

# Concurrent Styling, Engineering & Analysis for Body structural optimization

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## ABSTRACT:

The objective of this paper is to achieve structurally optimized body by improved approach of simultaneous styling & engineering analysis to understand structural behavior in the initial phase of body design. Understanding of the structural behavior through virtual validation of concept frame while styling is in progress can help to reduce the cycle time.

Traditionally body structure engineering and analysis is a lengthy process which starts sequentially after the computer aided styling (CAS) is available and concept & feasibility is completed. Conventional approach of body structure design involves surface generation with reference to benchmarking of vehicle for joinery and master section finalised. This conventional finite element method usually deals with a large sized computational model and thus hinders efficient design evaluation.

In new methodology, body structural performance targets are selected from benchmark vehicle. Design calculations are done and section properties of body critical members are determined. BIW is represented by 3D beam elements and the beam model strength analysis is conducted. NVH targets are also evaluated on beam model. A methodology is developed based on calculations for master sections & Chassis frame using shear flow method & combine loading (bending & torsion) for body. After selected materials, gauges (Thickness), geometric properties & manufacturing processes, final virtual validation analysis is carried out on 3D body data. The virtual validation results are in good correlation with the actual test results.

This methodology of structural optimization of body design provides an extremely fast route to ensuring the vehicle's body structure meets or exceeds the relevant basic structural targets, this is discussed in detail.

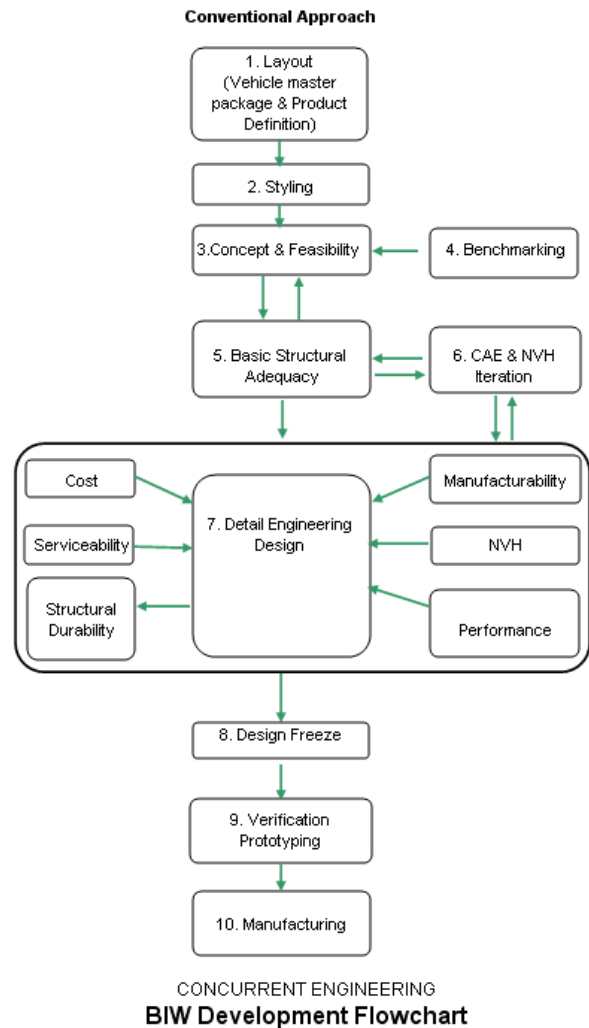
**OBJECTIVE:** The objective of this paper is to discuss the improved approach of BIW design. Understanding of the structural behaviour in the initial phase of BIW design can help to reduce the number of virtual prototypes and the time taken for their evaluation. This is based on concurrent styling, benchmarking, Engineering & Analysis.

## GOAL AND OBJECTIVE:

1. Reduction of Vehicle design and development cycle time.

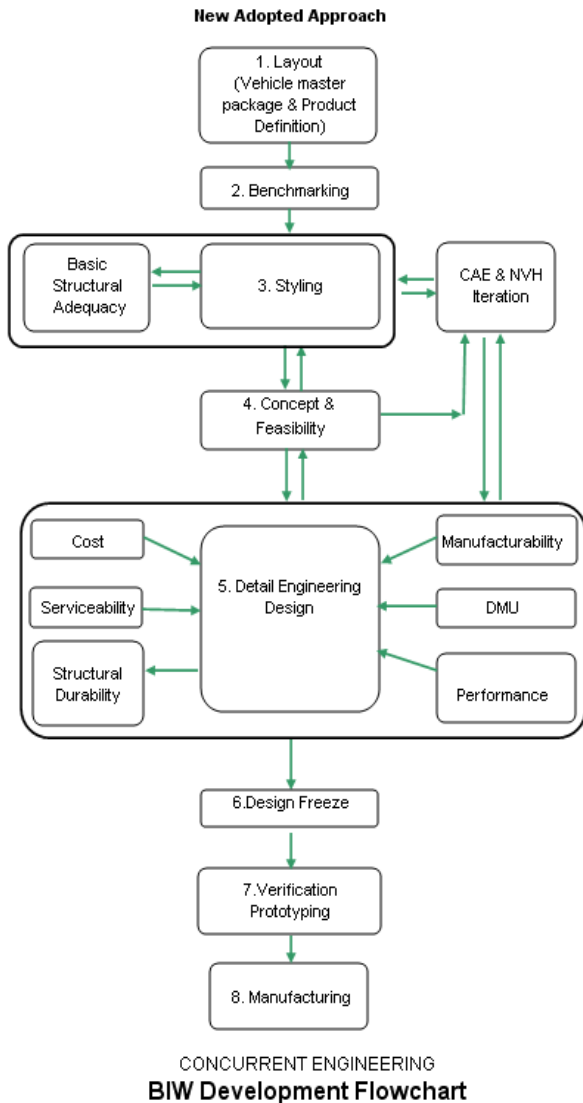
2. First Time Right structurally optimized design.
3. Reduce number of physical and virtual prototypes.
4. Understanding of structural behaviour in the initial phase of BIW design
5. Improved vehicle design

**CONVENTIONAL APPROACH:** Traditionally BIW structure engineering and analysis are lengthy process which starts sequentially after CAS is available. Conventional approach of body structure design is graphically represented on the flow chart below.



## NEW APPROACH:

Graphically represented on the flow chart below



In new methodology, basic body structural performance targets are set based on historical benchmark data. The new concept BIW structure is represented by tubular frame represented virtually inform of 3D beam elements joint to each other at nodes. The 3D beam elements represent critical master sections of the BIW responsible for achieving structural adequacy. Each 3D beam is then broken down in to multiple elements represented by 1D element virtually. 1D elements are assigned with cross section properties representing the master section.

- CAE is carried out on the BIW frame to verify the compliance with basic structural stiffness targets.
- Weak zones and critical joineries are identified.
- Master sections are redefined
- Critical joineries are strengthened by improving the joint definitions.
- Additional beams are introduced in the structure if necessary.
- Non performing beams are eliminated/ repositioned for optimized structural performance.

All above steps are concurrently undertaken while styling is in progress thereby saving time during final analysis.

## Beam Model Preparation

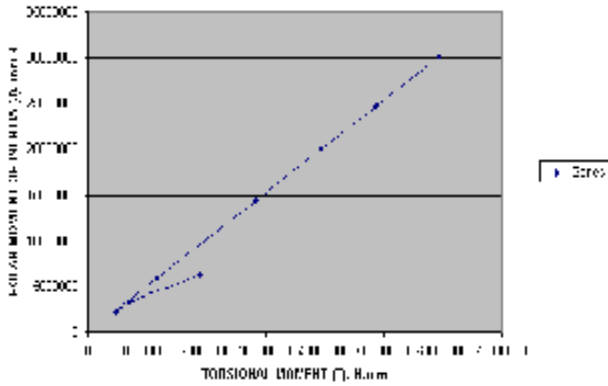
### STEP:1

As per structural performance targets selection of cross-sections is done based on manual calculation. A library of organs is used to generate Beam model efficiently. Some beam cross-sections and properties are listed in below table. Each project generates new organs creating an extensive knowledge bank. Such a bank is a resource of expertise and knowledge is thus readily transferred and the design process is not dependent on particular individuals and their subjective value judgments.

Side Sill Section					max Z I W	max J I W
THA	0.0	0.0	0.0	0.0		
Ixx	906772	269632	521475	693291		
Iyy	274770	152733	144690	114582		
Ixx-yy	72	98	82	70		
Zmax	6289.0	4314.2	7389.2	5779.2		
Zmin	681348	552891	481299	519592		
Zmax mm	6.283	4.314	7.389	5.779		
Zmin mm	681351.701	552894.729	481302.488	519595.784	3900377	
Z I W	38446.3366-51	31385.2286-1	52886.24352	34366.51875	33893.845	

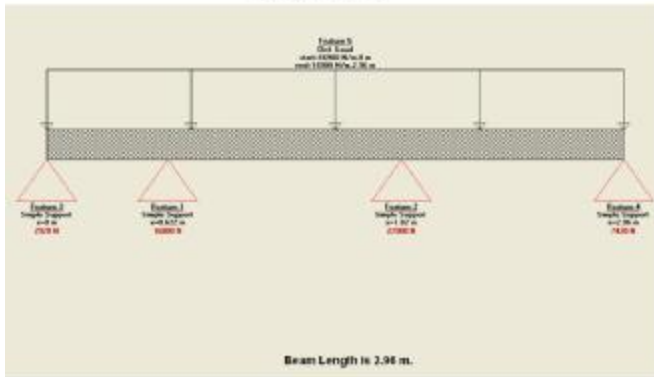
Chassis Long Member					max Z I W	max J I W
THA	0	0	0	0		
Ixx	8450322	580567.012	31958.352	324860.592	362847.372	
Iyy	487850	4524324632	479399.292	32916.202	452521.852	
Ixx-yy	50.50	40.50	40.80	50.888	50.50	
Zmax	244.82	14325	11422	19682	18212	
Zmin	2804.078	1894609	1248229	1244229	1284519	
max / 100 mm	0.411	0.401	0.424	0.436	0.412	
Z I W	3194.1128	2538925.347	3704485.174	370394.510	3701758.283	5194811
J I W	33858.48203	25785.98332	4033184205	402801.81209	25885.98841	33858.482





For body section calculation, Shear flow method used.

Forces values



Considering roof impact as UDL

Calculation of moment of inertia by two different consideration				
CONSIDERING PILLAR AS AXIAL LOADING				
PILLAR	REACTION (kN)	LENGTH (MM)	YOUNG'S MODULUS (N/MM <sup>2</sup> )	MOMENT OF INERTIA (I) (mm <sup>4</sup> )
A	200	650	200000	6521.249573
B	1800	1375	200000	139270.9414
C	2200	1350	200000	162265.9184
D	720	1350	200000	58957.34125

CALCULATION BY CHASSIS REACTION BY 50% OVERLOAD 1+0				
			I for LH & RH pillar (mm <sup>4</sup> )	I for single pillar (mm <sup>4</sup> )
A	876	650	200000	1656.373162
B	8130	1375	200000	22732.82614
C	6470	1350	200000	61806.59136
D	1900	1350	200000	17928.81562

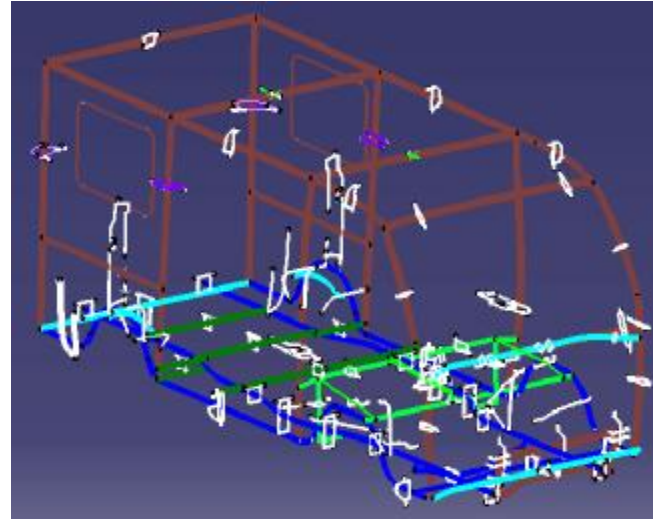
Calculation of bending moment, shear force, cross section area and section modulus by 1:1 load for 1:1:1							
Member	Equation	joint strength	section modulus	area cross of material	equivalent stress	area considering factor of safety	area considering factor of safety 1
1	Area of front panel	100					
2	Area of front panel	100					
3	Area of front panel	100					
4	Area of front panel	100					
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100	Area of front panel	100					

Section properties like, Section Modulus, Moment of inertia, Polar moment of inertia comparison done with benchmark data.

Software used: MS Excel and Beam Boy

**STEP: 3**

Based on initial rough cut styling surface a beam model is prepared taking structural & nonstructural members into account all the features that are finalized from the product definition. The beam model master sections that best fit the quantitative and qualitative criteria of product definition is selected. This beam model is subjected to CAE & NVH analysis for determining the structural adequacy.



2D section placed along the neutral fiber.

Software used: Catia V5R17

**STEP: 4**

**CAE & NVH ANALYSIS:**

**CAE ANALYSIS:**

Bending and torsion analysis is carried out to identify weak beams and critical joineries.

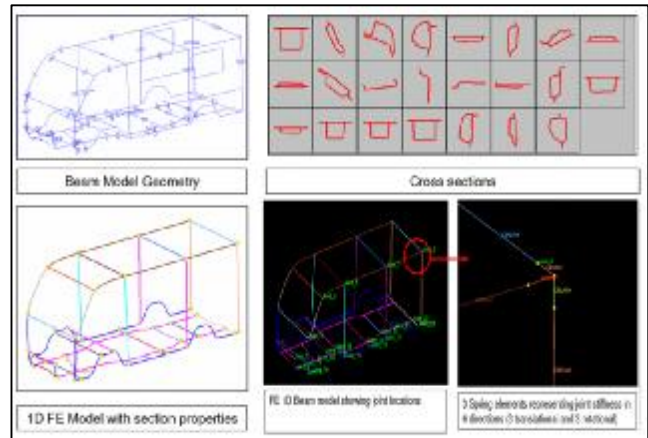
**Bending Stiffness:** The main static bending loads are transverse loads acting vertically downwards on the body, such as engine, passengers etc. Additional bending occurs from the dynamic behavior of the vehicle such as surface irregularities. To design a BIW with a high bending stiffness has to ensure section modulus is higher in Z-direction as the second moment of area of the body will be higher.

The second moment of area of a section is the constant that measures how much of the beams material is distributed about the neutral surface of bending. Material near to the neutral axis doesn't contribute much to the I value. For example beams such as I beams are considered very stiff in bending however they are not good in torsion. Techniques such as corrugating thin sheet metal is often used in body design to increase the second moment of area of thin sections.

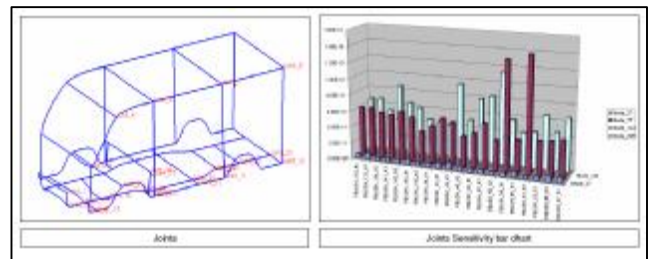
**Torsional Stiffness:** A BIW also has to be stiff enough to withstand loads that produce twisting moments and hence must be stiff in torsion. Torsional loads occur frequently when a vehicle drives over uneven terrain; however the main torsional loads occur on account of dynamic loads during high speed cornering. A BIW that is not sufficiently stiff to withstand these loads can have catastrophic results.

Torsional stiffness is essentially the ability of a structure to resist twisting loads. (i.e. it's the constant of proportionality between the applied torque and the angle of deflection)

Essentially the aim of the BIW structural designer is to get the structure to behave as closed to a closed box as Modes corresponding to the peak point Mobility possible. This is achieved by incorporating bending and torsional structural elements into the body of the vehicle.



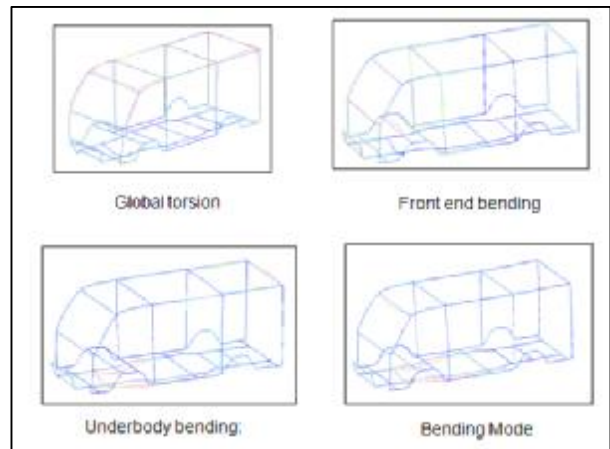
Beam model – modeling of Sections Table & joints



Joint sensitivity analysis

	Front Suspension	Spring Dishes	Cradle Front	Cradle Rear	Transmission	Rear Suspension Front	Rear Suspension Rear
Baseline	52.8	49.4	58.7	57.2	51.4	52.7	51.1
B Pillar Modified	51.1	49.1	48.4	48.9	58.7	52.1	51.4
Updated	50.9	49.1	48.4	48.8	58.1	51.8	50.6
Proposal 1	50.7	49.9	48.4	48.8	58.0	51.8	50.0
Proposal 2	50.7	48.9	48.1	48.8	58.2	51.8	48.9
Proposal 3	49.1	49.4	48.1	50	50	51.8	49.0
Proposal 4	52.3	49	52	50.4	58.0	51.8	50.0

Comparison of response at cradle & suspension mountings on body, for multiple iterations– to find best fit



**NVH ANALYSIS:** In order to have good NVH, it is necessary to place global modes of body like bending, torsion & matchboxing away from idle excitation frequency & should be well separated to avoid coupling. Also it is necessary to ensure that the powertrain & suspension mounting locations on body have sufficient local stiffness so that forces coming from road & powertrain don't affect the tactile vibrations & incab noise. Global modes are governed mostly by the body sections & the local modes by the joint stiffness. Global & local stiffness of the body can be evaluated in terms of normal modes and point mobility respectively. In beam model sections are defined as properties using Hyperbeam module in Hypermesh 10.0 which can be easily modified for multiple iterations. Joint stiffness is modeled using CBUSH (spring) elements. Joint stiffness is calculated by carrying out static stiffness analysis of FE models of joint. Further joint sensitivity analysis is carried out to find out which joints need to be strengthening to improve the normal modes & point mobility. Thus using beam model body sections & joints are optimized with normal modes & point mobility as governing parameters.

#### **STEP: 5**

Final changes done as per the CAE / NVH results and again step 4 repeated. CAE & NVH analysis provide complementary results leading to an optimized BIW structure. After achieving the final results target Detail Design Engineering start.

#### **Advantages:**

Time taken in last development of BIW was: Benchmarking: 2 months, Concept feasibility: 3 months and for CAE 8 months.

With new adopted approach time taken is: 8 months for benchmarking, Concept feasibility and CAE by concurrent engineering. Time save is 5 months.

With above tangible advantages also having some intangible advantages are NVH & structural optimization of the BIW performed at the earliest phase of the vehicle design process, reduces the number of physical & virtual prototypes.

#### **Conclusion:**

The new approach of BIW development drastically reduces the development time, cost & improves first time right quotient. This approach also enhances the BIW structural performance with minimum iterations. This approach is extensively used in all upcoming vehicle models of Mahindra & Mahindra Ltd. India.

#### **References:**

1. Vehicle **Body Engineering**. by **J. Pawlowski**
2. Handbook of **automotive body and system design** by **John Fenton**

#### **Guided By:**

1. **Prashant Navsariwala Body system Design**, Sr. Manager, Mahindra & Mahindra Ltd. India
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