffness. These deformation-prone regions were identified as critical design areas requiring structural improvement. Based on this interpretation, it was concluded that the baseline cabin floor required stiffness enhancement to shift the lower natural frequencies above the critical excitation range. Therefore, topography optimization was selected as the most suitable method to improve the structural stiffness of the cabin floor by introducing optimized bead patterns in the identified weak regions.

## 6.2 Topography Optimization of Cabin Floor

### 6.2.1 Design Variable

For performing topography optimization, it is essential to define appropriate design variables that control the geometric modification of the shell surface and enable the generation of bead patterns. In the present study, the design variables were defined over the cabin floor panel using the DTPL (Design Topography Parameter) card in OptiStruct. The DTPL card allows controlled out-of-plane deformation of shell elements normal to the panel surface, which enables the solver to generate optimized bead patterns for stiffness improvement. The selection of the design region was based on the modal analysis results of the baseline cabin floor model. The extracted mode shapes were carefully studied to identify regions showing maximum deformation, as these regions indicate lower stiffness and higher vibration sensitivity. Such areas are considered structurally weak and therefore become the primary target zones for optimization.

Based on the mode shape interpretation, the design space was defined selectively over these critical regions so that optimization could be performed only where stiffness enhancement was required. At the same time, practical packaging constraints and surrounding component clearances were also considered while defining the design domain. This ensures that bead generation occurs only in feasible regions without causing interference with adjacent BIW components or violating assembly requirements. As a result, the optimized design exhibits reduced deformation, higher natural frequencies, and improved overall dynamic behaviour. Therefore, correct definition of the design variable is a critical step, as it directly influences the effectiveness of the optimization and determines the final stiffness improvement achieved in the cabin floor structure.

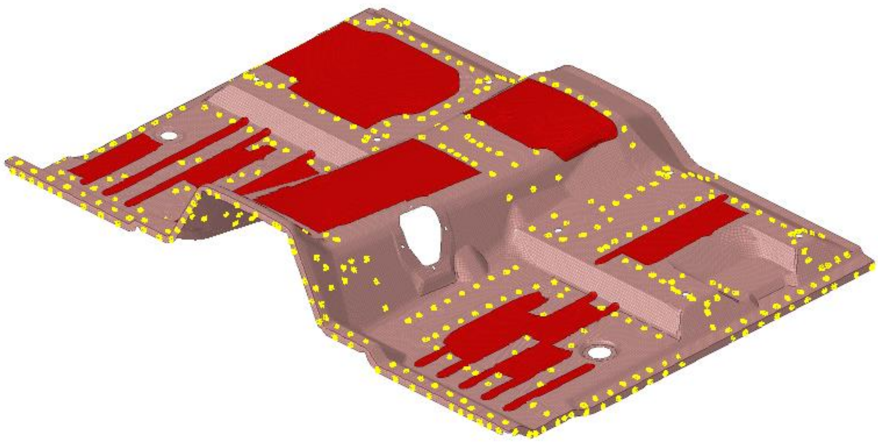


**Fig 6.5 Design Variable**

The selected design variable region for topography optimization is shown in Figure 6.5, where the highlighted red area represents the allowable design space for bead generation.

**Table No. 6.1 Design Parameters**

| Sr.No. | Parameters | Value |
|---|---|---|
| 1 | Minimum Width | 20 mm |
| 2 | Draw Angle | 70 |
| 3 | Draw Height | 7.5 mm |
| 4 | Maximum Width | 30 mm |
| 5 | Upper Bound | 1.0 |

All these parameters were finalized in consultation with the design alignment to ensure that the optimized geometry aligns with real vehicle packaging conditions and manufacturing capability. By incorporating these practical constraints directly into the optimization process, the final bead pattern generated by the solver becomes both structurally effective and industrially manufacturable, which is essential in real-world automotive product development.

### 6.3 Topography Optimization Parameters

After defining the design variables and design parameters, the next step in topography optimization is to define the optimization parameters that control the solver behavior. These parameters determine what structural response must be improved, what design limitations must be satisfied, and what final optimization target must be achieved. In OptiStruct, topography optimization is primarily controlled through three key parameters: Response, Constraint, and Objective.

#### 6.3.1 Topography Optimization Response

Responses are performance measures used by the solver to evaluate structural behaviour during each optimization iteration. In this study, two responses were defined: Frequency Response and Bead Fraction Response. The frequency response was selected as the primary structural response because the main objective of this work is to improve cabin floor stiffness through natural frequency enhancement. The first four natural modes were selected for optimization, as these lower-order modes are the most critical for automotive NVH performance and are highly susceptible to road and powertrain excitation. The bead fraction response was defined to control the amount of bead formation within the design region. This ensures that bead generation occurs only in structurally important areas, enabling efficient stiffness improvement without unnecessary geometric modification.

#### 6.3.2 Optimization Process Constraint

Constraints are applied to ensure that the optimized design remains practical and manufacturable. In the present study, the bead fraction was used as the optimization constraint with a value of 0.5, meaning only 50% of the selected design space was allowed to form beads. This constraint prevents excessive bead generation, avoids over-stiffening, maintains stamping feasibility, and ensures that reinforcement is applied only in the most critical deformation regions identified from baseline modal analysis.

#### 6.3.3 Objective Function

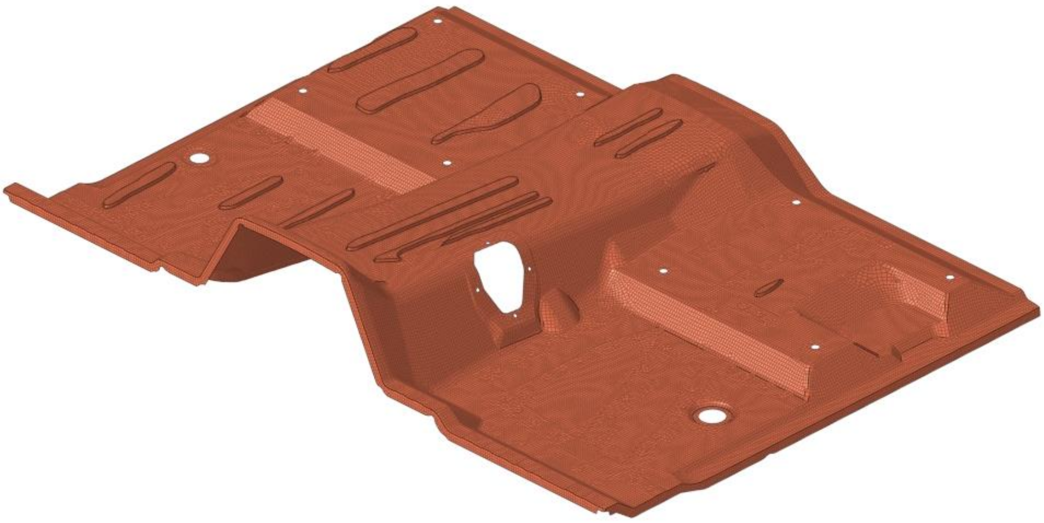
The objective function defines the final target of the optimization process. In this study, the objective was defined as “Maximize Frequency” using the frequency response in OptiStruct. Maximizing natural frequency directly corresponds to increasing structural stiffness without adding material or increasing thickness. The optimization specifically targeted the first four natural frequencies, as these modes strongly influence vehicle vibration and resonance behaviour. During optimization, OptiStruct iteratively generates bead patterns in weak structural regions, increasing local bending stiffness and shifting the natural frequencies away from the critical excitation range. This approach improves dynamic stability, reduces resonance risk, enhances NVH performance, and supports lightweight vehicle design through geometry-based stiffness improvement.

### 6.4 Topography Optimization Execution

After defining the design variables, design parameters, responses, constraints, and objective function, the complete topography optimization model was submitted to the OptiStruct solver for execution. The analysis was run in background mode, allowing the solver to perform the optimization process independently through multiple iterations. Initially, OptiStruct performs a model verification check to ensure proper geometry, connectivity, material properties, boundary conditions, and optimization setup. Once verified, the iterative optimization process begins, where the solver gradually modifies the shell geometry by generating and updating bead patterns within the defined design region.

During each iteration, the solver evaluates the selected responses, particularly the first four natural frequencies, and compares them with the defined objective of frequency maximization, while simultaneously satisfying the imposed bead fraction constraint. Based on this evaluation, the bead geometry is updated to improve structural stiffness and dynamic performance.

The optimization continues until the convergence criteria are achieved, such as stabilization of the objective function, minimal change in design variables, or completion of the defined iteration limit. After convergence, OptiStruct generates the final optimized bead pattern along with output files such as



iteration history and convergence plots for result evaluation.

Fig. 6.6 Topography Optimization of Cabin Floor

Thus, Fig 6.6 shows the transforms the baseline cabin floor into an optimized, structurally improved, and manufacturable design through an automated iterative process.

### 6.2.5 Mode Shape of Topography Optimization

After completion of topography optimization, the optimized cabin floor model was subjected to modal analysis to evaluate its improved dynamic performance and validate the effectiveness of the generated bead patterns. This step served as the final verification of whether the optimization successfully enhanced structural stiffness and vibration characteristics.

To ensure a consistent comparison, the same analysis conditions used for the baseline model—including material properties, shell thickness, boundary conditions, and EIGRL settings—were retained for the optimized model. The updated natural frequencies and corresponding mode shapes were extracted using the OptiStruct solver, with primary focus on the first four critical modes. The optimized mode shapes were examined in HyperView, where reduced deformation was observed in previously identified weak regions. This confirmed that the generated bead patterns effectively reinforced the critical areas and improved both local and global stiffness of the cabin floor.

A significant upward shift in natural frequencies was observed, indicating enhanced dynamic stiffness and reduced susceptibility to resonance under operating conditions such as road and powertrain excitation. In addition, the optimized mode shapes showed more uniform deformation patterns, demonstrating improved load distribution and structural stability.

These results confirm that topography optimization is an effective method for improving the stiffness and NVH performance of thin sheet metal structures through geometric modification alone, without increasing material thickness. Since manufacturing constraints were included during optimization, the final design also remains practical and suitable for automotive production.

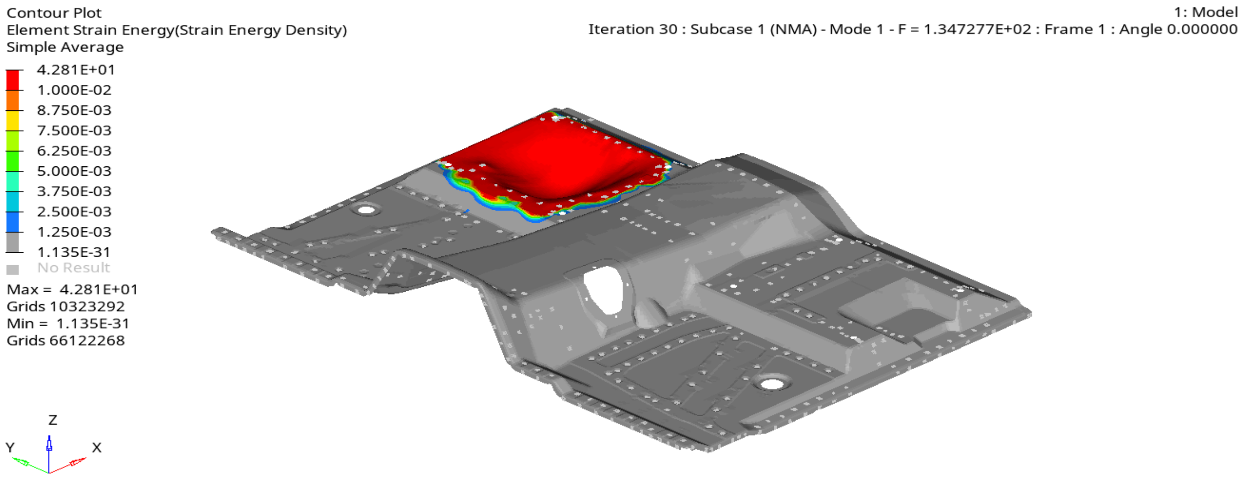



**Fig 6.7 Topography Mode 1**

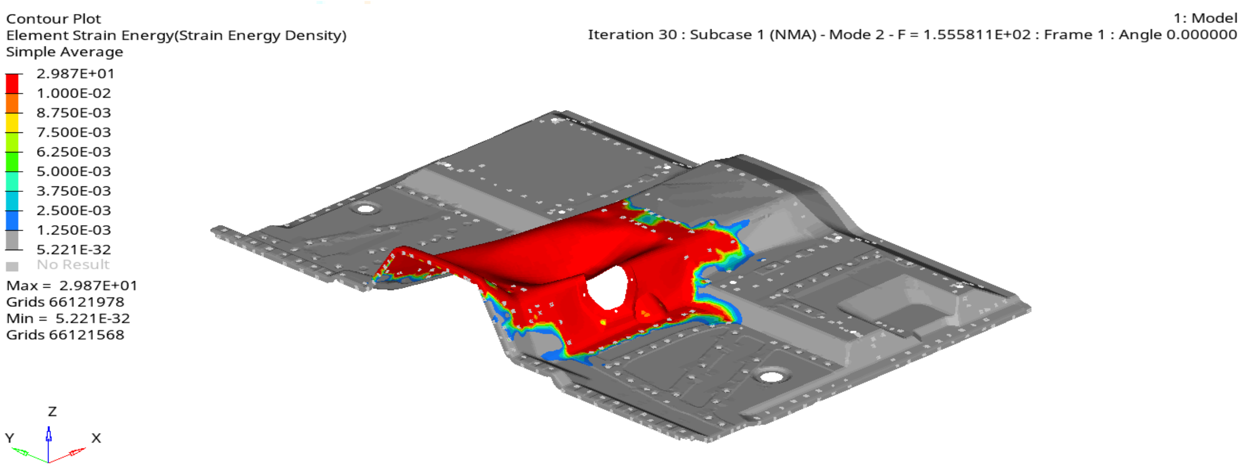



**Fig. 6.8 Topography Mode 2**

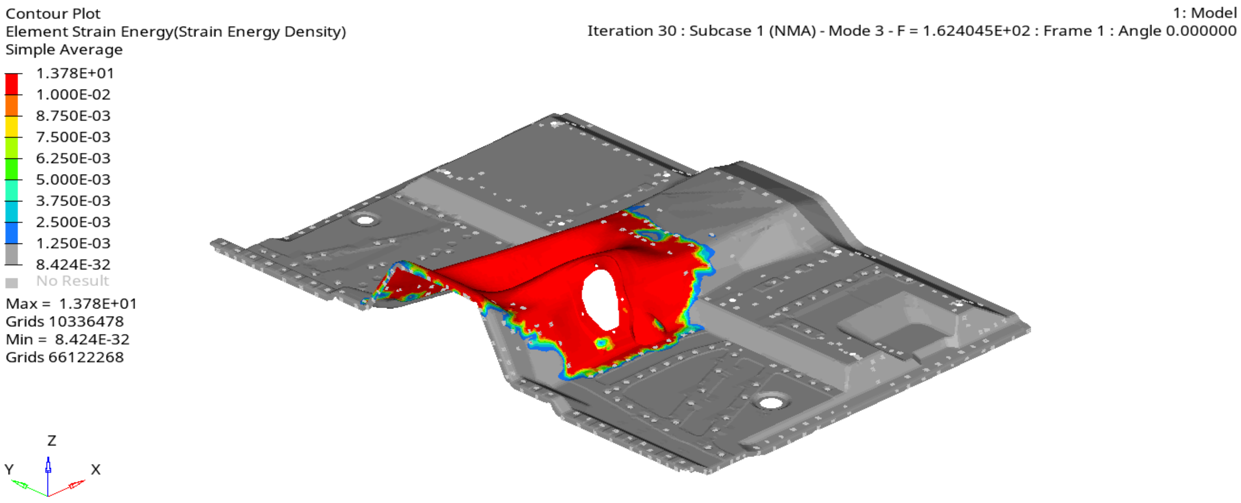



**Fig. 6.9 Topography Mode 3**

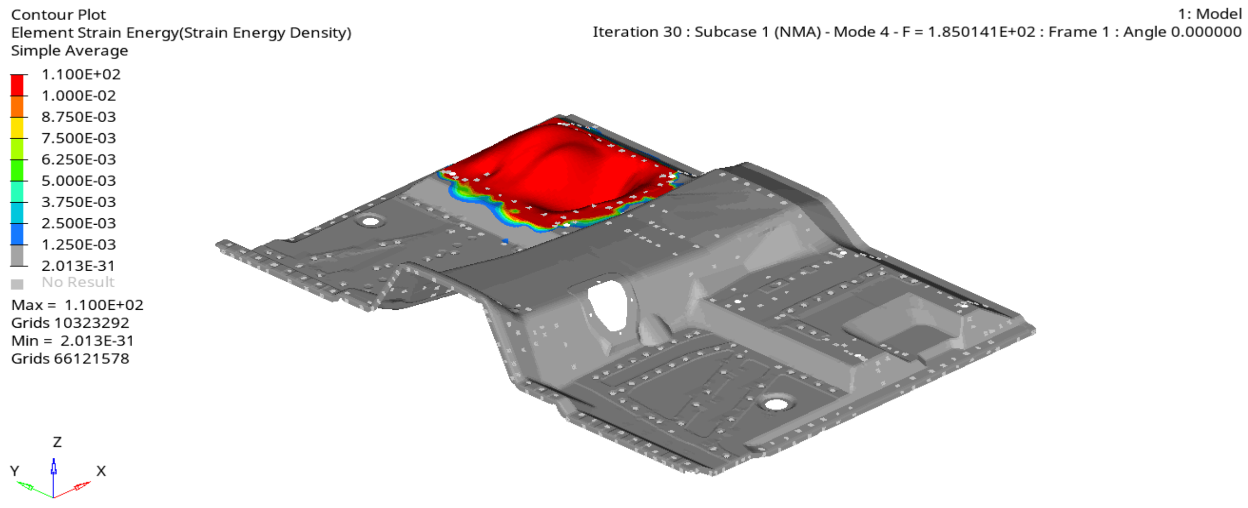



Fig. 6.10 Topography Mode 4

After completion of topography optimization, the optimized cabin floor model was evaluated through modal analysis to assess its dynamic performance. The results showed a significant increase in natural frequencies, confirming improved structural stiffness and the effectiveness of the generated bead patterns.

A major improvement was observed in the first natural frequency, which increased to approximately 134 Hz, shifting it above the critical excitation range and thereby reducing the possibility of structural resonance under operating conditions. The higher-order modes also showed frequency improvement, indicating overall stiffness enhancement across the cabin floor.

Mode shape analysis in HyperView showed reduced deformation in the optimized regions where bead patterns were introduced, confirming effective local reinforcement. Additionally, the deformation became more uniformly distributed, indicating improved load transfer and better global stiffness distribution.

These results validate that topography optimization successfully improved the dynamic behaviour and NVH performance of the cabin floor through efficient geometric modification while maintaining practical design feasibility.

**Table No 6.2 Mode Comparison of Baseline and Optimized Cabin Floor**

| Sr. No. | Baseline Modes (Hz) | Optimization Modes (Hz) |
|---|---|---|
| 1 | 50.12 | 134.72 |
| 2 | 90.97 | 155.58 |
| 3 | 111.45 | 162.40 |
| 4 | 125.71 | 185.01 |

A comparison of the natural frequencies obtained from the baseline and optimized cabin floor models was carried out to evaluate the effectiveness of the topography optimization process. The results clearly show a significant increase in the natural frequencies after optimization. The first natural frequency improved from 50.12 Hz in the baseline model to 134.72 Hz in the optimized model, indicating a major enhancement in global structural stiffness. Similarly, the second, third, and fourth modes increased from 90.97 Hz to 155.58 Hz, 111.45 Hz to 162.40 Hz, and 125.71 Hz to 185.01 Hz, respectively.

This substantial increase across all four critical modes confirms that the optimized bead patterns effectively enhanced the dynamic stiffness of the cabin floor. More importantly, all optimized frequencies shifted above the critical road excitation range, significantly reducing the possibility of structural resonance during actual vehicle operation. This improvement directly contributes to better NVH (Noise, Vibration, and Harshness) performance and overall vehicle ride comfort.

**Table No 6.3 Mass Comparison of Baseline and Optimized Cabin Floor**

| | Mass (Kg) |
|---|---|
| Baseline Floor | 13.71 |
| Optimization Floor | 13.89 |

In addition to frequency improvement, the mass of the cabin floor was also evaluated to ensure that the achieved stiffness enhancement did not result in a significant weight increase. The baseline cabin floor mass was 13.71 kg, while the optimized cabin floor mass increased slightly to 13.89 kg. This indicates a mass increase of only 0.18 kg, which is negligible compared to the substantial improvement achieved in natural frequencies and structural stiffness. The results confirm that topography optimization successfully improved the dynamic performance of the cabin floor with minimal mass penalty, thereby satisfying the important automotive design objective of achieving higher stiffness with near weight neutrality.

### 6.2.5 Validation of Optimized Cabin Floor with Respect to NVH Performance

To validate whether the optimized cabin floor frequencies are acceptable from an NVH perspective, the obtained natural frequencies were assessed with respect to the vehicle operational excitation range, particularly the road-induced excitation frequencies. In automotive structures, resonance occurs when the natural frequency of a structural component coincides with or lies very close to the dominant excitation frequencies generated by road irregularities, tire-road interaction, or powertrain inputs. Under such conditions, vibration amplitudes increase significantly, leading to higher interior noise and reduced passenger comfort.

According to Kumar and Patel [7], vehicle body panels such as the cabin floor are major contributors to interior cabin noise, particularly when their structural modes fall within the operational excitation range. Their study demonstrated that shifting panel natural frequencies away from dominant excitation frequencies is one of the most effective methods for reducing structure-borne noise transmission into the passenger compartment. Based on this established NVH principle, the validation criterion adopted in the present work was to shift the critical cabin floor modes above the road excitation band (0–130 Hz). After topography optimization, all critical modes were successfully shifted beyond this excitation range, creating sufficient frequency separation (detuning margin) between the excitation source and the structural natural frequencies.

Therefore, based on frequency detuning principles, mode shape validation, and the findings reported by Kumar and Patel [7], it can be concluded that the optimized cabin floor design satisfies the required NVH criteria and significantly reduces the risk of resonance-related interior noise problems.

**Conclusion**

Based on the baseline modal results, topography optimization was performed by defining appropriate design variables, responses, constraints, and objective functions. The first four natural frequencies were selected as key responses for improvement, as these modes significantly influence the structural behaviour and NVH performance. A bead fraction constraint was applied to ensure controlled and manufacturable bead formation across the design space.

After completing the optimization, the optimized model was re-analysed using the same modal setup to ensure a consistent comparison. The results showed a significant improvement in natural frequencies, with the first mode increasing from approximately 50 Hz to 134 Hz. The remaining modes also exhibited improved frequencies, all exceeding 40 Hz, indicating an overall enhancement in structural stiffness. Additionally, the optimized mode shapes showed reduced deformation in critical regions due to the introduction of bead patterns.

The study clearly demonstrates that topography optimization is an effective technique for improving the stiffness and dynamic characteristics of thin sheet metal structures such as a cabin floor. The optimized bead patterns enhance load distribution and reduce vibration levels without adding significant mass, making it a practical and efficient solution for automotive BIW design.

Overall, the results confirm that the implemented optimization approach successfully achieved the objective of increasing natural frequencies and improving structural performance, thereby contributing to better NVH characteristics of the vehicle.

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