# Concept design of Vehicle Structure for the purpose of computing torsional and bending stiffness

**M.Mohseni Kabir[1], M.Izanloo[1], A.Khalkhali*[2]**

1. M.Sc. Automotive Simulation and Optimal Design Research Laboratory, School Of Automotive Engineering, Iran University of Science and Technology, Tehran, Iran

2. Assistant Professor, Automotive Simulation and Optimal Design Research Laboratory, School Of Automotive Engineering, Iran University of Science and Technology, Tehran, Iran

Email: ab_khalkhali@iust.ac.ir

**Abstract**

Automotive design engineers face the challenging problem of developing products in highly competitive markets. In this regard, using conceptual models in the first step of automotive development seems so necessary. In this paper, to make a body in white conceptual model, an engineering approach is developed for the replacement of beam-like structures, joints, and panels in a vehicle model. The proposed replacement methodology is based on the reduced beam, joint, and panel modeling approach, which involves a geometric analysis of beam member cross-sections and a static analysis of joints. In order to validate the proposed approach, an industrial case-study is presented. Two static load cases are defined to compare the original and the concept model by evaluating the stiffness of the full vehicle under torsion and bending in accordance with the standards used by automotive original equipment manufacturer (OEM) companies. The results show high accuracy of the concept models in comparison with the original model in bending and torsional stiffness prediction.

***Keywords:*** *Concept Modeling, Body in white, Beam, Joint, Panel, Bending stiffness, Torsional Stiffness.*

.

## 1. Introduction

Nowadays, CAE (Computer-Aided Engineering) methods are applied to predict the various functional performances attributes and adapt the design according to the results of the virtual simulations [1]. In the early design phase, when exact geometrical information is not available, the techniques based on detailed CAD and FE models are not directly applicable [2]. Recent, research efforts have been focused on the use of CAE as a support in the concept phase of the vehicle design process when performance characteristics attributes are defined, while detailed geometrical data are still unavailable [3-5]. In the vehicle design process, three phases can be considered. Concept phase, detailed engineering phase and Refinement Engineering phase as shown in Figure 1.

The conceptual vehicle body currently concentrates on its specific merits to afford the first stage predictions about the global performances of mass, stiffness, and strength for simplified body-in-white (BIW) structure [6]. Among the methods based on predecessor FE models, the reduced beam and joint modeling approach have been recently proposed by Donder et al [1]. The concept model is then used to efficiently modify the properties of beam-like sections and joint connections in vehicle FE models. Moroncini presents a conceptual modeling by using a beam and shell elements. By presenting an arbitrary cross section beams in a modeling process, the actual geometry of cross sections remains unchanged [7]. Various solutions exist for the joints among which





[ DOI: 10.22068/ijae.7.2.2372 ]

static reduction [1, 8-9], dynamic reduction [10], concept models with springs [11], etc.

In this paper, a method for concept modeling of a vehicle is developed. The original mesh of beams, joints, and panels are replaced by concept elements. Then concept model of vehicle's BIW is verified by static indicators (bending and torsional stiffness). Finally the effect of the situation of the equivalent beam in vehicle modeling is investigated.

## 2. Vehicle Concept Modeling

The concept models are characterized by subdividing the structure into beam-like structures, joints, and panels. In this paper The LMS Virtual.Lab (Rev10) Vehicle Concept Modeling Workbench [12] is used to reduce the size and complexity of the large FE model. The properties of the beam-like structures are obtained directly from the refined FE model and then represented by equivalent beam elements. The methodology for creating the concept model of vehicle can be summarized as the procedure consisting of these steps: the detailed mesh of beam members is replaced by a series of 2-node beam elements. The properties of the equivalent beams are calculated by analyzing the mass distribution along a proper number of cross sections in the original FE model. Finally, the original mesh of beams is removed and replaced by concept beams.

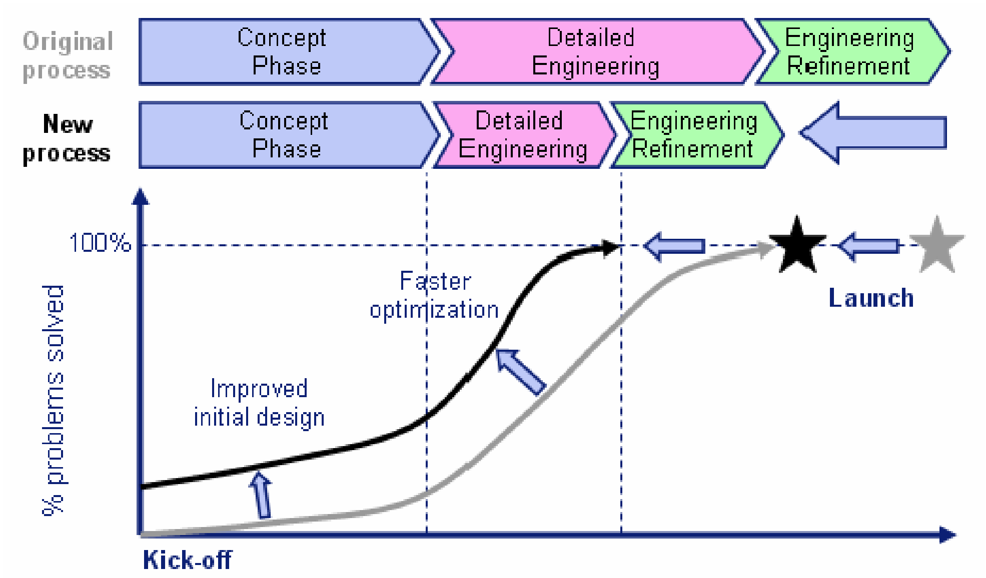



**Fig1.** Analysis Leads Design process in automotive design [1]



[ DOI: 10.22068/ijae.7.2.2372 ]

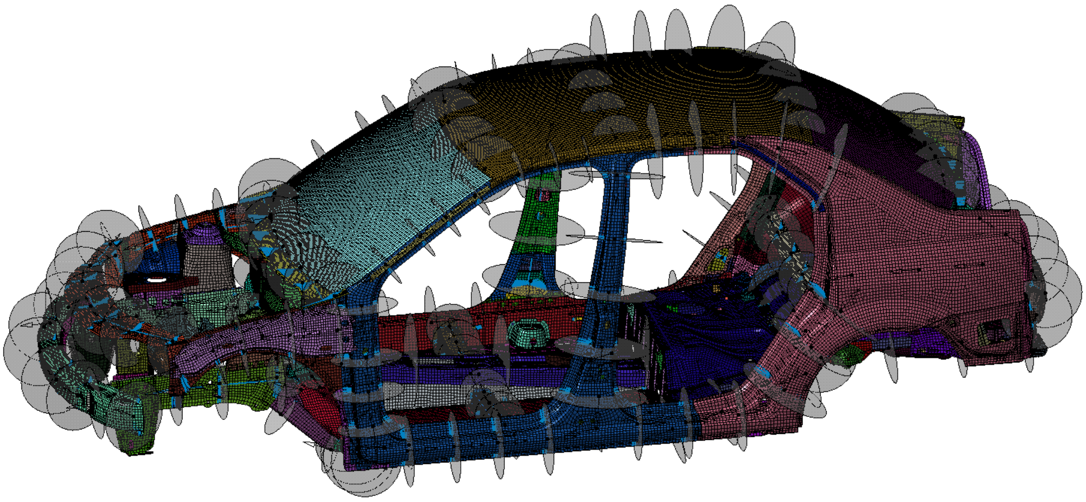


**Fig2.**: Sections defined on the beams to simplify the BIW

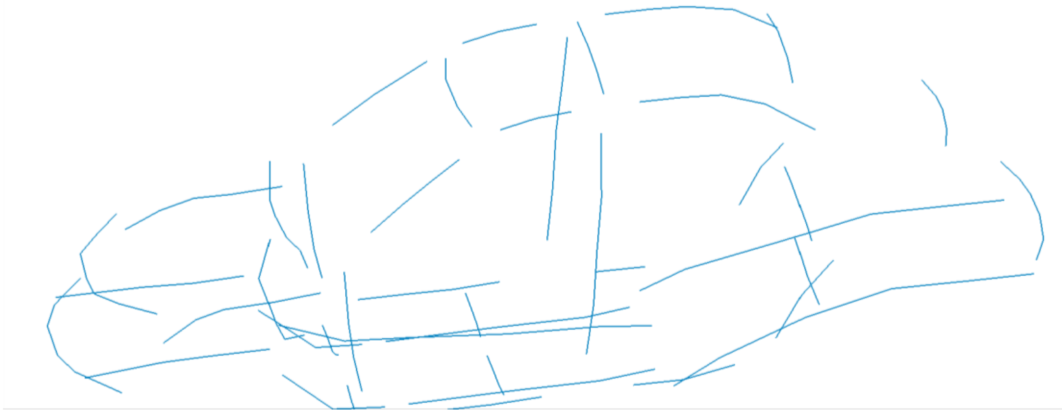


**Fig3.**: Equivalent beam modeling of the BIW

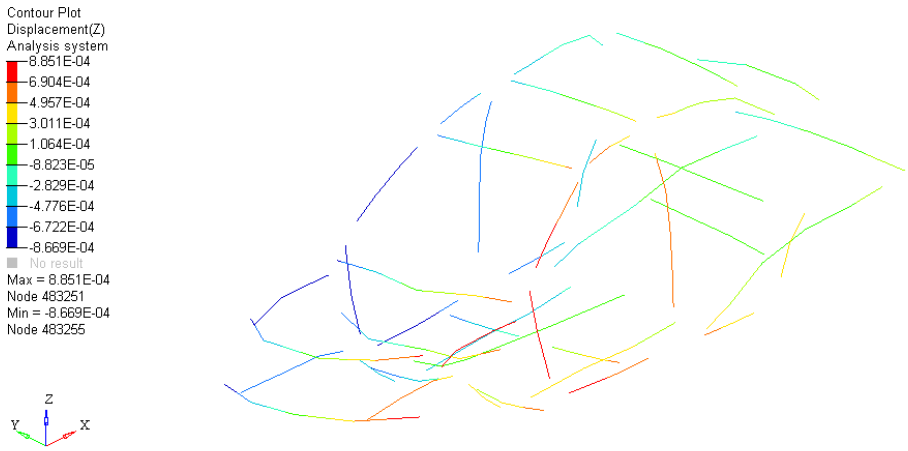



**Fig4.**: Displacement contour of concept vehicle model in torsion analysis





[ DOI: 10.22068/ijae.7.2.2372 ]

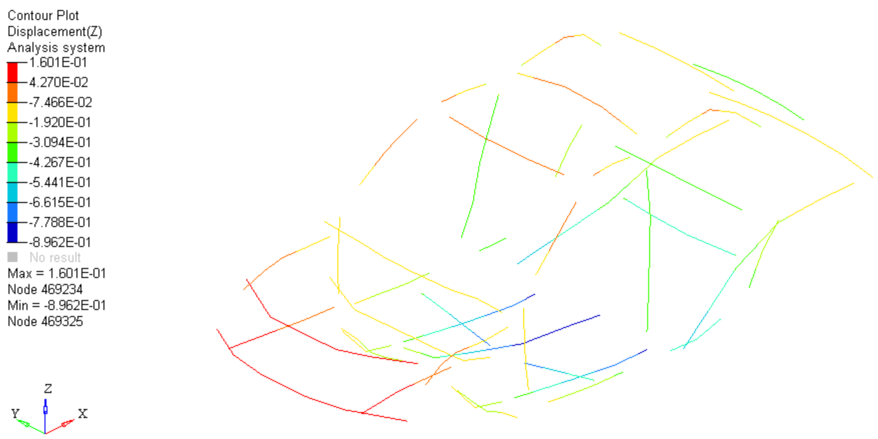



**Fig5.** Displacement contour of concept vehicle model in bending analysis

**Table 1:** The values of bending stiffness and torsional stiffness of original and Concept model and differences percent

| Model | Original model | Concept model | Percent difference |
|---|---|---|---|
| Bending stiffness | 13600 | 13184 | 3.15% |
| Torsional stiffness | 14600 | 14261 | 2.37% |

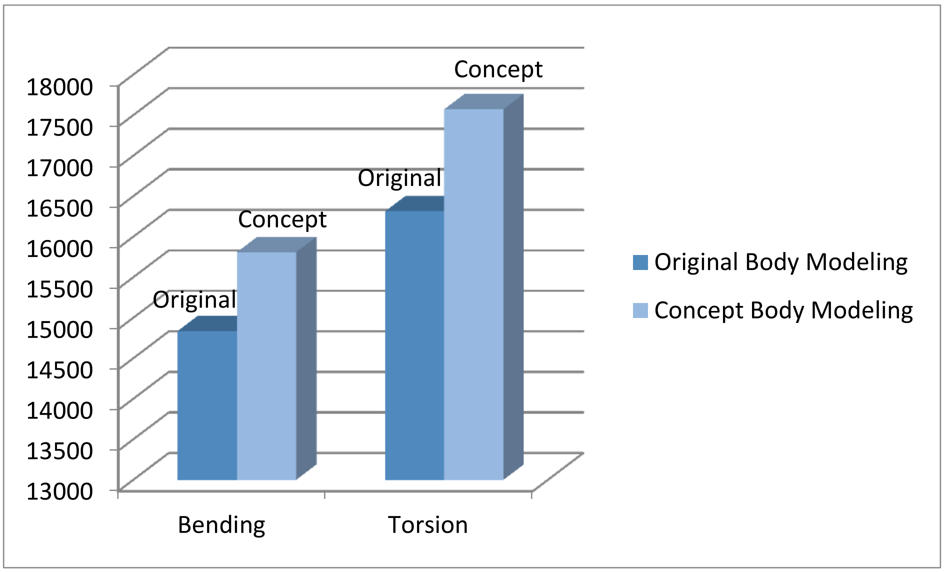



**Fig6.** Comparison of bending stiffness and torsional stiffness between original and concept models



[ DOI: 10.22068/ijae.7.2.2372 ]

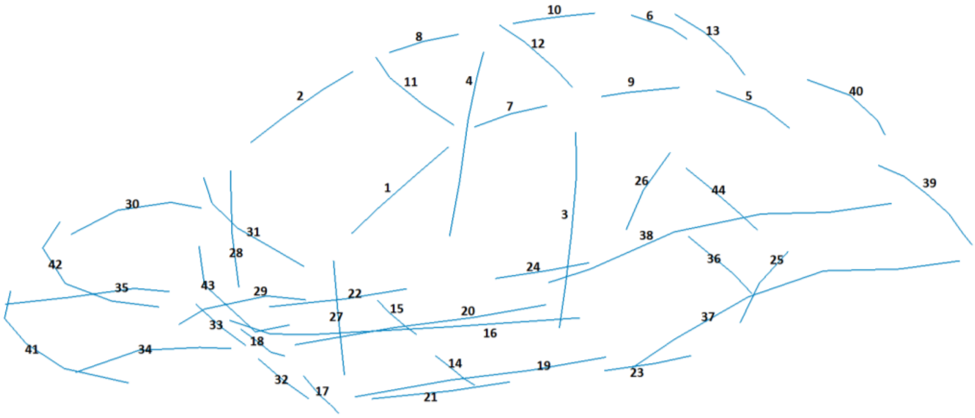



**Fig7.** Identification numbers of the equivalent beams

Automotive joints are the second main part of a BIW to be conceptualized. Once a joint is identified as that part of the body where concept beams are connected, a joint group is created that consists of the original mesh, delimited by the end sections of all converging beams, and includes the terminal nodes of each concept beam as well as the interpolation elements. Guyan reduction [13] is used to compute a static super element that contains stiffness relations between the end points of the joint (i.e. the beam center nodes). Guyan reduction involves partitioning the stiffness matrix into the connection DOFs and the internal DOFs, and applying a static reduction to the connection DOFs. The matrix equation can then be solved to find the displacements of the DOF subset of interest (i.e. the beam center node DOFs). Guyan reduction is the most common method for static condensation. It returns an exact reduced stiffness matrix, exploiting some static considerations between the master nodes of the joint [14].

The panels have an important contribution to the body stiffness. Concept panels are 2D components with a much coarser mesh than the original models. The concept panels are 2D elements with a much coarser mesh than the original models which some principal nodes of the real panel are used in order to the shape of the panel is approximately kept. A connection between the concept panel and the concept beams and joints is achieved by rigid elements.

## 4. Industrial case study

The CAD-to-CAE cycle takes time: currently, about 6 weeks are required to prepare the necessary data to create the BIW FE model, which is too long to allow a tight integration of traditional CAE tools in the concept design stage. In the concept phase, the focus is on the global stiffness, which is governed by a simplified geometry of main load-carrying components: linear elastic beams, joints, (a small subset of) panels. Simplified FE models can thus be used rather than detailed models for the early design process of the main load-carrying components. the FE model of a vehicle body, formed by over 100 panels, modeled with linear shell elements and assembled by means of about 3000 RBE2 Element connections.

To illustrate the concept modeling methodology described in Section 3, 44 beam-like members and 10 joint are to be replaced by conceptual elements as shown in Figure 2, 3. Finally, the vehicle concept model will be completed by three panels included front windshield, Rear windshield and the roof panels of the vehicle.

To validate the proposed approach, two static indicators of the full vehicle performance are considered. To assess the static behavior, the torsional and bending stiffness of the BIW is calculated. In torsion modeling, the body is clamped at the rear suspensions and reverse forces are applied at the front suspensions. Torsional stiffness is calculated by determining the displacement of the application load point. Displacement contour in the torsion analysis modeling of concept model result is shown in Figure 4.



[ DOI: 10.22068/ijae.7.2.2372 ]

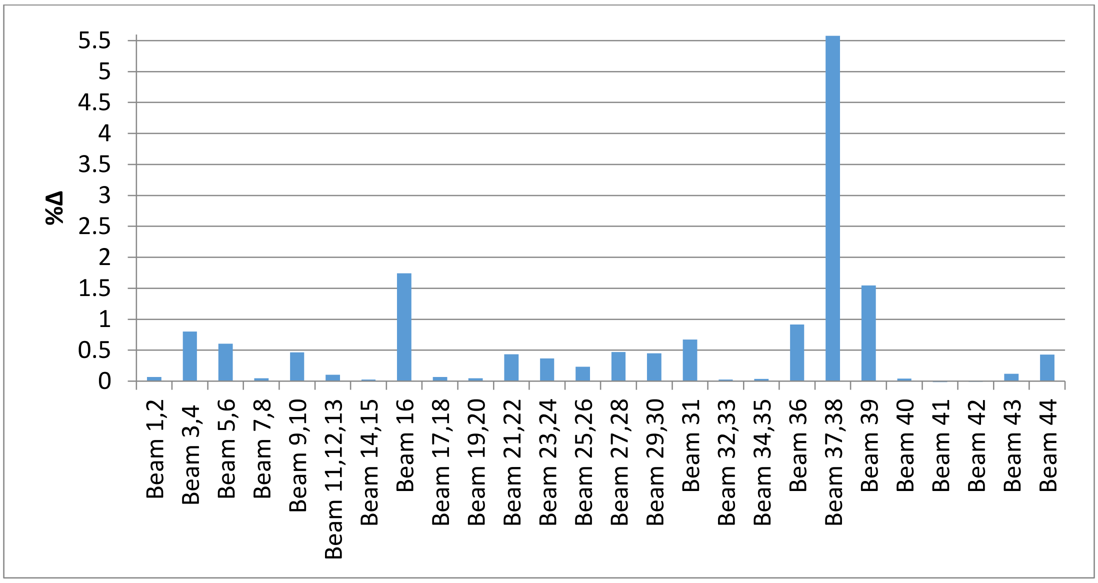
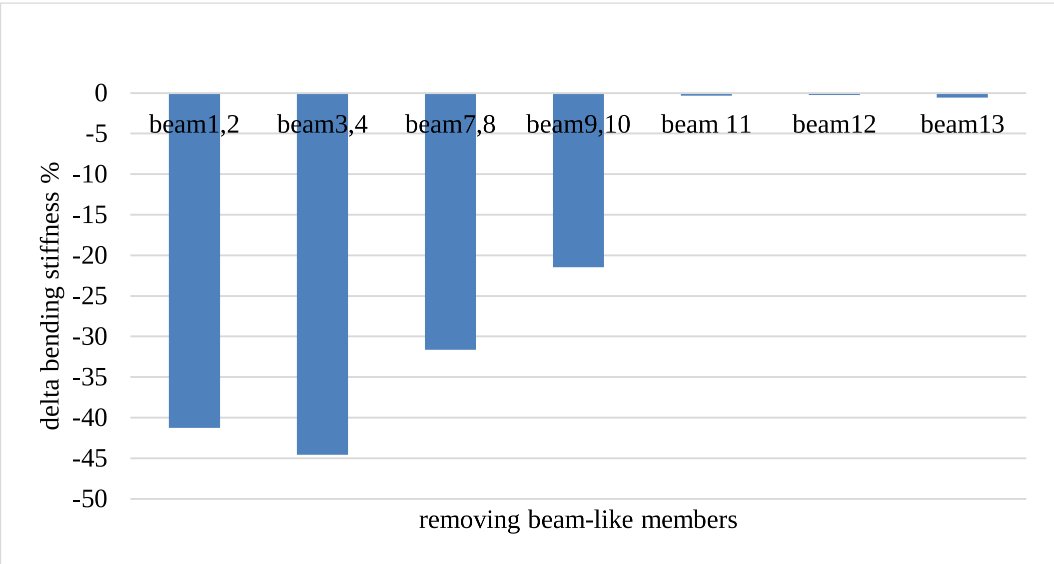


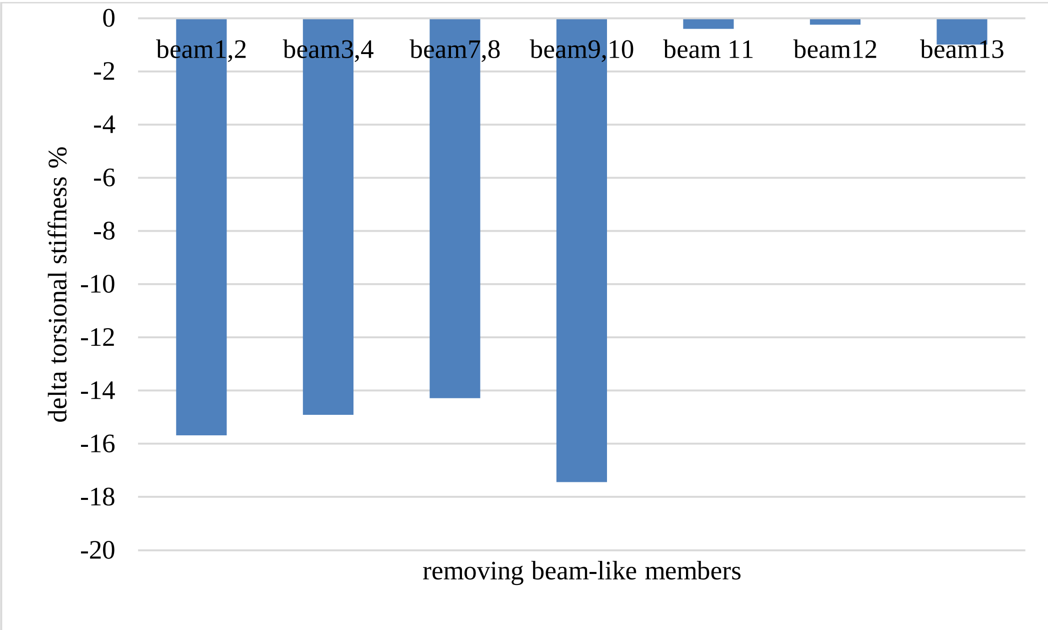

**Fig8.**: Evaluate effect of simplifying each beam separately




(a)



[ DOI: 10.22068/ijae.7.2.2372 ]




(b)

**Fig9.** Effects of removing beam-like members on (a) bending stiffness (b)torsional stiffness

Bending analysis is aimed to consider the strength of BIW bearing bending. For bending modeling, the body is clamped at the rear and front suspension and applied forces in passenger's seat. Bending stiffness is calculated by determining the displacement of under B-pillar due to applied loads. Displacement contour in the torsion analysis modeling of vehicle concept model result is shown in Figure 5.

To verify, the achieved results of bending stiffness and torsional stiffness for concept model are compared with the results of original model as shown in Figure 6 along with the Table 1. According to Table 1 as well as Figure 6, Concept models result is stiffer than their detailed FE counterparts. From the result can be concluded that with good approximation conceptual models can be used to model the vehicle body.

Identification numbers of the equivalent beams of the BIW is shown in Figure 7. Due to the symmetry of the vehicle body model, 44 equivalent beams are considered with 26 separate analysis in order to evaluate the effect of the situation of an equivalent beam in vehicle modeling. In Figure 8 the effect of simplifying each beam separately are computed.

As a sensitivity analysis to evaluate the effect of beam-like members on bending and torsional stiffness of vehicle BIW, a series of static analysis are performed. In each of the analyses, one beam-like member is removed and the stiffness of the BIW is calculated again. In this way, each of the beam-like members is labeled, as shown in Figure 7. In the Figure 9, the influence of each beam on the vehicle stiffness is indicated as percentage difference with the base model. It is expected that all modifications result in a loss of stiffness, i.e. a negative relative difference. The result shows B-pillars have the significant effect on the BIW stiffness. By removing B-pillars, bending and torsional stiffness are reduced %44 and %15 respectively. The results also show that transversal roof-rails have the least effect on bending and torsional stiffness.

## 5. Conclusion

The advantages of using this simplified modeling are to make the modification process easier and quicker and to save the calculation time (With a few elements.). In this paper, a conceptual modeling technique is applied to simplify the beams, joints, and panels. The proposed approach is illustrated by using an industrial case study. Two load cases were defined and analyzed to compare the original and the concept models of vehicle in terms of bending and torsional stiffness. The results show high accuracy of the concept models in comparison with the original model in bending and torsional stiffness prediction which proves that the proposed approach can be used as a valid tool also in the early phases of the vehicle design and development process.





[ DOI: 10.22068/ijae.7.2.2372 ]

## References

[1]. M. Shephard, M. Beall, R. O’Bara, and B. Webster, (2004). Toward simulation-based design, Finite Elements in Analysis and Design, 40(12):1575–1598.

[2]. S. Dondersa, Y.Takahashia, R.Hadjita, T.VanLangenhovea, M.Brughmansa, B. VanGenechtenb, W.Desmetb, , (2009). A reduced beam and joint concept modeling approach to optimize global vehicle body dynamics, Finite Elements in Analysis and Design 45, 439—455.

[3]. H. Shiozaki, Y. Kamada, S. Kurita, S. Goossens, J. Van Herbruggen, V. Cibrario, and L. Poppelaars. (2005). CAE based vehicle development to reduce development time. In Proceedings of the JSAE Annual Congress, number 20, Yokohama, Japan.

[4]. R. Hadjit, M. Brughmans, H. Shiozaki, (2005). Application of fast body optimization procedures to shorten car development cycles, in: Proceedings of the JSAE Annual Congress, vol. 18, Yokohama, Japan.

[5]. Torstenfelt B, Klarbring A. (2007). Conceptual optimal design of modular car product families using simultaneous size, shape and topology optimization. Finite Elem Anal Des;43:1050–61.

[6]. Wei Chen and Wenjie Zuo, (2014). Component sensitivity analysis of conceptual vehicle body for lightweight design under static and dynamic stiffness demands, * Int. J. Vehicle Design, Vol. 66, No. 2.

[7]. Moroncini A, Cremers L, Kroiss M (2010), NVH structural optimization using beams and shells FE concept models in the early car development phase at BMW. In: Proceedings of the international conference on noise and vibration engineering – ISMA 2010, Leuven, Belgium.

[8]. S. Donders, Computer-Aided Engineering Methodologies for Robust Auto- motive NVH Design, Ph.D. Thesis, K.U. Leuven, 2008.

[9]. D. Mundo, A. Maressa, N. Rizzo, S. Donders, W. Desmet, A database frame- work for industrial vehicle body concept modelling, in: Proceedings of the 3rd WSEAS International Conference on Finite Differences - Finite Elements - Finite Volumes - Boundary Elements, F-and-B ’10, 2010.

[10]. P. Mihaylova, N. Baldanzini, A. Pratellesi, M. Pierini,On the improvement of concept modeling of joints within simplified finite element models with application. to structural dynamics, in: Proceedings of the International Conference on Noise and Vibration Engineering—ISMA 2010,2010.

[11]. G. Osborne, G. Prater, A. Shahhosseini, Finite element concept modelling methodologies for pickup truck boxes, Int. J. Heavy Vehicle Syst. 17 (1) (2010) 1–17.

[12]. LMS International, LMS Virsual.Lab Sturctures, Rev 10-SL3Guyan RJ (1965) Reduction of stiffness and mass matrices. AIAA J 3:380

[13]. G. De Gaetano, D. Mundo, I. Cosco, C. Maletta, S. Donders, (2014). Concept Modelling of Vehicle Joints and Beam-Like Structures through Dynamic FE-Based Methods, Hindawi Publishing Corporation Shock and Vibration Volume, Article ID 303567, 9 pages.





[ DOI: 10.22068/ijae.7.2.2372 ]