King Mongkut's University of Technology Thonburi

Design of Lightweight Electric Bus in Thailand using Composite Materials

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Outline

- Introduction
- Design Concept and Criteria
- Numerical Model
- Structural Analysis
- Parametric Study
- Design Improvement
- Conclusions

Introduction

International Energy Agency

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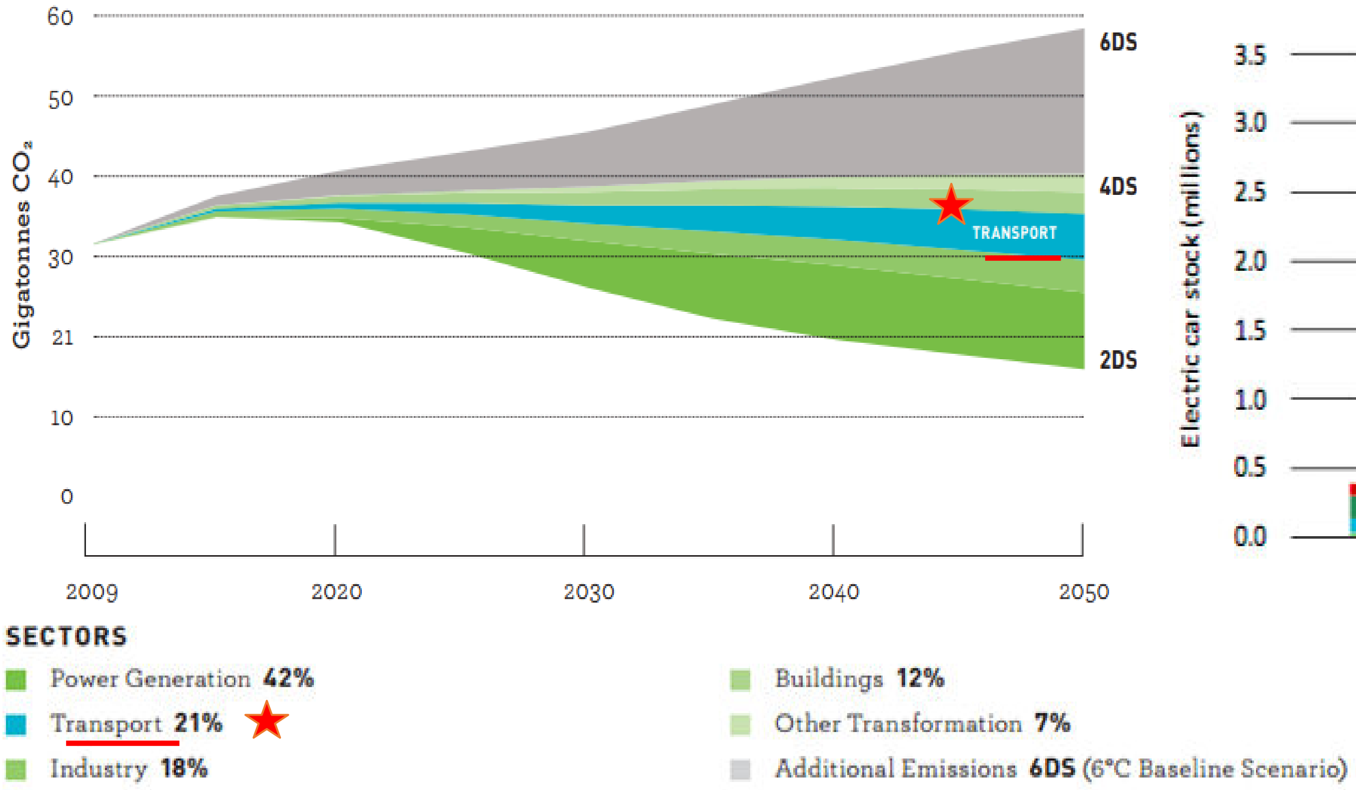
- The International Energy Agency, IEA forecast the 6 degree warming in 2050.

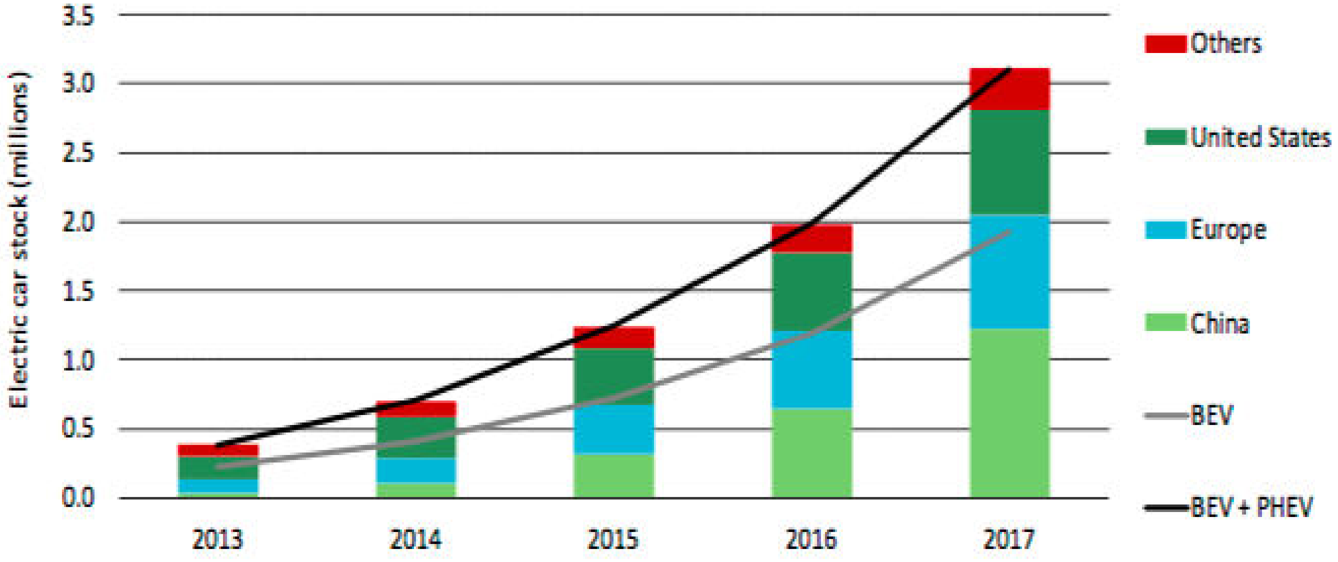
- 2 degree scenario by IEA.



Source: IEA, Global EV Outlook, 2013.

- Evolution of the global electric car stock, 2013-17.

- EV stock surpassed 3 million vehicles in 2017.



Source: IEA, Global EV Outlook, 2018.

Design Concepts

1. Electric Bus is designed for intercity transport and multi-purpose utilization with 24 seated passengers.

- Electric Bus is more safe and replaced current inter-city vans.

2. Driving range projects to be 300 kilometers.

- Routes are planned from Bangkok to surrounding cities including Kanchanaburi and Chonburi.

3. Electric bus will be charged at a starting station.

- Battery has to have an enough capacity for round trip.

4. Composite materials are used to fabricate a body of electric bus.

- The body is constructed by a monocoque structure with top and bottom parts

Design Concepts and Criteria

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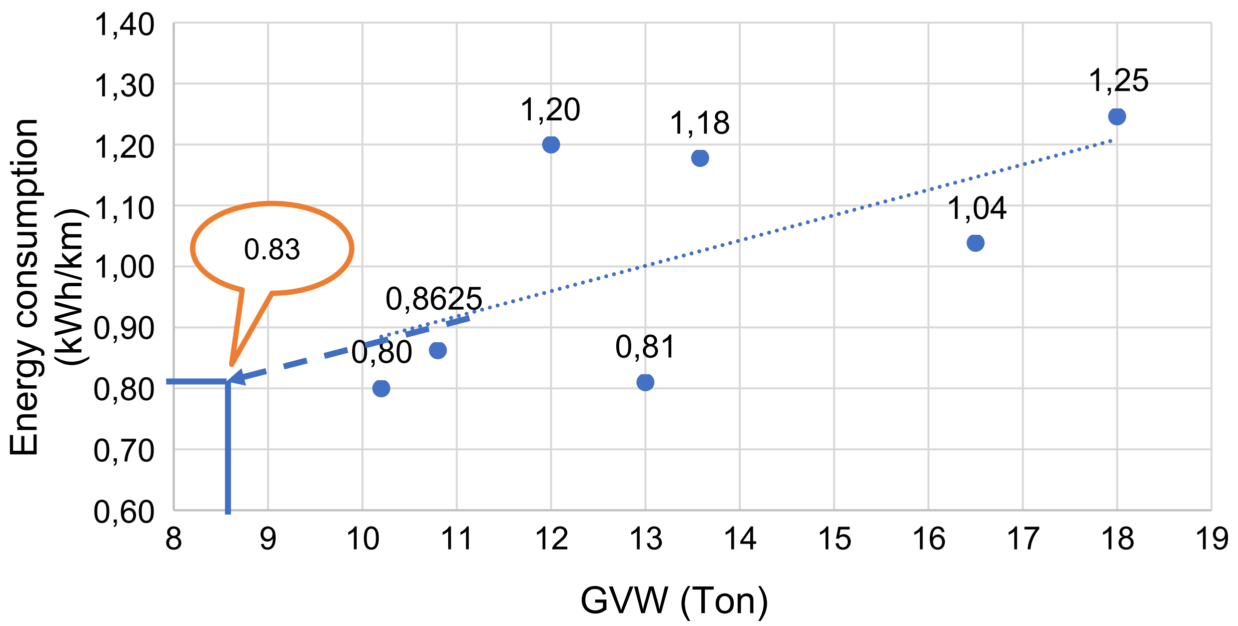
A scaling analysis is performed based on specifications of electric buses to design an adequate battery capacity against expected driving range of 300 km.

Relation of energy consumption and gross vehicle weight (GVW)



Conclusions on Battery Capacity

- An actual battery capacity for service should be calculated at 80% of full capacity.
- A required battery capacity is 320 kWh and weight of battery is 1,280 kg based on energy density of 250 Wh/kg.

Design Criteria

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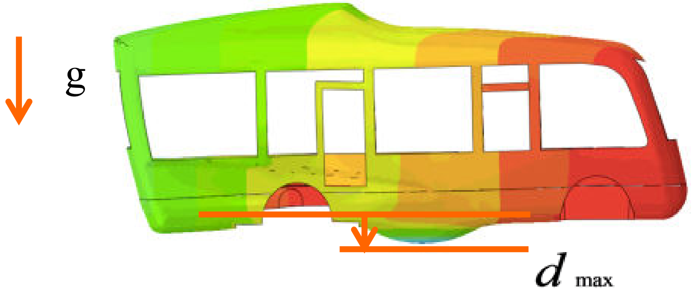
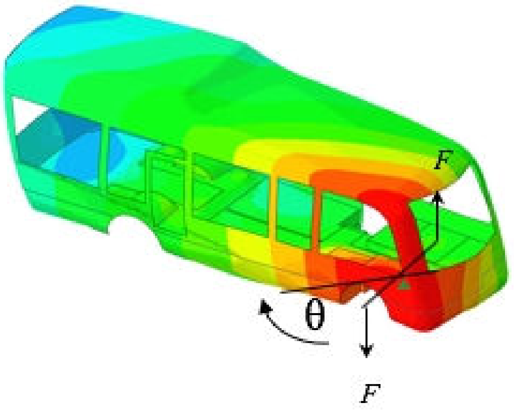
Structural Requirements

- ❑ Bending Stiffness ≥ 36,000 N/mm
- is ability of vehicle body for carrying the weight of components.



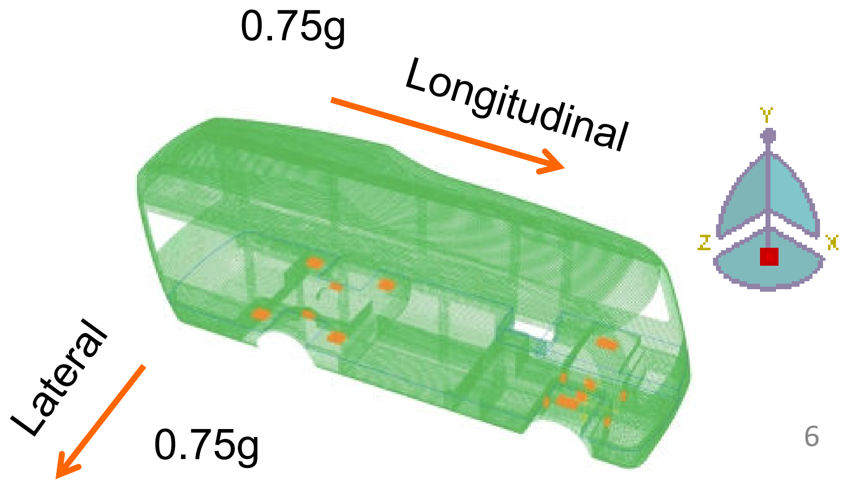
- ❑ Torsional Stiffness: 18,000-40,000 Nm/deg
  - is the structural rigidity of bus body to withstand twisting.



- ❑ Natural Frequency
- 1st mode of bending frequency > 5 Hz

Driving Conditions

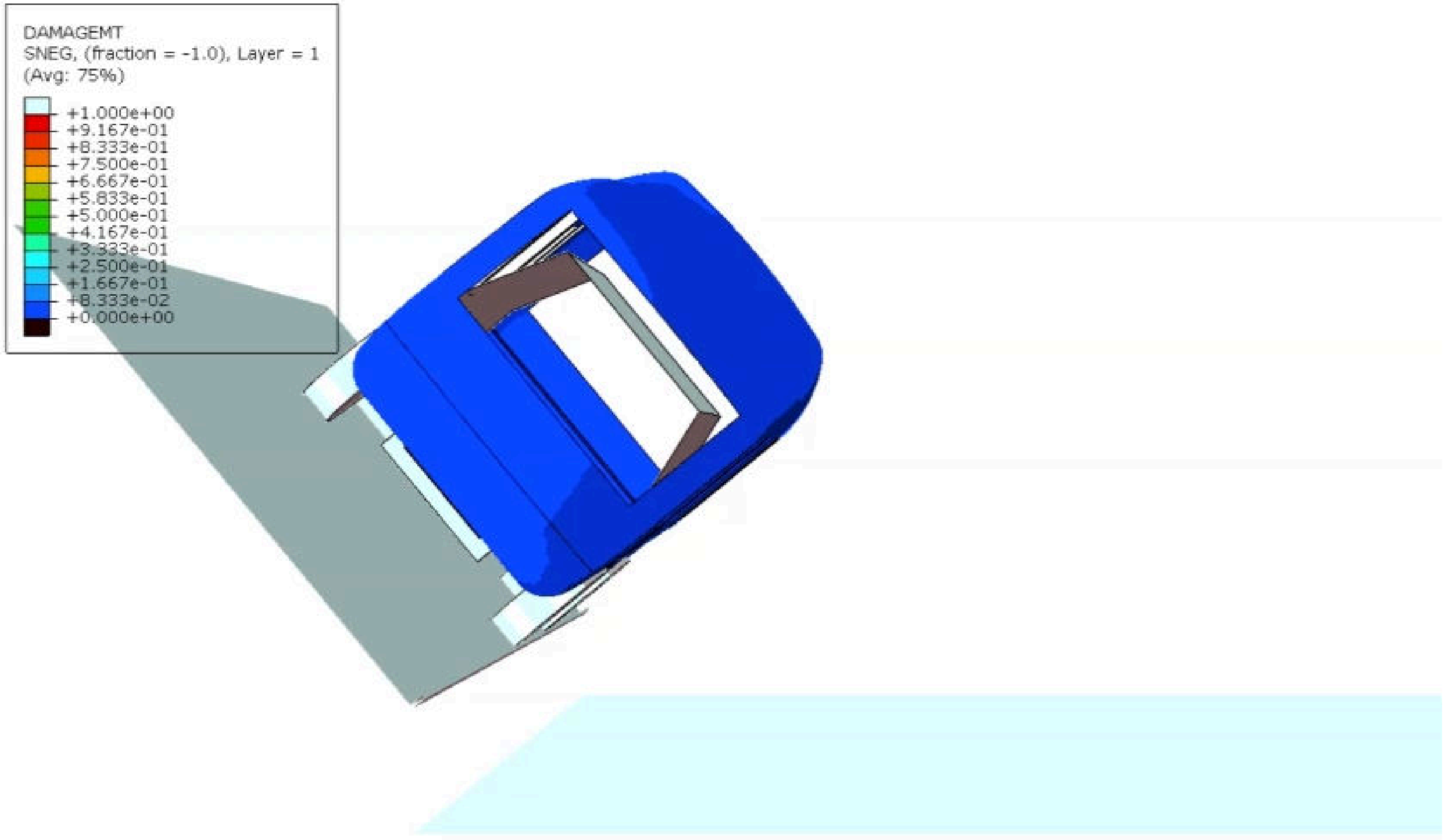
- ❑ Longitudinal Loading occurs when the bus is accelerated or decelerated.
- ❑ Lateral Loading happens when the vehicle is driven around the corner or turning.



Design Criteria

Rollover Test by UN ECE-R66

- United Nations Economic Commission for Europe (UN ECE) is a working party cooperated for creating regulatory framework.
- Applied to single-deck vehicles designed for carriage of more than 22 passengers excluding passengers and crew.
- Rollover test and criteria are shown in the video.



Numerical model

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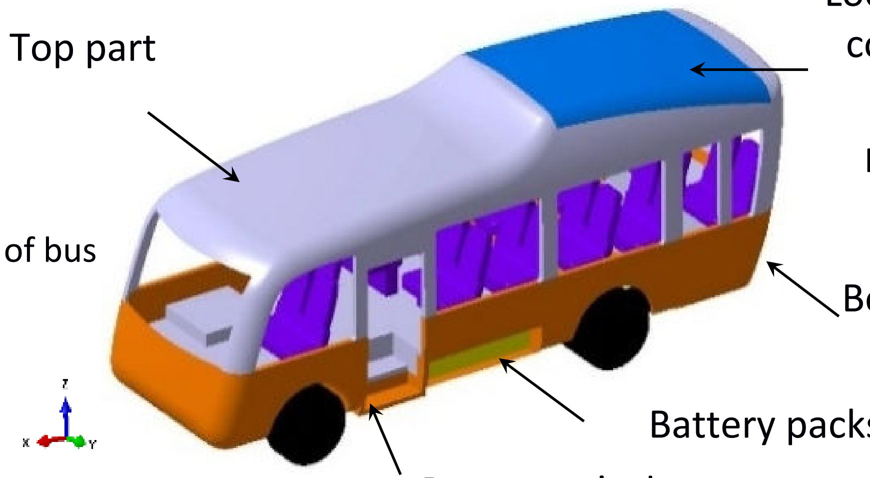
Materials for monocoque structure

Materials	Type
Core	DIAB DIVINYCELL H100
Face	glass cloth with density of **400 g/m2 (G400)**
	glass cloth with density of **600 g/m2 (G600)**
	carbon cloth with density of **200 g/m2 (C200)**

- The initiation of material failure is detected by Hashin criteria.

Monocoque structure



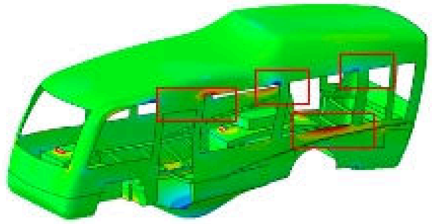
Dimensions	meters
Width	2.55
Length	8
Height	3.2

Structural analysis

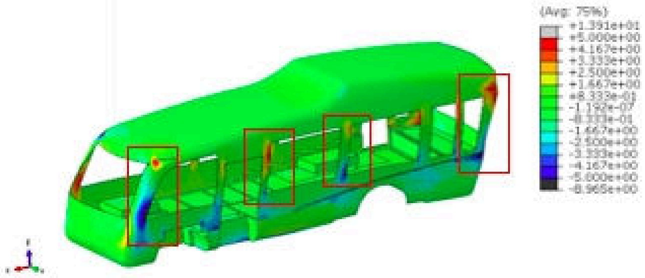
Preliminary investigation

- Initially, G400/epoxy face and foam core are assigned to the entire bus components as the first model in the analysis stage.

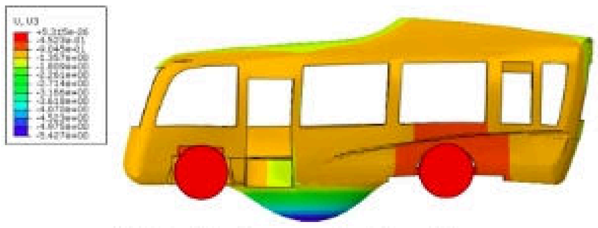
Static analysis



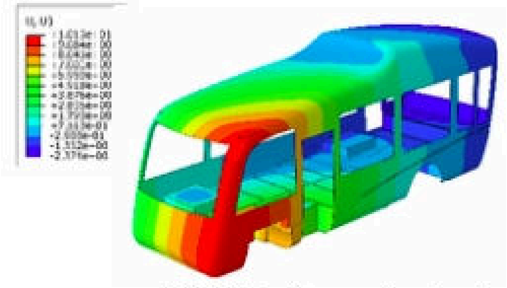
(a) Stress distribution (σ_{11}) under longitudinal load



(b) Stress distribution (σ_{22}) under lateral load

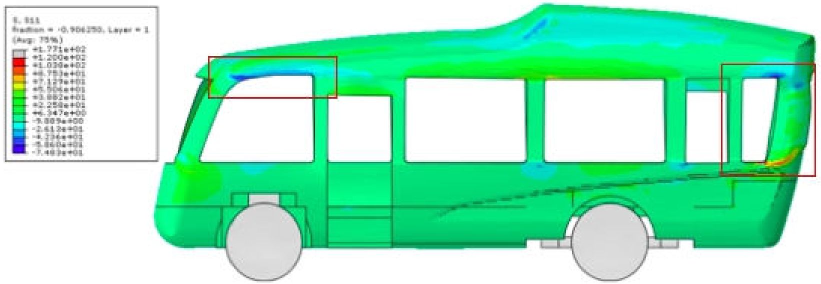


(c) Deflection under bending



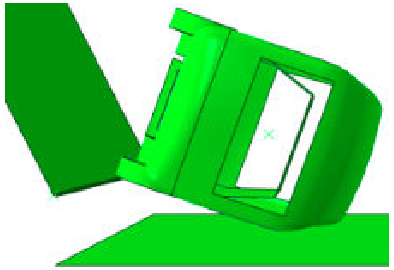
(d) Deflection under torsion

Roll-over simulation by means of explicit dynamic

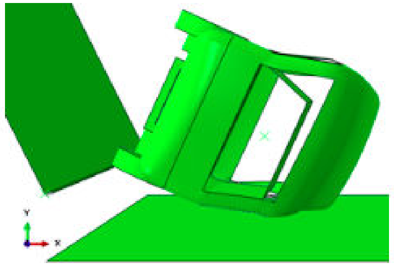


Consecutive roll-over simulation at each stage

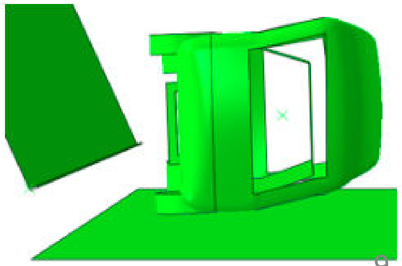
t = 0 sec



t = 2.55 sec



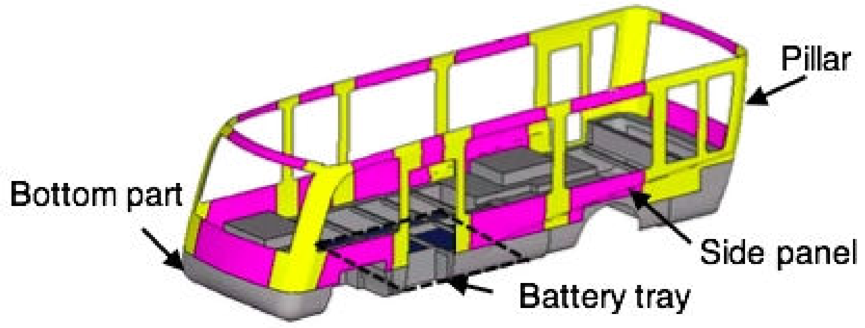
t = 2.66 sec



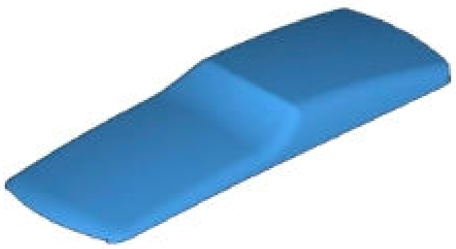
t = 3.08 sec

Structural analysis

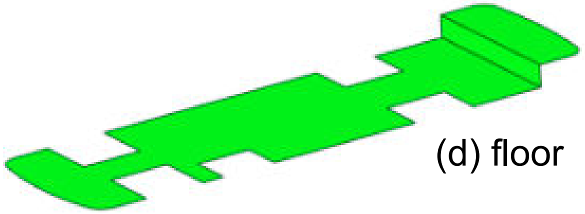
- According to considerations of stress localizations under each load case, the bus structure is therefore partitioned into 7 components.



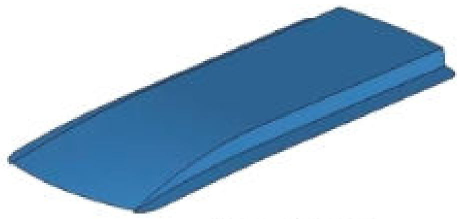
(a) Pillar, Side panel, Bottom part, Battery tray



(b) Roof cover



(d) floor



(c) Ceiling

Redesigned and modified model

- Bending stiffness of the bus is **extremely insufficient** due to a **large deformation** at the battery tray location.

$$K_B = 21{,}722 < 36{,}000 \text{ N/mm}$$

⇩

- Battery tray is partially replaced the face material of G400 by C200 that provides higher modulus and also increase the core thickness.

Bottom part	Side panel	Floor	Pillar	Battery tray	Ceiling	Roof cover
G400			G600	C200 G400	G400	G400
Foam			Foam	Foam	Foam	
G400			G600	G400 C200	G400	

Baseline model: $K_B = 32{,}042$ N/mm

Parametric study

Methodology

Establish bending and torsional stiffness as responses of interest

↓

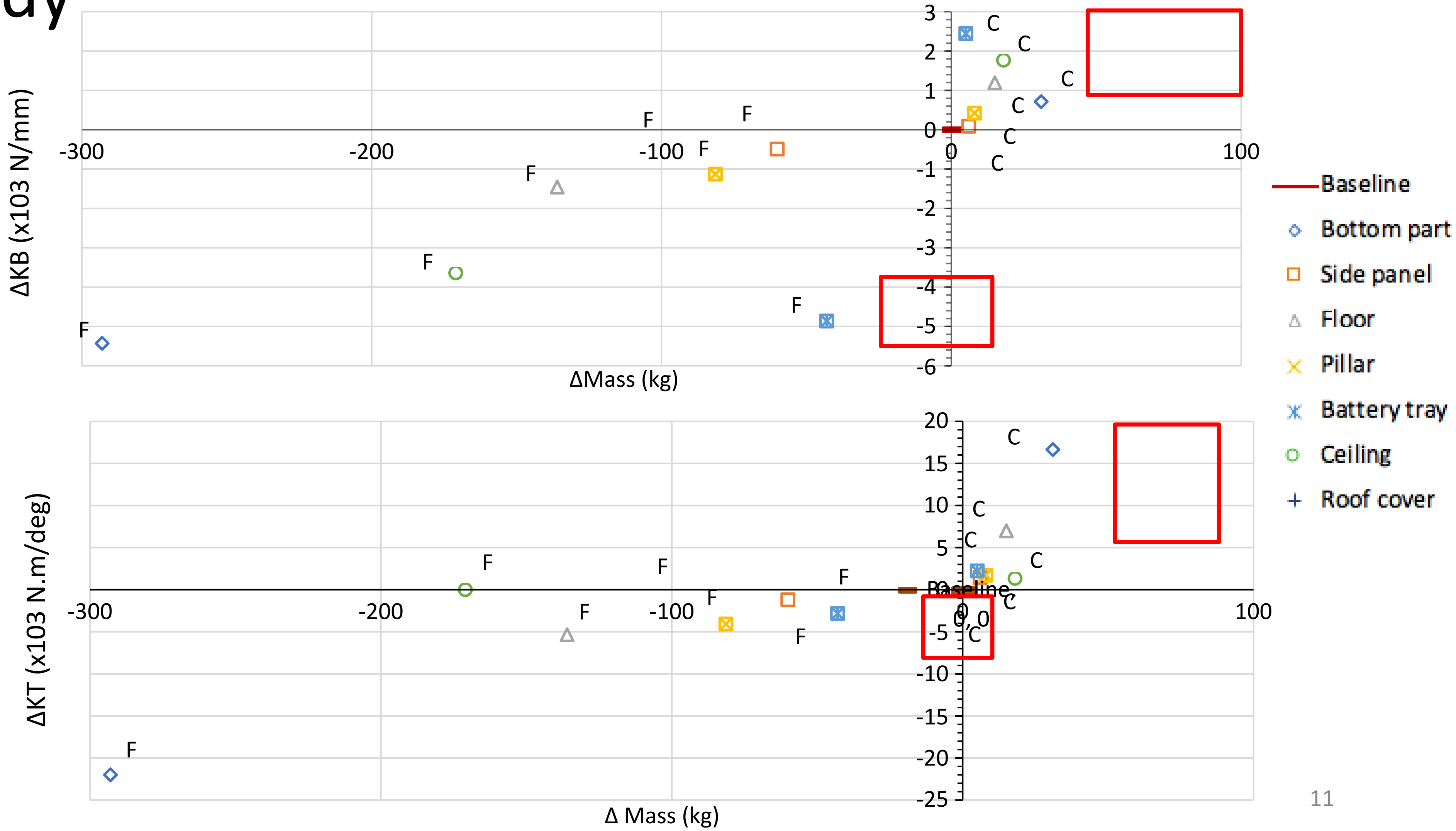
Thickness variations

- **increasing** the core thickness of each component by **10 mm** or
- **reducing** the face's thickness on each side of the sandwich structure by **3 mm**

↓

Improve structural stiffness based on specific stiffness determination

ΔK/ΔM



Parametric study results

- Functions of structural mass and stiffnesses can be linearly formulated.

Component	Δt_C = 10 mm					Δt_F = -3 mm				
	ΔM	ΔK_B	ΔK_T	$\Delta K_B/\Delta M$	$\Delta K_T/\Delta M$	ΔM	ΔK_B	ΔK_T	$\Delta K_B/\Delta M$	$\Delta K_T/\Delta M$
Bottom part	31	714	16645	23.0	536.9	-293	-5429	-21988	18.5	75.0
Side panel	6	88	1458	14.7	242.9	-60	-490	-1194	8.2	19.9
Floor	15	1194	6997	79.6	466.5	-136	-1457	-5350	10.7	39.3
Pillar	8	423	1718	52.8	214.7	-81	-1128	-4081	13.9	50.1
Battery tray	5	2443	2231	488.7	446.1	-43	-4863	-2826	113.1	65.7
Ceiling	18	1768	1341	98.2	74.5	-171	-3639	0	21.3	0
Roof cover	No core for this component					-91	-294	-1403	3.2	15.4

Note: units of ΔM is kg, ΔK_B is N/mm, ΔK_T is N.m/deg, $\Delta K_B/\Delta M$ is N/mm/kg and $\Delta K_T/\Delta M$ is N.m/deg/kg

$$\begin{bmatrix} Mass \\ K_B \\ K_T \end{bmatrix} = \begin{bmatrix} 1841 \\ 32042 \\ 95787 \end{bmatrix} + \begin{bmatrix} 3.1 & 0.6 & 1.5 & 0.8 & 0.5 & 1.8 \\ 71.4 & 8.8 & 119.4 & 42.3 & 244.3 & 176.8 \\ 1664.5 & 145.8 & 699.7 & 171.8 & 223.1 & 134.1 \end{bmatrix} \begin{bmatrix} \Delta t_{C,Bottom} \\ \Delta t_{C,Panel} \\ \Delta t_{C,Floor} \\ \Delta t_{C,Pillar} \\ \Delta t_{C,BatteryTray} \\ \Delta t_{C,Ceiling} \end{bmatrix} + \begin{bmatrix} 48.8 & 10 & 22.7 & 13.6 & 7.2 & 28.5 & 30.3 \\ 904.9 & 81.7 & 242.8 & 187.9 & 810.5 & 606.6 & 98.1 \\ 3664.7 & 199.1 & 891.6 & 680.6 & 471.1 & 0 & 467.7 \end{bmatrix} \begin{bmatrix} \Delta t_{F,Bottom} \\ \Delta t_{F,Panel} \\ \Delta t_{F,Floor} \\ \Delta t_{F,Pillar} \\ \Delta t_{F,BatteryTray} \\ \Delta t_{F,Ceiling} \\ \Delta t_{F,RoofCover} \end{bmatrix}$$

Constants of baseline — Core terms — Face terms

Design improvement

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- The requirements entail:
  Increasing in K_B by approximately 4,000 N/mm
  K_T exceeding the requirement by 45,787 N.m/deg
- To enhance the K_B of the bus body, the parameters with high specific K_B are considered.
- Benefits from the reduction in face thickness the most are the roof structure and side panel as the K_B is insensitive to the change in face thickness.

Comparisons of structural responses obtained from established formulation and FE analysis

Responses	Equation	FEA	% Difference
M (kg)	1,783.3	1,782	0.1
K_B (N/mm)	36,772	36,487	0.8
K_T (N.m/deg)	111,998	102,329	9.4

Bottom part	Side panel	Floor	Pillar	Battery tray	Ceiling	Roof cover
G400	G400, Δt_F = -2 mm	G400	G600	C200 / G400	G400	G400, Δt_F = -2 mm
Foam	Foam	Foam, Δt_C = +20 mm	Foam, Δt_C = +10 mm	Foam, Δt_C = +20 mm	Foam	
G400	G400, Δt_F = -2 mm	G400	G600	G400 / C200	G400	

Conclusions

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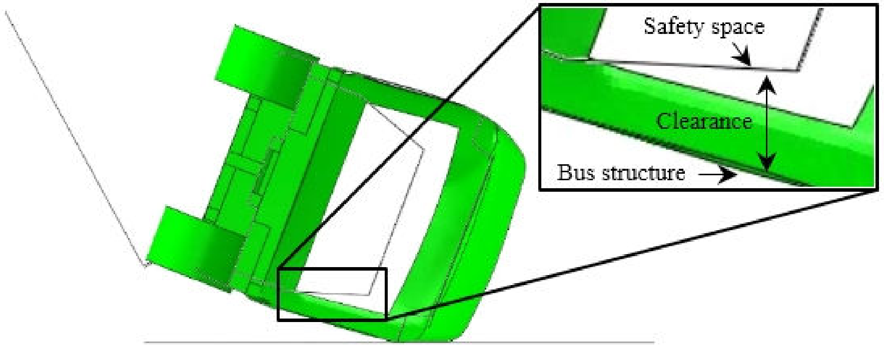
Design condition		Criteria	Result of the proposed model
Bending stiffness		≥ 36,000 N/mm	36,487 N/mm
Torsional stiffness		≥ 40,000 Nm/degs	102,329 Nm/degs
Maximum stress under longitudinal loading		do not exceed max. strength of 207 MPa	10 MPa at passenger door
Maximum stress under lateral loading		do not exceed max. strength of 207 MPa	15 MPa at front window
Natural frequency	1st bending mode	≥ 5 Hz	21.2 Hz
	1st torsional mode	≥ 5 Hz	16.6 Hz
Rollover test		Bus structure do not intrude into residual space	Residual space is preserved



Maximum deformation of bus structure and clearance between structure and survival area

Conclusions

- This paper presents a parametric study and methodology to preliminarily design an 8-m electric bus structure for Thailand by using sandwich-structured composite.
- Parametric study delivers the level of significance in changing each design parameters to the specific stiffnesses of the bus monocoque.
- The equations for prompt prediction of structural performances are formulated to tailor the responses of interest.
- The improved design meets with the required stiffnesses and its structural mass is practically reduced compared with existing buses.

Thank you